

Mandatory Access Control in PostgreSQL - giving users ownership of their data

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Outline

- ▶ why take data ownership seriously?
- ▶ why Mandatory Access Control?
- ▶ a brief introduction to the `pg-need-to-know` module
- ▶ a use case to demonstrate features:
 - ▶ For users: ownership, insight and consent-based usage
 - ▶ For administrators: fine-grained access control, audit information
 - ▶ For developers: a rich REST API, with a built-in authorization model
- ▶ optionally: a look at some implementation details

Why take data ownership seriously?

- ▶ Regulations of the GDPR
 - ▶ increased focus on data privacy and protection
 - ▶ right to access
 - ▶ right to be forgotten
 - ▶ data portability
 - ▶ consent-based data usage
 - ▶ increased demand for audit information
- ▶ Respecting people

Why Mandatory Access Control?

- ▶ *enforcible* policies, in contrast to Discretionary Access Control
- ▶ enables consent-based data access
- ▶ supports granular access needs

pg-need-to-know

- ▶ PostgreSQL “module” - really just a set of tables, views, and functions
- ▶ implements Mandatory Access Control
- ▶ more limited approach than SEPostgreSQL
- ▶ source: <https://github.com/leondutoit/pg-need-to-know>
- ▶ written in PL/pgSQL
 - ▶ procedural language, extending SQL with control structures
 - ▶ used to create functions
 - ▶ ~1000 sloc, another ~1500 for tests
- ▶ uses Row-Level Security policies to implement MAC
- ▶ designed to be used via a REST API

Row-Level Security

- ▶ Row-Level Security introduced in PostgreSQL 9.5
- ▶ policy expression evaluated during SQL query execution, for each row
- ▶ can use row values as input to functions or expressions specified in the policy
- ▶ if true then row returned, if false then not

Security policies

CREATE POLICY:

```
CREATE POLICY name ON table_name  
[ AS { PERMISSIVE | RESTRICTIVE } ]  
[ FOR { ALL | SELECT | INSERT | UPDATE | DELETE } ]  
[ TO { role_name | PUBLIC | CURRENT_USER | SESSION_USER } ]  
[ USING ( using_expression ) ]  
[ WITH CHECK ( check_expression ) ]
```

Use case

Key terms:

- ▶ data owner: provides data about themselves
- ▶ data user: analyses data about others
- ▶ admin: creates access control policies

Use case

Assume the following setup:

- ▶ data owners: A, B, C, D, E, F
- ▶ data users: X, Y, Z
- ▶ tables: `spending_habits`, `personal_details`, containing data from all data owners

Use case

Now suppose we need to set up the following access control rules in our DB:

- ▶ data users X, and Y should only have access to data in table `spending_habits` and only data from owners A, B, C, D
- ▶ data user Z should have access to all data - i.e. tables `spending_habits`, `personal_details`

Use case

A hypothetical sequence of events:

1. admin creates tables
2. data owners and data users register themselves, data is collected
3. admin creates groups, adds members, adds table grants
4. data is analysed
5. users manage their own data
6. admins get audit insights
7. developers create applications using composing these features

Table creation

```
set role admin_user;
SET
select table_create(
  '{"table_name": "spending_habits",
    "columns": [
      {"name": "spending", "type": "int",
        "description": "Amount spent in NOK"},
      {"name": "item_type", "type": "text",
        "description": "Type of item purchased"},
      {"name": "purchase_date", "type": "date",
        "description": "Year-Month-Day on which purchase occurred"} ],
    "description": "data about spending habits"}'::json,
  'mac');
table_create
-----
Success
(1 row)
```

Figure 1:Creating a new table

User registration

- ▶ can require consent before user registration
- ▶ data collection not possible without registration

Group setup, table grants

- ▶ can link consent(s) to groups via group metadata
- ▶ group1
 - ▶ members: ((X, Y), (A, B, C, D))
 - ▶ select table access grant: (spending_habits)
- ▶ group2
 - ▶ members: ((Z), (A, B, C, D, E, F))
 - ▶ select table access grants: (spending_habits, personal_details)

Data analysis

```
set session "request.jwt.claim.user" = 'user_X';
SET
select current_setting('request.jwt.claim.user');
current_setting
-----
user_X
(1 row)

select * from spending_habits;
      row_id      | row_owner | row_originator | spending | item_type | purchase_date
-----+-----+-----+-----+-----+-----
4ad3b11e-32ff-42a1-850c-aff1f93f190e | owner_A  | owner_A        |      140 | food      | 2019-01-02
975f2758-5749-4915-bac1-48530f703062 | owner_A  | owner_A        |      100 | drink     | 2019-01-03
899efca4-a935-4e0d-ba25-29c4413d7c2a | owner_B  | owner_B        |       60 | drink     | 2019-01-02
7ef73351-1e7d-4f26-989b-d55fa0f1bfa5 | owner_B  | owner_B        |       78 | drink     | 2019-01-04
1be698b3-e1c0-4b98-a236-f273883f67dc | owner_C  | owner_C        |     1020 | travel    | 2019-01-04
c225db92-2171-4d21-9b7a-67c4ef0ad942 | owner_C  | owner_C        |      101 | food      | 2019-01-04
123f6322-130a-4b13-8f2a-2dbe0f0a9523 | owner_D  | owner_D        |      230 | travel    | 2019-01-05
ca97c462-7fea-49ce-8bde-fcef08a910ab | owner_D  | owner_D        |      448 | travel    | 2019-01-06
(8 rows)

select * from personal_details;
psql:./src/11-user-X-data-access.sql:7: ERROR:  access denied to table
CONTEXT:  PL/pgSQL function ntk.data_user_group_membership_with_correct_privileges(uuid,text,text) line 18 at
RAISE
```

Figure 2: User X's data access

Data analysis

```
set session "request.jwt.claim.user" = 'user_Z';
```

```
SET
```

```
select * from spending_habits;
```

row_id	row_owner	row_originator	spending	item_type	purchase_date
4ad3b11e-32ff-42a1-850c-aff1f93f190e	owner_A	owner_A	140	food	2019-01-02
975f2758-5749-4915-bac1-48530f703062	owner_A	owner_A	100	drink	2019-01-03
899efca4-a935-4e0d-ba25-29c4413d7c2a	owner_B	owner_B	60	drink	2019-01-02
7ef73351-1e7d-4f26-989b-d55fa0f1bfa5	owner_B	owner_B	78	drink	2019-01-04
1be698b3-e1c0-4b98-a236-f273883f67dc	owner_C	owner_C	1020	travel	2019-01-04
c225db92-2171-4d21-9b7a-67c4ef0ad942	owner_C	owner_C	101	food	2019-01-04
123f6322-130a-4b13-8f2a-2dbe0f0a9523	owner_D	owner_D	230	travel	2019-01-05
ca97c462-7fea-49ce-8bde-fcef08a910ab	owner_D	owner_D	448	travel	2019-01-06
fc56af9e-b361-4f9d-814a-3cab834730fd	owner_E	owner_E	10230	housing	2019-01-01
d2f1e45f-e3c0-4fae-8c3d-1470fc4fb75e	owner_F	owner_F	209	food	2019-01-06

```
(10 rows)
```

```
select * from personal_details;
```

row_id	row_owner	row_originator	name	age
5a2a949e-89e5-413d-b268-27516e4924b4	owner_A	owner_A	James Martin	44
336d4202-394c-4abc-9231-3127431df3e8	owner_B	owner_B	Sandra Fourie	18
ce67a250-dc92-48b1-882f-ef68c9ba9687	owner_C	owner_C	Willem White	11
e0ab7e50-3f81-4180-9c5e-b0423e8e17af	owner_D	owner_D	Lee Simpson	84
0b8cb4f0-78a0-448d-8ad5-173e94e1c488	owner_E	owner_E	Gerhard du Preez	23
0a7280e6-e19c-457f-82db-d2b40190ef7d	owner_F	owner_F	Hannah Furgeson	33

Figure 3: User Z's data access

Data ownership

- ▶ right to access
- ▶ data portability
- ▶ right to be forgotten

Right to access

```
set role data_owner;
SET
set session "request.jwt.claim.user" = 'owner_A';
SET
select * from spending_habits;
```

row_id	row_owner	row_originator	spending	item_type	purchase_date
4ad3b11e-32ff-42a1-850c-aff1f93f190e	owner_A	owner_A	140	food	2019-01-02
975f2758-5749-4915-bac1-48530f703062	owner_A	owner_A	100	drink	2019-01-03

(2 rows)

```
select * from personal_details;
```

row_id	row_owner	row_originator	name	age
5a2a949e-89e5-413d-b268-27516e4924b4	owner_A	owner_A	James Martin	44

(1 row)

Press any key to execute: (ans/14 owner_A group remove sel

Figure 4:Owner A's data access

Data portability

- ▶ owner A can simply download their data

Right to be forgotten

```
set session "request.jwt.claim.user" = 'owner_B';
SET
select * from spending_habits;
      row_id | row_owner | row_originator | spending | item_type | purchase_date
-----+-----+-----+-----+-----+-----
 899efca4-a935-4e0d-ba25-29c4413d7c2a | owner_B | owner_B |      60 | drink | 2019-01-02
 7ef73351-1e7d-4f26-989b-d55fa0f1bfa5 | owner_B | owner_B |      78 | drink | 2019-01-04
(2 rows)

select * from personal_details;
      row_id | row_owner | row_originator | name | age
-----+-----+-----+-----+-----
 336d4202-394c-4abc-9231-3127431df3e8 | owner_B | owner_B | Sandra Fourie | 18
(1 row)

select user_delete_data();
psql:./src/15-owner-B-delete-data.sql:8: NOTICE: cannot delete data from test1, permission denied
psql:./src/15-owner-B-delete-data.sql:8: NOTICE: cannot delete data from testing, permission denied
user_delete_data
-----
all data deleted
(1 row)

select * from spending_habits;
 row_id | row_owner | row_originator | spending | item_type | purchase_date
-----+-----+-----+-----+-----+-----
(0 rows)

select * from personal_details;
 row_id | row_owner | row_originator | name | age
-----+-----+-----+-----+-----
(0 rows)
```

Figure 5: Owner B deletes their data

Audit insights

- ▶ data access
- ▶ access control changes
- ▶ user initiated group removals
- ▶ user initiated data deletions
- ▶ data updates

Audit: data access

```
select * from event_log_data_access;
```

request_time	table_name	row_id	data_user	data_owner
2019-01-09 10:34:45.646518+01	spending_habits	8719fc2e-5a59-4db0-906f-d844b496de2b	user_X	owner_A
2019-01-09 10:34:45.646518+01	spending_habits	89b9bfe9-460f-47aa-bb25-b71ae78d7219	user_X	owner_A
2019-01-09 10:34:45.646518+01	spending_habits	fbcb12163-20e7-4889-b5db-a89e6c8dc210	user_X	owner_B
2019-01-09 10:34:45.646518+01	spending_habits	3307c91a-1d57-4725-b239-53c94f5bb568	user_X	owner_B
2019-01-09 10:34:45.646518+01	spending_habits	94989d0f-8537-4b0a-993c-59687a475f35	user_X	owner_C
2019-01-09 10:34:45.646518+01	spending_habits	8478942d-b37e-4f6d-9985-e12661b81234	user_X	owner_C
2019-01-09 10:34:45.646518+01	spending_habits	1a314e10-1768-45b0-bc0c-992b60c17b0c	user_X	owner_D
2019-01-09 10:34:45.646518+01	spending_habits	dbdf9389-38ff-4561-90bd-a496ed7cb5b6	user_X	owner_D
2019-01-09 10:34:47.853098+01	spending_habits	8719fc2e-5a59-4db0-906f-d844b496de2b	user_Z	owner_A
2019-01-09 10:34:47.853098+01	spending_habits	89b9bfe9-460f-47aa-bb25-b71ae78d7219	user_Z	owner_A
2019-01-09 10:34:47.853098+01	spending_habits	fbcb12163-20e7-4889-b5db-a89e6c8dc210	user_Z	owner_B
2019-01-09 10:34:47.853098+01	spending_habits	3307c91a-1d57-4725-b239-53c94f5bb568	user_Z	owner_B
2019-01-09 10:34:47.853098+01	spending_habits	94989d0f-8537-4b0a-993c-59687a475f35	user_Z	owner_C
2019-01-09 10:34:47.853098+01	spending_habits	8478942d-b37e-4f6d-9985-e12661b81234	user_Z	owner_C
2019-01-09 10:34:47.853098+01	spending_habits	1a314e10-1768-45b0-bc0c-992b60c17b0c	user_Z	owner_D
2019-01-09 10:34:47.853098+01	spending_habits	dbdf9389-38ff-4561-90bd-a496ed7cb5b6	user_Z	owner_D
2019-01-09 10:34:47.853098+01	spending_habits	f3d9bbd8-58fa-42a6-a150-d9bb44a2e2d4	user_Z	owner_E
2019-01-09 10:34:47.853098+01	spending_habits	276e1f83-8739-4c62-9eb3-e8724fd5ff04	user_Z	owner_F
2019-01-09 10:34:47.878906+01	personal_details	31b62746-e497-42e7-848e-82438898785b	user_Z	owner_A
2019-01-09 10:34:47.878906+01	personal_details	ff695fec-2f96-40d6-b3ed-42090892c88d	user_Z	owner_B
2019-01-09 10:34:47.878906+01	personal_details	378207c9-022a-48e3-ba82-d418b5b7c76f	user_Z	owner_C
2019-01-09 10:34:47.878906+01	personal_details	bdcfdb9b-153d-44ed-857c-26f76064e6e7	user_Z	owner_D
2019-01-09 10:34:47.878906+01	personal_details	df105084-e8e3-4d2d-bb9e-5ee3e836feb8	user_Z	owner_E
2019-01-09 10:34:47.878906+01	personal_details	41a8bf9c-a1e1-409d-a9f3-264c8c4e962b	user_Z	owner_F

(24 rows)

Figure 6: Data access audit logs

Audit: access control changes

```
select * from event_log_access_control;
```

id	event_time	event_type	group_name	target
383	2019-01-07 15:49:00.550321+01	group_create	group1	
384	2019-01-07 15:49:02.68408+01	group_create	group2	
385	2019-01-07 15:49:04.53359+01	group_member_add	group1	owner_A
386	2019-01-07 15:49:04.53359+01	group_member_add	group1	owner_B
387	2019-01-07 15:49:04.53359+01	group_member_add	group1	owner_C
388	2019-01-07 15:49:04.53359+01	group_member_add	group1	owner_D
389	2019-01-07 15:49:04.53359+01	group_member_add	group1	user_X
390	2019-01-07 15:49:04.53359+01	group_member_add	group1	user_Y
391	2019-01-07 15:49:07.356862+01	group_member_add	group2	user_Z
392	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_A
393	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_B
394	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_C
395	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_D
396	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_E
397	2019-01-07 15:49:07.365324+01	group_member_add	group2	owner_F
398	2019-01-07 15:49:10.540968+01	table_grant_add_select	group1	spending_habits
399	2019-01-07 15:49:11.772743+01	table_grant_add_select	group2	spending_habits
400	2019-01-07 15:49:11.785069+01	table_grant_add_select	group2	personal_details

(18 rows)

Figure 7: Access control audit logs

Audit: user initiated group removals

```
select * from event_log_user_group_removals;  
      removal_date          | user_name | group_name  
-----+-----+-----  
2019-01-07 15:49:30.547254+01 | owner_A   | group1  
(1 row)
```

Figure 8:User group removals audit logs

Audit: user initiated data deletions

```
set role admin_user;
SET
set session "request.jwt.claim.user" = '';
SET
select * from event_log_user_data_deletions;
  user_name |          request_date
-----+-----
owner_B    | 2019-01-07 15:49:32.350643+01
(1 row)
```

Figure 9:User data deletion audit logs

Audit: data updates

```
select * from event_log_data_updates;
```

updated_time	updated_by	table_name	row_id	column_name	old_data	new_data
2019-01-07 15:49:41.236255+01	owner_C	personal_details	ce67a250-dc92-48b1-882f-ef68c9ba9687	age	11	55

(1 row)

Figure 10:Data update audit logs

Application development

Architecture:

webapp -> REST -> (pg-need-to-know, PostgreSQL)

- ▶ developers can focus on business logic
- ▶ authorization taken care of
- ▶ authentication is left to the webapp implementor

postgrest

- ▶ `pg-need-to-know` designed to be used with `postgrest`
- ▶ open source project written in Haskell
- ▶ provides a REST API for any PostgreSQL DB
- ▶ <https://github.com/leondutoit/pg-need-to-know/blob/master/api/http-api.md>
- ▶ `pg-need-to-know` requires a custom compilation of this server due to audit logging
- ▶ available here:
<https://github.com/leondutoit/postgrest-need-to-know>

Authentication requirements

- ▶ webapp must provide an access token at request time
- ▶ a JWT with the following claims:
 - ▶ `exp:` expiry time
 - ▶ `role:` `<data_owner, data_user, admin_user>`
 - ▶ `user:` user name
- ▶ pg-need-to-know provides a `/token` endpoint for access token generation
- ▶ but developers can implement their own
- ▶ reference client for HTTP API:
<https://github.com/leondutoit/py-need-to-know>

Implementation details

```
Table "public.spending_habits"
  Column      | Type      | Collation | Nullable | Default
-----+-----+-----+-----+-----
row_id       | uuid     |           | not null | gen_random_uuid()
row_owner    | text     |           | not null | current_setting('request.jwt.claim.user'::text)
row_ordinator | text     |           | not null | current_setting('request.jwt.claim.user'::text)
spending     | integer  |           |          |
item_type    | text     |           |          |
purchase_date | date     |           |          |

Check constraints:
    "spending_habits_row_ordinator_check" CHECK (row_ordinator = current_setting('request.jwt.claim.user'::text))
Foreign-key constraints:
    "spending_habits_row_ordinator_fkey" FOREIGN KEY (row_ordinator) REFERENCES ntk.registered_users(_user_name)
    "spending_habits_row_owner_fkey" FOREIGN KEY (row_owner) REFERENCES ntk.registered_users(_user_name)
Policies (forced row security enabled):
    POLICY "data_user_select_policy" FOR SELECT
        TO data_user
        USING (ntk.data_user_group_membership_with_correct_privileges(row_id, row_owner, 'spending_habits'::text))
    POLICY "row_ordinator_update_policy" FOR UPDATE
        USING (ntk.is_row_ordinator(row_ordinator))
    POLICY "row_ownership_delete_policy" FOR DELETE
        USING (ntk.is_row_owner(row_owner))
    POLICY "row_ownership_insert_policy" FOR INSERT
        WITH CHECK (true)
    POLICY "row_ownership_select_policy" FOR SELECT
        USING (ntk.is_row_owner(row_owner))
    POLICY "row_ownership_update_policy" FOR UPDATE
        USING (ntk.is_row_owner(row_owner))
Triggers:
    immutable_trigger BEFORE UPDATE ON spending_habits FOR EACH ROW EXECUTE PROCEDURE ntk.ensure_internal_columns_are_immutable()
    update_trigger AFTER UPDATE ON spending_habits FOR EACH ROW EXECUTE PROCEDURE ntk.log_data_update()
```

Figure 11:Example table definition

More info

- ▶ watch a demo recording:
<https://asciinema.org/a/c3XlYrfnoLixofqiSbx8p0l21>
- ▶ read the docs: <https://github.com/leondutoit/pg-need-to-know/tree/master/docs>
- ▶ this presentation, and materials:
<https://github.com/leondutoit/pg-ntk-demo>