Securing PostgreSQL – Exploring the PostgreSQL STIG and Beyond

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Securing PostgreSQL

- PostgreSQL and Ecosystem: Security Features
- Security Technical Implementation Guide (STIG)
- Related postgresql.conf settings and pg_hba.conf rules
- Appendix: pgaudit, set_user, RLS Timetravel

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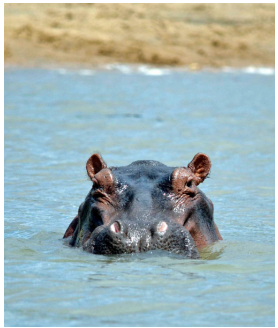
http://www.postgresql.org

https://postgresql.us/

Security

- International Recognition
  - Common Criteria, ISO/IEC 15408 (CC)
  - Security Technical Implementation Guide (STIG)
  - Center for Internet Security (CIS) Benchmark (Work in Progress)
- Features
  - Perimeter
  - Internal
  - Chronological



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Security - Perimeter

- Operating System
  - OS Configuration
    - FIPS 140-2 compliance
    - STIG
  - Discretionary Access Control (DAC)
    - Not privileged account
    - Runtime perm checks
  - Mandatory Access Control (MAC)
    - SELinux: Confined (RHEL - MCS Policy)
  - Encryption at rest
    - Filesystem encryption, many options

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Security - Perimeter

- Client-server
  - Authentication
    - Host based authentication
    - Internal: md5*, SCRAM**, PAM, peer, SSL cert
    - External: GSSAPI, SSPI, LDAP, RADIUS
  - Encryption in transit
    - SSL

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Security - Internal

- DAC
  - ROLE
    - vs. USER and GROUP
    - Hierarchical
  - GRANT and REVOKE
    - Follows SQL Standard reasonably closely
    - Covers virtually all DB Objects
  - Encryption
    - pg_crypto: PGP, OpenSSL; hashing and encryption
    - Application encryption always possible

Security - Internal

- set_user extension
  - Allows switching users and privilege escalation with enhanced logging and control
  - GRANT EXECUTE on set_user functions to otherwise unprivileged users
  - Switch the effective user when needed to perform specific actions
    - ALTER superuser to NOLOGIN, escalate with `set_user_u()`
    - Use connection pool, multiplex unprivileged users with `set_user()`
  - Enhanced logging ensures an audit trail
  - More detail in Appendix

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Security - Internal

- MAC
  - sepgsql: SELinux bindings
    - RBAC Type Enforcement covers most DB Objects
    - Can combine with custom SELinux policy for powerful control
- Row Level Security
  - Tables can have row security policies
  - Restrict, on a per-user basis
    - Which rows visible to normal queries
    - What can be inserted, updated, or deleted

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Security - Chronological

- Error logging and reporting
  - stderr, csvlog, eventlog (Windows only), and syslog
  - Many options: where, when, what
  - Remote via syslog, ship with logstash/beats
- pgaudit extension
  - Enhanced logging for audit purposes
    - More granular
    - Resists obfuscation
  - Session-based (coarse grained)
  - Object-based (fine grained)
  - More detail in Appendix

Security - Chronological

- Trigger based history
  - Event triggers - DDL
  - DML triggers - JSON, hstore, timestamp range datatype
  - Audit trigger example
- RLS Policy
  - Use timestamp range datatype
  - Policy makes only current version visible by default
  - Old versions saved via trigger
  - Partitioning keeps current and old row separated
  - Example in Appendix

Terms

- Defense Information Systems Agency (DISA)
  - Combat Support Agency
  - Provides, operates, and assures:
    - command and control
    - information sharing capabilities
    - globally accessible enterprise information infrastructure

Terms

- Security Technical Implementation Guides (STIGs)
  - Configuration standards for DOD systems
  - Contain technical guidance to "lock down" systems/software

Terms

- Control Correlation Identifier (CCI)
  - Standard id and description for each of the singular, actionable statements that comprise an Information Assurance (IA) control or IA best practice
  - Allows traceability of security requirements from origin to low-level implementation

PostgreSQL STIG

- PostgreSQL 9.X on RHEL Security Technical Implementation Guide (STIG)
  - Offers security-conscious enterprises a comprehensive guide for configuration and operation of open source PostgreSQL
  - Based on the Database Security Requirements Guide (SRG) Version 2 Release 6
  - Derives controls from NIST Special Publication (SP) 800-53, Revision 4
  - Red Hat Enterprise Linux 7.X
  - PostgreSQL 9.5+
  - 111 Rules
  - All Open Source Components

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PostgreSQL STIG

- Provides guidance to address requirements associated with:
  - Auditing
  - Logging
  - Data Encryption at Rest
  - Data Encryption Over the Wire
  - Access Controls
  - Administration
  - Authentication
  - Protecting against SQL Injection

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Appendixes

- Instructions and code samples
- Assist with the implementation of the Fixes in the main STIG document
- Useful in many PostgreSQL deployments
- Verify applicability and tailor it as necessary

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Appendixes

- Covered:
  - Sample account lockout script
  - pgaudit installation and configuration
  - General logging and remote logging configuration
  - RLS use example SQL script
  - pgcrypto installation
  - Finding and checking PGDATA
  - SSL configuration guide (detailed)

Notes

- Requires RHEL to enable FIPS 140-2 compliant cryptographic modules
- STIG is but one component of a robust defense-in-depth
  - Use along with the applicable operating system and network STIGs
  - Train users in importance of good security practices
- Rules, checks, fixes are generic
  - Verify each rule and examples applicable
  - Tailor as necessary for your environment

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Anatomy of a Rule

- General Info: title, identifiers, severity category
- Discussion: describes security issue under consideration
- Check: how to check compliance with the rule
- Fix: how to remediate for compliance with the rule
- References: related CCI and NIST standards

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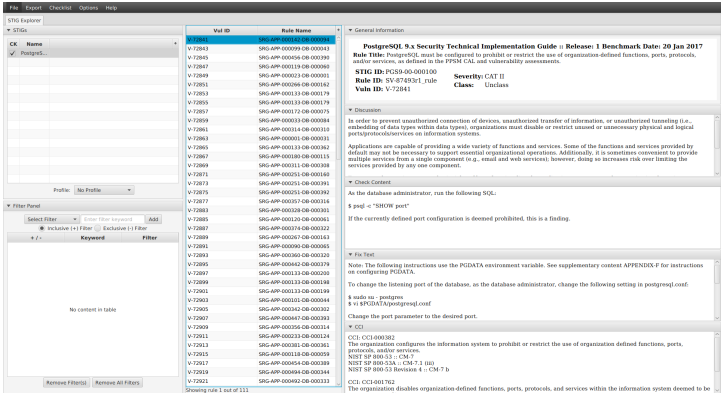
Severity Category Codes

- Measure of vulnerabilities used to assess security posture
- Rules assigned CAT I, II, or III
- With respect to Confidentiality, Availability, or Integrity (CAI):
  - CAT I: exploit directly and immediately results in loss of CAI
  - CAT II: exploit has potential to result in loss of CAI
  - CAT III: existence degrades measures to protect against loss of CAI

STIG Viewer

- STIG Viewer:
  https://iase.disa.mil/stigs/Pages/stig-viewing-guidance.aspx
- `java -jar STIGViewer-2.5.4.jar`

STIG Viewer - Demo



STIG Checker

- STIG Checker
  https://github.com/CrunchyData/pgstigcheck-inspec
- Open source
- Work in progress
- Uses chef/inspec
- Other versions planned, e.g. OpenSCAP

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Enterprise PostgreSQL

General Information

Rule Title: PostgreSQL must be configured to prohibit or restrict the use of organization-defined functions, ports, protocols, and/or services, as defined in the PPSM CAL and vulnerability assessments.
STIG ID: PGS9-00-000100
Rule ID: SV-87493r1_rule
Vuln ID: V-72841
Severity: CAT II
Class: Unclass

Discussion

In order to prevent unauthorized connection of devices, unauthorized transfer of information, or unauthorized tunneling (i.e., embedding of data types within data types), organizations must disable or restrict unused or unnecessary physical and logical ports/protocols/services on information systems.

Applications are capable of providing a wide variety of functions and services. Some of the functions and services provided by default may not be necessary to support essential organizational operations. Additionally, it is sometimes convenient to provide multiple services from a single component (e.g., email and web services); however, doing so increases risk over limiting the services provided by any one component.

Discussion

To support the requirements and principles of least functionality, the application must support the organizational requirements providing only essential capabilities and limiting the use of ports, protocols, and/or services to only those required, authorized, and approved to conduct official business or to address authorized quality of life issues.

Database Management Systems using ports, protocols, and services deemed unsafe are open to attack through those ports, protocols, and services. This can allow unauthorized access to the database and through the database to other components of the information system.

Check

As the database administrator, run the following SQL:

```
$ psql -c "SHOW port"
```

If the currently defined port configuration is deemed prohibited, this is a finding.

Fix

Note: The following instructions use the PGDATA environment variable. See supplementary content APPENDIX-F for instructions on configuring PGDATA.

To change the listening port of the database, as the database administrator, change the following setting in postgresql.conf:

```
$ sudo su - postgres
$ vi $PGDATA/postgresql.conf
```

Change the port parameter to the desired port.

Next, restart the database:

```
# SYSTEMD SERVER ONLY
$ systemctl restart postgresql-9.5
# INITD SERVER ONLY
$ service postgresql-9.5 restart
```

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Fix

Note: psql uses the default port 5432 by default. This can be changed by specifying the port with psql or by setting the PGPORT environment variable:

```
$ psql -p 5432 -c "SHOW work_mem"
$ export PGPORT=5432
```

References

CCI: CCI-000382
The organization configures the information system to prohibit or restrict the use of organization defined functions, ports, protocols, and/or services.
NIST SP 800-53 :: CM-7
NIST SP 800-53A :: CM-7.1 (iii)
NIST SP 800-53 Revision 4 :: CM-7 b

CCI: CCI-001762
The organization disables organization-defined functions, ports, protocols, and services within the information system deemed to be unnecessary and/or nonsecure.
NIST SP 800-53 Revision 4 :: CM-7 (1) (b)

STIG Related Configs

```
shared_preload_libraries = 'pgaudit'

pgaudit.log = 'all, -misc'
pgaudit.log_catalog = on
pgaudit.log_level = 'log'
pgaudit.log_parameter = on
pgaudit.log_relation = on
pgaudit.log_statement_once = off
pgaudit.role = 'auditor'

log_connections = on
log_disconnections = on
log_error_verbosity = default
log_line_prefix = '%m %a %u %d %r %p %s %c %e: '
log_file_mode = 0600
```

STIG Related Configs

```
log_destination = 'syslog'
syslog_facility = 'LOCAL0'
syslog_ident = 'postgres'
client_min_messages = error

log_timezone = 'UTC'
password_encryption = on

ssl = on
ssl_ca_file = '/some/protected/directory/root.crt'
ssl_crl_file = '/some/protected/directory/root.crl'
ssl_cert_file = '/some/protected/directory/server.crt'
ssl_key_file = '/some/protected/directory/server.key'
```

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STIG Related Configs

```
# Set these parameters to organizational requirements:
port = 5432
max_connections = N
statement_timeout = X
tcp_keepalives_idle = Y
tcp_keepalives_interval = Z
tcp_keepalives_count = Q
```

Host Based Authentication File

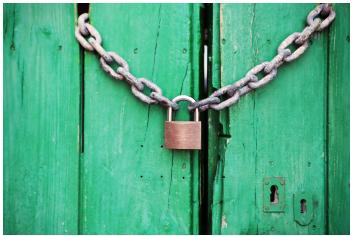
- pg_hba.conf
- Which hosts are allowed to connect
- How clients are authenticated
- Which PostgreSQL user names they can use
- Which databases they can access

Host Based Authentication File

- Read on server startup
- Must reload postmaster for changes to take effect
- First line matching conn type, address, database, and user is used for authentication
- If line picked and authentication fails, access denied
- If no line matches, access denied

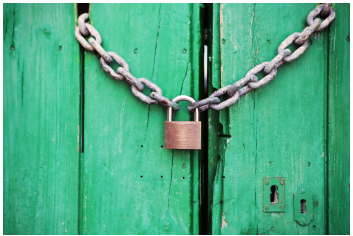
Host Based Authentication File

```
# CONN-TYPE  DATABASE  USER     ADDRESS     METHOD    OPTIONS
# local      <dbname>  <user>               <method>  [<opts>]
# host       <dbname>  <user>   <address>   <method>  [<opts>]
# hostssl    <dbname>  <user>   <address>   <method>  [<opts>]
# hostnossl  <dbname>  <user>   <address>   <method>  [<opts>]

# Default values on Debian-variants
local        all       postgres              peer
local        all       all                   peer
host         all       all      127.0.0.1/32 md5
host         all       all      ::1/128      md5

# RHEL7
local        all       all                   peer
host         all       all      127.0.0.1/32 ident
host         all       all      ::1/128      ident
```



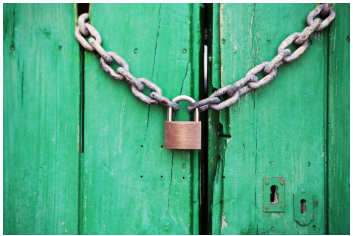
Connection

- Specifies type of connection the rule matches
- `local`: Unix-domain socket
- `host`: Either plain or SSL-encrypted TCP/IP socket
- `hostssl`: SSL-encrypted TCP/IP socket
- `hostnossl`: Plain TCP/IP socket



Database

- Specifies set of databases the rule matches
- `all`: Wildcard
- `sameuser`: Database name matches user name
- `samerole`: User part of role/group matching database name
- `replication`: `all` keyword does not match `replication`
- `<dbname>[,<dbname>]`: One or more specific database names
- `@<filename>`: Separate file containing names to match

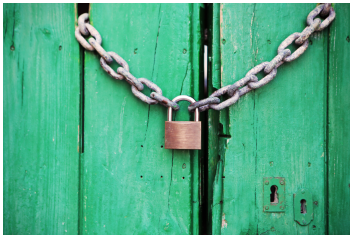


User

- Specifies set of users the rule matches
- `all`: Wildcard
- `<username>[,<username>]`: One or more user names
- `+<groupname>`: Any roles that are directly or indirectly members of this role
- `@<filename>`: Separate file containing names to match

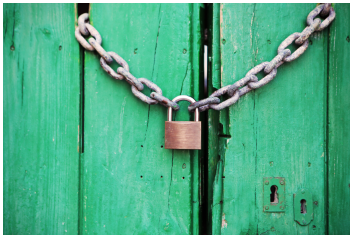
Address

- Specifies set of client hosts the rule matches
- `<IPAddr>/<CIDR-Mask>`: Host or Network
- `<IPAddr> <Mask>`: Host or Network
- `[.]<hostname>`: [suffix] actual FQ hostname
- `samehost`: match any of server's own IP addresses
- `samenet`: match any address in any subnet that server directly connected to



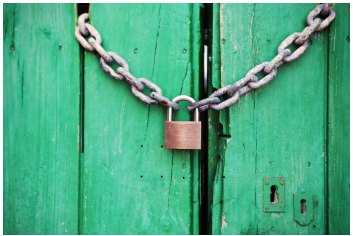
Method

- Specifies authentication method to use when connection matches rule
- `trust`
- `md5`, `password`
- `cert`
- `peer`, `pam`, `ident`
- `gss`, `sspi`, `ldap`, `radius`
- `reject`



Options

- Set of options for the authentication in the format NAME=VALUE
- Options depend on authentication method
- Refer to "Client Authentication" section of docs



STIG Related HBA settings

- An auth-method of "password" is explicitly forbidden
- Although auth-method "md5" not explicitly banned, FIPS 140-2 compliance blocks it
- Use auth-method of cert, gss, sspi, or ldap unless justified and approved
- Every role must have unique authentication requirements
- LOGIN roles must not be shared

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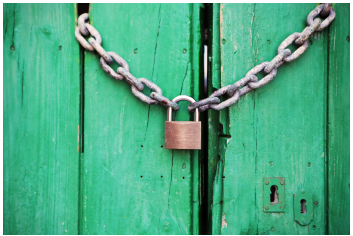
STIG Related HBA settings

- With auth-method cert:
  - hostssl entries must contain clientcert=1
  - User mapping must be used as appropriate
  - CRL file must exist and be used



```
# pg_hba.conf example rule
hostssl all bob samenet cert clientcert=1 map=ssl-test

# example client command
psql "postgresql://<HOSTNAME>:<PORT>/postgres?sslmode=verify-full" -U bob
```

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Questions?

Thank You!
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pgaudit

- Repository: https://github.com/pgaudit/pgaudit
- Provides detailed session and/or object audit logging
- Uses standard PostgreSQL logging facility
- Goal is to produce audit logs required for compliance
- Supports session and object level logging

Session Logging

- `read`: SELECT and COPY when the source is a relation or a query
- `write`: INSERT, UPDATE, DELETE, TRUNCATE, and COPY when the destination is a relation
- `function`: Function calls and DO blocks
- `role`: Statements related to roles and privileges: GRANT, REVOKE, CREATE/ALTER/DROP ROLE
- `ddl`: All DDL that is not included in the ROLE class
- `misc`: Miscellaneous commands, e.g. DISCARD, FETCH, CHECKPOINT, VACUUM
- `all`: All statements

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Session Logging

```
-- Example:
-- Enable session logging for all DML and DDL
set pgaudit.log = 'write, ddl';

-- Enable session logging for all commands except MISC
set pgaudit.log = 'all, -misc';
```

Object Logging

- Logs statements affecting particular relation
- Only SELECT, INSERT, UPDATE and DELETE commands are supported
- Intended to be a finer-grained replacement for `pgaudit.log = 'read, write'`
- Implemented via the roles system (`pgaudit.role` setting)
- Relation (TABLE, VIEW, etc.) audit logged when audit role has (or inherits) permissions for the executed command

Object Logging

```
-- Example:
-- Set pgaudit.role to auditor and grant SELECT and DELETE privileges
-- on the account table. Any SELECT or DELETE statements on the account
-- table will now be logged:

set pgaudit.role = 'auditor';

grant select, delete
   on public.account
   to auditor;
```

Installation and Settings

- See U_PostgreSQL_9-x_V1R1_Supplemental.pdf
- Section 2.2. Appendix B for installation and configuration
- STIG configuration:

```
shared_preload_libraries = 'pgaudit'
pgaudit.log = 'all, -misc'
pgaudit.log_catalog = on
pgaudit.log_level = 'log'
pgaudit.log_parameter = on
pgaudit.log_relation = on
pgaudit.log_statement_once = off
pgaudit.role = 'auditor'
```

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set_user

- set_user allows switching users and optionally privilege escalation with enhanced logging and control
- Useful when users must escalate to superuser or object owner roles to perform needed maintenance tasks
- Also useful to multiplex unprivileged users with common connection

Superuser abuse

```
CREATE FUNCTION malloc(integer) RETURNS bigint
    LANGUAGE c IMMUTABLE STRICT LEAKPROOF
    AS '$libdir/plpgsql', 'malloc';

CREATE FUNCTION strdup(bigint) RETURNS cstring
    LANGUAGE c IMMUTABLE STRICT LEAKPROOF
    AS '$libdir/plpgsql', 'strdup';

CREATE FUNCTION open(cstring, integer) RETURNS integer
    LANGUAGE c IMMUTABLE STRICT LEAKPROOF
    AS '$libdir/plpgsql', 'open';

CREATE FUNCTION read(integer, bigint, integer) RETURNS integer
    LANGUAGE c IMMUTABLE STRICT LEAKPROOF
    AS '$libdir/plpgsql', 'read';
```

Superuser abuse

```
WITH
  buf(d) AS (select malloc(3312)),
  rd(l)  AS (select read(open('/etc/passwd'::cstring, 0),
                         buf.d,
                         3311) from buf)
SELECT rd.l AS size, left(strdup(buf.d)::text,188) AS first_few_lines
FROM rd, buf;
 size |                first_few_lines
------+-------------------------------------------------
 3311 | root:x:0:0:root:/root:/bin/bash                +
      | daemon:x:1:1:daemon:/usr/sbin:/usr/sbin/nologin+
      | bin:x:2:2:bin:/bin:/usr/sbin/nologin           +
      | sys:x:3:3:sys:/dev:/usr/sbin/nologin           +
      | sync:x:4:65534:sync:/bin:/bin/sync
(1 row)
```

Concept

- GRANT EXECUTE on `set_user()` and/or `set_user_u()` to otherwise unprivileged users
- Can switch the effective user when needed to perform specific actions
- Optional enhanced logging ensures an audit trail
- Once one or more unprivileged users able to run `set_user_u()`, ALTER superuser to NOLOGIN
- Multiplex unprivileged users, e.g. with connection pools

Overview

- When an allowed user executes `set_user('rolename')` or `set_user_u('rolename')`, several actions occur:
  - Current effective user becomes rolename
  - Role transition is logged, with specific notation if rolename is a superuser
  - Optionally `ALTER SYSTEM` commands will be blocked
  - Optionally `COPY PROGRAM` commands will be blocked
  - Optionally `SET log_statement` and variations will be blocked
  - If `set_user.block_log_statement = on` and rolename is a database superuser, current `log_statement` setting is changed to "all", meaning every SQL statement executed

Overview

- `reset_user()` function executed to restore the original user
- At that point, these actions occur:
  - Role transition is logged
  - `log_statement` setting is set to its original value
  - Blocked command behaviors return to normal

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Superuser Escalation

- EXECUTE permission on `set_user_u('rolename')` required
- `set_user.superuser_whitelist` provides additional filter
- If `set_user.superuser_whitelist = ''`, escalation is blocked
- If `set_user.superuser_whitelist = '*'`, escalation is unfiltered
- Default is `set_user.superuser_whitelist = '*'`
- Combination of DAC (`GRANT EXECUTE ...`) and configuration (`set_user.superuser_whitelist`) allows two person control

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Unprivileged Multiplexing

- EXECUTE permission on `set_user('rolename')` or `set_user('rolename','token')` required
- `set_user('rolename','token')`: token stored in session lifetime memory
  - `reset_user('token')` must be called instead of `reset_user()`
  - Provided token is compared with the stored token
  - If tokens do not match, or if a token was provided to `set_user` but not `reset_user`, ERROR occurs.

RLS Timetravel

- Possible alternative to "history" tables
- Use RLS to filter based on point in time
- Use PG10 partitioning to keep history separate from current

RLS Timetravel

```
CREATE TABLE timetravel
(
  id int8,
  f1 text not null,
  tr tstzrange not null default tstzrange(clock_timestamp(), 'infinity', '[]')
) PARTITION BY RANGE (upper(tr));

CREATE TABLE timetravel_current PARTITION OF timetravel
(
  primary key (id, tr) DEFERRABLE
) FOR VALUES FROM ('infinity') TO (MAXVALUE);
CREATE INDEX timetravel_current_tr_idx ON timetravel_current USING GIST (tr);

CREATE TABLE timetravel_history PARTITION OF timetravel
(
  primary key (id, tr) DEFERRABLE
) FOR VALUES FROM (MINVALUE) TO ('infinity');
CREATE INDEX timetravel_history_tr_idx ON timetravel_history USING GIST (tr);
```

RLS Timetravel

```
CREATE OR REPLACE FUNCTION get_pit() RETURNS timestamptz AS $$
  SELECT
  CASE WHEN current_setting('tt.cts', true) IS NULL OR
            current_setting('tt.cts', true) = '' THEN
    clock_timestamp()
  ELSE
    current_setting('tt.cts', true)::timestamptz
  END
$$ LANGUAGE sql;

-- only current rows are visible
-- unless tt.cts is defined, in which case get rows current as of that time
ALTER TABLE timetravel ENABLE ROW LEVEL SECURITY;
CREATE POLICY p1 ON timetravel
USING (tr @> get_pit())
WITH CHECK (/* NEW */tr @> clock_timestamp() OR
            /* OLD */ upper(tr) <= clock_timestamp());
```

RLS Timetravel

```
CREATE OR REPLACE FUNCTION modify_timetravel()
RETURNS TRIGGER AS $$
  DECLARE
    ctr timestamptz := clock_timestamp();
  BEGIN
    OLD.tr = tstzrange(lower(OLD.tr), ctr, '[)');
    INSERT INTO timetravel VALUES (OLD.*);
    IF (TG_OP = 'UPDATE') THEN
      NEW.tr = tstzrange(ctr, 'infinity', '[]');
      RETURN NEW;
    ELSIF (TG_OP = 'DELETE') THEN
      RETURN OLD;
    END IF;
  END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER timetravel_audit BEFORE DELETE OR UPDATE
ON timetravel_current FOR EACH ROW EXECUTE PROCEDURE modify_timetravel();
```

RLS Timetravel

```
GRANT ALL ON timetravel TO dba;
SET SESSION AUTHORIZATION dba;

INSERT INTO timetravel(id, f1)
SELECT g.i, 'row-' || g.i::text
FROM generate_series(1,1000000) AS g(i);

RESET SESSION AUTHORIZATION;
VACUUM FREEZE ANALYZE timetravel;
SET SESSION AUTHORIZATION dba;
```

RLS Timetravel

```
-- NOTE: Point In Time (pit) is after update to id 42 and before delete of id 4242
UPDATE timetravel SET f1 = 'update number 1' WHERE id = 42 RETURNING lower(tr) AS pit \gset

DELETE FROM timetravel WHERE id = 4242;

SELECT * FROM timetravel WHERE id in (42, 4242);
 id |       f1        |                      tr
----+-----------------+-----------------------------------------------
 42 | update number 1 | ["2017-09-03 16:44:22.160023-07",infinity]
```

RLS Timetravel

```
UPDATE timetravel SET f1 = 'update number 2' WHERE id = 42;
SELECT * FROM timetravel WHERE id = 42;
 id |       f1        |                      tr
----+-----------------+-----------------------------------------
 42 | update number 2 | ["2017-09-03 16:44:24.206489-07",infinity]

UPDATE timetravel SET f1 = 'update number 3' WHERE id = 42;
SELECT * FROM timetravel WHERE id = 42;
 id |       f1        |                      tr
----+-----------------+-----------------------------------------
 42 | update number 3 | ["2017-09-03 16:44:25.270849-07",infinity]
```

RLS Timetravel

```
SELECT set_config('tt.cts', :'pit', false);
          set_config
-------------------------------
 2017-09-03 16:44:22.160023-07

SELECT * FROM timetravel WHERE id in (42, 4242) ORDER BY 1, 3;
  id  |       f1        |                                  tr
------+-----------------+-------------------------------------------------------------------
   42 | update number 1 | ["2017-09-03 16:44:22.160023-07","2017-09-03 16:44:24.206489-07")
 4242 | row-4242        | ["2017-09-03 16:44:04.406047-07","2017-09-03 16:44:23.173052-07")
```

RLS Timetravel

```
RESET SESSION AUTHORIZATION;

SELECT * FROM timetravel WHERE id in (42, 4242) ORDER BY 1, 3;
  id  |       f1        |                                 tr
------+-----------------+-------------------------------------------------------------------
   42 | row-42          | ["2017-09-03 16:44:04.34601-07","2017-09-03 16:44:22.160023-07")
   42 | update number 1 | ["2017-09-03 16:44:22.160023-07","2017-09-03 16:44:24.206489-07")
   42 | update number 2 | ["2017-09-03 16:44:24.206489-07","2017-09-03 16:44:25.270849-07")
   42 | update number 3 | ["2017-09-03 16:44:25.270849-07",infinity]
 4242 | row-4242        | ["2017-09-03 16:44:04.406047-07","2017-09-03 16:44:23.173052-07")
```