Adaptive Query Opt. (PostgreSQL)

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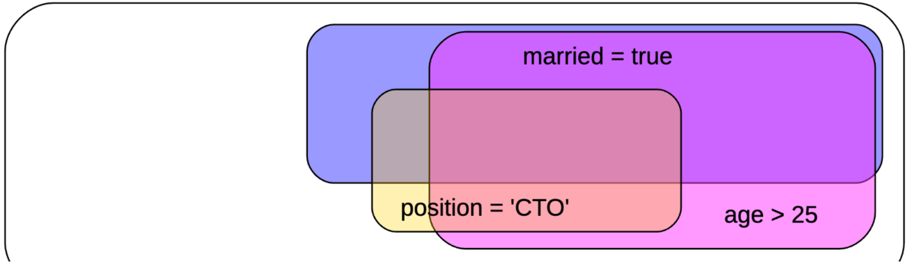
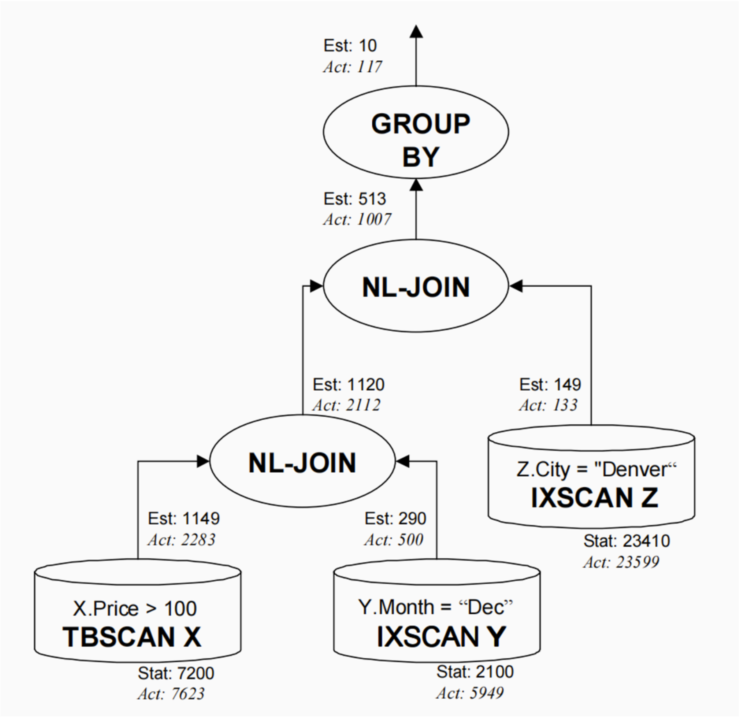
Motivation

```sql
SELECT * FROM users
WHERE age > 25 AND married = true
AND position = 'CTO';
```

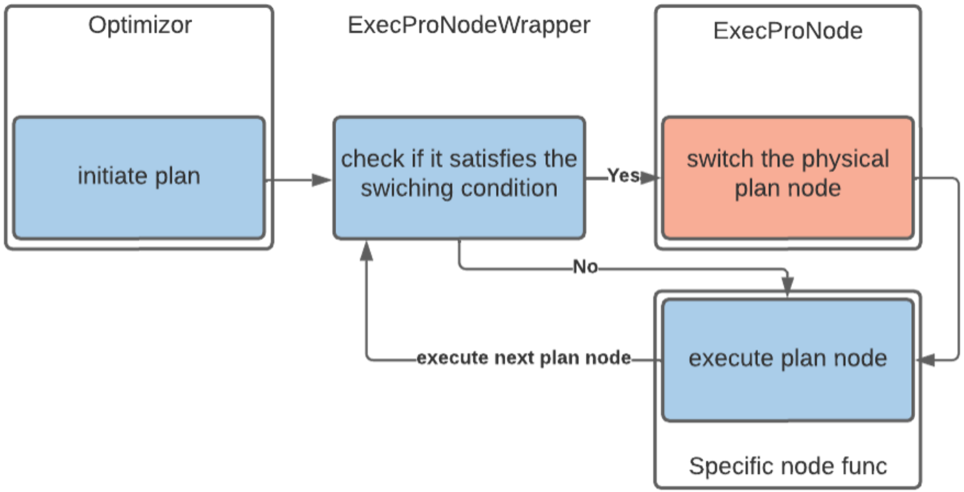




High-level Goal of this Project

Our goal is to research the possibility to switch query plan at the execution phase!

Adaptively Plan Node Switching (75% goal) – Done
Plan Node Can be adaptively replaced



Approach 1: Adaptively Plan Node Switching

```
noisepage_db=# CREATE INDEX identifier_index on chicken (identifier);
CREATE INDEX
noisepage_db=# EXPLAIN Select * from chicken where identifier < 30;
                                              QUERY PLAN
------------------------------------------------------------------------------------------------
 Index Scan using identifier_index on chicken  (cost=0.42..2001.72 rows=40000 width=140)
   Index Cond: (identifier < 30)
(2 rows)
```

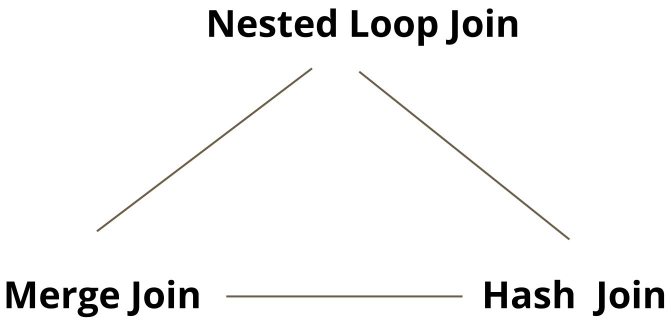
- Template-based
- Implement as a wrapper
- Stop the query execution if certain conditions are satisfied
- Index scan -> Seq scan (finished before mid-term)

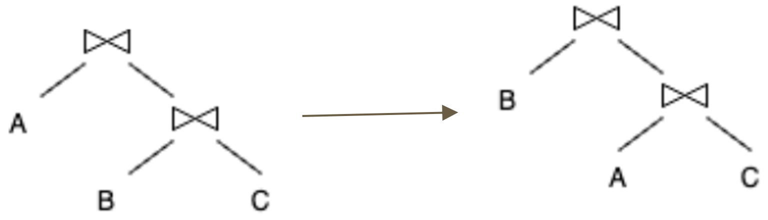
Plan Node Switching -> Plan Tree Switching

Goal: switch join method + switch join order

Why don't we use plan node switching?

- Needs complex transformation between data structures. (6 transformers)
- Missing information.
- Single-level join order switching is not enough.
- It's difficult to implement multi-level join ordering switch.
- Wants a unified and generalized method.





Switch Join Method? – Done (90% goal)
Adaptively Plan Tree Switching

1. **Store** the sub-optimal plan in advance (different join methods)
2. If aqo is enabled & need switching,
   - Initialize the sub-optimal plan
   - **Re-execute using the sub-optimal plan**

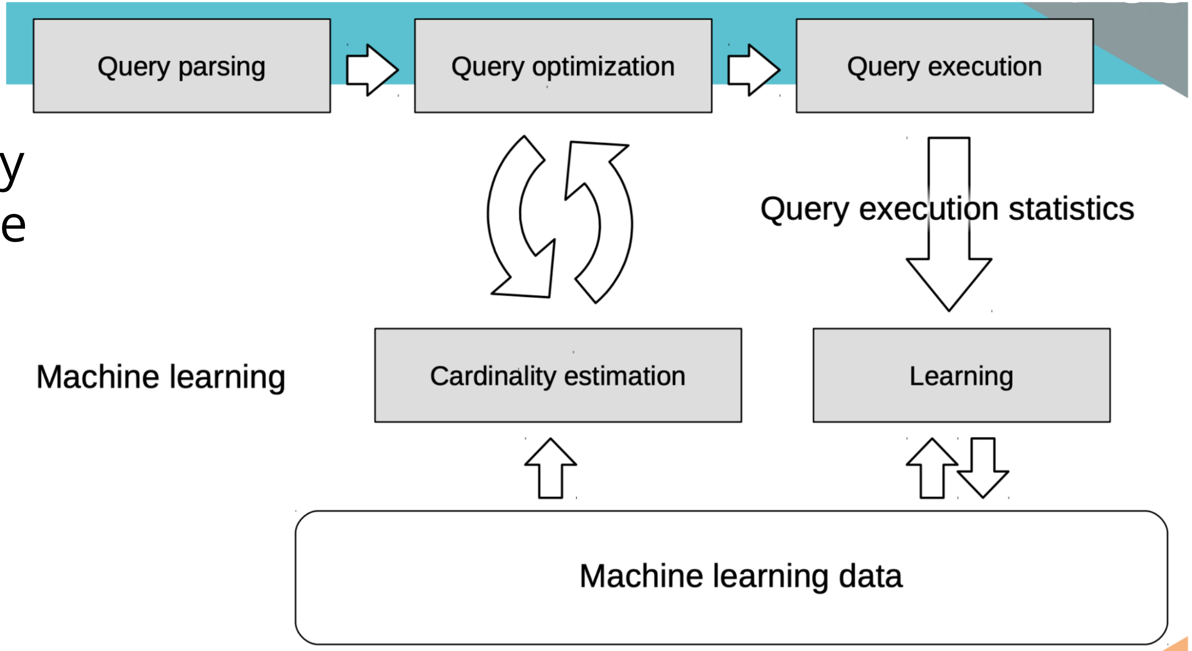
```
2023-05-04 16:54:03.380 UTC [125248] LOG:  do recycle new
2023-05-04 16:54:03.380 UTC [125248] STATEMENT:  select f1.farm_name,f2.farm_name,f3.farm_name from farm f1 join farm f2 on f1.min_age_weeks =
2023-05-04 16:54:03.380 UTC [125248] LOG:  aqo best path:{HASHPATH :pathtype 40 :parent_relids (b 1 2) :required_outer (b) :parallel_aware fals
00 :pathkeys <> :jointype 0 :inner_unique false :outerjoinpath {PATH :pathtype 20 :parent_relids (b 1) :required_outer (b) :parallel_aware fals
 :pathkeys <>} :innerjoinpath {PATH :pathtype 20 :parent_relids (b 2) :required_outer (b) :parallel_aware false :parallel_safe true :parallel_w
({RESTRICTINFO :clause {OPEXPR :opno 620 :opfuncid 287 :opresulttype 16 :opretset false :opcollid 0 :inputcollid 0 :args ({VAR :varno 1 :varatt
ocation 75} {VAR :varno 2 :varattno 2 :vartype 700 :vartypmod -1 :varcollid 0 :varlevelsup 0 :varnosyn 2 :varattnosyn 2 :location 94}) :locatio
:leakproof false :has_volatile 2 :security_level 0 :clause_relids (b 1 2) :required_relids (b 1 2) :outer_relids (b) :nullable_relids (b) :left
ergeopfamilies (o 1970) :left_em {EQUIVALENCEMEMBER :em_expr {VAR :varno 1 :varattno 2 :vartype 700 :vartypmod -1 :varcollid 0 :varlevelsup 0 :
onst false :em_is_child false :em_datatype 700} :right_em {EQUIVALENCEMEMBER :em_expr {VAR :varno 2 :varattno 2 :vartype 700 :vartypmod -1 :var
lable_relids (b) :em_is_const false :em_is_child false :em_datatype 700} :outer_is_left true :hashjoinoperator 620 :left_hasheqoperator 620 :ri
ncid 287 :opresulttype 16 :opretset false :opcollid 0 :inputcollid 0 :args ({VAR :varno 1 :varattno 2 :vartype 700 :vartypmod -1 :varcollid 0 :
```

We cannot guarantee the performance of the suboptimal plan since the production of the suboptimal plan can **still based on wrong estimations**.

How to solve the problem?

Let’s welcome Machine Learning!
-> **better estimation**

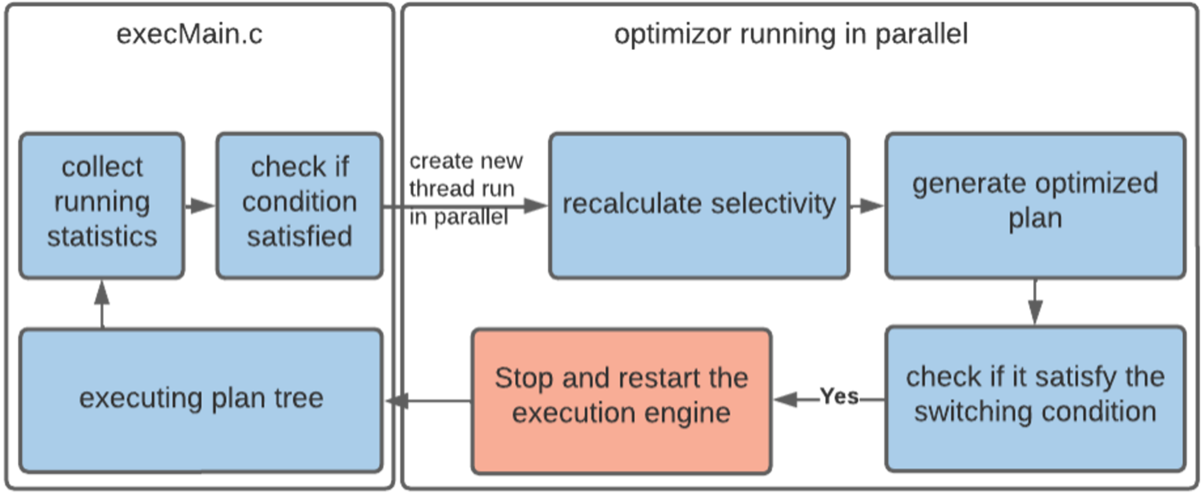
If the new plan is obviously better than the old one, we **stop the execution and switch to the new plan.**



Can we do better? (105% goal)

The current KNN is fast but we may need more complex methods later, which will possibly **take more time**.

Multi-processing !



Approach 2: Adaptively Plan Tree Switching

Key Points:

How to start a new process:

+ aqo_bgworker_background_process_startup()
    + RegisterDynamicBackgroundWorker(&worker, &handle)
    + startup_background_process_main(Datum main_arg)
    + Tried Using shared memory :(

How to achieve “communication”:

+ **Store** the old plan
+ The subprocess reads the old plan and **compares** it with the new plan
+ If better (estimated cost < old cost), send a **signal** + write down the new plan
+ If main process receives the signal -> stop execution + change plan + initialize and execute the plan
+ Main process -> Do no use for estimation but collect feed stats to the model

  Background process -> Use ML for estimation

Baseline query plan:

```
----------------------------------------------------------------
Aggregate  (cost=85645.56..85645.57 rows=1 width=32) (actual ti
  ->  Gather  (cost=51879.08..85645.55 rows=2 width=17) (actual
        Workers Planned: 2
        Workers Launched: 2
        ->  Nested Loop  (cost=50879.08..84645.35 rows=1 width=
              ->  Nested Loop  (cost=50878.65..84644.88 rows=1
                    ->  Parallel Hash Join  (cost=50878.23..846
                          Hash Cond: (mc.movie_id = mk.movie_ic
                          ->  Parallel Seq Scan on movie_compar
                          ->  Parallel Hash  (cost=50878.05..50
                                Buckets: 65536 (originally 1024
                                ->  Hash Join  (cost=2626.14..5
                                      Hash Cond: (mk.keyword_ic
                                      ->  Parallel Seq Scan on
                                      ->  Hash  (cost=2626.12..
                                            Buckets: 1024  Batc
                                            ->  Seq Scan on key
                                                  Filter: (keyw
                                                  Rows Removed
                    ->  Index Scan using company_name_pkey on c
                          Index Cond: (id = mc.company_id)
                          Filter: ((country_code)::text = '[nl]
                          Rows Removed by Filter: 1
              ->  Index Scan using title_pkey on title t  (cost
                    Index Cond: (id = mc.movie_id)
Planning Time: 1.837 ms
Execution Time: 1508.714 ms
```

Multiprocess version:

```
------------------------------------------------------------
Finalize Aggregate  (cost=97427.81..97427.82 rows=1 width=32
  ->  Gather  (cost=97427.59..97427.80 rows=2 width=32) (act
        Workers Planned: 2
        Workers Launched: 2
        ->  Partial Aggregate  (cost=96427.59..96427.60 rows
              ->  Parallel Hash Join  (cost=63819.48..96424.
                    Hash Cond: (mc.movie_id = t.id)
                    ->  Parallel Hash Join  (cost=4740.12..3
                          Hash Cond: (mc.company_id = cn.id)
                          ->  Parallel Seq Scan on movie_com
                          ->  Parallel Hash  (cost=4722.92..
                                Buckets: 4096  Batches: 1  M
                                ->  Parallel Seq Scan on com
                                      Filter: ((country_code
                                      Rows Removed by Filter
                    ->  Parallel Hash  (cost=58861.45..58861
                          Buckets: 65536  Batches: 1  Memory
                          ->  Nested Loop  (cost=2626.57..58
                                ->  Hash Join  (cost=2626.14
                                      Hash Cond: (mk.keyword
                                      ->  Parallel Seq Scan
                                      ->  Hash  (cost=2626.1
                                            Buckets: 1024  B
                                            ->  Seq Scan on
                                                  Filter: (k
                                                  Rows Remov
                                ->  Index Scan using title_p
                                      Index Cond: (id = mk.m
Planning Time: 6.393 ms
Execution Time: 1439.578 ms
```

Evil bug 😈

```
023-04-28 03:00:28.163 UTC [38451] LOG:  background worker "aqo background" (PID 38566) was terminated by signal 11: Segmentation fault
```

Evil bug 😈
There is a reason people treat warnings as failures!

```
aqo.c: In function 'startup_background_process_main':
aqo.c:410:5: warning: ISO C90 forbids mixed declarations and code [-Wdeclaration-after-statement]
  410 |     const char * query_string = MyBgworkerEntry->bgw_extra;
      |     ^~~~~
aqo.c:412:19: warning: implicit declaration of function 'pg_plan_queries' [-Wimplicit-function-declaration]
  412 |     List * plan = pg_plan_queries(DatumGetPointer(main_arg), query_string,
      |                   ^~~~~~~~~~~~~~~
aqo.c:412:19: warning: initialization of 'List *' from 'int' makes pointer from integer without a cast [-Wint-
aqo.c:412:5: warning: ISO C90 forbids mixed declarations and code [-Wdeclaration-after-statement]
  412 |     List * plan = pg_plan_queries(DatumGetPointer(main_arg), query_string,
      |     ^~~~
```

Current Test Coverage

1. Test case for correctness

1. AQO make check to make sure that model is running correctly

1. Run benchmark for both correctness and performance

Code quality

- Good:
  - Use a guc variable for control (flexible + generalized)
  - Abstract the common part (concise + readable)
  - Write comments (easy to understand + maintain)
  - Validation check (security + robustness)
- Bad:
  - Insufficient Script Check
  - Hard coding

Introduction to our benchmark: JOB

- Join Ordering Benchmark:
  - "How Good Are Query Optimizers, Really?" by Viktor Leis at., PVLDB Volume 9, No. 3, 2015
- IMDB Dataset:
  - Based on **real-world dataset** "Internet Movie Database"
  - Full of **correlations and non-uniform** data distributions
  - Contains 21 tables and is very large
- JOB Queries:
  - Based on IMDB Dataset
  - Focus on **join ordering**
  - challenging for cardinality estimators

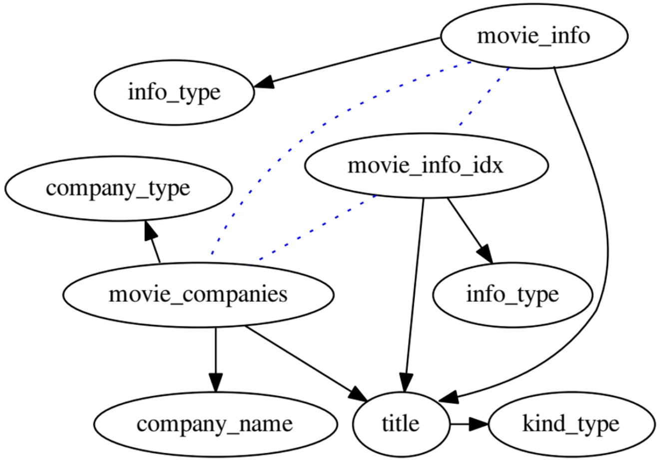


Figure 2: Typical query graph of our workload

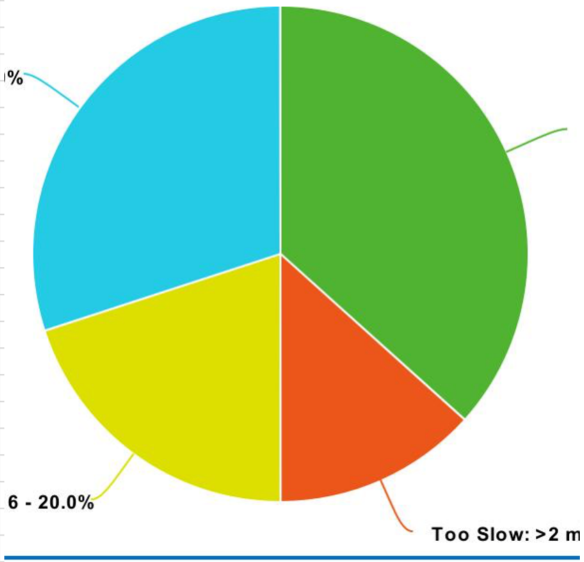
From paper "How Good Are Query Optimizers, Really?"

Benchmark Results on JOB (125% goal)

	base_1	base_2	base_3	**base_avg**	multi_1	nulti_2	multi_3	**multi_avg**	if
1a	790.4	698.7	713.7	**734.3**	525.8	525.9	542.6	**531.4**	faster
1b	545.2	684.0	599.9	**609.7**	399.1	396.4	408.7	**401.4**	faster
1c	659.2	866.2	572.1	**699.2**	431.5	433.0	439.7	**434.7**	faster
2a	1213.7	1172.3	1191.6	**1192.5**	670.2	668.8	696.1	**678.3**	faster
2b	1156.5	1242.3	1232.8	**1210.5**	637.3	636.1	634.5	**636.0**	faster
2c	1374.5	1216.3	1552.4	**1381.1**	566.9	556.9	552.6	**558.8**	faster
3a	3459.112	3514.232	3443.99	**3472.4**	3255.412	3036.633	3305.476	**3199.2**	same
3b	1753.994	1882.727	1641.399	**1759.4**	1655.424	1599.157	1690.388	**1648.3**	same
3c	2175.199	2281.588	2293.991	**2250.3**	1943.013	1966.708	1931.699	**1947.1**	same
4a	833.81	756.113	826.271	**805.398**					
4b	654.4	644.6	1067.9	**788.9**	477.3	463.6	482.0	**474.3**	faster
4c	993.873	857.636	949.586	**933.6983333**					
5a	586.276	521.884	456.812	**521.7**	279.7	264.5	310.9	**285.0**	faster
5b	389.0	339.8	406.0	**378.3**	260.1	288.5	294.3	**281.0**	faster
5c	2119.563	2353.573	2099.76	**2191.0**	1850.974	1850.63	2043.974	**1915.2**	same
6a	3386.672	3319.672	3477.385	**3394.6**	6740.0	8205.8	8286.3	**7744.0**	slower
6b	3371.631	3445.023	3484.529	**3433.727667**					
6c	3218.902	3352.92	3352.921	**3308.2**	11150.3	10317.5	11150.3	**10872.7**	slower
7a	4525.2	4700.9	4318.2	**4514.8**	2966.9	3150.3	2945.6	**3020.9**	faster
7b	3223.415	3376.853	3292.282	**3297.5**	3045.502	2990.835	3015.799	**3017.4**	same
7c	6022.958	5948.215	6111.585	**6027.6**	4165.6	3981.3	4171.9	**4106.3**	faster
8a	2963.995	3019.798	2821.104	**2935.0**	2963.8	3009.7	3032.3	**3001.9**	same
8b	2801.645	2938.337	3039.854	**2926.6**	27594.9	27242.0	27289.2	**27375.4**	slower
8c	7900.462	8017.525	7899.916	**7939.3**	7920.713	7738.812	8236.452	**7965.3**	same
9a	4371.496	4498.63	4411.735	**4427.3**	5708.5	5607.3	5604.1	**5640.0**	slower
9b	3252.645	3236.819	3081.874	**3190.4**	5954.9	6377.2	5604.1	**5978.7**	slower
9c	4336.901	4763.168	4548.448	**4549.5**					
10a	3430.023	3401.248	3571.106	**3467.5**	3376.594	3320.884	3304.734	**3334.1**	same
10b	3350.946	3377.193	3417.622	**3381.9**	3326.711	3271.639	3076.179	**3224.8**	same
10c	4475.686	4425.701	4605.28	**4502.2**	4764.283	4641.384	4604.979	**4670.2**	same

ms	
same	0.8*base ~ 1.2*base
faster	<0.8*base
slower	>1.2*base
	longer than 2min

Execution time calculated until ML converge (few trail trains not counted here)



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8c	7900.462	8017.525	7899.916	7939.3	7920.713	7738.812	8236.452	7965.3	same
9a	4371.496	4498.63	4411.735	4427.3	5708.5	5607.3	5604.1	5640.0	slower
9b	3252.645	3236.819	3081.874	3190.4	5954.9	6377.2	5604.1	5978.7	slower
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ms	
same	0.8*base ~ 1.2*base
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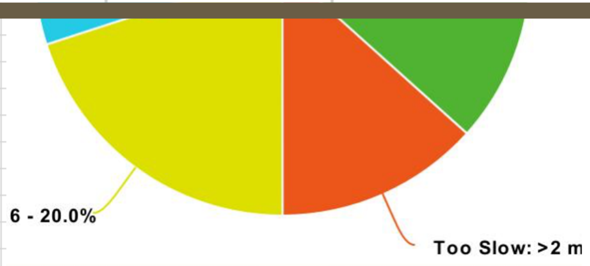
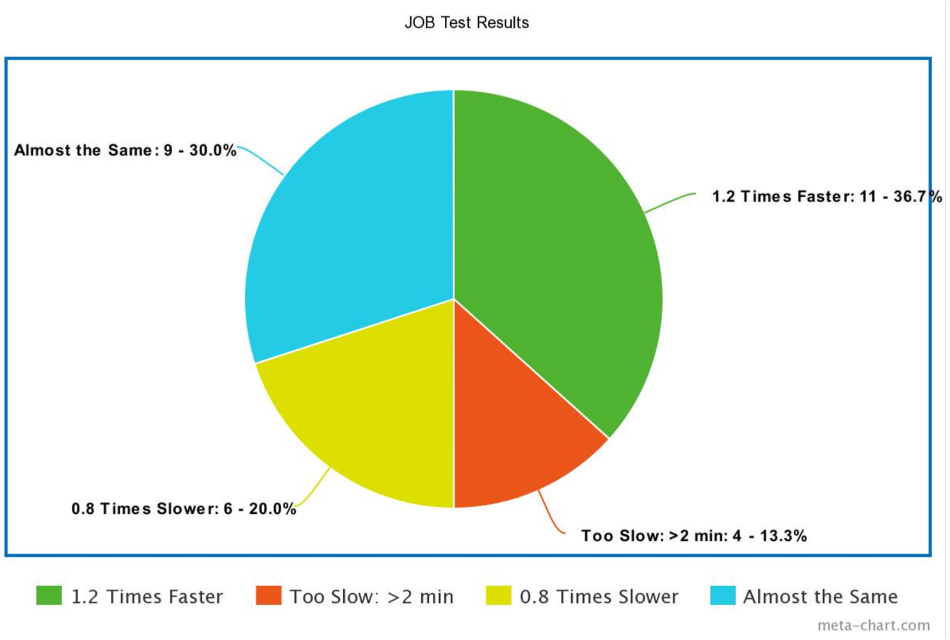
	longer than 2min

50% Faster!!



Benchmark Results on JOB (125% goal)

- **Pro**:
  - Great performance (36.7%) Improvement in Simple Query
  - ML **have chance** to learn better query plans through trial
- **Con**:
  - ML performance worse than baseline in first few runs
  - ML performance is **unstable**
  - Hard to converge on **complex** queries



Execution time calculated until ML converge (few trail trains not counted here)

Future Work

- Better testing: Unit test
- Add execution time to the current cost
- Using more complex ML algorithms
- Considering other techniques including sampling

Resources

1. Join Order Benchmark (JOB)
2. Adaptive query optimization: https://github.com/postgrespro/aqo
3. Computation resources
4. Code review pipeline
5. Kudos to various PostgreSQL extension resources from Wan and Abby