       Use of the HSS/LMS Hash-based Signature Algorithm with CBOR Object
                    Signing and Encryption (COSE)
                     draft-ietf-cose-hash-sig-08

Abstract

   This document specifies the conventions for using the Hierarchical
   Signature System (HSS) / Leighton-Micali Signature (LMS) hash-based
   signature algorithm with the CBOR Object Signing and Encryption
   (COSE) syntax. The HSS/LMS algorithm is one form of hash-based
   digital signature; it is described in RFC 8554.

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1. **Introduction**

   This document specifies the conventions for using the Hierarchical
   Signature System (HSS) / Leighton-Micali Signature (LMS) hash-based
   signature algorithm with with the CBOR Object Signing and Encryption
   (COSE) [RFC8152] syntax. The LMS system provides a one-time digital
   signature that is a variant of Merkle Tree Signatures (MTS). The HSS
   is built on top of the LMS system to efficiently scale for a larger
   numbers of signatures. The HSS/LMS algorithm is one form of hash-
   based digital signature, and it is described in [HASHSIG]. The HSS/
   LMS signature algorithm can only be used for a fixed number of
   signing operations. The number of signing operations depends upon
   the size of the tree. The HSS/LMS signature algorithm uses small
   public keys, and it has low computational cost; however, the
   signatures are quite large. The HSS/LMS private key can be very
   small when the signer is willing to perform additional computation at
   signing time; alternatively, the private key can consume additional
   memory and provide a faster signing time. The HSS/LMS signatures
   [HASHSIG] are currently defined to use exclusively SHA-256 [SHS].

[1.1](). Motivation

Recent advances in cryptanalysis [[BH2013]()] and progress in the development of quantum computers [[NAS2019]()] pose a threat to widely deployed digital signature algorithms. As a result, there is a need to prepare for a day that cryptosystems such as RSA and DSA that depend on discrete logarithm and factoring cannot be depended upon.

If large-scale quantum computers are ever built, these computers will have more than a trivial number of quantum bits (qubits) and they will be able to break many of the public-key cryptosystems currently in use. A post-quantum cryptosystem [[PQC]()] is a system that is secure against against such large-scale quantum computers. It is open to conjecture when it will be feasible to build such computers; however, RSA [[RFC8017]()], DSA [[DSS]()], ECDSA [[DSS]()], and EdDSA [[RFC8032]()] are all vulnerable if large-scale quantum computers come to pass.

Since the HSS/LMS signature algorithm does not depend on the difficulty of discrete logarithm or factoring, the HSS/LMS signature algorithm is considered to be post-quantum secure. The use of HSS/ LMS hash-based signatures to protect software update distribution will allow the deployment of future software that implements new cryptosystems. By deploying HSS/LMS today, authentication and integrity protection of the future software can be provided, even if advances break current digital signature mechanisms.

[1.2](). Terminology

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.

[2](). LMS Digital Signature Algorithm Overview

This specification makes use of the hash-based signature algorithm specified in [[HASHSIG]()], which is the Leighton and Micali adaptation [[LM]()] of the original Lamport-Diffie-Winternitz-Merkle one-time signature system [[M1979]()][M1987][[M1989a]()][M1989b].

The hash-based signature algorithm has three major components:

o Hierarchical Signature System (HSS) -- see Section 2.1;

o Leighton-Micali Signature (LMS) -- see Section 2.2; and

o Leighton-Micali One-time Signature Algorithm (LM-OTS) -- see
      Section 2.3.

As implied by the name, the hash-based signature algorithm depends on
a collision-resistant hash function. The hash-based signature
algorithm specified in [HASHSIG] currently makes use of the SHA-256
one-way hash function [SHS], but it also establishes an IANA registry
to permit the registration of additional one-way hash functions in
the future.

2.1. Hierarchical Signature System (HSS)

The hash-based signature algorithm specified in [HASHSIG] uses a
hierarchy of trees. The Hierarchical N-time Signature System (HSS)
allows subordinate trees to be generated when needed by the signer.
Otherwise, generation of the entire tree might take weeks or longer.

An HSS signature as specified in [HASHSIG] carries the number of
signed public keys (Nspk), followed by that number of signed public
keys, followed by the LMS signature as described in Section 2.2. The
public key for the top-most LMS tree is the public key of the HSS
system. The LMS private key in the parent tree signs the LMS public
key in the child tree, and the LMS private key in the bottom-most
tree signs the actual message. The signature over the public key and
the signature over the actual message are LMS signatures as described
in Section 2.2.

The elements of the HSS signature value for a stand-alone tree (a top
tree with no children) can be summarized as:

    u32str(0) ||
    lms_signature /* signature of message */

where, the notation comes from [HASHSIG].

The elements of the HSS signature value for a tree with Nspk signed
public keys can be summarized as:

```
   u32str(Nspk) ||
   signed_public_key[0] ||
   signed_public_key[1] ||
       ...
   signed_public_key[Nspk-2] ||
   signed_public_key[Nspk-1] ||
   lms_signature  /* signature of message */
```

where, as defined in Section 3.3 of [HASHSIG], a signed_public_key is
the lms_signature over the public key followed by the public key
itself. Note that Nspk is the number of levels in the hierarchy of
trees minus 1.

2.2. Leighton-Micali Signature (LMS)

Subordinate LMS trees are placed in the the HSS structure discussed
in Section 2.1. Each tree in the hash-based signature algorithm
specified in [HASHSIG] uses the Leighton-Micali Signature (LMS)
system. LMS systems have two parameters. The first parameter is the
height of the tree, h, which is the number of levels in the tree
minus one. The [HASHSIG] includes support for five values of this
parameter: h=5; h=10; h=15; h=20; and h=25. Note that there are 2^h
leaves in the tree. The second parameter is the number of bytes
output by the hash function, m, which is the amount of data
associated with each node in the tree. The [HASHSIG] specification
supports only SHA-256, with m=32. An IANA registry is defined so
that other hash functions could be used in the future.

The [HASHSIG] specification supports five tree sizes:

```
   LMS_SHA256_M32_H5;
   LMS_SHA256_M32_H10;
   LMS_SHA256_M32_H15;
   LMS_SHA256_M32_H20; and
   LMS_SHA256_M32_H25.
```

The [HASHSIG] specification establishes an IANA registry to permit
the registration of additional hash functions and additional tree
sizes in the future.

The [HASHSIG] specification defines the value I as the private key
identifier, and the same I value is used for all computations with
the same LMS tree. The value I is also available in the public key.
In addition, the [HASHSIG] specification defines the value T[i] as
the m-byte string associated with the ith node in the LMS tree, where
and the nodes are indexed from 1 to $2^{(h+1)}-1$. Thus, T[1] is the
m-byte string associated with the root of the LMS tree.

The LMS public key can be summarized as:

```
u32str(lms_algorithm_type) || u32str(otstype) || I || T[1]
```

As specified in [HASHSIG], the LMS signature consists of four
elements: the number of the leaf associated with the LM-OTS
signature, an LM-OTS signature as described in Section 2.3, a
typecode indicating the particular LMS algorithm, and an array of
values that is associated with the path through the tree from the
leaf associated with the LM-OTS signature to the root. The array of
values contains the siblings of the nodes on the path from the leaf
to the root but does not contain the nodes on the path itself. The
array for a tree with height h will have h values. The first value
is the sibling of the leaf, the next value is the sibling of the
parent of the leaf, and so on up the path to the root.

The four elements of the LMS signature value can be summarized as:

```
u32str(q) ||
ots_signature ||
u32str(type) ||
path[0] || path[1] || ... || path[h-1]
```

2.3. Leighton-Micali One-time Signature Algorithm (LM-OTS)

The hash-based signature algorithm depends on a one-time signature
method. This specification makes use of the Leighton-Micali One-time
Signature Algorithm (LM-OTS) [HASHSIG]. An LM-OTS has five
parameters:

   n - The number of bytes output by the hash function. For
        SHA-256 [SHS], n=32.

   H - A preimage-resistant hash function that accepts byte strings
        of any length, and returns an n-byte string.

   w - The width in bits of the Winternitz coefficients. [HASHSIG]
        supports four values for this parameter: w=1; w=2; w=4; and
        w=8.

   p - The number of n-byte string elements that make up the LM-OTS
        signature.

   ls - The number of left-shift bits used in the checksum function,
        which is defined in Section 4.5 of [HASHSIG].

The values of p and ls are dependent on the choices of the parameters
n and w, as described in Appendix B of [HASHSIG].

The [HASHSIG] specification supports four LM-OTS variants:

    LMOTS_SHA256_N32_W1;
    LMOTS_SHA256_N32_W2;
    LMOTS_SHA256_N32_W4; and
    LMOTS_SHA256_N32_W8.

The [HASHSIG] specification establishes an IANA registry to permit
the registration of additional hash functions and additional
parameter sets in the future.

Signing involves the generation of C, which is an n-byte random
value.

The LM-OTS signature value can be summarized as the identifier of the
LM-OTS variant, the random value, and a sequence of hash values (y[0]
through y[p-1]) as described in Section 4.5 of [HASHSIG]:

    u32str(otstype) || C || y[0] || ... || y[p-1]

3. Hash-based Signature Algorithm Identifiers

The CBOR Object Signing and Encryption (COSE) [RFC8152] supports two
signature algorithm schemes. This specification makes use of the
signature with appendix scheme for hash-based signatures.

The signature value is a large byte string as described in Section 2.
The byte string is designed for easy parsing. The HSS, LMS, and
LMOTS components of the signature value format include counters and
type codes that indirectly provide all of the information that is
needed to parse the byte string during signature validation.

When using a COSE key for this algorithm, the following checks are
made:

   o The 'kty' field MUST be 'HSS-LMS'.

   o If the 'alg' field is present, it MUST be 'HSS-LMS'.

   o If the 'key_ops' field is present, it MUST include 'sign' when
      creating a hash-based signature.

   o If the 'key_ops' field is present, it MUST include 'verify'
      when verifying a hash-based signature.

   o If the 'kid' field is present, it MAY be used to identify the
      top of the HSS tree. In [HASHSIG], this identifier is called
      'I', and it is the 16-byte identifier of the LMS public key
      for the tree.

4. Security Considerations

   The Security considerations from [RFC8152] and [HASHSIG] are relevant
   to implementations of this specification.

   There are a number of security considerations that need to be taken
   into account by implementers of this specification.

   Implementations MUST protect the private keys. Compromise of the
   private keys may result in the ability to forge signatures. Along
   with the private key, the implementation MUST keep track of which
   leaf nodes in the tree have been used. Loss of integrity of this
   tracking data can cause a one-time key to be used more than once. As
   a result, when a private key and the tracking data are stored on non-
   volatile media or stored in a virtual machine environment, failed
   writes, virtual machine snapshotting or cloning, and other
   operational concerns must be considered to ensure confidentiality and
   integrity.

   When generating an LMS key pair, an implementation MUST generate each
   key pair independently of all other key pairs in the HSS tree.

   An implementation MUST ensure that a LM-OTS private key is used to
   generate a signature only one time, and ensure that it cannot be used
   for any other purpose.

   The generation of private keys relies on random numbers. The use of
   inadequate pseudo-random number generators (PRNGs) to generate these
   values can result in little or no security. An attacker may find it
   much easier to reproduce the PRNG environment that produced the keys,
   searching the resulting small set of possibilities, rather than brute
   force searching the whole key space. The generation of quality

random numbers is difficult, and [RFC4086] offers important guidance
in this area.

The generation of hash-based signatures also depends on random
numbers. While the consequences of an inadequate pseudo-random
number generator (PRNG) to generate these values is much less severe
than in the generation of private keys, the guidance in [RFC4086]
remains important.

5. Operational Considerations

The public key for the hash-based signature is the key at the root of
Hierarchical Signature System (HSS). In the absence of a public key
infrastructure [RFC5280], this public key is a trust anchor, and the
number of signatures that can be generated is bounded by the size of
the overall HSS set of trees. When all of the LM-OTS signatures have
been used to produce a signature, then the establishment of a new
trust anchor is required.

To ensure that none of tree nodes are used to generate more than one
signature, the signer maintains state across different invocations of
the signing algorithm. Section 12.2 of [HASHSIG] offers some
practical implementation approaches around this statefulness. In
some of these approaches, nodes are sacrificed to ensure that none
are used more than once. As a result, the total number of signatures
that can be generated might be less than the overall HSS set of
trees.

6. IANA Considerations

IANA is requested to add entries for hash-based signatures in the
"COSE Algorithms" registry and hash-based public keys in the "COSE
Key Types" registry.

6.1. COSE Algorithms Registry Entry

The new entry in the "COSE Algorithms" registry [IANA] has the
following columns:

      Name: HSS-LMS

      Value: TBD1 (Value between -256 and 255 to be assigned by IANA,
                     with a preferrence for -46)

      Description: HSS/LMS hash-based digital signature

      Reference: This document (Number to be assigned by RFC Editor)

      Recommended: Yes

6.2. COSE Key Types Registry Entry

   The new entry in the "COSE Key Types" registry [IANA] has the
   following columns:

      Name: HSS-LMS

      Value: TBD2 (Value to be assigned by IANA)

      Description: Public key for HSS/LMS hash-based digital signature

      Reference: This document (Number to be assigned by RFC Editor)

6.3. COSE Key Type Parameters Registry Entry

   The new entry in the "COSE Key Type Parameters" registry [IANA] has
   the following columns:

      Key Type: TBD2 (Value to be assigned above by IANA)

      Name: pub

      Label: TBD3 (Value to be assigned by IANA)

      CBOR Type: bstr

      Description: Public key for HSS/LMS hash-based digital signature

      Reference: This document (Number to be assigned by RFC Editor)

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7.1. Normative References

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Appendix A. Examples

   This appendix provides a non-normative example of a COSE full message
   signature and an example of a COSE_Sign1 message. This section is
   formatted according to the extended CBOR diagnostic format defined by
   [RFC8610].

   The programs that were used to generate the examples can be found at
   https://github.com/cose-wg/Examples.

A.1. **Example COSE Full Message Signature**

   This section provides an example of a COSE full message signature.

   Size of binary file is 2560 bytes.

   {{{ RFC Editor: This example assumes that -46 will be assigned for
   the HSS-LMS algorithm. If another value is assigned, then the
   example needs to be regenerated. }}}

   98(
     [
       / protected / h'a10300' / {
           \ content type \ 3:0
         } / ,
       / unprotected / {},
       / payload / 'This is the content.',
       / signatures / [
         [
           / protected / h'a101382d' / {
               \ alg \ 1:-46 \ HSS-LMS \
             } / ,
           / unprotected / {
             / kid / 4:'ItsBig'
           },
           / signature / h'00000000000000010000000391291de76ce6e24d1e2a
   9b60266519bc8ce889f814deb0fc00edd3129de3ab9b6bfa3bf47d007d844af7db74
   9ea97215e82f456cbdd473812c6a042ae39539898752c89b60a276ec8a9feab900e2
   5bdfe0ab8e773aa1c36ae214d67c65bb68630450a5db2c7c6403b77f6a9bf4d30a02
   19db5cced884d7514f3cbd19220020bf3045b0e5c6955b32864f16f97da02f0cbfea
   70458b07032e30b0342d75b8f3dc6871442e6384b10f559f5dc594a214924c48ccc3
   37078665653fc740340428138b0fb5154f2f2cb291ad05ace7acae60031b2d09b2f4
   17712d1c01e34b165af2e070f5a521a85a5fb3dd2a6288947bcbd5e2265d3670bd61
   92eb2bf643964e2783d84aec343f8e3571e4fcf09cbeea94e80470aa7252d1c733a5
   535907e66c7b9f0b88b159dc2a7370ee47f13e7e134d3d05e5f53fac640b784a9b0f
   183fe14217325626f487cc8d8cb9eaf0abb174ee0b7076cf39c45037cefdf3f1e61b
   5174581214c09870b72c39737ec4c46a96199b66cad2990bcbe5bb1abfde99107c7f
   7289395bf2a433598ede0b1969f23db949afb5b4d33831dae6c641a6355f8f9bf16c
   dffc4bf86891b93a557c2152ac8a1de51c995344cc10cc4bc9ecfbb4e418bed0f334
   af165339e6725dc4fc1e995521e1be8a566d59b57cd130903b42d07087d63646ef8f
   c1e9e9071bb67a123fdec3f37638cdaf0f4bf3084074069171c17885b9431ad908d3
   6a6f8a826256d2aa34f8aa0731a357c060db8e80fefd61b1c323890e640633b98d17
   5d4d6ebff800a71cfc864ec02837de9d0e079f0f400acafd56805cb273e631ba395d
   23e86acf6eae63181a5afe1f0a361cbbd5fefeb7db0c95591ec3128e80dfbea9ca0f
   89fc035d761c05d41e7a010892c42e8e2af62aa604f4e214c0bb08075481f9cc307a
   555adf333b9424f209b89f161032e413b047ae5ab0aa15643bb4c643446d2c9829eb
   256e7375ce9639047a24a44f4da446b7359556f3ab3484c56511c68a140dc0531f65
   3105800d9f20990d4ebdc5ceea918d7ae95c0d7ec69a00d6a936b25fc19b9dfc5561

400f046191136c367038d6a9d0e0ae30dcdc4733712cbd5a2aee35315eff5c1a7e08
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3f294dd9d0aa84f3ce3b083a5879a4762a756e9b41f4bdf8b71418073b0a0d4a9c13
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01be32b9d911b66da13a1528c32a9694c899a772f8e1fe00c17eceb343e737d72cba
06cf5ddac9a4d3df7ef391cf6595a6d8c14b0d80f93023b1b3d4371239da98b67a1b
6a379422616282a16e8d1f97a130baf21e572bcca91abb760eac6957f9b1b05e49e2
d181874ac6dd160d1c717b73bd28ef55f08d47466d5aef754814c7e206fa9e2ec533
85d14d52f7769d95ea50524ffb20dc7275b04d71d1967e3bbc6ed481f1fc5a15e78a
1fd967d96045625645dbd173cccdd97661e995ce47d6b3ead96ee6d006a5ce6f4c97
77fe2e3f91bebe877cac8c6486dfce0315dc71bbb93879759b8981c5ff2e11deb809
abf4280ee93d1711e73645b410acb518538ce3d4bda1e355c988f068165668e99d6a
8de356b4b13298036ad05d526c4a5e2591612a477b7e86550adde128cd71ee651d44
99699000a02979e42bbccf32c83b1eb0ff99aa4d352e20e0b3382422df2c2ed4ce90
c94cf1a359e92ef971dc6db06047a333c2ebe827eb6d5f2811fdbe0bf0f12bf2094e
0dcd8e418f3f691a60ceb0cefb6f45f47883d6b9f320950e91266740c6dbfad6b3cf
e56de0aa6658b0dc893bb6e49e6294537a7878e86cfc8e6c150675db1a89d188ea6e
fe7d88ff57b39b8610e392811ee097ca61c4841e0fbd346ed3ff6a5e412acb0d9f13
022df2e7fdaa8e0face7366c8ffe6f446995b564fc3d59c70fecdb60a25e28650417
157f43f3e72c3afc601509641cfd099a78130e1f7ba8333502ad4f036f46411a43d0
35e2ca0ed0c346d9aac5df05196c95c38e6e52763ed896b6d02464a910dda6cca340
24e3b9c3723d26e2886ad724dd56ea285e8e4b60beec924d55dd700c38877b74552f
ea1f8741579b02061416131db390f628522885236b51f7aef23167d3a5fe5eadcd88
b0e99b2b6bc56b0dea4fb22146294766c28e5e7c834dbdcb6bfdd7bd8455252522ff
2e974f6fd3fda176749b7cdced5b9aba092b2982c89cb7d2b36348928c8f01170618
ecff14d9e0eed9d88d97e38bcf7a837f674be5243fc624c8afd3d105f462bfa939b8
143a3a98f78fbb8c915e00bdbbf707b12c45784f4d1cb1426b583a0d5fbec1f5ea6d
0067c090168cb788e532aca770c7be366ec07e7808f1892b00000006ed1ce8c6e437
918d43fba7bd9385694c41182703f6b7f704deedd9384ba6f8bc362c948646b3c984
8803e6d9ba1f7d3967f709cddd35dc77d60356f0c36808900b491cb4ecbbabec128e
7c81a46e62a67b57640a0a78be1cbf7dd9d419a10cd8686d16621a80816bfdb5bdc5
6211d72ca70b81f1117d129529a7570cf79cf52a7028a48538ecdd3b38d3d5d62d26
246595c4fb73a525a5ed2c30524ebb1d8cc82e0c19bc4977c6898ff95fd3d310b0ba
e71696cef93c6a552456bf96e9d075e383bb7543c675842bafbfc7cdb88483b3276c

```
    29d4f0a341c2d406e40d4653b7e4d045851acf6a0a0ea9c710b805cced4635ee8c10
    7362f0fc8d80c14d0ac49c516703d26d14752f34c1c0d2c4247581c18c2cf4de48e9
    ce949be7c888e9caebe4a415e291fd107d21dc1f084b1158208249f28f4f7c7e931b
    a7b3bd0d824a4570'
        ]
      ]
    ]
  )
```

A.2. Example COSE_Sign1 Message

This section provides an example of a COSE_Sign1 message.

Size of binary file is 2552 bytes.

{{{ RFC Editor: This example assumes that -46 will be assigned for
the HSS-LMS algorithm. If another value is assigned, then the
example needs to be regenerated. }}}

```
18(
  [
    / protected / h'a101382d' / {
        \ alg \ 1:-46 \ HSS-LMS \
      } / ,
    / unprotected / {
      / kid / 4:'ItsBig'
    },
    / payload / 'This is the content.',
    / signature / h'000000000000000000000000391291de76ce6e24d1e2a9b60
  266519bc8ce889f814deb0fc00edd3129de3ab9b9aa5b5ac783bdf0fe689f57fb204
  f1992dbc1ce2484f316c74bce3f2094cfa8e96a4a9548cead0f78ee5d549510d1910
  f647320448ae27ecce77249802a0c39c645bf8db08573af52c93d91fd0e217f245c7
  52c176b81514eb6e3067e0fbb329225eaa88c7d21635e32ae84213f89018cb06f1b8
  4e61eac348b690d7c6265c19f9d868952d99826aecd417b5279dd674cd951c306016
  cfee4fee3bfcf5ee5a5ad08b5b4f53bc93995f26cfe7c0c1c5ba2574c1f2d8470993
  e8bd47ef9b9cf309ef895226e92be60683459009611defbb9a43217956a0ab2959bb
  da0feca39de37e7c4a6cd8a5314d6b02b377406d5a5e589e91feaa9f2e4ec1682ba1
  f633c7784499323e40da651f71d3c19e38c634d898b0c508324c0bfcf7c5f0a8c014
  b4af200a739f96cddba94daf86ce80c76158d4f5cf3cd2ba9f1393df47e556887f91
  68540485242a05ec6bcc76659ec3d0d2fedae3fd1608a701c226f5fd83c9b1ed3152
  ddac7426c30e3390bec8f1da6174abe8d3568c9b76b149eb077d61ac15b8fb11b8ce
  5f9d14e448e216f375e1f96a52d39619459b131026143e8809bad408f5ef66cd3da2
  27431e68670c0b4b2c3801e1e9025b1ebed218e0956967158ccc274c704adcd8cc23
  c149a89eda25478742dadc15f233844535e4021000b5d557313d4f271875680e6d5e
  7f6681fdd19f8b9a748cabb2377aac1387fdb80e618eb7d69a368729ca9a092af91e
  be1c584c35fe62734d1d53d10b35dd02093a201c889ad37a558b610f1ab00179a11f
  881600e944cedc47a7ae6d828009d7c61ffea9dd5aa5406408e2e85dc056e47b5758
  9eaba18e792f4631af62d4588a1818167274273c69e7a0735be5dada7e224e3b178b
```

    3b093212eb74e762f564a26d577aa22ebd8c7b4a999419908e2f2d9c8689dc923905
    c198b9ee335d1e0de6d689655f446dffea997b6e58f5f648415233ede3b9d8a2db29
    e8c3dde5d8dbd55e6348cd9f421783db090e087de46425d62d513597b00d7de32fad
    87752a79cee8b2a38b1e0f2562836721cbbfba20f131130c009a436b93a0bb44fcbb
    86228b1bf1a35f4fc626817924eaebd5b78d64a7970d18dade90cf0ad759b1c45d95
    3c08cd1189685077c5a56069da0944669d797496f8f886fea6f792598db2ac66b657
    af838ed3c3a914dffbb164170a1f63250b125eda53ecaeaf6ee0d2b8a3c804104d7e
    d575b66469bc59f37eec6c6f6fb19e0f7ea02d7c85306230063adb58950589f6ffaf
    f1407233828ae0dfbe5889e5de00bb640a4bc24c3f704488fa669676a9ebbbed399b
    8a9ac0ee4cc944f864b21f642e04f610319ac9271f8bd820e77e41dac6553d234d94
    80e26142c0fa37416651d6450e1f2082bd0213d6783e1ae3cc5c5af677c3316e173b
    a4716d6bc8a9d89383f8b025a0859b99a43daeaf8ddaed46d223b9b503651a67560b
    feb2f35ba544722620ec4086dcc77e6e87bb53f1f18c38368662be460ede31325cae
    aebf018a6fa9d32e3c3a6898e15fe114dcce51241c61afabc36de3608b4d342712a8
    33615c6131e89e1d46b713d9638a08b5a768d53af0298b9c874ded7084358223840c
    2e78cd6fbfca695279a4c1883bb7de81b04a069de8277f7f5109c16938347a643713
    c9ac36fffc8bf141e899f48bc25c7b636d43bebcfa7742d4e1462263e56732ad2021
    eef8ce84023c4959cfd250343d62074724907de9d49ea2f6c968fd9e9bf28feafcdc
    81702108805dec60f2781272d2425a6ee29c66122d2c557867c1a5aed82131e06fc3
    84ecf49017e1c9d6cf63b9f2285ccf890cbb9bbf796e0fd02101948b7ef663849367
    7b33fd787d9d3fc2c7cc7babc21af8c748afb80cf86b45dc89f0b9c7959621e85b98
    b542dc263db9255273bb9054a7f194748f28373ba123d73fc71fef43e7e2ac9a8000
    8e85cf2f04aa433075dfc54c4de24a341ebf7cf1e6b383dbba85898fdc368017fd67
    c153e7a991a3a3cee6dae4fbe2fe6f25a8df314140a8176c8e6fd0c6f042ca66eb6a
    bba9a2502bb6dfa52960ae86a942a673e4e45439594fefcd2974e20554d1dc70b8e0
    34fd1787801343d5f6edc95ce0348c25727c771526e3fd4effb5f16e25a1ea3dcd82
    82e778e91ae9b339a5013c77fd6ea2432704e293f5e82a24121c73900bea4b4ef14a
    2adc1ab3c68224bae1de9c61a48b84e84c1b0e83701be3d988012a24fa40268c8d6e
    f1fd2818ae8e4b6f52f89beab6bfdd1ff1b7ecd573edff3703b800b5b2a206f451f1
    bf2713b4ae9085bd7fe34ad4306a290e4cdb7817ee9ab7ccfb816d002b619f77d46d
    7dd0f8eefe10f5c0f9723ffdb14ca75a185543770f41508b9983d5eed78225bc6e21
    f876bfdd08fe8bc63e0cb253c7dfc67c330897c515244f3f631682f2141eba48ca86
    dfff9206f78edcb9dec4b2371aeddbe141ef96a10957e29a94747c4438fb30b14d37
    e7428eb7fbe4f9d870e72f35f55847f230374bdf56dcae6c129b4468ebaedc340ff4
    cc160c6b410e2d8989488ac8ef9a9febbf65ad4fdfba532a8122ef82dc1a4ffc361c
    bf9f752b36aa9821683d5f3f5842f90134eb423d5cbc76858b4c0a7ba798ec94a089
    fdb24b5b25f42d7b6bb8192f07b98eb2de1fe7bc8b6c740fa5cde6fb4890d2f17916
    64a96c25a0a71a541025b5ec825eed91f393505473e21d0620177993982e6c1b6bf9
    1b777b5ab5739b84946c518c7e6aa0e689e9ad1d34e6ef6ca0e709c4aefecd6f2594
    b017940742aceb72c5a52d7d47a3a74f9d09eb84cf82b349de32278a771cebc31ebc
    580c09b11799b1f0e6d11d75b17e389d259c531f957a1e699250711df2e36f64f21c
    92eff698a392d92df0b2f91991408a076b83149e025a9ffba1ff1caed916a2fc1ac5
    d3081c30b5c64b7d677c314b6e76ac20ed8bb4a4c0eb465ae5c0c265969264b27e6d
    54c266f79e58e2fa6a381069090bec00189562abcf831adc86a05a2fc7ffaa70dbd3
    fa60e09d447cd76b2ff2b851c38e72650ade093ba8bd000000067b95de445abf8916
    1dff4b91a4a9e3bf156a39a4660f98f06bf3f017686d9dfc362c948646b3c9848803
    e6d9ba1f7d3967f709cddd35dc77d60356f0c36808900b491cb4ecbbabec128e7c81
    a46e62a67b57640a0a78be1cbf7dd9d419a10cd8686d16621a80816bfdb5bdc56211

      d72ca70b81f1117d129529a7570cf79cf52a7028a48538ecdd3b38d3d5d62d262465
      95c4fb73a525a5ed2c30524ebb1d8cc82e0c19bc4977c6898ff95fd3d310b0bae716
      96cef93c6a552456bf96e9d075e383bb7543c675842bafbfc7cdb88483b3276c29d4
      f0a341c2d406e40d4653b7e4d045851acf6a0a0ea9c710b805cced4635ee8c107362
      f0fc8d80c14d0ac49c516703d26d14752f34c1c0d2c4247581c18c2cf4de48e9ce94
      9be7c888e9caebe4a415e291fd107d21dc1f084b1158208249f28f4f7c7e931ba7b3
      bd0d824a4570'
        ]
)

Appendix B. Acknowledgements

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