
ssl-mgr

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1.1 Overview

Certificate management tool.

By way of background, I wrote this with 3 goals. Specifically to:

- simplify certificate management - (i.e. automatic, simple and robust)
- support *dns-01* acme challenge with Letsencrypt (and *http-01*)
- support *DANE TLS*

The aim is to make things as robust, complete and as simple to use as possible. Under the hood, make it sensible and be as automated as is feasible. A good tool does things correctly and makes it as easy and simple as it can be; but no simpler.

In practical terms, there are only 2 common commands that are needed with *sslm-mgr*:

- **renew** - creates the new certificate(s) in *next* : current ones remain in *curr*.
- **roll** - moves *next* to become the new *curr*.

Once things are set up these can be run out of cron - renew, then wait, then roll. Clean and simple. Strictly speaking, rolling of certs is only needed when they are advertized via DNS (say) and rolling provides a mechanism for both old and new keys to be made available for some period while DNS servers update. The last step is to advertize new certs only. Changing to new certs without rolling can be problematic if some DNS servers still have the old certs.

While there are lots of other command line options, the **-s, --status** option provides a convenient view of all managed certificates along with their expiration and time remaining before renewal. The **sslm-info** standalone program provides a convenient way to display information about certs (or chains of certs), CSRs etc.

N.B. DNSSEC is required for DANE otherwise it is not needed. However, I do recommend using DNSSEC and I have made available the tool I use to manage it DNS/DNSSEC⁴.

DANE can use either self-signed certs or known CA signed certs. *sslm-mgr* makes it straightforward to create self-signed certs as well. However, in practice, it is safer to use CA signed certs for SMTP to avoid delivery problems in the event some servers require CA chain of trust. We therefore recommend using CA signed certificates and therefore publishing DANE TLSA records using those certificates. Each MX will have its own TLSA record.

While DANE may be used for other TLS services, such as https, in practice it is only used with email.

For convenience, there is a PDF version of this document in the Docs directory.

⁴ dns_tools : https://github.com/gene-git/dns_tools

1.2 Key Features

- Handles creating new and renewing certificates
- Generates key pairs and Certificate Signing Request, CSR, to provide maximum control
- Supports http-01 and dns-01 acme challenges
- Outputs DNS files for acme DNS-01 authentication as well as optional DANE TLSA files. These files are to be included by the apex domain zone file. This makes updates straightforward.
- Uses certbot in manual mode to handle communication with letsencrypt, account tracking etc.
- Processes multiple domains, where each domain each can have multiple certs for different purposes.

1.3 New / Interesting

Recent changes and important info goes here.

- Reduce log messages to stdout. Keep details in log file. Increase the saved log files to 200k plus 4 backup files.
- All git tags are signed with arch@sapience.com key which is available via WKD or download from <https://www.sapience.com/tech>. Add the key to your package builder gpg keyring. The key is included in the Arch package and the source= line with *?signed* at the end can be used to verify the git tag. You can also manually verify the signature
- Support Letsencrypt alternate root chain.

Set via *ca_preferred_chain* option in *ca-info.conf* file (see example file).

By default LE root cert is *ISRG Root X1* (RSA). Since it is standard to use ECC for certificates, it is preferable to use LE *ISRG Root X2* (ECC) which is smaller and faster since less data is exchanged during TLS handshake.

X2 cert is cross-signed by X1 cert, so any client trusting X1 should trust X2.

Some more info here: [LE Certificates](#): and [Compatibility](#).

- Fixed: sslm-info now shows all SANS including IP addresses.
- Fixed: typo in dns_primary when domain specific dns server provided caused it not to be used.
- Feature: config services list can now be wildcard (ALL or *) same as command line
- New config variable : *renew_expire_days_spread* (default 0) When set to value > 0, renew will happen between *expiry_days* \pm *spread* days. Where *spread* days is randomly drawn from a uniform distribution between -*spread* and *spread*. Using this keeps the average renewal time the same but with multiple certificates this helps renewals not all fall on same day even if have same expiration.
- Improve messages
- New config option *post_copy_cmd*

For each server getting copies of certs may run this command on machine on which sslm-mgr is running. The command is passed server hostname as an argument. Usage Example: if a server needs a file permission change for an application user to read private key(s). This option is a list of *[server-host, command]* pairs. See [Config ssl-mgr.conf](#)

- X509v3 Extended Key Usage adds “Time Stamping”
- Changed sslm-dhparm to generate RFC-7919 Negotiated Finite Field Diffie-Hellman Ephemeral Parameters files - with the default now set to *ffdhe8192* instead of *ffdhe4096*. User options *-k* overrides the default as usual

NB If you manually update DH files in prod-certs, then push to all servers:

```
sslm-mgr dev -certs-prod
```

NB TLSv1.3 restricts DH key exchange to named groups only.

- openssl trusted certificates there is ExtraData after the cert which has the trust data. cryptography.x509 will not load this so strip it off. see : <https://github.com/pyca/cryptography/issues/5242>
- Add a working example of self signed web cert in examples/ca-self. Create ca-certs (./make-ca) then generate new web cert signed by that ca. (sslm-mgr -renew; sslm-mgr -roll)
- It seems letsencrypt dns-01 challenge may not always use the apex domain's authoritative servers or perhaps their (secondary) checks might lag more. At least it seems that way lately. We tackle this with the addition of 2 new variables to the top level config:
 - *dns-check-delay*. Given in seconds, this causes a delay before attempting to validate that all authoritative servers have up to date acme challenge dns txt records. Defaults to 240 seconds - this may well need to be made longer. Obviously, this does lead to longer run times - by design.
 - *dns_xtra_ns*. List of nameservers (hostname or ip) which will be checked to have up to date acme challenge dns txt records in addition to each apex domain authoritative nameserver. Default value is:
`dns_xtra_ns = ['1.1.1.1', '8.8.8.8', '9.9.9.9', '208.67.222.222']`
 - improve the way nameservers are checked for being up to date with acme challenges. First check the primary has all the acme challenge TXT records. Then check all nameservers, including the *xtra_ns* have the same serial as the primary
 - While things can take longer than previous versions, teting to date has shown it to be robust and working well with letsencrypt.

1.4 More Detail

The tool keeps and manages 2 versions of every set of data. Each set of data is comprised of certificates, keys, CSRs, etc.

One version of the data has the current (aka *curr*) set and the other has the next set (aka *next*). *curr* are those currently in use while *next* are those that are on deck to become the next current set.

Key rolling is standard practice and should be familiar to those who have implemented *DNSSEC*. A *roll* is a robust method of updating keys/certs with new ones in a way that ensures nothing breaks.

The current key/cert is always advertised in DNS. After creating new keys/certs, DNS is then upated to advertise both the current and the newly created next ones.

An appropriate amount of time needs to pass with both current and next in DNS before doing the *roll*. This gives the time needed for DNS servers to refresh. Once refreshed, the DNS servers now have both the current and the next set of keys/certs.

After sufficient time, update a second time, and now only the new keys (the new current ones) are advertised in DNS.

A *roll* is required for *DNSSEC* as well as for *DANE*, which we manage.

Without any loss of functionality and to keep things nice and simple, we treat every update as requiring a key roll.

Again, a *roll* is required for *DANE TLS* but is not needed for things such as web server certificate update.

Furthermore, admin always has the control, should it be needed, to do whatever they choose.

e.g. Using *-f* will force things to happen (a roll or create new certs and so on.)

1.4.1 Curr & Next

These are kept in directories that contain different versions of the same set of files. Of course *next* has newer versions.

In order of creation these are:

File	What
privkey.pem	the private key
csr.pem	certificate signing request
cert.pem	certificate
chain.pem	CA root + intermediate certs
fullchain.pem	Our cert.pem + CA chain
bundle.pem	Our privkey + fullchain
info	Contains date/time when next was rolled to curr (curr only)

Once config is setup, a cron/timer to run *renew* followed by *roll* 2 or 3 hours later should take care of everything. Can be run daily or weekly.

1.4.2 Diffie-Hellman Parameters

There is also a tool, *sslm-dhparm*, which generates Diffie-Hellman parameters. This can be added to the cron file.

By default *sslm-dhparm* only generates new parameters if they are more than 120 days old, or absent. This can therefore be run weekly without issues.

Note: The new, preferred and now default DH parameters are based on RFC-7919 [rfc_7919](#) pre-defined named groups. The default is *ffdhe4096*. Pre-defined named groups only need to be generated once and will only be generated if absent.

Strictly these don't need to be in cron, but its convenient to have the program check and create the DH parameters should they be missing. May happen occasionally when adding new domain.

The 6 month default refresh, only applies for non RFC-7919 params, and is recommended because it can be a bit time consuming to generate them. Actual time varies with key size.

When using a pre-defined named group (e.g. *ffdhe4096*), it is very quick to produce and tool simply checks if file exists without any age requirement. These are only created once.

Sample cron files are provided in the examples directory.

1.4.3 More Details

There are several additional commands that offer fine grained control, in case its needed. These are discussed in detail below. One example is the *-f* or *-force* option which does what the name suggests.

The tool handles keys, certificate signing requests (CSR) and certs. It also takes care of generating DANE TLSA DNS records should you want to use them and reloads/restarts specific servers whenever they need it. Each server has defined dependencies which trigger restarts whenever those dependencies have changed.

For example, a web server may depend on one or more apex domain certificates and will be restarted when any of those certs change.

It needs external support tools such as zone signing for DNSSEC and restarting dns servers as well as reloading web or mail servers to ensure new certs are picked up. These are provided via the top level config file.

There is support for private/self-signed CAs and Letsencrypt CA. Letsencrypt acme validation challenges³ can use either http or dns; dns is preferred whenever possible.

³ acme-challenge : <https://letsencrypt.org/docs/challenge-types/>

1.4.4 DANE

For DANE TLSA records, care must be taken to properly *roll* new keys. Key rolling ensures that the *next* key and the *curr* key are both advertised in DNS for some period. After some time the new key can be made *curr*. This waiting period should be long enough to provide sufficient time for all DNS servers to pick up both old and new new keys before DNS is changed to only show the new ones. It's reasonable to wait 2 x the DNS TTL or longer.

After that wait time, the new (*next*) keys can be then be made available as the new *curr* ones. Applications, mail really, can now use the new keys since the world has both sets of keys.

Then DNS servers can then be updated again, this time with just the new (now *curr*) keys in the TLSA records. DANE key roll is similar to key roll for DNSSEC. DANE TLSA actually requires DNSSEC.

DANE was designed as an alternative to third party certificate authorities like letsencrypt which means its fine to used self signed or CA signed certs. While DANE could be used for web servers to date it is really only used for email.

The companion *dns_tools* package takes care of all our DNSSEC needs^{Page 1, 4}:

And I recommend using it to simplify the DNS refresh needed for validating Letsencrypt acme challenges using *DNS-01* as well as for DANE TLSA. A DNS refresh means resign zones (when using DNSSEC) and then restarting the primary dns server.

DANE TLSA records contain the public key, or a hash of that key, and thus need to be refreshed whenever that key changes; this is the key roll. It also means that if the key is kept the same, then the TLSA records aren't changing⁵. *ssl-mgr* has an option to re-use the public key when certs are being renewed, and this allows the TLSA records to remain unchanged. In that case no key roll is needed until that key is changed. Some may find this useful.

It basically means using the same certificate signing request, CSR, to get a new cert. The CSR contains the public key associated with the private key. So if keys dont change CSR doesn't change either, and the same CSR can be re-used.

However, I find *ssl-mgr* makes it so simple to renew with new keys, that I don't see much point in reusing the old keys. Of course using new keys offers a security benefit.

Note that each MX for the mail domain will have a TLSA record as required by the standard.

1.4.5 Acme Challenge

Using *DNS-01* to validate Letsencrypt acme challenges is done by adding the challenge TXT records to DNS, signing the zones (if using DNSSEC) and pushing them out, so that Letsencrypt can subsequently check those DNS records match appropriately and then they provide the requested cert. Some tool to do that DNS refresh is needed for this pupose. I use *dns_tools* to do that. DNS refresh also happens after DANE TLSA records are updated.

This should run on the DNS signing server. This allows files with DNS records, acme challenges and TLSA, to be written to accessible directories on same machine. I may enhance this to allow the dns signing server to be remote, some day.

⁵ DANE can use either public key or the cert. Cert does change when it's renewed even if the public key is unchanged. I believe pretty much everyone uses the public key not the cert in TLSA reords.

GETTING STARTED

The first order of business is creating the config files. These specify everything that's needed.

This includes the shared config *ssl-mgr.conf* which includes the commands to restart servers (web, mail), where to put the acme challenge files (web or dns) and where the final certificates are to be stored.

Each certificate to be issued has it's own *service* config file.

The sample configs provided in *examples/conf.d* provide a template to get started.

2.1 Tools

The main tool for generating and managing certificates is *ssl-mgr*. As usual, help is available using *-h*.

There is also a dev mode, providing access to some lower lever tasks. You probably should seldom, if ever, need dev mode, but in case you do, it is activated by using the *dev* command as the first argument.

For example help would be done using

```
ssl-mgr dev -h
```

The tools provided :

Tool	Purpose
ssl-m-auth-hook	internal - used with certbot's manual hook option
ssl-m-dhparm	generate Diffie Hellman paramater file(s)
ssl-m-info	display info about cert.pem, csr.pem, chain.pem, privkey.pem, etc
ssl-m-mgr	primary tool for certificate management
ssl-m-verify	verifies any cert.pem file using public key from chain.pem

2.2 Groups & Services

To help us organize all the data we introduce groups and services.

What are groups? There are only two kinds of groups: Certificate Authorities and Apex Domains. CA can be self-signed or Letsencrypt et al.

2.2.1 Groups

Certificate Authorities:

The job of a CA is to take a CSR and send back a signed cert.

- Self signed
 - self-signed certs use intermediate CA to sign certs. Intermediate CA, in turn, is signed by self signed root CA. Using self signed is a good place to start when getting set up and exploring.

- Letsencrypt

When comfortable, using their test server, which is more generous with limits, is a good way to prepare for the final version. LE's test server is invoked by using the *-t* option. When all is working as you desire, simply drop the test option and you're ready to go live.

Apex Domains:

An Apex domain is the *main* part of the domain that has it's own DNS authority.

If *example.com* has a DNS SOA record, then it would be the apex domain and any subdomain, such as *foo.example.com* would be a part of that apex domain. So, whenever we deal with DNS, we always deal with the apex domain.

2.2.2 Services

Each service gets 1 certificate.

An apex domain may want/need different certs for different services. Each service has one certificate.

An apex domain, for example, may have a mail service and a web service. Each of these has it's own unique cert. Now, mail may use 2 certs, elliptic curve and RSA, then we would simply have 2 services for mail. In this case lets call them *mail-ec* and *mail-rsa* and lets call the web service *web-ec*. Its good to name services in a way thats useful for administrator - it has no significance to the code other than the name must be a good filename so cannot contain / etc.

In the same vein, for self signed CA certs, we have 2 items - a *root* cert and an *intermediate* cert where each belongs the special group *ca*. Again, each of these is a separate service.

Since each service has its own certificate, each has its own X509 name which describe what it is. This includes things like Common Name, Alternative Names and organization. In this case it includes info about the keys to be used and which entity is provides the signed certificate.

Each service has it's information provided by a service file. It has all the information needed to create keys and CSRs as well as certs. This include key type, various *name* fields along with which CA should be used. The *name* fields are essentially x509 Name⁶ fields. These include things like Common Name, Organization and so on.

CSR (certificate signing request) contains the *subject* organization (thats the apex domain org) information along with the public key. The private key is kept in a separate file. The CSR is sent to the CA which, all being well, returns a (signed) certificate.

The resulting cert and certificate chain(s) are kept together with the key and CSR files. A cert is signed by the *Issuer* and in addition to the signature contains the public key. The *chain* file contains the public key and x509 Name of the certificate issuer.

There are a couple of tools provided (*sslm-verify* and *sslm-info*) that make it easy to validate a certificate or display information about it. *sslm-info* works on all the *sslm-mgr* outputs : keys, csrs, certs, chains, fullchains and bundles.

2.3 Key/Cert Files

- CSR (certificate signing request)

Each certificate for is generated from its CSR which contains the public key. Public key is generated from the private key so there is no need to save a public key.

⁶ x509 Name <https://en.wikipedia.org/wiki/X.509>

A CSR is always used to make a cert. This provides control as well as consistency across CAs, be they self or other. The public key is in the CSR and also in the certificate provided and signed by the CA. We support both RSA and Elliptic Curve (EC) keys. EC is strongly preferred. In fact, while RSA keys are still used they are only needed by ancient client software for browsers and email. That said, RSA is still in common use for DKIM⁷ signing for some reason. We DKIM sign outbound mail with both RSA and EC.

- Cert

Each cert contains the public key which is signed by the CA. It carries the *subject* apex domain name along with 'subject alternative names' or SANS. SANS allow a certificate to contain multiple domain or subdomain names. The *issuer*, which signed the certificate, has its name in the cert as well. Name in this context is an X509 name meaning, common name, organization, organization unit and so on.

- Certificate chains

- **chain** = CA root cert + Signing CA cert

Signing CA cert is usually the CA Intermediate cert(s) Note that the root cert may or may not be included by CAs other than LE For those client chain = signing ca

- **fullchain** = Domain cert + chain

- **bundle** = priv-key + fullchain.

A bundle is just a chain made of the private key plus the fullchain. This is preferred by postfix⁸.

- Private key

Also called simply the *key*. It is stored in a file with restricted permissions. The companion public key can be generated from the private key. By always generating the public key from the private key, they are guaranteed to remain consistent.

Key, CSR and certificate files are stored in the convenient PEM format. Certificates use X509.V3⁹ which provides for *extensions* such as SANS which are critical to have. CSR files use PKCS#10¹⁰ which can carry the same set of X509 extensions.

2.4 Tool Commands

As mentioned above, once things are set up for your use case, then all that's needed is periodically run

```
sslm-mgr -renew
```

which will check get new certs, if it's time to renew. A couple of hours later make those certs live by doing:

```
sslm-mgr -roll
```

2.4.1 sslm-mgr

Has 2 modes - a *regular* mode and a developer or *dev* mode. In either case, the groups and services are read from the *ssl-mgr* config file. The config file values *can* be overridden from the command line.

To specify a group and service(s) on the command line use the format:

```
... <group-name>:<service_1>,<service_2>,...
```

⁷ DKIM -> <https://datatracker.ietf.org/doc/html/rfc6376>

⁸ Postfix TLS -> https://www.postfix.org/postconf.5.html#smtpd_tls_chain_files

⁹ X509 V3 -> <https://datatracker.ietf.org/doc/html/rfc5280>

¹⁰ PKCS#10 CSR -> <https://www.rfc-editor.org/rfc/rfc2986>

For example, for a domain with multiple services, you can limit to one or two services using:

```
sslm-mgr -s example.com:mail-ec
sslm-mgr -s example.com:mail-ec,mail-rsa
```

Help command for *sslm-mgr* :

```
sslm-mgr -h
usage: /usr/bin/sslm-mgr [-h] [-v] [-f] [-r] [-d] [-t] [-n] [-s] [-renew] [-roll]
                        [-roll-mins MIN_ROLL_MINS] [-dns] [-clean-keep CLEAN_KEEP] [-clean-all]
                        [grps_svcs ...]

SSL Manager

positional arguments:
grps_svcs              List groups/services: grp1:[sv1, sv2,...] grp2:[ALL] ...
                        (default: from config)

options:
-h, --help              show this help message and exit
-v, --verb              More verbose output
-f, --force              Forces on for renew / roll regardless if too soon
-r, --reuse              Reuse curr key with renew. tlsa unchanged if using selector=1
↳ (pubkey)
-d, --debug              debug mode : print dont do
-t, --test              Letsencrypt --test-cert
-n, --dry-run            Letsencrypt --dry-run
-s, --status              Display cert status. With --verb shows more info
-renew, --renew           Renew keys/csr/cert keep in next (config renew_expire_days)
-roll, --roll            Roll Phase : Make next new curr, copy to production, refresh
↳ dns if needed
-roll-mins MIN_ROLL_MINS, --min-roll-mins MIN_ROLL_MINS
                        Only roll if next is older than this (config min_roll_mins)
-dns, --dns-refresh      dns: Use script to sign zones & restart primary (config dns.
↳ restart_tool)
-clean-keep CLEAN_KEEP, --clean-keep CLEAN_KEEP
                        Clean database dirs keeping newest N (see --clean-all)
-clean-all, --clean-all
                        Clean up all grps/svcs not just active domains

For dev options add "dev" as 1st argument
```

When more control is needed then *dev* mode offers above commands plus few more options. To see developer help:

```
# sslm-mgr dev -h
usage: /usr/bin/sslm-mgr ... [-keys] [-csr] [-cert] [-copy] [-ntoc] [-certs-prod]
                        [grps_svcs ...]

SSL Manager Dev Mode

positional arguments:
grps_svcs              List groups/services: grp1:[sv1, sv2,...] grp2:[ALL] ...
↳ (default: see config)
```

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```

options:
... same as above plus:
-keys, --new-keys      Make next new keys
-csr, --new-csr        Make next CSR
-cert, --new-cert      Make new next/cert
-copy, --copy-csr      Copy curr key to next (used by --reuse)
-ntoc, --next-to-curr  Move next to curr
-certs-prod, --certs-to-prod
                        Copy keys/certs : (mail, web, tlsa, etc)

```

For standard options drop "dev" as 1st argument

2.5 Config Files

Sample configs are show in Appendix [Appendix](#) and the files themselves are provided in *examples/conf.d* directory.

When first setting up its a good idea to start with creating a self signed CA and use that. When you're ready then change the signing CA to letsencrypt in the service file and run with the LE test-cert server by using

```
sslm-mgr --test
```

You may also use the letsencrypt *--dry-run* option.

Once that is working for you then you use the normal LE server by dropping the test option.

Config files are located in *conf.d*. There are 2 shared configs and one config for each group/service. Service configs files resides under their *group* directory.

The common configs are *ssl-mgr.conf* and *ca-info.conf* and are used for all groups and services.

ssl-mgr.conf is the main config file and we'll go over it in detail below. It includes the list of domains and their services. If it's needed, the tool can also take 1 or more groups and services on the command line.

ca-info.conf is a list of available CAs. Each CA name can be referenced in service configs to request that CA to provide the certificate.

As described earlier, there are 2 kinds of groups: *CA* and *Domain* groups. The *CA* group is for self created CAs while *domain* are named by the apex domain. Each group item has 1 or more *services*.

Each service gets it's own certificate. Typically services are named for the purpose they are used for (mail, web etc) but also for any characteristics of the certificate, such key type (RSA, Elliptic Curve) and sometimes by the CA as well.

Each (*group*, *service*) pair is described by it's own config located in the file:

```
conf.d/<group>/<service>
```

This file describes the organization and details for one service. This includes Which CA is to sign the certificate as well as any DANE TLS¹¹ info needed to generate TLSA records.

N.B. Each service is to be signed by the designated CA.

If you want 2 certs signed by 2 different CAs, e.g. both self and letsencrypt, then each would have it's own separate service and associated config file.

E.g. mail-self and mail-le. For each domain, the TLSA records for all services are aggregated into a single file, *tlsa.rr* to be included by the DNS server.

¹¹ TLSA <https://datatracker.ietf.org/doc/html/rfc6698>

N.B.

letsencrypt signing the same CSR counts towards their limits independent of validation method used (http-01 or dns-01).

2.5.1 Service Config

Info for each service to create it's cert. Each domain may have separate certs for different services (mail, web, etc). Each service must therefore have it's own unique config file. Its good practice to use separate certs for each different use cases, to help mitigate any impact of key related security issues.

Each config provides:

- Organization info (CN, O, OU, SAN_Names, ...)
- name, org, service (mail, web etc)
- **Which CA should will be requested to sign this cert**
 - validation method). Self signed dont need a validation method.
 - Letsencrypt, for example, allows http-01 and dns-01 as validation methods.
- DANE TLS info - list of (port, usage, selector, match) - e.g. (25,3,1,1)
- Key type for the public/private key pair

2.6 Output

All generated data is keyy in a dated directory under the *db* dir and links are provided for *curr* and *next*

- curr -> db/<date-time>
- next -> db/<date-time>
- prev -> db/<date-time>

After a cert has been successful generated, each dir will contain :

File	What
privkey.pem	private key
csr.pem	certificate signing request
cert.pem	certificate
chain.pem	root + intermediate CA cert
fullchain.pem	cert.pem + cert + chain
bundle.pem	privkey + fullchain
info	Contains date/time when next was rolled to curr (curr only)

The bundle.pem file, which has the priv key, is preferred by postfix to provide atomic update and avoid potential race during updates. That could happen if key and cert are read from separate files.

In addition there are the acme challenge files. The *ssl-mgr.conf* file is where to specify where to store these files.

2.6.1 DNS-01 Validation

For dns-01 the location is specified as a directory:

```
[dns]
    acme_dir = '...'
```


The acme challenges will be saved into a file under `<acme_dir>` with apex domain name as suffix:

```
<acme_dir>/acme-challenge.<apex_domain>
```

The format of the DNS resource record is per RFC 8555¹² spec. The challenge file should be included by the DNS zone file for that apex domain. Once the challenge session is complete, the file will be replaced by an empty file, which ensures that there are no errors including it in the domain zone file.

2.6.2 HTTP-01 Validation

For http-01 validation the location is specified by `server_dir` directory:

```
[web]
server_dir = '...'
```

The individual challenge files, one per (sub)domain will be saved in a file following RFC 8555¹³ spec:

```
<server_dir>/<apex_domain>/.well-known/acme-challenge/<token>
```

If the web server is not local then ssh will be used to deliver the file the remote server.

N.B. In all cases please ensure that the process has appropriate write permissions.

2.6.3 DANE-TLSA DNS File

If DANE is on for any service, then the TLSA records will be saved under one or more directories specified in the `[dns]` section of `ssl-mgr.conf`.

```
[dns]
...
tlsa_dirs = [<tlsa_1>, <tlsa_2>, ...]
```

Each directory, `<tlsa_1>`, `<tlsa_2>` etc, will be populated with one file per apex_domain containing the TLSA records for that domain. The file will be named:

N.B. Mail server needs a TLSA record for each key/certificate is used. If, for example, postfix is set up to use either *RSA* or *EC* certs, then you **must** provide a TLSA record for both of them. And there must be record for the apex domain as well as every MX host. We determine the MX hosts via DNS lookup of the apex domain.

```
tlsa.<apex_domain>
```

Each file should be included by the DNS zone file for that apex domain.

2.7 Certbot

A few notes on certbot and how we're using it.

In addition to the database directory (`db`) there is also a `cb` dir which is provided to certbot. Certbot uses to keep letsencrypt accounts. Each group-service has its own everything - this includes it's own certbot `cb` and thus separately registered LE (Letsencrypt) account for each service.

We are using certbot in manual mode. This gives us a lot of control and allows us to use our own generated CSR as well as to specify where the resulting cert and chain files get stored.

¹² DNS-01 Acme Challenge URI -> <https://datatracker.ietf.org/doc/html/rfc8555#section-8.4>

¹³ HTTP-01 Acme Challenge URI -> <https://datatracker.ietf.org/doc/html/rfc8555#section-8.3>

When sending a CSR with apex domain plus sub-domains, each (sub)domain gets a challenge and each challenge must be validated by LE before cert is issued. Challenges can be validated by acme http-01 or dns-01. Wildcard sub-domains (*.example.com) can only be validated using dns-01.

Certbot sends each challenge to a *hook* program. The *hook* program is called once per challenge. Information about the challenge and which sub-domain are passed to the *hook* program in environment variables. Env variables also tell the program how many more challenges remain to be sent. Once all the challenges have been delivered - and only after the *hook* program returns - LE will then seek to validate all of the acme challenges, whether http or dns validation is being used.

This is actually really good - it means that we can push all the challenges out - and wait for every DNS authoritative name server to have the TXT records before allowing the hook to return once it has every acme challenge.

In older versions of certbot, validation took place after each sub-domain challenge, and for DNS that meant dns refresh - wait for NS to update - LE checks and sends next challenge. This could potentially very long wait times - I read of some folks waiting many hours. Now with the new way as described above, whether DNS or HTTP challenge, it takes only seconds or minutes.

It seems to me that LE checks directly with each authoritative NS, which is the most efficient way to check - rather than waiting on some random recursive server to get updated.

2.8 TLSA Note

The service config allows DANE to be specified.

The input field takes the form of a list, one item per port:

```
dane_tls = [[25, 'tcp', 3, 1, 1], [...], ...]
```

Each item has port (25 here), the network protocol (tcp) along with *usage* (3), *selector* (1) and *hash_type* (also 1).

You should use (3,1,1).

The dane records normally contain the current TLSA records. During rollover they contain both current and next ones, and after rollover completes, and next becomes current then we're back to the normal case with only current TLSA records.

Each apex domain has it's own file of TLSA records, *tlsa.<apex_domain>*.

The *ssl-mgr.conf* DNS section also specifies where these DNS TLSA record files should be copied to - so that the DNS tools can include them in the apex domain zone file.

The best way to handle the dane resource records is by using \$INCLUDE in dns zone file to picks up *tlsa.<apex_domain>* file.

DNS server is refreshed (i.e. zone files signed and primary server is restarted) whenever a dane tlsa file changes.

The TLSA records change when the private key is updated (leading to change in the hash itself) or when the dane-info is changed (e.g. change of ports or other dane info). It certainly changes after a *renew* builds new keys/certs in *next* and after *roll* when the new *curr* is updated.

For doing rollover properly, order is important.

```
curr → curr + next → DNS
```

After 2xTTL or longer:

```
next → curr → update mail server → refresh DNS
```

sslm-mgr takes care of this.

While it is true that reusing a key, means not having to deal with key rollover as often, that only helps when doing things manually. And in fact even doing it manually, doing things less frequently may mean mistakes are more likely. There is also a small security reduction obviously in reusing a key.

When things are automated, as here with *sslm-mgr* taking care of everything, then there is little benefit to key reuse. So we support it, but we recommend just renew and roll and all will be fine :)

2.9 sslm-mgr application

2.9.1 Usage

To run - go to terminal and use :

```
sslm-mgr --help
```

2.9.2 Configuration

The configuration file for ssl-mgr is ...

```
/etc/ssl-mgr/config
```

2.10 Log files

Logs are found:

```
${HOME}/log/ssl-mgr
```


3.1 Self Signed CA

The *examples/ca-self* directory has sample how to do this. The CA has a self-signed root certificate (*my-root*) along with an intermediate certificate (*my-int*) which is signed by the root cert. Other certs are then signed by the intermediate certificate.

The 2 public CA certs then need to be added to the linux certificate trust store. To do this copy each cert as below and update the trust store:

```
cp certs/ca/my-root/curr/cert.pem /etc/ca-certificates/trust-source/anchors/my-root.  
↪pem  
cp certs/ca/my-int/curr/cert.pem /etc/ca-certificates/trust-source/anchors/my-int.pem  
update-ca-trust
```

Since browsers do not typically use the system certificate store the same certs will need to be imported into each browser. This can be done manually in the GUI or using *certutil* provided by the *nss* package. Modern browsers typically keep the certificates in a file called *cert9.db* which can be updated using for example something like this (untested):

```
cert9='<path-to>/cert9.db'  
cdirc=$(dirname $cert9)  
certutil -A -n "my-int" -t "TC,C,TC" -i xxx/my-int/curr/cert.pem -d sql:$cdirc
```

Please see *certutil* man pages for more info.

3.2 Sample Cron File

```
#  
# Renew certs  
# - avoid dnsec key rolls times  
#   dns_tools uses locking so just nice not to overlap  
#   dnsssec renews on 2nd of every month at 8 am and rolls 10 am  
# - certs renew (check) every Tue afternoon and roll 2 hours later  
#  
30 14 * * 2 root /usr/bin/sslm-mgr -renew  
30 16 * * 2 root /usr/bin/sslm-mgr -roll  
  
#  
# update dh parms:  
# will update if existing file is older than min age.  
# The default min age is 120 days. Use -a to change min age.
```

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```
# Update early morning ahead of any cert renewal.
#
30 2 5 * 2 root /usr/bin/sslm-dhparm -s /etc/ssl-mgr/prod-certs
```

3.3 Config ca-info.conf

```
[le-dns]      # Used to sign client certs
    ca_desc = 'Letsencrypt: dns-01 validation'
    ca_type = 'certbot'
    ca_validation = 'dns-01'

[le-http]     # Used to sign client certs
    ca_desc = 'Letsencrypt: http-01 validation'
    ca_type = 'certbot'
    ca_validation = 'http-01'

[my-root]    # To sign our own intermediate 'sub' certs
    ca_desc = 'My Self signed root : EC signs my intermediate certs'
    ca_type = 'self'

[my-sub]     # Used to sign client certs
    ca_desc = 'My intermediate : EC signs client certs'
    ca_type = 'self'
```

3.4 Config ssl-mgr.conf

```
[globals]
    verb = true
    sslm_auth_hook = '/usr/lib/ssl-mgr/sslm-auth-hook'      # For certbot
    prod_cert_dir = '/etc/ssl-mgr/prod-certs'
    logdir = '/var/log/ssl-mgr/ssl-mgr/Logs'

    clean_keep = 5
    min_roll_mins = 90
    renew_expire_days = 30

    dns_check_delay = 240
    dns_xtra_ns = ['1.1.1.1', '8.8.8.8', '9.9.9.9', '208.67.222.222']

    post_copy_cmd = [['example.com', '/etc/ssl-mgr/tools/update-permissions'],
                     ['voip.example.com', '/etc/ssl-mgr/tools/voip-checker']]
    ]

#
# Groups & Services
#
[[groups]]
    active=true
```

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```

    domain='example.net'
    services=['web-ec']

[[groups]]
    active=true
    domain = 'example.com'
    services = ['mail-ec', 'mail-rsa', 'web-ec']

[[groups]]
    active=true
    domain = 'ca'
    services = ['my-root', 'my-sub']

#
# DNS primary provides authorized NS (name servers) and MX hosts of apex_domain
# Must have at least one for acme dns-01
#
[[dns_primary]]
    domain = 'default'
    server = '10.1.2.3'
    port = 11153

[[dns_primary]]
    domain = 'example.com'
    server = '10.1.2.3'
    port = 11153

#
# Servers
#
[dns]
    restart_cmd = '/etc/dns_tools/scripts/resign.sh'
    acme_dir = '/etc/dns_tool/dns/external/staging/zones/include-acme'
    tlsa_dirs = ['/etc/dns_tool/internal/staging/zones/include-tlsa',
                '/etc/dns_tool/external/staging/zones/include-tlsa',
                ]

    # restart trigger when dns (TLSA) zones have changed.
    depends = ['dns']

[smtp]
    servers = ['smtp1.internal.example.com', 'smtp2.internal.example.com']
    # If using sni_maps
    #restart_cmd = ['/usr/bin/postmap -F lmbd:/etc/postfix/sni_maps', '/usr/bin/
↳ postfix reload']
    restart_cmd = '/usr/bin/postfix reload'
    svc_depends = [['example.com', ['mail-rsa', 'mail-ec']]]
    depends = ['dns']

[imap]
    servers = ['imap.internal.example.com']
    restart_cmd = '/usr/bin/systemctl restart dovecot'

```

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```

    svc_depends = [['example.com', ['mail-rsa', 'mail-ec']]]

[web]
    servers = ['web.internal.example.com']
    restart_cmd = '/usr/bin/systemctl reload nginx'
    server_dir = '/srv/http/Sites' # Used for acme http-01 validation
    svc_depends = [['any', ['web-ec']]]

[other]
    # these servers get copies of certs
    servers = ['backup.internal.example.com', 'voip.internal.example.com']
    restart_cmd = ''

```

3.5 Config Service : example.com/mail-ec

```

#
# example.com : mail-ec
#
name = 'Example.com Mail'
group = 'example.com'
service = 'mail-ec'

#signing_ca = 'my-sub'
#signing_ca = 'le-http'
signing_ca = 'le-dns'
renew_expire_days = 30

# Include tls.example.com in zone file to use
# => [[port, proto, usage, selector, match], ...]
dane_tls = [[25, 'tcp', 3, 1, 1]]

[KeyOpts]
    ktype = 'ec'
    ec_algo = 'secp384r1'

[X509]
    # X509Name details
    CN = 'example.com'
    O = 'Example Company'
    OU = 'IT Mail'
    L = ''
    ST = ''
    C = 'US'
    email = 'hostmaster@example.com' # required to register with letsencrypt

    sans = ['example.com', 'smtp.example.com', 'imap.example.com', 'mail.example.com']

```


3.6 Directory tree structure

Directory Structure. By default we only use EC keys, can add RSA if required. We use 'ec' as a label to keep things clear and allow easy way to change to new key types (RSA or other).

Input:

```
conf.d/
  ssl-mgr.conf
  ca-info.conf

  example.com/
    mail-ec
    mail-rsa
    web-ec

  example.net/
    web-ec

  ca/
    my-root
    my-sub
  ...
```

Output - Final Production Certs:

```
prod-certs/
  example.com/
    tlsa.example.com

    dh/
      dh2048.pem
      dh4096.pem
      dhparam.pem -> dh4096.pem
      ...
    mail-ec/
      curr/
        privkey.pem
        csr.pem
        chain.pem
        fullchain.pem
        cert.pem
        bundle.pem
        tlsa.rr
        info
    web-ec/
      ...
    ...
```

Output - Internal Data

```
certs/
  example.com/
    tlsa.example.com
```

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```
mail-ec/
  curr -> db/date1
  next -> db/date2

  db/date1/
    csr.pem
    privkey.pem
    cert.pem
    chain.pem
    fullchain.pem
    bundle.pem
    tlsa.rr
  cb/
    [files used by cerbot]

web-ec/
  curr -> db/date1
  next -> db/date2

  db/date1/
    ...
  cb/
    [files used by cerbot]

.. other services

example.net/
  ...
```

3.7 Installation

Available on

- [Github](#)
- [Archlinux AUR](#)

On Arch you can build using the provided PKGBUILD in the packaging directory or from the AUR. To build manually, clone the repo and :

```
rm -f dist/*
/usr/bin/python -m build --wheel --no-isolation
root_dest="/"
./scripts/do-install $root_dest
```

When running as non-root then set root_dest a user writable directory

3.8 Dependencies

- Run Time :

Package	Comment
python	3.13 or later
dnspython	
cryptography	
dateutil	
netaddr	
lockmgr	Ensures only 1 app runs at a time

- Building Package:

Package	Comment
git	
hatch	
wheel	
build	
installer	
rsync	
sphinx	Optional (build) docs:
texlive-latexextra	Optional (build) docs aka texlive tools

3.9 Philosophy

We follow the *live at head commit* philosophy. This means we recommend using the latest commit on git master branch. We also provide git tags.

This approach is also taken by Google¹².

3.10 License

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- SPDX-FileCopyrightText: © 2023-present Gene C <arch@sapience.com>

¹ <https://github.com/google/googletest>

² <https://abseil.io/about/philosophy#upgrade-support>

CHANGELOG

[5.7.1] — 2025-03-11

After latex update we needed to fix building latex pdf to avoid error
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.7.0] — 2025-02-28

DANE update:

for port 25 tlsa records are generated for each MX record same as always.
But now, if port is not 25, then TLSA records are for each subdomain in the x509
→ SAN domain list.
There is also a capability to specify this with additional element in the dane_tls
→ item which can be "MX" or "SANS"
Expand dane tlsa example config file
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.6.0] — 2025-02-09

Less logging to stdout when not verbose. Keep details in log file
Increase default saved logs to 200k plus 4 backup files
Avoid double log of cert expiration when renewing.
Once when checking and again when renewing
fix: time_to_renew() now returns the expiration string and caller chooses to log or
→ not
small logging improvements
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.4.0] — 2025-01-10

Time to cert expiration now shown with more granularity
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.2.0] — 2024-12-31

Git tags are now signed.
Add git signing key to Arch Package
Bump python vers
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.1.0] — 2024-12-16

Add support **for** certbot `--preferred-chain` flag **in** `ca-info.conf`
New config **for** letsencrypt CA : `preferred_chain` defaults to unset (uses LE default).
e.g. to switch to newer ECC root **set**: `ca_preferred_chain = "ISRG Root X2"`
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[5.0.0] — 2024-12-13

Bug Fix: Its **not** an error **if** `copy_file(src, dst)` when `src` non-existent.
=> copying to production failed incorrectly **if** a `tlsa` file was missing when none_
↪ was needed/generated
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[4.9.0] — 2024-11-27

Fix typo **in** `dns` server when separate server provided **for** specific domain(s)
`conf.d/ssl-mgr.conf` - services can now be wildcard services (ALL **or** *)
Every file **in** group directory that **is** a service config will be included **as** service
add **self** signed wild card example
Fix bug **with** `sslm-info` **not** showing IP addresses **in** SAN
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[4.5.0] — 2024-10-21

* New config variable : `renew_expire_days_spread` (default 0)
When set to value > 0, renew will happen between `expiry_days ±spread` days.
Where spread days is randomly drawn from a uniform distribution between `-spread`
↪ and `spread`.
Using this keeps the average renewal time the same but with multiple certificates
this helps renewals not all fall on same day even if have same expiration.
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[4.4.0] — 2024-10-21

update Docs/Changelog.rst Docs/ssl-mgr.pdf
use `ipaddress` instead of `netaddr`
Improve messages; more compact
Some lint picking
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[4.3.0] — 2024-08-18

New config option `*post_copy_cmd*`
For each server getting copies of certs may run this command on machine on_
↪ which `sslm-mgr` **is** running.
The command **is** passed server hostname **as** an argument.
Usage Example: **if** a server needs a file permission change **for** an application_
↪ user to read private key(s).
This option **is** a **list** of `*[server-host, command]*` pairs
update Docs/Changelog.rst Docs/ssl-mgr.pdf

[4.2.0] — 2024-08-17

X509v3 Extended Key Usage adds `"Time Stamping"`
Changed `sslm-dhparm` to generate RFC-7919

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```

Negotiated Finite Field Diffie-Hellman Ephemeral Parameters files - with the
↪default
  now set to ffdhe8192 instead of ffdhe4096. User options -k overrides the default
↪as usual
  NB push prod certs to all servers using: sslm-mgr dev -certs-prod
  NB TLSv1.3 restricts DH key exchange to named groups only.
openssl trusted certificates there is ExtraData after the cert
  which has the trust data. cryptography.x509 will not load this so strip it off.
  see : https://github.com/pyca/cryptography/issues/5242
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[4.0.2] — 2024-06-11

```

Tweak readme
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[4.0.1] — 2024-06-11

```

Add netaddr as a dependency (used for having IP addresses in alt-names)
Add couple of comments to end of readme about using self-signed certs
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[4.0.0] — 2024-06-11

```

Bug fix: CA certs need to be marked as CA and set certificate signing ability
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.7.0] — 2024-05-29

```

Add comment to Readme about new self signed CA example
Tweak log message on cert expiration
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.6.0] — 2024-05-28

```

Skip writing tlsa file if woule be empty.
Be more tolerant of missing input
Add working example for self signed web server
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.5.0] — 2024-05-26

```

bug fix with self signed root cert expiration not using sign_end_days in config
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.4.0] — 2024-05-26

```

bugfix for self signed cert - fix argument typo
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.3.0] — 2024-05-26

```

Avoid errors when missing servers
update Docs/Changelog.rst Docs/ssl-mgr.pdf

```

[3.2.4] — 2024-05-22

```
README updates
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[3.2.2] — 2024-05-21

```
More readme updates
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[3.2.1] — 2024-05-21

```
update readme
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[3.2.0] — 2024-05-20

```
Tweak logging - more info about nameserver checks and visually tidier
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[3.1.1] — 2024-05-20

```
Seems possible that letsencrypt dns-01 may not always use the apex domain
    authoritative servers or perhaps their (secondary) check can lag more. At least ↵
↵it seems that way lately.
    We tackle this with the addition of 2 new variables to the top level config:
    See README : dns-check-delay and dns_extra_ns.
improve the way nameservers are checked for being up to date with acme challenges.
    First check the primary has all the acme challenge TXT records. Then check
    all nameservers, including the *extra_ns* have the same serial as the primary
Code improvements and cleanup in dns module.
buglet whereby the cleanup code was incorrectly calling for dns nameserver validation.
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.5.0] — 2024-04-23

```
Adjust for upcoming python changes.
Some argparse options have been deprecated in 3.12 and will be removed in 3.14
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.4.0] — 2024-04-21

```
Enhance non-dns restart_cmd to allow a list of commands. Useful for postfix when ↵
↵using sni_maps which must be rebuilt to get new certificates
remove duplicate depends in PKGBUILD
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.3.1] — 2024-03-29

```
more little readme changes
minor readme tweak
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.3.0] — 2024-03-29


```
Add PKGBUILD depends : certbot and optdepends: dns_tools
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.2.1] — 2024-03-29

```
update Docs/Changelog.rst
update project version
Fix typo in PKGBUILD
update Docs/Changelog.rst Docs/ssl-mgr.pdf
```

[2.2.0] — 2024-03-29

```
update cron sample file comment
Initial Commit
```


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HOW TO HELP WITH THIS PROJECT

Thank you for your interest in improving this project. This project is open-source under the MIT license.

6.1 Important resources

- [Git Repo](#)

6.2 Reporting Bugs or feature requests

Please report bugs on the issue tracker in the git repo. To make the report as useful as possible, please include

- operating system used
- version of python
- explanation of the problem or enhancement request.

6.3 Code Changes

If you make code changes, please update the documentation if it's appropriate.

CONTRIBUTOR COVENANT CODE OF CONDUCT

7.1 Our Pledge

In the interest of fostering an open and welcoming environment, we as contributors and maintainers pledge to making participation in our project and our community a harassment-free experience for everyone, regardless of age, body size, disability, ethnicity, sex characteristics, gender identity and expression, level of experience, education, socio-economic status, nationality, personal appearance, race, religion, or sexual identity and orientation.

7.2 Our Standards

Examples of behavior that contributes to creating a positive environment include:

- Using welcoming and inclusive language
- Being respectful of differing viewpoints and experiences
- Gracefully accepting constructive criticism
- Focusing on what is best for the community
- Showing empathy towards other community members

Examples of unacceptable behavior by participants include:

- The use of sexualized language or imagery and unwelcome sexual attention or advances
- Trolling, insulting/derogatory comments, and personal or political attacks
- Public or private harassment
- Publishing others' private information, such as a physical or electronic address, without explicit permission
- Other conduct which could reasonably be considered inappropriate in a professional setting

7.3 Our Responsibilities

Maintainers are responsible for clarifying the standards of acceptable behavior and are expected to take appropriate and fair corrective action in response to any instances of unacceptable behavior.

Maintainers have the right and responsibility to remove, edit, or reject comments, commits, code, wiki edits, issues, and other contributions that are not aligned to this Code of Conduct, or to ban temporarily or permanently any contributor for other behaviors that they deem inappropriate, threatening, offensive, or harmful.

7.4 Scope

This Code of Conduct applies both within project spaces and in public spaces when an individual is representing the project or its community. Examples of representing a project or community include using an official project e-mail address, posting via an official social media account, or acting as an appointed representative at an online or offline event. Representation of a project may be further defined and clarified by project maintainers.

7.5 Enforcement

Instances of abusive, harassing, or otherwise unacceptable behavior may be reported by contacting the project team at [<arch@sapience.com>](mailto:arch@sapience.com). All complaints will be reviewed and investigated and will result in a response that is deemed necessary and appropriate to the circumstances. The Code of Conduct Committee is obligated to maintain confidentiality with regard to the reporter of an incident. Further details of specific enforcement policies may be posted separately.

7.6 Attribution

This Code of Conduct is adapted from the Contributor Covenant, version 1.4, available at <https://www.contributor-covenant.org/version/1/4/code-of-conduct.html>

7.7 Interpretation

The interpretation of this document is at the discretion of the project team.

INDICES AND TABLES