CSEN604 Databases II Project Report

Environment

The queries were run on the following environment:

- PostgreSQL 14.3, compiled by Visual C++ build 1914, 64-bit
- Windows 10 Version 21H2 (OS Build 19044.1706)
- Processor AMD Ryzen 9 5900X 12-Core Processor
- RAM 64 GB 3200 MHz

No changes were made to the Postgres default configuration.

Schema 1

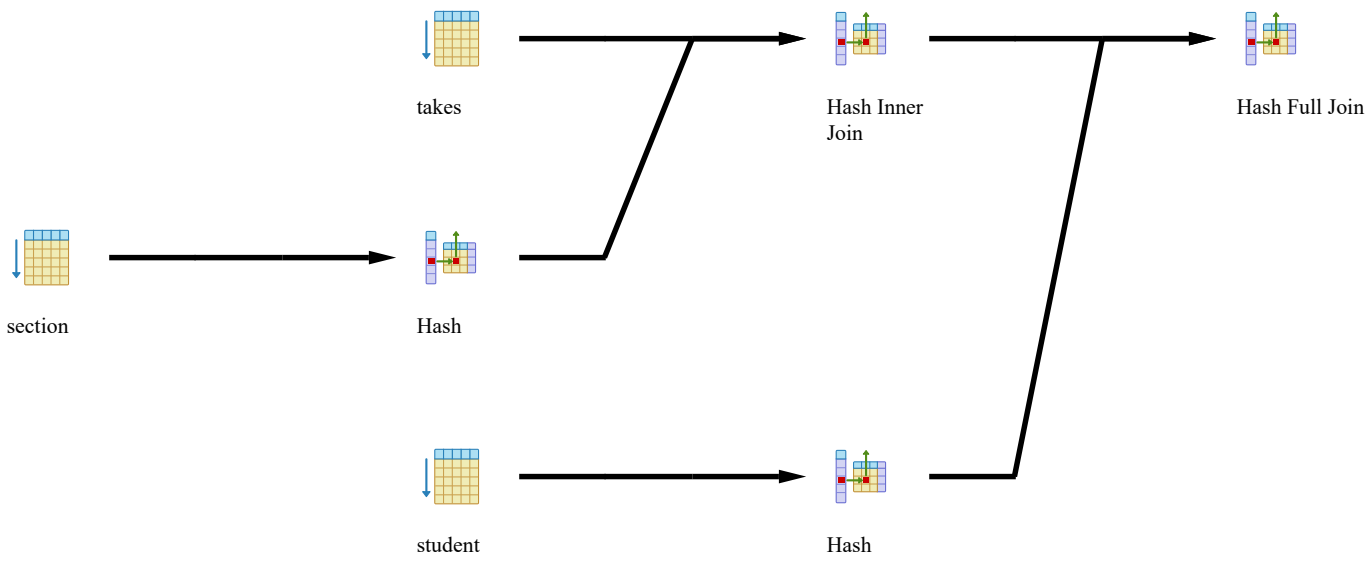
Query 1

Display a list of all students in the CSEN department, along with the course sections, if any, that they have taken in Semester 1 2019; all course sections from Spring 2019 must be displayed, even if no student from the CSEN department has taken the course section.

```
select *
        from (select *
        from student
        where
        department = 'CSEN') as CS1_student
        full outer join
        (select *
        from takes t inner join section s
        on t.section_id = s.section_id
        where semester = 1
        and
        year = 2019) as sem1_student
        on CS1_student.id = sem1_student.student_id
```

Without Any Optimization

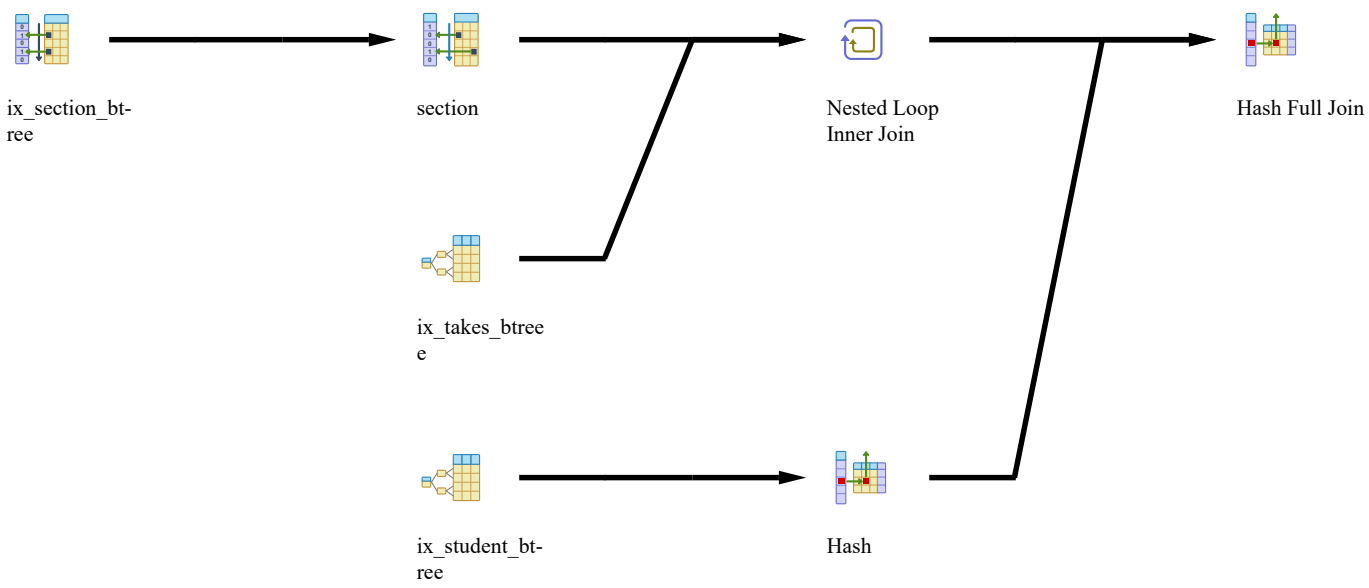
Query returns 136611 records



Run 1	Run 2	Run 3	Average	Planning	Cost
233.928ms	253.611ms	234.665ms	240.735ms	0.202ms	37451.36

With B-TREE indices

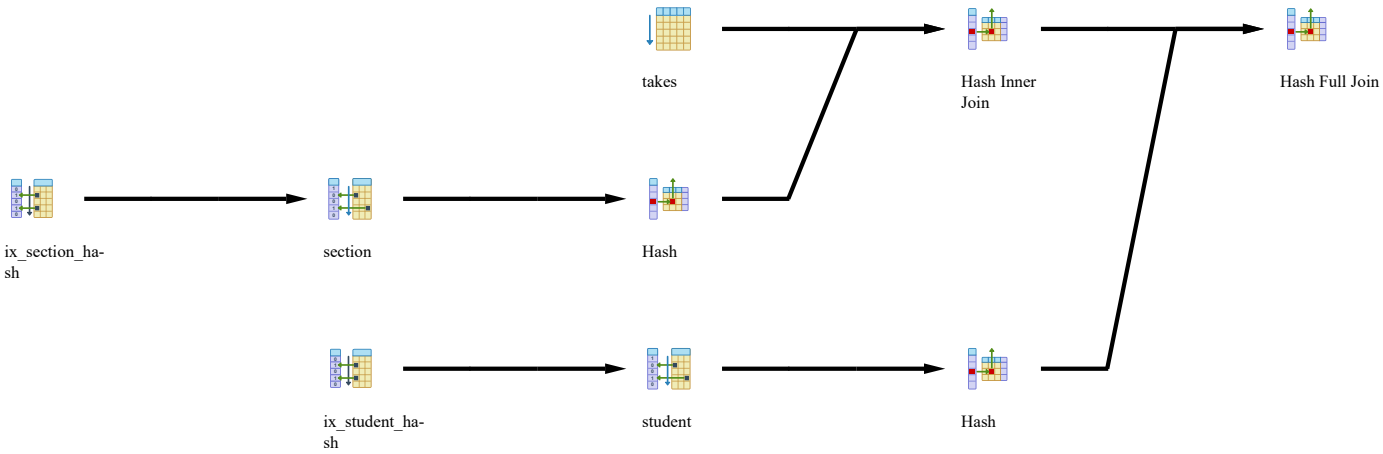
```
create index "ix_student_btree" on "student" using btree ("department");
create index "ix_section_btree" on "section" using btree ("semester", "year");
create index "ix_takes_btree" on "takes" using btree ("section_id", "student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
103.546ms	74.385ms	68.097ms	82.009ms	0.257ms	33955.53	91%	34%

With Hash indices

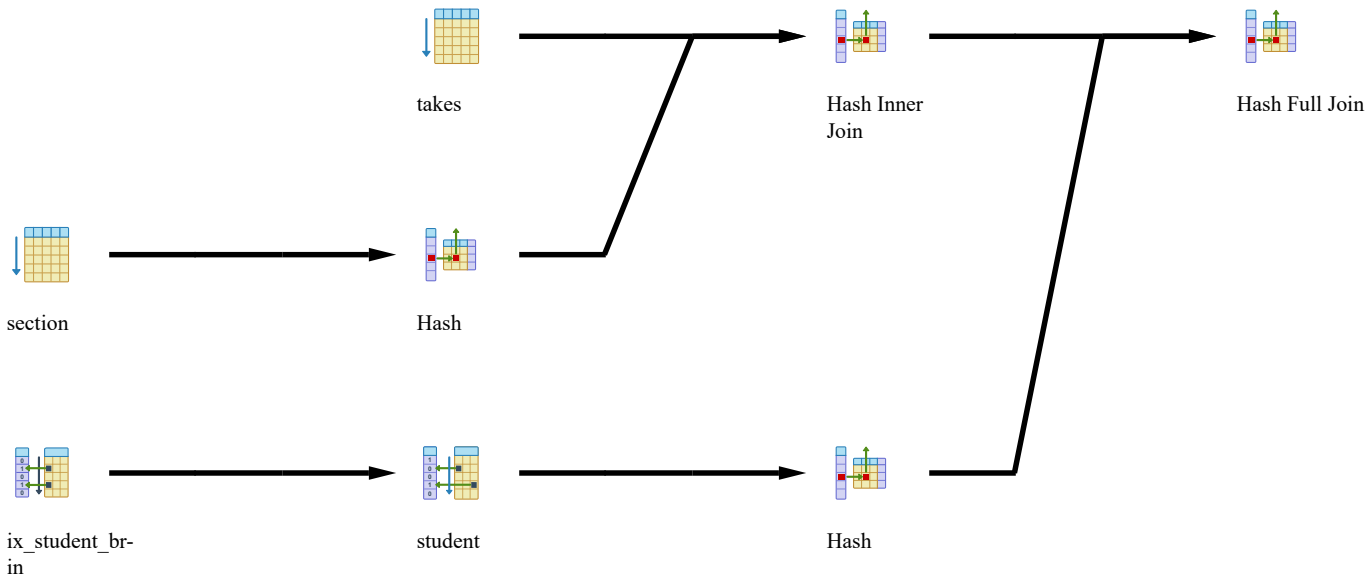
```
create index "ix_student_hash" on "student" using hash ("department");
create index "ix_section_hash" on "section" using hash ("year");
create index "ix_takes_hash" on "takes" using hash ("student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
213.008ms	218.789ms	211.343ms	214.38ms	0.253ms	36145.62	97%	89%

With BRIN indices

```
create index "ix_student_brin" on "student" using brin ("department");
create index "ix_section_brin" on "section" using brin ("semester", "year");
create index "ix_takes_brin" on "takes" using brin ("student_id");
```

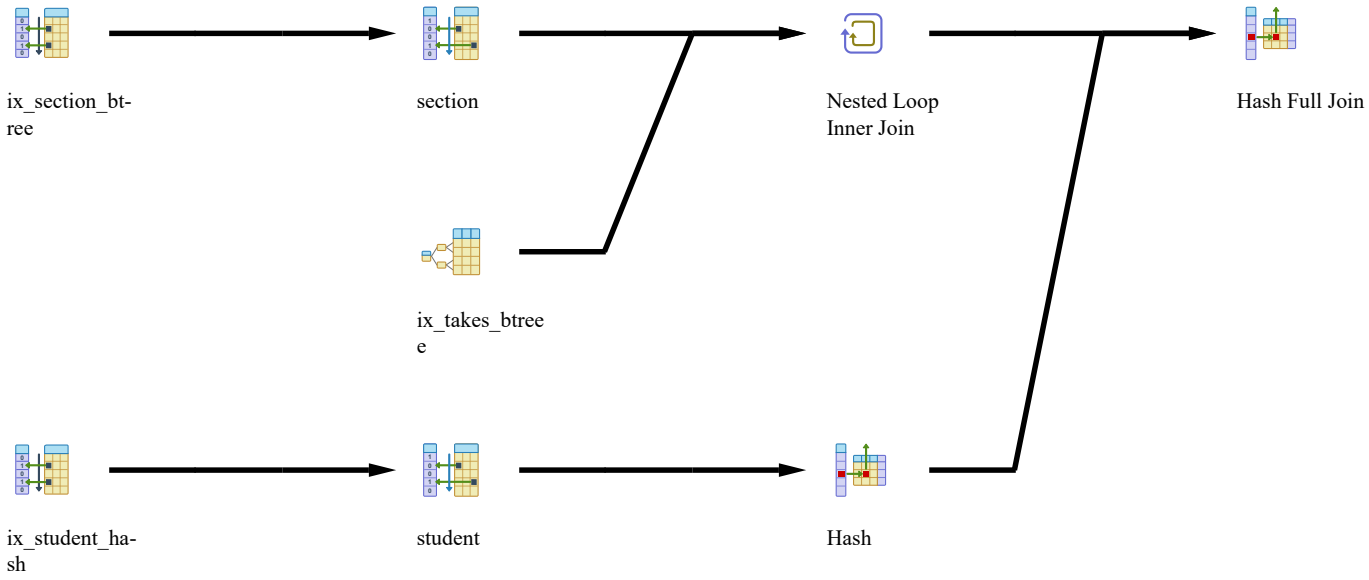


Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
219.42ms	219.346ms	211.564ms	216.777ms	0.208ms	36437.81	97%	90%

With Mixed indices

```
create index "ix_student_hash" on "student" using hash ("department");
create index "ix_section_btree" on "section" using btree ("semester", "year");
```

```
create index "ix_takes_btree" on "takes" using btree ("section_id", "student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
78.041ms	67.96ms	67.818ms	71.273ms	0.222ms	34779.02	93%	30%

Improved SQL

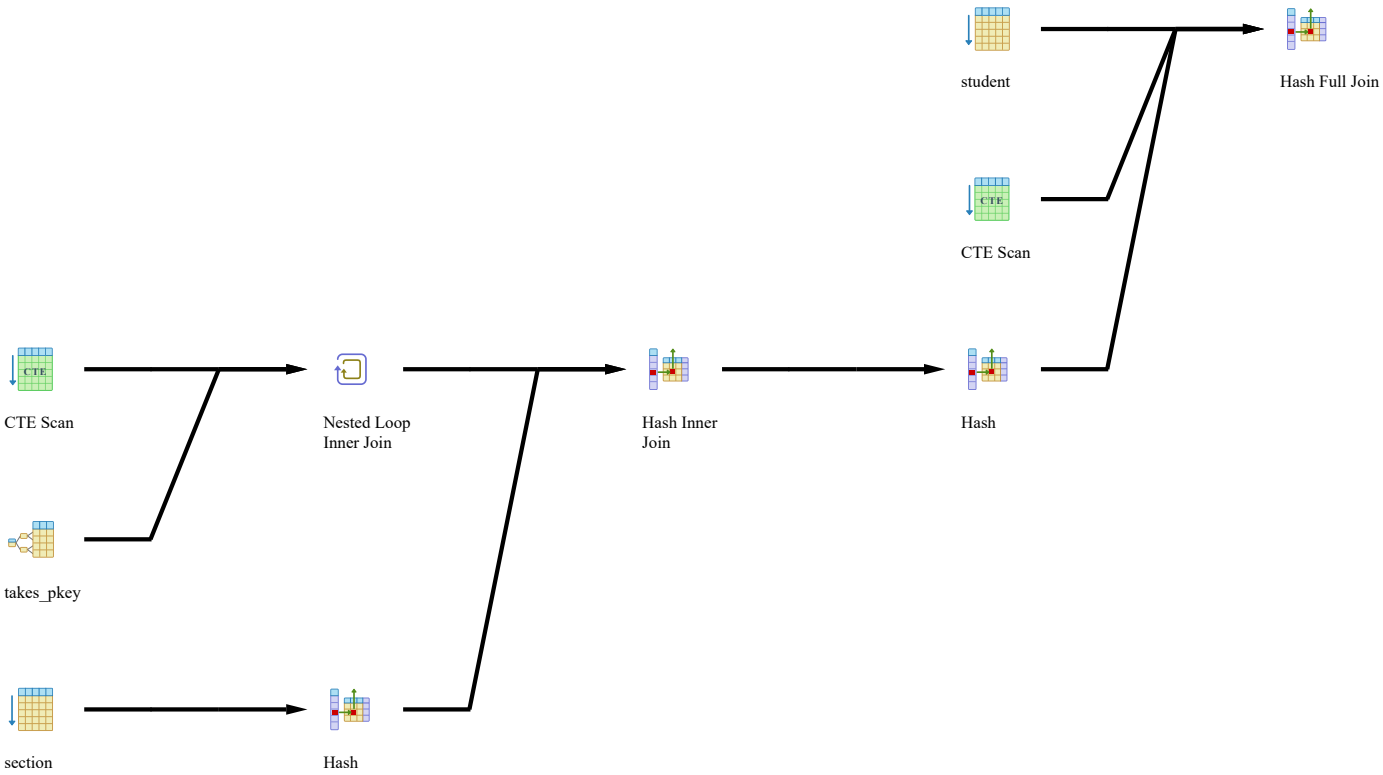
The original query had a flaw. It was supposed to get all courses from Spring 2019 even if no CSEN student took the course. However, since it was joining with `takes`, it would return the same course many times. For example, if 100 *non-CSEN* students took course, the course would be listed 100 times. Fixing the query significantly reduced the number of returned rows while maintaining the original requirement and therefore had significant impact on execution time.

We recommend creating B-Tree indices on `student` `section` and `takes` tables as indicated in the create index statements below.

```
with s as (select * from section where semester = 1 and year = 2019),
        cs1_student as (select * from student where department = 'CSEN'),
        sem1_student as (select takes.*, s.* from takes inner join s on takes.section_id = s.section_id inner join
cs1_student on cs1_student.id = takes.student_id)
        select * from cs1_student full outer join sem1_student on CS1_student.id = sem1_student.student_id;
```

Without Any Optimization

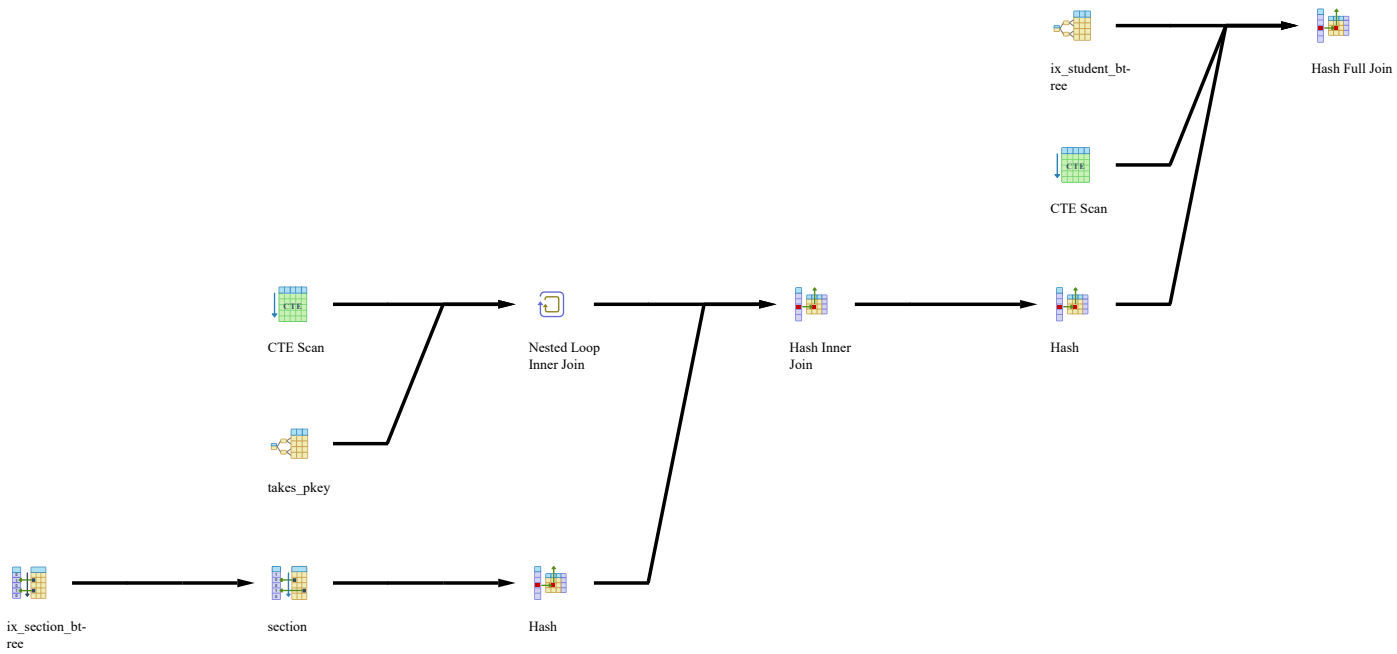
Query returns 3242 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
20.399ms	19.095ms	19.003ms	19.499ms	0.32ms	33145.21	89%	8%

With B-TREE indices

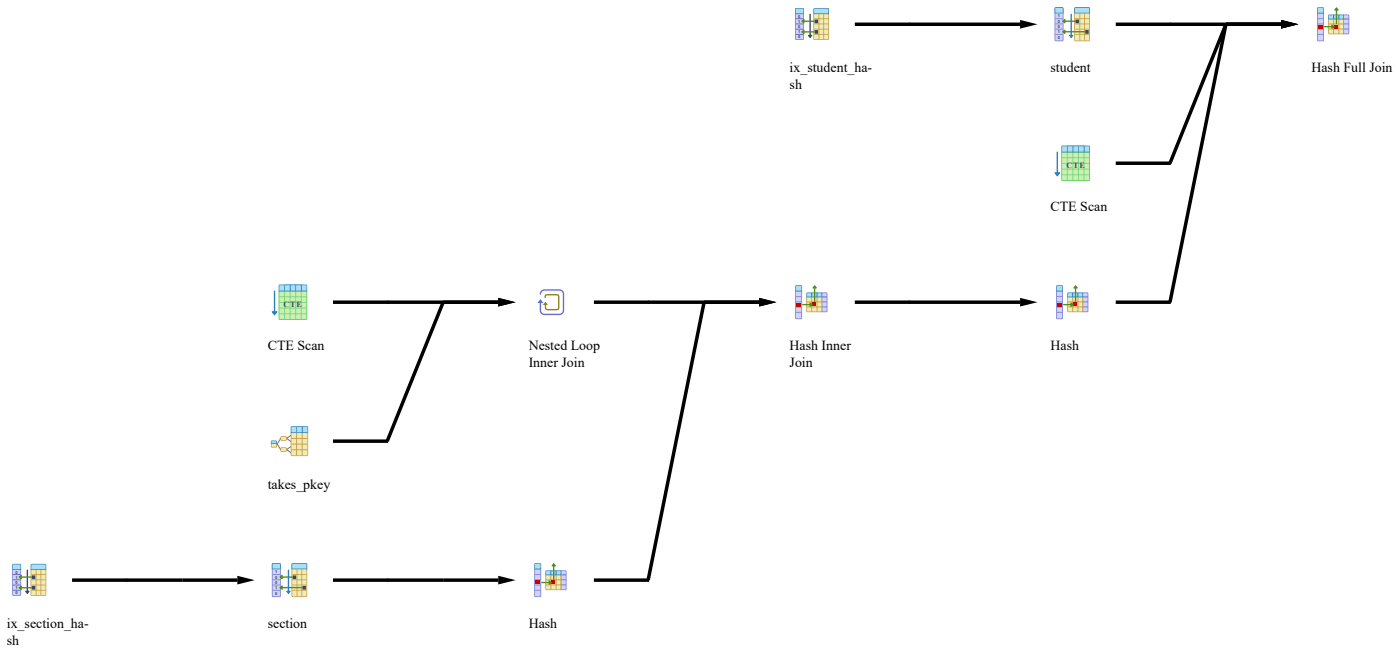
```
create index "ix_student_btree" on "student" using btree ("department");
create index "ix_section_btree" on "section" using btree ("semester", "year");
create index "ix_takes_btree" on "takes" using btree ("section_id", "student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
16.329ms	14.642ms	13.219ms	14.73ms	0.358ms	31240.8	94%	76%	92%	18%

With Hash indices

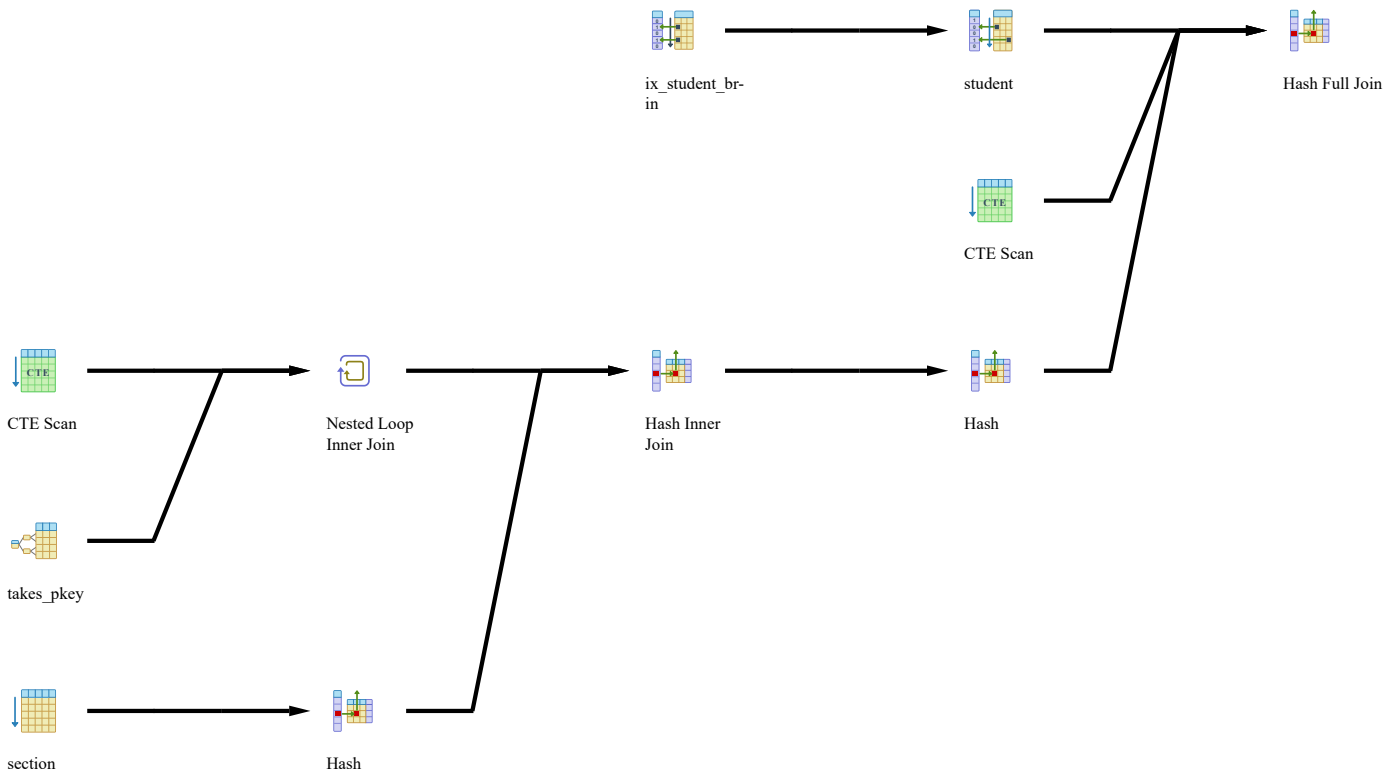
```
create index "ix_student_hash" on "student" using hash ("department");
create index "ix_section_hash" on "section" using hash ("year");
create index "ix_takes_hash" on "takes" using hash ("student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
15.23ms	12.724ms	13.37ms	13.775ms	0.292ms	32841.49	99%	71%	91%	6%

With BRIN indices

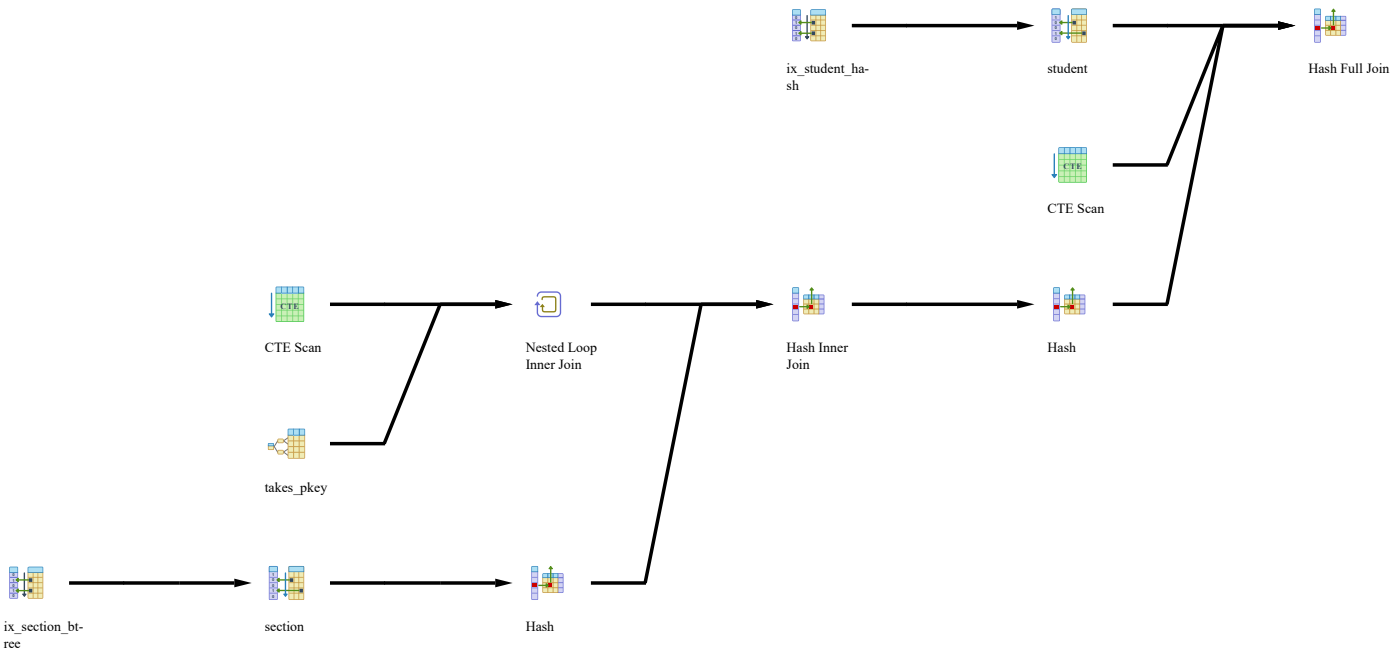
```
create index "ix_student_brin" on "student" using brin ("department");
create index "ix_section_brin" on "section" using brin ("semester", "year");
create index "ix_takes_brin" on "takes" using brin ("student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
14.582ms	13.907ms	13.276ms	13.922ms	0.309ms	32878.83	99%	71%	90%	6%

With Mixed indices

```
create index "ix_student_hash" on "student" using hash ("department");
create index "ix_section_btree" on "section" using btree ("semester", "year");
create index "ix_takes_btree" on "takes" using btree ("section_id", "student_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
13.069ms	12.574ms	13.676ms	13.106ms	0.368ms	31916.62	96%	67%	92%	18%

Schema 2

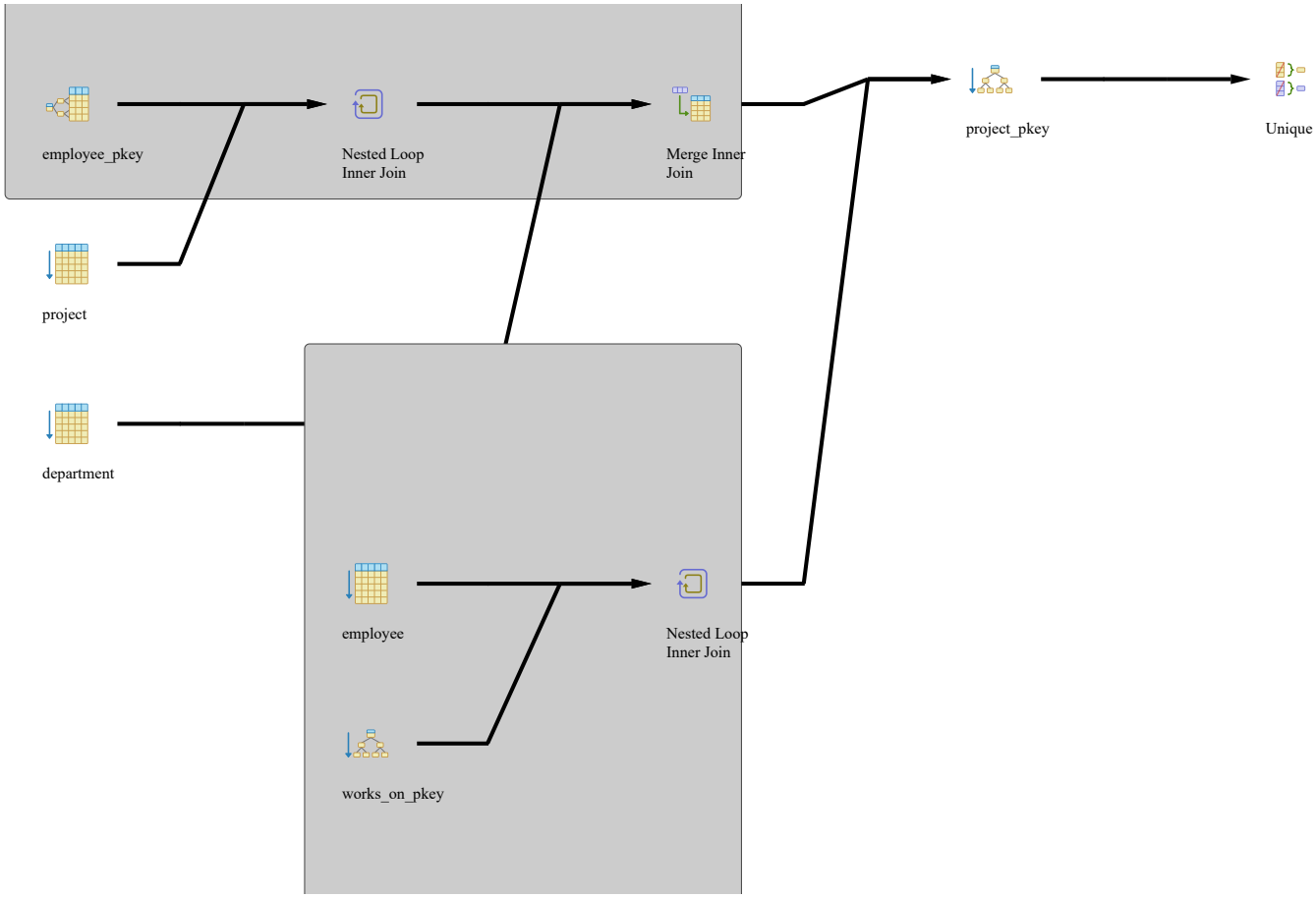
Query 2

Select all projects if employee with last name `'employee1'` is a manager of any department, otherwiser get projects employee with last name `'employee1'` is working on.

```
select distinct pnumber
        from project
        where pnumber in
        (select pnumber
            from project, department d, employee e
            where e.dno = d.dnumber
            and d.mgr_snn = ssn
            and e.lname='employee1' )
            or pnumber in (select pno
                from works_on, employee
                where essn=ssn and lname='employee1' )
```

Without Any Optimization

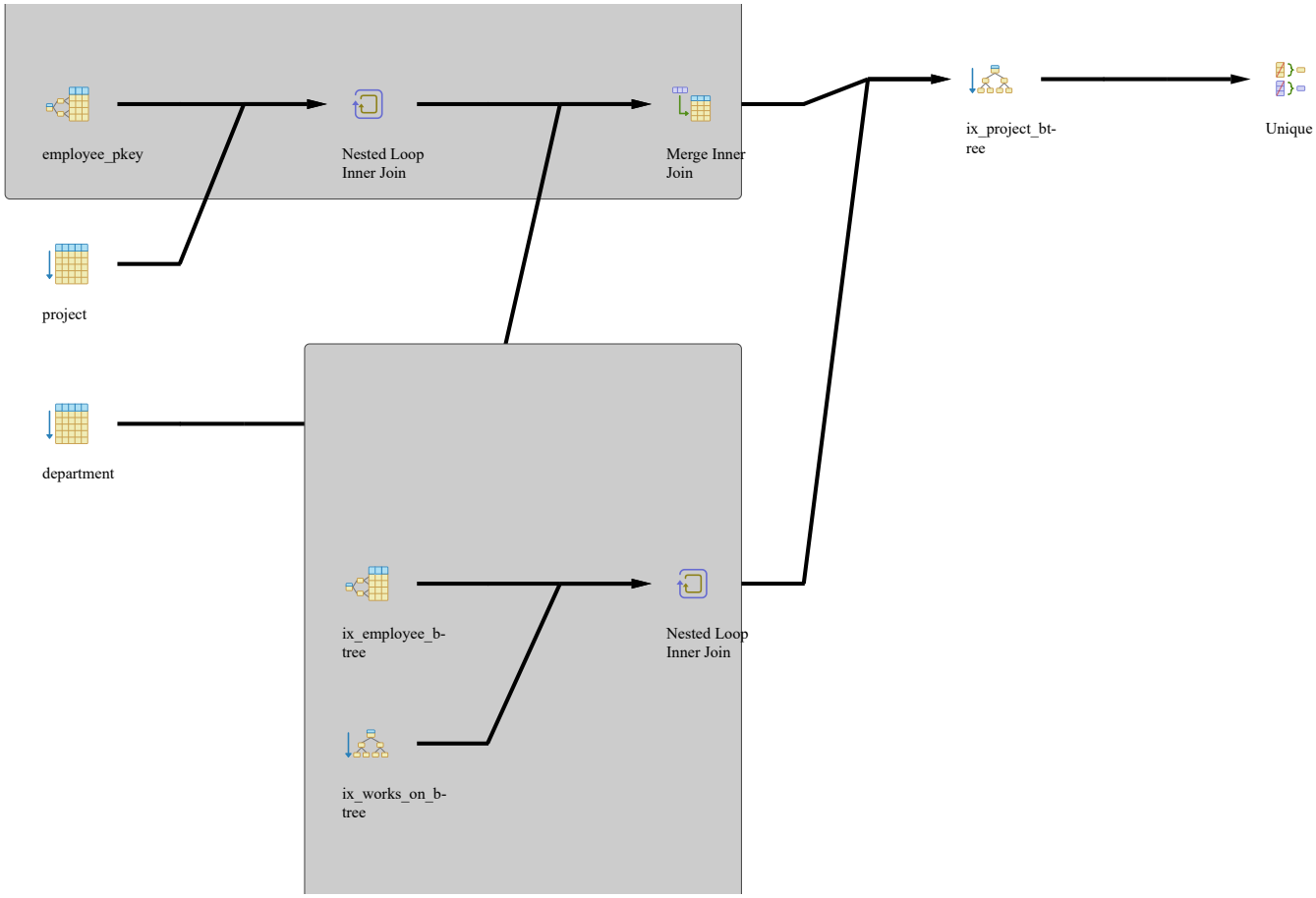
Query returns 600 records



Run 1	Run 2	Run 3	Average	Planning	Cost
7.236ms	5.013ms	4.648ms	5.632ms	0.328ms	1062.24

With B-TREE indices

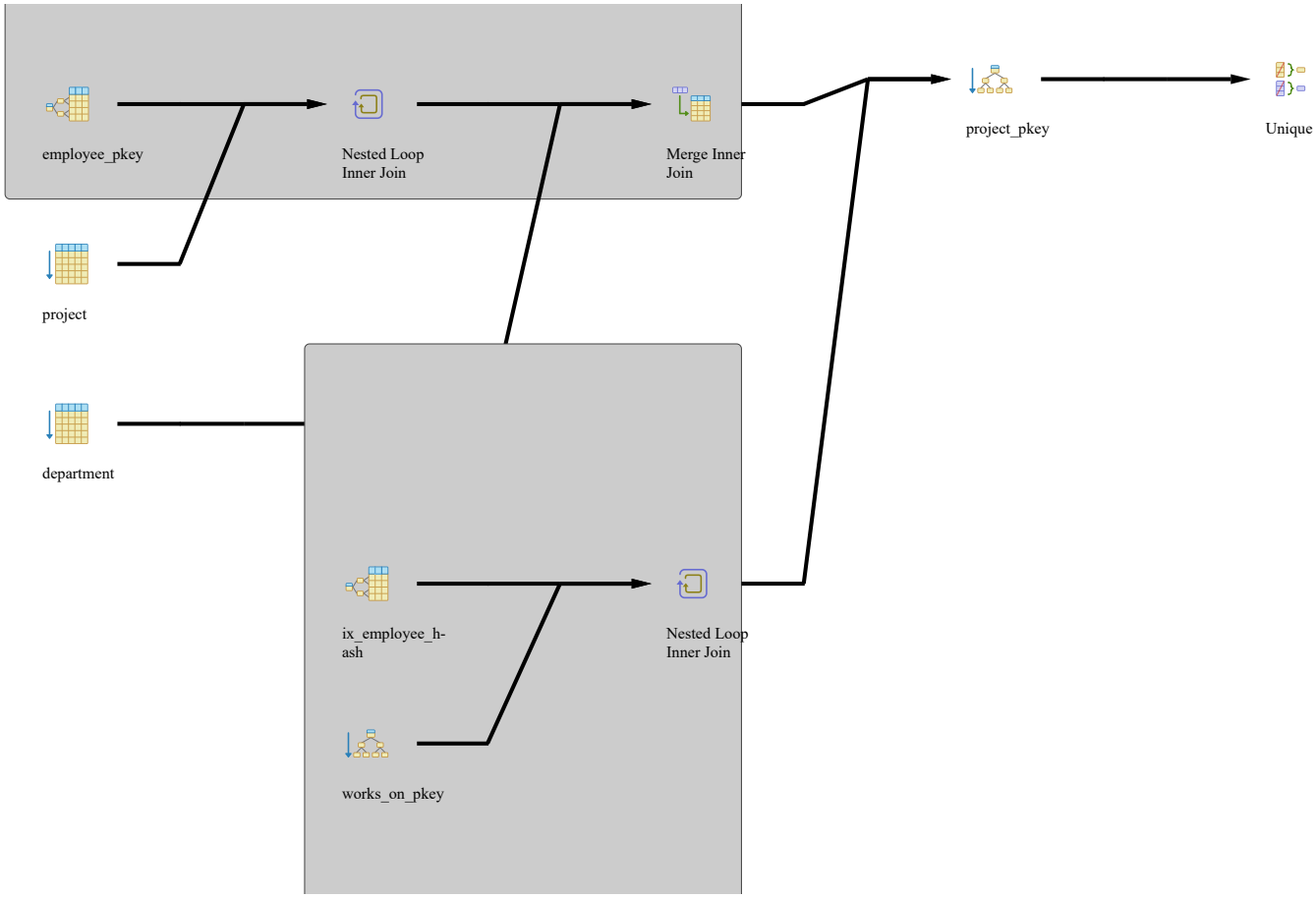
```
create index "ix_department_btree" on "department" using btree ("mgr_snn") include ("dnumber") ;
create index "ix_employee_btree" on "employee" using btree ("lname") include ("dno") ;
create index "ix_project_btree" on "project" using btree ("pnumber");
create index "ix_works_on_btree" on "works_on" using btree ("essn") include ("pno") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
4.064ms	3.951ms	3.784ms	3.933ms	0.364ms	607.54	57%	70%

With Hash indices

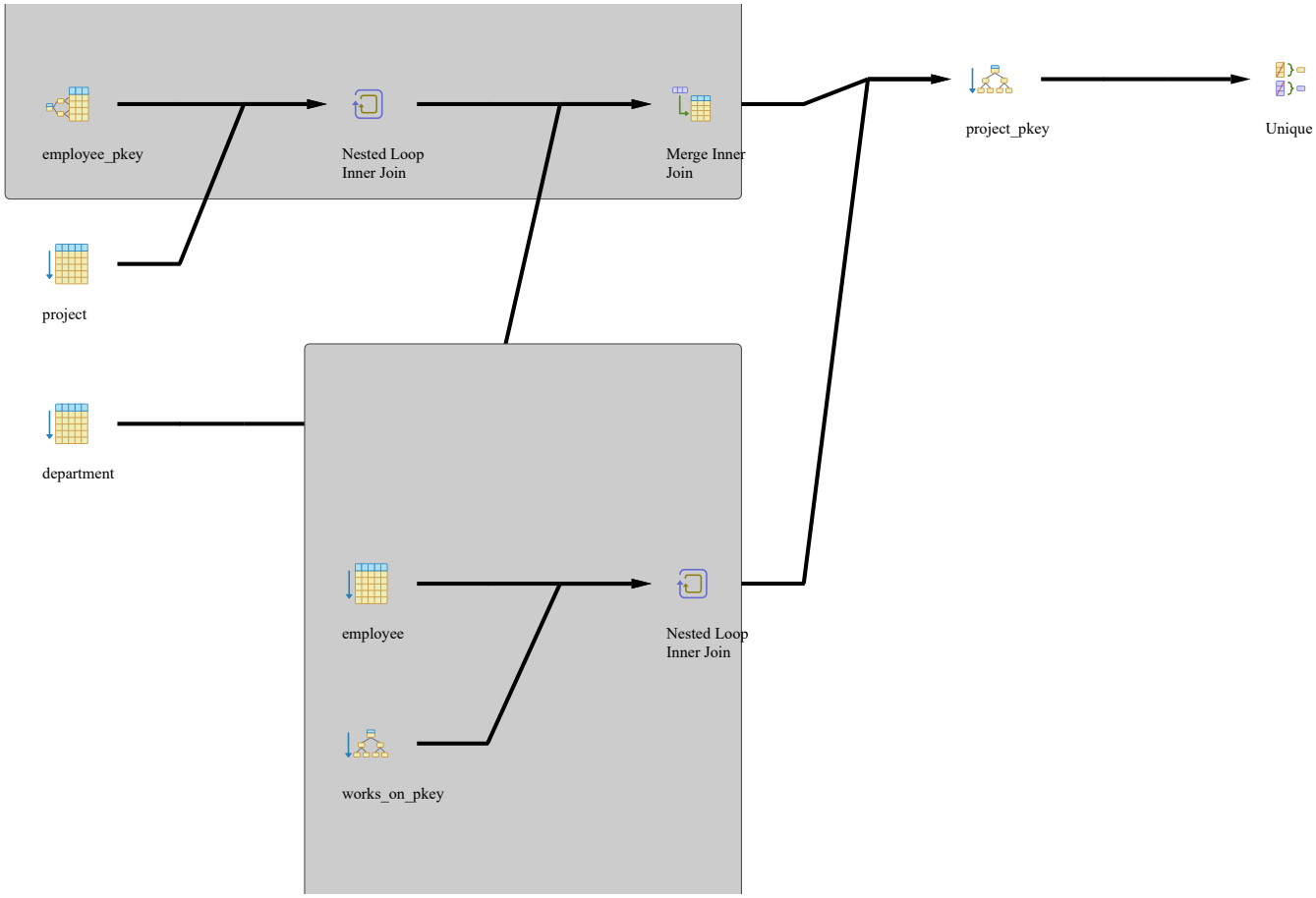
```
create index "ix_department_hash" on "department" using hash ("mgr_snn");
create index "ix_employee_hash" on "employee" using hash ("lname");
create index "ix_project_hash" on "project" using hash ("pnumber");
create index "ix_works_on_hash" on "works_on" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
3.809ms	3.879ms	3.773ms	3.82ms	0.287ms	607.25	57%	68%

With BRIN indices

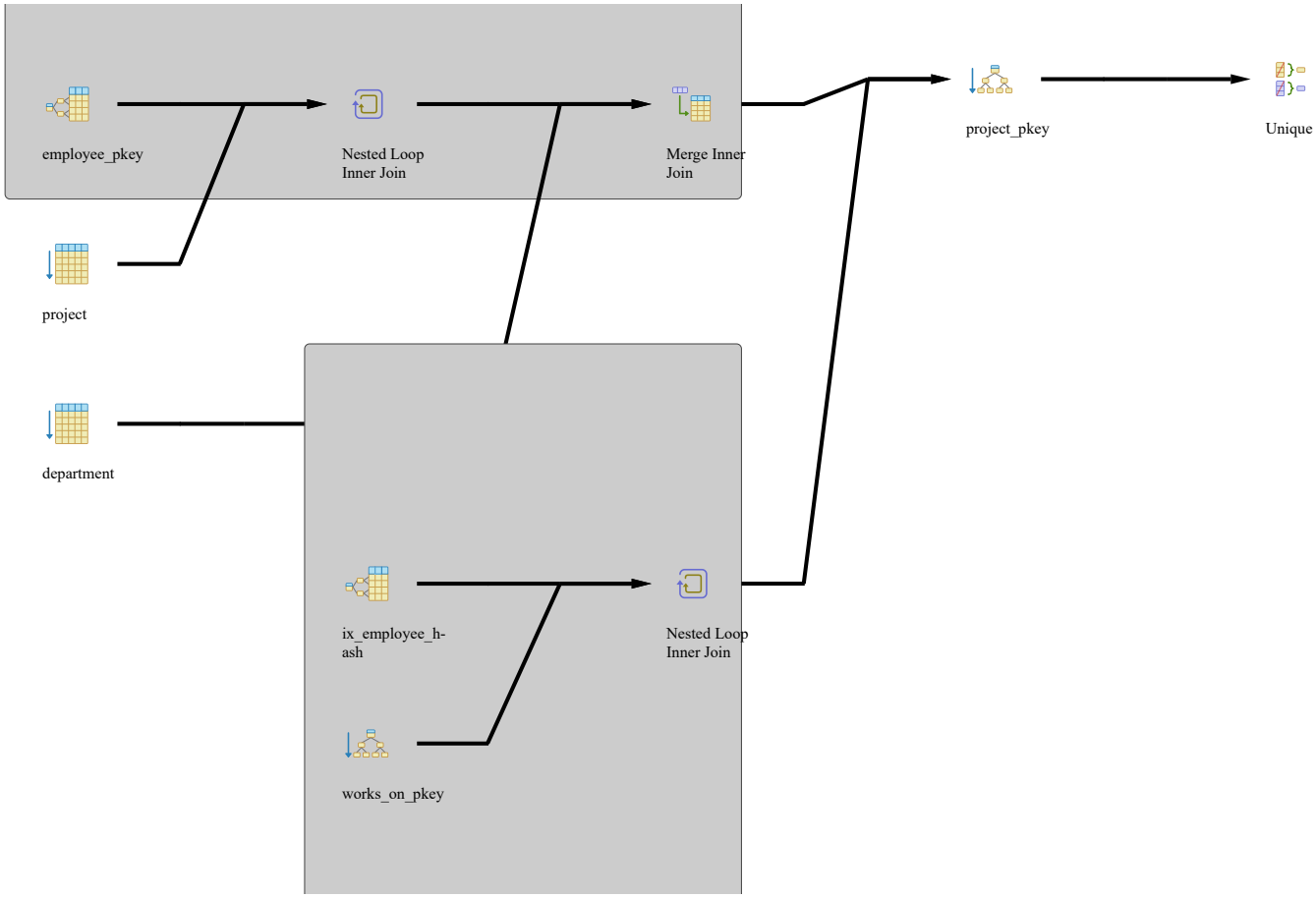
```
create index "ix_department_brin" on "department" using brin ("mgr_snn");
create index "ix_employee_brin" on "employee" using brin ("lname");
create index "ix_project_brin" on "project" using brin ("pnumber");
create index "ix_works_on_brin" on "works_on" using brin ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
4.625ms	5.178ms	4.549ms	4.784ms	0.326ms	1062.24	100%	85%

With Mixed indices

```
create index "ix_department_btree" on "department" using btree ("mgr_snn");
create index "ix_employee_hash" on "employee" using hash ("lname");
create index "ix_project_hash" on "project" using hash ("pnumber");
create index "ix_works_on_btree" on "works_on" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
3.983ms	3.845ms	3.987ms	3.938ms	0.351ms	607.25	57%	70%

Improved SQL

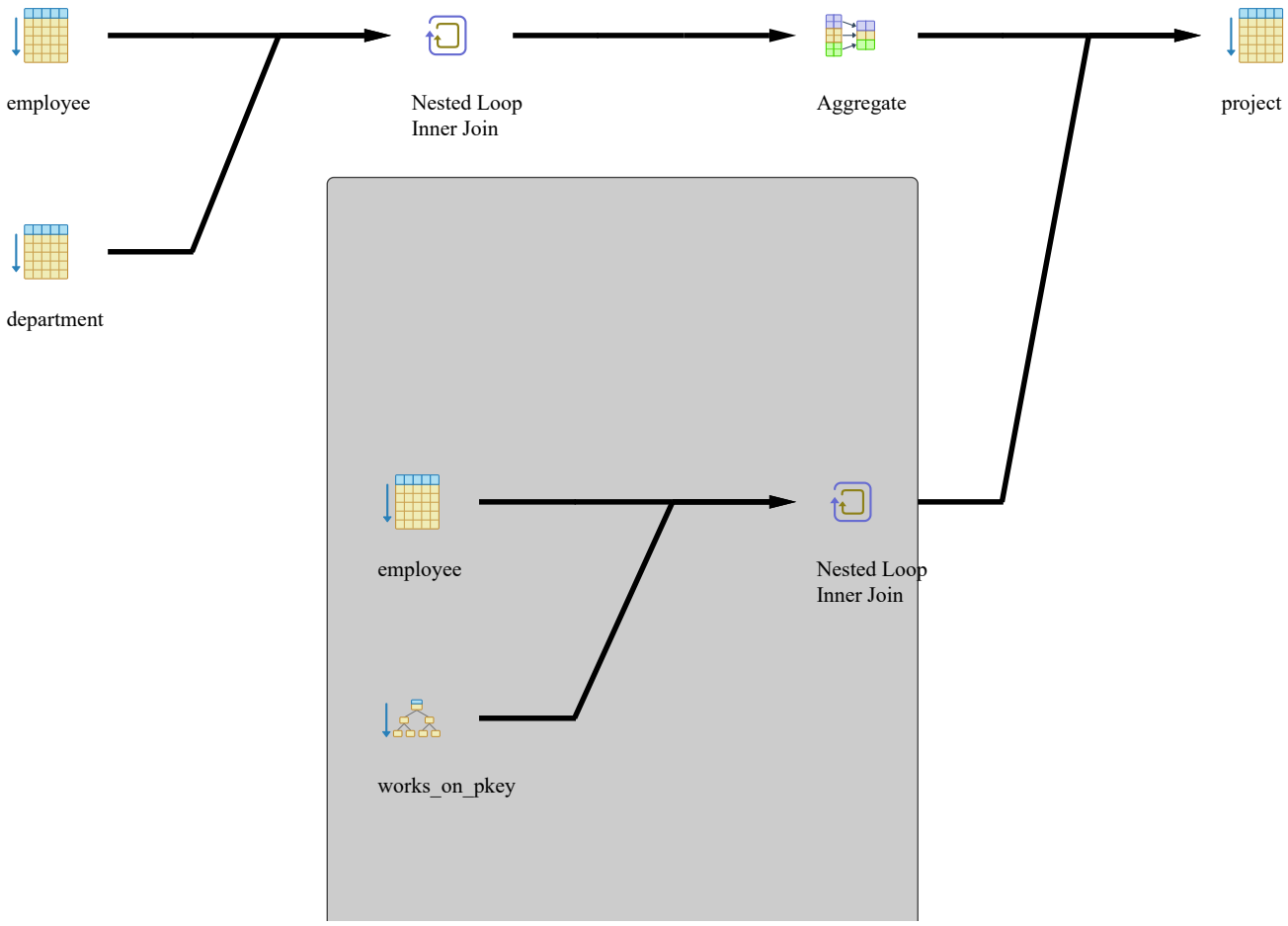
Table project is not used as condition at all in the first inner query of the original query, also the data from department or employee. The query output varies only by the count. Hence we wrote improved query like that. The new query has better performance with and without indexes.

We recommend creating B-Tree indices on `department`, `employee`, `works_on` and `project` tables as indicated in the create index statements below.

```
with c as (select count(*) n from employee e, department d where mgr_snn = ssn and dno = dnumber and lname =
'employee1')
    select pnumber from project
    where pnumber in (select pno as pnumber from works_on, employee where essn=ssn and lname = 'employee1')
    or (select n from c) <> 0
```

Without Any Optimization

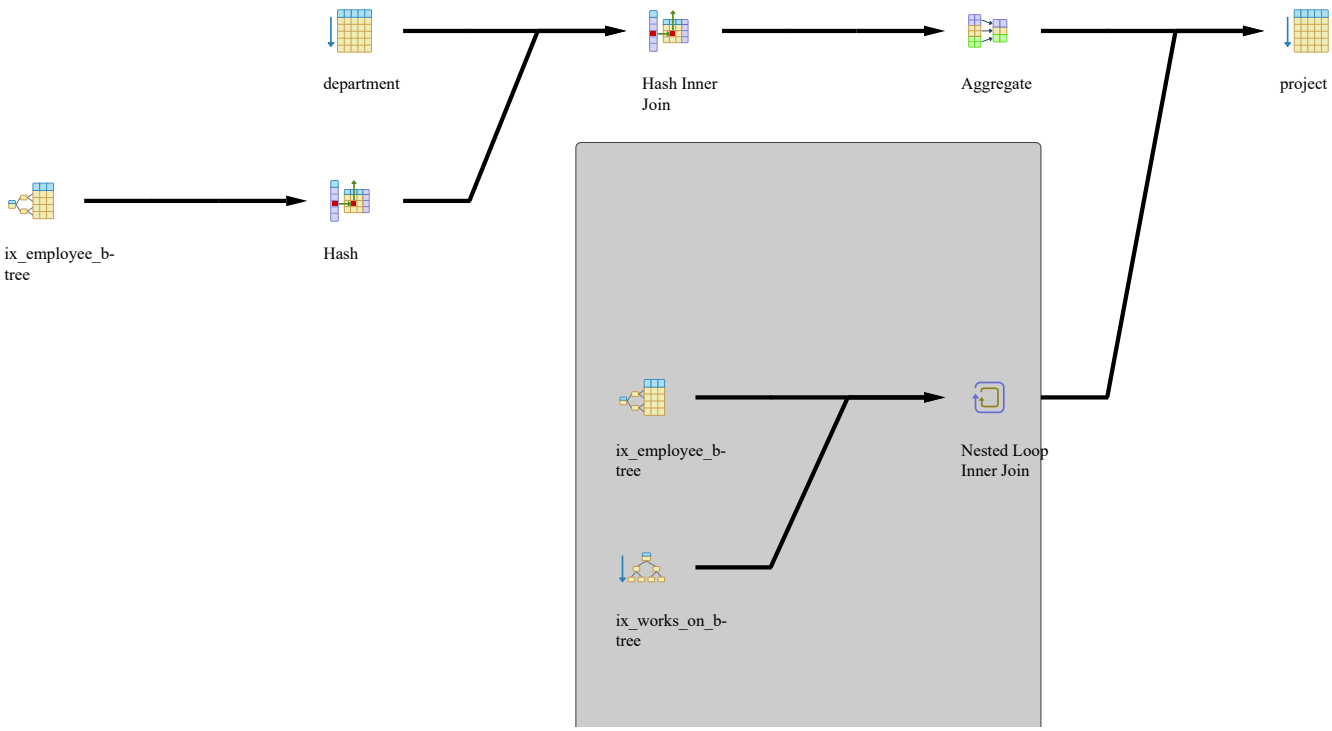
Query returns 600 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
3.44ms	3.17ms	2.863ms	3.158ms	0.263ms	1210.12	114%	56%

With B-TREE indices

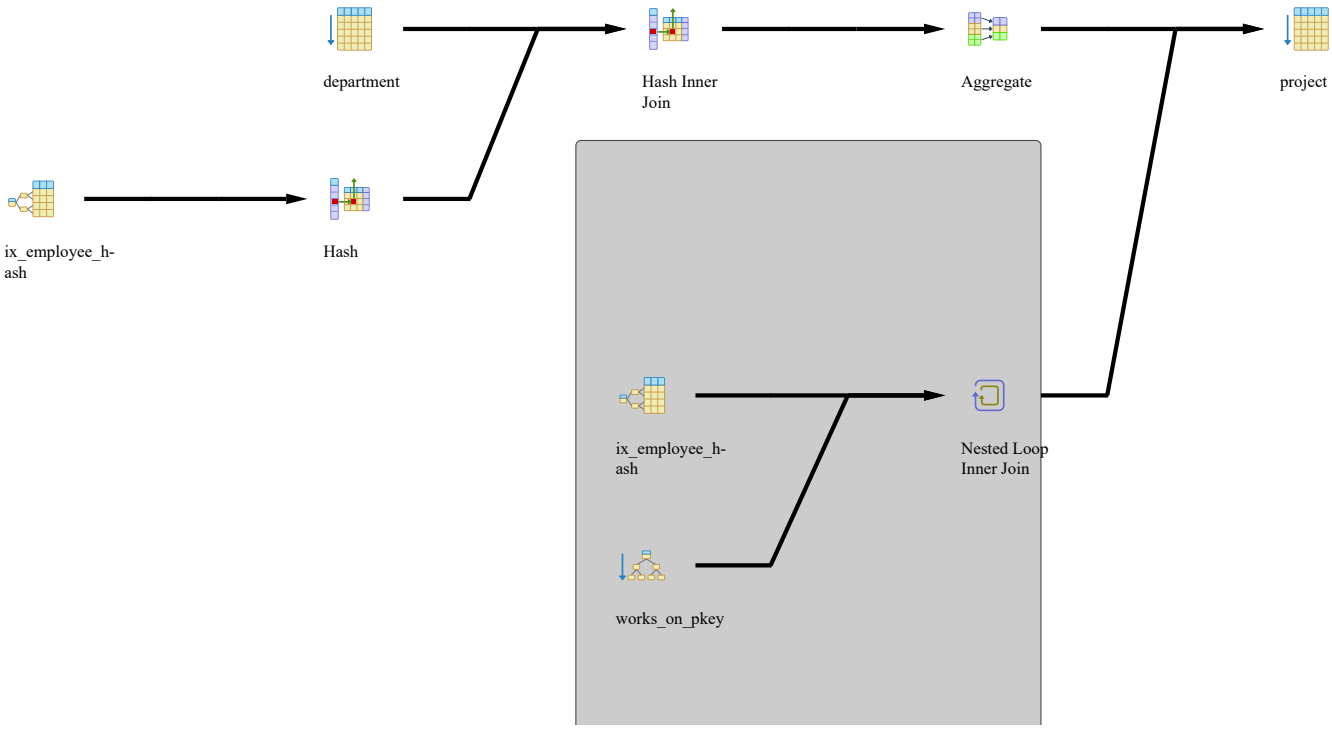
```
create index "ix_department_btree" on "department" using btree ("mgr_snn") include ("dnumber") ;
create index "ix_employee_btree" on "employee" using btree ("lname") include ("dno") ;
create index "ix_project_btree" on "project" using btree ("pnumber");
create index "ix_works_on_btree" on "works_on" using btree ("essn") include ("pno") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
1.194ms	1.121ms	1.182ms	1.166ms	0.313ms	299.28	25%	37%	49%	30%

With Hash indices

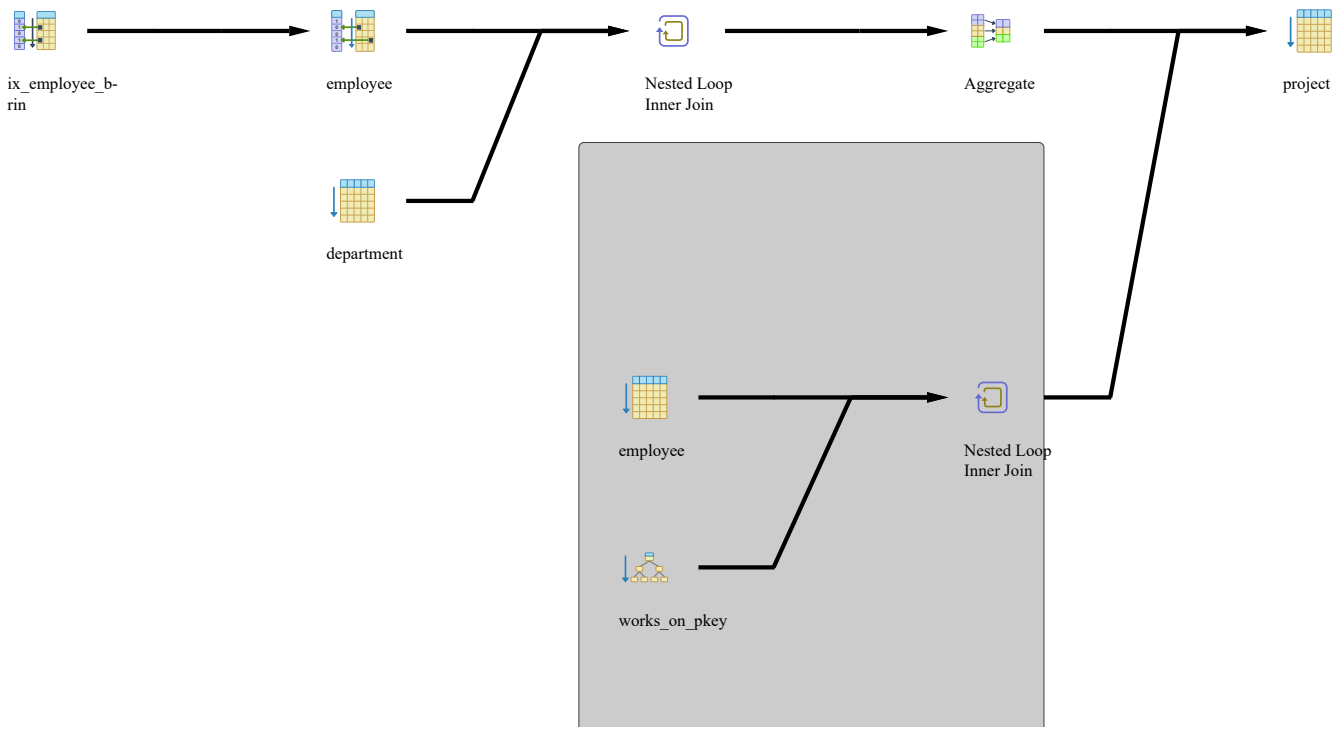
```
create index "ix_department_hash" on "department" using hash ("mgr_snn");
create index "ix_employee_hash" on "employee" using hash ("lname");
create index "ix_project_hash" on "project" using hash ("pnumber");
create index "ix_works_on_hash" on "works_on" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
1.118ms	1.362ms	1.109ms	1.196ms	0.267ms	298.71	25%	38%	49%	31%

With BRIN indices

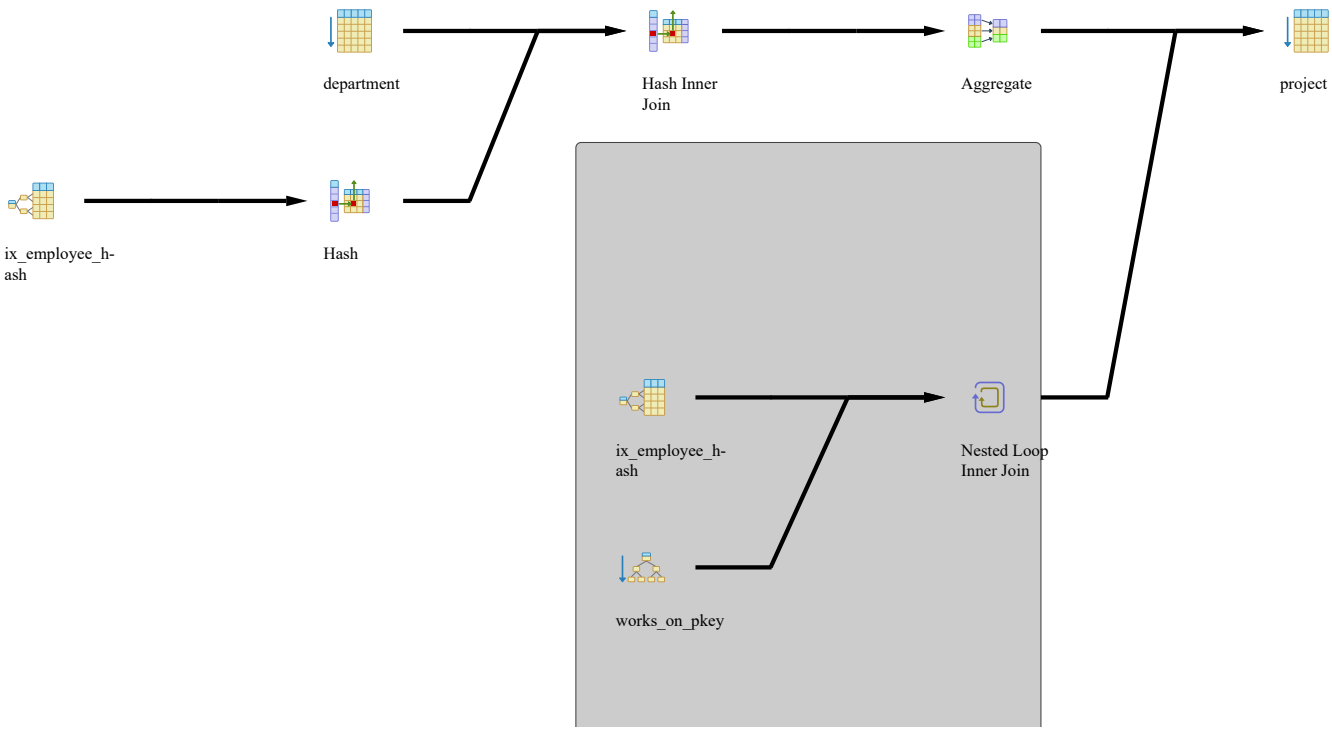
```
create index "ix_department_brin" on "department" using brin ("mgr_snn");
create index "ix_employee_brin" on "employee" using brin ("lname");
create index "ix_project_brin" on "project" using brin ("pnumber");
create index "ix_works_on_brin" on "works_on" using brin ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
2.646ms	2.644ms	2.675ms	2.655ms	0.299ms	1200.31	99%	84%	113%	55%

With Mixed indices

```
create index "ix_department_btree" on "department" using btree ("mgr_snn");
create index "ix_employee_hash" on "employee" using hash ("lname");
create index "ix_project_hash" on "project" using hash ("pnumber");
create index "ix_works_on_btree" on "works_on" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
1.265ms	1.083ms	1.12ms	1.156ms	0.282ms	298.71	25%	37%	49%	29%

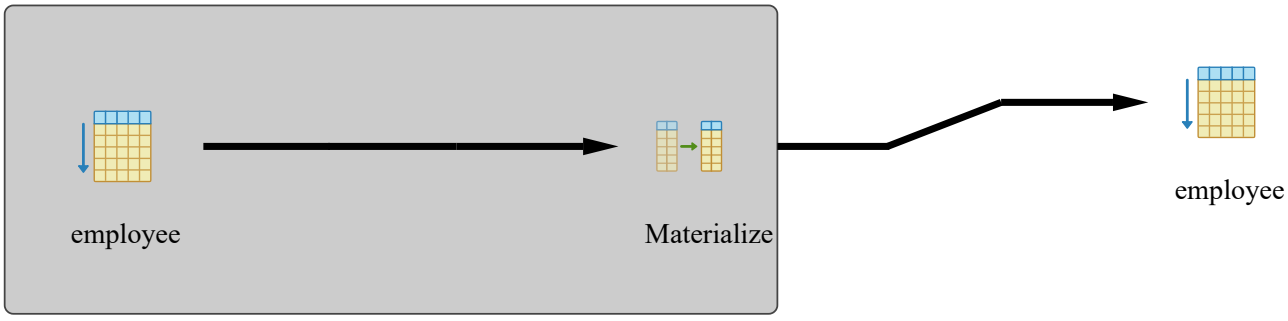
Query 3

Select the names of employees whose salary is greater than the salary of all the employees in department 5

```
select lname, fname
        from employee
        where salary > all (
        select salary
        from employee
        where dno=5 )
```

Without Any Optimization

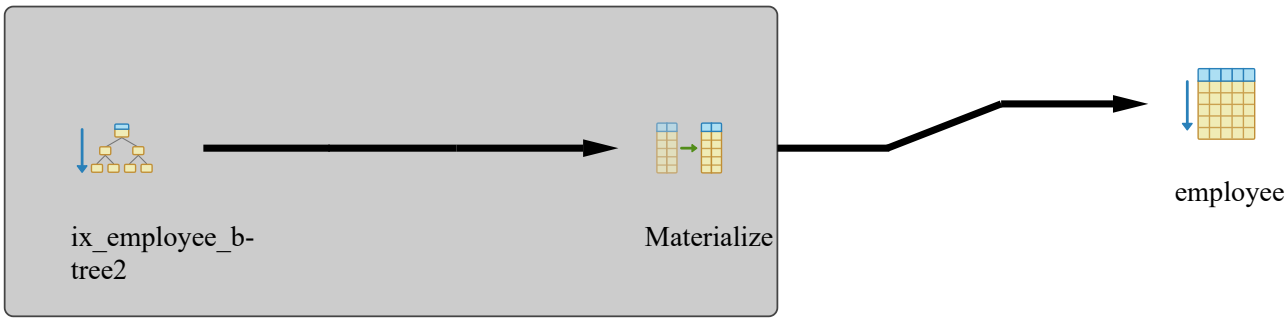
Query returns 124 records



Run 1	Run 2	Run 3	Average	Planning	Cost
6.691ms	6.649ms	6.317ms	6.552ms	0.047ms	3711903

With B-TREE indices

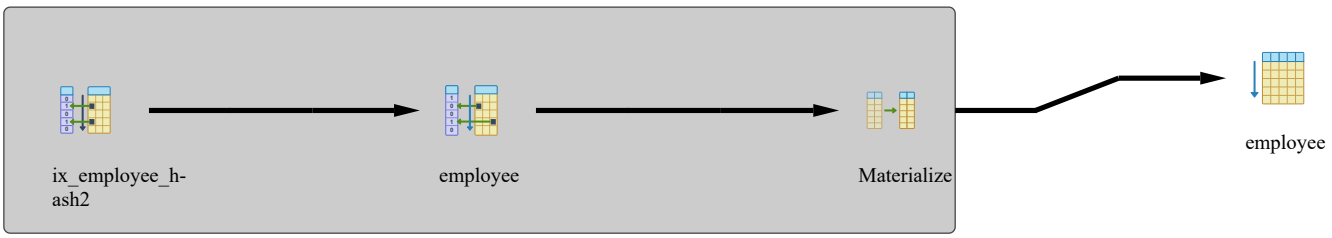
```
create index "ix_employee_btree" on "employee" using btree ("salary");
create index "ix_employee_btree2" on "employee" using btree ("dno") include ("salary") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.837ms	5.73ms	5.642ms	5.736ms	0.069ms	57263.28	2%	88%

With Hash indices

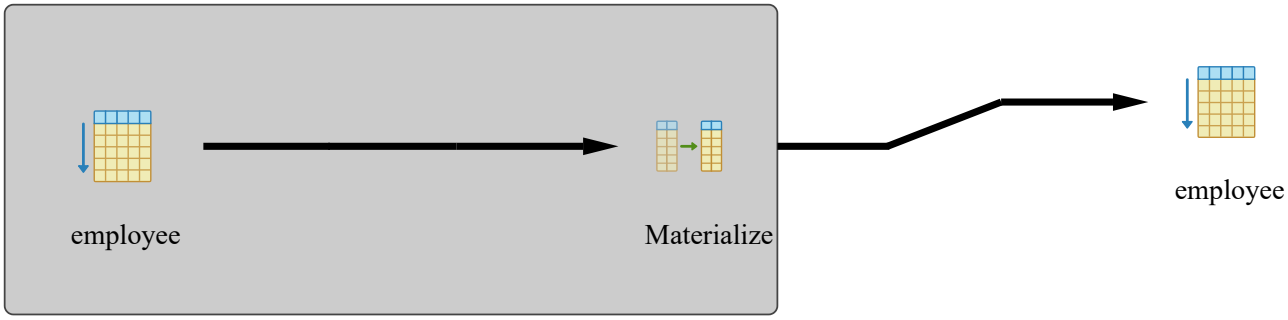
```
create index "ix_employee_hash" on "employee" using hash ("salary");
create index "ix_employee_hash2" on "employee" using hash ("dno");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.625ms	5.679ms	5.431ms	5.578ms	0.043ms	1750150.61	47%	85%

With BRIN indices

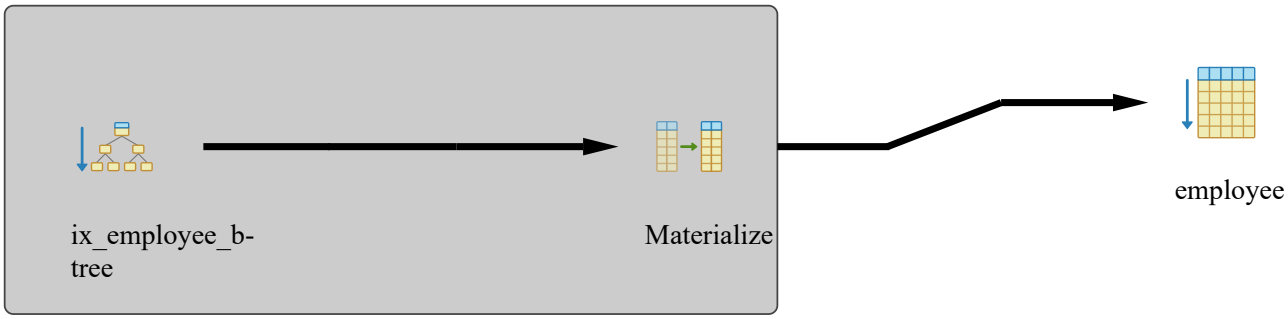
```
create index "ix_employee_brin" on "employee" using brin ("salary");
create index "ix_employee_brin2" on "employee" using brin ("dno");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
6.811ms	6.45ms	6.353ms	6.538ms	0.057ms	3711903	100%	100%

With Mixed indices

```
create index "ix_employee_brin" on "employee" using brin ("salary");
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.465ms	5.493ms	5.448ms	5.469ms	0.055ms	57263.28	2%	83%

Improved SQL

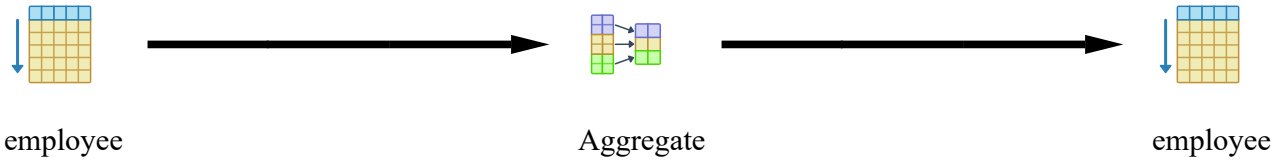
using `salary > (select max(salary))` instead of `salary > all` yielded a drastically lower cost and execution time since the query engine is comparing the salary with the maximum value instead of comparing with all values. The improvement is noticed with and without using indices.

We recommend creating B-Tree indices on `employee` table as indicated in the create index statements below.

```
select lname, fname
from employee
where salary > (
select max(salary)
from employee
where dno=5 )
```

Without Any Optimization

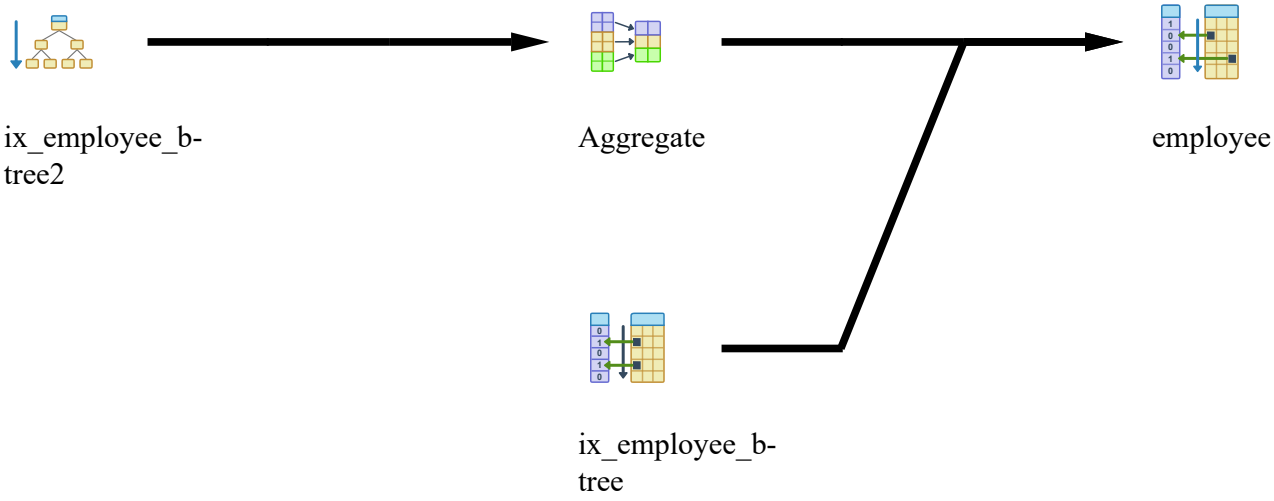
Query returns 124 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
1.973ms	1.99ms	1.858ms	1.94ms	0.078ms	926.32	0%	30%

With B-TREE indices

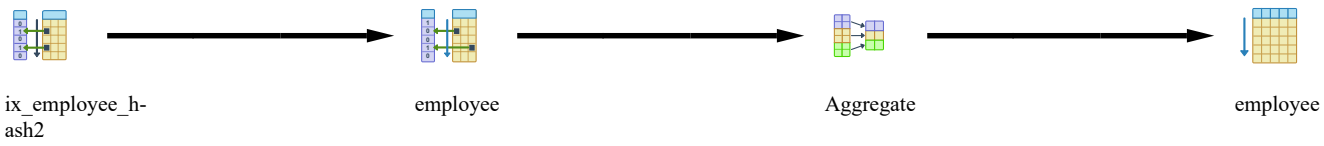
```
create index "ix_employee_btree" on "employee" using btree ("salary");
create index "ix_employee_btree2" on "employee" using btree ("dno") include ("salary") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.272ms	0.097ms	0.109ms	0.159ms	0.107ms	438.05	47%	8%	1%	3%

With Hash indices

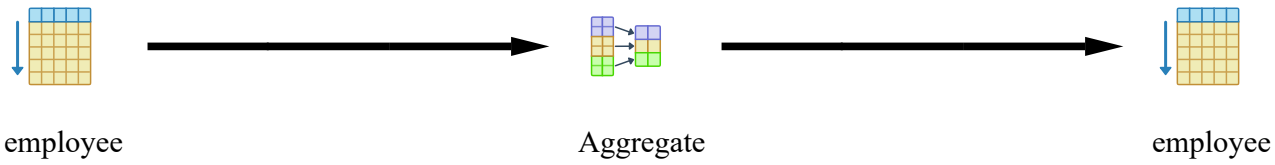
```
create index "ix_employee_hash" on "employee" using hash ("salary");
create index "ix_employee_hash2" on "employee" using hash ("dno");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
1.198ms	1.075ms	1.02ms	1.098ms	0.09ms	686.06	74%	57%	0%	20%

With BRIN indices

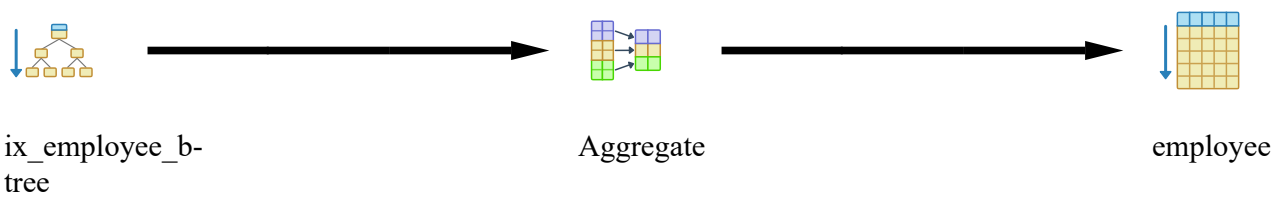
```
create index "ix_employee_brin" on "employee" using brin ("salary");
create index "ix_employee_brin2" on "employee" using brin ("dno");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
2.118ms	2.036ms	1.848ms	2.001ms	0.111ms	926.32	100%	103%	0%	31%

With Mixed indices

```
create index "ix_employee_brin" on "employee" using brin ("salary");
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
1.109ms	1.281ms	1.135ms	1.175ms	0.101ms	469.77	51%	61%	1%	21%

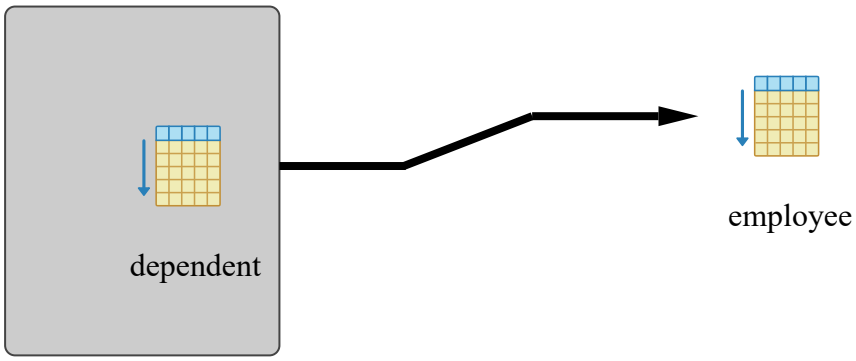
Query 4

Retrieve the name of each employee who has a dependent with the same first name and is the same sex as the employee.

```
select e.fname, e.lname
        from employee as e
        where e.ssn in (
        select essn
        from dependent as d
        where e.fname = d.dependent_name
        and
        e.sex = d.sex )
```

Without Any Optimization

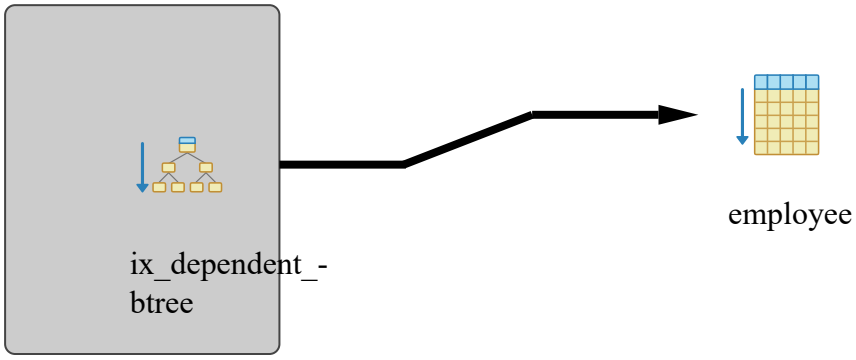
Query returns 307 records



Run 1	Run 2	Run 3	Average	Planning	Cost
656.699ms	657.073ms	664.529ms	659.434ms	0.072ms	148483

With B-TREE indices

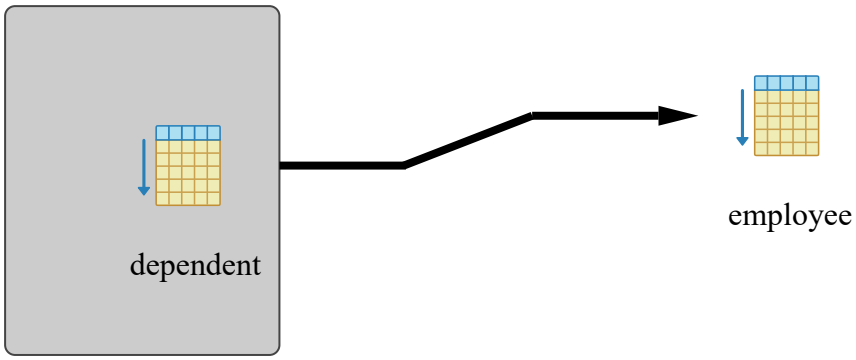
```
create index "ix_employee_btree" on "employee" using btree ("fname", "sex") include ("ssn") ;
create index "ix_dependent_btree" on "dependent" using btree ("dependent_name", "sex", "essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
39.03ms	38.726ms	38.333ms	38.696ms	0.085ms	69043	46%	6%

With Hash indices

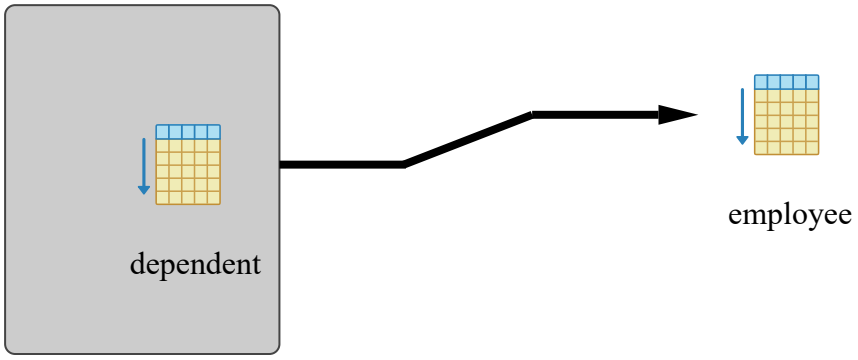
```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_hash" on "dependent" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
653.918ms	655.116ms	664.307ms	657.78ms	0.075ms	148483	100%	100%

With BRIN indices

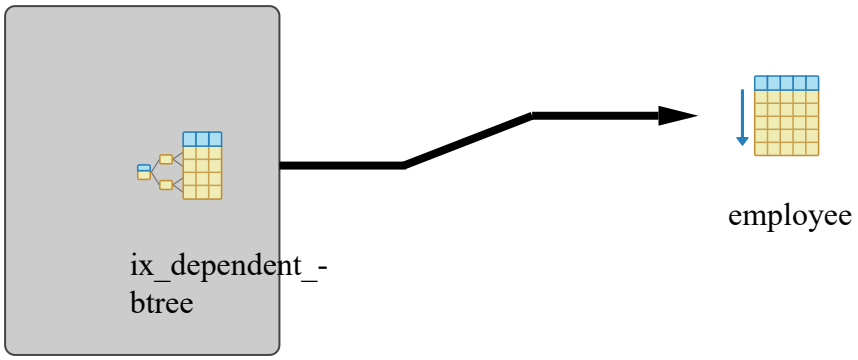
```
create index "ix_employee_brin" on "employee" using brin ("ssn");
create index "ix_dependent_brin" on "dependent" using brin ("dependent_name");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
666.562ms	664.994ms	656.225ms	662.594ms	0.091ms	148483	100%	100%

With Mixed indices

```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_btree" on "dependent" using btree ("dependent_name");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
37.198ms	37.211ms	37.086ms	37.165ms	0.108ms	69043	46%	6%

Improved SQL

The original query caused the Postgresql engine to scan the employee table as shown in query plan diagram above. When chaning the query to use `exists` keyword instead of `in`, the engine used another plan where it did a merge inner join and an index scan instead of a table scan on employee table. In both queries the dependent table is scanned, but using the index in the merge inner join resulted in a better performance.

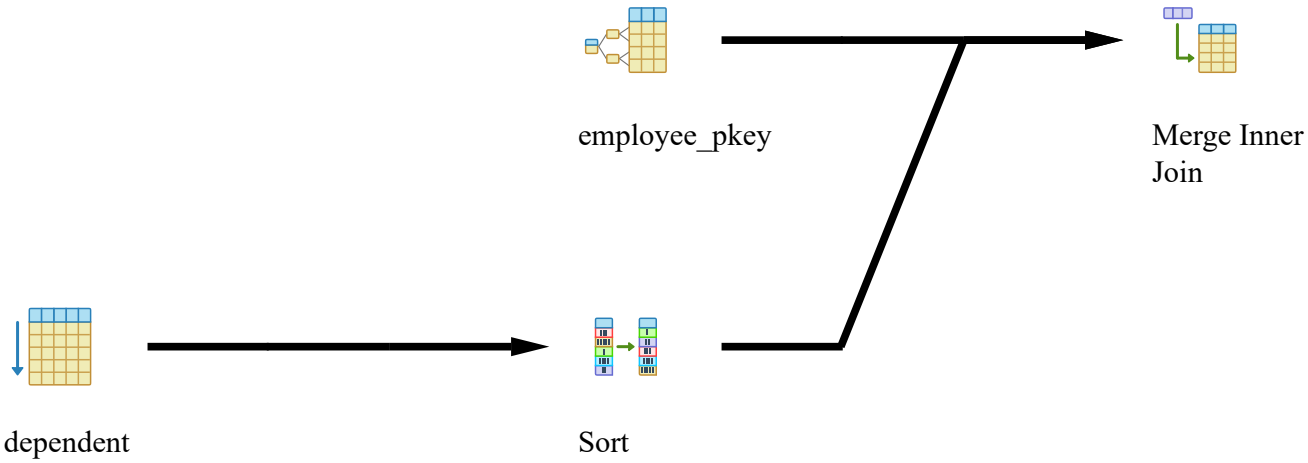
We recommend creating B-Tree indices on `dependent` and `employee` tables as indicated in the create index statements below.

```
select e.fname, e.lname
        from employee as e
        where EXISTS (
        select essn
        from dependent as d
```

```
        where e.fname = d.dependent_name
        and
        e.sex = d.sex and d.essn = e.ssn)
```

Without Any Optimization

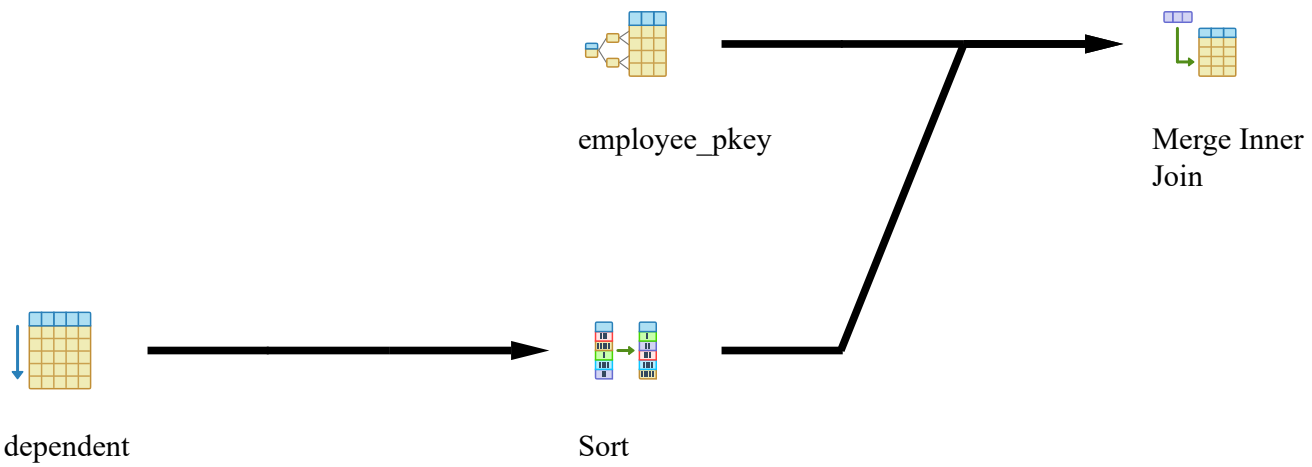
Query returns 307 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
0.376ms	0.397ms	0.544ms	0.439ms	0.175ms	94.3	0%	0%

With B-TREE indices

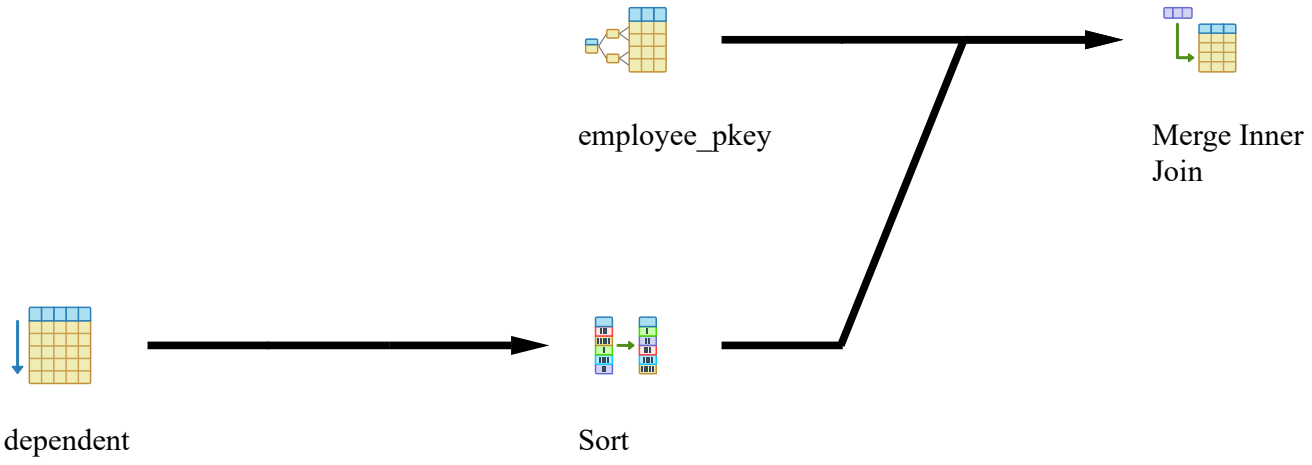
```
create index "ix_employee_btree" on "employee" using btree ("fname", "sex") include ("ssn") ;
create index "ix_dependent_btree" on "dependent" using btree ("dependent_name", "sex", "essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.403ms	0.352ms	0.454ms	0.403ms	0.2ms	94.3	100%	92%	0%	1%

With Hash indices

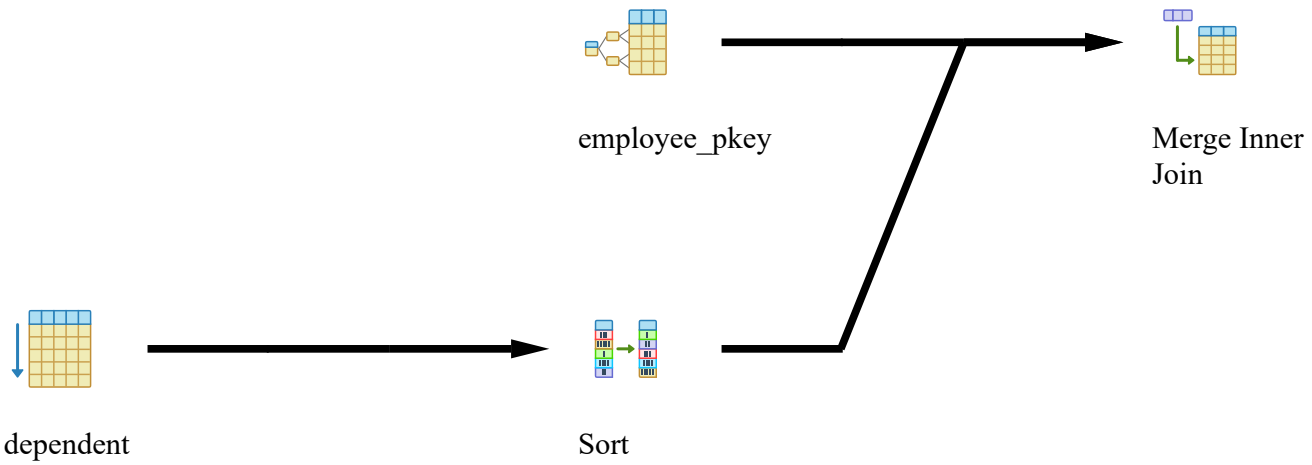
```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_hash" on "dependent" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.378ms	0.357ms	0.358ms	0.364ms	0.141ms	94.3	100%	83%	0%	0%

With BRIN indices

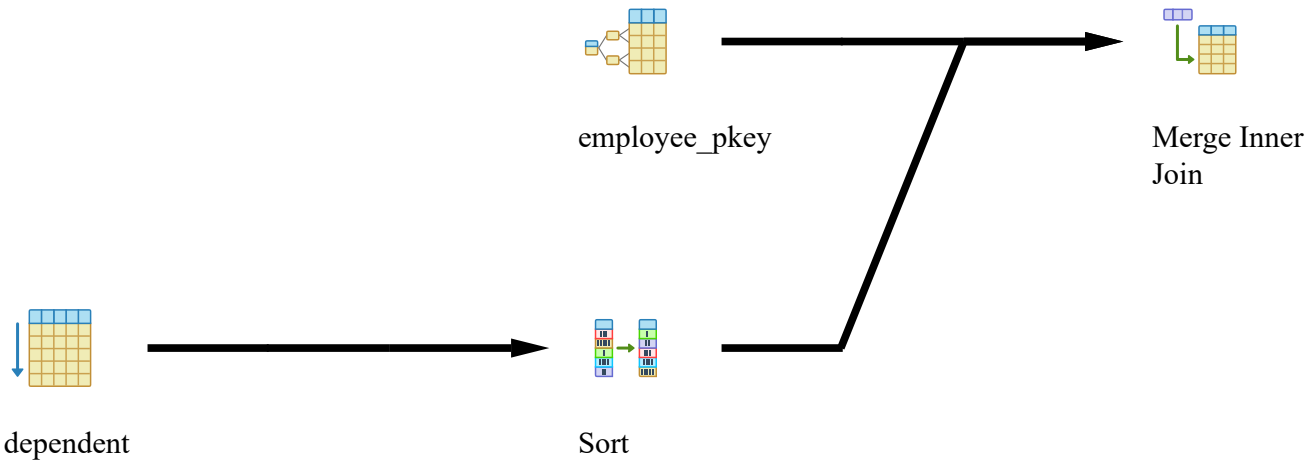
```
create index "ix_employee_brin" on "employee" using brin ("ssn");
create index "ix_dependent_brin" on "dependent" using brin ("dependent_name");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.383ms	0.386ms	0.366ms	0.378ms	0.162ms	94.3	100%	86%	0%	0%

With Mixed indices

```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_btree" on "dependent" using btree ("dependent_name");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.382ms	0.39ms	0.384ms	0.385ms	0.179ms	94.3	100%	88%	0%	1%

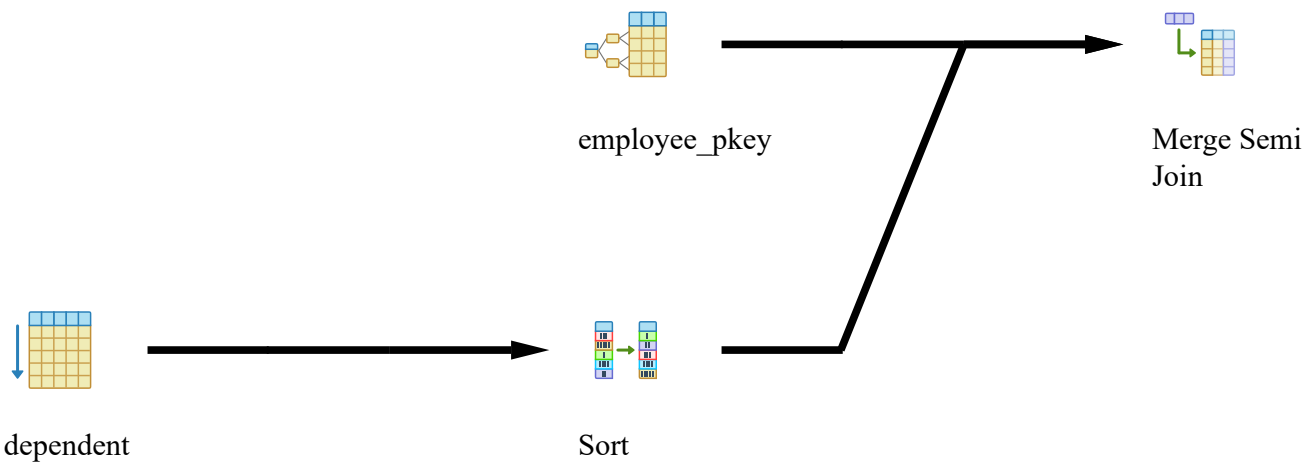
Query 5

Retrieve the names of employees who have dependents.

```
select fname, lname
        from employee
        where exists ( select *
         from dependent
         where ssn=essn )
```

Without Any Optimization

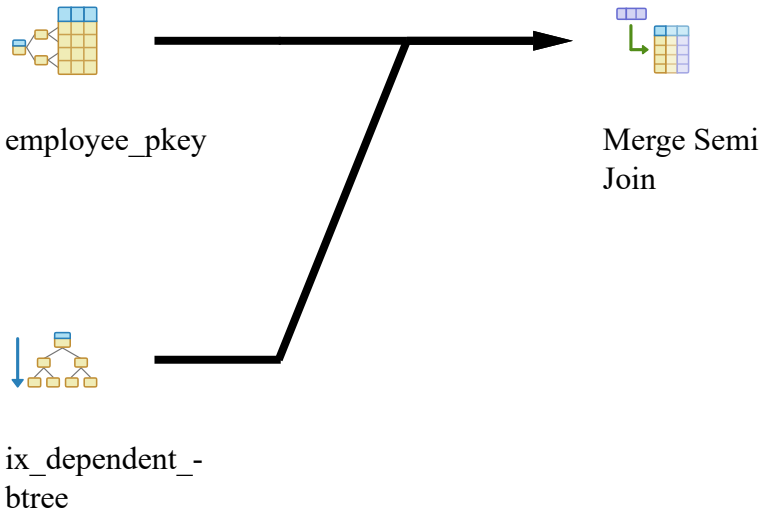
Query returns 700 records



Run 1	Run 2	Run 3	Average	Planning	Cost
0.351ms	0.283ms	0.28ms	0.305ms	0.083ms	90.8

With B-TREE indices

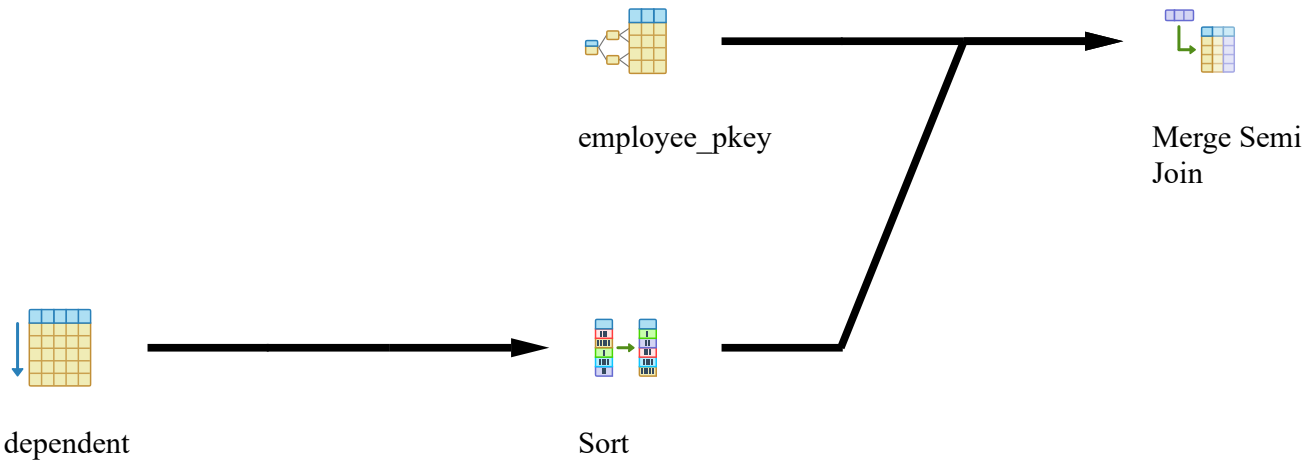
```
create index "ix_employee_btree" on "employee" using btree ("ssn") include ("fname", "lname");
create index "ix_dependent_btree" on "dependent" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.268ms	0.379ms	0.245ms	0.297ms	0.114ms	78.75	87%	97%

With Hash indices

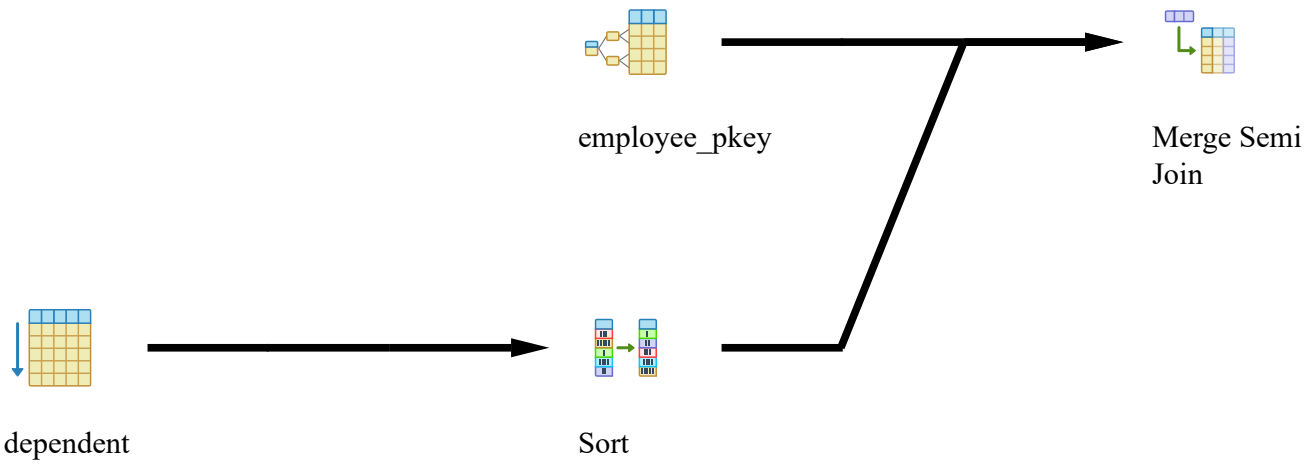
```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_hash" on "dependent" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.3ms	0.308ms	0.284ms	0.297ms	0.1ms	90.8	100%	97%

With BRIN indices

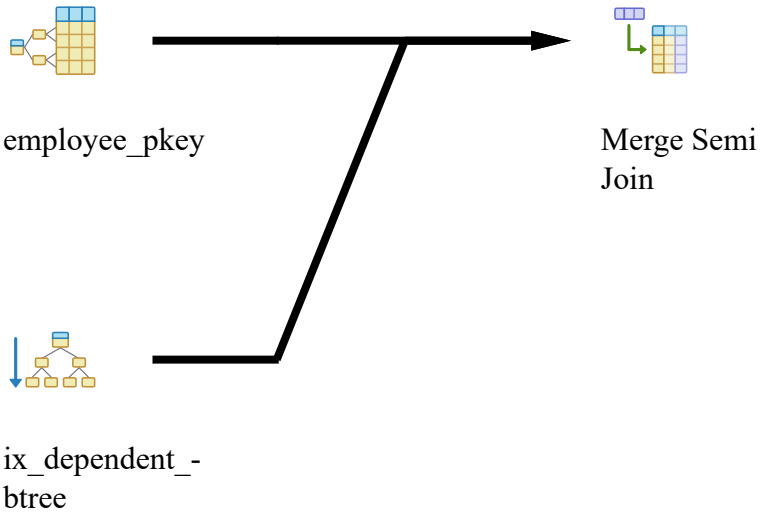
```
create index "ix_employee_brin" on "employee" using brin ("ssn");
create index "ix_dependent_brin" on "dependent" using brin ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.446ms	0.41ms	0.3ms	0.385ms	0.137ms	90.8	100%	126%

With Mixed indices

```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_btree" on "dependent" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes

Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.314ms	0.261ms	0.24ms	0.272ms	0.105ms	78.75	87%	89%

Improved SQL

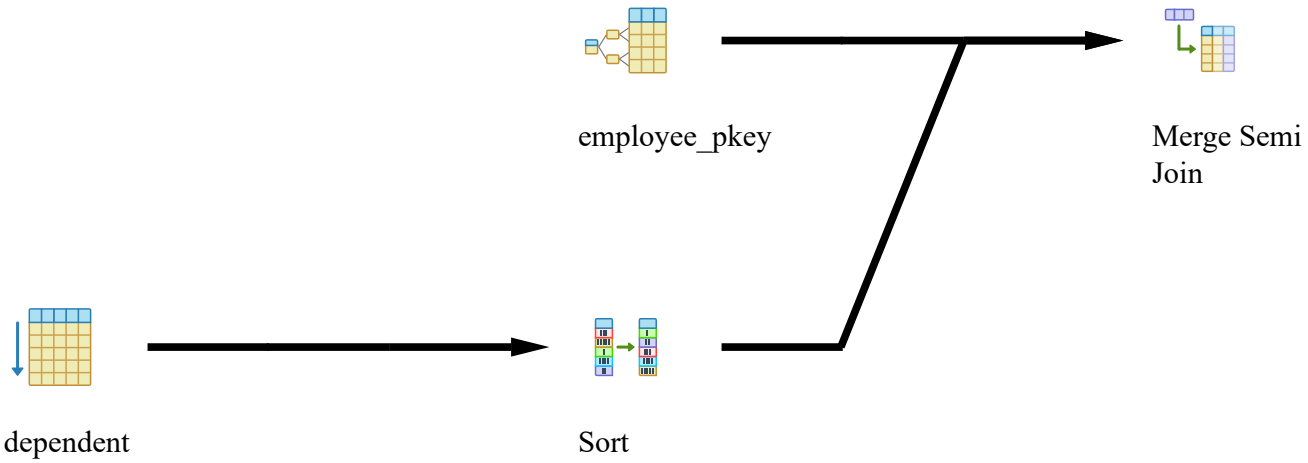
We couldn't improve this query. Here the data returned from dependents is not filtered unlike query 4. So the engine used merge semi join in both the cases here because merge joins are preferred when the data on both sides of the join is large. Therefore in query 5 changing between `in' and` exists` keywords had no effect while in query 4 it had.

We recommend creating B-Tree indices on `dependent` and `employee` tables as indicated in the create index statements below.

```
select fname, lname
        from employee
        where ssn in ( select essn
         from dependent
         )
```

Without Any Optimization

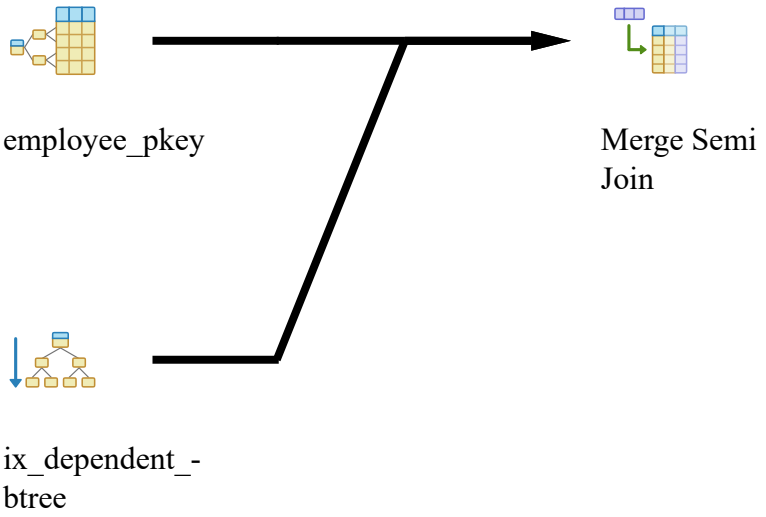
Query returns 700 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
0.385ms	0.287ms	0.296ms	0.323ms	0.11ms	90.8	100%	106%

With B-TREE indices

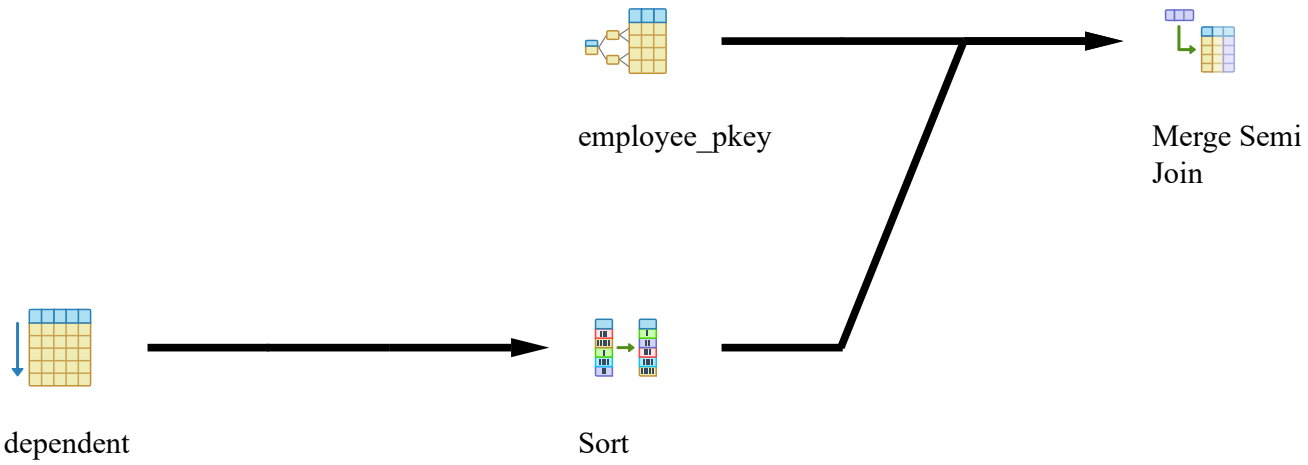
```
create index "ix_employee_btree" on "employee" using btree ("ssn") include ("fname", "lname");
create index "ix_dependent_btree" on "dependent" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.386ms	0.253ms	0.244ms	0.294ms	0.128ms	78.75	87%	91%	100%	99%

With Hash indices

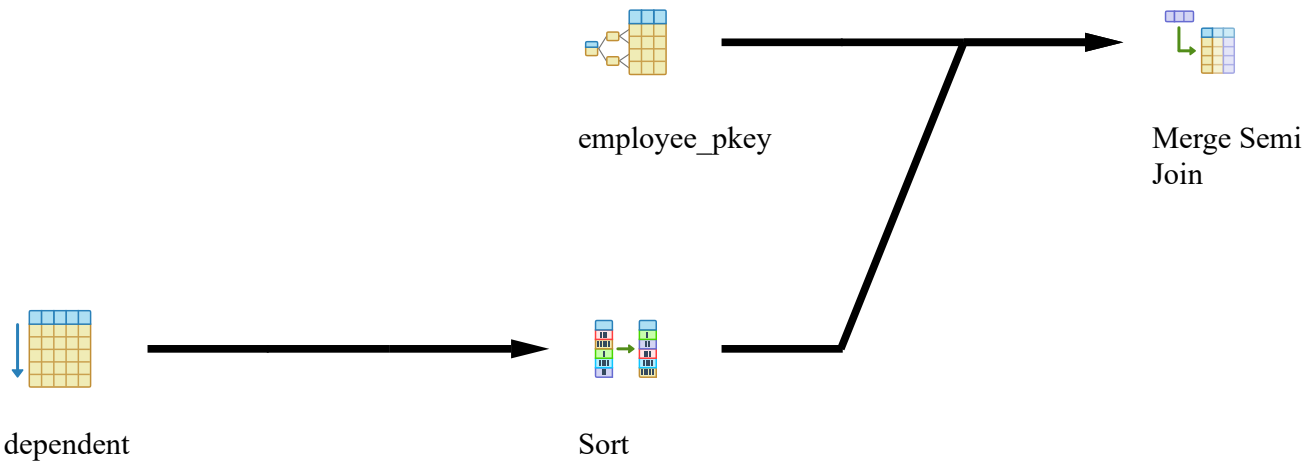
```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_hash" on "dependent" using hash ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.324ms	0.306ms	0.279ms	0.303ms	0.103ms	90.8	100%	94%	100%	102%

With BRIN indices

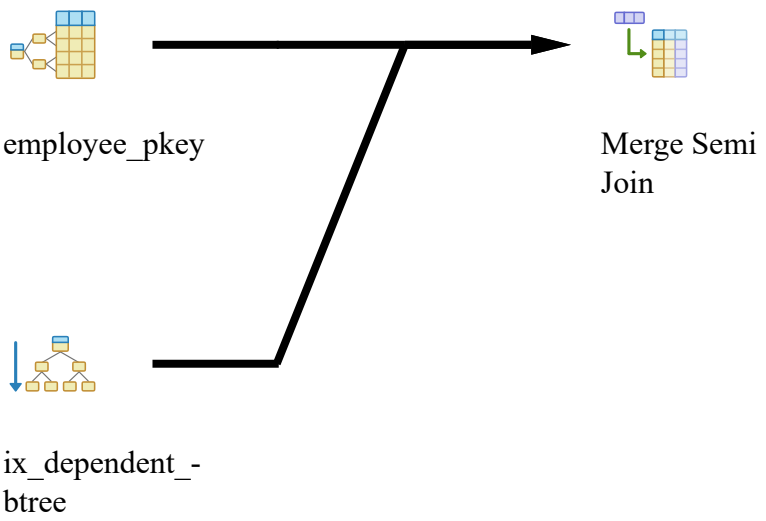
```
create index "ix_employee_brin" on "employee" using brin ("ssn");
create index "ix_dependent_brin" on "dependent" using brin ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.308ms	0.448ms	0.282ms	0.346ms	0.115ms	90.8	100%	107%	100%	90%

With Mixed indices

```
create index "ix_employee_hash" on "employee" using hash ("ssn");
create index "ix_dependent_btree" on "dependent" using btree ("essn");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.268ms	0.246ms	0.24ms	0.251ms	0.098ms	78.75	87%	78%	100%	92%

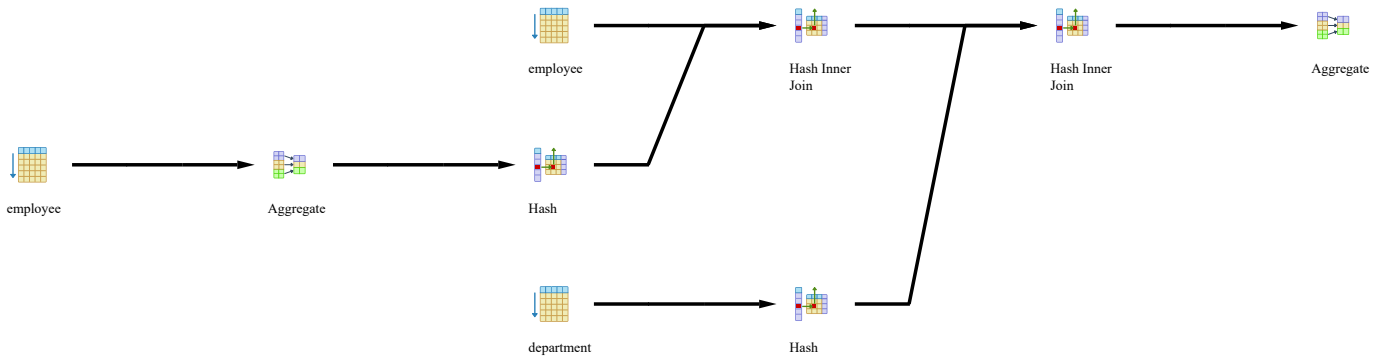
Query 6

For each department that has more than five employees, retrieve the department number and the number of its employees who are making more than $40,000.

```
select dnumber, count(*)
        from department, employee
        where dnumber=dno
        and
        salary > 40000
        and
        dno in (
         select dno
         from employee
         group by dno
         having count (*) > 5)
        group by dnumber
```

Without Any Optimization

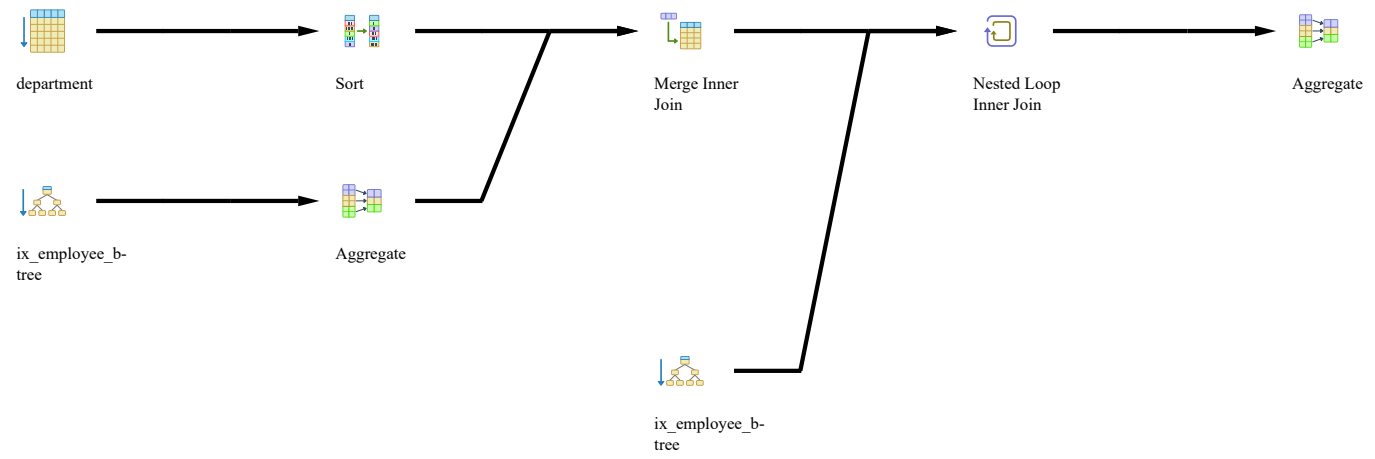
Query returns 150 records



Run 1	Run 2	Run 3	Average	Planning	Cost
6.17ms	5.867ms	6.06ms	6.032ms	0.197ms	1009.39

With B-TREE indices

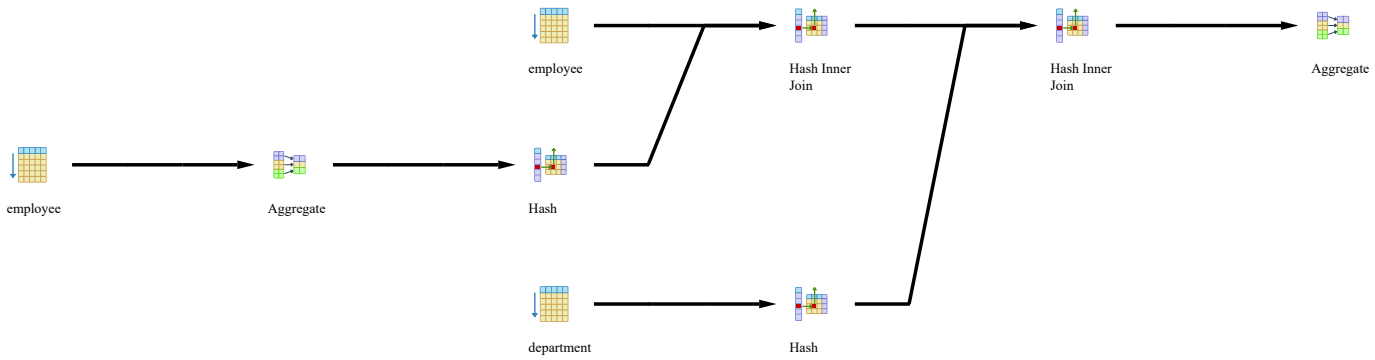
```
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary");
create index "ix_department_btree" on "department" using btree ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
3.78ms	3.205ms	3.512ms	3.499ms	0.27ms	732.65	73%	58%

With Hash indices

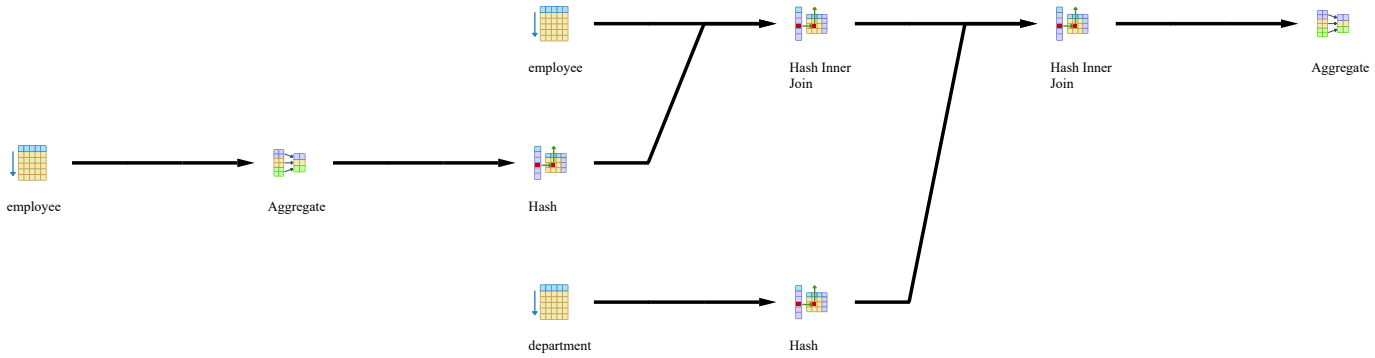
```
create index "ix_employee_hash" on "employee" using hash ("dno");
create index "ix_department_hash" on "department" using hash ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.766ms	5.59ms	5.414ms	5.59ms	0.224ms	1009.39	100%	93%

With BRIN indices

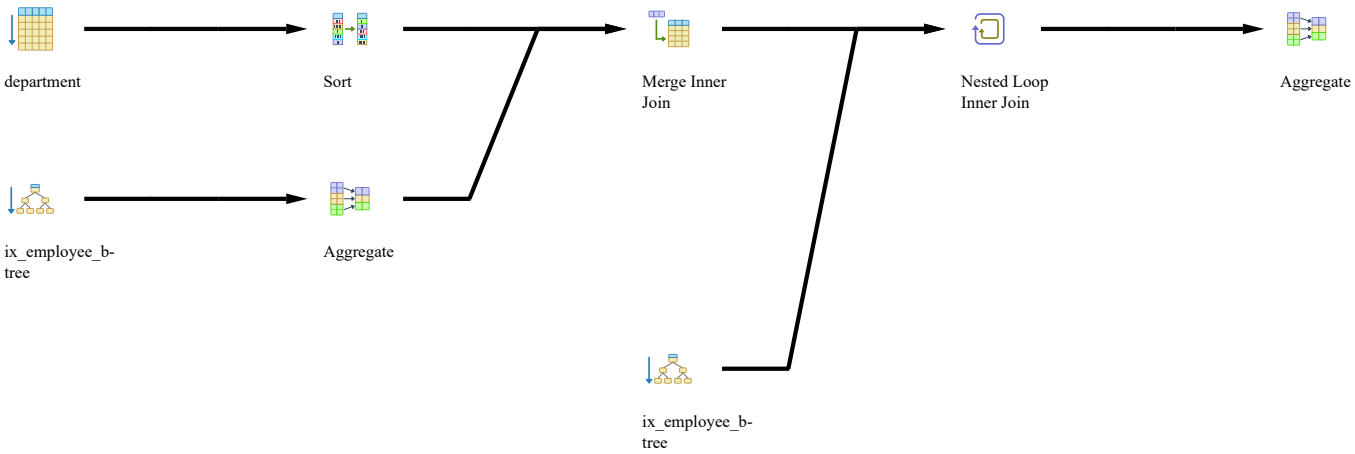
```
create index "ix_employee_brin" on "employee" using brin ("dno");
create index "ix_department_brin" on "department" using brin ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.867ms	5.446ms	5.706ms	5.673ms	0.234ms	1009.39	100%	94%

With Mixed indices

```
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary");
create index "ix_department_hash" on "department" using hash ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
3.551ms	3.207ms	3.19ms	3.316ms	0.237ms	732.65	73%	55%

Improved SQL

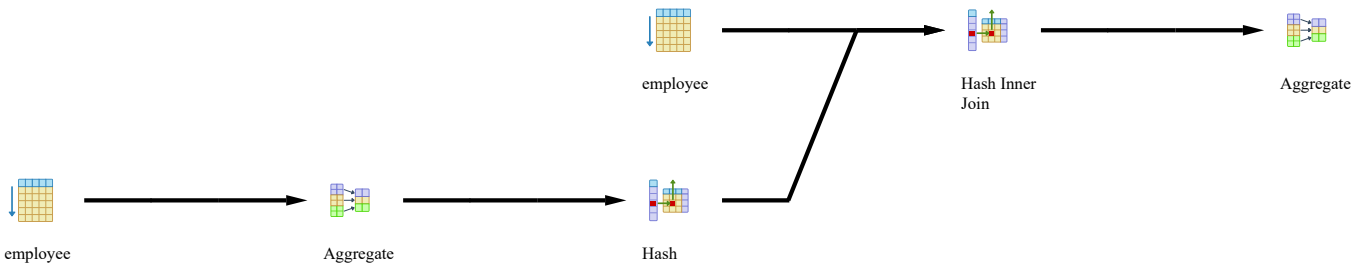
The original query used the `dnumber` column from `department` table and no other columns. Since that column is already in the `employee` table, there is no need to include `department` table in the query. The improved query had a slightly lower cost because of that.

We recommend creating B-Tree indices on `department` and `employee` tables as indicated in the create index statements below.

```
select dno, count(*)
    from employee
    where salary > 40000 and dno in (
        select dno
        from employee
        group by dno
        having count (*) > 5)
    group by dno
```

Without Any Optimization

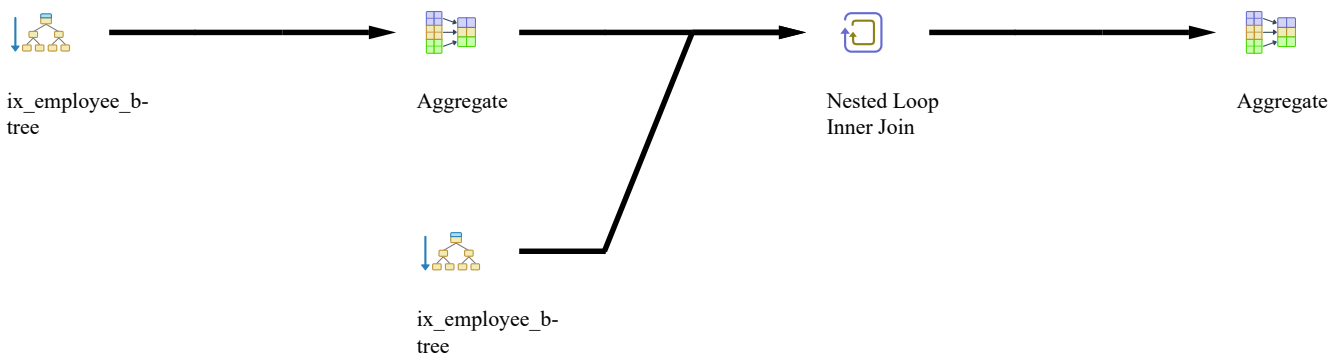
Query returns 150 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
5.067ms	5.047ms	4.876ms	4.997ms	0.082ms	998.29	99%	83%

With B-TREE indices

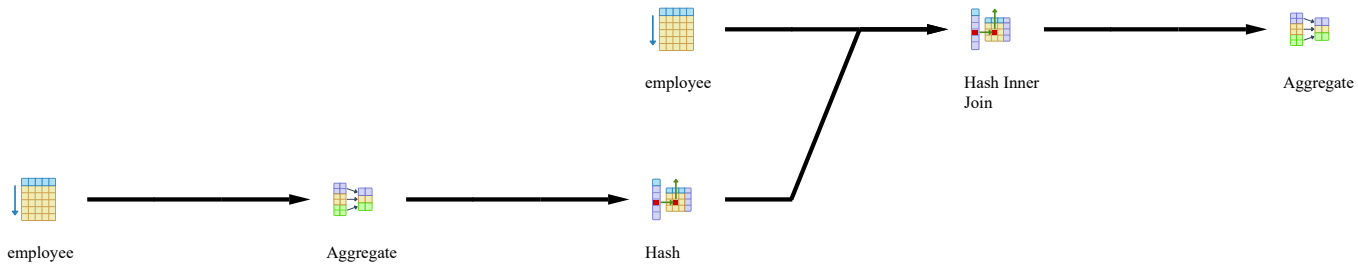
```
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary");
create index "ix_department_btree" on "department" using btree ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
3.364ms	3.122ms	3.102ms	3.196ms	0.106ms	793.02	79%	64%	108%	91%

With Hash indices

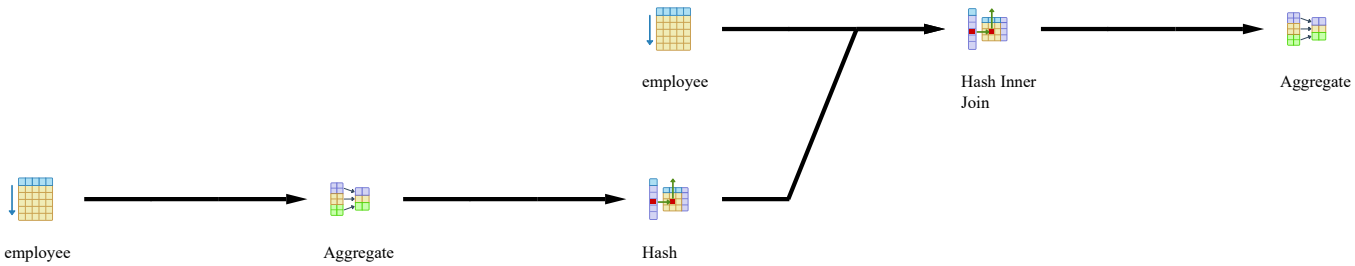
```
create index "ix_employee_hash" on "employee" using hash ("dno");
create index "ix_department_hash" on "department" using hash ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
4.987ms	5.01ms	4.883ms	4.96ms	0.106ms	998.29	100%	99%	99%	89%

With BRIN indices

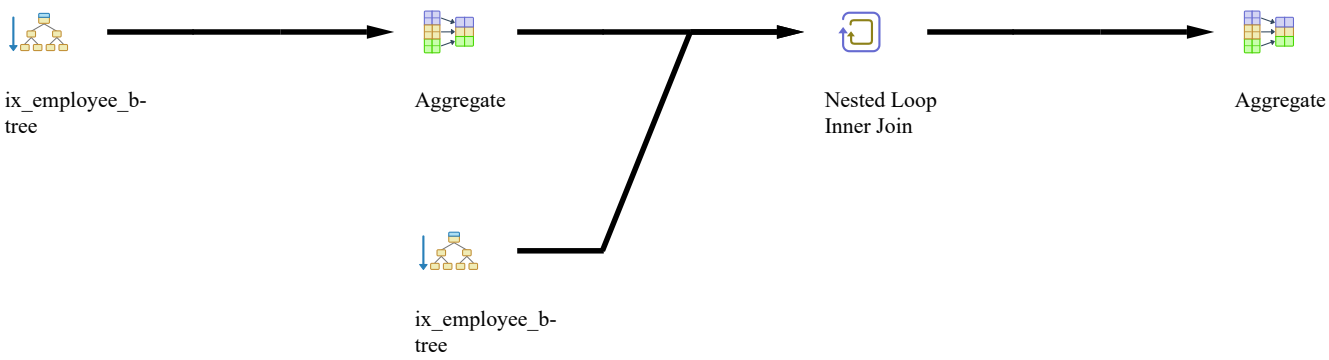
```
create index "ix_employee_brin" on "employee" using brin ("dno");
create index "ix_department_brin" on "department" using brin ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
5.087ms	5.372ms	4.836ms	5.098ms	0.101ms	998.29	100%	102%	99%	90%

With Mixed indices

```
create index "ix_employee_btree" on "employee" using btree ("dno") include ("salary");
create index "ix_department_hash" on "department" using hash ("dnumber");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
3.291ms	3.122ms	3.311ms	3.241ms	0.111ms	793.02	79%	65%	108%	98%

Schema 3

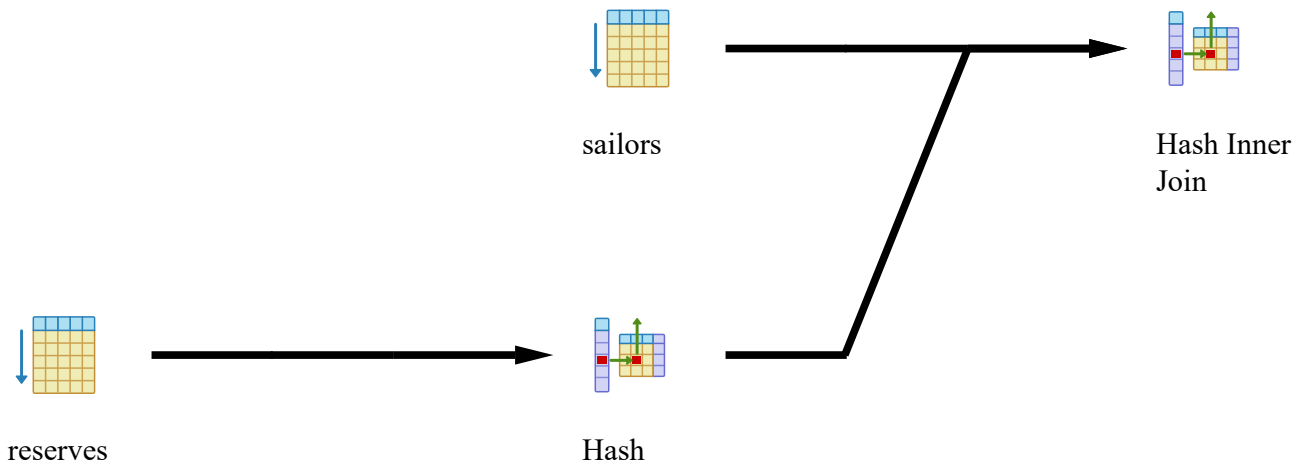
Query 7

Find the names of sailors who have reserved boat 103.

```
select s.sname
        from sailors s
        where
        s.sid in (select r.sid
        from reserves r
        where r.bid = 103)
```

Without Any Optimization

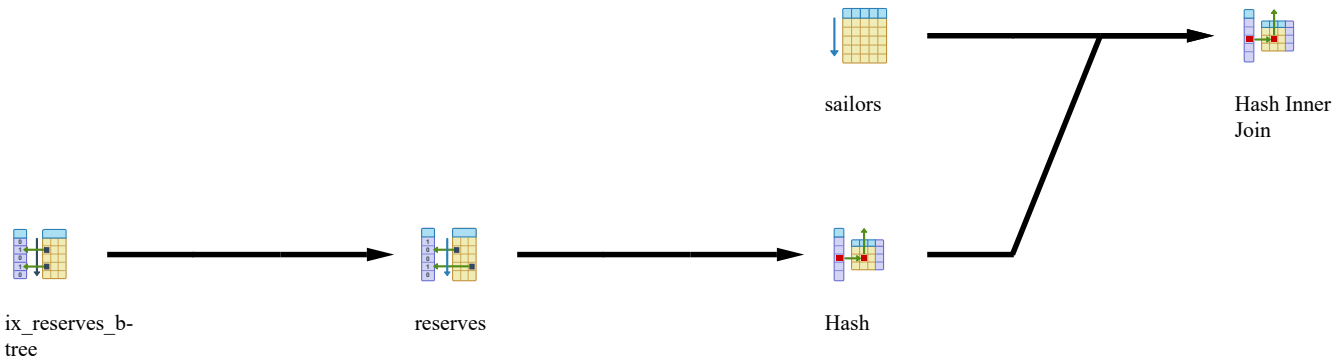
Query returns 705 records



Run 1	Run 2	Run 3	Average	Planning	Cost
4.894ms	3.003ms	2.999ms	3.632ms	0.133ms	1035.12

With B-TREE indices

```
create index "ix_sailors_btree" on "sailors" using btree ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
2.196ms	2.073ms	2.076ms	2.115ms	0.195ms	615.84	59%	58%

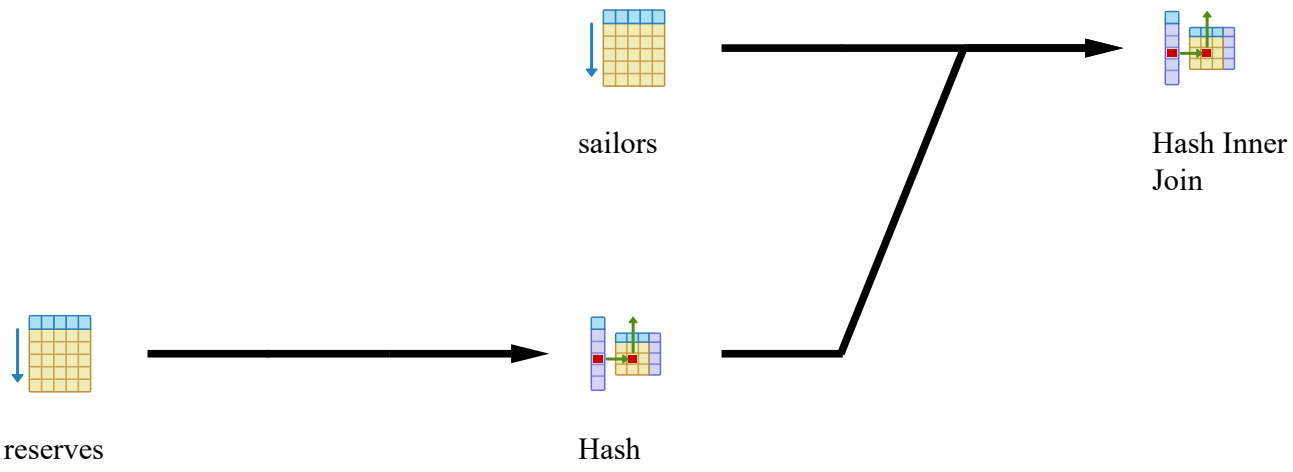
With Hash indices

```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
```

Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
2.235ms	2.021ms	1.891ms	2.049ms	0.136ms	623.42	60%	56%

With BRIN indices

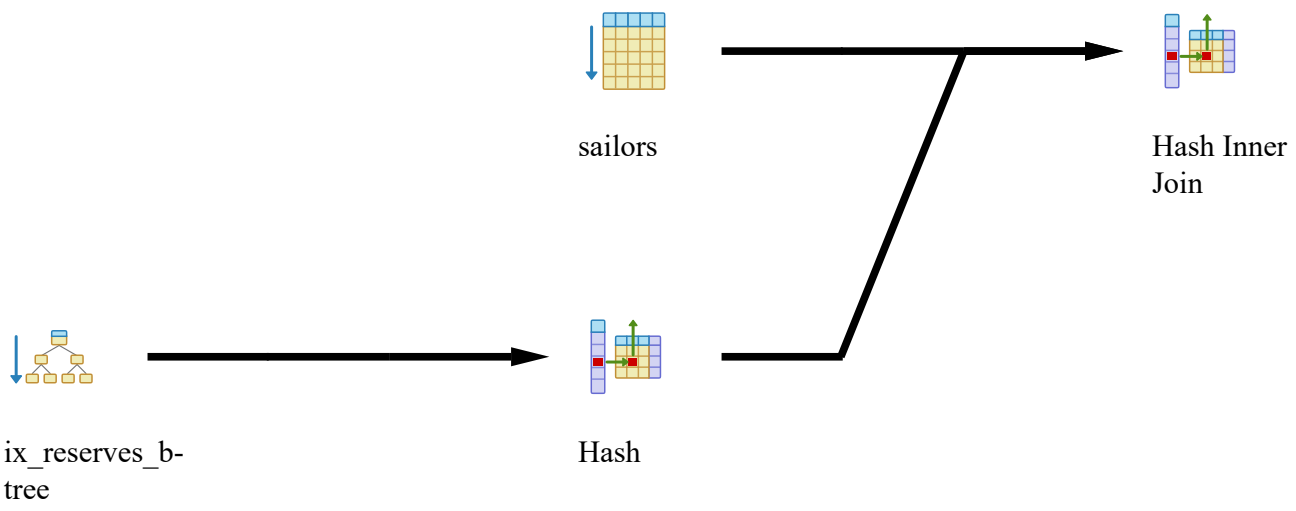
```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
3.347ms	3.534ms	3.105ms	3.329ms	0.147ms	1035.24	100%	92%

With Mixed indices

```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
2.068ms	1.967ms	1.933ms	1.989ms	0.192ms	428.39	41%	55%

Improved SQL

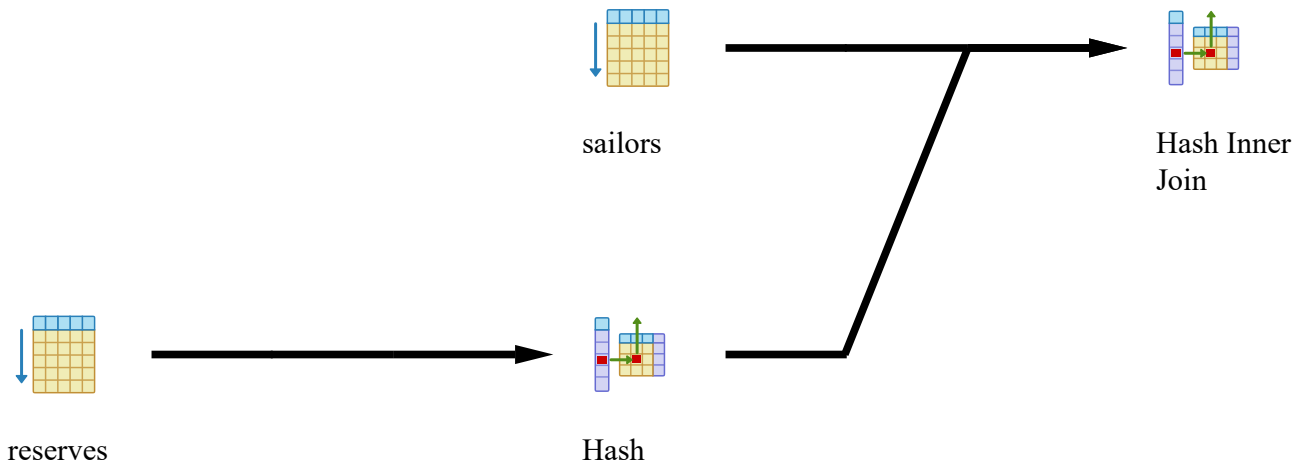
We couldn't optimize this query in terms of performance, but the inner join may be more readable. It's worth noting that inner join in this query doesn't affect the result vs using `in` keyword because the `reserves` table has a primary key on `bid` and `sid` .

We recommend creating B-Tree indices on `sailors` and `reserves` tables as indicated in the create index statements below.

```
select s.sname
    from sailors s
    inner join reserves r on r.sid = s.sid where r.bid = 103
```

Without Any Optimization

Query returns 705 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
3.383ms	3.057ms	3.044ms	3.161ms	0.131ms	1035.12	100%	87%

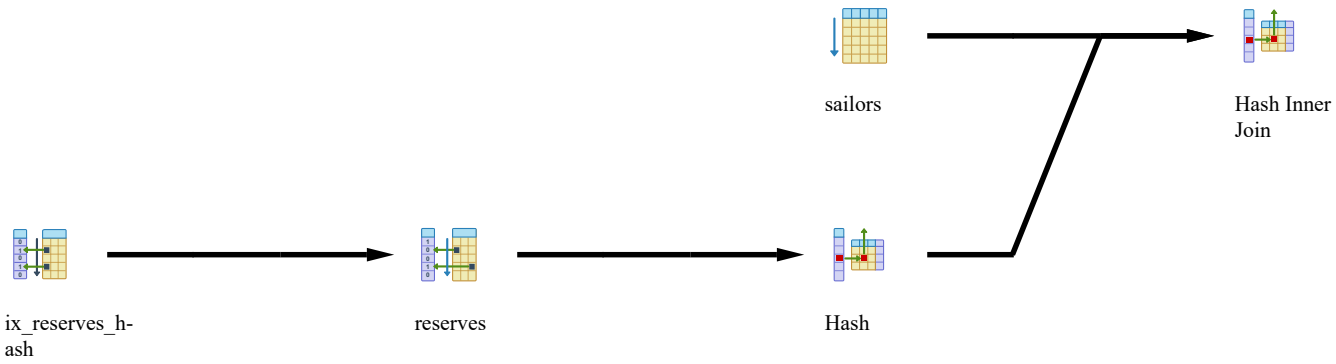
With B-TREE indices

```
create index "ix_sailors_btree" on "sailors" using btree ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid");
```

Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
2.692ms	2.128ms	1.97ms	2.263ms	0.173ms	616.2	60%	72%	100%	107%

With Hash indices

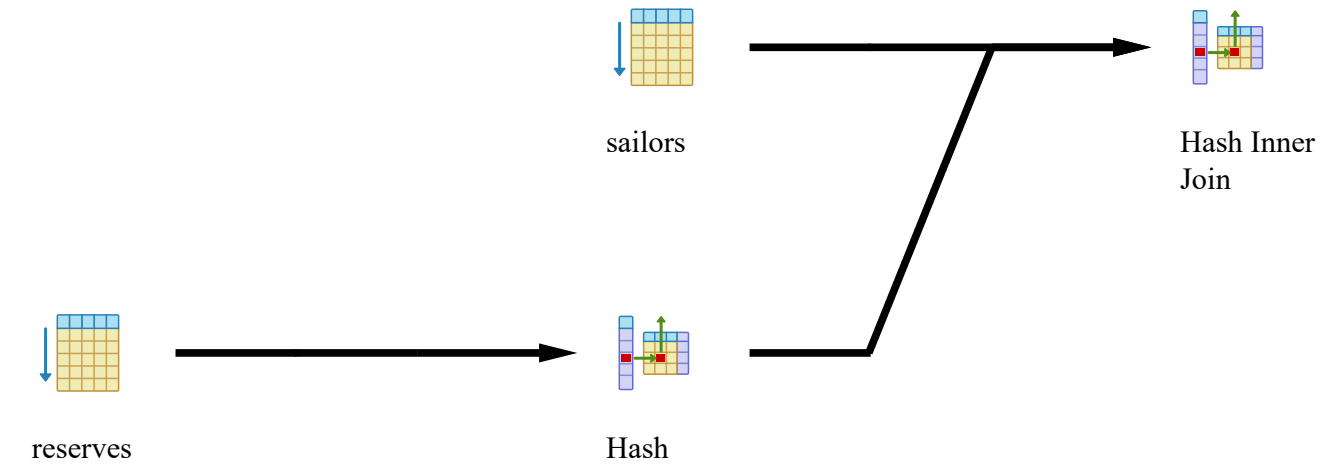
```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
2.332ms	2.169ms	1.885ms	2.129ms	0.118ms	624.83	60%	67%	100%	104%

With BRIN indices

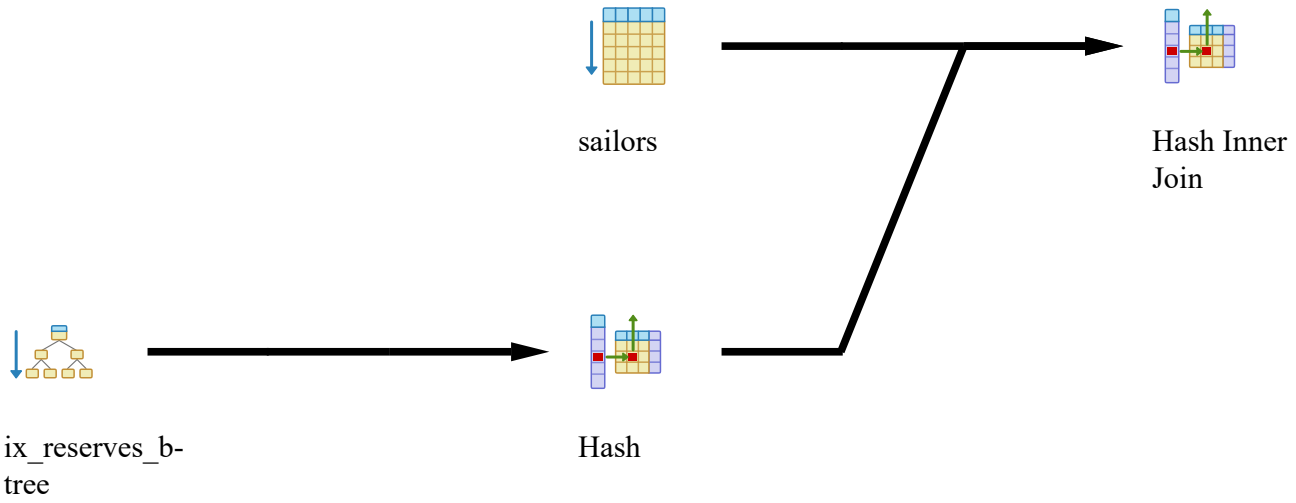
```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
3.541ms	3.086ms	3.292ms	3.306ms	0.168ms	1035.3	100%	105%	100%	99%

With Mixed indices

```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
2.179ms	1.98ms	1.93ms	2.03ms	0.169ms	428.15	41%	64%	100%	102%

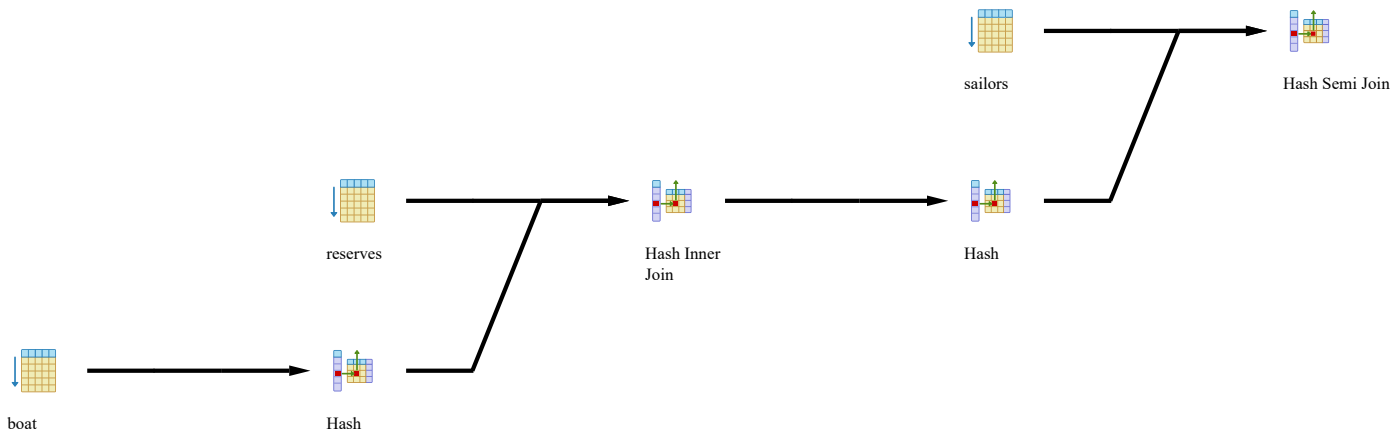
Query 8

Find the names of sailors who have reserved a red boat.

```
select s.sname
    from sailors s
            where s.sid in ( select r.sid
            from reserves r
            where r. bid in (select b.bid
                from boat b
                where b.color = 'red'));
```

Without Any Optimization

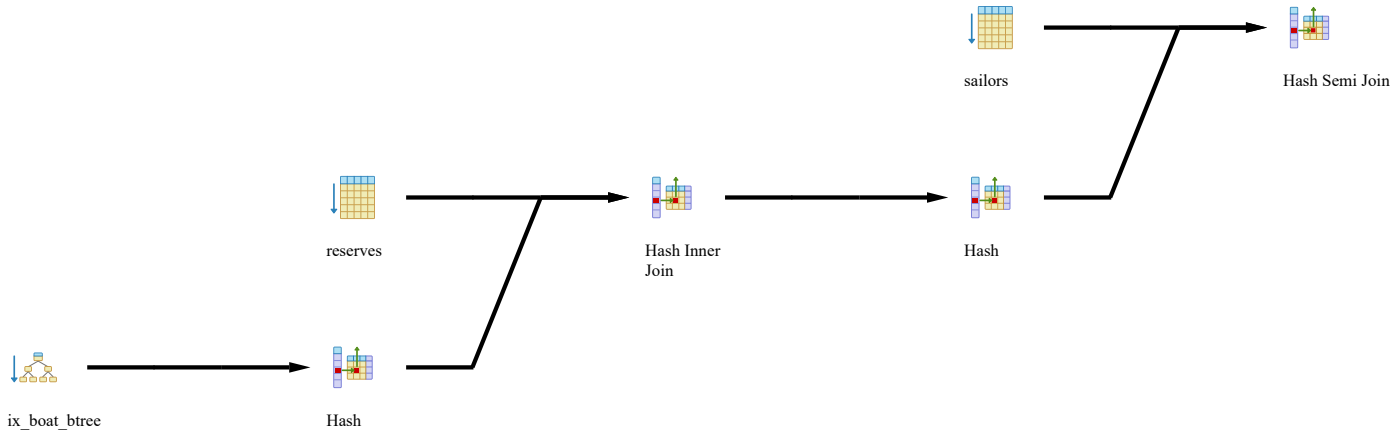
Query returns 3093 records



Run 1	Run 2	Run 3	Average	Planning	Cost
5.864ms	5.956ms	6.262ms	6.027ms	0.221ms	1192.95

With B-TREE indices

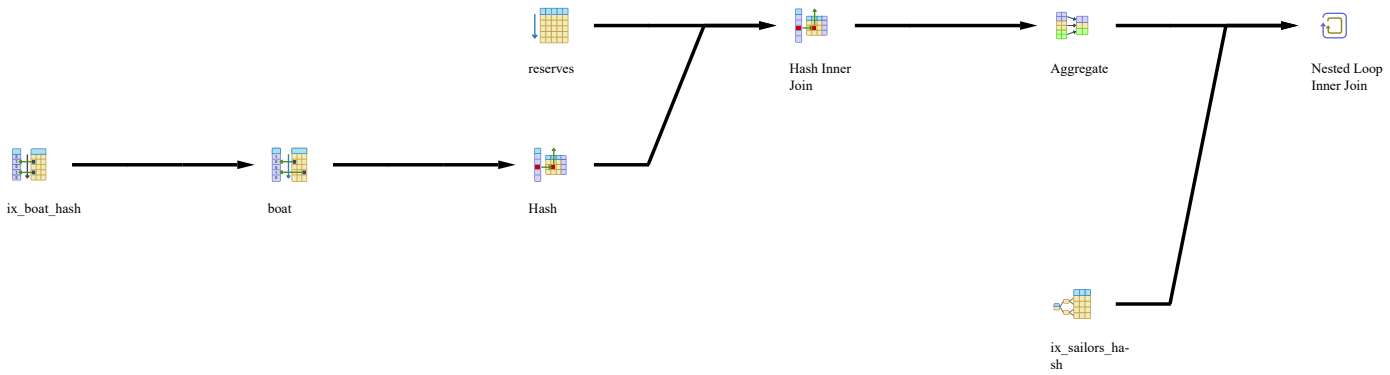
```
create index "ix_sailors_btree" on "sailors" using btree ("sid") include ("sname") ;
create index "ix_reserves_btree" on "reserves" using btree ("sid") include ("bid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.511ms	6.112ms	5.859ms	5.827ms	0.236ms	1143.98	96%	97%

With Hash indices

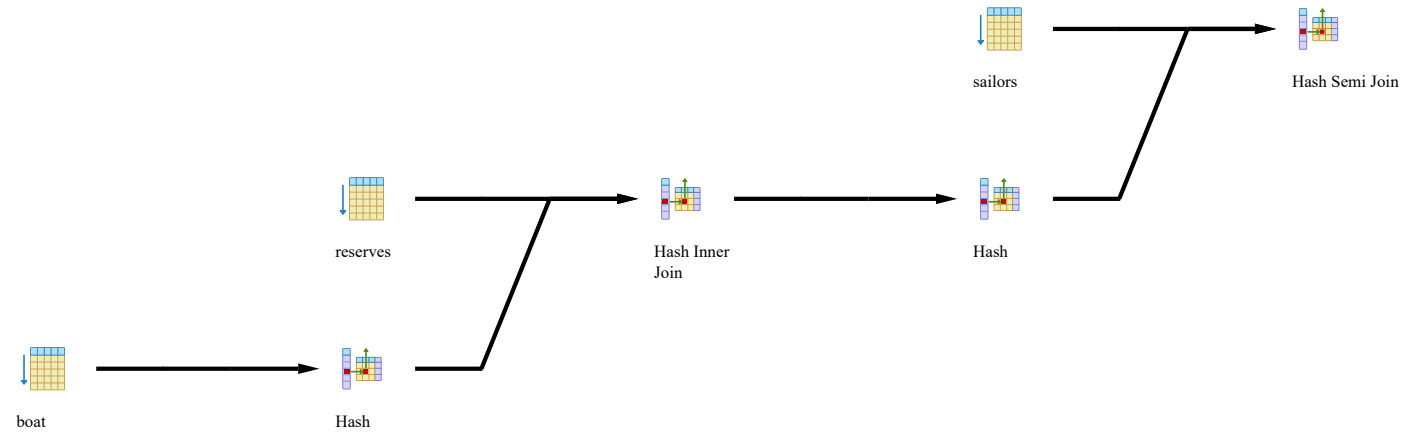
```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_hash" on "boat" using hash ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
7.137ms	6.372ms	5.974ms	6.494ms	0.26ms	951.94	80%	108%

With BRIN indices

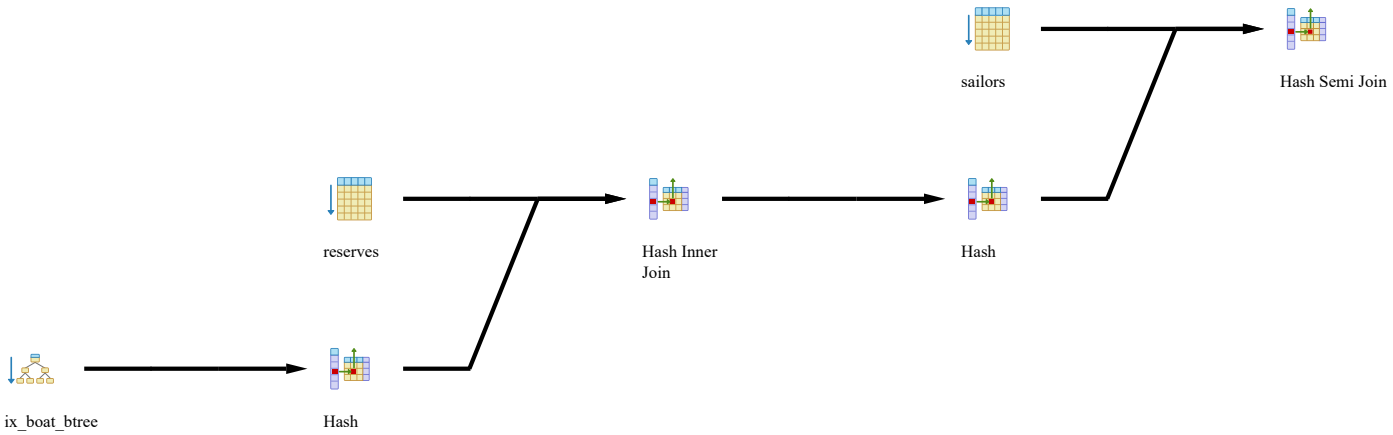
```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
create index "ix_boat_brin" on "boat" using brin ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
6.828ms	6.155ms	5.782ms	6.255ms	0.196ms	1192.95	100%	104%

With Mixed indices

```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.877ms	5.992ms	5.491ms	5.787ms	0.269ms	1143.98	96%	96%

Improved SQL

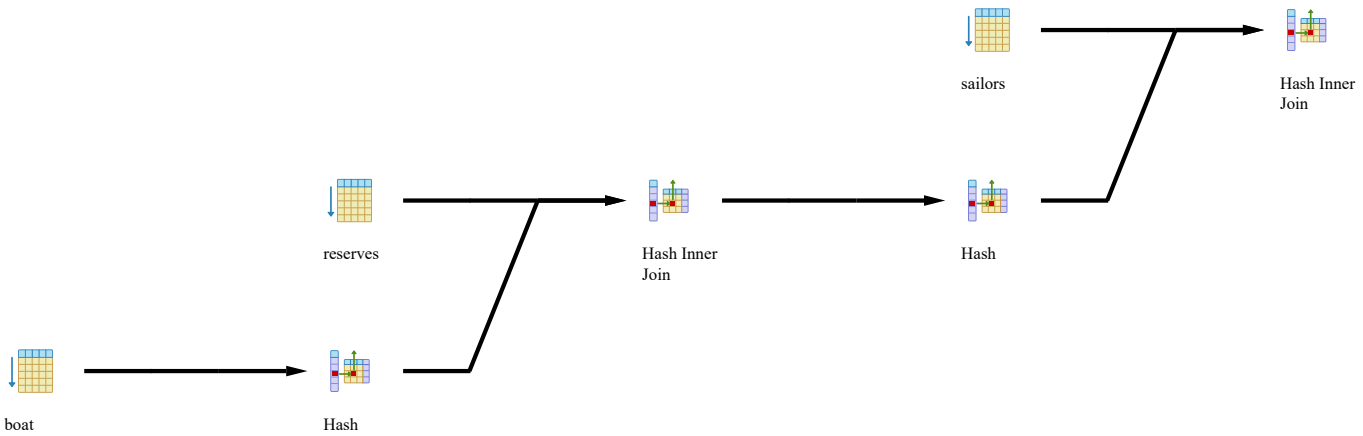
We could not find a query with better performance, but the improved query has better readablity because it has less nested queries.

We recommend creating B-Tree indices on `boat`, `sailors` and `reserves` tables as indicated in the create index statements below.

```
select s.sname from sailors s
    inner join reserves r on r.sid = s.sid
    inner join boat b on r.bid = b.bid
    where b.color = 'red'
```

Without Any Optimization

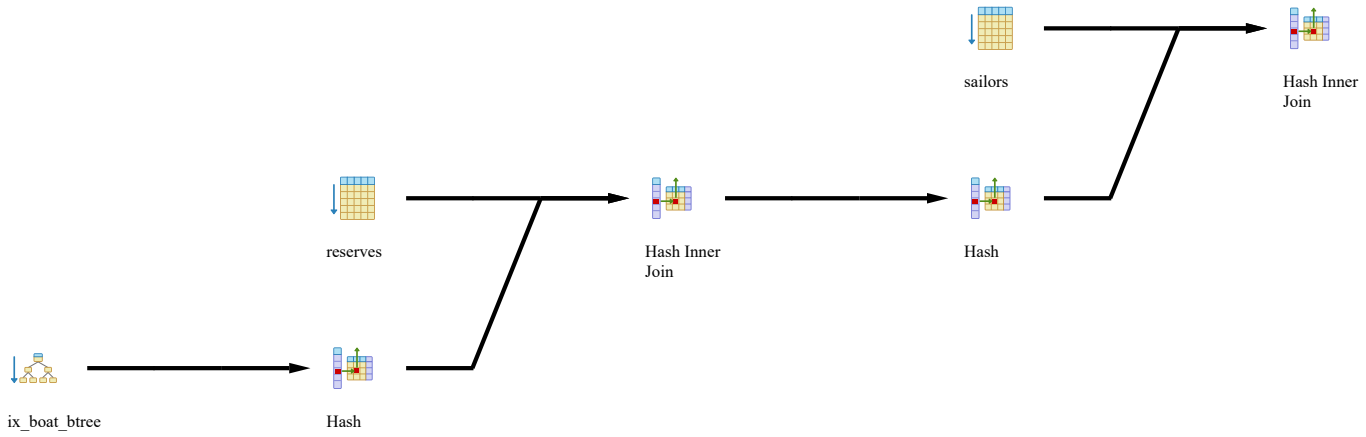
Query returns 3377 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
6.321ms	5.578ms	6.441ms	6.113ms	0.279ms	1268.51	106%	101%

With B-TREE indices

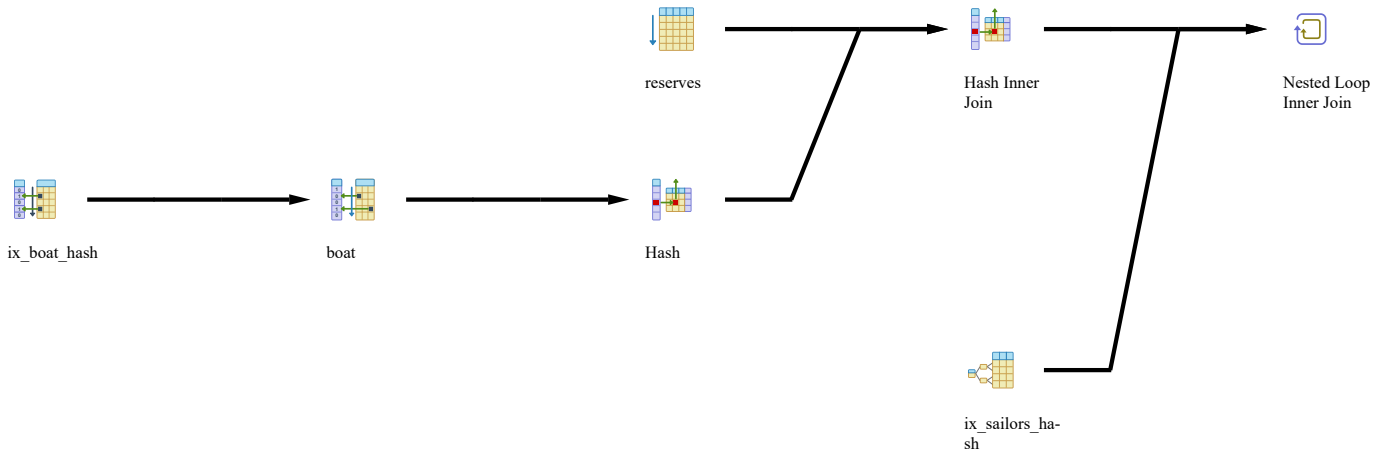
```
create index "ix_sailors_btree" on "sailors" using btree ("sid") include ("sname") ;
create index "ix_reserves_btree" on "reserves" using btree ("sid") include ("bid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
6.146ms	6.117ms	6.768ms	6.344ms	0.324ms	1219.54	96%	104%	107%	109%

With Hash indices

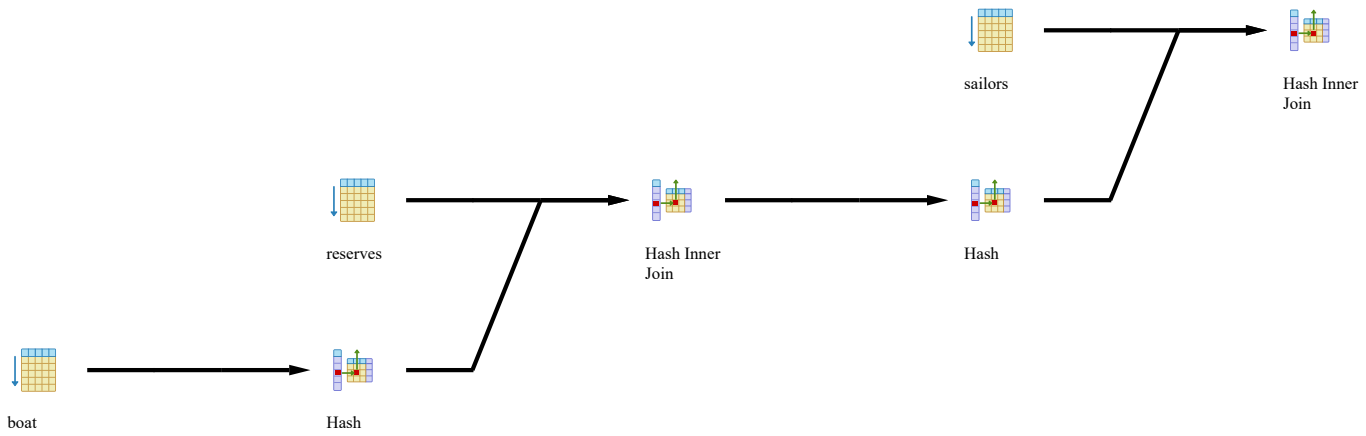
```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_hash" on "boat" using hash ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
5.998ms	6.51ms	5.771ms	6.093ms	0.279ms	826.08	65%	100%	87%	94%

With BRIN indices

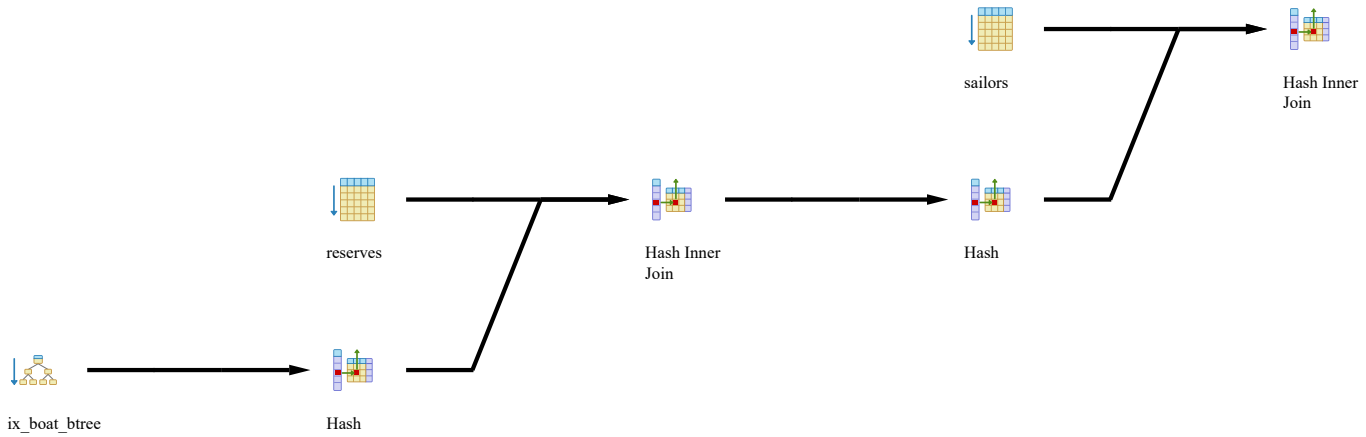
```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
create index "ix_boat_brin" on "boat" using brin ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
6.182ms	5.836ms	6.172ms	6.063ms	0.274ms	1244.76	98%	99%	104%	97%

With Mixed indices

```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
5.661ms	5.681ms	5.814ms	5.719ms	0.277ms	1219.54	96%	94%	107%	99%

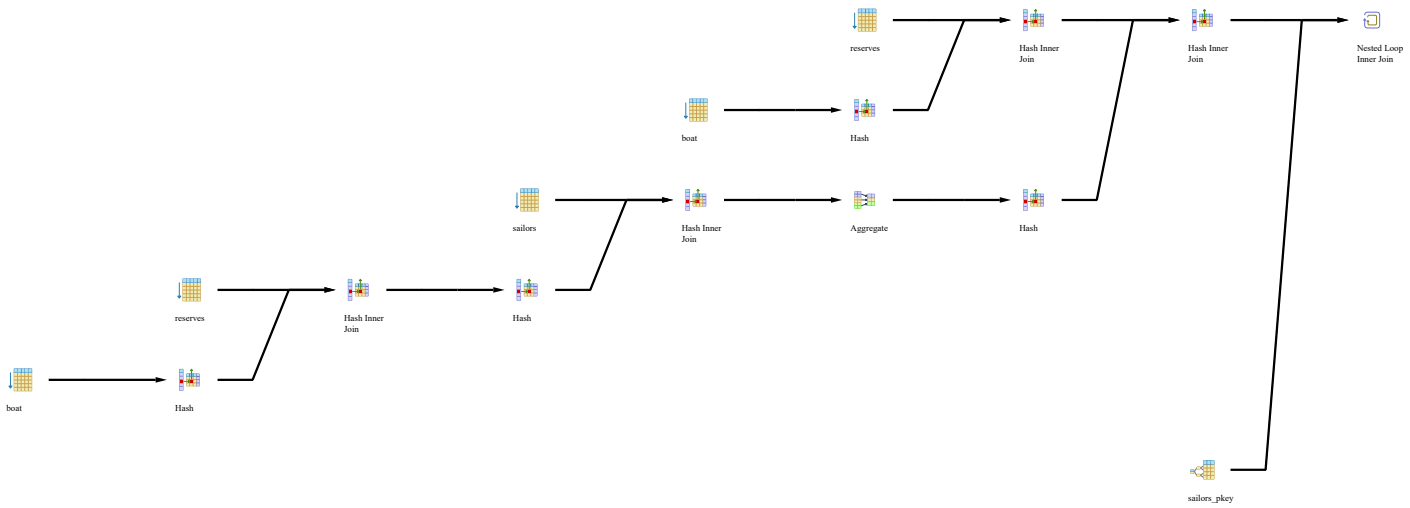
Query 9

Find the names of sailors who have reserved both a red and a green boat.

```
select s.sname
        from sailors s, reserves r, boat b
            where s.sid = r.sid
            and
            r.bid = b.bid
            and
            b.color = 'red'
            and
            s.sid in ( select s2.sid from sailors s2, boat b2, reserves r2  where s2.sid = r2.sid
                and r2.bid = b2.bid
                and b2.color = 'green');
```

Without Any Optimization

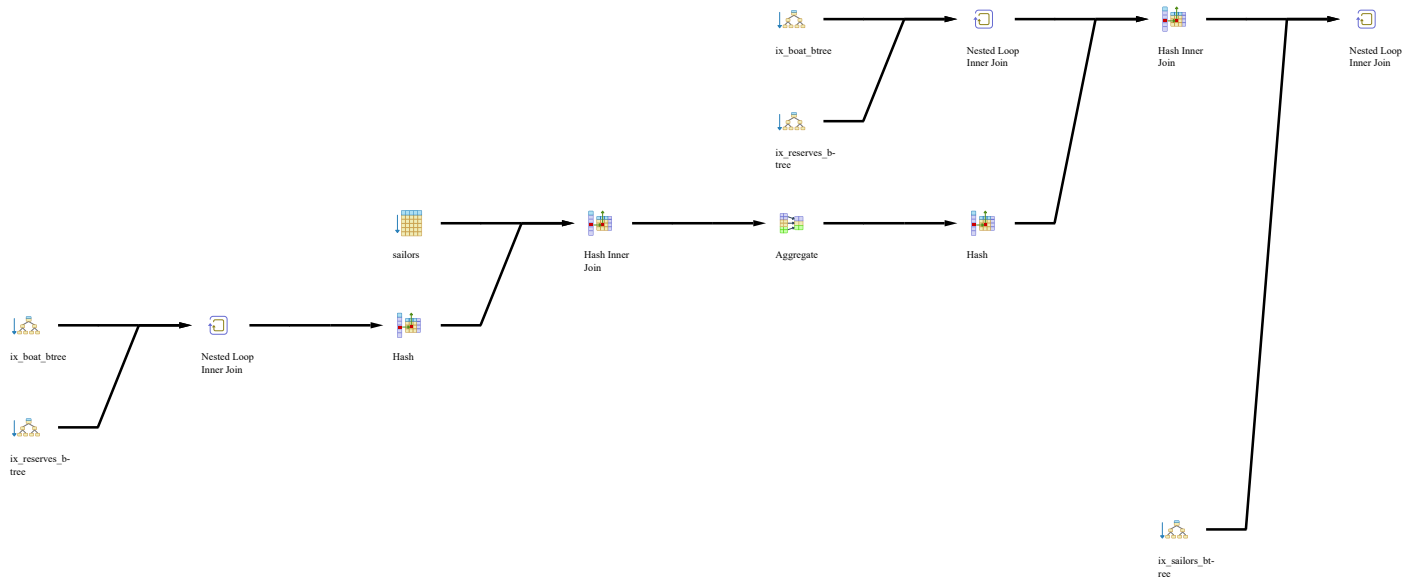
Query returns 539 records



Run 1	Run 2	Run 3	Average	Planning	Cost
11.433ms	10.819ms	10.187ms	10.813ms	0.682ms	2286.27

With B-TREE indices

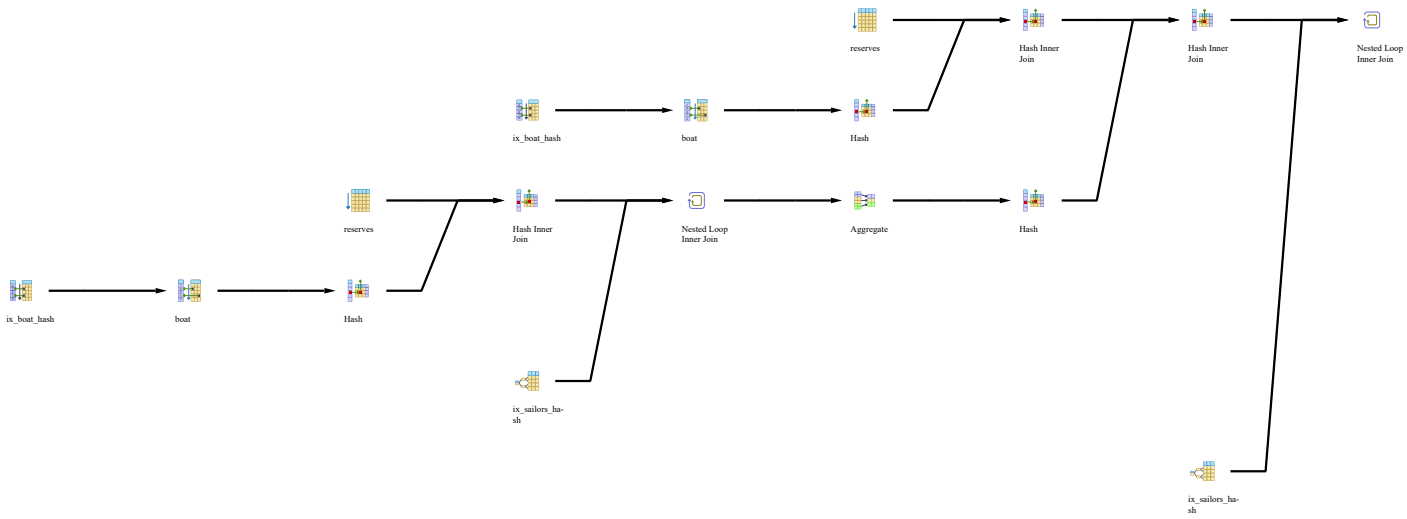
```
create index "ix_sailors_btree" on "sailors" using btree ("sid") include ("sname") ;
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
6.189ms	5.644ms	5.054ms	5.629ms	0.785ms	2065.73	90%	52%

With Hash indices

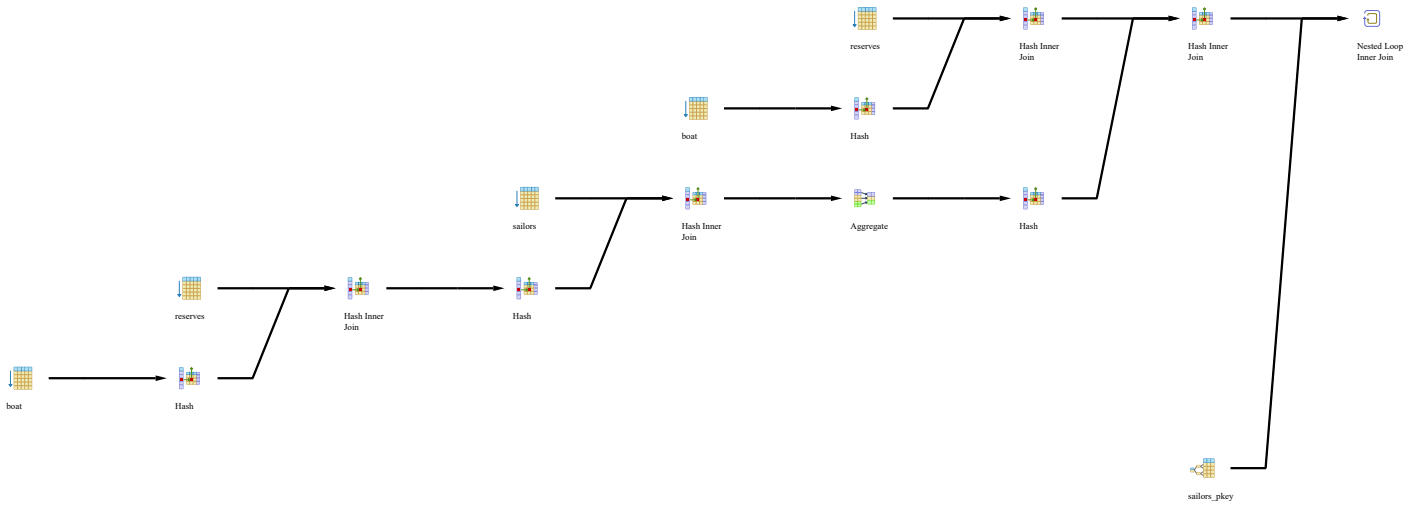
```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_hash" on "boat" using hash ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
11.818ms	11.018ms	10.404ms	11.08ms	0.788ms	1635.87	72%	102%

With BRIN indices

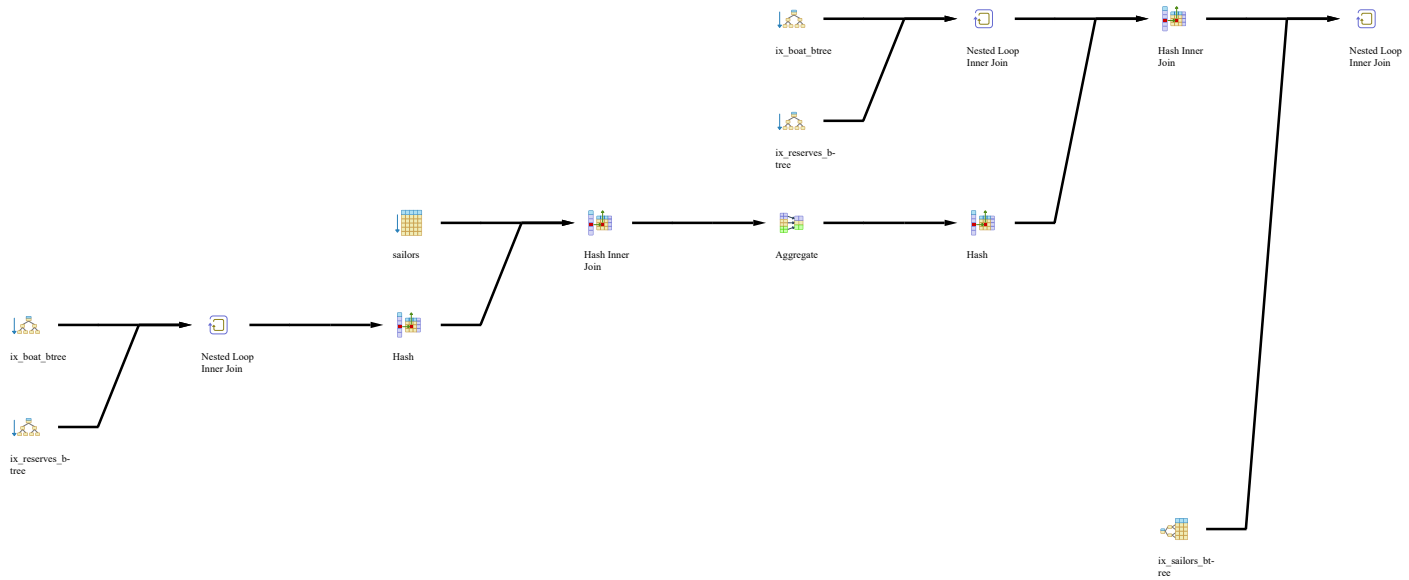
```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
create index "ix_boat_brin" on "boat" using brin ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
12.169ms	10.694ms	10.808ms	11.224ms	0.731ms	2286.27	100%	104%

With Mixed indices

```
create index "ix_sailors_btree" on "sailors" using btree ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
5.915ms	5.254ms	5.825ms	5.665ms	0.815ms	2072.81	91%	52%

Improved SQL

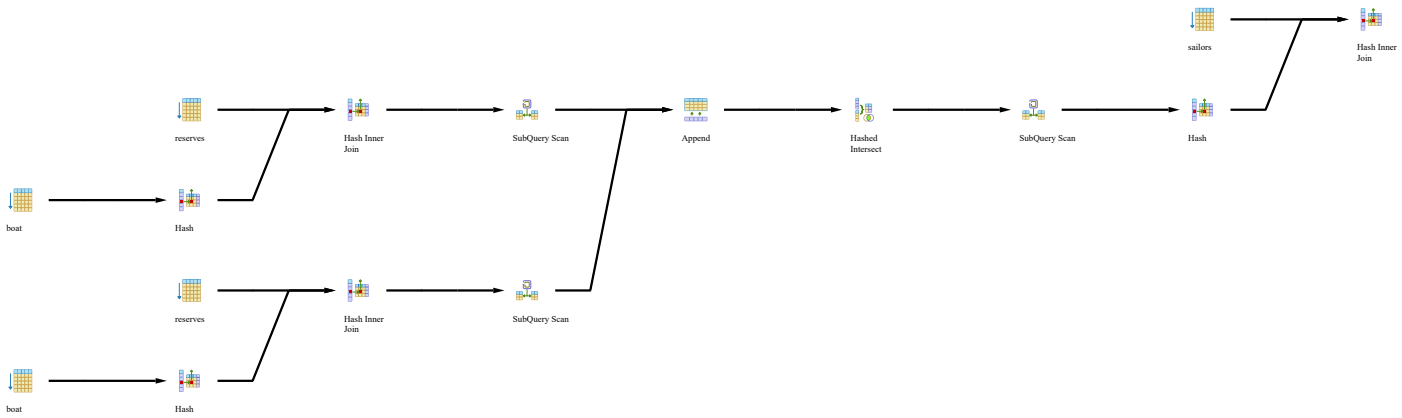
Using CTEs not only made the query more readable, but also caused a small improvement in cost and time of the query.

We recommend creating B-Tree indices on `boat`, `sailors` and `reserves` tables as indicated in the create index statements below.

```
with bgreen as (select bid from boat where color = 'green'),
        bred as (select bid from boat where color = 'red'),
        rgreen as (select sid from reserves where bid in (select bid from bgreen)),
        rred as (select sid from reserves where bid in (select bid from bred))
        select sname from sailors where sid in (select sid from rgreen intersect select sid from rred)
```

Without Any Optimization

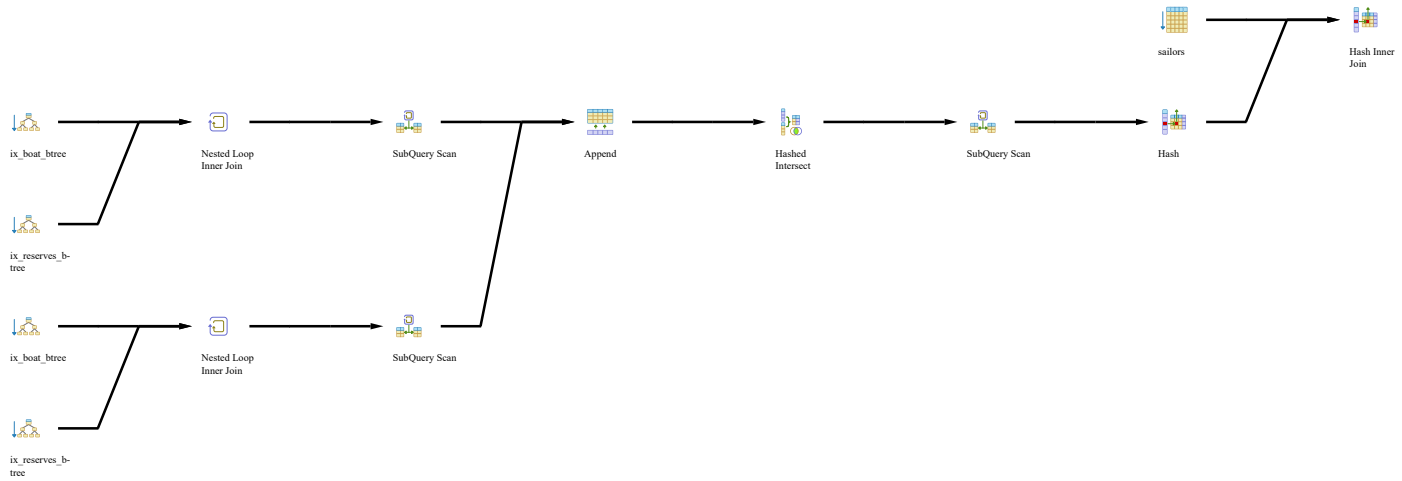
Query returns 490 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
9.852ms	9.333ms	9.144ms	9.443ms	0.224ms	1996.65	87%	87%

With B-TREE indices

```
create index "ix_sailors_btree" on "sailors" using btree ("sid") include ("sname") ;
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```

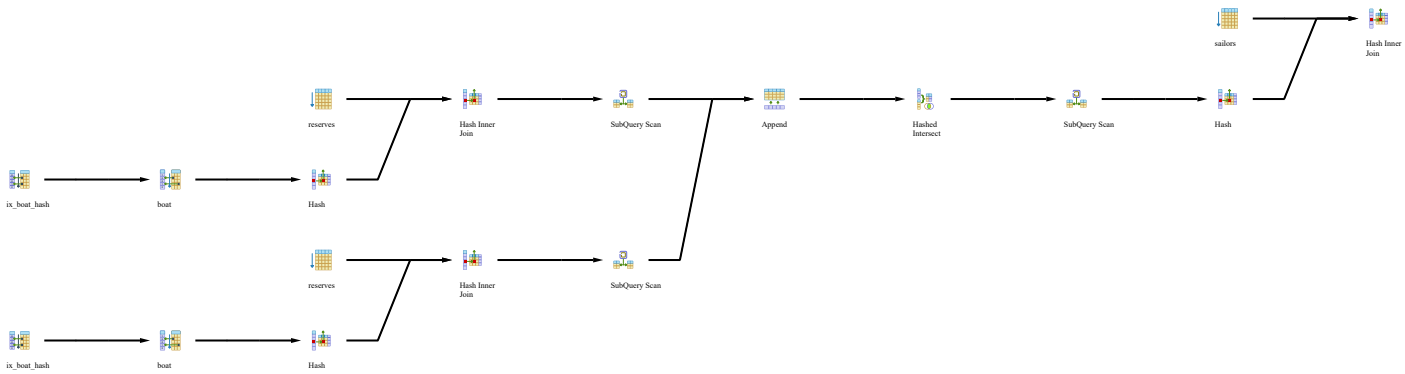


Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized

Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
4.178ms	4.333ms	4.305ms	4.272ms	0.383ms	1783.2	89%	45%	86%	76%

With Hash indices

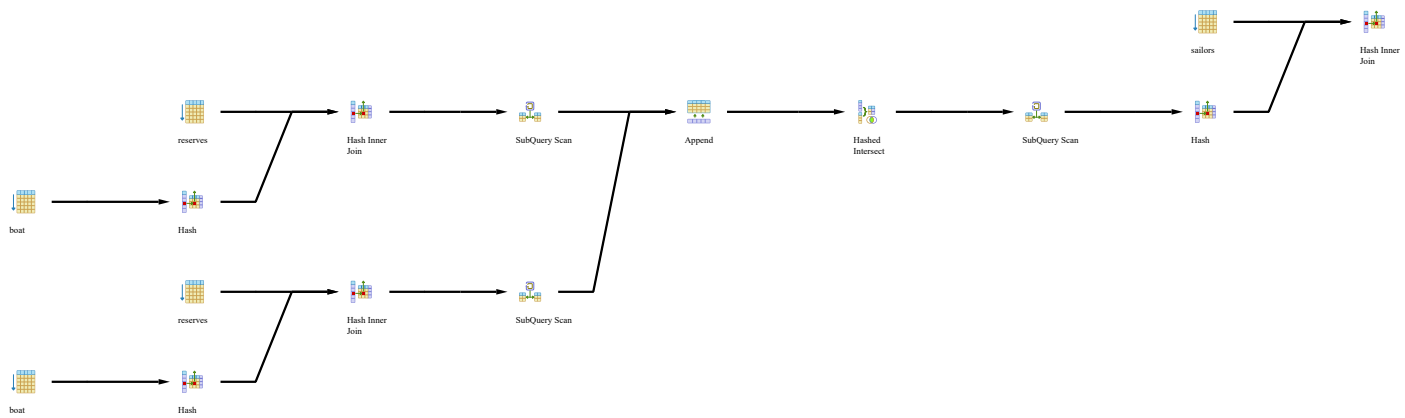
```
create index "ix_sailors_hash" on "sailors" using hash ("sid");
create index "ix_reserves_hash" on "reserves" using hash ("bid");
create index "ix_boat_hash" on "boat" using hash ("color");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
9.598ms	8.895ms	9.168ms	9.22ms	0.263ms	1949.8	98%	98%	119%	83%

With BRIN indices

```
create index "ix_sailors_brin" on "sailors" using brin ("sid");
create index "ix_reserves_brin" on "reserves" using brin ("bid");
create index "ix_boat_brin" on "boat" using brin ("color");
```

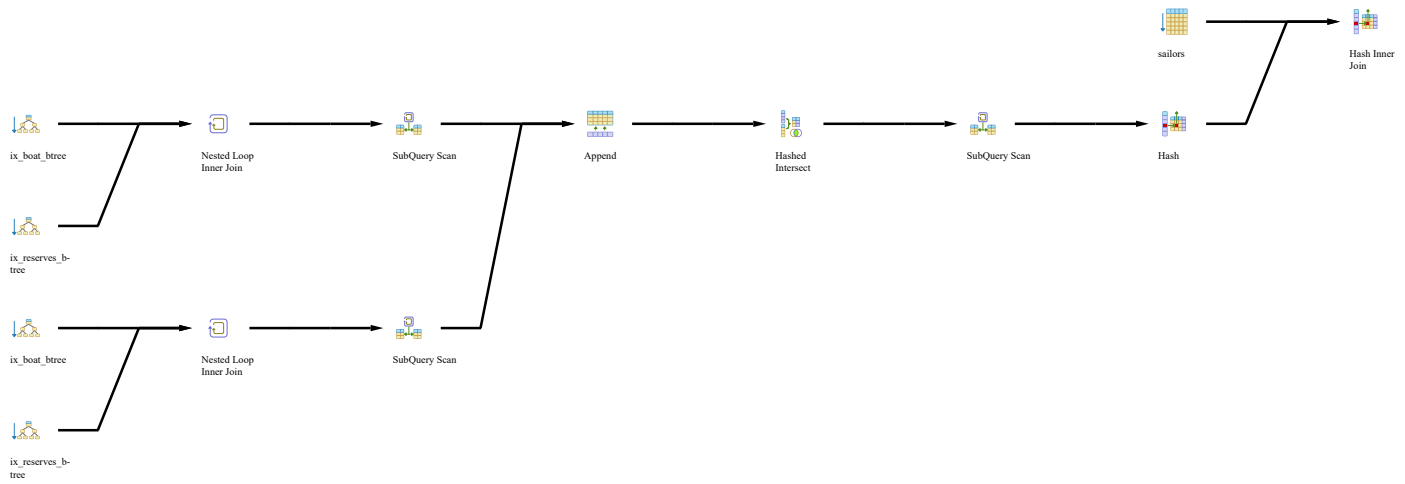


Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized

Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
10.596ms	9.751ms	10.165ms	10.171ms	0.311ms	1996.65	100%	108%	87%	91%

With Mixed indices

```
create index "ix_sailors_btree" on "sailors" using btree ("sid");
create index "ix_reserves_btree" on "reserves" using btree ("bid") include ("sid") ;
create index "ix_boat_btree" on "boat" using btree ("color") include ("bid") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
4.154ms	4.321ms	3.923ms	4.133ms	0.307ms	1783.2	89%	44%	86%	73%

Schema 4

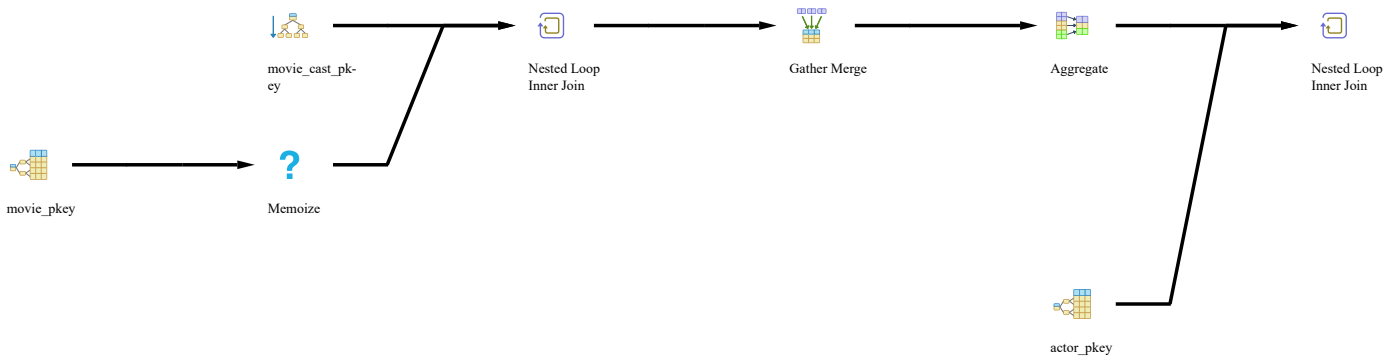
Query 10

List all the information of the actors who played a role in the movie 'Annie Hall'.

```
select *
        from actor
            where act_id in (
                select act_id
                    from movie_cast
                    where mov_id in(
                        select mov_id
                        from movie
                        where mov_title ='Annie Hall'
                    )
            )
```

Without Any Optimization

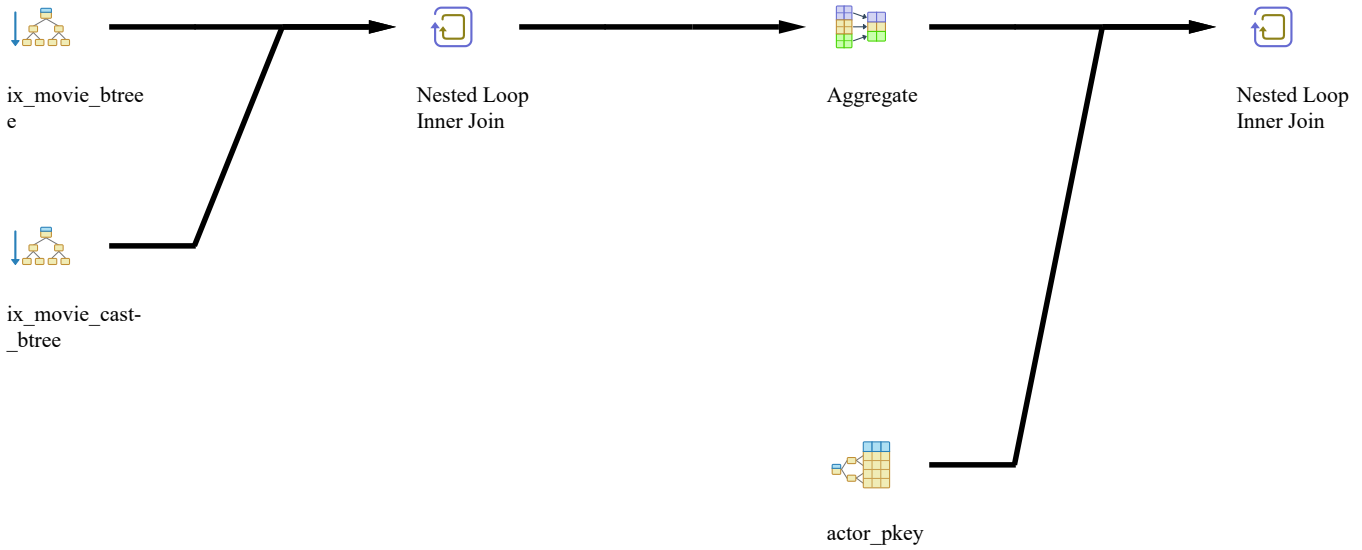
Query returns 374 records



Run 1	Run 2	Run 3	Average	Planning	Cost
34.609ms	30.28ms	29.901ms	31.597ms	0.2ms	3503.52

With B-TREE indices

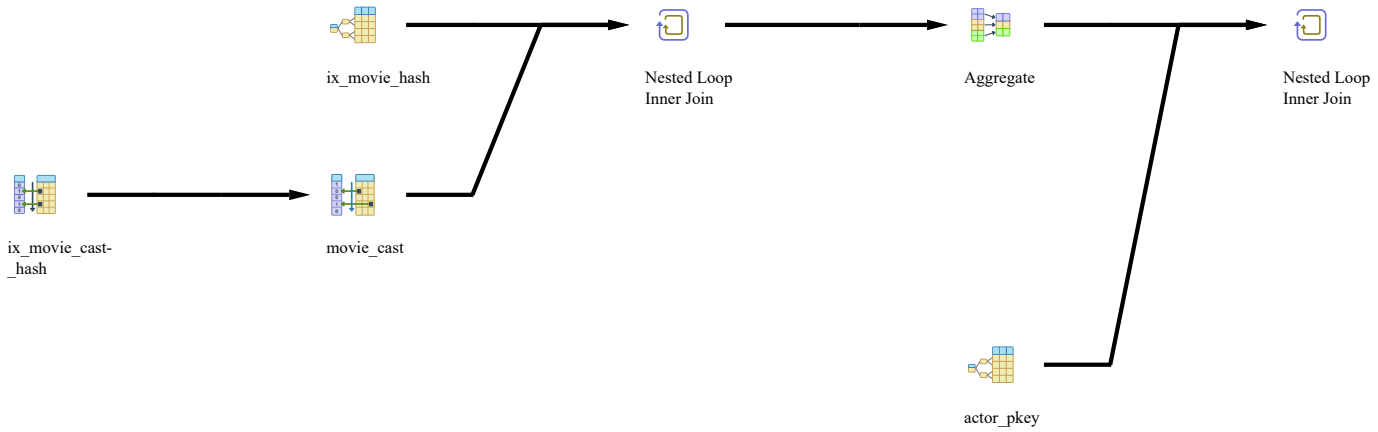
```
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("act_id") ;
create index "ix_movie_btree" on "movie" using btree ("mov_title") include ("mov_id") ;
create index "ix_actor_btree" on "actor" using btree ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.574ms	0.662ms	0.681ms	0.639ms	0.268ms	46.44	1%	2%

With Hash indices

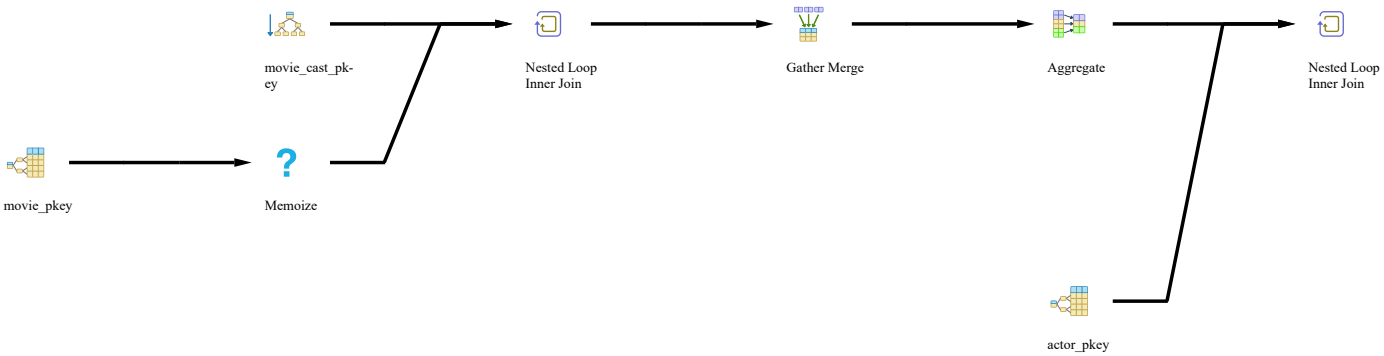
```
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_actor_hash" on "actor" using hash ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.683ms	0.583ms	0.603ms	0.623ms	0.216ms	766.47	22%	2%

With BRIN indices

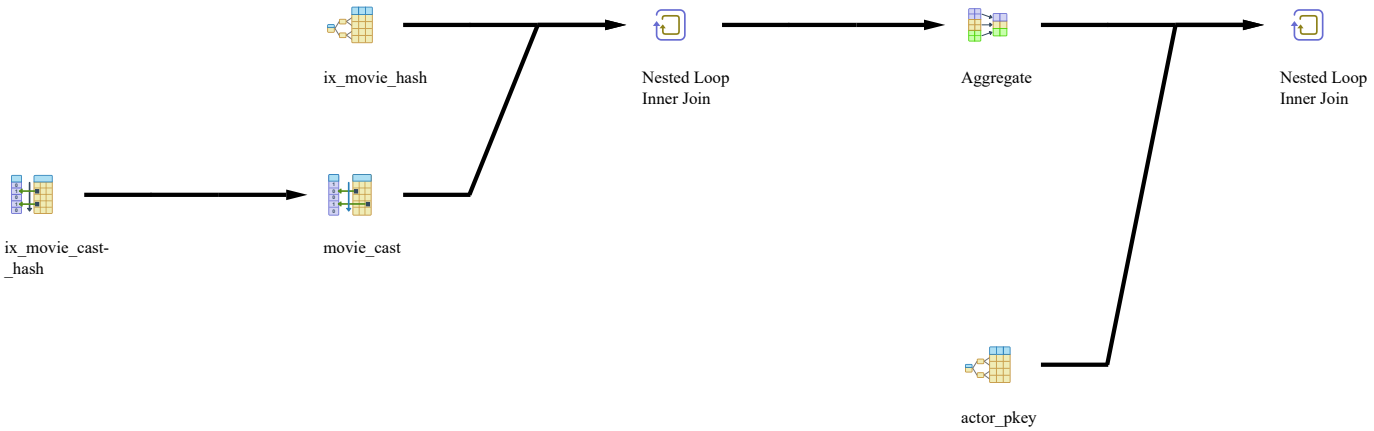
```
create index "ix_movie_cast_brin" on "movie_cast" using brin ("mov_id");
create index "ix_movie_brin" on "movie" using brin ("mov_title");
create index "ix_actor_brin" on "actor" using brin ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
33.628ms	29.69ms	29.976ms	31.098ms	0.32ms	3503.51	100%	98%

With Mixed indices

```
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_actor_btree" on "actor" using btree ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.666ms	0.665ms	0.575ms	0.635ms	0.171ms	766.45	22%	2%

Improved SQL

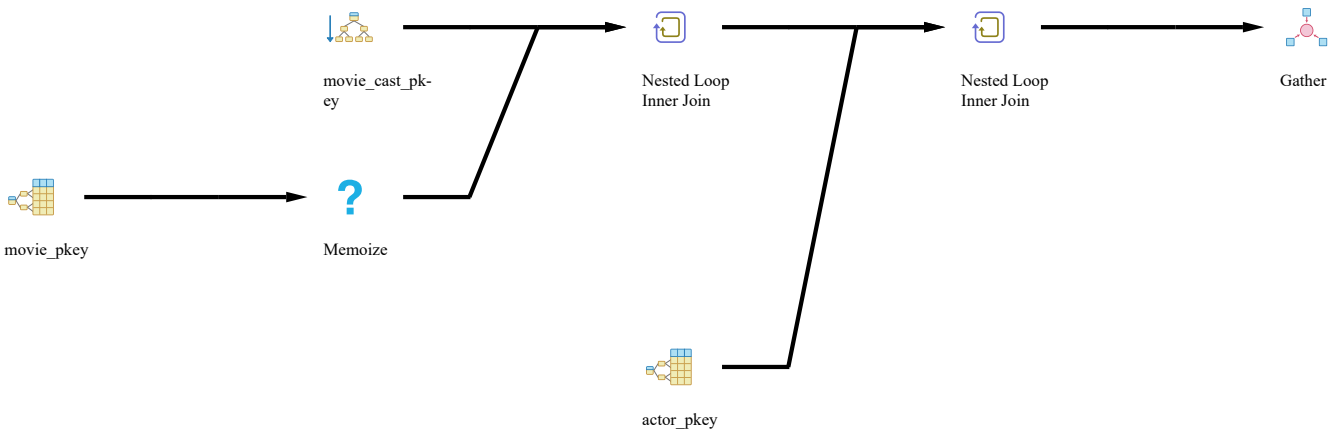
The improved query used simple inner joins which made the query plan simpler in case of using no indexes even though the cost is similar. However, when using B-Tree indices, the cost and the execution time of the improved query are lower. The use of inner joins is possible for this query because `movie_cast` table has a primary key on both `act_id` and `mov_id` columns, so the output of the query won't change vs using `in` keyword.

We recommend creating B-Tree indices on `movie_cast`, `movie_` and `actor` tables as indicated in the create index statements below.

```
select a.*
    from actor a
    inner join movie_cast mc on mc.act_id = a.act_id
    inner join movie m on m.mov_id = mc.mov_id
    where m.mov_title = 'Annie Hall'
```

Without Any Optimization

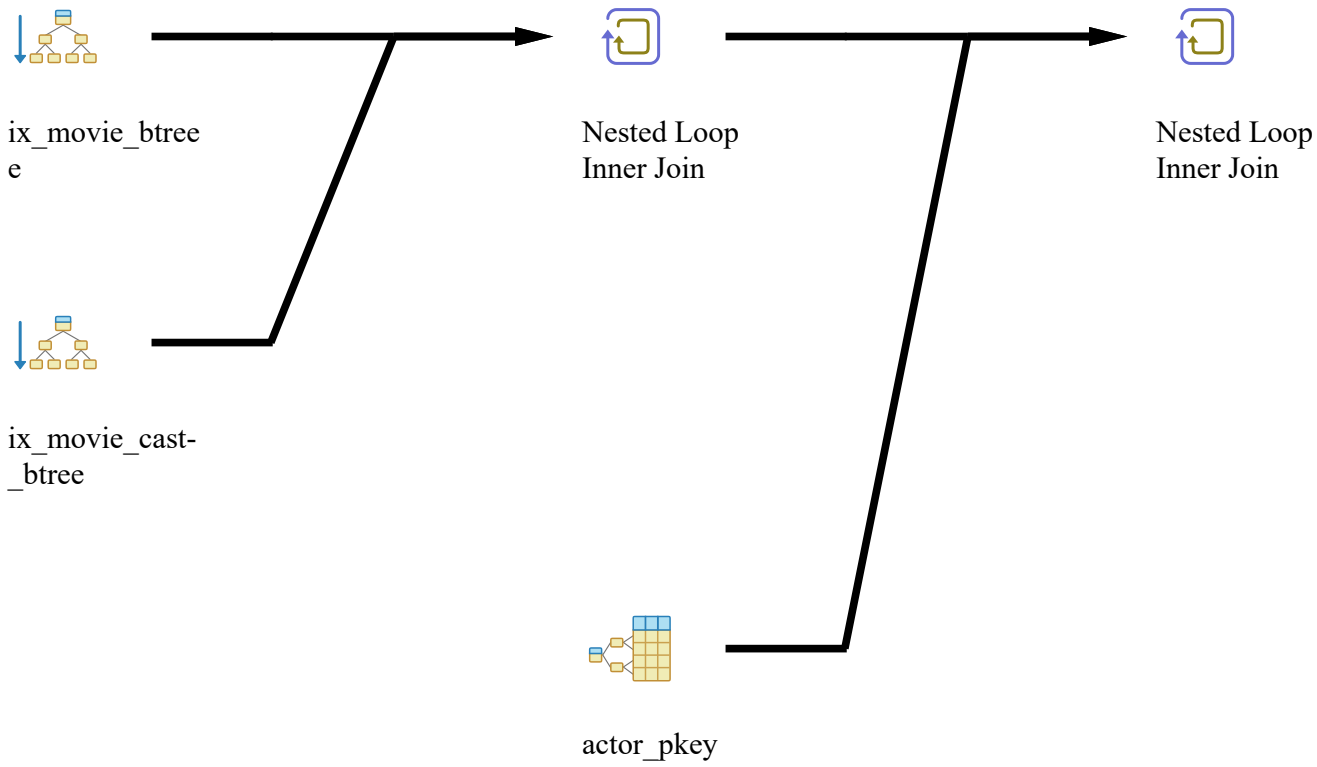
Query returns 374 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
26.338ms	21.758ms	23.94ms	24.012ms	0.268ms	3499.48	100%	76%

With B-TREE indices

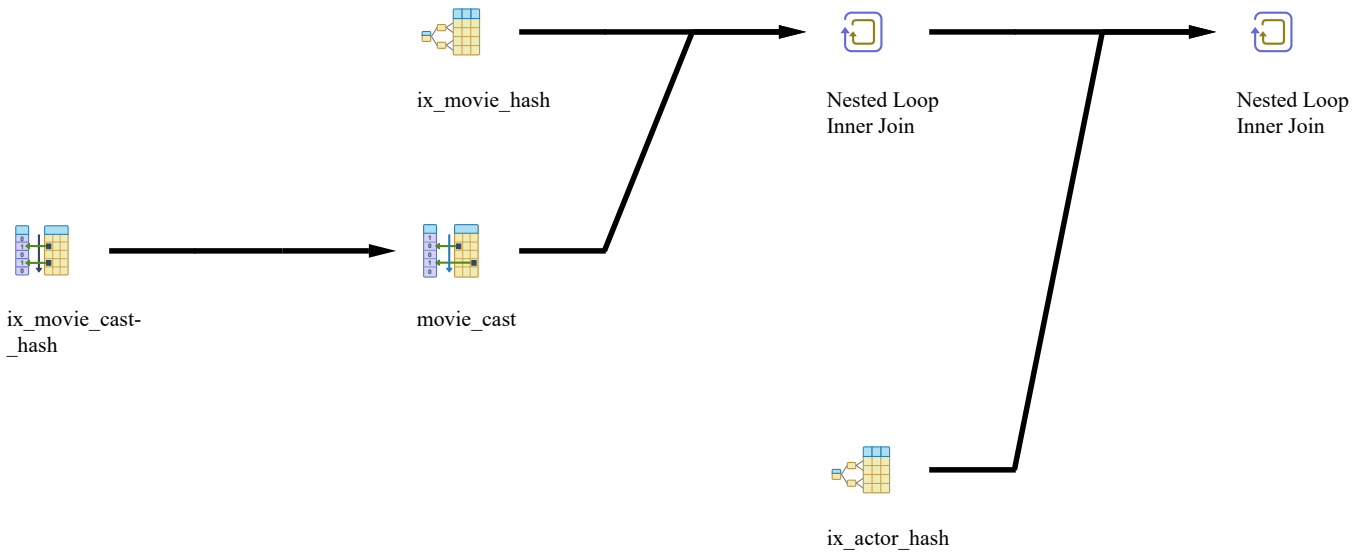
```
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("act_id") ;
create index "ix_movie_btree" on "movie" using btree ("mov_title") include ("mov_id") ;
create index "ix_actor_btree" on "actor" using btree ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.48ms	0.567ms	0.362ms	0.47ms	0.295ms	42.41	1%	2%	91%	74%

With Hash indices

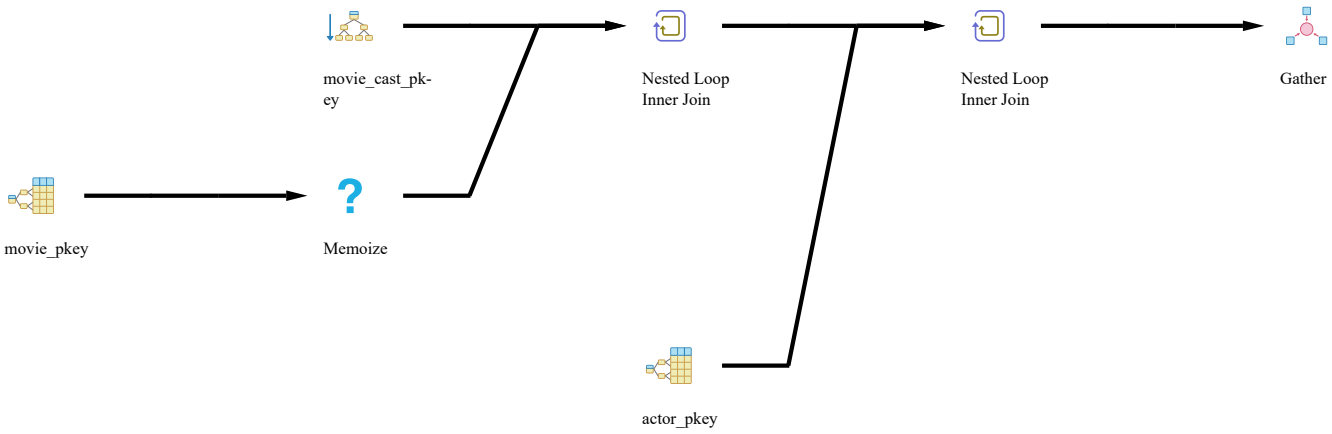
```
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_actor_hash" on "actor" using hash ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.892ms	0.817ms	0.782ms	0.83ms	0.264ms	762.18	22%	3%	99%	133%

With BRIN indices

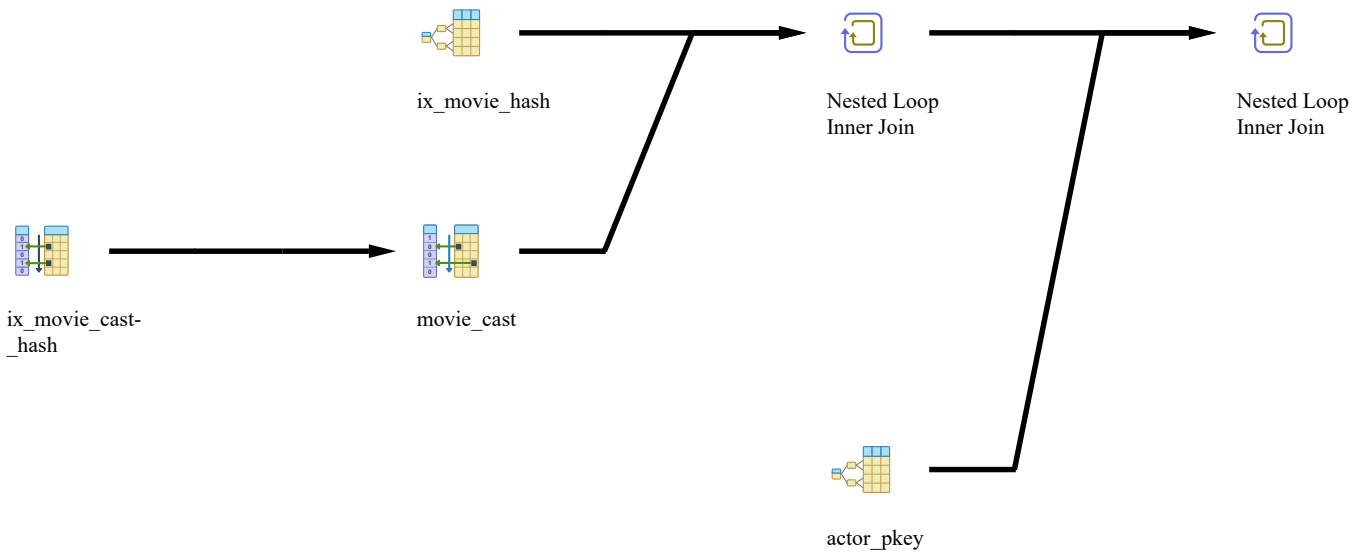
```
create index "ix_movie_cast_brin" on "movie_cast" using brin ("mov_id");
create index "ix_movie_brin" on "movie" using brin ("mov_title");
create index "ix_actor_brin" on "actor" using brin ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
25.339ms	25.844ms	22.012ms	24.398ms	0.248ms	3499.48	100%	102%	100%	78%

With Mixed indices

```
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_actor_btree" on "actor" using btree ("act_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.744ms	0.611ms	0.534ms	0.63ms	0.31ms	762.47	22%	3%	99%	99%

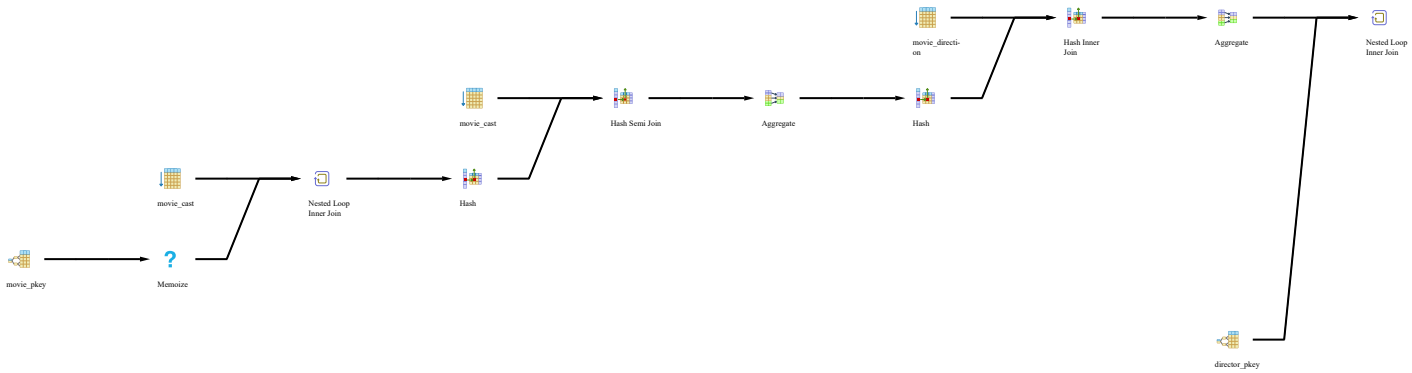
Query 11

Find the name of the director (first and last names) who directed a movie that casted a role for 'Eyes Wide Shut'

```
select dir_fname, dir_lname
    from director
    where dir_id in(
        select dir_id
            from movie_direction
            where mov_id in(
                select mov_id
                    from movie_cast
                    where role =any(
                        select role
                            from movie_cast
                            where mov_id in(
                                select mov_id
                                    from movie
                                    where mov_title='Eyes Wide Shut'
                                )
                        )
                )
            )
```

Without Any Optimization

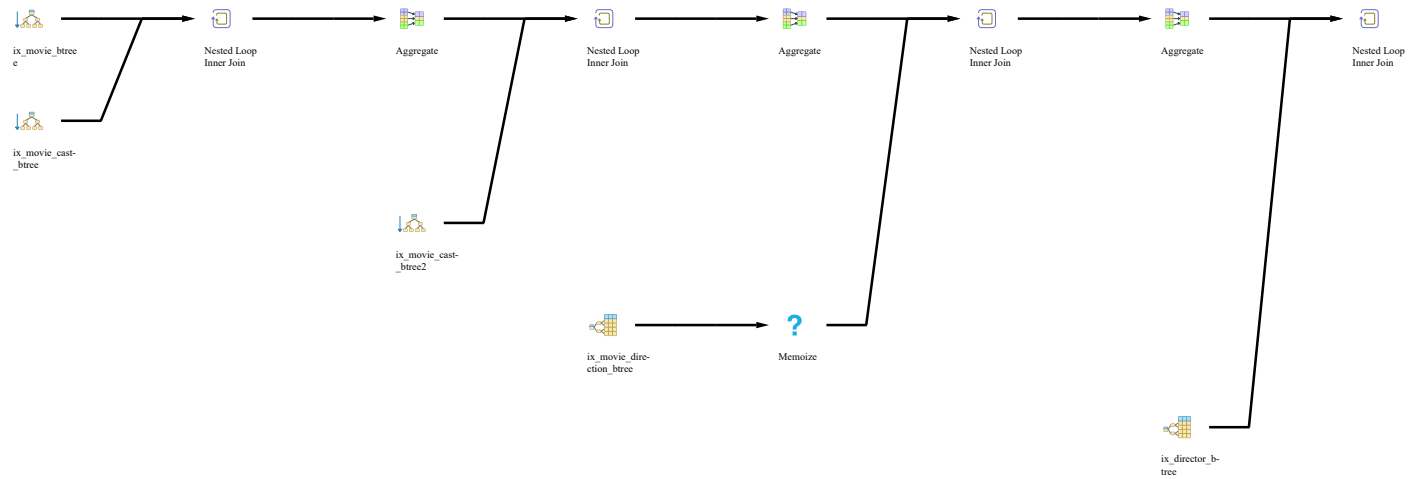
Query returns 5 records



Run 1	Run 2	Run 3	Average	Planning	Cost
24.917ms	24.285ms	27.245ms	25.482ms	0.401ms	5400.02

With B-TREE indices

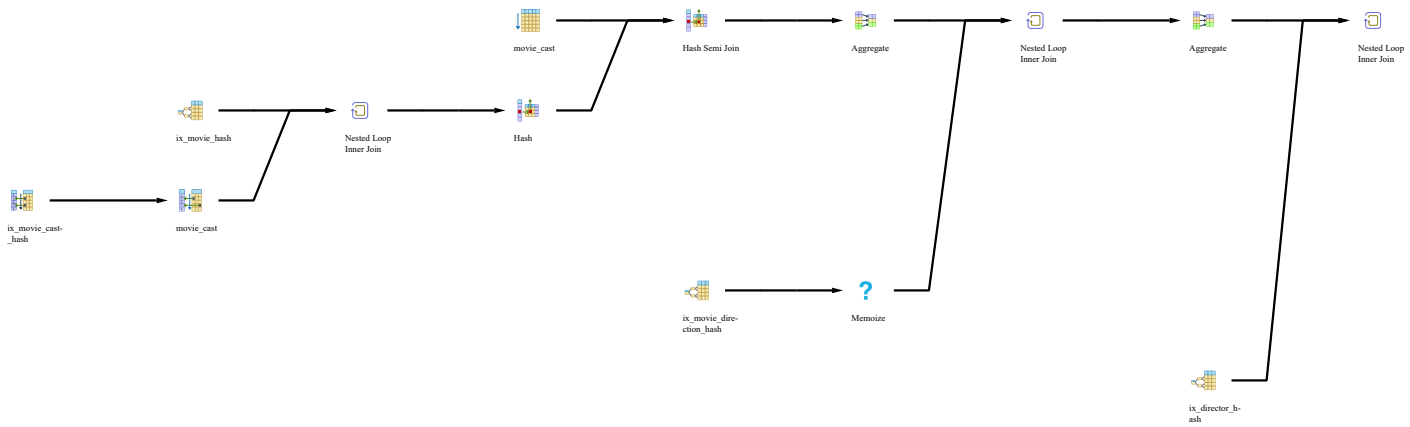
```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("role") ;
create index "ix_movie_cast_btree2" on "movie_cast" using btree ("role") include ("mov_id") ;
create index "ix_movie_btree" on "movie" using btree ("mov_title") include ("mov_id") ;
create index "ix_director_btree" on "director" using btree ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.871ms	0.825ms	0.792ms	0.829ms	0.542ms	146.16	3%	3%

With Hash indices

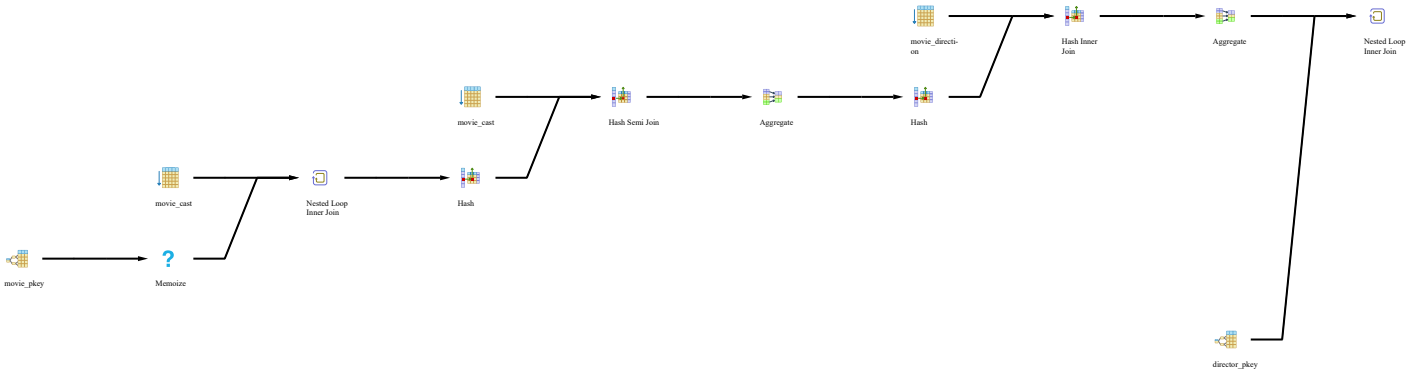
```
create index "ix_movie_direction_hash" on "movie_direction" using hash ("mov_id");
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_director_hash" on "director" using hash ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
8.183ms	9.489ms	8.35ms	8.674ms	0.501ms	2515.91	47%	34%

With BRIN indices

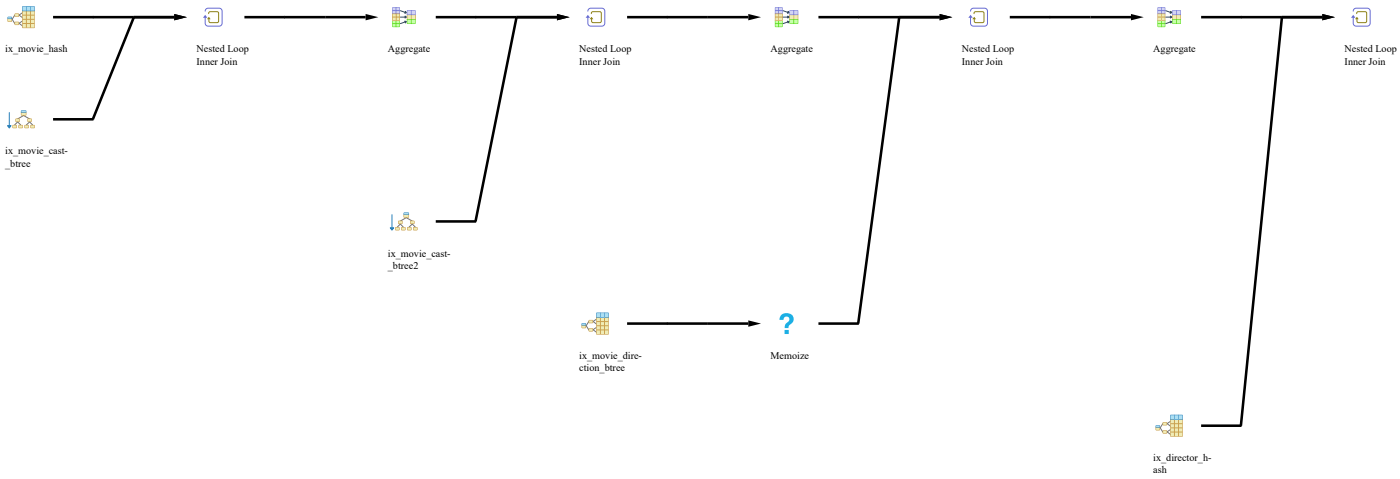
```
create index "ix_movie_direction_brin" on "movie_direction" using brin ("mov_id");
create index "ix_movie_cast_brin" on "movie_cast" using brin ("mov_id");
create index "ix_movie_brin" on "movie" using brin ("mov_title");
create index "ix_director_brin" on "director" using brin ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
25.089ms	24.547ms	24.23ms	24.622ms	0.45ms	5400.02	100%	97%

With Mixed indices

```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("role") ;
create index "ix_movie_cast_btree2" on "movie_cast" using btree ("role") include ("mov_id") ;
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_director_hash" on "director" using hash ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.868ms	0.782ms	0.892ms	0.847ms	0.508ms	120.26	2%	3%

Improved SQL

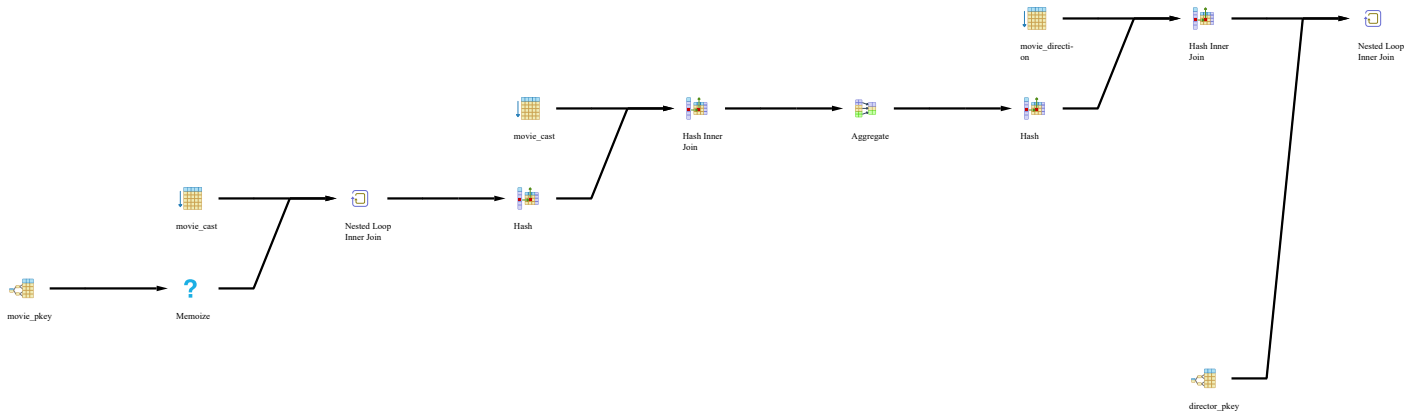
THE CTE and the joins made the improved query more readable, and a small reduction of the query cost and time when using B-Tree indices since there 2 more aggregate steps in the original query's plan.

We recommend creating B-Tree indices on `movie_cast`, `movie`, `movie_direction` and `director` tables as indicated in the create index statements below.

```
WITH movs as (select mc2.mov_id from
            movie m
            inner join movie_cast mc
            on m.mov_id = mc.mov_id
            inner join movie_cast mc2 on mc2.role = mc.role
            where mov_title = 'Eyes Wide Shut'
            )
        select dir_fname, dir_lname
    from director d
    inner join movie_direction md
    on md.dir_id = d.dir_id
    where mov_id in (select mov_id from movs)
```

Without Any Optimization

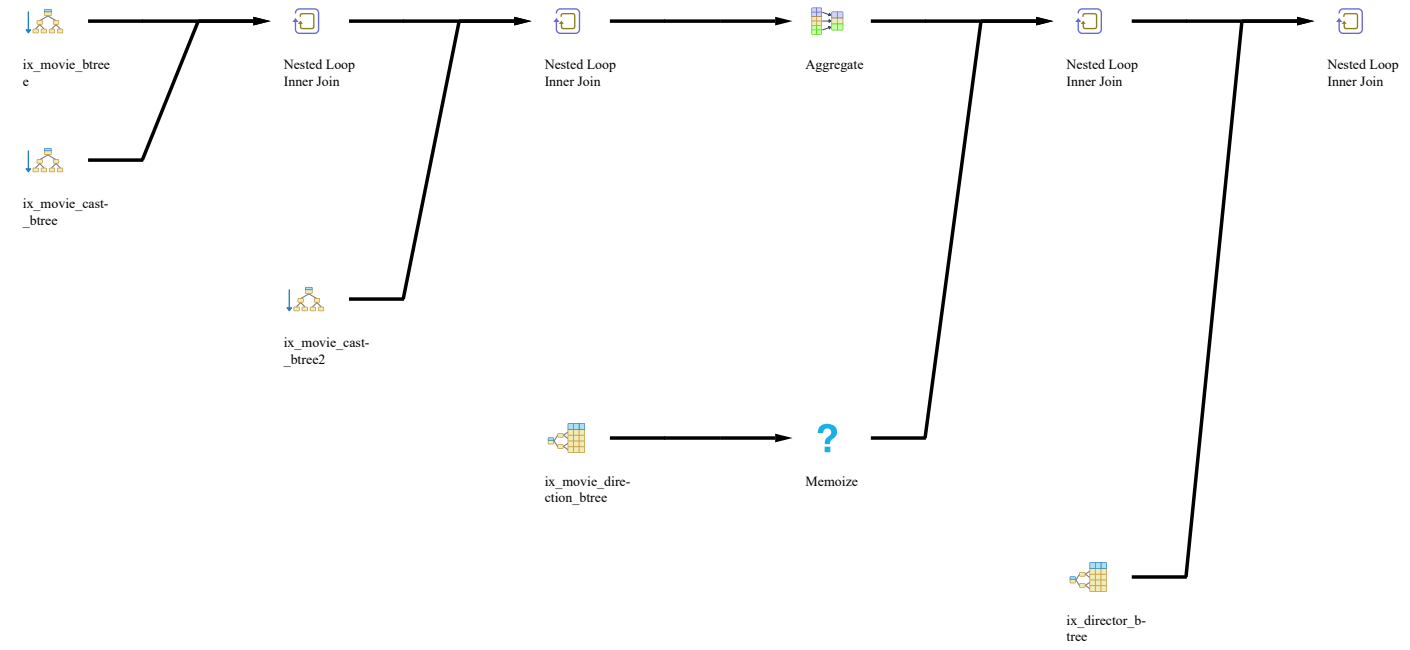
Query returns 5 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
25.026ms	25.526ms	25.819ms	25.457ms	0.465ms	5488.58	102%	100%

With B-TREE indices

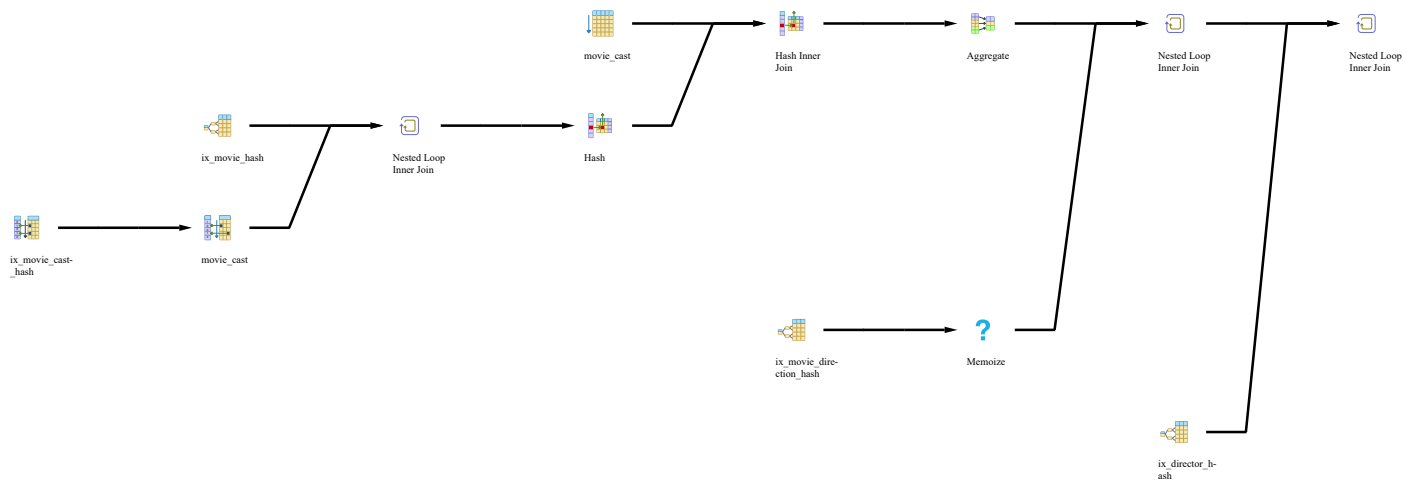
```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("role") ;
create index "ix_movie_cast_btree2" on "movie_cast" using btree ("role") include ("mov_id") ;
create index "ix_movie_btree" on "movie" using btree ("mov_title") include ("mov_id") ;
create index "ix_director_btree" on "director" using btree ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.848ms	0.781ms	0.783ms	0.804ms	0.601ms	136.42	2%	3%	93%	97%

With Hash indices

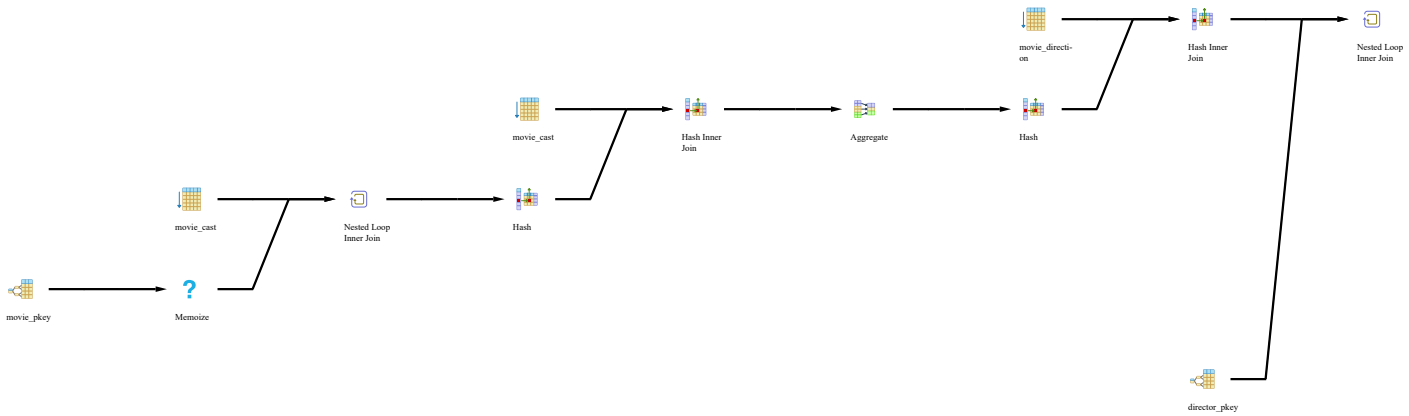
```
create index "ix_movie_direction_hash" on "movie_direction" using hash ("mov_id");
create index "ix_movie_cast_hash" on "movie_cast" using hash ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_director_hash" on "director" using hash ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
8.405ms	8.499ms	8.313ms	8.406ms	0.516ms	2604.4	47%	33%	104%	97%

With BRIN indices

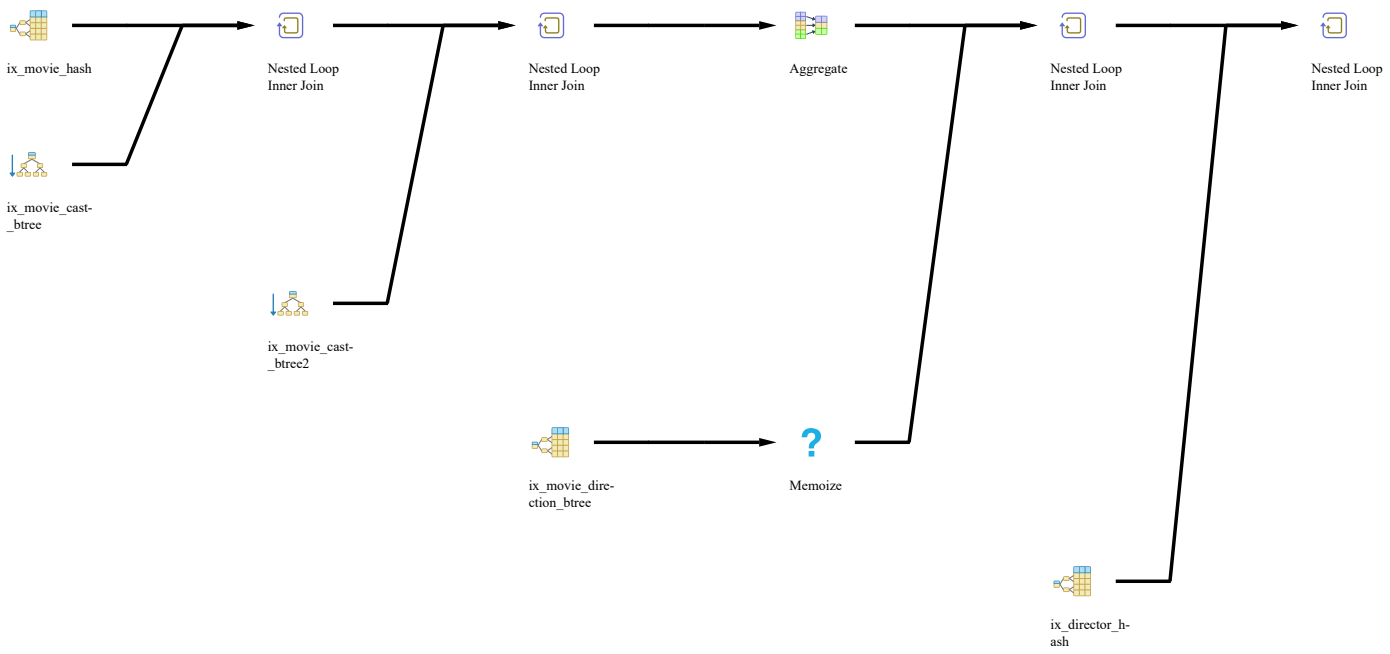
```
create index "ix_movie_direction_brin" on "movie_direction" using brin ("mov_id");
create index "ix_movie_cast_brin" on "movie_cast" using brin ("mov_id");
create index "ix_movie_brin" on "movie" using brin ("mov_title");
create index "ix_director_brin" on "director" using brin ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
25.082ms	29.228ms	25.203ms	26.504ms	0.501ms	5488.57	100%	104%	102%	108%

With Mixed indices

```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_cast_btree" on "movie_cast" using btree ("mov_id") include ("role") ;
create index "ix_movie_cast_btree2" on "movie_cast" using btree ("role") include ("mov_id") ;
create index "ix_movie_hash" on "movie" using hash ("mov_title");
create index "ix_director_hash" on "director" using hash ("dir_id");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.81ms	0.774ms	0.745ms	0.776ms	0.65ms	111.45	2%	3%	93%	92%

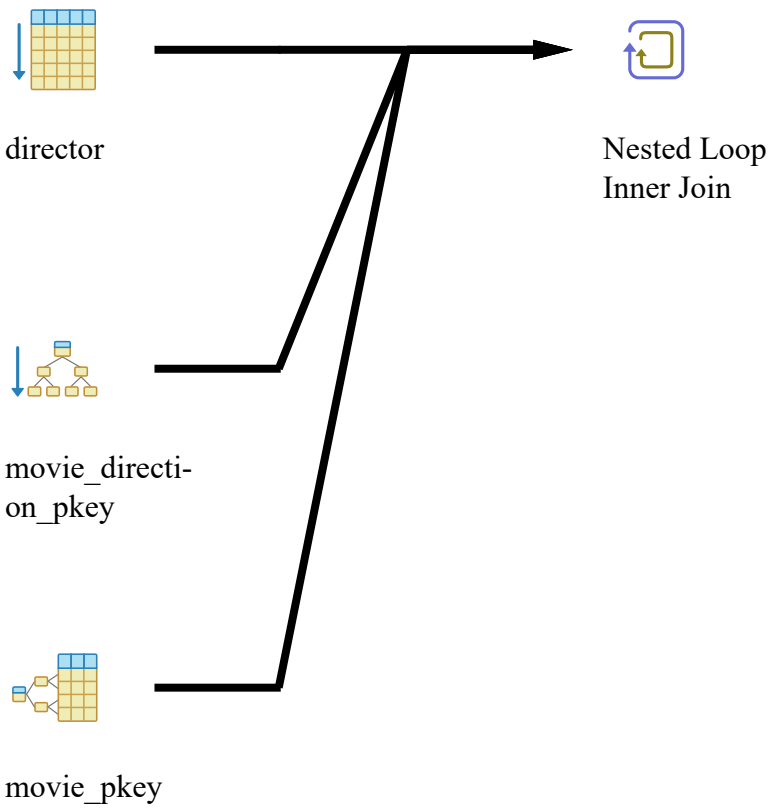
Query 12

Find the titles of all movies directed by the director whose first and last name are Woddy Allen.

```
select mov_title
    from movie
    where mov_id in (
        select mov_id
            from movie_direction
            where dir_id= (select dir_id
                    from director
                        where dir_fname='Woddy' and dir_lname='Allen'
                )
            )
```

Without Any Optimization

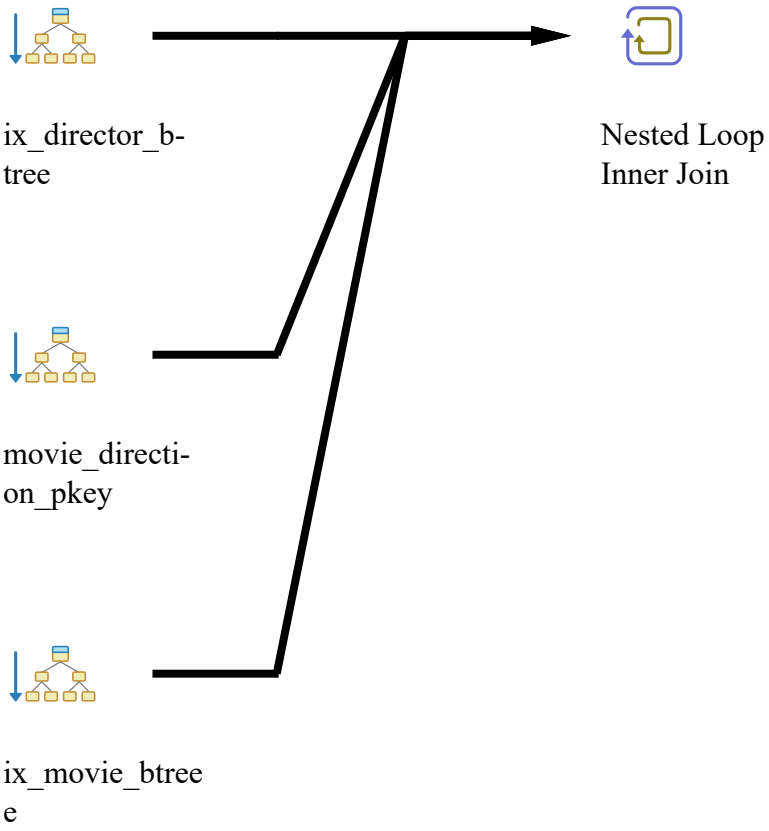
Query returns 351 records



Run 1	Run 2	Run 3	Average	Planning	Cost
0.67ms	0.624ms	0.641ms	0.645ms	0.134ms	159.61

With B-TREE indices

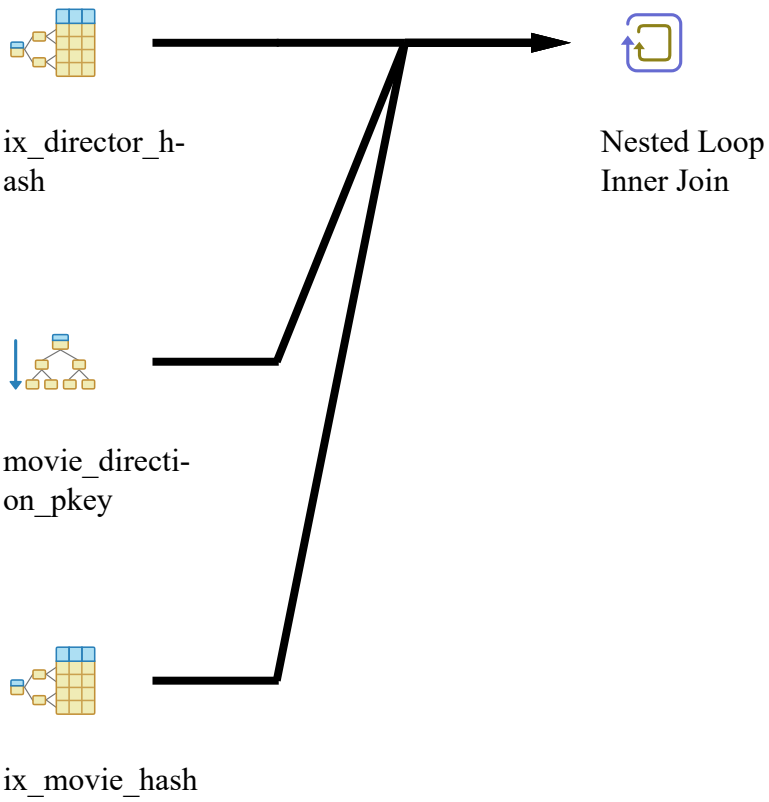
```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("dir_id");
create index "ix_movie_btree" on "movie" using btree ("mov_id") include ("mov_title") ;
create index "ix_director_btree" on "director" using btree ("dir_fname", "dir_lname") include ("dir_id") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.341ms	0.328ms	0.33ms	0.333ms	0.163ms	13.04	8%	52%

With Hash indices

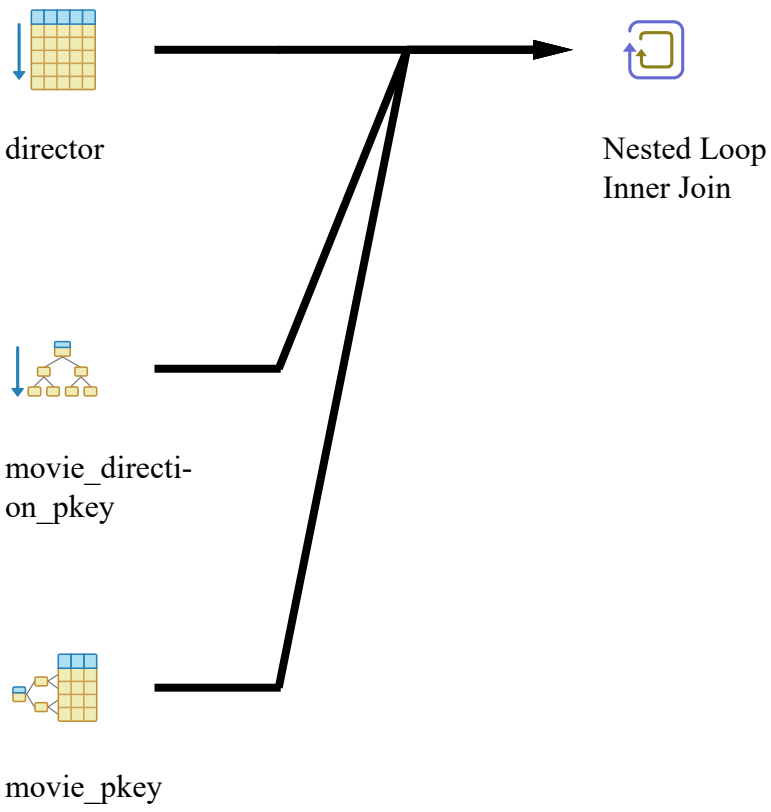
```
create index "ix_movie_direction_hash" on "movie_direction" using hash ("dir_id");
create index "ix_movie_hash" on "movie" using hash ("mov_id");
create index "ix_director_hash" on "director" using hash ("dir_lname");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.598ms	0.66ms	0.529ms	0.596ms	0.171ms	20.34	13%	92%

With BRIN indices

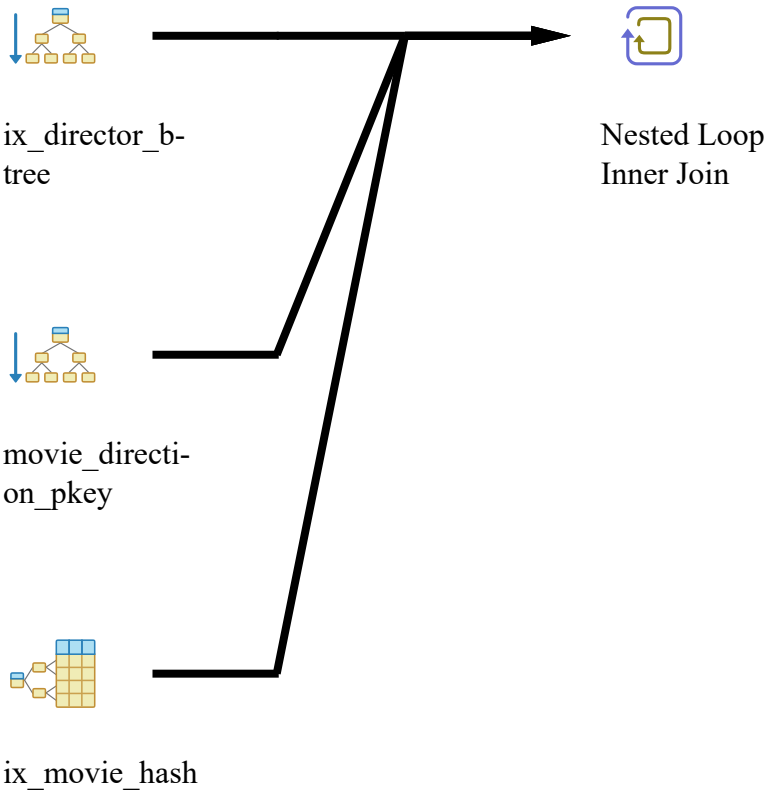
```
create index "ix_movie_direction_brin" on "movie_direction" using brin ("dir_id");
create index "ix_movie_brin" on "movie" using brin ("mov_id");
create index "ix_director_brin" on "director" using brin ("dir_lname");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.641ms	0.629ms	0.628ms	0.633ms	0.133ms	159.61	100%	98%

With Mixed indices

```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_id");
create index "ix_director_btree" on "director" using btree ("dir_fname", "dir_lname") include ("dir_id") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes
0.638ms	0.579ms	0.293ms	0.503ms	0.144ms	16.62	10%	78%

Improved SQL

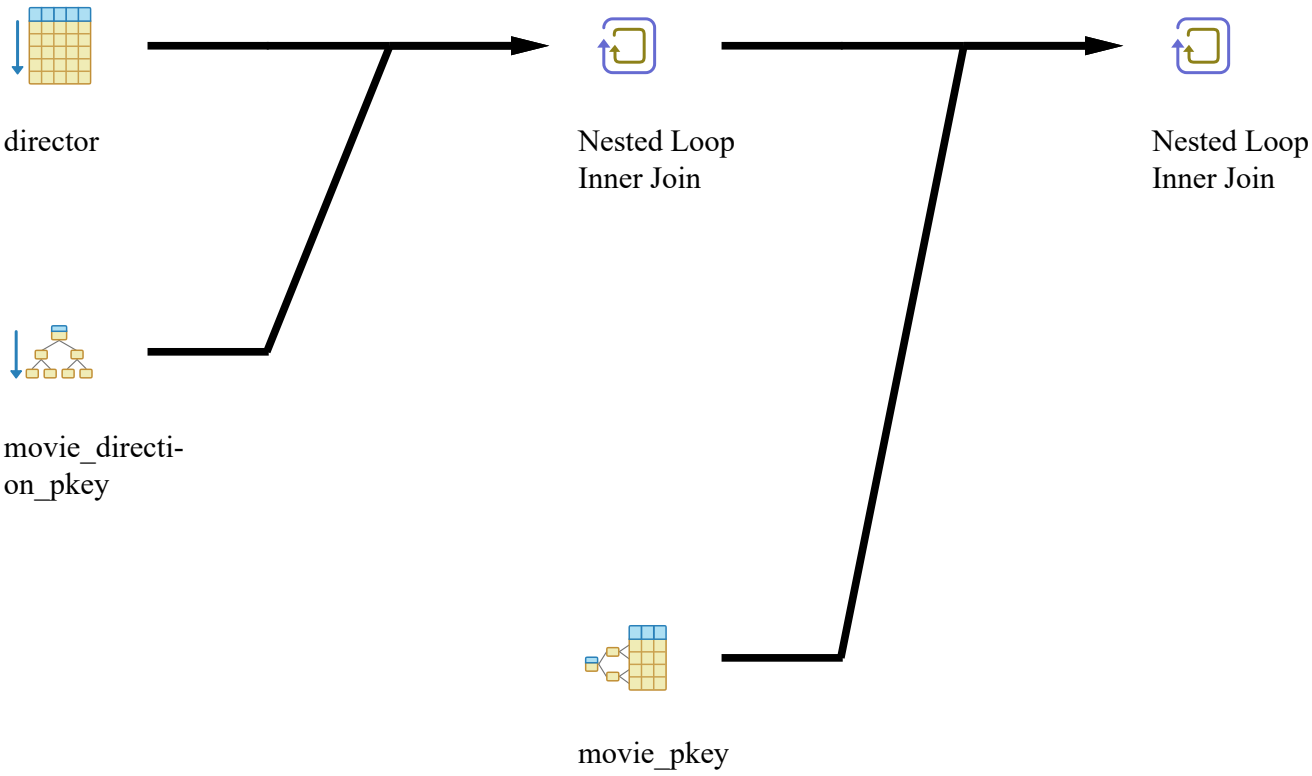
The improved query reduced the cost when using B-Tree indices. The execution time is about the same. The noticeable different is that in the original query, the engine's plan had one nested loop inner join with 3 tables, while in the improved query case it had 2 nested loop inner joins with 2 tables each.

We recommend creating B-Tree indices on `movie`, `movie_direction` and `director` tables as indicated in the create index statements below.

```
WITH wa as (select dir_id from director where dir_fname='Woddy' and dir_lname='Allen'),
wa_movies as (select mov_id from movie_direction where dir_id in (select dir_id from wa))
select mov_title
from movie m inner join wa_movies on m.mov_id = wa_movies.mov_id
```

Without Any Optimization

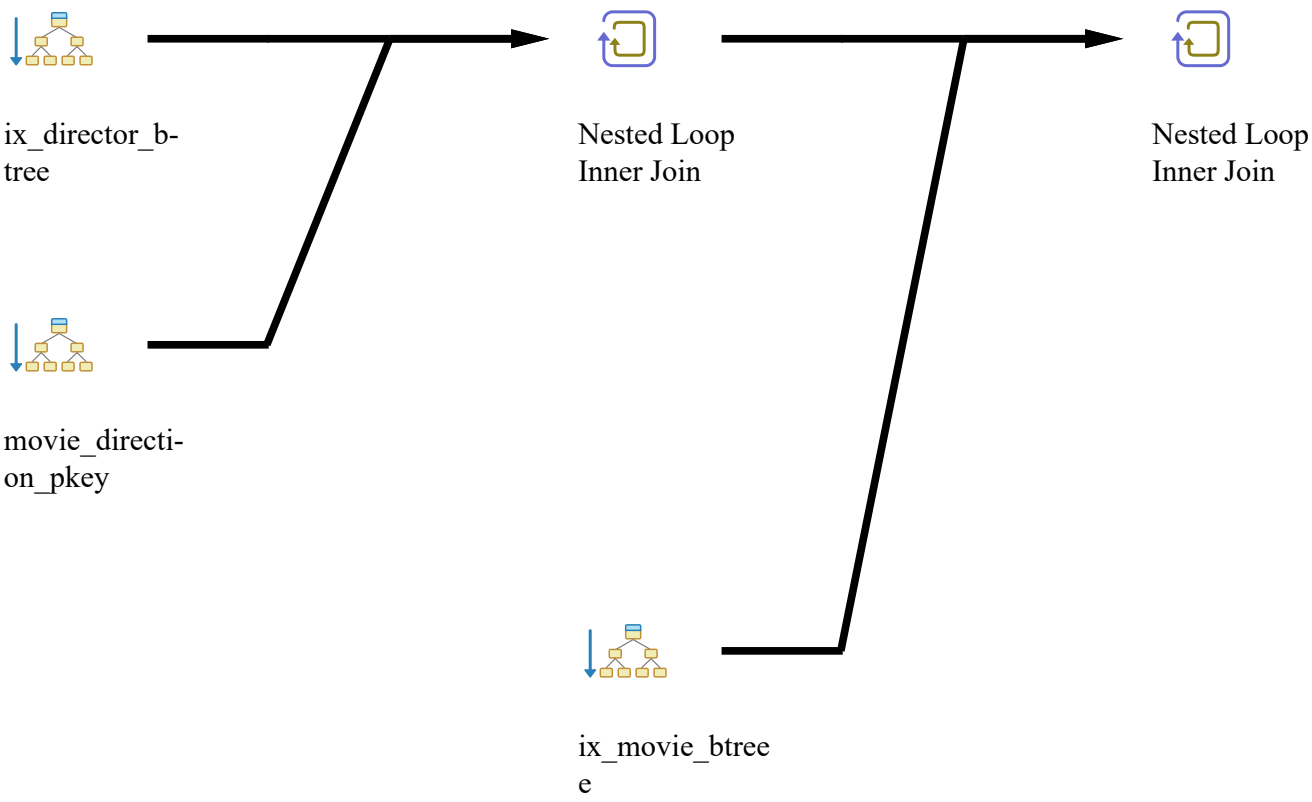
Query returns 351 records



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs Unoptimized	Time vs Unoptimized
0.666ms	0.67ms	0.642ms	0.659ms	0.191ms	153.09	96%	102%

With B-TREE indices

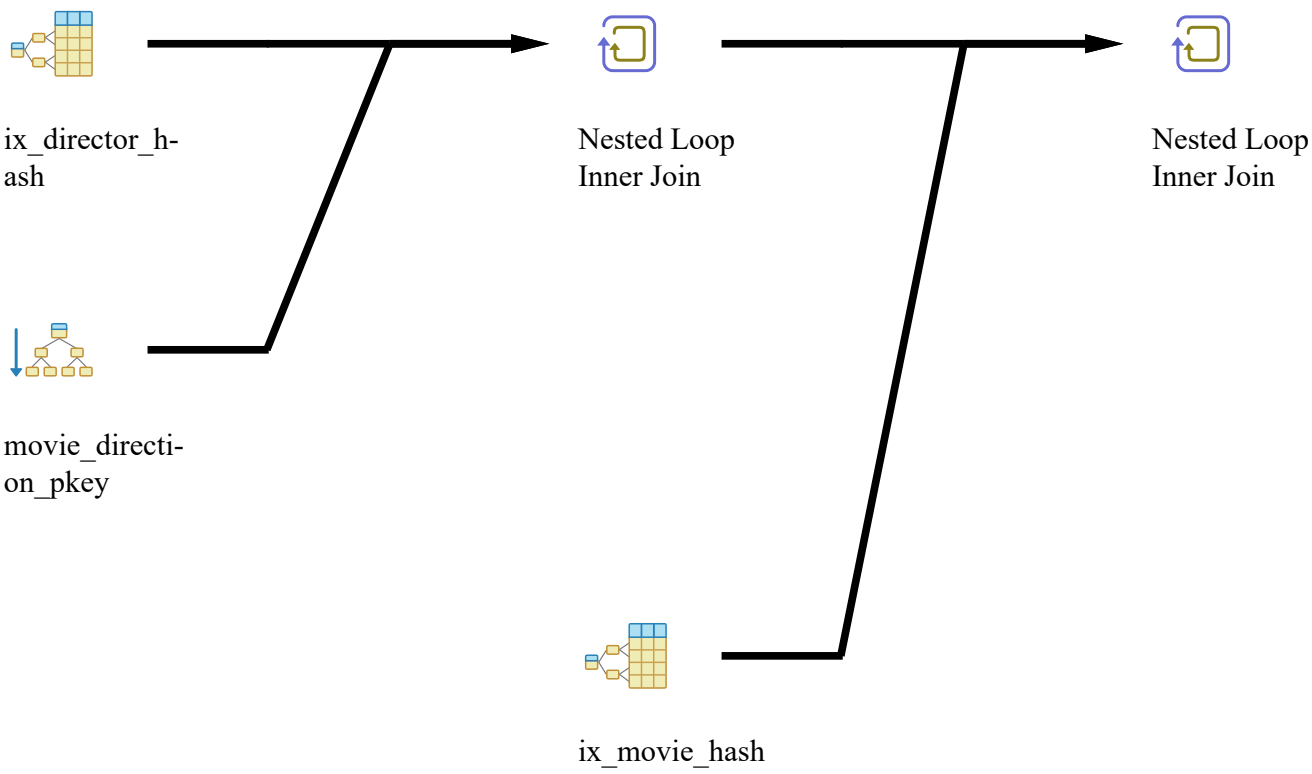
```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("dir_id");
create index "ix_movie_btree" on "movie" using btree ("mov_id") include ("mov_title") ;
create index "ix_director_btree" on "director" using btree ("dir_fname", "dir_lname") include ("dir_id") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.329ms	0.331ms	0.328ms	0.329ms	0.237ms	9.67	6%	50%	74%	99%

With Hash indices

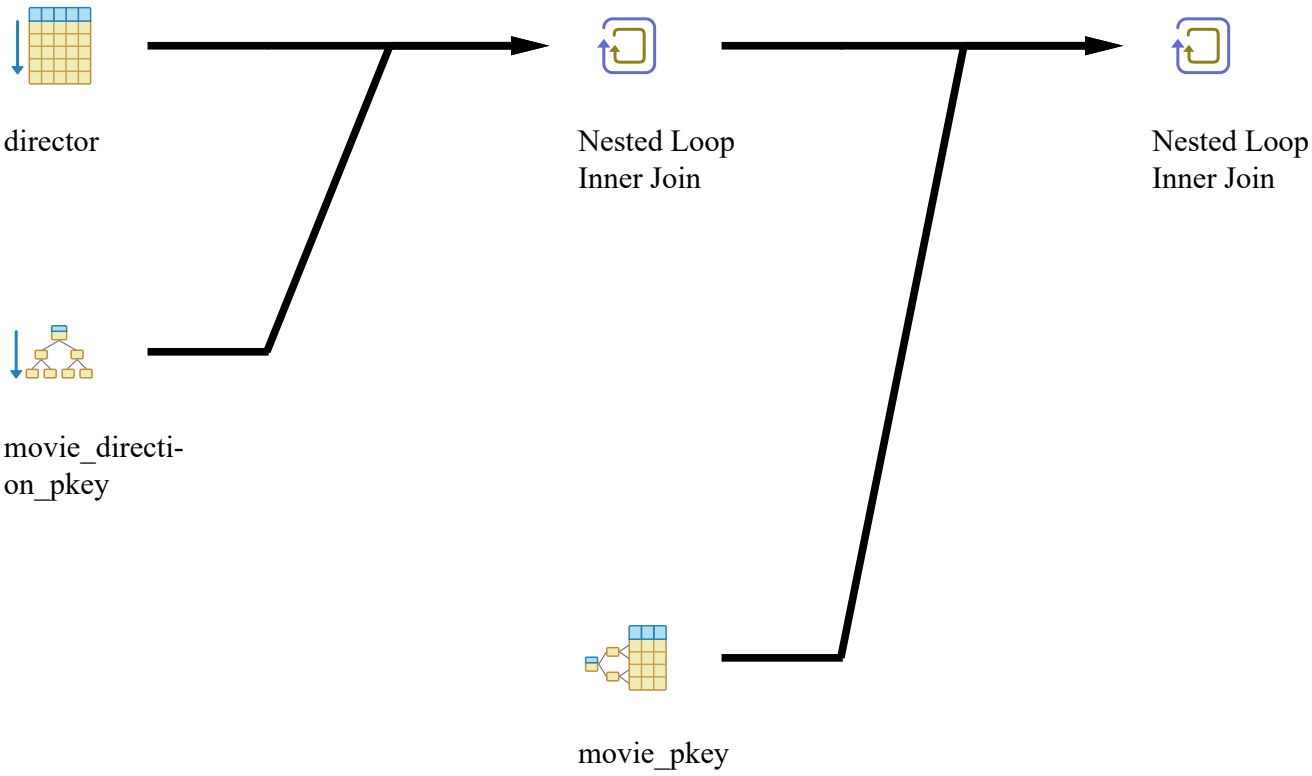
```
create index "ix_movie_direction_hash" on "movie_direction" using hash ("dir_id");
create index "ix_movie_hash" on "movie" using hash ("mov_id");
create index "ix_director_hash" on "director" using hash ("dir_lname");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.567ms	0.61ms	0.413ms	0.53ms	0.249ms	13.97	9%	80%	69%	89%

With BRIN indices

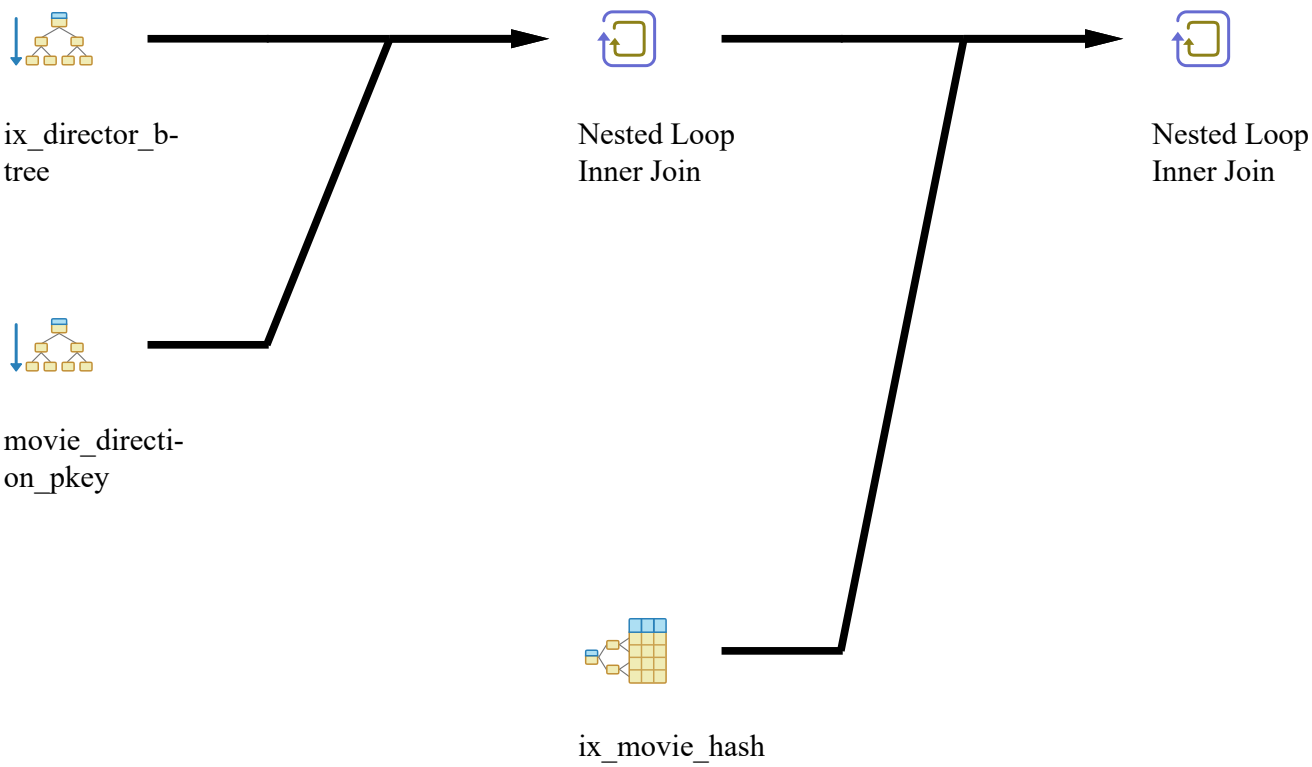
```
create index "ix_movie_direction_brin" on "movie_direction" using brin ("dir_id");
create index "ix_movie_brin" on "movie" using brin ("mov_id");
create index "ix_director_brin" on "director" using brin ("dir_lname");
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.723ms	0.645ms	1.087ms	0.818ms	0.257ms	153.09	100%	124%	96%	129%

With Mixed indices

```
create index "ix_movie_direction_btree" on "movie_direction" using btree ("mov_id");
create index "ix_movie_hash" on "movie" using hash ("mov_id");
create index "ix_director_btree" on "director" using btree ("dir_fname", "dir_lname") include ("dir_id") ;
```



Run 1	Run 2	Run 3	Average	Planning	Cost	Cost vs w/o Indexes	Time vs w/o Indexes	Cost vs Unoptimized	Time vs Unoptimized
0.624ms	0.656ms	0.583ms	0.621ms	0.235ms	10.25	7%	94%	62%	123%

Conclusion

In all queries the B-Tree index performed better than Hash and BRIN indices. B-Tree also had the advantage of supporting an index on multiple columns which is not supported in either Hash or BRIN. Also B-Tree support `include` clause, which can improve the performance by including a column with the index, and therefore making the engine skip the step where it has to lookup the value after using the index.

The Hash index did improve the performance of many queries, however the B-Tree index always performed better.

As for the BRIN index, it had no effect whatsoever on most queries.