Dashboards with Grafana

DATA 503: Fundamentals of Data Engineering

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This lecture connects the presentation layer of a data pipeline to PostgreSQL on Railway. We review why dashboards matter, how Grafana fits the stack, how views and crosstabs prepare data for visualization, then follow a full path: deploy PostgreSQL 18, restore a class dump with pg_restore, add Grafana with a persistent config database, and build panels from curated views. A LaTeX lab handout supports in-class practice.

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1 Learning Objectives

1.1 What You Will Be Able to Do

1. Explain where dashboards sit in a pipeline and why Grafana is a reasonable choice for SQL-backed analytics
2. Read and reason about dashboard-oriented views (aggregations, joins, classifications)
3. Interpret `crosstab()` pivots from `tablefunc` and know when a table panel in Grafana is the right visualization
4. Provision PostgreSQL 18 on Railway and restore a custom-format dump with `pg_restore` using the public database URL
5. Deploy Grafana on Railway with a separate `grafana` database for persistence and connect it to pipeline data with a read-only role
6. Build several panel types (bar, horizontal bar, grouped bar, table) from named views and pivot queries

1.2 Course Connection

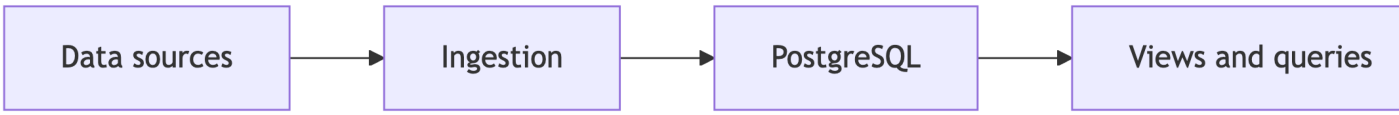
This ties ingestion and modeling work to stakeholder-facing delivery: live, shareable visuals over the same database your pipeline maintains.

2 Part 1: Dashboards in the Pipeline

2.1 The Presentation Layer

Dashboards are the **presentation layer**. They turn vetted SQL into charts and tables other people can read without learning `JOIN` syntax.

2.2 Where Grafana Sits



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Grafana does not replace your ETL jobs. It **reads** from PostgreSQL (ideally through views and restricted users) and renders results on a schedule or on demand.

2.3 What Makes a Good Pipeline Dashboard?

- **Live connection** to the database, not a one-off CSV export
- **Refresh** so panels stay current as data lands
- **Shareable** links for reviews and demos
- **Layered layout:** headline metrics on top, comparisons in the middle, detail tables below

3 Part 2: Grafana Overview

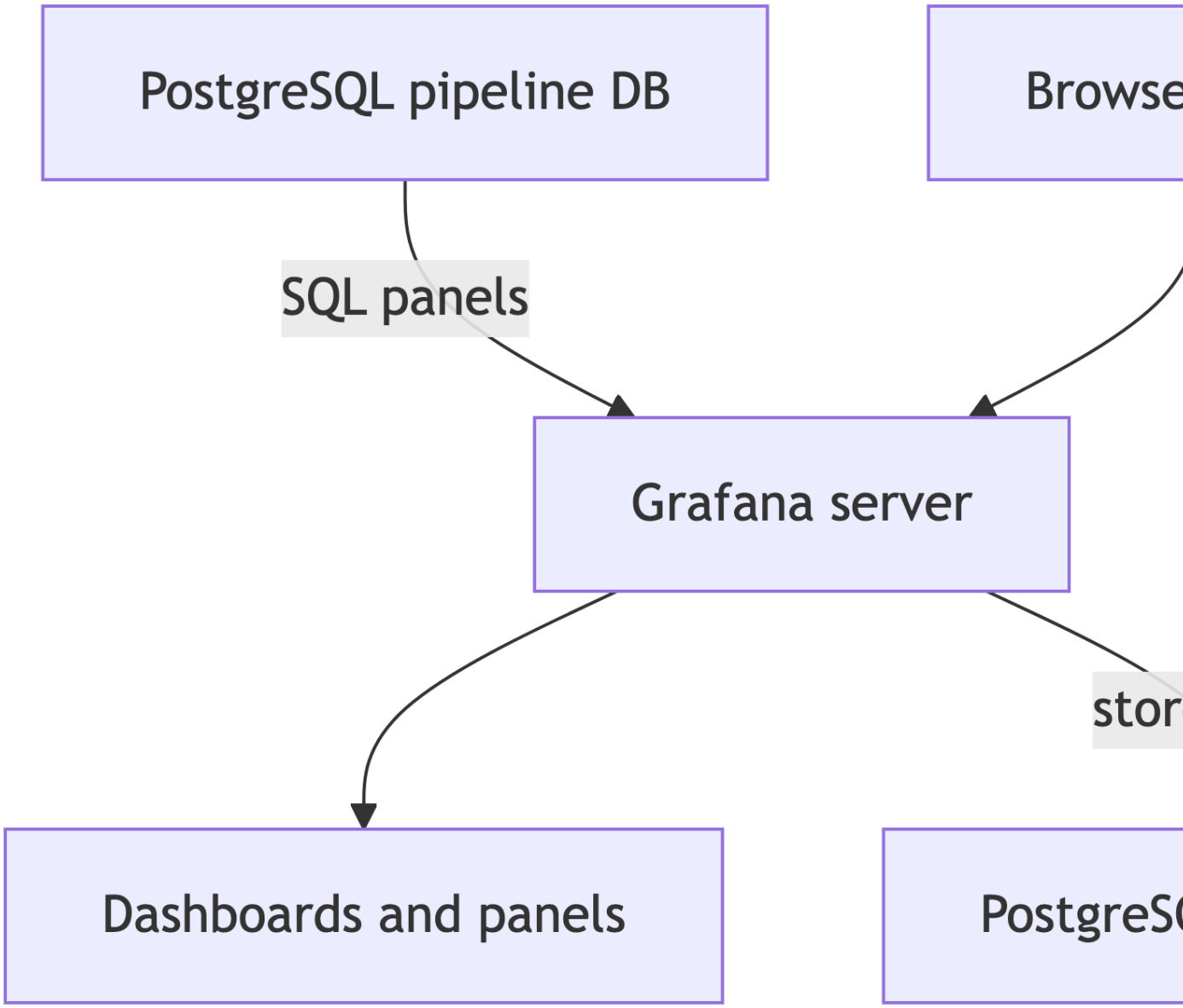
3.1 What Grafana Is

Grafana is an open-source observability and dashboarding platform. It started in metrics and logs, but its PostgreSQL data source is mature: you write SQL, Grafana maps columns to charts.

3.2 Why Grafana for This Course?

- **PostgreSQL-native** data source with a SQL editor
- **Many panel types:** time series, bar, table, stat, pie, heatmap, and more
- **Variables** for filters (dropdowns that rewrite queries)
- **Alerting** when a query crosses a threshold
- **Fits Railway:** can run next to your database; serverless mode reduces idle cost

3.3 Grafana Architecture (Two Databases)



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1. **Analytics data** lives in your pipeline database (after restore, that is the class dataset).
2. **Grafana metadata** (dashboards, users, data source definitions) should live in a **separate** database so you can rebuild or clone pipeline data without losing UI work.

4 Part 3: Views for Dashboards

4.1 Why Views?

A **view** is a named `SELECT`. It behaves like a read-only table for clients.

- Hides long joins and aggregations behind one name
- Reuse the same logic from Grafana, APIs, and ad hoc queries
- Lets you grant `SELECT` on views to a read-only role without exposing base tables
- When logic changes, you update the view once, not every panel

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Views do not magically cache results unless you use a **materialized** view. For class-scale data, ordinary views are fine.

4.2 Dataset After Restore

After you restore `railway_dump.dump`, you should see the census, business, temperature, and survey tables from the advanced-queries style curriculum, plus the views below (names may match exactly).

Table	Approximate role
`us_counties_pop_est_2019`	County population and components of change
`cbp_naics_72_establishments`	Food and accommodation establishments by area
`temperature_readings`	Daily readings for three stations
`ice_cream_survey`	Long-format survey responses

5 Part 4: Dashboard-Ready Views (Review)

5.1 View: `v_state_population_summary`

State-level totals and natural increase. Good for **sorted bar charts** or **tables**.

```
CREATE OR REPLACE VIEW v_state_population_summary AS
SELECT
    state_name,
    count(*) AS num_counties,
    sum(pop_est_2019) AS total_pop,
    round(avg(pop_est_2019), 0) AS avg_county_pop,
    sum(births_2019) AS total_births,
```

```
    sum(deaths_2019) AS total_deaths,
    sum(births_2019) - sum(deaths_2019) AS natural_increase
FROM us_counties_pop_est_2019
GROUP BY state_name
ORDER BY total_pop DESC;
```

5.2 View: `v_state_migration_rates`

Rates per thousand and a direction label. Good for **horizontal bar** charts and color by category.

```
CREATE OR REPLACE VIEW v_state_migration_rates AS
WITH state_migration AS (
    SELECT
        state_name,
        sum(international_migr_2019 + domestic_migr_2019) AS net_migration,
        sum(pop_est_2018) AS base_pop
    FROM us_counties_pop_est_2019
    GROUP BY state_name
)
SELECT
    state_name,
    base_pop,
    net_migration,
    round((net_migration / base_pop::numeric) * 1000, 2) AS migration_rate_per_thousand,
    CASE
        WHEN net_migration > 0 THEN 'Gaining'
        WHEN net_migration < 0 THEN 'Losing'
        ELSE 'Stable'
    END AS migration_direction
FROM state_migration
ORDER BY migration_rate_per_thousand DESC;
```

5.3 View: `v_county_growth_summary`

Aggregates counties by growth category. Natural **pie** or **stat** panels.

```
CREATE OR REPLACE VIEW v_county_growth_summary AS
WITH county_growth AS (
    SELECT
        county_name,
        state_name,
```

```
        pop_est_2019,
        CASE
            WHEN pop_est_2019 > pop_est_2018 THEN 'Growing'
            WHEN pop_est_2019 < pop_est_2018 THEN 'Shrinking'
            ELSE 'Stable'
        END AS growth_category
    FROM us_counties_pop_est_2019
)
SELECT
    growth_category,
    count(*) AS num_counties,
    sum(pop_est_2019) AS total_pop,
    round(avg(pop_est_2019), 0) AS avg_county_pop,
    round(count(*)::numeric / (SELECT count(*) FROM us_counties_pop_est_2019) * 100, 1)
        AS pct_of_counties
FROM county_growth
GROUP BY growth_category
ORDER BY num_counties DESC;
```

5.4 View: `v_state_estabs_per_capita`

Establishments per thousand residents by state. Good **ranked bar** chart.

```
CREATE OR REPLACE VIEW v_state_estabs_per_capita AS
WITH estabs AS (
    SELECT st, sum(establishments) AS establishment_count
    FROM cbp_naics_72_establishments
    GROUP BY st
),
pop AS (
    SELECT state_name, sum(pop_est_2018) AS total_pop
    FROM us_counties_pop_est_2019
    GROUP BY state_name
)
SELECT
    pop.state_name,
    pop.total_pop,
    estabs.establishment_count,
    round((estabs.establishment_count / pop.total_pop::numeric) * 1000, 1)
        AS estabs_per_thousand
FROM estabs
```

```
JOIN pop ON estabs.st = pop.state_name
ORDER BY estabs_per_thousand DESC;
```

5.5 View: `v_seasonal_temperatures`

Season labels for each station. Ideal **grouped bar** chart.

```
CREATE OR REPLACE VIEW v_seasonal_temperatures AS
WITH labeled_readings AS (
    SELECT
        station_name,
        CASE
            WHEN date_part('month', observation_date) IN (12, 1, 2) THEN 'Winter'
            WHEN date_part('month', observation_date) IN (3, 4, 5)  THEN 'Spring'
            WHEN date_part('month', observation_date) IN (6, 7, 8)  THEN 'Summer'
            WHEN date_part('month', observation_date) IN (9, 10, 11) THEN 'Fall'
        END AS season,
        max_temp,
        min_temp
    FROM temperature_readings
)
SELECT
    station_name,
    season,
    round(avg(max_temp), 1) AS avg_max_temp,
    round(avg(min_temp), 1) AS avg_min_temp,
    count(*) AS num_readings
FROM labeled_readings
GROUP BY station_name, season
ORDER BY station_name,
    CASE season
        WHEN 'Winter' THEN 1
        WHEN 'Spring' THEN 2
        WHEN 'Summer' THEN 3
        WHEN 'Fall' THEN 4
    END;
```

5.6 View: `v_population_tiers`

County tiers by size. Strong **population share** story in one table.

```sql
CREATE OR REPLACE VIEW v_population_tiers AS
WITH tiers AS (
    SELECT
        county_name,
        state_name,
        pop_est_2019,
        CASE
            WHEN pop_est_2019 >= 500000 THEN 'Metro'
            WHEN pop_est_2019 >= 100000 THEN 'Urban'
            WHEN pop_est_2019 >= 50000 THEN 'Suburban'
            ELSE 'Rural'
        END AS tier
    FROM us_counties_pop_est_2019
)
SELECT
    tier,
    count(*) AS num_counties,
    sum(pop_est_2019) AS total_pop,
    round(avg(pop_est_2019), 0) AS avg_county_pop,
    round(sum(pop_est_2019)::numeric /
        (SELECT sum(pop_est_2019) FROM us_counties_pop_est_2019) * 100, 1)
        AS pct_of_total_pop
FROM tiers
GROUP BY tier
ORDER BY
    CASE tier
        WHEN 'Metro' THEN 1
        WHEN 'Urban' THEN 2
        WHEN 'Suburban' THEN 3
        WHEN 'Rural' THEN 4
    END;
```

5.7 Quick Check: Views vs. Inline SQL in Grafana

Why define views instead of pasting huge queries into every panel?

- **A.** Views always cache results for Grafana
- **B.** Views give a stable, reusable interface and cleaner permissions
- **C.** Grafana cannot run SQL
- **D.** Views refresh on a timer automatically

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B. Non-materialized views still run fresh SQL. The win is naming, reuse, and security boundaries.

6 Part 5: Crosstabs and Pivot-Style Reporting

6.1 `tablefunc` and Long-to-Wide Data

Reporting often needs **wide** tables: one row per entity, many metric columns. Raw surveys and events are usually **long**: one row per observation.

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PostgreSQL provides `crosstab()` through the extension:

```
CREATE EXTENSION IF NOT EXISTS tablefunc;
```

6.2 Ice Cream Survey Pivot

Long format: one row per person and flavor choice. Wide format: offices on rows, flavors as columns.

```
SELECT *
FROM crosstab(
    'SELECT office, flavor, count(*)
     FROM ice_cream_survey
     GROUP BY office, flavor
     ORDER BY office',
    'SELECT flavor
     FROM ice_cream_survey
     GROUP BY flavor
     ORDER BY flavor'
)
AS (office text,
    chocolate bigint,
    strawberry bigint,
    vanilla bigint);
```

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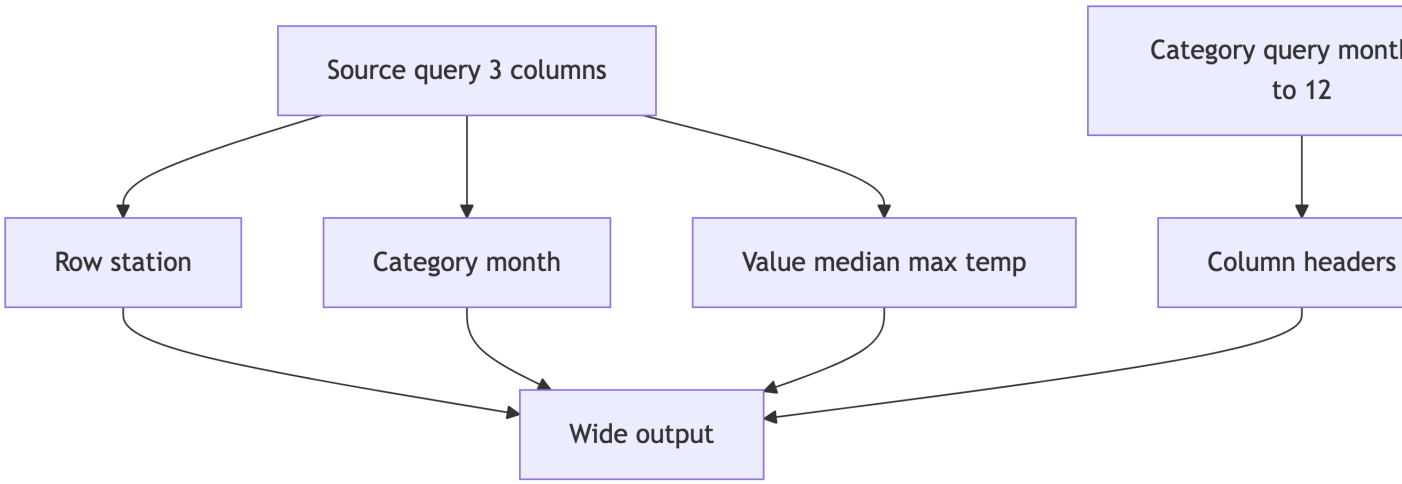
Grafana note: This returns a **table** shape. Use a **Table** panel, not a bar chart, unless you unpivot again in SQL.

6.3 Temperature Median Pivot by Month




```sql
SELECT *
FROM crosstab(
    'SELECT station_name,
            date_part(''month'', observation_date),
            percentile_cont(.5)
                WITHIN GROUP (ORDER BY max_temp)
     FROM temperature_readings
     GROUP BY station_name,
              date_part(''month'', observation_date)
     ORDER BY station_name',
    'SELECT month FROM generate_series(1,12) month'
)
AS (station text,
    jan numeric(3,0), feb numeric(3,0), mar numeric(3,0),
    apr numeric(3,0), may numeric(3,0), jun numeric(3,0),
    jul numeric(3,0), aug numeric(3,0), sep numeric(3,0),
    oct numeric(3,0), nov numeric(3,0), dec numeric(3,0));
```

6.4 Quick Check: `crosstab()` Shape

The **source** query passed to `crosstab()` must return how many columns?

- **A.** 2
- **B.** 3
- **C.** 4

- **D.** It depends on the number of categories

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B. Row id, category, value. The second query lists category labels for column order.

7 Part 6: Follow-Along — PostgreSQL 18 and Restore

7.1 Step 1: New Railway Project and Postgres 18

1. In Railway, create a **new project** (empty is fine).
2. **Add PostgreSQL**. In the database service **Settings**, choose **PostgreSQL 18** if the platform exposes a version selector or image tag; otherwise use the image your instructor pins for this term.
3. Wait until the service is healthy. Open **Variables** (or **Connect**) and copy the **public** database URL Railway exposes for external access (often named `DATABASE_PUBLIC_URL`, or shown under **Public network** / **TCP Proxy** on the Connect tab). You will use this same URL style for Beekeeper, pgAdmin, `psql`, and `pg_restore` on your laptop.

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Important: Anything you run **on your own computer** must use that **public** URL. Private hostnames such as `*.railway.internal` only resolve inside Railway's network and will fail from your laptop.

7.2 Step 2: Download the Dump

From Canvas, download `railway_dump.dump`. This file is a **custom-format** archive intended for PostgreSQL 18 and `pg_restore`.

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If you cannot install client tools, use the optional plain `railway_dump.sql` from Canvas instead (run it in Beekeeper or pgAdmin, or with `psql -f`).

7.3 Step 3: Restore with `pg_restore`

In a terminal on the machine that has the file:

```
export DATABASE_PUBLIC_URL="postgresql://USER:PASSWORD@PUBLIC_HOST:PORT/railway"
pg_restore --verbose --no-owner --no-acl -d "$DATABASE_PUBLIC_URL" railway_dump.dump
```

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- `--no-owner --no-acl` avoid errors about roles and permissions that do not exist on Railway.
- The database name in the URL is often `railway`; use whatever Railway shows.
- Client version: prefer **pg_restore 18** to match the server. Older clients sometimes fail against newer servers.

7.4 Step 4: Verify in a SQL Client

Connect with **Beekeeper Studio** or **pgAdmin** using the **public** URL (paste the full URL or fill host, port, user, password, and database from it). Confirm:

- Tables such as `us_counties_pop_est_2019`, `ice_cream_survey`, `temperature_readings`
- Views such as `v_state_population_summary`
- Extension `tablefunc` if the dump included it (needed for `crosstab()` examples)

7.5 Step 5: Plain SQL Fallback

If `pg_restore` is not available:

1. Download `railway_dump.sql` from Canvas.
2. Execute the entire script while connected to your Railway database (Beekeeper **Run**, pgAdmin **Query Tool**, or `psql "$DATABASE_PUBLIC_URL" -f railway_dump.sql`).

8 Part 7: Follow-Along — Grafana on Railway

8.1 Create the `grafana` Database

In Beekeeper or pgAdmin, connected to the **same** Postgres server:

```
1 CREATE DATABASE grafana;
```

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Grafana will store dashboards here. Skipping this step usually means **lost dashboards** after redeploys.

8.2 Add Grafana (Template)

1. In the same Railway project, **Create** then **Template** and search **Grafana**.
2. Deploy. Note the **public URL** Grafana receives; set `GF_SERVER_ROOT_URL` to that full `https://...` value after the first deploy if the template asks for it.

8.3 Environment Variables (Checklist)

Admin login

Key	Value
`GF_SECURITY_ADMIN_USER`	`admin`
`GF_SECURITY_ADMIN_PASSWORD`	strong password you keep

Grafana config database

Key	Value
`GF_DATABASE_TYPE`	`postgres`
`GF_DATABASE_HOST`	**host:port** from the same **public** Postgres URL you use in Beekeeper (not a private internal hostname)
`GF_DATABASE_NAME`	`grafana`
`GF_DATABASE_USER`	`postgres` (unless Railway uses another superuser name)
`GF_DATABASE_PASSWORD`	from Postgres service variables
`GF_DATABASE_SSL_MODE`	usually **`require`** when using the public endpoint (match Railway's docs if the test fails)

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Enable **Serverless** on Grafana if you want the service to sleep when idle.

8.4 Read-Only Role for Panel Queries

Still connected to the **pipeline** database (not `grafana`):

```
CREATE USER grafanareader WITH PASSWORD 'use_a_strong_password';

GRANT USAGE ON SCHEMA public TO grafanareader;
GRANT SELECT ON ALL TABLES IN SCHEMA public TO grafanareader;
ALTER DEFAULT PRIVILEGES IN SCHEMA public
    GRANT SELECT TO grafanareader;
```

. . .

In Grafana, add the **PostgreSQL data source** for the pipeline database using the **public** host and port (same as Beekeeper), database name (often **`railway`**), user **`grafanareader`**, and **TLS/SSL mode `require`** unless Railway's Connect instructions say otherwise.

9 Part 8: Demo — Build Panels Step by Step

Assume you are logged into Grafana as admin and the PostgreSQL data source **Save & test** succeeded against the restored database.

9.1 Demo A: Top States by Population (Bar Chart)

1. **Dashboards** then **New** then **New dashboard**.
2. **Add visualization**. Pick your **PostgreSQL** data source.
3. Set query editor to **Code** (SQL). Paste:

```sql
SELECT state_name, total_pop
FROM v_state_population_summary
ORDER BY total_pop DESC
LIMIT 15;
```

4. Visualization: **Bar chart**.
5. In **Panel options**, set category field to `state_name` and value field to `total_pop`.
6. Title the panel clearly, for example **Top 15 states by estimated 2019 population**.

9.2 Demo B: Migration Rates (Horizontal Bar)

1. **Add visualization** on the same dashboard.
2. SQL:

```sql
SELECT state_name, migration_rate_per_thousand, migration_direction
FROM v_state_migration_rates
ORDER BY migration_rate_per_thousand DESC
LIMIT 20;
```

3. Visualization: **Bar chart**, orientation **horizontal**.
4. Optional: under **Overrides**, color by field `migration_direction` (map Gaining, Losing, Stable to different colors).
5. Title: **Net migration rate per 1,000 residents (selected states)**.

9.3 Demo C: Seasonal Temperatures (Grouped Bar)

1. **Add visualization**.
2. SQL:

```sql
SELECT station_name, season, avg_max_temp
FROM v_seasonal_temperatures;
```

3. Visualization: **Bar chart**, mode **grouped** (exact control names vary by Grafana version; look for grouping by `station_name` with `season` as series or x-axis categories depending on the panel).
4. Title: **Average max temperature by station and season**.

9.4 Demo D (Optional Table): Ice Cream Crosstab

1. **Add visualization** then choose **Table**.
2. Paste the full `crosstab` query from Part 5 (ice cream example).
3. Run query. Confirm columns are office plus flavor counts.
4. Title: **Ice cream preferences by office (pivot)**.

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Talking point: Views feed most charts; pivots often stay as **tables** unless you reshape data further for chart types.

10 Part 9: Your Turn

10.1 During Class

Replicate the follow-along: **Postgres 18**, **restore**, **Grafana** with **`grafana` database**, **read-only user**, then build a dashboard with **at least four** panels. Mix views and at least one **table** (a view or a crosstab query).

10.2 Take-Home Reference

Download the lab steps as **grafana-lab-handout.pdf** or the LaTeX source **grafana-lab-handout.tex** if you want to edit or recompile locally. Your instructor may mirror the PDF on Canvas.

11 Summary

Topic	Takeaway
Pipeline role	Dashboards visualize vetted data; they are not the transform layer
Views	Named, reusable, permission-friendly interfaces for panels

Topic	Takeaway
Crosstabs	`crosstab()` builds wide tables; great for **Table** panels
Restore	`pg_restore --no-owner --no-acl -d "$DATABASE_PUBLIC_URL" file.dump`
Grafana persistence	Separate `grafana` database for config
Security	Read-only DB user for Grafana queries

11.1 References

1. Grafana documentation
2. Grafana PostgreSQL data source
3. Railway documentation
4. PostgreSQL CREATE VIEW
5. PostgreSQL tablefunc (`crosstab`)
6. PostgreSQL pg_restore