AUTO PLAN TUNING USING FEEDBACK LOOP

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Who I am?

- **Tatsuro Yamada**
  - From Tokyo, Japan

- **Work**
  - for NTT Open Source Software Center
  - Database consulting for NTT Group companies
  - Oracle_fdw committer
  - Organizers of PGConf.Asia

- **Interest**
  - Listening to Bossa-nova and Jazz samba
  - Skiing, Craft beer
  - Plan tuning

Agenda

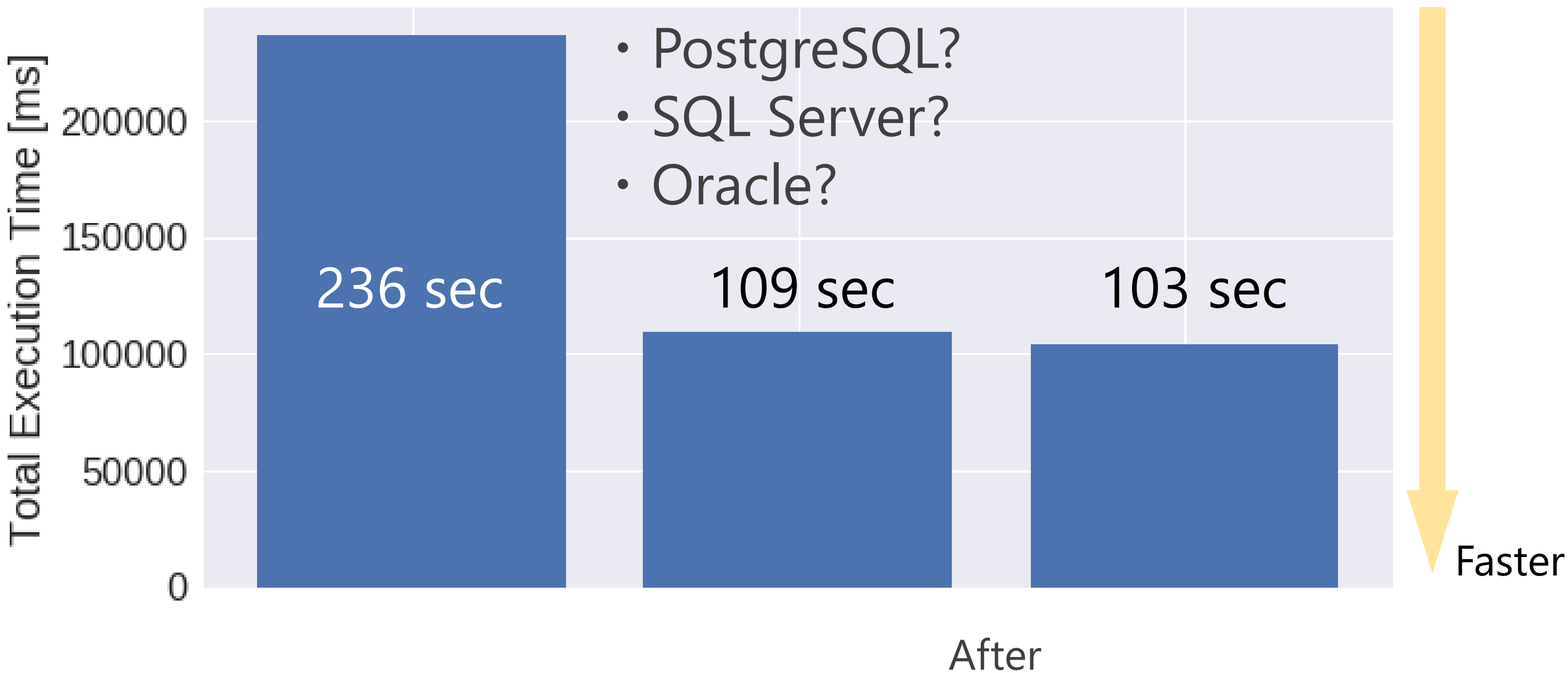
1. Background of plan tuning
2. Mechanism of pg_plan_advsr
3. Verification of effectiveness using JOB [1]
4. Demonstration
5. Using aqo and pg_plan_advsr together
6. Conclusion

[1] Join order benchmark

Background of plan tuning

Question

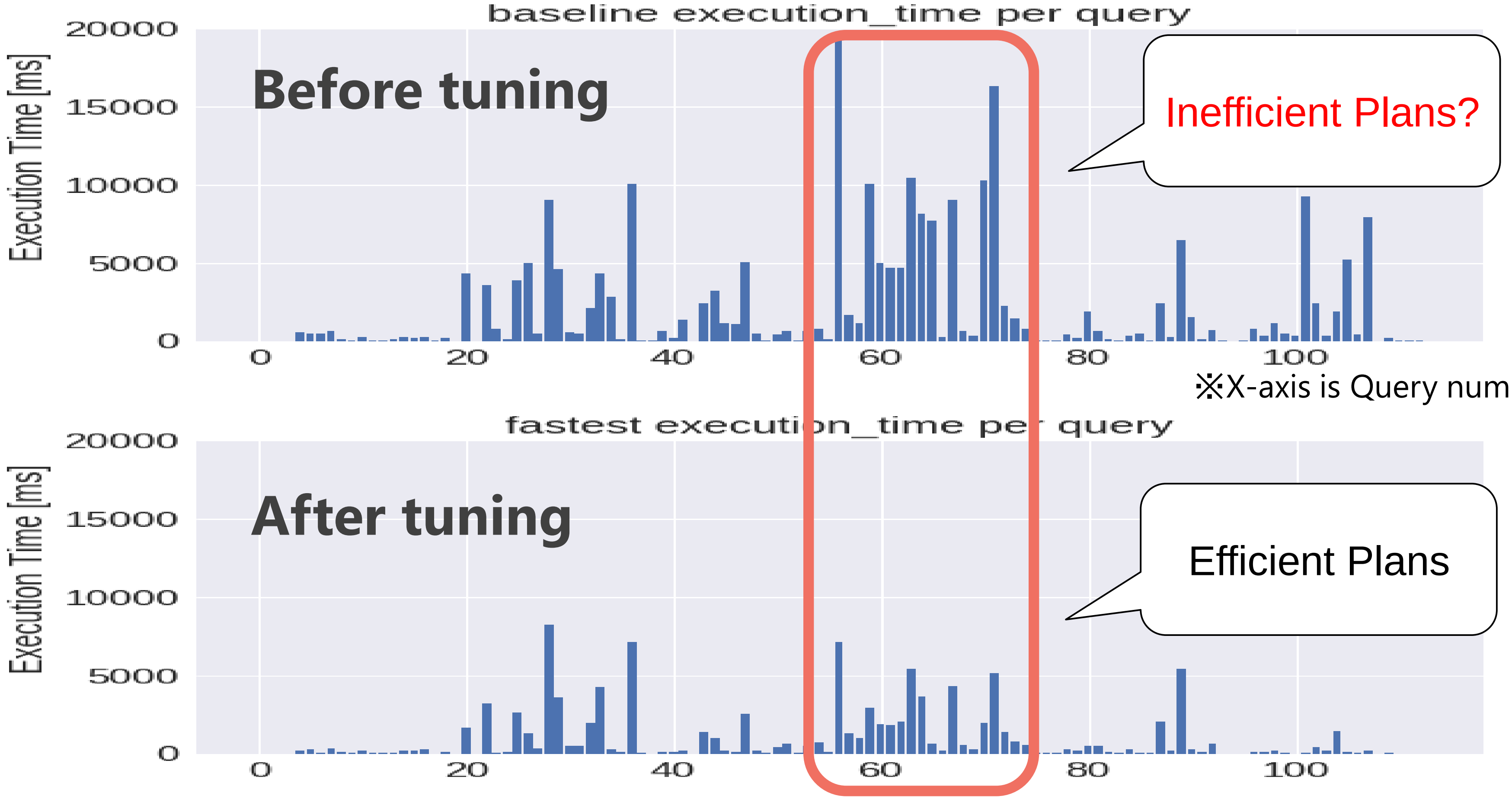
- **What are these graphs?**



These are before and after plan tuning in PostgreSQL

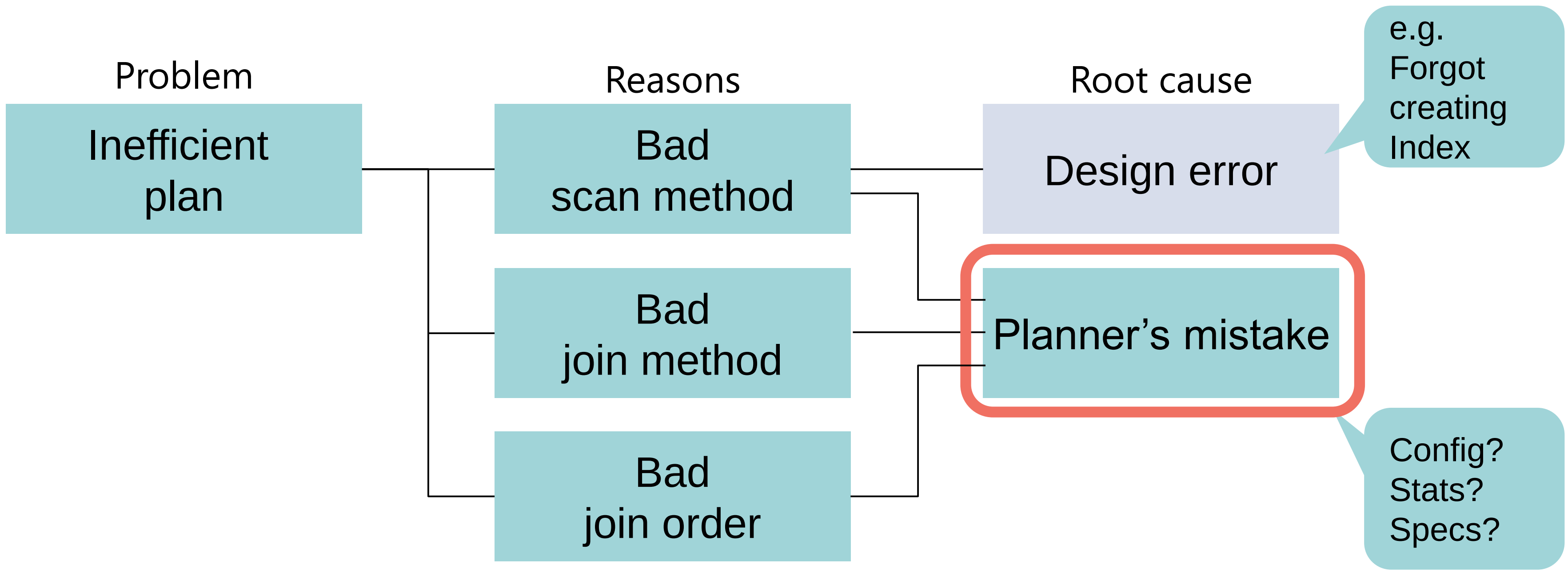
Difference between Before and After tuning

- Almost all queries execution time are decreasing. Especially, middle part of the graph.



※X-axis is Query number

Where is the cause of an inefficient plan?



Planner takes mistakes sometimes.
What kind of mistakes?

Well known examples of planner mistakes

Innovative R&D by NTT

- **Cardinality estimation error**
  (aka **Row count estimation error)**
  - Over estimate
    - Estimated Rows = 5000 but Actual Rows = 1
  - Under estimate
    - Estimated Rows = 1 but Actual Rows = 50000

See Appendix:
planner's behavior

- The Ideally, there should be no cardinality estimation error.

- Such mistakes tend to select an inefficient plan.

DBA and user have to do various tunings to get efficient plan.

See: https://blog.pgaddict.com/posts/common-issues-with-planner-statistics

NTT

Conventional plan tuning methods

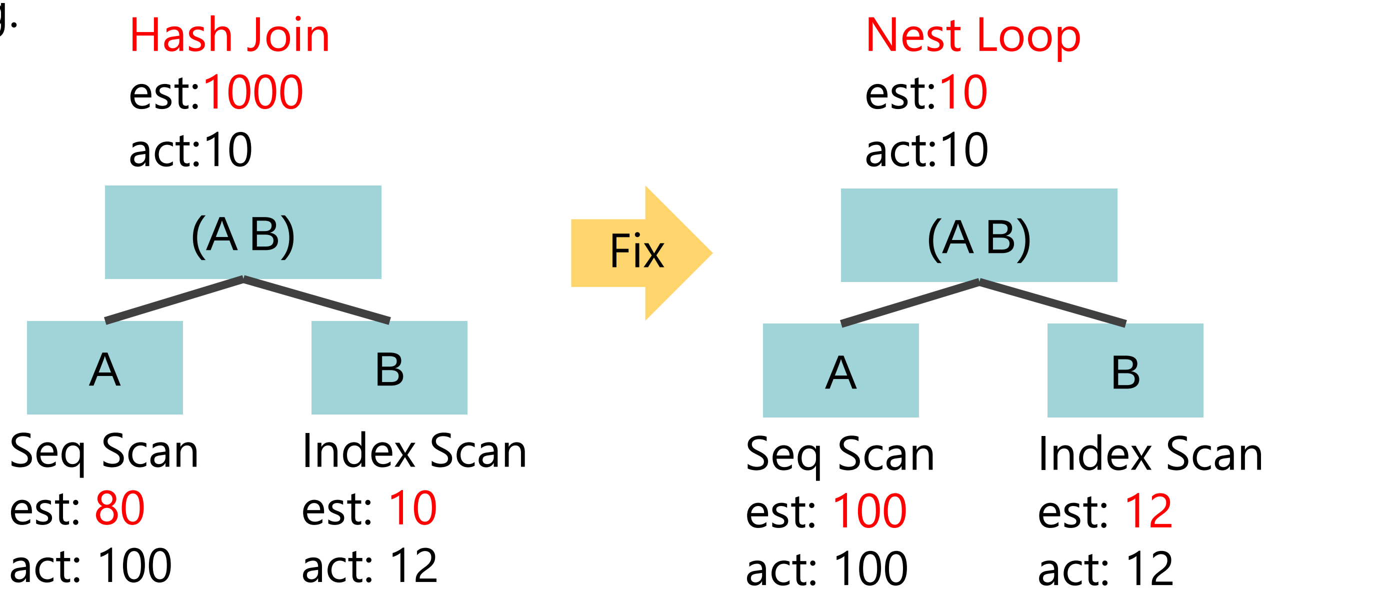
- **Improve accuracy of estimated rows**
  - Change the acquisition timing and sampling amount for Stats
  - Use extended statistics
  - Use pg_dbms_stats
- **Modify scan, join methods and join order**
  - Index tuning
  - Use GUC parameter
  - Rewrite queries
  - Use Optimizer Hint

DBA and user use EXPLAIN ANALYZE command for the tunings

Idea for getting more efficient plan

- **If we can correct cardinality estimations directly, can we be got more efficient plan?!**
  - Because, we know Actual rows by Explain Anayze command.

e.g.

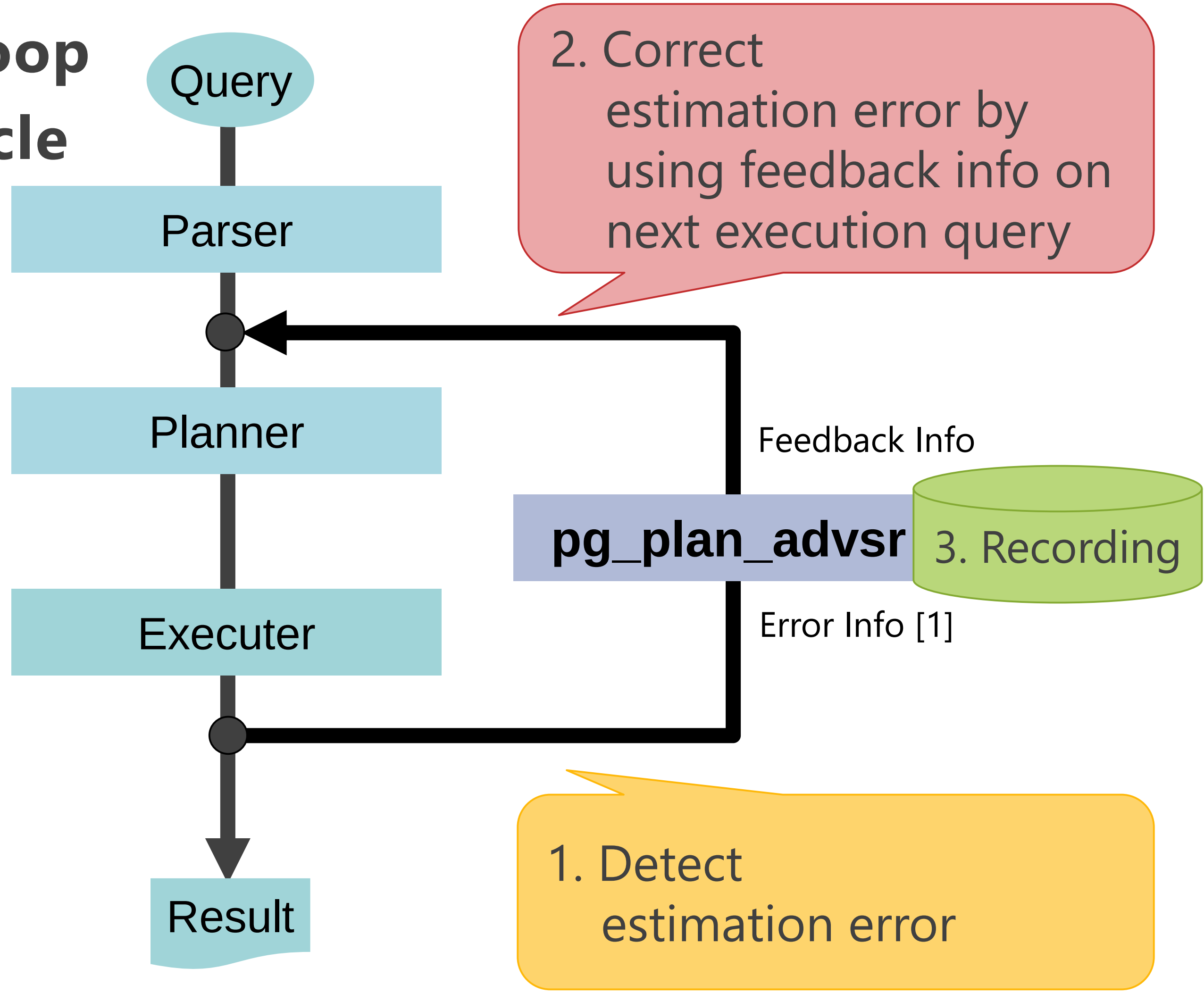


The idea is simple, but implementation is hard because there is no interface to correct.

Mechanism of pg_plan_advsr

Rough concept of pg_plan_advsr

- Use Feedback Loop
- Enable PDCA cycle



[1] The difference between Estimated rows and Actual rows

Three main features

1. Detect estimation error and Create Feedback info

- Feedback info is a corrective info made by estimation error
  -> ROWS hint
- Also, create hints to reproduce a plan
  -> SCAN, JOIN, LEADING hints

See: Apendix

2. Correct estimation error

- To fix estimation rows by feedback info genelate a new efficient plan on next query iteration

3. Record plan history

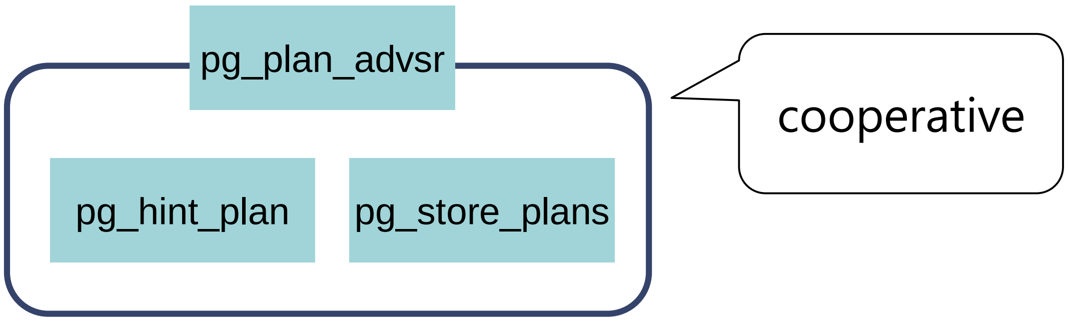
- Store query, plan, execution time, feedback info, hints for reproduce a plan and so on

Implementation of pg_plan_advsr

1. Detect estimation error to create feedback info
   - **ExecutorEnd_hook**
   - **New walker of queryDesc**

2. Correct estimation error by using feedback info
   - **pg_hint_plan's Hint table** feature and ROWS hints

3. Record Plan history
   - **ExecutorEnd_hook**
   - Create **Plan_history table** to store all info
   - **pg_store_plans** is also used complementary



Use cases

- **When**
  - This extension is assumed to be used in the plan tuning process (test phase) within system development.
- **How to use**
  - Use **EXPLAIN ANALYZE** command until no estimation error.
- **Note**
  - Stable data (no updates) during tuning is a precondition because changing data doesn’t get converged.

Verification of effectiveness using Join order benchmark

Verification of effectiveness using Join order benchmark

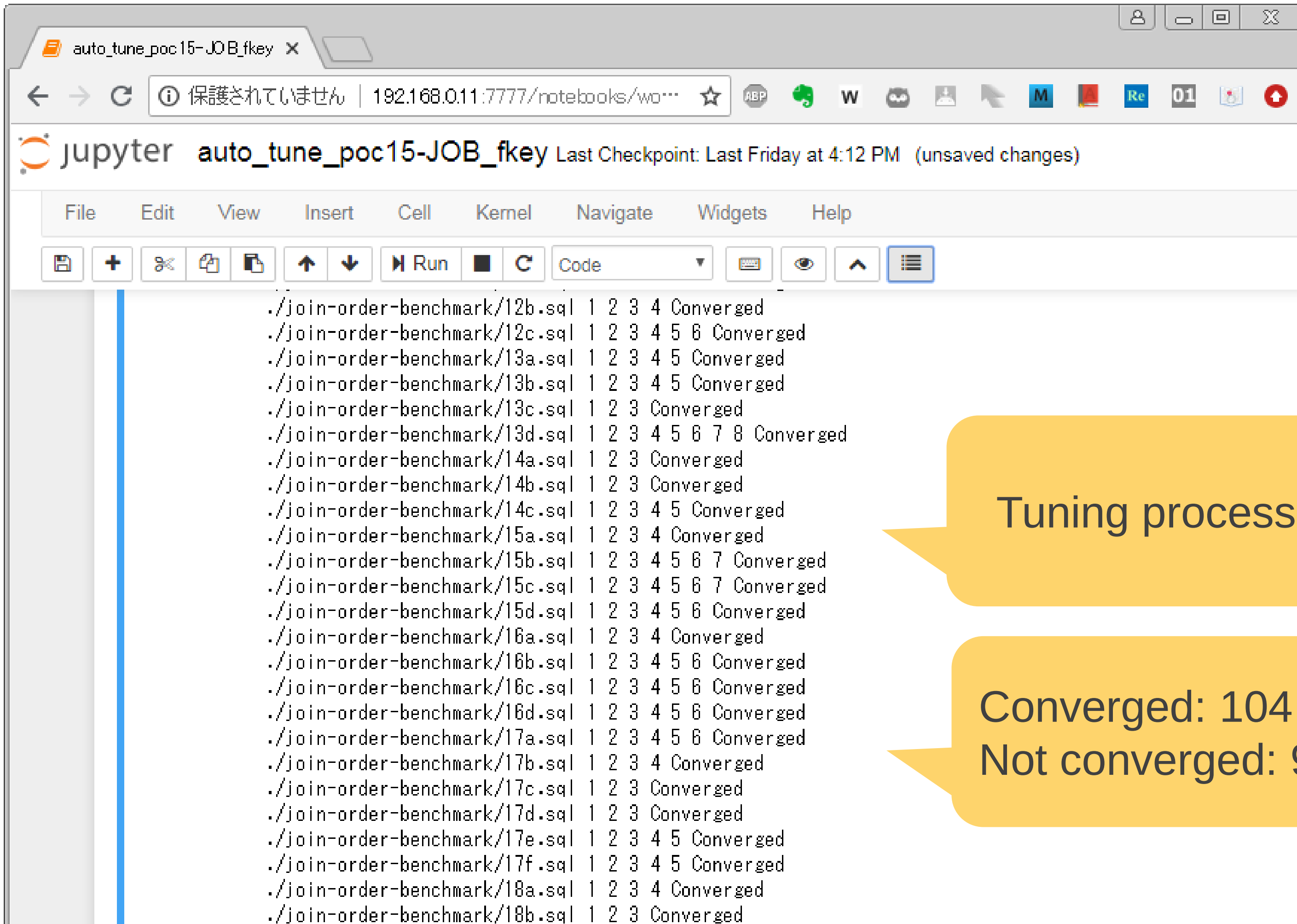
Preconditions:

- **PG 10.4**
- Data is stable and **on memory** (using pg_prewarm)
- Iterations for tuning: **Maximum 64 times per query**
- Benchmark tool: **Join order benchmark** (113 queries)
- Parameters
  - random_page_cost 2
  - shared_buffers 2GB
  - work_mem 16MB
  - default_statistics_target 100
  - geqo_threshold 18
  - max_worker_processes 8
  - max_parallel_workers_per_gather 0
  - max_parallel_workers 0
  - shared_preload_libraries = pg_hint_plan, pg_plan_advsr, pg_store_plans

OS: Centos 7.1
CPU: i7-2600 3.4GHz 4core / 8thread
Mem: 16GB
Disk: SSD

My frontend tool

- Jupyter notebook with psycopg2



Tuning process: 3000 sec

Converged: 104 queries
Not converged: 9 queries

Top 5 highly effective query

- Achieved a great benefit for Query 29c and 31c

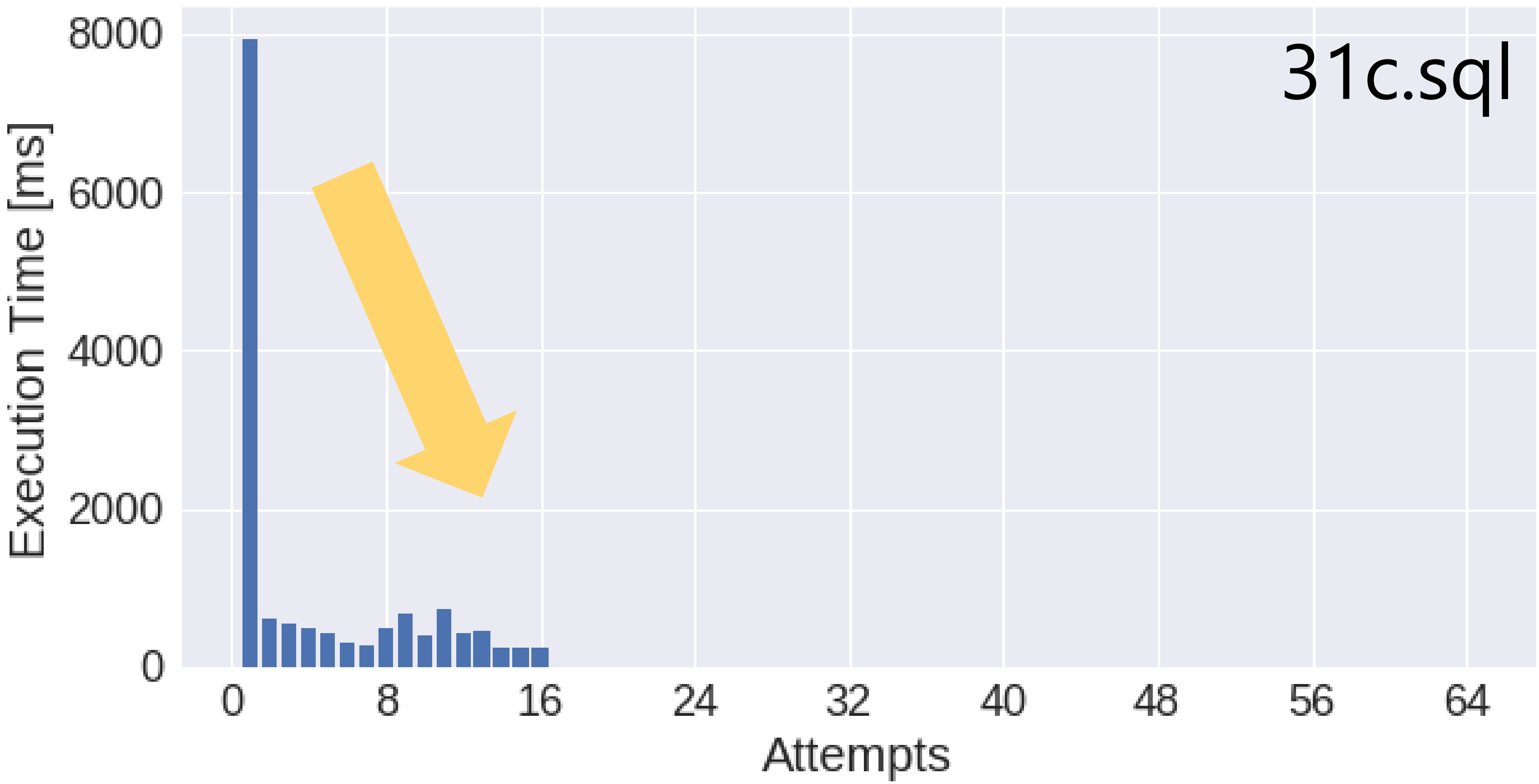
Query 31c of join order benchmark

- 31c.sql includes 10 joins and 4 aggregate functions.

```
SELECT MIN(mi.info) AS movie_budget,
       MIN(mi_idx.info) AS movie_votes,
       MIN(n.name) AS writer,
       MIN(t.title) AS violent_liongate_movie
FROM cast_info AS ci,
     company_name AS cn,
     info_type AS it1,
     info_type AS it2,
     keyword AS k,
     movie_companies AS mc,
     movie_info AS mi,
     movie_info_idx AS mi_idx,
     movie_keyword AS mk,
     name AS n,
     title AS t
WHERE ci.note IN ('(writer)',
                  '(head writer)',
                  '(written by)',
                  '(story)',
                  '(story editor)')
AND cn.name LIKE 'Lionsgate%'
AND it1.info = 'genres'
AND it2.info = 'votes'
AND k.keyword IN ('murder',
                  'violence',
                  'blood',
                  'gore',
                  'death',
                  'female-nudity',
                  'hospital')
AND mi.info IN ('Horror',
                'Action',
                'Sci-Fi',
                'Thriller',
                'Crime',
                'War')
AND t.id = mi.movie_id
AND t.id = mi_idx.movie_id
AND t.id = ci.movie_id
AND t.id = mk.movie_id
AND t.id = mc.movie_id
AND ci.movie_id = mi.movie_id
AND ci.movie_id = mi_idx.movie_id
AND ci.movie_id = mk.movie_id
AND ci.movie_id = mc.movie_id
AND mi.movie_id = mi_idx.movie_id
AND mi.movie_id = mk.movie_id
AND mi.movie_id = mc.movie_id
AND mi_idx.movie_id = mk.movie_id
AND mi_idx.movie_id = mc.movie_id
AND mk.movie_id = mc.movie_id
AND n.id = ci.person_id
AND it1.id = mi.info_type_id
AND it2.id = mi_idx.info_type_id
AND k.id = mk.keyword_id
AND cn.id = mc.company_id;
```

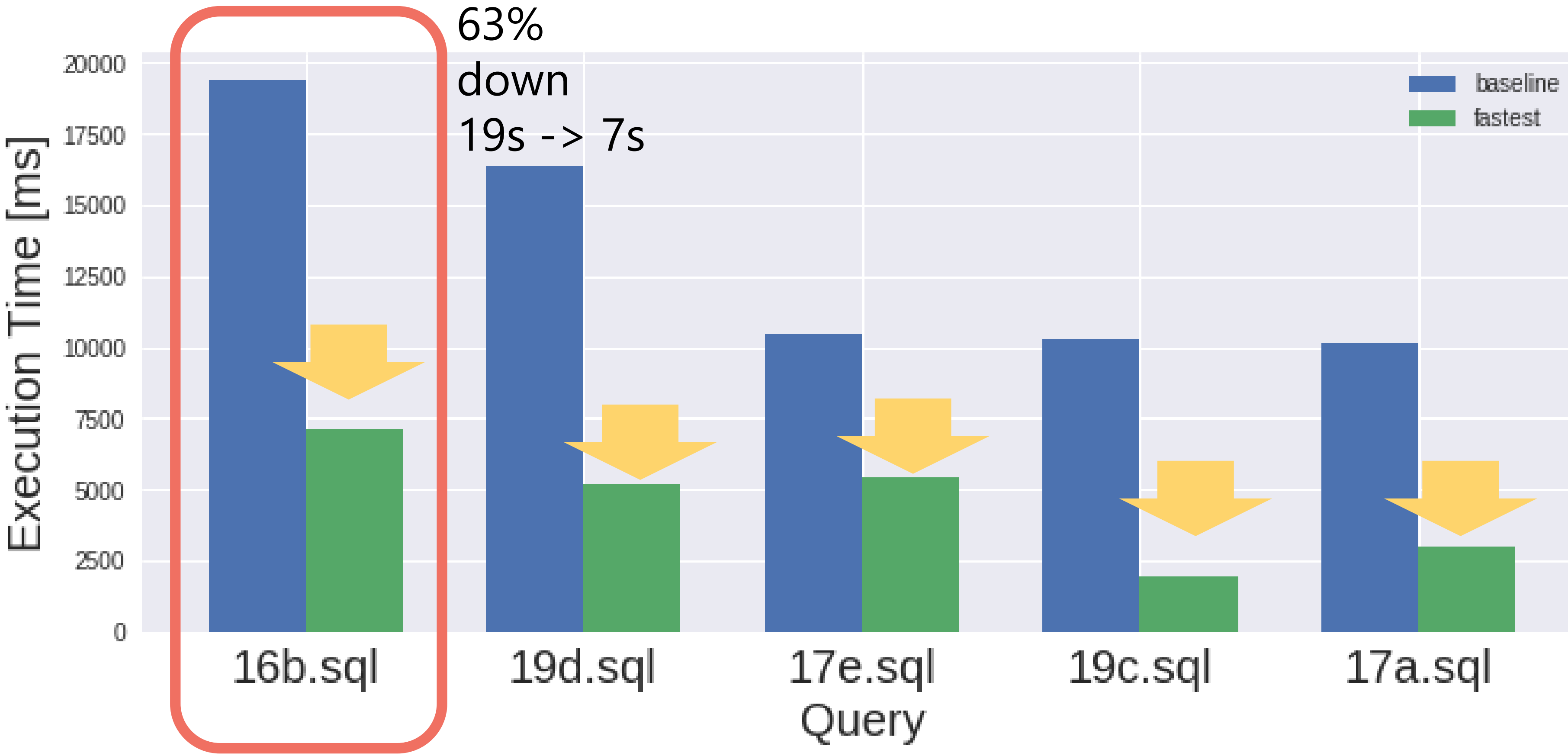
Expected behavior of execution times

- Ideally, it would be nice to get the following behavior for all queries



Top 5 long execution times

- The execution times were halved.



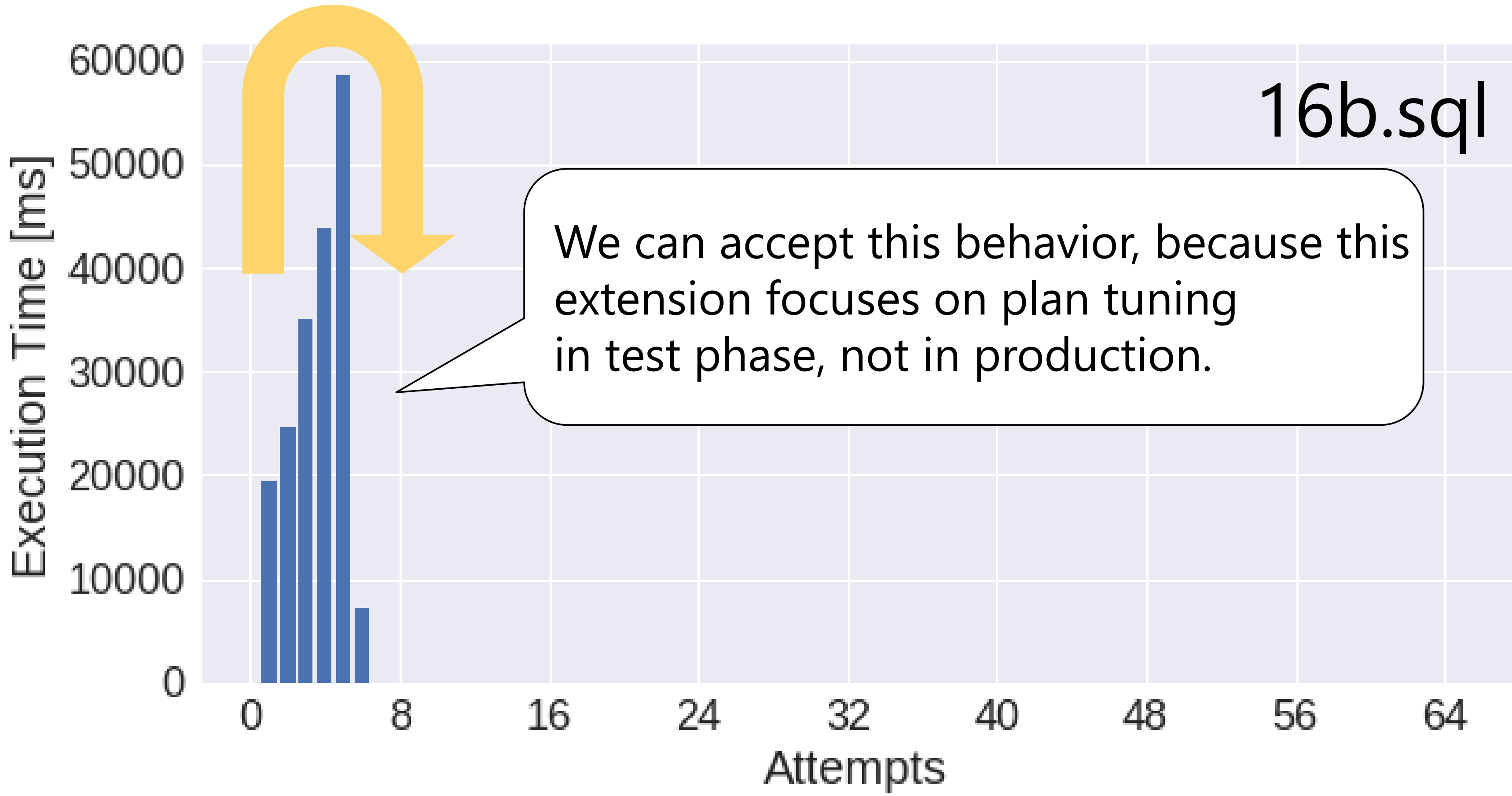
Query 16b of join order benchmark

- 16b.sql includes 7 joins and 2 aggregate functions.

```
SELECT MIN(an.name) AS cool_actor_pseudonym,
           MIN(t.title) AS series_named_after_char
FROM aka_name AS an,
     cast_info AS ci,
     company_name AS cn,
     keyword AS k,
     movie_companies AS mc,
     movie_keyword AS mk,
     name AS n,
     title AS t
WHERE cn.country_code ='[us]'
  AND k.keyword ='character-name-in-title'
  AND an.person_id = n.id
  AND n.id = ci.person_id
  AND ci.movie_id = t.id
  AND t.id = mk.movie_id
  AND mk.keyword_id = k.id
  AND t.id = mc.movie_id
  AND mc.company_id = cn.id
  AND an.person_id = ci.person_id
  AND ci.movie_id = mc.movie_id
  AND ci.movie_id = mk.movie_id
  AND mc.movie_id = mk.movie_id;
```

Execution Time history of query 16b

- Good plan after several bad plans. Is is Okay?



Plan history of Q16b

- The history table has all information of plan tuning.

(ms)

Times	Queryid	Plan_id	Execution_time	Total_diffs
0	…	**671501202**	**19396.89**	**9670384**
1	…	3725435884	24567.85	9504160
2	…	3151720077	35021.45	13242801
3	…	150735307	43750.84	17546662
4	…	1918733225	58548.67	23380179
5	…	**1368113010**	**7145.19**	**0**

Rows_hint	Scan_hint	Join_hint	Lead_hint
…	…	…	…

- You can see the Plan id had changed until the last time.

Feedback control has worked!

"Total_diffs" is the sum of row count estimation errors in the joins

Plan changes of Q16b

Iterations: 0 1 2 3 4 5

```
6
 Aggregate
   ->  Hash Join
         Hash Cond: (an.person_id = n.id)
         ->  Seq Scan on aka_name an
         ->  Hash
               Buckets: 262144  Batches: 16  Memory Usage: 12256kB
               ->  Hash Join
                     Hash Cond: (ci.person_id = n.id)
                     ->  Nested Loop
                           Join Filter: (t.id = ci.movie_id)
                           ->  Hash Join
                                 Hash Cond: (mc.company_id = cn.id)
                                 ->  Nested Loop
                                       ->  Nested Loop
                                             ->  Nested Loop
                                                   ->  Seq Scan on keyword k
                                                         Filter: (keyword = 'character-name-in-title'::text)
                                                         Rows Removed by Filter: 134169
                                                   ->  Bitmap Heap Scan on movie_keyword mk
                                                         Recheck Cond: (keyword_id = k.id)
                                                         Heap Blocks: exact=11541
                                                         ->  Bitmap Index Scan on keyword_id_movie_keyword
                                                               Index Cond: (keyword_id = k.id)
                                             ->  Index Scan using title_pkey on title t
                                                   Index Cond: (id = mk.movie_id)
                                       ->  Index Scan using movie_id_movie_companies on movie_companies mc
                                             Index Cond: (movie_id = t.id)
                                 ->  Hash
                                       Buckets: 131072  Batches: 1  Memory Usage: 4007kB
                                       ->  Seq Scan on company_name cn
                                             Filter: ((country_code)::text = '[us]'::text)
                                             Rows Removed by Filter: 150154
                           ->  Index Scan using movie_id_cast_info on cast_info ci
                                 Index Cond: (movie_id = mk.movie_id)
                     ->  Hash
                           Buckets: 524288  Batches: 16  Memory Usage: 13245kB
                           ->  Seq Scan on name n
```

Plan shapes of Q16b

First iteration

```
Aggregate  (cost=4645.64..4645.65 rows=1 width=64) (actual time=20608.515..20608.515 rows=1 loops=1)
  ->  Nested Loop  (cost=7.51..4630.64 rows=2999 width=33) (actual time=5.001..19980.694 rows=3710592 loops=1)
        Join Filter: (n.id = an.person_id)
        ->  Nested Loop  (cost=7.09..4021.98 rows=1253 width=25) (actual time=4.989..12126.936 rows=2832555 loops=1)
              ->  Nested Loop  (cost=6.66..3456.63 rows=1253 width=21) (actual time=4.974..4445.613 rows=2832555 loops=1)
                    Join Filter: (t.id = ci.movie_id)
                    ->  Nested Loop  (cost=6.09..3333.83 rows=66 width=29) (actual time=4.768..886.401 rows=68316 loops=1)
                          ->  Nested Loop  (cost=5.67..3251.47 rows=186 width=33) (actual time=4.738..431.818 rows=148552 loops=1)
                                ->  Parallel Nested Loop  (cost=5.24..3231.47 rows=34 width=25) (actual time=4.724..225.903 rows=41840 loops=1)
                                      ->  Nested Loop  (cost=4.81..3215.61 rows=34 width=4) (actual time=4.714..65.081 rows=41840 loops=1)
                                            ->  Seq Scan on keyword k  (cost=0.00..2626.12 rows=1 width=4) (actual time=0.445..10.156 rows=1 loops=1)
                                                  Filter: (keyword = 'character-name-in-title'::text)
                                                  Rows Removed by Filter: 134169
                                            ->  Bitmap Heap Scan on movie_keyword mk  (cost=4.81..586.42 rows=307 width=8) (actual time=4.267..47.872 rows=41840 loops=1)
                                                  Recheck Cond: (keyword_id = k.id)
                                                  Heap Blocks: exact=11541
                                                  ->  Bitmap Index Scan using keyword_id_movie_keyword  (cost=0.00..4.74 rows=307 width=0) (actual time=2.816..2.816 rows=41840 loops=1)
                                                        Index Cond: (keyword_id = k.id)
```

Last iteration

```
Aggregate  (cost=569619.76..569619.77 rows=1 width=64) (actual time=7724.114..7724.114 rows=1 loops=1)
  ->  Hash Join  (cost=488969.61..551066.80 rows=3710592 width=33) (actual time=6148.042..7284.667 rows=3710592 loops=1)
        Hash Cond: (an.person_id = n.id)
        ->  Seq Scan on aka_name an  (cost=0.00..20409.43 rows=901343 width=20) (actual time=0.006..125.215 rows=901343 loops=1)
        ->  Hash  (cost=434198.68..434198.68 rows=2832555 width=25) (actual time=6147.564..6147.564 rows=2832555 loops=1)
              Buckets: 262144  Batches: 16  Memory Usage: 12256kB
              ->  Hash Join  (cost=172645.20..434198.68 rows=2832555 width=25) (actual time=1244.367..5588.425 rows=2832555 loops=1)
                    Hash Cond: (ci.person_id = n.id)
                    ->  Nested Loop  (cost=6986.59..183304.07 rows=2832555 width=21) (actual time=57.009..2836.849 rows=2832555 loops=1)
                          Join Filter: (t.id = ci.movie_id)
                          ->  Hash Join  (cost=6986.02..56192.08 rows=68316 width=29) (actual time=56.826..536.766 rows=68316 loops=1)
                                Hash Cond: (mc.company_id = cn.id)
                                ->  Nested Loop  (cost=5.67..47336.27 rows=148552 width=33) (actual time=5.417..443.411 rows=148552 loops=1)
                                      ->  Nested Loop  (cost=5.24..22733.15 rows=41840 width=25) (actual time=5.382..251.833 rows=41840 loops=1)
                                            ->  Nested Loop  (cost=4.81..3215.61 rows=41840 width=4) (actual time=5.366..70.316 rows=41840 loops=1)
                                                  ->  Seq Scan on keyword k  (cost=0.00..2626.12 rows=1 width=4) (actual time=0.556..10.051 rows=1 loops=1)
                                                        Filter: (keyword = 'character-name-in-title'::text)
                                                        Rows Removed by Filter: 134169
```

```
->  Nested Loop  (rows=      2999) (actual rows=3710592)
      ->  Nested Loop  (rows=1253) (actual rows=2832555 )
      ->  Index Scan using ... an  (rows=2) (actual rows=1)
```

```
->  Hash Join  (rows=3710592) (actual rows=3710592)
      ->  Seq Scan on ... an  (rows=901343) (actual rows=901343)
      ->  Hash  (rows=2832555) (actual rows=2832555)
```

Fixed

- By correcting estimated rows on lower nodes, join method and join order on the top node got fixed automatically.

Plan history of Q16b

- Various hints are stored in the history table.

Times	Queryid	Plan_id	Execution_time	Total_diffs
0	…	671501202	19396.89	9670384
1	…	3725435884	24567.85	9504160
2	…	3151720077	35021.45	13242801
3	…	150735307	43750.84	17546662
4	…	1918733225	58548.67	23380179
5	…	1368113010	7145.19	0

Rows_hint	Scan_hint	Join_hint	Lead_hint
…	…	…	…

Rows hint of Q16b

- Rows Hints allow to override estimated rows on joins.

Times	Plan id	Rows_hint	Scan_hint	Join_hint	Lead_hint
…	…	…	…	…	…

- These are “feedback information” for plan.

Rows hint of Q16b

- We can check feedback information to check ROWS hints.

Times	Rows_hint	Total_diffs
0	ROWS(an ci cn k mc mk n t #3710592) …	9670384
1	…	9504160
2	…	13242801
3	…	17546662
4	ROWS(ci k mc mk n t #7796926) …	23380179
5	Nothing!!	0

Scan, Join and Leading hints of Q16b

- pg_plan_advsr also generated and stored these hints.

Times	Plan id	Rows_hint	Scan_hint	Join_hint	Lead_hint
…	…	…	…	…	…

- **Why these hints are stored?**
- Because
  - These **hints can expresses a plan structure**.
  - By using these hints, you can do followings:

    1) **Reproduce the plan at a certain point**
    2) **Move the plan to other databases**
    3) Try your idea to modify the hints manually

Leading hints of Q16b

Scan_hint	Join_hint	Lead_hint
…	…	…

- Table "an" moved to left-most side from right-most side.

times	Lead_hint
0	LEADING((((((((k mk)t)mc)cn)ci)n)an))
1	…
2	…
3	…
4	…
5	LEADING((an ((((((k mk)t)mc)cn)ci)n)))

We can understand plan changes easily by using these hints.

Summary

- pg_plan_advsr was able to improve the plan by reducing row count estimation error.
- In the measurement result, it reduced about 50% in execution time.
- It is possible to utilize execution information as a feedback info for auto plan tuning.
- DBA and user are able to get efficient plan easily by pg_plan_advsr!

Short Demonstration

- **Scenario**
  1. Prewarm all tables
  2. Execute **“psql –f 31c.sql” 8 times** for auto plan tuning
  3. Check Plan history table to see plan changes

- **Eenvironment**
  - This Laptop (i5-6300U 2.4GHz 2core/4 thread,
    Mem 16GB, SSD,
    CentOS7.1 on VirtualBox)
  - PostgreSQL configuration is same as before

Using aqo and pg_plan_advsr together

- **Idea: If these extension work together, it can be got benefits?**
  - aqo is a sophisticated plan tuning extension since it corrects base and join relations
  - pg_plan_advsr has a lot of limitations because now is in POC phase

- **Experimental result by using 31c.sql**
  - It works fine! Settings:
    shared_preload_libraries = pg_hint_plan, pg_plan_advsr, pg_store_plans, aqo
  - aqo and pg_plan_advsr work together complementaly

- **Benefits**
  - Get more efficient plan than pg_plan_advsr (because aqo)
  - Allow to create hints for reproduce a plan
  - Allow to check plan changes using plan history table

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Conclusion

- In this talk, I have shared my experience of trying to get more efficient plans for complex queries using my POC extension: pg_plan_advsr.

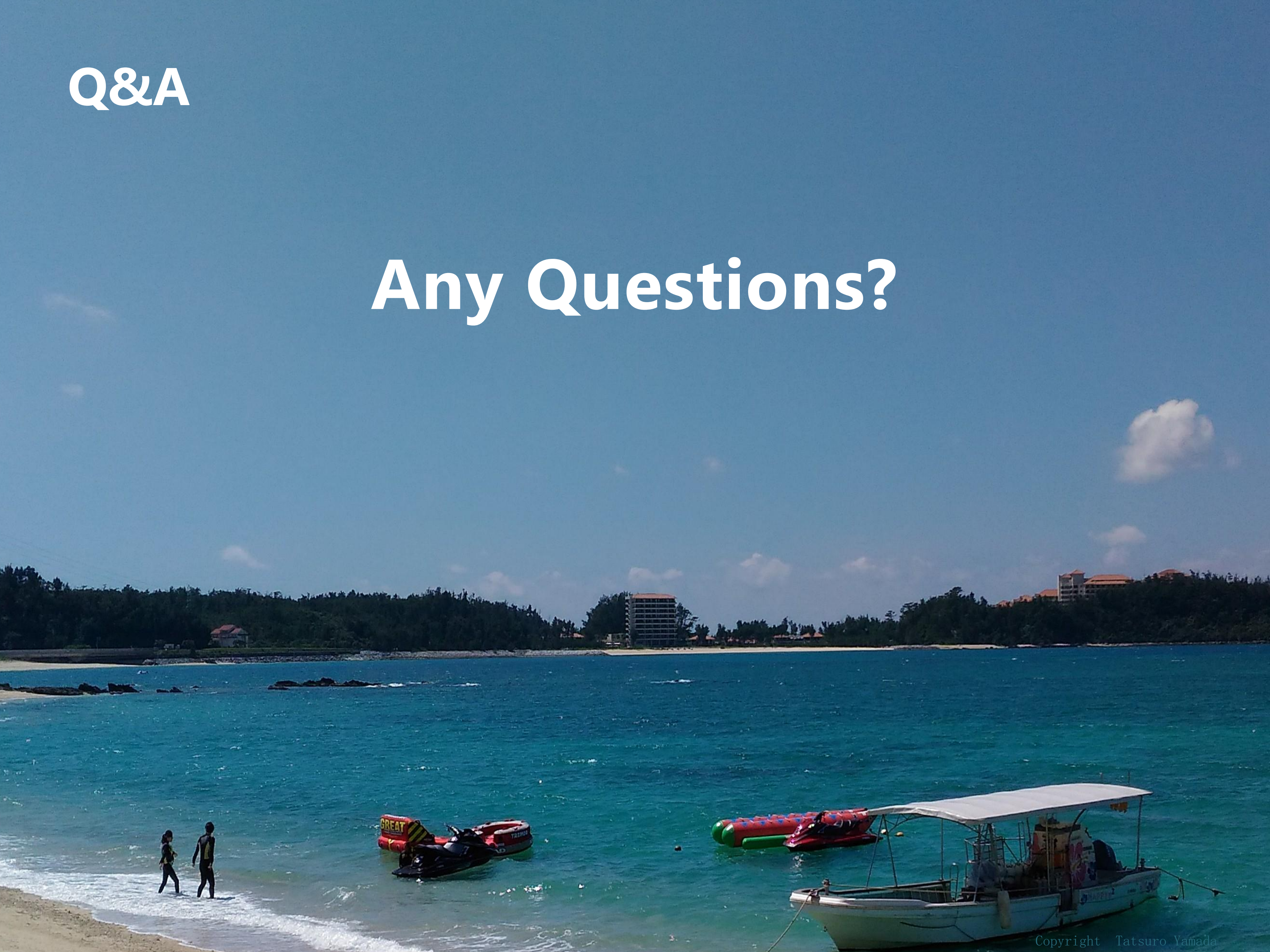
- I hope that I was able to prove that PostgreSQL can be improved to get more efficient plan using feedback loop.

- I believe the improvement is a key challenge to reach future PostgreSQL such as Autonomous Database.


Thank you! Спасибо!
Plan for better Plan
yamatattsu@gmail.com

Q&A

Any Questions?



Appendix

- Revisit Planner behavior
- Control engineering: Feedback Loop
- Limitations and status of pg_plan_advsr
- Thoughts about future PostgreSQL
- Other examples of verification effect
- Brief explanation of pg_hint_plan's hints
- Join order benchmark
- Extensions from NTT OSS Center
- References

Revisit Planner behavior

- The planner "guesses" a plan using cost base optimization.

- With a simple notion of "cost", each plan node's cost can be calculated by the following formula [1].

$$\mathrm{Cost} = c_{\mathrm{seq}} n_{\mathrm{seq}} + c_{\mathrm{rand}} n_{\mathrm{rand}} + c_{\mathrm{tup}} n_{\mathrm{tup}} + \cdots$$

Seq. I/O *Random I/O* *CPU cost per tuple*

$$= \mathbb{C} \cdot \mathbb{N}$$

$\mathbb{C}$ Cost of single operation

e.g.
- seq_page_cost
- random_page_cost

$\mathbb{N}$ Estimated number of each operation

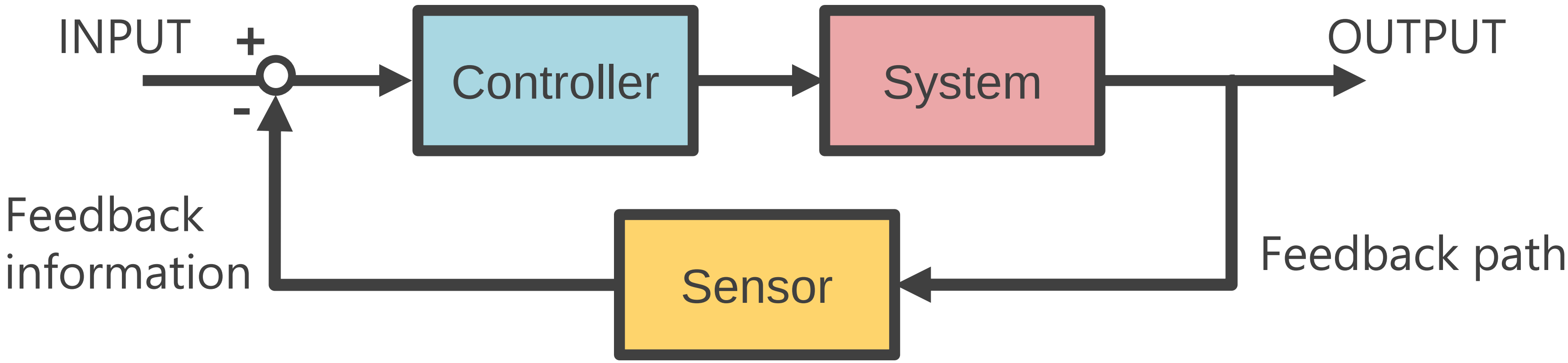
- Cardinality estimation with statistics

- If “C” or “N” is wrong, the cost estimate is wrong. That may lead to an inefficient plan.

[1] cited from: “Beyond EXPLAIN: Query Optimization From Theory To Code” by YutoHayamizu, RyojiKawamichi PGCon 2016

Control engineering: Feedback Loop

- **This is used to achieve the desired output.**
- **Theory**: Feedback is a mechanism that compares the output target value with the actual output value and automatically controls the output value and the target value to be equal.



https://en.wikipedia.org/wiki/Control_theory
https://en.wikipedia.org/wiki/Control_engineering

Limitations, Future work and Status

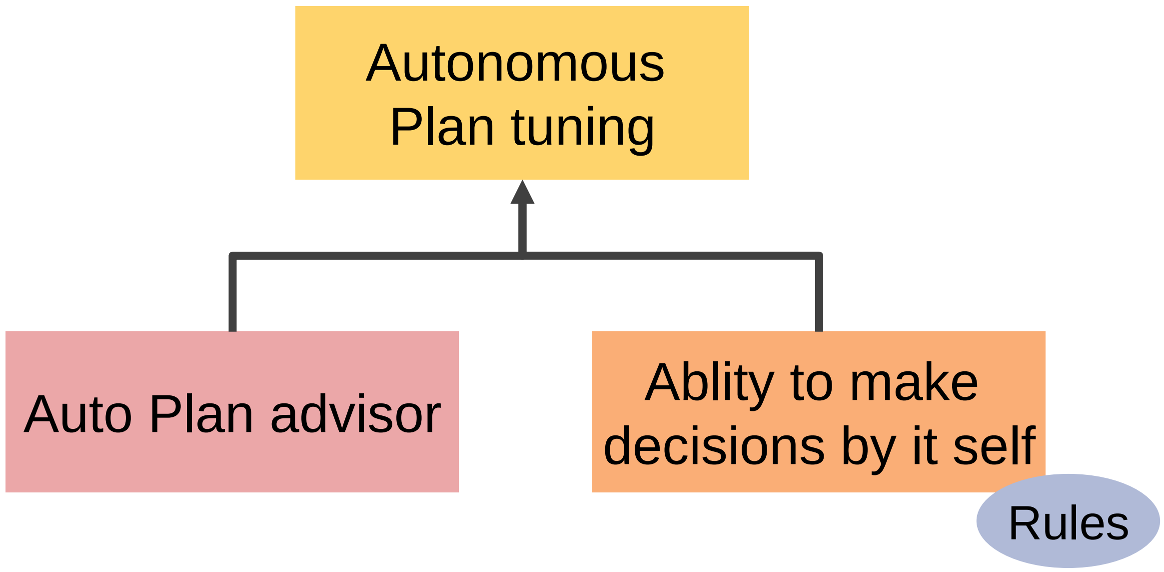
- **Limitations**
  - Only correct join row estimates (It is pg_hint_plan's limitation)
  - Initplan and subplan are not supported
  - Does not support concurrent execution …
- **Future work**
  - Remove above limitations
  - Reduce iterations by using sophisticated search argolism
  - Create new feature which is sugest Extended Stats syntax
  - Create "Tom Lane button" to send query and inefficient plan to pgsql-hackers ML to improve planner
- **Status**
  - POC phase, now working on refactor a code

Thoughts about the future PostgreSQL

Autonomous Database

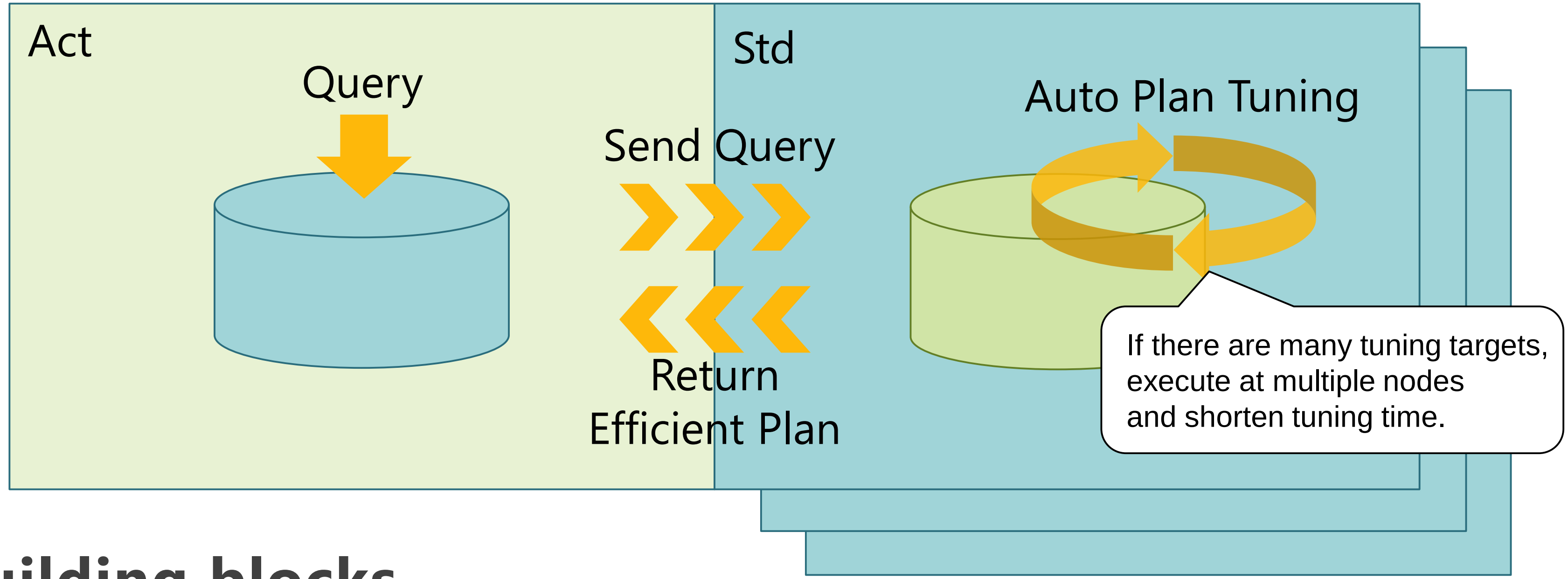
- **Autonomous Features**
  - Upgrade
  - Tuning
  - Maintenance task

- **Idea**



Ideas for autonomous databases using replicationed PostgreSQL

• Rough concept



• Building blocks

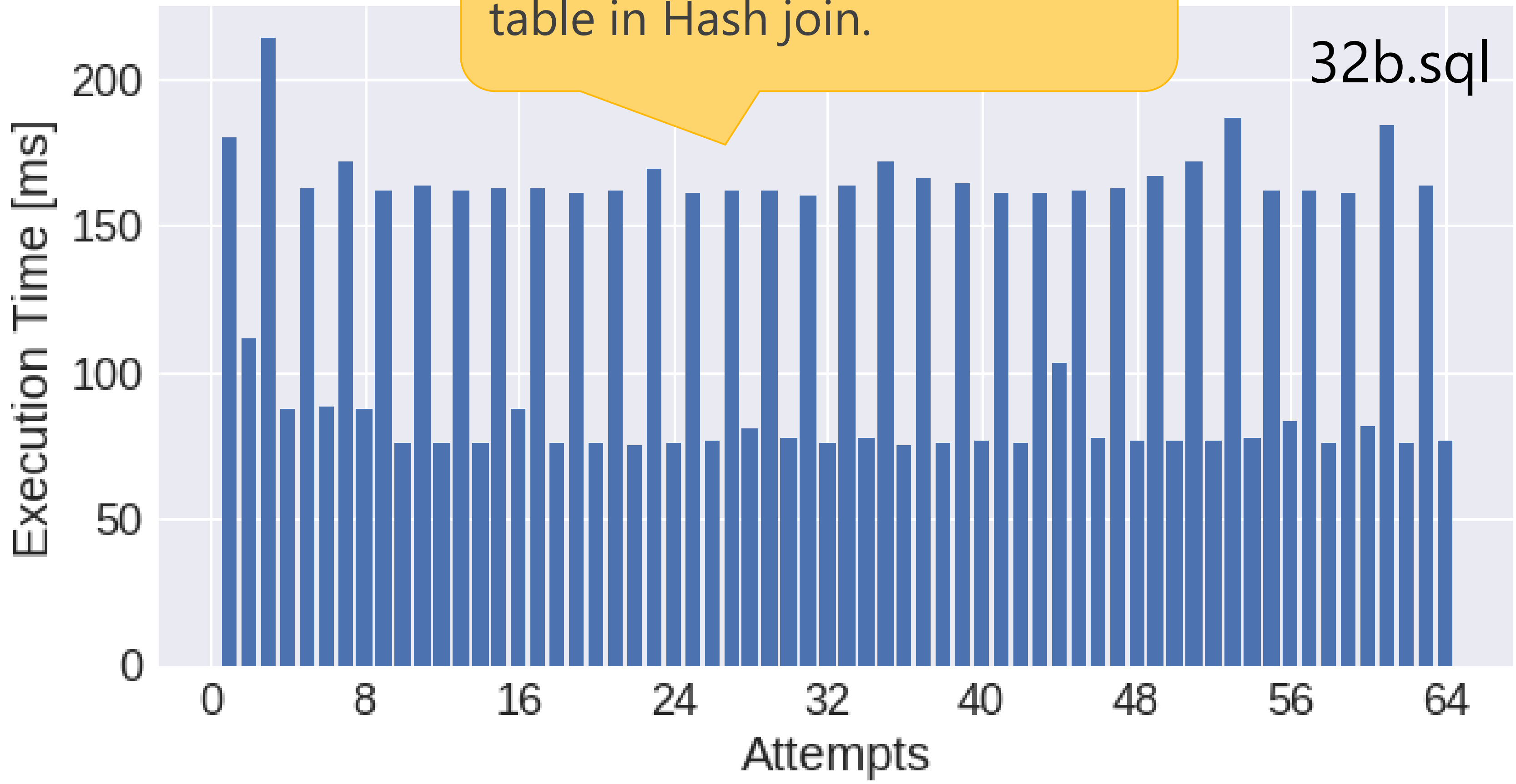
- Provide easy access to plan tree or explain analyze result: New hook
- Interfaces to adjust estimated rows on base/join relations: New API
- Avoid query cancellation on standby side: Improvement
- Store all plans like a pg_stat_statement: Improvement

<Examples>

Sample: Not converged query (Q32b)

- Oscillated…

It is changed Outer and Inner table in Hash join.



Brief explanation of pg_hint_plan's hints

- **Samples**: scan method, join method, join order, and row correction hint.

Hint	Effect
INDEXSCAN(A) …	Forces "index scan" on table "A"
NESTLOOP(A B) …	Forces "nested loop" to the join consists of the table "A" and "B".
LEADING((A B) C)	Forces "join order" as specified. Firstly A join B, after that (A B) join C.
ROWS(A B #10)	Corrects row number of a result of the join consists of table "A" and "B".

Scan method

Join method

Join order

Row correction

A, B and C are Table or Alias

See: https://github.com/ossc-db/pg_hint_plan/blob/master/doc/hin

Scan hints of Q16b

Scan_hint	Join_hint	Lead_hint
…	…	…

- Several Index scans replaced with Seq scans.

times	Scan_hint
0	INDEXSCAN(cn) INDEXONLYSCAN(n) INDEXSCAN(an) …
1	…
2	…
3	…
4	SEQSCAN(cn) SEQSCAN(n) SEQSCAN(an) …

Join hints of Q16b

Scan_hint	Join_hint	Lead_hint
…	…	…

- Some Join methods were changed.

times	Join_hint
0	NESTLOOP(an ci cn k mc mk n t) NESTLOOP(ci cn k mc mk n t) …
1	…
2	…
3	…
4	…
5	HASHJOIN(an ci cn k mc mk n t) HASHJOIN(ci cn k mc mk n t) …

Join order benchmark

- **GitHub**
  - https://github.com/gregrahn/join-order-benchmark

Extensions from NTT OSS Center

- **GitHub**
  - https://github.com/ossc-db
    - pg_hint_plan
    - pg_store_plans
    - pg_dbms_stats
    - pg_reorg
    - pg_rman
    - pg_bulkload
    - dblink_plus
    - Syncdb
    - db_syntax_diff
- **SourceForge**
  - https://sourceforge.net/projects/pgstatsinfo/
    - pg_statsinfo
    - pg_stats_reporter

References

- **"How Good Are Query Optimizers, Really?"**

  by Viktor Leis, Andrey Gubichev, Atans Mirchev, Peter Boncz, Alfons Kemper, Thomas Neumann
  PVLDB Volume 9, No. 3, 2015
  http://www.vldb.org/pvldb/vol9/p204-leis.pdf

- **"Query optimization through the looking glass, and what we found running the Join Order Benchmark"**

  by Viktor Leis, Bernhard Radke, Andrey Gubichev, Atanas Mirchev, Peter Boncz, Alfons Kemper, Thomas Neumann

  https://db.in.tum.de/~leis/papers/lookingglass.pdf

- **My session at PGCon 2016**
  - https://www.pgcon.org/2016/schedule/attachments/422_A%20Challenge%20of%20Huge%20Billing%20System%20Migration_20160520.pdf

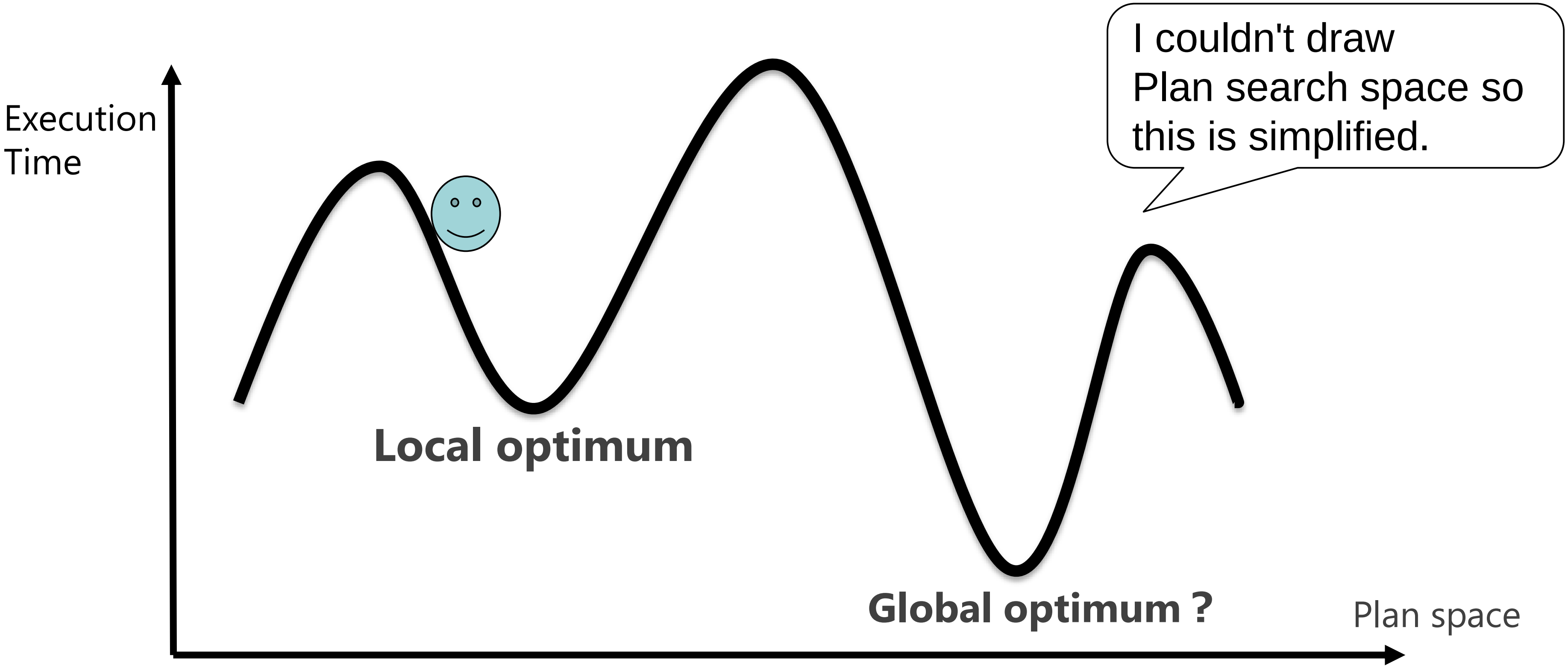
References

- **Beyond EXPLAIN: Query Optimization From Theory To Code**
  - by YutoHayamizu, RyojiKawamichi
  - https://www.pgcon.org/2016/schedule/attachments/433_PGCON2016_beyond_explain.pdf

- **AQO**
  - by Oleg Ivanov
  - https://github.com/postgrespro/aqo

What is going on with this extension?

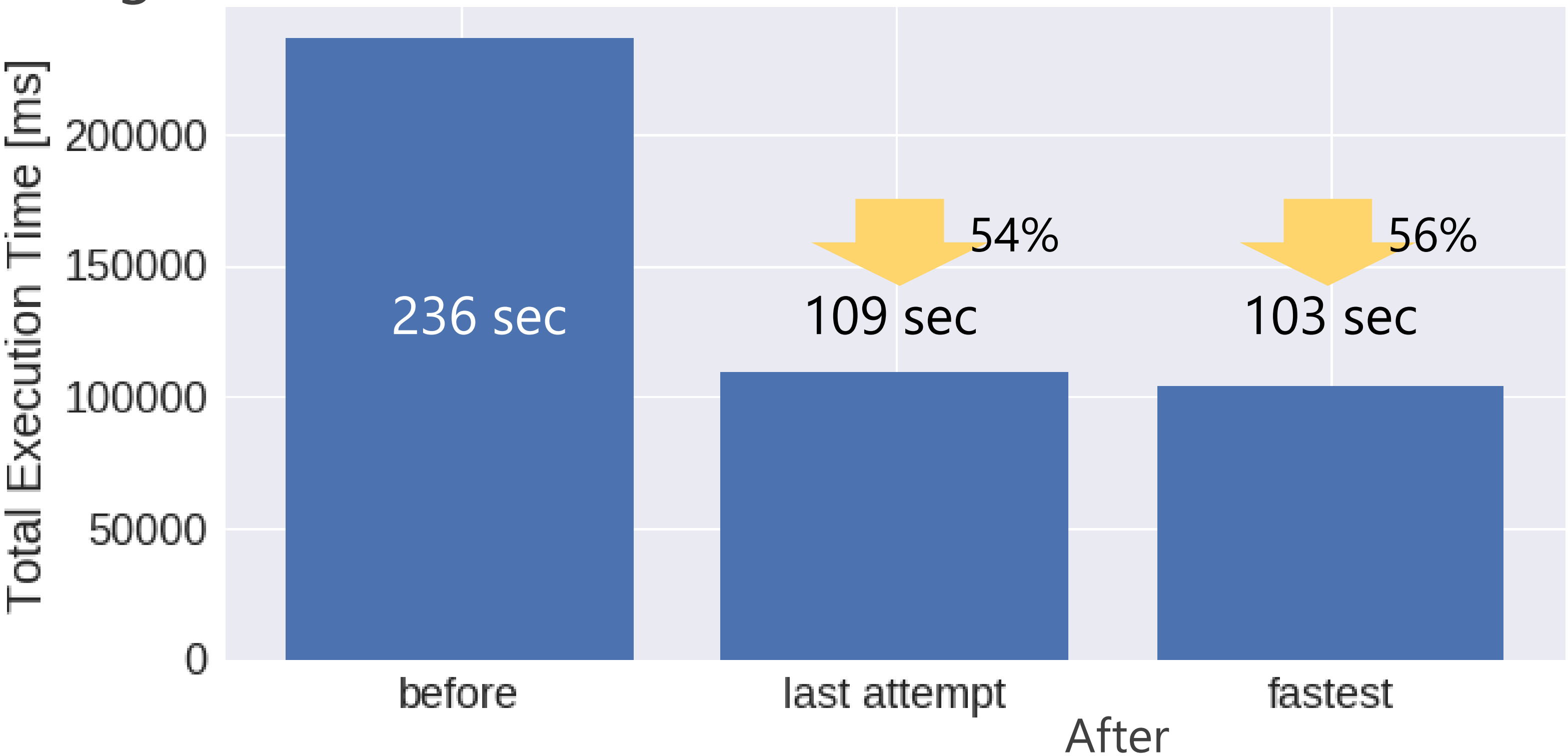
- pg_plan_advsr does Local search to find an efficient plan.



- In the search process, the plan may temporarily get worse.

Results

- Query execution time is **reduced by 50%** of the original (236sec -> 103sec)



- **What's happened?**

Reverification of plan tuning effect

- I rechecked the plan tuning effect by using baseline and fastest plans.
  - **Operations**
    1. Add fastest hints (Scan, Join method and Join order) to fastest.sql.
    2. Shutdown PG and clear OS cache
    3. Prewarm whole tables
    4. Run "psql –f baseline.sql and fastest.sql" three times.
  - **Result**

(ms)

Types	first	second	third
baseline.sql	252.93	233.57	233.87
fastest.sql	138.58	118.40	118.38

Reduced 48% on average, Good!!