Un Éléphant de Première Classe

A bit of History

1970

A Relational Model of Data for Large Shared Data Banks

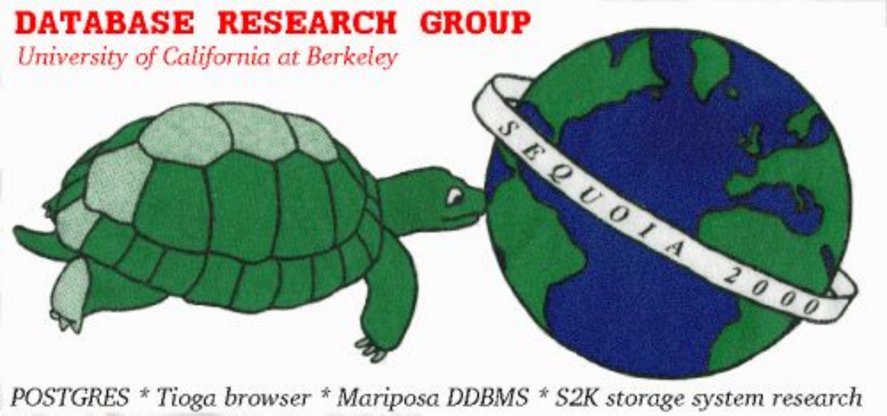
E. F. Codd
IBM Research Laboratory, San Jose, California

1970 - 1979 System R

1973 - 1985 Ingres & Quel

1989

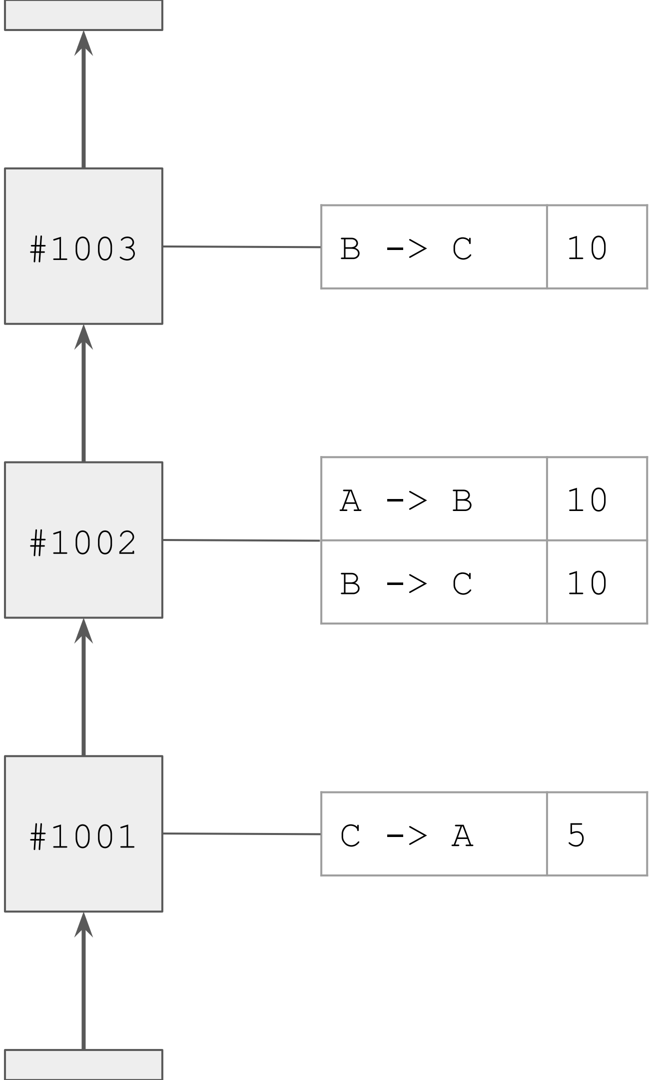
Postgres & PostQuel



1996 PostgreSQL

Why this talk ?

LEDGER



A	1001	+5
A	1002	-10
B	1001	+10
B	1002	+10
C	1001	-10
C	1002	-10

+

cassandra

❌ Optimized for write-based workflow

cassandra

- ❌ Optimized for write-based workflow
- ❌ Heavy in term of maintenance

cassandra

- ❌ Optimized for write-based workflow
- ❌ Heavy in term of maintenance
- ❌ Joins must be performed on the application side

Applicative joins ?

```scala
class OrderService:

  val orderRepository: OrderRepository       = ???
  val customerRepository: CustomerRepository = ???

  def findLatestOrdersWithCustomer(): Seq[OrderWithCustomer] =
    val latests = orderRepository.findLatestOrders()

    val result = ListBuffer.empty[OrderWithCustomer]

    latests.foreach: order =>
      val customer = customerRepository.findById(order.curstomerID)
      result.addOne(OrderWithCustomer(order, customer))

    result.toList
```

✅ Great for our read-heavy workflow

✅ Lighter maintenance and cheaper (50%)

✅ Joins can just be joins !

What is first class Postgres ?

- Database is at the center of the system
- The schema is the source of truth
- Treat SQL as a *real programming language*
- Commit to Postgres features

Setup your development loop

Tools for composition

Step up your indexing game

Data types shenanigans

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Hardware Setup

- Modern hardware is worth it
- Scaling vertically is a viable strategy
- On-prem kube (rancher) + bare metal PG

Dual Intel Xeon Gold 5515+ - 16c/32t - 3.2GHz/3.6GHz

256GB DDR5 ECC 4800MHz

2x SSD NVMe 960GB Datacenter Class Soft RAID

6× 3.84TB SSD NVMe Soft RAID

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~ 400 €

Software Setup

Use a migration tool (we use flyway)

Prefer idempotent migrations

Think about scheduling baselines

Abuse comments on everything !

Abuse comments on everything !

```sql
-- Transaction => block join table, a.k.a. confirmation (inclusion of a transaction in a block)
create table v2.chain_tx_block
(
   block_hash text not null,
   tx_id      text not null,

   unique (tx_id),
   primary key (block_hash, tx_id),
   foreign key (tx_id)      references v2.chain_tx (tx_id),
   foreign key (block_hash) references v2.chain_block (block_hash) on delete cascade
);
comment on table v2.chain_tx_block is 'represents the inclusion of a transaction in a block (a.k.a., a
confirmation) - note that it can be a minority fork block';
comment on column v2.chain_tx_block.tx_id is 'transaction identifier (immutable, globally unique identifier,
typically transaction hash)';
comment on column v2.chain_tx_block.block_hash is 'block identifier (immutable, globally unique)';
```

No ORM : prefer data access libraries

```
skunk.exception.PostgresErrorException:
🔥
🔥  Postgres ERROR 42804 raised in transformAssignedExpr (parse_target.c:595)
🔥
🔥    Problem: Column "success" is of type boolean but expression is of type bigint.
🔥       Hint: You will need to rewrite or cast the expression.
🔥
🔥  The statement under consideration was defined
🔥    at /Users/raphael.lemaitre/Developer/projects/ledger/atlas/modules/polkadot/src/main/scala/polkadot/queries/ExtrinsicTable.scala:18
🔥
🔥    INSERT INTO extrinsics
🔥                SELECT height                                      AS height,
🔥                       index                                       AS index,
🔥                       data ->> 'hash'                             AS hash,
🔥                       data -> 'method' ->> 'pallet'               AS pallet,
🔥                       data -> 'method' ->> 'method'               AS method,
🔥                       (data ->> 'nonce') :: bigint                AS nonce,
🔥                       data -> 'signature' -> 'signer' ->> 'id'    AS signer,
🔥                       data -> 'args'                              AS args,
🔥                       (data ->> 'tip') ::bigint                   AS tip,
🔥                       (data -> 'info' ->> 'weight') :: bigint     AS weight,
🔥                       data -> 'info' ->> 'class'                  AS class,
🔥                       (data -> 'info' ->> 'partialFee') :: bigint AS partial_fee,
🔥                       data -> 'era'                               AS era,
🔥                       (data -> 'success') :: bigint              AS success,
🔥                        └─── Column "success" is of type boolean but expression is of type bigint.
🔥                       (data -> 'paysFee') :: boolean              AS pays_fee
🔥                FROM raw_extrinsics
🔥                WHERE height >= $1 AND height <= $2
🔥
🔥  If this is an error you wish to trap and handle in your application, you can do
🔥  so with a SqlState extractor. For example:
🔥
🔥    doSomething.recoverWith { case SqlState.DatatypeMismatch(ex) =>  ...}
🔥
```

Use a proper SQL editor (DataGrip, DBeaver)

`psql` can be a very powerful tool

`psql` tips :

- `\e` Open the EDITOR with the latest query you typed. Closing run the buffer.
- `\e myfile.sql` Open the EDITOR with the file in it.
- `\x` For extended display
- `\watch 1` Repeat the query every 1 second

Testing SQL

Testing with a real DB

- Testcontainers + fixtures to add migration
- Cache DB instances !
- Never use sqlite / h2 / derby anymore

Crafting SQL Tests

- Test on the boundaries.
  - Typed language -> Input / Output models then translate into domain
  - Dynamic languages -> check aggressively
  - Defense in depth strategies

- Test functions and procedures

- Make tooling around sql files (syntax highlighting)

Testing on real data

Use transactions to benchmark your migrations before running them with migrations

```
begin isolation level read committed;  -- Queries sees data before it starts
begin isolation level repeatable read; -- Queries sees data before the tx started
begin isolation level serializable;    -- repeatable read + error if write conflict

-- Migrate, migrate, migrate

savepoint before_risky_thing;

-- Migrate, migrate, migrate

-- Oh no ! I deleted the prod table :/

rollback to before_risky_thing; -- Rollback to savepoint, restoring the state

-- Migrate, migrate, migrate

commit; -- or abort if you want your migrations to pick it up
```

Optimizing

```
EXPLAIN (ANALYZE, COSTS, VERBOSE, BUFFERS)
```

```
explain (analyse, verbose, costs, buffers)
select header_id, tx_index, address
from log
     join address on contract_id = address_id
where (header_id, tx_index) = (2278166300, 290);

                                              QUERY PLAN

----------------------------------------------------------------------------------------------------------
 Nested Loop  (cost=[...] rows=10 width=33) (actual time=0[...] rows=5 loops=1)
   Output: log.header_id, log.tx_index, address.address
   Inner Unique: true
   Buffers: shared hit=30
   ->  Index Scan using log_pkey on v2.log  (cost=[...]) (actual time=[...] rows=5 loops=1)
      Output: [columns]
      Index Cond: ((log.header_id = '2278166300'::bigint) AND (log.tx_index = 290))
      Buffers: shared hit=5
   ->  Index Scan using address_pkey on v2.address  (cost=[...]) (actual time=[...] rows=1 loops=5)
      Output: address.address_id, address.address
      Index Cond: (address.address_id = log.contract_id)
      Buffers: shared hit=25
 Query Identifier: -8177880399755634493
 Planning:
   Buffers: shared hit=10
 Planning Time: 0.467 ms
 Execution Time: 0.094 ms
(17 rows)
```

Always `analyse` after large inserts

`Scans` are the name of the game

- `Seq Scan` Traverse in order : maybe an index is missing ?
- `Index Scan` Scans a table heap using an index
- `Index Only Scan` Only touches the index pages
- `Bitmap Index Scan` Build a bitmap from an index
- `Bitmap Heap Scan` Build a bitmap from the heap
- `TID Scan` Directly access physical data

`Sort` is a very costly operation

- `union, distinct` introduce a sort
- Cover the order with the indices (and preserve order through the query)
- Sorting large set can spill on disk : `set work_mem` can help

`Shared Hit`	data is coming from cached pages
`Read`	data is coming from disk

`Rows Removed by Filter` means your indices are not efficient enough explain.dalibo.com

Setup your development loop

Tools for composition

Step up your indexing game

Data types shenanigans

```sql
select first_name
     , last_name
     , performance_rating
     , project_count
from (select employee_id
           , first_name
           , last_name
           , performance_rating
      from employees
      where performance_rating >= 4.5) as employee_performance
     join (select employee_id
                , count(project_id) as project_count
           from employee_projects
           group by employee_id) as project_allocations
      using (employee_id)
where pa.project_count > 1
order by performance_rating desc
       , project_count desc
;
```

Oh no ! Subselects everywhere

- Each clause that require a *set of record*
  - can be replaced by a subselect

- Each clause that require a *value*
  - can be replaced by a subselect that yields only ONE element

Common Table Expression

```sql
with employee_performance as
       (select employee_id, first_name, last_name, performance_rating
        from employees
        where performance_rating >= 4.5 )

   , project_allocations as
       (select employee_id, count(project_id) as project_count
        from employee_projects
        group by employee_id )

   , high_performers_multiple_projects as
       (select first_name, last_name, performance_rating, project_count
        from employee_performance ep
        join project_allocations pa using (employee_id)
        where project_count > 1)

select *
from high_performers_multiple_projects
order by performance_rating desc, project_count desc;
```

Common Table Expression

- Extract logical subqueries from the main one
- Can even be recursive (but out of the scope of this talk)
- Warning : They can introduce memoization
  - `materialized`/`not materialized` prefixes

Views

```sql
create view employee_performance as
     select employee_id, first_name, last_name, performance_rating
     from employees
     where performance_rating ⩾ 4.5;

create view project_allocations as
     select employee_id, count(project_id) as project_count
     from employee_projects
     group by employee_id;

select first_name
     , last_name
     , performance_rating
     , project_count
from employee_performance
     join project_allocations using (employee_id)
where project_counts > 1
order by (performance_rating, project_count) desc
;
```

Views

- Extract logical subqueries into reusable piece of code
- Allow neat tricks for schema upgrade !
- Warning : Documentation

Remember ?

```
select first_name
     , last_name
     , performance_rating
     , project_count
from (select employee_id
           , first_name
           , last_name
           , performance_rating
      from employees
      where performance_rating ≥ 4.5) as employee_performance
     join (select employee_id
                , count(project_id) as project_count
           from employee_projects
           group by employee_id) as project_allocations
       using (employee_id)
where pa.project_count > 1
order by performance_rating desc
       , project_count desc
;
```

Remember ?

```
select first_name
     , last_name
     , performance_rating
     , (select count(project_id)
        from employee_projects ep
        where employee_id = ep.employee_id) as project_count

from employees

where performance_rating >= 4.5
  and project_count > 1

order by performance_rating desc
       , project_count desc
;
```

Functions

```sql
create function get_project_count( employee_id int )
returns bigint as $$
begin return
     select count(project_id)
     from employee_projects ep
     where employee_id = ep.employee_id;
end;
$$ language plpgsql;
```

Functions

```sql
select first_name
     , last_name
     , performance_rating
     , get_project_count(employee_id) as project_count

from employees

where performance_rating >= 4.5
  and project_count > 1

order by ( performance_rating, project_count ) desc
;
```

Functions

- In a functional language, using functions is a good idea
- As testable as any SQL query
- Composes way better than fragments

Set returning functions

```sql
create function project_stats( employee_id int )
returns table ( rd_project_count      bigint
              , it_project_count      bigint
              , pi_project_count      bigint
              , mean_project_duration interval) as $$
begin return query
     select count(project_id) filter (where type = 'R&D') as rd_project_count
          , count(project_id) filter (where type = 'IT')  as it_project_count
          , count(project_id) filter (where type = 'PI')  as pi_project_count
          , avg(age(start_at, end_at)) as mean_project_duration
     from employee_projects ep
     where employee_id = ep.employee_id;
end;
$$ language plpgsql;
```

SRF + Lateral

```
select first_name
     , last_name
     , performance_rating
     , rd_project_count
     , it_project_count
     , pi_project_count
     , mean_project_duration

from employees
     join lateral project_allocations(employee_id) on true

where performance_rating ⩾ 4.5
  and project_count > 1

order by ( performance_rating, project_count ) desc
;
```

SRF + Lateral

```
select first_name
     , last_name
     , performance_rating
     , rd_project_count
     , it_project_count
     , pi_project_count
     , mean_project_duration

from employees
   , lateral project_allocations(employee_id)

where performance_rating ⩾ 4.5
  and project_count > 1

order by ( performance_rating, project_count ) desc
;
```

Setup your development loop

Tools for composition

Step up your indexing game

Data types shenanigans

Indices 101

Persistent data structure to speed up data access:

- `btree` default index type.
  - Allows range lookup and sorting
- `gin` inverted index.
  - Allows multi-key lookup but no sorting.
- `gist` framework to create complex datatype indices.
  - Allows distance based lookup and sorting

Indices 101

Stored in pages like tables : hence `tablespace`

```
create index ...
tablespace nvme_drive;
```

Only one index can be used to scan in order

```sql
create table action (
    id      bigserial   primary key,
    user_id uuid        not null,
    ts      timestamptz not null,
    asset   text        not null,
    status  text        not null
);
```

Multicolumns indices

```
create index on action (user_id, ts desc)
```

Order of the columns is important !

- ✅ `user_id = ???`
- ✅ `user_id = ??? and ts <= ???`
- ❌ `ts between ??? and ???`

Multicolumns indices

```
create index on action (user_id, ts desc)
```

Order of the columns is important !

- ✅ `order by user_id`
- ✅ `order by user_id, ts desc`
- ❌ `order by ts`
- ❌ `order by ts desc, user_id`

Included fields in index

```
create index on action (user_id, ts desc)
include (asset)
```

- Can make a query skip heap storage
- `IndexOnlyScan` vs `IndexScan`
- Useful when joining partial data

Partial Index

```
create index on action (user_id, ts desc)
include (asset)
where status = 'canceled'
```

- Reduce index size (and potentially increase performance)
- Can be combined with `unique` to enforce uniqueness on a subsets of rows

Clustered Tables

```
cluster table_name using idx_action_user_id_ts;
```

- Physically **reorders table rows** based on an **index**.
- Faster index-based scans (esp. range queries).

Clustered Tables

```
cluster table_name using idx_action_user_id_ts;
```

- **Table locked** during clustering (exclusive access).
- Needs **manual re-cluster**
- Can increase **write overhead** if frequently updated.

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Using domains

```
create domain invoice_total_amount as numeric(20,2)
check (
    value > 0 and value <= 1000000
)
constraint invoice_total_amount_range_check;
```

Using domains

```
create table invoice (
    id          bigserial            primary key,
    customer_id bigint               not null,
    issued_at   date                 not null,
    total       invoice_total_amount not null
);
```

Using complex data types : ranges & multiranges

- ranges are continuous intervals (e.g. dates, numbers)

- multiranges are sets of non-overlapping ranges

- Lots of operator / functions that handle all the tricky use cases
  - overlap
  - open / closed bounds

- Indexing support using gist and `btree_gist`

Using complex data types : ranges & multiranges

```
create table subscription (
    id            bigserial primary key,
    user_id       bigint    not null,
    active_period daterange not null
);
```

Using complex data types : ranges & multiranges

```
create index on subscription using gist (active_period);
```

Using complex data types : ranges & multiranges

```
select * from subscription
where active_period @> date '2025-06-01';

select * from subscription
where active_period -|- daterange('2025-06-01', '2025-07-01');
```

Using complex data types : exclude constraints

```
create table room_booking (
    id            bigserial primary key,
    room_id       bigint    not null,
    booked_period tsrange   not null,

    exclude using gist (
        room_id       with =,
        booked_period with &&
    )
);
```

Using complex data types : arrays

- collection of elements
- overhead for small collection is huge (24 bytes)
- Indexable using `GIN` (warning: no sorting!)
    - `@>` (inclusion)
    - `&&` (overlap)
- For key-value, use `hstore`

Using complex data types : arrays and aggregations

```
with exploded(post_id, tag) as
     (select post_id, unnest(tags) from posts)

select post_id
     , array_agg(tag order by tag)
       filter (where tag <> 'draft')
       as cleaned
from exploded
group by post_id;
```

Using complex data types : ltree

- ltree stores hierarchical labels (path in a tree)
- lquery : pattern-matching syntax for querying ltrees
- indexable (GiST) on ltree and ltree[]

Using complex data types : ltree

```sql
create extension if not exists ltree;

create table product_category (
    id   serial primary key,
    name text  not null,
    path ltree not null
);

create index idx_product_path_gist
    on product_category
    using gist (path);
```

Using complex data types : ltree

```sql
-- 1. in Electronics
-- 2. Exactly 2-3 levels are left free
-- 3. Last label must be LED, OLED, or Speakers
-- 4. Exclude any category whose path contains Refurbished anywhere

select id, name, path
from   product_category
where  path ~ 'electronics.*{2,3}.{led|oled|speakers} & !*.refurbished';
```

`JSONB` : If your data has a schema : don't.

Using complex data types : jsonb

- Joins are fast.

- TOAST (The Oversized-Attribute Storage Technique)
    - Compressing and storing large field values (like long text or bytea) out-of-line in a separate pages to preserve row byte length

    - Reads are slower

Using complex data types : jsonb

- base `GIN`
  - `data @> '{"status": "active"}'   -- contains`
  - `data ? 'email'                   -- exsits`
- path `GIN (data jsonb_path_ops)`
  - only for `@>`
- btree on extracted values
  - `create index idx_data_price on my_table ((data ->> 'price'))`

`JSONB` : Great for aggregations

Using complex data types : jsonb aggregations

```sql
create table transactions (
     transaction_id   uuid        primary key default gen_random_uuid(),
     account_id       uuid        not null references accounts(account_id),
     transaction_date timestamptz not null
);

create table transaction_assets (
     detail_id        uuid    primary key default gen_random_uuid(),
     transaction_id   uuid    not null references transactions(transaction_id),
     asset_name       text    not null,
     amount           numeric not null
);
```

Using complex data types : jsonb

```
create function get_transaction_transfers(transaction_id_input uuid)
returns jsonb
language plpgsql as $$
begin
     return select jsonb_agg(to_jsonb(*) - 'transaction_id')
            from transaction_assets
            where transaction_id = transaction_id_input;
end;
$$;
```

Using complex data types : jsonb

```
select transaction_id
     , transaction_date
     , get_transaction_transfers(transaction_id) as transfers
from transactions
where account_id = '<account_id>';
```

Using complex data types : cube

Builtin extension to manipulate *hyper-rectangles* and *points*

- spatial indexing
- Effectively multivariate order-independant index
- range-based searching.

Using complex data types : the cube's trick

```
create table customer_profile (
    customer_id serial primary key,
    logins integer not null,
    session_duration numeric(5,2) not null,
    purchases integer not null
);
```

Using complex data types : the cube's trick

```
create index customer_behavior_idx
on customer_profile
using gist (
    cube(array[
        logins::float8,
        session_duration::float8,
        purchases::float8
    ])
);
```

Using complex data types : the cube's trick

```
select *
from customer_profile
where
     cube(array[ logins::float8, session_duration::float8,
purchases::float8])
  <@ cube(array[10,20,1],array[50,40,10]);
```

Using complex data types : the cube's trick

```
                                              QUERY PLAN
----------------------------------------------------------------------------------------------
 Bitmap Heap Scan on customer_profile  (cost=1.26..3.42 rows=2 width=24)
   Recheck Cond: (cube(ARRAY[...]) <@ '(10, 20, 1),(50, 40, 10)'::cube)
   ->  Bitmap Index Scan on customer_behavior_idx  (cost=0.00..1.26 rows=2 width=0)
         Index Cond: (cube(ARRAY[...]) <@ '(10, 20, 1),(50, 40, 10)'::cube)
```

What is first class Postgres ?

- Database is at the center of the system
- The schema is the source of truth
- Treat SQL as real code
- Commit to Postgres features

This meeting could have been an email.

This meeting could have been an email.

This service could have been a table.