Dissecting Partitioning

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This presentation shows the purpose, effect, and optimizations of Postgres's partitioning implementation.

https://momjian.us/presentations

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Outline

1. Purpose and history
2. Partitioning in action
3. Partition pruning
4. Partition-local optimizations
5. Time-based partitioning
6. Row migration
7. psql support
8. Limitations
9. Complex architectures

1. Purpose and History

https://www.flickr.com/photos/photo_oto/

Purpose of Partitioning

- Query efficiency
  - faster sequential scans for partition-key-qualified queries
  - shallower indexes for faster index scans
  - improve cache efficiency for frequently accessed partitions
  - partition-local optimizations
- Data customization
  - partition-specific indexes, constraints, and triggers
- Maintenance
  - improve efficiency of modified row cleanup
  - movement of partitions to tablespaces with different storage characteristics
  - easily attach/detach partitions for maintenance
  - simpler bulk operations, including removal of old time-based partitions

https://www.postgresql.org/docs/current/ddl-partitioning.html

https://hevodata.com/learn/postgresql-partitions/

https://www.youtube.com/watch?v=edQZauVU-ws

Partitioning Prior to Postgres 10

Prior to Postgres 10, partitioning was accomplished by combining:

- Inheritance
- CHECK constraints and *constraint_exclusion*
- Triggers for INSERT routing of new rows
- Triggers for UPDATEs that change partitioned key columns
- Use of external tools like pg_partman (https://github.com/pgpartman/pg_partman)

https://momjian.us/main/blogs/pgblog/2013.html#March_8_2013

Enhancing Partitioning Capabilities

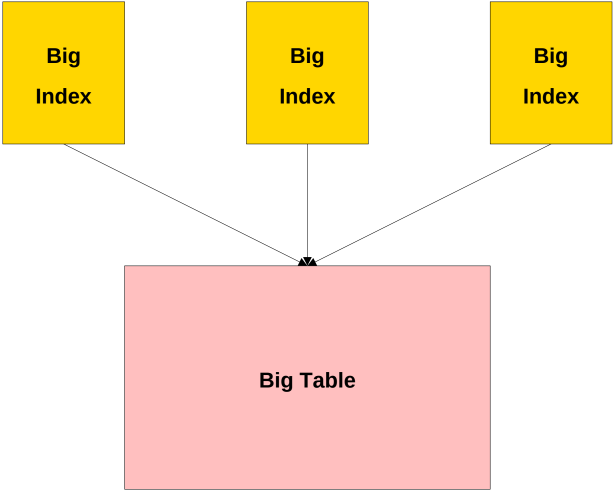
Postgres 10 and later added:

- Range, hash, and list partition syntax
- DEFAULT partitions*
- PRIMARY KEYs on partitioned* tables and FOREIGN KEYs to and from partitioned tables
- More efficient pruning
- Executor-stage pruning
- Partition-local optimizations
- Used with foreign data wrappers

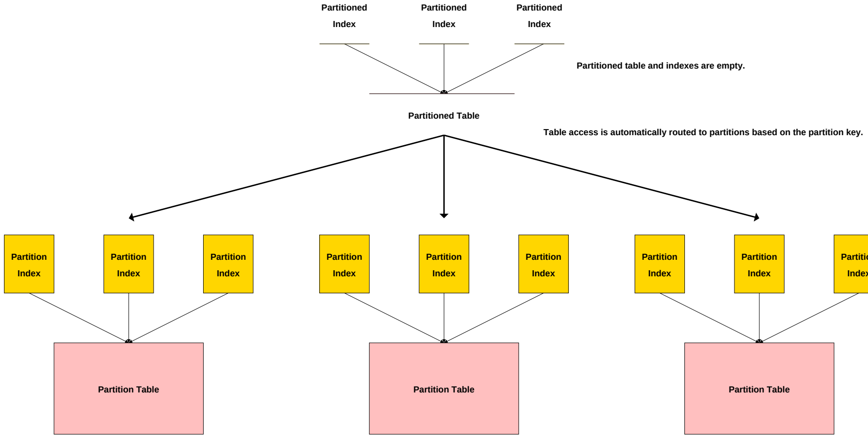
* "Partitioned tables" are parent tables that are referenced in most queries and store no data, while "partitions" are tables where the data is stored.

https://momjian.us/main/blogs/pgblog/2017.html#September_11_2017

Without Partitioning



With Partitioning



2. Partitioning in Action

https://www.flickr.com/photos/105105658@N03/

Range Partitioned Table Creation

```
CREATE TABLE range_partitioned (name TEXT)
PARTITION BY RANGE (name);

CREATE TABLE range_partition_less_j
PARTITION OF range_partitioned
FOR VALUES FROM (MINVALUE) TO ('j');

CREATE TABLE range_partition_j_to_s
PARTITION OF range_partitioned
FOR VALUES FROM ('j') TO ('s');

CREATE TABLE range_partition_s_greater
PARTITION OF range_partitioned
FOR VALUES FROM ('s') TO (MAXVALUE);
```

Summary and causal information is in blue; significant information is in red. All the queries used in this presentation are available at https://momjian.us/main/writings/pgsql/partitioning.sql.

DEFAULT Partition Table Creation

```
-- Range partitioned tables require DEFAULT partitions for NULL storage.
-- CHECK prevents non-NULLs and avoids partition scan checking for
-- values that might be in the newly-created partition.
CREATE TABLE range_partition_nulls
PARTITION OF range_partitioned
(CHECK (name IS NULL))
DEFAULT;
```

The Result

```
\d+ range_partitioned
                   Partitioned table "public.range_partitioned"
 Column | Type | Collation | Nullable | Default | Storage  | Compression |…
--------+------+-----------+----------+---------+----------+-------------+…
 name   | text |           |          |         | extended |             |…
Partition key: RANGE (name)
Partitions: range_partition_j_to_s FOR VALUES FROM ('j') TO ('s'),
            range_partition_less_j FOR VALUES FROM (MINVALUE) TO ('j'),
            range_partition_s_greater FOR VALUES FROM ('s') TO (MAXVALUE),
            range_partition_nulls DEFAULT
```

Hash Partitioned Table Creation

```
CREATE TABLE hash_partitioned (name TEXT)
PARTITION BY HASH (name);

CREATE TABLE hash_partition_mod_0
PARTITION OF hash_partitioned
FOR VALUES WITH (MODULUS 3, REMAINDER 0);

CREATE TABLE hash_partition_mod_1
PARTITION OF hash_partitioned
FOR VALUES WITH (MODULUS 3, REMAINDER 1);

CREATE TABLE hash_partition_mod_2
PARTITION OF hash_partitioned
FOR VALUES WITH (MODULUS 3, REMAINDER 2);
```

The Result

```
\d+ hash_partitioned
                   Partitioned table "public.hash_partitioned"
 Column | Type | Collation | Nullable | Default | Storage  | Compression |…
--------+------+-----------+----------+---------+----------+-------------+…
 name   | text |           |          |         | extended |             |…
Partition key: HASH (name)
Partitions: hash_partition_mod_0 FOR VALUES WITH (modulus 3, remainder 0),
            hash_partition_mod_1 FOR VALUES WITH (modulus 3, remainder 1),
            hash_partition_mod_2 FOR VALUES WITH (modulus 3, remainder 2)
```

List Partitioned Table Creation

```
CREATE TYPE employment_status_type AS ENUM ('employed', 'unemployed', 'retired');

CREATE TABLE list_partitioned (
    name TEXT,
    employment_status employment_status_type
)
PARTITION BY LIST (employment_status);

CREATE TABLE list_partition_employed
PARTITION OF list_partitioned
FOR VALUES IN ('employed');

CREATE TABLE list_partition_unemployed
PARTITION OF list_partitioned
FOR VALUES IN ('unemployed');

-- allow NULL partition key values
CREATE TABLE list_partition_retired_and_null
PARTITION OF list_partitioned
FOR VALUES IN ('retired', NULL);
```

The Result

```
\d+ list_partitioned
                  Partitioned table "public.list_partitioned"
      Column       |          Type          | Collation | Nullable | Default |…
-------------------+------------------------+-----------+----------+---------+…
 name              | text                   |           |          |         |…
 employment_status | employment_status_type |           |          |         |…
Partition key: LIST (employment_status)
Partitions: list_partition_employed FOR VALUES IN ('employed'),
            list_partition_retired_and_null FOR VALUES IN ('retired', NULL),
            list_partition_unemployed FOR VALUES IN ('unemployed')
```

Populating the Range Partitioned Table

```
-- This method of generating random data is explained at
-- https://momjian.us/main/blogs/pgblog/2012.html#July_24_2012
INSERT INTO range_partitioned
SELECT
(
    SELECT initcap(string_agg(x, ''))
    FROM (
        SELECT chr(ascii('a') + floor(random() * 26)::integer)
        FROM generate_series(1, 2 + (random() * 8)::integer + b * 0)
    ) AS y(x)
)
FROM generate_series(1, 100000) AS a(b);
```

Populating the Hash Partitioned Table

```
INSERT INTO hash_partitioned
SELECT
(
    SELECT initcap(string_agg(x, ''))
    FROM (
        SELECT chr(ascii('a') + floor(random() * 26)::integer)
        FROM generate_series(1, 2 + (random() * 8)::integer + b * 0)
    ) AS y(x)
)
FROM generate_series(1, 100000) AS a(b);
```

Populating the List Partitioned Table

```
INSERT INTO list_partitioned
SELECT
(
    SELECT initcap(string_agg(x, ''))
    FROM (
        SELECT chr(ascii('a') + floor(random() * 26)::integer)
        FROM generate_series(1, 2 + (random() * 8)::integer + b * 0)
    ) AS y(x)
),
(
    SELECT CASE floor(random() * 3 + b * 0)
           WHEN 0 THEN 'employed'::employment_status_type
               WHEN 1 THEN 'unemployed'::employment_status_type
               WHEN 2 THEN 'retired'::employment_status_type
       END
)
FROM generate_series(1, 100000) AS a(b);
```

Inserting NULL Values

```
INSERT INTO range_partitioned VALUES (NULL);
INSERT INTO hash_partitioned VALUES (NULL);
INSERT INTO list_partitioned VALUES ('test', NULL);
```

Creating Indexes

```
CREATE INDEX i_range_partitioned ON range_partitioned (name);
CREATE INDEX i_hash_partitioned ON hash_partitioned (name);
CREATE INDEX i_list_partitioned ON list_partitioned (name);

ANALYZE;
```

Where are NULLs Stored?

```
-- NULLs are stored in the DEFAULT range partition.
SELECT *, tableoid::regclass
FROM  range_partitioned
WHERE name IS NULL;
  name  |       tableoid
--------+----------------------
 (null) | range_partition_nulls

-- NULLs are always stored in the REMAINDER 0 hash partition;
-- see src/backend/partitioning/partbounds.c:compute_partition_hash_value()
SELECT *, tableoid::regclass
FROM  hash_partitioned
WHERE name IS NULL;
  name  |       tableoid
--------+---------------------
 (null) | hash_partition_mod_0

-- NULLs are stored in the list partition for NULL values.
SELECT *, tableoid::regclass
FROM  list_partitioned
WHERE employment_status IS NULL;
 name | employment_status |            tableoid
------+-------------------+-------------------------------
 test | (null)            | list_partition_retired_and_null
```

tableoid is an invisible column that returns the OID of the table where the row is stored.

First Five Range Partitioned Rows

```
SELECT *, tableoid::regclass
FROM  range_partitioned
ORDER BY 2, 1
LIMIT 5;
 name |        tableoid
------+-------------------------
 Aa   | range_partition_less_j
 Aa   | range_partition_less_j
 Aa   | range_partition_less_j
 Aa   | range_partition_less_j
 Aa   | range_partition_less_j
```

Random Range Partitioned Rows

```
WITH sample AS
(
    SELECT *, tableoid::regclass
    FROM  range_partitioned
    ORDER BY random()
    LIMIT 5
)
SELECT * FROM sample
ORDER BY 2, 1;
   name    |          tableoid
-----------+---------------------------
 Gmgarubn  | range_partition_less_j
 Ousrtai   | range_partition_j_to_s
 Pbtmufce  | range_partition_j_to_s
 Qgt       | range_partition_j_to_s
 Ymsqpxkxm | range_partition_s_greater
```

Random Hash Partitioned Rows

```
WITH sample AS
(
    SELECT *, tableoid::regclass
    FROM  hash_partitioned
    ORDER BY random()
    LIMIT 5
)
SELECT * FROM sample
ORDER BY 2, 1;
   name    |       tableoid
-----------+----------------------
 Yxh       | hash_partition_mod_0
 Asp       | hash_partition_mod_1
 Bgbvewd   | hash_partition_mod_1
 Jemquglx  | hash_partition_mod_2
 Xtlvuqc   | hash_partition_mod_2
```

Random List Partitioned Rows

```
WITH sample AS
(
    SELECT *, tableoid::regclass
    FROM  list_partitioned
    ORDER BY random()
    LIMIT 5
)
SELECT * FROM sample
ORDER BY 3, 2, 1;
    name     | employment_status |               tableoid
------------+-------------------+---------------------------------
 Iwxcn      | employed          | list_partition_employed
 Btlfaascx  | unemployed        | list_partition_unemployed
 Sz         | unemployed        | list_partition_unemployed
 Xpdi       | unemployed        | list_partition_unemployed
 Uwunkpdhmv | retired           | list_partition_retired_and_null
```

Selecting Range Partition Boundaries

```
-- Use lower case for range boundaries if your collation sorts lower case first for case-insensitive equal string,
-- e.g., range 'j' to 's' would include 'j', but 'J' to 'S' would not.  'ja' would be in 'J' to 'S' since 'ja' is
-- not case-insensitive equal to 'J'.
SHOW lc_collate;
 lc_collate
-------------
 en_US.UTF-8

-- Case ordering ignored because of case-insensitive inequality.
-- https://www.unicode.org/reports/tr10/#Scope
SELECT 'a' < 'J' AND 'J' < 'z';
 ?column?
----------
 t

SELECT 'ja' < 'Jb' AND 'Jc' < 'jd';
 ?column?
----------
 t

-- Case ordering only honored for case-insensitive equality.
SELECT 'ja' < 'Ja';
 ?column?
----------
 t

SELECT 'island' < 'Island' AND 'islaNd' < 'iSland';
 ?column?
----------
 t
```

3. Partition Pruning

https://www.flickr.com/photos/anguskirk/

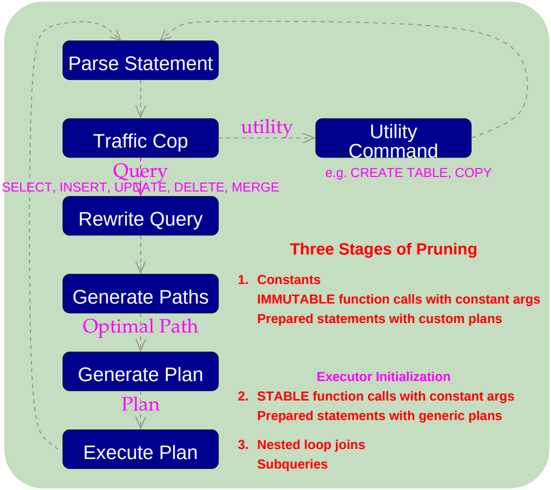
Pruning Stages

Pruning eliminates access to unnecessary partitions. There are three possible stages of pruning, earlier ones being more efficient than later ones:

1. Optimizer
   - shown by EXPLAIN
2. Executor initialization
   - shown by EXPLAIN (ANALYZE) as “Subplans Removed”
   - appears under “Append” and “Merge Append”
   - see src/backend/executor/execPartition.c::ExecInitPartitionPruning()
3. Executor running
   - shown by EXPLAIN (ANALYZE) as “never executed”
   - happens during “Append” and “Merge Append”
   - see src/backend/executor/execPartition.c::ExecFindMatchingSubPlans()

https://momjian.us/main/presentations/performance.html#optimizer
https://momjian.us/main/presentations/performance.html#beyond

Pruning Stages Diagram



Pruning Using NULL Constants: Stage 1

```
\set EXPLAIN 'EXPLAIN (COSTS OFF)'

:EXPLAIN SELECT *
FROM range_partitioned
WHERE name IS NULL;
                     QUERY PLAN
-----------------------------------------------------
 Seq Scan on range_partition_nulls range_partitioned
   Filter: (name IS NULL)

-- NULLs are always stored in the REMAINDER 0 hash partition.
:EXPLAIN SELECT *
FROM hash_partitioned
WHERE name IS NULL;
                                          QUERY PLAN
--------------------------------------------------------------------------------------------
 Index Only Scan using hash_partition_mod_0_name_idx on hash_partition_mod_0 hash_partitioned
   Index Cond: (name IS NULL)

:EXPLAIN SELECT *
FROM list_partitioned
WHERE employment_status IS NULL;
                          QUERY PLAN
--------------------------------------------------------------
 Seq Scan on list_partition_retired_and_null list_partitioned
   Filter: (employment_status IS NULL)
```

Pruning Using Non-NULL Constants: Stage 1

```
:EXPLAIN SELECT *
FROM range_partitioned
WHERE name = 'Ma';
                                            QUERY PLAN
----------------------------------------------------------------------------------------------------
 Index Only Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned
   Index Cond: (name = 'Ma'::text)

:EXPLAIN SELECT *
FROM hash_partitioned
WHERE name = 'Ma';
                                          QUERY PLAN
-----------------------------------------------------------------------------------------------
 Index Only Scan using hash_partition_mod_2_name_idx on hash_partition_mod_2 hash_partitioned
   Index Cond: (name = 'Ma'::text)

:EXPLAIN SELECT *
FROM  list_partitioned
WHERE employment_status = 'retired';
                            QUERY PLAN
--------------------------------------------------------------------
 Seq Scan on list_partition_retired_and_null list_partitioned
   Filter: (employment_status = 'retired'::employment_status_type)
```

Use of Pruning and Per-Partition Index: Stage 1

```
:EXPLAIN SELECT *
FROM list_partitioned
WHERE employment_status = 'retired' AND
      name = 'Ma';
                                                  QUERY PLAN
-----------------------------------------------------------------------------------------------------------------
 Index Scan using list_partition_retired_and_null_name_idx on list_partition_retired_and_null list_partitioned
   Index Cond: (name = 'Ma'::text)
   Filter: (employment_status = 'retired'::employment_status_type)

\d+ list_partitioned
                                            Partitioned table "public.list_partitioned"
      Column       |          Type          | Collation | Nullable | Default | Storage  | Compression | Stats target | Description
-------------------+------------------------+-----------+----------+---------+----------+-------------+--------------+-------------
 name              | text                   |           |          |         | extended |             |              |
 employment_status | employment_status_type |           |          |         | plain    |             |              |
Partition key: LIST (employment_status)
Indexes:
    "i_list_partitioned" btree (name)
Partitions: list_partition_employed FOR VALUES IN ('employed'),
            list_partition_retired_and_null FOR VALUES IN ('retired', NULL),
            list_partition_unemployed FOR VALUES IN ('unemployed')
```

Pruning of Custom-Plan Prepared Statements: Stage 1

```
PREPARE part_test AS
SELECT *
FROM range_partitioned
WHERE name = $1;

:EXPLAIN  EXECUTE part_test('Ba');
                                            QUERY PLAN
---------------------------------------------------------------------------------------------------
 Index Only Scan using range_partition_less_j_name_idx on range_partition_less_j range_partitioned
   Index Cond: (name = 'Ba'::text)

:EXPLAIN  EXECUTE part_test('Ma');
                                            QUERY PLAN
---------------------------------------------------------------------------------------------------
 Index Only Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned
   Index Cond: (name = 'Ma'::text)

:EXPLAIN  EXECUTE part_test('Ta');
                                               QUERY PLAN
---------------------------------------------------------------------------------------------------------
 Index Only Scan using range_partition_s_greater_name_idx on range_partition_s_greater range_partitioned
   Index Cond: (name = 'Ta'::text)
```

By default, custom plans are used for the first five executions, and then generic plans optionally used.

Pruning of Generic-Plan Prepared Statements: Stage 2

```
\set EXPLAIN_ANALYZE 'EXPLAIN (ANALYZE, SUMMARY OFF, TIMING OFF, COSTS OFF)'

-- force a generic plan
SET plan_cache_mode TO force_generic_plan;

-- Pruning happens during executor initialization
:EXPLAIN_ANALYZE EXECUTE part_test('Ba');
                                                             QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=9 loops=1)
   Subplans Removed: 2
   ->  Index Only Scan using range_partition_less_j_name_idx on range_partition_less_j range_partitioned_1 (actual rows=9 loops=1)
         Index Cond: (name = $1)
         Heap Fetches: 0

:EXPLAIN_ANALYZE EXECUTE part_test('Ma');
                                                             QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=6 loops=1)
   Subplans Removed: 2
   ->  Index Only Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned_1 (actual rows=6 loops=1)
         Index Cond: (name = $1)
         Heap Fetches: 0

:EXPLAIN_ANALYZE EXECUTE part_test('Ta');
                                                                 QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=12 loops=1)
   Subplans Removed: 2
   ->  Index Only Scan using range_partition_s_greater_name_idx on range_partition_s_greater range_partitioned_1 (actual rows=12 loops=1)
         Index Cond: (name = $1)
         Heap Fetches: 0
```

Pruning of IMMUTABLE Function Calls

```
-- IMMUTABLE function calls are evaluated in the optimizer.
\do+ ||
                                                List of operators
   Schema   | Name |   Left arg type    |   Right arg type   |    Result type     |    Function     |             Description
------------+------+--------------------+--------------------+--------------------+-----------------+-------------------------------------
 pg_catalog | ||   | anycompatible      | anycompatiblearray | anycompatiblearray | array_prepend   | prepend element onto front of array
 pg_catalog | ||   | anycompatiblearray | anycompatible      | anycompatiblearray | array_append    | append element onto end of array
 pg_catalog | ||   | anycompatiblearray | anycompatiblearray | anycompatiblearray | array_cat       | concatenate
 pg_catalog | ||   | anynonarray        | text               | text               | anytextcat      | concatenate
 pg_catalog | ||   | bit varying        | bit varying        | bit varying        | bitcat          | concatenate
 pg_catalog | ||   | bytea              | bytea              | bytea              | byteacat        | concatenate
 pg_catalog | ||   | jsonb              | jsonb              | jsonb              | jsonb_concat    | concatenate
 pg_catalog | ||   | text               | anynonarray        | text               | textanycat      | concatenate
 pg_catalog | ||   | text               | text               | text               | textcat         | concatenate
 pg_catalog | ||   | tsquery            | tsquery            | tsquery            | tsquery_or      | OR-concatenate
 pg_catalog | ||   | tsvector           | tsvector           | tsvector           | tsvector_concat | concatenate
```

Pruning of IMMUTABLE Function Calls

```
\x on

\df+ textcat
-[ RECORD 1 ]-------+------------------------------
Schema              | pg_catalog
Name                | textcat
Result data type    | text
Argument data types | text, text
Type                | func
Volatility          | immutable
Parallel            | safe
Owner               | postgres
Security            | invoker
Access privileges   |
Language            | internal
Source code         | textcat
Description         | implementation of || operator

\x off
```

Pruning of IMMUTABLE Function Calls: Stage 1

```
:EXPLAIN_ANALYZE SELECT *, tableoid::regclass
FROM range_partitioned
WHERE name = 'M' || 'a';
                                                      QUERY PLAN
------------------------------------------------------------------------------------------------------------------------
 Index Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned (actual rows=6 loops=1)
   Index Cond: (name = 'Ma'::text)
```

Pruning of STABLE Function Calls

```
-- STABLE function calls can also cause this.
\x on

\df+ concat
List of functions
-[ RECORD 1 ]-------+-------------------
Schema              | pg_catalog
Name                | concat
Result data type    | text
Argument data types | VARIADIC "any"
Type                | func
Volatility          | stable
Parallel            | safe
Owner               | postgres
Security            | invoker
Access privileges   |
Language            | internal
Source code         | text_concat
Description         | concatenate values

\x off
```

Pruning of STABLE Function Calls: Stage 2

```
-- pruning happens during executor initialization
:EXPLAIN_ANALYZE SELECT *, tableoid::regclass
FROM range_partitioned
WHERE name = concat('M', 'a');
                                                          QUERY PLAN
-------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=6 loops=1)
   Subplans Removed: 2
   ->  Index Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned_1 (actual rows=6 loops=1)
         Index Cond: (name = concat('M', 'a'))
```

Pruning of Subqueries: Stage 3

```
CREATE TABLE nested_outer (name) AS VALUES ('Pa'), ('Qa'), ('Ra');

ANALYZE nested_outer;

-- pruning happens during executor running
:EXPLAIN_ANALYZE SELECT *
FROM range_partitioned
WHERE name IN (SELECT * FROM nested_outer);
                                                                QUERY PLAN
------------------------------------------------------------------------------------------------------------------------------------------
 Nested Loop (actual rows=24 loops=1)
   ->  HashAggregate (actual rows=3 loops=1)
         Group Key: nested_outer.name
         Batches: 1  Memory Usage: 24kB
         ->  Seq Scan on nested_outer (actual rows=3 loops=1)
   ->  Append (actual rows=8 loops=3)
         ->  Index Only Scan using range_partition_less_j_name_idx on range_partition_less_j range_partitioned_1 (never executed)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Index Only Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned_2 (actual rows=8 loops=3)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Index Only Scan using range_partition_s_greater_name_idx on range_partition_s_greater range_partitioned_3 (never executed)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Seq Scan on range_partition_nulls range_partitioned_4 (never executed)
               Filter: (nested_outer.name = name)
```

Pruning of Joins: Stage 3

```
-- pruning happens during executor running
:EXPLAIN_ANALYZE SELECT *
FROM nested_outer JOIN range_partitioned USING (name);
                                                    QUERY PLAN
-------------------------------------------------------------------------------------------------------------------------------------------
 Nested Loop (actual rows=24 loops=1)
   ->  Seq Scan on nested_outer (actual rows=3 loops=1)
   ->  Append (actual rows=8 loops=3)
         ->  Index Only Scan using range_partition_less_j_name_idx on range_partition_less_j range_partitioned_1 (never executed)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Index Only Scan using range_partition_j_to_s_name_idx on range_partition_j_to_s range_partitioned_2 (actual rows=8 loops=3)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Index Only Scan using range_partition_s_greater_name_idx on range_partition_s_greater range_partitioned_3 (never executed)
               Index Cond: (name = nested_outer.name)
               Heap Fetches: 0
         ->  Seq Scan on range_partition_nulls range_partitioned_4 (never executed)
               Filter: (nested_outer.name = name)
```

4. Partition-Local Optimizations

https://www.flickr.com/photos/donaldjudge/

Partition-Local Optimizations

Partition-local optimizations perform operations on individual partitions and combine their results, rather than operating only on partitioned tables as a whole. Postgres currently supports such optimizations for aggregates and joins.
Combining partition-local results can be expensive, and therefore these optimizations are disabled by default. Performance testing is recommended before enabling these for production queries.

Aggregates Without partitionwise_aggregate: Range

```
-- partitionwise_aggregate is disabled by default.
:EXPLAIN_ANALYZE SELECT name, COUNT(*)
FROM range_partitioned
GROUP BY name;
                                              QUERY PLAN
----------------------------------------------------------------------------------------------------
 HashAggregate (actual rows=90608 loops=1)
   Group Key: range_partitioned.name
   Batches: 5  Memory Usage: 8241kB  Disk Usage: 1552kB
   ->  Append (actual rows=100001 loops=1)
         ->  Seq Scan on range_partition_less_j range_partitioned_1 (actual rows=34626 loops=1)
         ->  Seq Scan on range_partition_j_to_s range_partitioned_2 (actual rows=34535 loops=1)
         ->  Seq Scan on range_partition_s_greater range_partitioned_3 (actual rows=30839 loops=1)
         ->  Seq Scan on range_partition_nulls range_partitioned_4 (actual rows=1 loops=1)
```

Aggregates Without partitionwise_aggregate: Hash

```
:EXPLAIN_ANALYZE SELECT name, COUNT(*)
FROM hash_partitioned
GROUP BY name;
                                         QUERY PLAN
----------------------------------------------------------------------------
 HashAggregate (actual rows=90645 loops=1)
   Group Key: hash_partitioned.name
   Batches: 5  Memory Usage: 8241kB  Disk Usage: 1544kB
   ->  Append (actual rows=100001 loops=1)
         ->  Seq Scan on hash_partition_mod_0 hash_partitioned_1 (actual rows=33530 loops=1)
         ->  Seq Scan on hash_partition_mod_1 hash_partitioned_2 (actual rows=32979 loops=1)
         ->  Seq Scan on hash_partition_mod_2 hash_partitioned_3 (actual rows=33492 loops=1)
```

Aggregates Without partitionwise_aggregate: List

```
:EXPLAIN_ANALYZE SELECT employment_status, COUNT(*)
FROM list_partitioned
GROUP BY employment_status;
                                         QUERY PLAN
------------------------------------------------------------------------------------------
 HashAggregate (actual rows=4 loops=1)
   Group Key: list_partitioned.employment_status
   Batches: 1  Memory Usage: 24kB
   ->  Append (actual rows=100001 loops=1)
         ->  Seq Scan on list_partition_employed list_partitioned_1 (actual rows=33027 loops=1)
         ->  Seq Scan on list_partition_unemployed list_partitioned_2 (actual rows=33467 loops=1)
         ->  Seq Scan on list_partition_retired_and_null list_partitioned_3 (actual rows=33507 loops=1)
```

Aggregates With partitionwise_aggregate: Range

```
SET enable_partitionwise_aggregate = true;

-- needed because the cost of combining per-partition HashAggregates results
-- with many distinct values is high
SET cpu_tuple_cost = 0;

:EXPLAIN_ANALYZE SELECT name, COUNT(*)
FROM range_partitioned
GROUP BY name;
                                            QUERY PLAN
----------------------------------------------------------------------------------------------------
 Append (actual rows=90608 loops=1)
   ->  HashAggregate (actual rows=31382 loops=1)
         Group Key: range_partitioned.name
         Batches: 1  Memory Usage: 4113kB
         ->  Seq Scan on range_partition_less_j range_partitioned (actual rows=34626 loops=1)
   ->  HashAggregate (actual rows=31256 loops=1)
         Group Key: range_partitioned_1.name
         Batches: 1  Memory Usage: 4113kB
         ->  Seq Scan on range_partition_j_to_s range_partitioned_1 (actual rows=34535 loops=1)
   ->  HashAggregate (actual rows=27969 loops=1)
         Group Key: range_partitioned_2.name
         Batches: 1  Memory Usage: 3857kB
         ->  Seq Scan on range_partition_s_greater range_partitioned_2 (actual rows=30839 loops=1)
   ->  HashAggregate (actual rows=1 loops=1)
         Group Key: range_partitioned_3.name
         Batches: 1  Memory Usage: 24kB
         ->  Seq Scan on range_partition_nulls range_partitioned_3 (actual rows=1 loops=1)
```

Aggregates With partitionwise_aggregate: Hash

```
:EXPLAIN_ANALYZE SELECT name, COUNT(*)
FROM hash_partitioned
GROUP BY name;
                                        QUERY PLAN
---------------------------------------------------------------------------------------------
 Append (actual rows=90645 loops=1)
   ->  HashAggregate (actual rows=30465 loops=1)
         Group Key: hash_partitioned.name
         Batches: 1  Memory Usage: 4113kB
         ->  Seq Scan on hash_partition_mod_0 hash_partitioned (actual rows=33530 loops=1)
   ->  HashAggregate (actual rows=29868 loops=1)
         Group Key: hash_partitioned_1.name
         Batches: 1  Memory Usage: 4113kB
         ->  Seq Scan on hash_partition_mod_1 hash_partitioned_1 (actual rows=32979 loops=1)
   ->  HashAggregate (actual rows=30312 loops=1)
         Group Key: hash_partitioned_2.name
         Batches: 1  Memory Usage: 4113kB
         ->  Seq Scan on hash_partition_mod_2 hash_partitioned_2 (actual rows=33492 loops=1)
```

Aggregates With partitionwise_aggregate: List

```
-- not needed for the next query because few distinct values
RESET cpu_tuple_cost;

:EXPLAIN_ANALYZE SELECT employment_status, COUNT(*)
FROM list_partitioned
GROUP BY employment_status;
                                               QUERY PLAN
-----------------------------------------------------------------------------------------------------------
 Append (actual rows=4 loops=1)
   ->  HashAggregate (actual rows=1 loops=1)
         Group Key: list_partitioned.employment_status
         Batches: 1  Memory Usage: 24kB
         ->  Seq Scan on list_partition_employed list_partitioned (actual rows=33027 loops=1)
   ->  HashAggregate (actual rows=1 loops=1)
         Group Key: list_partitioned_1.employment_status
         Batches: 1  Memory Usage: 24kB
         ->  Seq Scan on list_partition_unemployed list_partitioned_1 (actual rows=33467 loops=1)
   ->  HashAggregate (actual rows=2 loops=1)
         Group Key: list_partitioned_2.employment_status
         Batches: 1  Memory Usage: 24kB
         ->  Seq Scan on list_partition_retired_and_null list_partitioned_2 (actual rows=33507 loops=1)

RESET enable_partitionwise_aggregate;
```

Cross Partition Join: Setup

```
CREATE TABLE range_partitioned2 (name TEXT)
PARTITION BY RANGE (name);

CREATE TABLE range_partition_less_j2
PARTITION OF range_partitioned2
FOR VALUES FROM (MINVALUE) TO ('j');

CREATE TABLE range_partition_j_to_s2
PARTITION OF range_partitioned2
FOR VALUES FROM ('j') TO ('s');

CREATE TABLE range_partition_s_greater2
PARTITION OF range_partitioned2
FOR VALUES FROM ('s') TO (MAXVALUE);

CREATE TABLE range_partition_nulls2
PARTITION OF range_partitioned2
(CHECK (name IS NULL))
DEFAULT;
```

Cross Partition Join: Populate

```
INSERT INTO range_partitioned2
SELECT
(
    SELECT initcap(string_agg(x, ''))
    FROM (
        SELECT chr(ascii('a') + floor(random() * 26)::integer)
        FROM generate_series(1, 2 + (random() * 8)::integer + b * 0)
    ) AS y(x)
)
FROM generate_series(1, 100000) AS a(b);

ANALYZE;
```

Cross Partition Join Without partitionwise_join

```
-- partitionwise_aggregate is disabled by default.
:EXPLAIN_ANALYZE SELECT *
FROM range_partitioned JOIN range_partitioned2 USING (name);
                                                QUERY PLAN
------------------------------------------------------------------------------------------------------------
 Hash Join (actual rows=67468 loops=1)
   Hash Cond: (range_partitioned.name = range_partitioned2.name)
   ->  Append (actual rows=100001 loops=1)
         ->  Seq Scan on range_partition_less_j range_partitioned_1 (actual rows=34626 loops=1)
         ->  Seq Scan on range_partition_j_to_s range_partitioned_2 (actual rows=34535 loops=1)
         ->  Seq Scan on range_partition_s_greater range_partitioned_3 (actual rows=30839 loops=1)
         ->  Seq Scan on range_partition_nulls range_partitioned_4 (actual rows=1 loops=1)
   ->  Hash (actual rows=100000 loops=1)
         Buckets: 131072  Batches: 1  Memory Usage: 4833kB
         ->  Append (actual rows=100000 loops=1)
               ->  Seq Scan on range_partition_less_j2 range_partitioned2_1 (actual rows=34646 loops=1)
               ->  Seq Scan on range_partition_j_to_s2 range_partitioned2_2 (actual rows=34606 loops=1)
               ->  Seq Scan on range_partition_s_greater2 range_partitioned2_3 (actual rows=30748 loops=1)
               ->  Seq Scan on range_partition_nulls2 range_partitioned2_4 (actual rows=0 loops=1)
```

Cross Partition Join With partitionwise_join

```
SET enable_partitionwise_join = true;

:EXPLAIN_ANALYZE SELECT *
FROM range_partitioned JOIN range_partitioned2 USING (name);
                                                           QUERY PLAN
------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=67468 loops=1)
   -> Hash Join (actual rows=23917 loops=1)
        Hash Cond: (range_partitioned_1.name = range_partitioned2_1.name)
        -> Seq Scan on range_partition_less_j range_partitioned_1 (actual rows=34626 loops=1)
        -> Hash (actual rows=34646 loops=1)
              Buckets: 65536  Batches: 1  Memory Usage: 1832kB
              -> Seq Scan on range_partition_less_j2 range_partitioned2_1 (actual rows=34646 loops=1)
   -> Hash Join (actual rows=23096 loops=1)
        Hash Cond: (range_partitioned_2.name = range_partitioned2_2.name)
        -> Seq Scan on range_partition_j_to_s range_partitioned_2 (actual rows=34535 loops=1)
        -> Hash (actual rows=34606 loops=1)
              Buckets: 65536  Batches: 1  Memory Usage: 1830kB
              -> Seq Scan on range_partition_j_to_s2 range_partitioned2_2 (actual rows=34606 loops=1)
   -> Hash Join (actual rows=20455 loops=1)
        Hash Cond: (range_partitioned_3.name = range_partitioned2_3.name)
        -> Seq Scan on range_partition_s_greater range_partitioned_3 (actual rows=30839 loops=1)
        -> Hash (actual rows=30748 loops=1)
              Buckets: 32768  Batches: 1  Memory Usage: 1428kB
              -> Seq Scan on range_partition_s_greater2 range_partitioned2_3 (actual rows=30748 loops=1)
   -> Nested Loop (actual rows=0 loops=1)
        -> Seq Scan on range_partition_nulls2 range_partitioned2_4 (actual rows=0 loops=1)
        -> Index Only Scan using range_partition_nulls_name_idx on range_partition_nulls range_partitioned_4 (never executed)
              Index Cond: (name = range_partitioned2_4.name)
              Heap Fetches: 0
```

5. Time-Based Partitioning

https://www.flickr.com/photos/amylovesyah/

Time-Based Partitioning

Time-based partitioning stores data in partitions based on some time component. New partitions need to be created to match time-based requirements, and old partitions can be archived, deleted, or moved to tablespaces with cheaper storage. Time-based partitioning have added complexity because of time zone and daylight saving time aspects.

Create Per-Month Partitions

```
CREATE TABLE month_partitioned (day DATE, temperature NUMERIC(5,2))
PARTITION BY RANGE (day);

CREATE TABLE month_partition_2023_01
PARTITION OF month_partitioned
FOR VALUES FROM ('2023-01-01') TO ('2023-02-01');

CREATE TABLE month_partition_2023_02
PARTITION OF month_partitioned
FOR VALUES FROM ('2023-02-01') TO ('2023-03-01');

CREATE TABLE month_partition_2023_03
PARTITION OF month_partitioned
FOR VALUES FROM ('2023-03-01') TO ('2023-04-01');

CREATE TABLE month_partition_other
PARTITION OF month_partitioned
DEFAULT;
```

Populate Per-Month Partitions

```
INSERT INTO month_partitioned
SELECT
(
    SELECT '2023-01-01'::date +
       floor(random() * ('2023-04-01'::date - '2023-01-01'::date) + b * 0)::integer
),
(
    SELECT floor(random() * 10000) / 100 + b * 0
)
FROM generate_series(1, 100000) AS a(b);

CREATE INDEX i_month_partitioned ON month_partitioned (day);

ANALYZE;
```

Random Partition Rows

```
WITH sample AS
(
    SELECT *, tableoid::regclass
    FROM  month_partitioned
    ORDER BY random()
    LIMIT 5
)
SELECT * FROM sample
ORDER BY 3, 1;
    day     | temperature |         tableoid
------------+-------------+-------------------------
 2023-01-16 |       64.45 | month_partition_2023_01
 2023-02-07 |       46.03 | month_partition_2023_02
 2023-02-13 |       87.14 | month_partition_2023_02
 2023-03-07 |       97.04 | month_partition_2023_03
 2023-03-08 |       59.02 | month_partition_2023_03
```

Partition Pruning

```
:EXPLAIN_ANALYZE  SELECT *
FROM month_partitioned
WHERE day = '2023-02-01';
                                        QUERY PLAN
------------------------------------------------------------------------------------------
 Bitmap Heap Scan on month_partition_2023_02 month_partitioned (actual rows=1169 loops=1)
   Recheck Cond: (day = '2023-02-01'::date)
   Heap Blocks: exact=170
   ->  Bitmap Index Scan on month_partition_2023_02_day_idx (actual rows=1169 loops=1)
         Index Cond: (day = '2023-02-01'::date)
```

Default Partition Usage

```
INSERT INTO month_partitioned VALUES ('2023-05-01', 87.31);

:EXPLAIN_ANALYZE SELECT *
FROM  month_partitioned
WHERE day = '2023-05-01';
                                  QUERY PLAN
------------------------------------------------------------------------------
 Seq Scan on month_partition_other month_partitioned (actual rows=1 loops=1)
   Filter: (day = '2023-05-01'::date)
```

Null Uses the DEFAULT Partition

```
INSERT INTO month_partitioned VALUES (NULL, 46.24);

:EXPLAIN_ANALYZE SELECT *
FROM  month_partitioned
WHERE day IS NULL;
                                   QUERY PLAN
------------------------------------------------------------------------------
 Seq Scan on month_partition_other month_partitioned (actual rows=1 loops=1)
   Filter: (day IS NULL)
   Rows Removed by Filter: 1
```

Attaching and Detaching Partitions

```
ALTER TABLE month_partitioned DETACH PARTITION month_partition_other;

INSERT INTO month_partitioned VALUES (NULL, 46.24);
ERROR:  no partition of relation "month_partitioned" found for row
DETAIL:  Partition key of the failing row contains (day) = (null).

ALTER TABLE month_partitioned ATTACH PARTITION month_partition_other DEFAULT;
```

Pruning Using a STABLE Function

```
-- Simulate CURRENT_DATE by using the STABLE function concat().
\set CURRENT_DATE concat('''2023-02-01''' || ''''''')::date

:EXPLAIN_ANALYZE SELECT *
FROM month_partitioned
WHERE day = :CURRENT_DATE;
                                            QUERY PLAN
---------------------------------------------------------------------------------------------------
 Append (actual rows=1169 loops=1)
   Subplans Removed: 3
   ->  Bitmap Heap Scan on month_partition_2023_02 month_partitioned_1 (actual rows=1169 loops=1)
         Recheck Cond: (day = (concat('2023-02-01'::text))::date)
         Heap Blocks: exact=170
         ->  Bitmap Index Scan on month_partition_2023_02_day_idx (actual rows=1169 loops=1)
               Index Cond: (day = (concat('2023-02-01'::text))::date)
```

Partition Expiration and Creation

```
CREATE TABLE month_partition_2023_04
PARTITION OF month_partitioned
FOR VALUES FROM ('2023-04-01') TO ('2023-05-01');

DROP TABLE month_partition_2023_01;
```

The table could also be archived before deletion or moved to a different tablespace. pg_partman (https://github.com/pgpartman/pg_partman) can help with auto-partition creation.

Create Timestamp with Time Zone Partitions

```
SET timezone = 'America/New_York';

CREATE TABLE month_ts_tz_partitioned (event_time TIMESTAMP WITH TIME ZONE, temperature NUMERIC(5,2))
PARTITION BY RANGE (event_time);

-- date evaluated at creation time
CREATE TABLE month_ts_tz_partition_2023_01
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-01-01') TO ('2023-02-01');

CREATE TABLE month_ts_tz_partition_2023_02
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-02-01') TO ('2023-03-01');

CREATE TABLE month_ts_tz_partition_2023_03
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-03-01') TO ('2023-04-01');

CREATE TABLE month_ts_tz_partition_other
PARTITION OF month_ts_tz_partitioned
DEFAULT;
```

DATE Data Type Has No Time Zone

```
SELECT EXTRACT(EPOCH FROM '2023-01-01'::date);
  extract
------------
 1672531200

SELECT EXTRACT(EPOCH FROM '2023-01-01 00:00:00-00'::timestamptz);
      extract
-------------------
 1672531200.000000

SELECT EXTRACT(EPOCH FROM '2023-01-01'::timestamptz);
      extract
-------------------
 1672549200.000000

SELECT EXTRACT(EPOCH FROM '2023-01-01 00:00:00-05'::timestamptz);
      extract
-------------------
 1672549200.000000
```

Populate Partitions

```
INSERT INTO month_ts_tz_partitioned
SELECT
(
    SELECT '2023-01-01 00:00:00'::timestamptz +
       (floor(random() *
              (extract(EPOCH FROM '2023-04-01'::timestamptz) -
               extract(EPOCH FROM '2023-01-01'::timestamptz)) +
              b * 0)::integer || 'seconds')::interval
),
(
    SELECT floor(random() * 10000) / 100 + b * 0
)
FROM generate_series(1, 100000) AS a(b);

-- add row to the DEFAULT partition
INSERT INTO month_ts_tz_partitioned VALUES ('2023-04-05 00:00:00', 50);

CREATE INDEX i_month_ts_tz_partitioned ON month_ts_tz_partitioned (event_time);

ANALYZE;
```

We must cast to TIMESTAMPTZ, not DATE, to align with the partition boundaries.

Partition Details

```
\d+ month_ts_tz_partitioned
                                    Partitioned table "public.month_ts_tz_partitioned"
   Column    |           Type           | Collation | Nullable | Default | Storage | Compression | Stats target | Description
-------------+--------------------------+-----------+----------+---------+---------+-------------+--------------+-------------
 event_time  | timestamp with time zone |           |          |         | plain   |             |              |
 temperature | numeric(5,2)             |           |          |         | main    |             |              |
Partition key: RANGE (event_time)
Indexes:
    "i_month_ts_tz_partitioned" btree (event_time)
Partitions: month_ts_tz_partition_2023_01 FOR VALUES FROM ('2023-01-01 00:00:00-05') TO ('2023-02-01 00:00:00-05'),
            month_ts_tz_partition_2023_02 FOR VALUES FROM ('2023-02-01 00:00:00-05') TO ('2023-03-01 00:00:00-05'),
            month_ts_tz_partition_2023_03 FOR VALUES FROM ('2023-03-01 00:00:00-05') TO ('2023-04-01 00:00:00-04'),
            month_ts_tz_partition_other DEFAULT
```

First Partition Row

```
SELECT CURRENT_TIMESTAMP;
       current_timestamp
-------------------------------
 2023-03-20 09:35:05.375191-04

SELECT *, tableoid::regclass
FROM  month_ts_tz_partitioned
ORDER BY 1
LIMIT 1;
       event_time        | temperature |            tableoid
------------------------+-------------+--------------------------------
 2023-01-01 00:01:26-05 |        8.14 | month_ts_tz_partition_2023_01
```

First Partition Row in a Different Time Zone

```
SET timezone = 'Asia/Tokyo';

SELECT CURRENT_TIMESTAMP;
       current_timestamp
-------------------------------
 2023-03-20 22:35:05.376393+09

SELECT *, tableoid::regclass
FROM  month_ts_tz_partitioned
ORDER BY 1
LIMIT 1;
       event_time       | temperature |            tableoid
------------------------+-------------+-------------------------------
 2023-01-01 14:01:26+09 |        8.14 | month_ts_tz_partition_2023_01
```

Partition Bounds Adjusted

```
\d+ month_ts_tz_partitioned
                                          Partitioned table "public.month_ts_tz_partitioned"
   Column    |           Type           | Collation | Nullable | Default | Storage | Compression | Stats target | Description
-------------+--------------------------+-----------+----------+---------+---------+-------------+--------------+-------------
 event_time  | timestamp with time zone |           |          |         | plain   |             |              |
 temperature | numeric(5,2)             |           |          |         | main    |             |              |
Partition key: RANGE (event_time)
Indexes:
    "i_month_ts_tz_partitioned" btree (event_time)
Partitions: month_ts_tz_partition_2023_01 FOR VALUES FROM ('2023-01-01 14:00:00+09') TO ('2023-02-01 14:00:00+09'),
            month_ts_tz_partition_2023_02 FOR VALUES FROM ('2023-02-01 14:00:00+09') TO ('2023-03-01 14:00:00+09'),
            month_ts_tz_partition_2023_03 FOR VALUES FROM ('2023-03-01 14:00:00+09') TO ('2023-04-01 13:00:00+09'),
            month_ts_tz_partition_other DEFAULT
```

The Same in UTC

```
SET timezone = 'UTC';

SELECT *, tableoid::regclass
FROM  month_ts_tz_partitioned
ORDER BY 1
LIMIT 1;
       event_time        | temperature |            tableoid
-------------------------+-------------+--------------------------------
 2023-01-01 05:01:26+00 |        8.14 | month_ts_tz_partition_2023_01
```

The Same in UTC

```
\d+ month_ts_tz_partitioned
                                  Partitioned table "public.month_ts_tz_partitioned"
   Column    |           Type           | Collation | Nullable | Default | Storage | Compression | Stats target | Description
-------------+--------------------------+-----------+----------+---------+---------+-------------+--------------+-------------
 event_time  | timestamp with time zone |           |          |         | plain   |             |              |
 temperature | numeric(5,2)             |           |          |         | main    |             |              |
Partition key: RANGE (event_time)
Indexes:
    "i_month_ts_tz_partitioned" btree (event_time)
Partitions: month_ts_tz_partition_2023_01 FOR VALUES FROM ('2023-01-01 05:00:00+00') TO ('2023-02-01 05:00:00+00'),
            month_ts_tz_partition_2023_02 FOR VALUES FROM ('2023-02-01 05:00:00+00') TO ('2023-03-01 05:00:00+00'),
            month_ts_tz_partition_2023_03 FOR VALUES FROM ('2023-03-01 05:00:00+00') TO ('2023-04-01 04:00:00+00'),
            month_ts_tz_partition_other DEFAULT
```

No Pruning of a Function Call on a Column

```
SET timezone = 'America/New_York';

:EXPLAIN_ANALYZE SELECT *
FROM month_ts_tz_partitioned
WHERE date(event_time) = '2023-02-05';
                                              QUERY PLAN
----------------------------------------------------------------------------------------------------
 Append (actual rows=1093 loops=1)
   ->  Seq Scan on month_ts_tz_partition_2023_01 month_ts_tz_partitioned_1 (actual rows=0 loops=1)
         Filter: (date(event_time) = '2023-02-05'::date)
         Rows Removed by Filter: 34240
   ->  Seq Scan on month_ts_tz_partition_2023_02 month_ts_tz_partitioned_2 (actual rows=1093 loops=1)
         Filter: (date(event_time) = '2023-02-05'::date)
         Rows Removed by Filter: 30075
   ->  Seq Scan on month_ts_tz_partition_2023_03 month_ts_tz_partitioned_3 (actual rows=0 loops=1)
         Filter: (date(event_time) = '2023-02-05'::date)
         Rows Removed by Filter: 34547
   ->  Seq Scan on month_ts_tz_partition_other month_ts_tz_partitioned_4 (actual rows=0 loops=1)
         Filter: (date(event_time) = '2023-02-05'::date)
         Rows Removed by Filter: 45
```

Date Range Can Be Pruned

```
:EXPLAIN_ANALYZE SELECT *
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-02-05' AND
      event_time <  '2023-02-06';
                                                QUERY PLAN
--------------------------------------------------------------------------------------------------------
 Bitmap Heap Scan on month_ts_tz_partition_2023_02 month_ts_tz_partitioned (actual rows=1093 loops=1)
   Recheck Cond: ((event_time >= '2023-02-05 00:00:00-05'::timestamp with time zone) AND
                  (event_time < '2023-02-06 00:00:00-05'::timestamp with time zone))
   Heap Blocks: exact=169
   ->  Bitmap Index Scan on month_ts_tz_partition_2023_02_event_time_idx (actual rows=1093 loops=1)
         Index Cond: ((event_time >= '2023-02-05 00:00:00-05'::timestamp with time zone) AND
                      (event_time < '2023-02-06 00:00:00-05'::timestamp with time zone))
```

Date Calculation Can Be Pruned

```
-- simulate CURRENT_TIMESTAMP by using the STABLE function concat().
\set CURRENT_TIMESTAMP concat('''2023-02-05 23:43:51''' || ''''''')::timestamptz

-- pruning happening during executor initialization
:EXPLAIN_ANALYZE SELECT *
FROM month_ts_tz_partitioned
WHERE event_time >  :CURRENT_TIMESTAMP - '24 hours'::interval AND
      event_time <= :CURRENT_TIMESTAMP;
                                                              QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------------------------
 Append (actual rows=1091 loops=1)
   Subplans Removed: 3
   ->  Bitmap Heap Scan on month_ts_tz_partition_2023_02 month_ts_tz_partitioned_1 (actual rows=1091 loops=1)
         Recheck Cond: ((event_time > ((concat('2023-02-05 23:43:51'::text))::timestamp with time zone - '24:00:00'::interval)) AND
                        (event_time <= (concat('2023-02-05 23:43:51'::text))::timestamp with time zone))
         Heap Blocks: exact=169
         ->  Bitmap Index Scan on month_ts_tz_partition_2023_02_event_time_idx (actual rows=1091 loops=1)
               Index Cond: ((event_time > ((concat('2023-02-05 23:43:51'::text))::timestamp with time zone - '24:00:00'::interval)) AND
                            (event_time <= (concat('2023-02-05 23:43:51'::text))::timestamp with time zone))
```

Timestamp Range Can Be Pruned

```
:EXPLAIN_ANALYZE SELECT *
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00';
                                                QUERY PLAN
---------------------------------------------------------------------------------------------------------
 Bitmap Heap Scan on month_ts_tz_partition_2023_03 month_ts_tz_partitioned (actual rows=1101 loops=1)
   Recheck Cond: ((event_time >= '2023-03-01 00:00:00-05'::timestamp with time zone) AND
                  (event_time < '2023-03-02 00:00:00-05'::timestamp with time zone))
   Heap Blocks: exact=187
   ->  Bitmap Index Scan on month_ts_tz_partition_2023_03_event_time_idx (actual rows=1101 loops=1)
         Index Cond: ((event_time >= '2023-03-01 00:00:00-05'::timestamp with time zone) AND
                      (event_time < '2023-03-02 00:00:00-05'::timestamp with time zone))
```

Where Are Per-Day Rows?

```
SELECT COUNT(*)
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00';
 count
-------
  1101
```

Where Are Per-Day Rows?

```
SELECT *, tableoid::regclass
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00'
ORDER BY 1
LIMIT 1;
       event_time       | temperature |            tableoid
------------------------+-------------+--------------------------------
 2023-03-01 00:00:20-05 |       49.85 | month_ts_tz_partition_2023_03

SELECT *, tableoid::regclass
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00'
ORDER BY 1 DESC
LIMIT 1;
       event_time       | temperature |            tableoid
------------------------+-------------+--------------------------------
 2023-03-01 23:59:35-05 |       27.94 | month_ts_tz_partition_2023_03
```

Query in a Different Time Zone

```
SET timezone = 'Asia/Tokyo';

:EXPLAIN_ANALYZE SELECT *
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00';
                                                    QUERY PLAN
-------------------------------------------------------------------------------------------------------------
 Append (actual rows=1109 loops=1)
   ->  Bitmap Heap Scan on month_ts_tz_partition_2023_02 month_ts_tz_partitioned_1 (actual rows=622 loops=1)
         Recheck Cond: ((event_time >= '2023-03-01 00:00:00+09'::timestamp with time zone) AND
                        (event_time < '2023-03-02 00:00:00+09'::timestamp with time zone))
         Heap Blocks: exact=166
         ->  Bitmap Index Scan on month_ts_tz_partition_2023_02_event_time_idx (actual rows=622 loops=1)
               Index Cond: ((event_time >= '2023-03-01 00:00:00+09'::timestamp with time zone) AND
                            (event_time < '2023-03-02 00:00:00+09'::timestamp with time zone))
   ->  Bitmap Heap Scan on month_ts_tz_partition_2023_03 month_ts_tz_partitioned_2 (actual rows=487 loops=1)
         Recheck Cond: ((event_time >= '2023-03-01 00:00:00+09'::timestamp with time zone) AND
                        (event_time < '2023-03-02 00:00:00+09'::timestamp with time zone))
         Heap Blocks: exact=169
         ->  Bitmap Index Scan on month_ts_tz_partition_2023_03_event_time_idx (actual rows=487 loops=1)
               Index Cond: ((event_time >= '2023-03-01 00:00:00+09'::timestamp with time zone) AND
                            (event_time < '2023-03-02 00:00:00+09'::timestamp with time zone))
```

Different Count

```
SELECT COUNT(*)
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00';
 count
-------
  1109
```

Partition Range

```
SELECT *, tableoid::regclass
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00'
ORDER BY 1
LIMIT 1;
       event_time        | temperature |            tableoid
-------------------------+-------------+--------------------------------
 2023-03-01 00:00:32+09 |       16.32 | month_ts_tz_partition_2023_02

SELECT *, tableoid::regclass
FROM month_ts_tz_partitioned
WHERE event_time >= '2023-03-01 00:00:00' AND
      event_time <  '2023-03-02 00:00:00'
ORDER BY 1 DESC
LIMIT 1;
       event_time        | temperature |            tableoid
-------------------------+-------------+--------------------------------
 2023-03-01 23:56:22+09 |       19.78 | month_ts_tz_partition_2023_03
```

Range Boundaries Are Set at Creation

```
-- caused by mismatch with America/New_York time zone boundaries
CREATE TABLE month_ts_tz_partition_2023_04
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-04-01') TO ('2023-05-01');
ERROR:  partition "month_ts_tz_partition_2023_04" would
    overlap partition "month_ts_tz_partition_2023_03"
LINE 3: FOR VALUES FROM ('2023-04-01') TO ('2023-05-01');
                         ^
```

Matching Rows in the DEFAULT Partition

```
SET timezone = 'America/New_York';

-- caused by daylight saving time change
CREATE TABLE month_ts_tz_partition_2023_04
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-04-01') TO ('2023-05-01');
ERROR:  updated partition constraint for default partition
    "month_ts_tz_partition_other" would be violated by some row
```

Move DEFAULT Rows to a New Partition

```
BEGIN WORK;

-- lock table and/or detach DEFAULT partition?
CREATE TEMP TABLE tmp_default AS
SELECT *
FROM month_ts_tz_partition_other
WHERE event_time >= '2023-04-01 00:00:00' AND
      event_time <  '2023-05-01 00:00:00';

DELETE FROM month_ts_tz_partition_other
WHERE event_time >= '2023-04-01 00:00:00' AND
      event_time <  '2023-05-01 00:00:00';

CREATE TABLE month_ts_tz_partition_2023_04
PARTITION OF month_ts_tz_partitioned
FOR VALUES FROM ('2023-04-01') TO ('2023-05-01');

INSERT INTO month_ts_tz_partitioned
SELECT * FROM tmp_default;

SELECT * FROM  month_ts_tz_partition_other;
 event_time | temperature
------------+-------------

COMMIT;
```

New Partition Contents

```
SELECT * FROM  month_ts_tz_partition_2023_04;
       event_time        | temperature
------------------------+-------------
 2023-04-05 00:00:00-04 |       50.00

SELECT * FROM  month_ts_tz_partition_other;
 event_time | temperature
------------+-------------
```

6. Row Migration

https://www.flickr.com/photos/ashokbo/

Rows in 'j' to 's' Partition

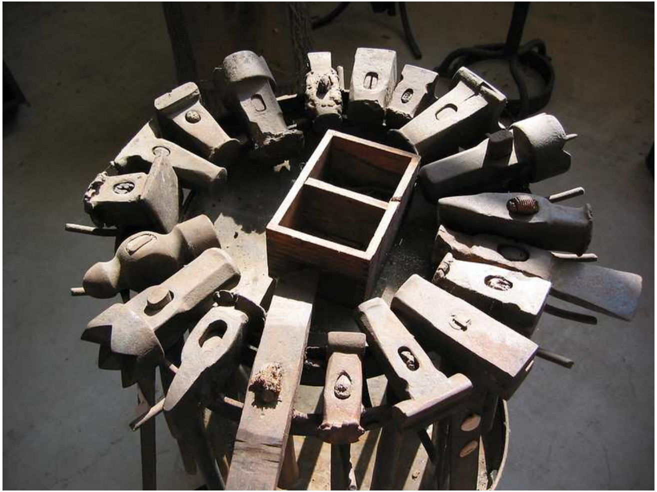
```
SELECT *, tableoid::regclass
FROM range_partitioned
WHERE name = 'Ma'
ORDER BY 2, 1;
 name |        tableoid
------+------------------------
 Ma   | range_partition_j_to_s
 Ma   | range_partition_j_to_s
 Ma   | range_partition_j_to_s
 Ma   | range_partition_j_to_s
 Ma   | range_partition_j_to_s
 Ma   | range_partition_j_to_s
```

Migration to Greater than 's' Partition

```
UPDATE range_partitioned
SET name = 'zz_' || name
WHERE name = 'Ma';

SELECT *, tableoid::regclass
FROM range_partitioned
WHERE name = 'zz_Ma'
ORDER BY 2, 1;
 name  |          tableoid
-------+---------------------------
 zz_Ma | range_partition_s_greater
 zz_Ma | range_partition_s_greater
 zz_Ma | range_partition_s_greater
 zz_Ma | range_partition_s_greater
 zz_Ma | range_partition_s_greater
 zz_Ma | range_partition_s_greater
```

8. psql Support



https://www.flickr.com/photos/feuilllu/

```
COMMENT ON TABLE range_partitioned IS 'Section 2';
COMMENT ON TABLE hash_partitioned IS 'Section 2';
COMMENT ON TABLE list_partitioned IS 'Section 2';
COMMENT ON TABLE range_partitioned2 IS 'Section 4';
COMMENT ON TABLE month_partitioned IS 'Section 5';
COMMENT ON TABLE month_ts_tz_partitioned IS 'Section 5';

\dPt+
                      List of partitioned tables
 Schema |          Name           |  Owner   | Total size | Description
--------+-------------------------+----------+------------+-------------
 public | hash_partitioned        | postgres | 3888 kB    | Section 2
 public | list_partitioned        | postgres | 4280 kB    | Section 2
 public | month_partitioned       | postgres | 2896 kB    | Section 5
 public | month_ts_tz_partitioned | postgres | 13 MB      | Section 5
 public | range_partitioned       | postgres | 3904 kB    | Section 2
 public | range_partitioned2      | postgres | 3888 kB    | Section 4
```

8. Limitations

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Partitioning Limitations

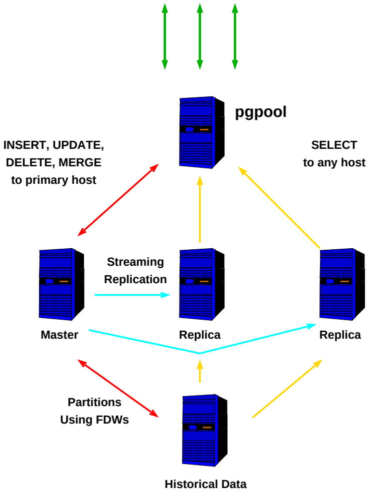
- Adding partitions
  - requires locking
    - partitions can be created, populated, and then attached to reduce locking
  - attached partition rows are verified unless CHECK constraints match partition bounds
  - requires DEFAULT partition scans unless CHECK constraints make it unnecessary
  - foreign table rows are not verified
- Removing partitions
  - requires locking
  - partitions can be detached CONCURRENTLY to reduce locking
- Function calls on columns cannot be pruned unless specified in the range
  - function calls on constants often can
- Unique indexes on partitioned tables must include the partition key columns
  - no global indexes, see https://momjian.us/main/blogs/pgblog/2020.html#July_1_2020
- CONCURRENT index creation on *partitioned* tables is not supported
  - CONCURRENT index creation on *partitions* is supported, and can then be attached

https://www.postgresql.org/docs/current/sql-altertable.html

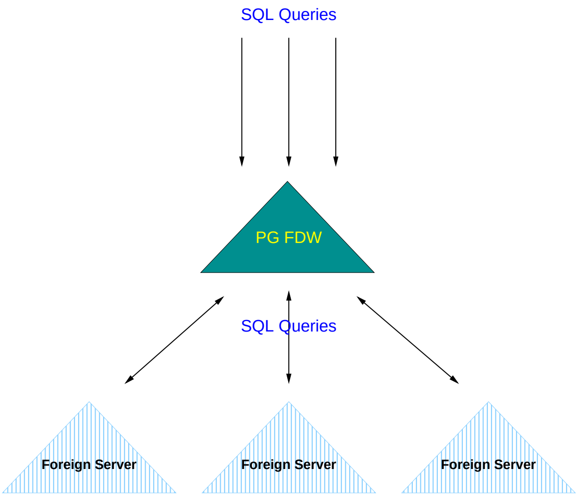
9. Complex Architectures

https://www.flickr.com/photos/alexdrop/

Foreign Servers for Archive Data



Sharding



https://momjian.us/main/presentations/performance.html#sharding

Conclusion

https://momjian.us/presentations

https://www.flickr.com/photos/maxbraun/