

pgmoneta

Developer Guide

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1 Introduction

pgmoneta is a backup / restore solution for PostgreSQL.

Ideally, you would not need to do backups and disaster recovery, but that isn't how the real World works.

Possible scenarios that could happen

- Data corruption
- System failure
- Human error
- Natural disaster

and then it is up to the database administrator to get the database system back on-line, and to the correct recovery point.

Two key factors are

- Recovery Point Objective (RPO): Maximum targeted period in which data might be lost from an IT service due to a major incident
- Recovery Time Objective (RTO): The targeted duration of time and a service level within which a business process must be restored after a disaster (or disruption) in order to avoid unacceptable consequences associated with a break in business continuity

You would like to have both of these as close to zero as possible, since RPO of 0 means that you won't lose data, and RTO of 0 means that your system recovers at once. However, that is easier said than done.

pgmoneta is focused on having features that will allow database systems to get as close to these goals as possible such that high availability of 99.99% or more can be implemented, and monitored through standard tools.

pgmoneta is named after the Roman Goddess of Memory.

1.1 Features

- Full backup
- Restore
- Compression (gzip, zstd, lz4, bzip2)
- AES encryption support
- Symlink support
- WAL shipping support

- Hot standby
- Prometheus support
- Remote management
- Offline mode
- Transport Layer Security (TLS) v1.2+ support
- Daemon mode
- User vault

1.2 Platforms

The supported platforms are

- Fedora 32+
- RHEL 8 / RockyLinux 8
- RHEL 9 / RockyLinux 9
- FreeBSD
- OpenBSD

2 Installation

2.1 Fedora

You need to add the PostgreSQL YUM repository, for example for Fedora 40

```
dnf install -y https://download.postgresql.org/pub/repos/yum/reporpms/F-40-x86_64/pgdg-fedora-repo-latest.noarch.rpm
```

and do the install via

```
dnf install -y pgmoneta
```

Additional information

- PostgreSQL YUM
- Linux downloads

2.2 RHEL 8 / RockyLinux 8

```
dnf install -y https://dl.fedoraproject.org/pub/epel/epel-release-latest-8.noarch.rpm
dnf install -y https://download.postgresql.org/pub/repos/yum/reporpms/EL-8-x86_64/pgdg-redhat-repo-latest.noarch.rpm
```

and do the install via

```
dnf install -y pgmoneta
```

2.3 RHEL 9 / RockyLinux 9

```
dnf install -y https://dl.fedoraproject.org/pub/epel/epel-release-latest-9.noarch.rpm
dnf install -y https://download.postgresql.org/pub/repos/yum/reporpms/EL-9-x86_64/pgdg-redhat-repo-latest.noarch.rpm
```

and do the install via

```
dnf install -y pgmoneta
```

2.4 Compiling the source

We recommend using Fedora to test and run **pgmoneta**, but other Linux systems, FreeBSD and MacOS are also supported.

pgmoneta requires

- gcc 8+ (C17)
- cmake
- make
- libev
- OpenSSL
- zlib
- zstd
- lz4
- bzip2
- systemd
- rst2man
- libssh
- libcurl
- libarchive

```
dnf install git gcc cmake make libev libev-devel \  
           openssl openssl-devel \  
           systemd systemd-devel zlib zlib-devel \  
           libzstd libzstd-devel \  
           lz4 lz4-devel libssh libssh-devel \  
           libcurl libcurl-devel \  
           python3-docutils libatomic \  
           bzip2 bzip2-devel \  
           libarchive libarchive-devel
```

Alternative clang 8+ can be used.

2.4.1 RHEL / RockyLinux

On RHEL / Rocky, before you install the required packages some additional repositories need to be enabled or installed first.

First you need to install the subscription-manager

```
dnf install subscription-manager
```

It is ok to disregard the registration and subscription warning.

Otherwise, if you have a Red Hat corporate account (you need to specify the company/organization name in your account), you can register using

```
subscription-manager register --username <your-account-email-or-login> --  
password <your-password> --auto-attach
```

Then install the EPEL repository,

```
dnf install epel-release
```

Then to enable powertools

```
# On RHEL 8 / Rocky 8  
dnf config-manager --set-enabled codeready-builder-for-rhel-8-rhui-rpms  
dnf config-manager --set-enabled powertools  
dnf install https://dl.fedoraproject.org/pub/epel/epel-release-latest-8.  
noarch.rpm  
  
# On RHEL 9 / Rocky 9, PowerTools is called crb (CodeReady Builder)  
dnf config-manager --set-enabled codeready-builder-for-rhel-9-rhui-rpms  
dnf config-manager --set-enabled crb  
dnf install https://dl.fedoraproject.org/pub/epel/epel-release-latest-9.  
noarch.rpm
```

Then use the `dnf` command for **pgmoneta** to install the required packages.

2.4.2 FreeBSD

On FreeBSD, `pkg` is used instead of `dnf` or `yum`.

Use `pkg install <package name>` to install the following packages

```
git gcc cmake libev openssl libssh zlib-ng zstd liblz4 bzip2 curl \  
py39-docutils libarchive
```

2.4.3 Build

2.4.3.1 Release build The following commands will install **pgmoneta** in the `/usr/local` hierarchy.

```
git clone https://github.com/pgmoneta/pgmoneta.git  
cd pgmoneta  
mkdir build  
cd build  
cmake -DCMAKE_INSTALL_PREFIX=/usr/local ..
```



```
make
sudo make install
```

See RPM for how to build a RPM of **pgmoneta**.

2.4.3.2 Debug build The following commands will create a **DEBUG** version of **pgmoneta**.

```
git clone https://github.com/pgmoneta/pgmoneta.git
cd pgmoneta
mkdir build
cd build
cmake -DCMAKE_BUILD_TYPE=Debug ..
make
```

2.5 Compiling the documentation

pgmoneta's documentation requires

- pandoc
- texlive

```
dnf install pandoc texlive-scheme-basic \
'tex(footnote.sty)' 'tex(footnotebackref.sty)' \
'tex(pagecolor.sty)' 'tex(hardwrap.sty)' \
'tex(mdframed.sty)' 'tex(sourcesanspro.sty)' \
'tex(ly1enc.def)' 'tex(sourcecodepro.sty)' \
'tex(titling.sty)' 'tex(csquotes.sty)' \
'tex(zref-abspace.sty)' 'tex(needspace.sty)'
```

You will need the **Eisvogel** template as well which you can install through

```
wget https://github.com/Wandmalfarbe/pandoc-latex-template/releases/
download/2.4.2/Eisvogel-2.4.2.tar.gz
tar -xzf Eisvogel-2.4.2.tar.gz
mkdir -p $HOME/.local/share/pandoc/templates
mv eisvogel.latex $HOME/.local/share/pandoc/templates
```

where **\$HOME** is your home directory.

2.5.1 Build

These packages will be detected during **cmake** and built as part of the main build.

3 Git guide

Here are some links that will help you

- [How to Squash Commits in Git](#)
- [ProGit book](#)

3.1 Basic steps

3.1.1 Start by forking the repository

This is done by the “Fork” button on GitHub.

3.2 Clone your repository locally

This is done by

```
git clone git@github.com:<username>/pgmoneta.git
```

3.2.1 Add upstream

Do

```
cd pgmoneta
git remote add upstream https://github.com/pgmoneta/pgmoneta.git
```

3.2.2 Do a work branch

```
git checkout -b mywork main
```

3.2.3 Make the changes

Remember to verify the compile and execution of the code.

Use

```
[#xyz] Description
```

as the commit message where [#xyz] is the issue number for the work, and *Description* is a short description of the issue in the first line

3.2.4 Multiple commits

If you have multiple commits on your branch then squash them

```
git rebase -i HEAD~2
```

for example. It is `p` for the first one, then `s` for the rest

3.2.5 Rebase

Always rebase

```
git fetch upstream  
git rebase -i upstream/main
```

3.2.6 Force push

When you are done with your changes force push your branch

```
git push -f origin mywork
```

and then create a pull request for it

3.2.7 Format source code

Use

```
./uncrustify.sh
```

to format the source code

3.2.8 Repeat

Based on feedback keep making changes, squashing, rebasing and force pushing

3.2.9 Undo

Normally you can reset to an earlier commit using `git reset <commit hash> --hard`.

But if you accidentally squashed two or more commits, and you want to undo that, you need to know where to reset to, and the commit seems to have lost after you rebased.

But they are not actually lost - using `git reflog`, you can find every commit the HEAD pointer has ever pointed to. Find the commit you want to reset to, and do `git reset --hard`.

4 Architecture

4.1 Overview

pgmoneta use a process model (`fork()`), where each process handles one Write-Ahead Log (WAL) receiver to PostgreSQL.

The main process is defined in `main.c`.

Backup is handled in `backup.h` (`backup.c`).

Restore is handled in `restore.h` (`restore.c`) with linking handled in `link.h` (`link.c`).

Archive is handled in `achv.h` (`archive.c`) backed by restore.

Write-Ahead Log is handled in `wal.h` (`wal.c`).

Backup information is handled in `info.h` (`info.c`).

Retention is handled in `retention.h` (`retention.c`).

Compression is handled in `gzip.h` (`gzip.c`) and `zstandard.h` (`zstandard.c`).

4.2 Shared memory

A memory segment (`shmem.h`) is shared among all processes which contains the **pgmoneta** state containing the configuration and the list of servers.

The configuration of **pgmoneta** (`struct configuration`) and the configuration of the servers (`struct server`) is initialized in this shared memory segment. These structs are all defined in `pgmoneta.h`.

The shared memory segment is created using the `mmap()` call.

4.3 Network and messages

All communication is abstracted using the `struct message` data type defined in `message.h`.

Reading and writing messages are handled in the `message.h` (`message.c`) files.

Network operations are defined in `network.h` (`network.c`).

4.4 Memory

Each process uses a fixed memory block for its network communication, which is allocated upon startup of the process.

That way we don't have to allocate memory for each network message, and more importantly free it after end of use.

The memory interface is defined in `memory.h` (`memory.c`).

4.5 Management

pgmoneta has a management interface which defines the administrator abilities that can be performed when it is running. This include for example taking a backup. The `pgmoneta-cli` program is used for these operations (`cli.c`).

The management interface use Unix Domain Socket for communication.

The management interface is defined in `management.h`. The management interface uses its own protocol which always consist of a header

Field	Type	Description
<code>id</code>	Byte	The identifier of the message type

The rest of the message is depending on the message type.

4.5.1 Remote management

The remote management functionality uses the same protocol as the standard management method.

However, before the management packet is sent the client has to authenticate using SCRAM-SHA-256 using the same message format that PostgreSQL uses, e.g. `StartupMessage`, `AuthenticationSASL`, `AuthenticationSASLContinue`, `AuthenticationSASLFinal` and `AuthenticationOk`. The `SSLRequest` message is supported.

The remote management interface is defined in `remote.h` (`remote.c`).

4.6 libev usage

libev is used to handle network interactions, which is "activated" upon an `EV_READ` event.

Each process has its own event loop, such that the process only gets notified when data related only to that process is ready. The main loop handles the system wide “services” such as idle timeout checks and so on.

4.7 Signals

The main process of **pgmoneta** supports the following signals `SIGTERM`, `SIGINT` and `SIGALRM` as a mechanism for shutting down. The `SIGABRT` is used to request a core dump (`abort()`).

The `SIGHUP` signal will trigger a reload of the configuration.

It should not be needed to use `SIGKILL` for **pgmoneta**. Please, consider using `SIGABRT` instead, and share the core dump and debug logs with the **pgmoneta** community.

4.8 Reload

The `SIGHUP` signal will trigger a reload of the configuration.

However, some configuration settings requires a full restart of **pgmoneta** in order to take effect. These are

- `hugepage`
- `libev`
- `log_path`
- `log_type`
- `unix_socket_dir`
- `pidfile`

The configuration can also be reloaded using `pgmoneta-cli -c pgmoneta.conf conf reload`. The command is only supported over the local interface, and hence doesn't work remotely.

4.9 Prometheus

pgmoneta has support for Prometheus when the `metrics` port is specified.

The module serves two endpoints

- `/` - Overview of the functionality (`text/html`)
- `/metrics` - The metrics (`text/plain`)

All other URLs will result in a 403 response.

The metrics endpoint supports `Transfer-Encoding: chunked` to account for a large amount of data.

The implementation is done in `prometheus.h` and `prometheus.c`.

4.10 Logging

Simple logging implementation based on a `atomic_schar` lock.

The implementation is done in `logging.h` and `logging.c`.

4.11 Protocol

The protocol interactions can be debugged using Wireshark or `pgprtdbg`.

5 Encryption

5.1 Overview

AES Cipher block chaining (CBC) mode and AES Counter (CTR) mode are supported in **pgmoneta**. The default setup is no encryption.

CBC is the most commonly used and considered safe mode. Its main drawbacks are that encryption is sequential (decryption can be parallelized).

Along with CBC, CTR mode is one of two block cipher modes recommended by Niels Ferguson and Bruce Schneier. Both encryption and decryption are parallelizable.

Longer the key length, safer the encryption. However, with 20% (192 bit) and 40% (256 bit) extra workload compare to 128 bit.

5.2 Encryption Configuration

`none`: No encryption (default value)

`aes` | `aes-256` | `aes-256-cbc`: AES CBC (Cipher Block Chaining) mode with 256 bit key length

`aes-192` | `aes-192-cbc`: AES CBC mode with 192 bit key length

`aes-128` | `aes-128-cbc`: AES CBC mode with 128 bit key length

`aes-256-ctr`: AES CTR (Counter) mode with 256 bit key length

`aes-192-ctr`: AES CTR mode with 192 bit key length

`aes-128-ctr`: AES CTR mode with 128 bit key length

5.3 Encryption / Decryption CLI Commands

5.3.1 decrypt

Decrypt the file in place, remove encrypted file after successful decryption.

Command

```
pgmoneta-cli decrypt <file>
```

5.3.2 encrypt

Encrypt the file in place, remove unencrypted file after successful encryption.

Command

```
pgmoneta-cli encrypt <file>
```

5.4 Benchmark

Check if your CPU have AES-NI

```
cat /proc/cpuinfo | grep aes
```

Query number of cores on your CPU

```
lscpu | grep '^CPU(s):'
```

By default openssl using AES-NI if the CPU have it.

```
openssl speed -elapsed -evp aes-128-cbc
```

Speed test with explicit disabled AES-NI feature

```
OPENSSL_ia32cap="~0x2000002000000000" openssl speed -elapsed -evp aes-128-cbc
```

Test decrypt

```
openssl speed -elapsed -decrypt -evp aes-128-cbc
```

Speed test with 8 cores

```
openssl speed -multi 8 -elapsed -evp aes-128-cbc
```

```
Architecture:          x86_64
CPU op-mode(s):       32-bit, 64-bit
Address sizes:        39 bits physical, 48 bits virtual
Byte Order:           Little Endian
CPU(s):               12
On-line CPU(s) list: 0-11
Vendor ID:            GenuineIntel
Model name:           Intel(R) Core(TM) i7-9750H CPU @ 2.60GHz
CPU family:           6
Model:                158
Thread(s) per core:  2
Core(s) per socket:  6
Socket(s):            1
```

```
Stepping:          10
BogoMIPS:          5183.98
Flags:             fpu vme de pse tsc msr pae mce cx8 apic sep mtrr
                  pge mca cmov pat pse36 clflush mmx fxsr sse sse2 s
                  s ht syscall nx pdpe1gb rdtscp lm constant_tsc
                  rep_good nopl xtopology cpuid pni pclmulqdq
                  vmx ssse
                  3 fma cx16 pcid sse4_1 sse4_2 movbe popcnt aes
                  xsave avx f16c rdrand hypervisor lahf_lm abm 3
                  dnowpr
                  efetch invpcid_single pti ssbd ibrs ibpb stibp
                  tpr_shadow vnmi ept vpid ept_ad fsgsbase bmi1
                  avx2 s
                  mep bmi2 erms invpcid rdseed adx smap clflushopt
                  xsaveopt xsavec xgetbv1 xsaves flush_l1d
                  arch_capa
                  bilities
Virtualization features:
  Virtualization:  VT-x
  Hypervisor vendor: Microsoft
  Virtualization type: full
Caches (sum of all):
  L1d:             192 KiB (6 instances)
  L1i:             192 KiB (6 instances)
  L2:              1.5 MiB (6 instances)
  L3:              12 MiB (1 instance)
Vulnerabilities:
  Itlb multihit:   KVM: Mitigation: VMX disabled
  L1tf:            Mitigation; PTE Inversion; VMX conditional cache
                  flushes, SMT vulnerable
  Mds:             Vulnerable: Clear CPU buffers attempted, no
                  microcode; SMT Host state unknown
  Meltdown:        Mitigation; PTI
  Spec store bypass: Mitigation; Speculative Store Bypass disabled via
                  prctl and seccomp
  Spectre v1:      Mitigation; usercopy/swaps barriers and __user
                  pointer sanitization
  Spectre v2:      Mitigation; Full generic retpoline, IBPB
                  conditional, IBRS_FW, STIBP conditional, RSB filling
  Srbds:           Unknown: Dependent on hypervisor status
  Tsx async abort: Not affected

openssl version: 3.0.5
built on: Tue Jul  5 00:00:00 2022 UTC
options: bn(64,64)
compiler: gcc -fPIC -pthread -m64 -Wa,--noexecstack -O2 -flto=auto -ffat-
lto-objects -fexceptions -g -grecord-gcc-switches -pipe -Wall -Werror=
format-security -Wp,-D_FORTIFY_SOURCE=2 -Wp,-D_GLIBCXX_ASSERTIONS -
specs=/usr/lib/rpm/redhat/redhat-hardened-cc1 -fstack-protector-strong
-specs=/usr/lib/rpm/redhat/redhat-annobin-cc1 -m64 -mtune=generic -
fasynchronous-unwind-tables -fstack-clash-protection -fcf-protection -
```

```

O2 -flto=auto -ffat-lto-objects -fexceptions -g -grecord-gcc-switches -
pipe -Wall -Werror=format-security -Wp,-D_FORTIFY_SOURCE=2 -Wp,-
D_GLIBCXX_ASSERTIONS -specs=/usr/lib/rpm/redhat/redhat-hardened-cc1 -
fstack-protector-strong -specs=/usr/lib/rpm/redhat/redhat-annobin-cc1 -
m64 -mtune=generic -fasynchronous-unwind-tables -fstack-clash-
protection -fcf-protection -Wa,--noexecstack -Wa,--generate-missing-
build-notes=yes -specs=/usr/lib/rpm/redhat/redhat-hardened-ld -specs=/
usr/lib/rpm/redhat/redhat-annobin-cc1 -DOPENSSL_USE_NODELETE -DL_ENDIAN
-DOPENSSL_PIC -DOPENSSL_BUILDING_OPENSSL -DZLIB -DNDEBUG -DPURIFY -
DDEV_RANDOM="/dev/urandom\" -DSYSTEM_CIPHERS_FILE="/etc/crypto-
policies/back-ends/openssl.config"

```

The 'numbers' are in 1000s of bytes per second processed.

type	16 bytes	64 bytes	256 bytes	1024 bytes	8192
AES-128-CBC *	357381.06k	414960.06k	416301.23k	416687.10k	
	416175.45k	416268.29k			
AES-128-CBC	902160.83k	1496344.68k	1514778.62k	1555236.52k	
	1542537.22k	1569259.52k			
AES-128-CBC d	909710.79k	2941259.46k	5167110.31k	5927086.76k	
	6365967.70k	6349198.68k			
AES-128-CBC 8	3912786.36k	8042348.31k	9870507.86k	10254096.38k	
	10653332.82k	10310331.05k			
AES-128-CBC 8d	4157037.26k	12337480.36k	26613686.27k	29902703.27k	
	32306793.13k	31440366.25k			
AES-128-CTR *	146971.83k	165696.94k	574871.64k	634507.61k	
	676448.94k	668139.52k			
AES-128-CTR	887783.06k	2255074.22k	4800168.19k	5930596.01k	
	6431110.49k	6376062.98k			
AES-128-CTR d	793432.63k	2181439.06k	4541298.09k	5743022.42k	
	6480090.45k	6271221.76k			
AES-128-CTR 8	3833975.47k	10832239.55k	23757293.40k	28413146.79k	
	30514317.99k	30092356.27k			
AES-128-CTR 8d	3456838.44k	9749773.91k	22107652.18k	27229352.28k	
	30703026.18k	29387025.07k			
AES-192-CBC	853380.50k	1238507.90k	1299788.12k	1257189.03k	
	1272591.70k	1271840.77k			
AES-192-CBC d	876094.29k	2843770.82k	4523019.52k	5177496.92k	
	5442652.84k	5372559.36k			
AES-192-CTR	869039.84k	2285946.18k	4229439.91k	5049118.04k	
	5422994.77k	5309748.57k			
AES-192-CTR d	789470.51k	2177050.05k	4194812.76k	4935891.63k	
	5257865.90k	5323046.91k			
AES-256-CBC	834298.24k	1100648.64k	1117826.90k	1104301.40k	
	1130657.11k	1097285.63k			
AES-256-CBC d	843079.68k	2714917.67k	4084088.23k	4510005.59k	
	4557821.27k	4594783.57k			
AES-256-CTR	811325.74k	2222582.89k	3749333.08k	4412143.27k	
	4640549.55k	4554828.46k			

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AES-256-CTR d	730844.97k	2081179.20k	3673258.15k	4346793.64k
	4515722.58k	4594335.74k		

*: AES-NI disabled; 8: 8 cores; d: decryption

6 RPM

pgmoneta can be built into a RPM for Fedora systems.

6.1 Requirements

```
dnf install gcc rpm-build rpm-devel rpmlint make python bash coreutils
diffutils patch rpmdevtools chrpath
```

6.2 Setup RPM development

```
rpmdev-setuptree
```

6.3 Create source package

```
git clone https://github.com/pgmoneta/pgmoneta.git
cd pgmoneta
mkdir build
cd build
cmake -DCMAKE_BUILD_TYPE=Release ..
make package_source
```

6.4 Create RPM package

```
cp pgmoneta-$VERSION.tar.gz ~/rpmbuild/SOURCES
QA_RPATHS=0x0001 rpmbuild -bb pgmoneta.spec
```

The resulting RPM will be located in `~/rpmbuild/RPMS/x86_64/`, if your architecture is `x86_64`

7 Troubleshooting

7.1 Could not get version for server

If you get this `FATAL` during startup check your PostgreSQL logins

```
psql postgres
```

and

```
psql -U repl postgres
```

And, check the PostgreSQL logs for any error.

Setting `log_level` to `DEBUG5` in `pgmoneta.conf` could provide more information about the error.

8 Acknowledgement

8.1 Authors

pgmoneta was created by the following authors:

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8.2 Contributing

Contributions to **pgmoneta** are managed on GitHub

- Ask a question
- Raise an issue
- Feature request
- Code submission

Contributions are most welcome!

Please, consult our Code of Conduct policies for interacting in our community.

Consider giving the project a star on GitHub if you find it useful. And, feel free to follow the project on Twitter as well.

9 License

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9.1 libart

Our adaptive radix tree (ART) implementation is based on The Adaptive Radix Tree: ARTful Indexing for Main-Memory Databases and libart which has a 3-BSD license as

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