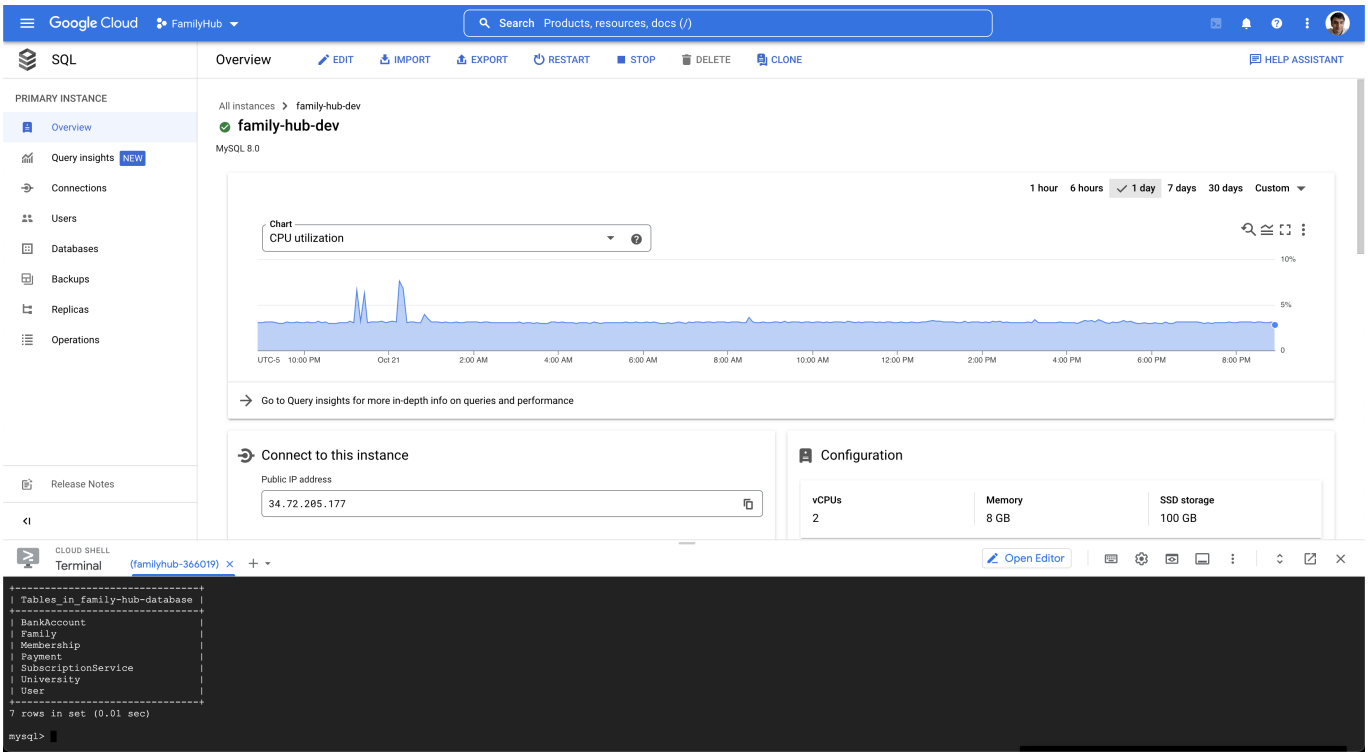
Database Design

The code that we used to populate the tables with simulated data can be found in the `generateDemoData.ipynb` file in this directory.

Proof of Database Connection and Tables Created



Proof of Table Size

```
mysql> select count(*) from Family;
+----------+
| count(*) |
+----------+
|     1000 |
+----------+
1 row in set (0.00 sec)

mysql> select count(*) from User;
+----------+
| count(*) |
+----------+
|     4999 |
+----------+
1 row in set (0.02 sec)

mysql> select count(*) from Membership;
+----------+
| count(*) |
+----------+
|     4000 |
+----------+
1 row in set (0.01 sec)

mysql>
```

DDL Commands

```
CREATE TABLE User (
    userID INT PRIMARY KEY,
    userName VARCHAR(255),
    email VARCHAR(255),
    universityID INT,
    FOREIGN KEY (universityID) REFERENCES University(universityID)
);

CREATE TABLE Family (
    familyID INT PRIMARY KEY,
    leaderID INT,
    accessType VARCHAR(255),
    serviceName VARCHAR(255),
    FOREIGN KEY (leaderID) REFERENCES User(userID),
    FOREIGN KEY (serviceName) REFERENCES SubscriptionService(serviceName)
);

CREATE TABLE SubscriptionService (
    serviceName VARCHAR(255) PRIMARY KEY,
```

```
    price DECIMAL(10,2),
    maxMembers INT
);

CREATE TABLE University (
    universityID INT PRIMARY KEY,
    universityName VARCHAR(255),
    city VARCHAR(255)
);

CREATE TABLE Membership (
    memberID INT,
    familyID INT,
    memberStatus VARCHAR(255),
    PRIMARY KEY (memberID, familyID),
    FOREIGN KEY (memberID) REFERENCES User(userID),
    FOREIGN KEY (familyID) REFERENCES Family(familyID)
);

CREATE TABLE BankAccount (
    accountName VARCHAR(255),
    platform VARCHAR(255),
    userID INT,
    PRIMARY KEY (accountName, platform),
    FOREIGN KEY (userID) REFERENCES User(userID)
);

CREATE TABLE Payment (
    paymentID INT PRIMARY KEY,
    payerID INT,
    recipientID INT,
    amount DECIMAL(10,2),
    paid BIT,
    deadline DATE,
    FOREIGN KEY (payerID) REFERENCES User(userID),
    FOREIGN KEY (recipientID) REFERENCES User(userID)
);
```

Advanced Queries

Query 1

Our first query returns the number of pending user invitations per university. We first join the `University` table with the `User` table, then group by the `universityID`. We order the output by descending number of users.

Code

```
select un.universityName, count(*) as numPending
from University un
natural join User us
```

```
join Membership m
on m.memberID = us.userID
where m.memberStatus = "Pending"
group by un.universityName
order by numPending desc;
```

Result

```
with pool.connect() as con:
    statement = '''
    select un.universityName, count(*) as numPending
    from University un
    natural join User us
    join Membership m
    on m.memberID = us.userID
    where m.memberStatus = "Pending"
    group by un.universityName
    order by numPending desc;
    '''
    result = con.execute(statement).fetchall()
    for row in result:
        print(row)
```

[123] ✓ 0.9s Python

```
('Harper College', 73)
('Northwestern University', 61)
('Yale University', 61)
('University of Illinois at Urbana-Champaign', 60)
('Harvard University', 57)
('Massachusetts Institute of Technology', 57)
```

Initial Performance

Below is the performance of our query without any added indexes. Between each index, we made sure to drop the added index from the previous part, to ensure standardization between comparisons.

```
| -> Sort: numPending DESC  (actual time=3.004..3.004 rows=6 loops=1)
    -> Table scan on <temporary>  (actual time=0.001..0.001 rows=6 loops=1)
        -> Aggregate using temporary table  (actual time=2.958..2.959 rows=6 loops=1)
            -> Nested loop inner join  (cost=683.50 rows=400) (actual time=0.388..2.652 rows=369 loops=1)
                -> Nested loop inner join  (cost=543.50 rows=400) (actual time=0.380..2.345 rows=369 loops=1)
                    -> Filter: (m.memberStatus = 'Pending')  (cost=403.50 rows=400) (actual time=0.365..1.670 rows=369 loops=1)
                        -> Table scan on m  (cost=403.50 rows=4000) (actual time=0.358..1.329 rows=4000 loops=1)
                    -> Filter: (us.universityID is not null)  (cost=0.25 rows=1) (actual time=0.002..0.002 rows=1 loops=369)
                        -> Single-row index lookup on us using PRIMARY (userID=m.memberID)  (cost=0.25 rows=1) (actual time=0.001..0.001 rows=1 loops=369)
                -> Single-row index lookup on un using PRIMARY (universityID=us.universityID)  (cost=0.25 rows=1) (actual time=0.001..0.001 rows=1 loops=369)
 |
+--------------------------------------------------------------------------------------------------------------------------------------------------------------------------
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---+
1 row in set (0.01 sec)
```
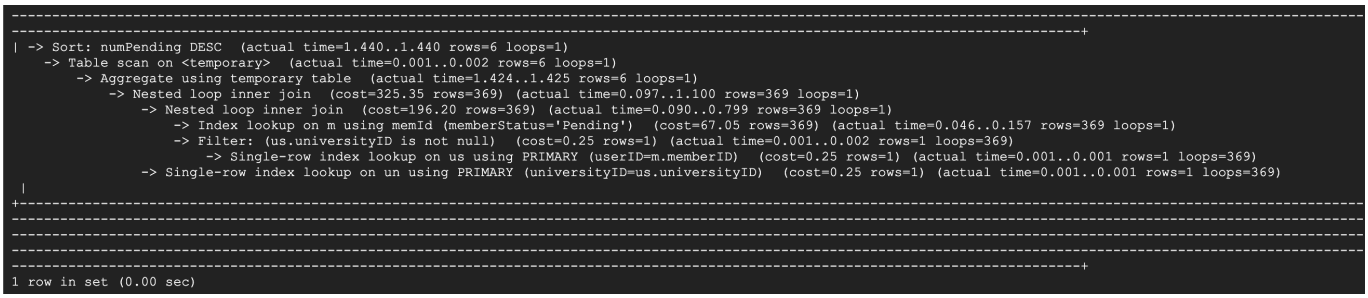

Index 1

For our first index design, we added an index on `Membership.memberStatus` because we filter on that column in the query.

```
alter table Membership add index memId(memberStatus);
```

The output of our analyze query follows:



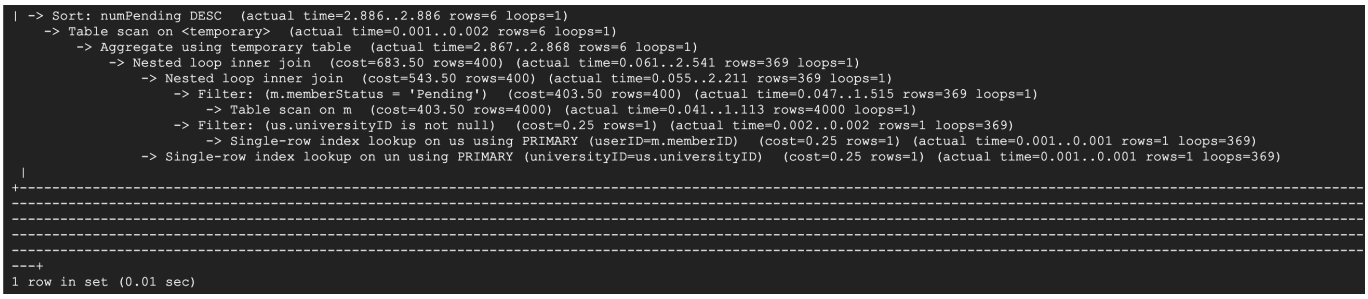
We see a speedup in the "Filter" command that addresses `m.memberStatus = "Pending"`, and an overall speedup in the whole query, so we can conclude that this index is a good optimization to add for this specific query.

Index 2

For our second index design, we added an index on `University.universityName` because we use it in the grouping step of our query.

```
alter table University add index uniName(universityName);
```

The output of our analyze query follows:



We see some marginal performance improvement on the aggregation step of the query, which means that we could still use this index design as well.

Index 3

For our third index design, we added an index on `User.userID`, which is used to join the two tables.

```
alter table User add index useId(userID);
```

The output of our analyze query follows:

```
| EXPLAIN
+--------------------------------------------------------------------------------------------------------------------------------------------------------------
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---------------------------------------------------------------------------------------------------------------------------------------------------------------
| -> Sort: numUsers DESC  (actual time=1.899..1.899 rows=6 loops=1)
    -> Stream results  (cost=962.26 rows=4793) (actual time=0.435..1.885 rows=6 loops=1)
        -> Group aggregate: count(0)  (cost=962.26 rows=4793) (actual time=0.430..1.878 rows=6 loops=1)
            -> Nested loop inner join  (cost=482.96 rows=4793) (actual time=0.105..1.589 rows=4999 loops=1)
                -> Index scan on un using PRIMARY  (cost=0.85 rows=6) (actual time=0.067..0.069 rows=6 loops=1)
                -> Index lookup on us using universityID (universityID=un.universityID)  (cost=13.78 rows=799) (actual time=0.017..0.199 rows=833 loops=6)
 |
+--------------------------------------------------------------------------------------------------------------------------------------------------------------
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---------------------------------------------------------------------------------------------------------------------------------------------------------------
1 row in set (0.01 sec)
```

We again see some improvement in the actual time of both the single iteration and total iteration times of the nested loop inner join. We actually also see speedups in the sort and aggregation processes, so this is also a good index to add for our query.

Query 2

Our second query returns the number of accepted users for every university and subscription service. We begin by joining the `User`, `Membership`, `Family`, `SubscriptionService`, and `University` tables. We then filter by accepted members, and group by both `universityID` and `serviceName`. We order the output by the `universityName` in ascending order and aggregated `numUsers` in descending order. Finally, we limit the length of the output to 15 rows for visualization.

Code

```sql
select un.universityName, ss.serviceName, count(*) as numUsers
from User us
join Membership m
    on m.memberID = us.userID
natural join Family f
natural join SubscriptionService ss
natural join University un
where m.memberStatus = "Accepted"
group by un.universityID, ss.serviceName
order by un.universityName asc, numUsers desc
limit 15;
```

Result

```python
with pool.connect() as con:
    statement = '''
    select un.universityName, ss.serviceName, count(*) as numUsers
    from User us
    join Membership m
        on m.memberID = us.userID
    natural join Family f
    natural join SubscriptionService ss
    natural join University un
    where m.memberStatus = "Accepted"
    group by un.universityID, ss.serviceName
    order by un.universityName asc, numUsers desc
    limit 15;
    '''
    result = con.execute(statement).fetchall()
    for row in result:
        print(row)
```

[118] ✓ 0.1s Python

```
('Harper College', 'Netflix', 135)
('Harper College', 'Spotify', 131)
('Harper College', 'Amazon Prime Video', 126)
('Harper College', 'Hulu', 99)
('Harper College', 'Disney+', 90)
('Harvard University', 'Netflix', 107)
('Harvard University', 'Disney+', 106)
('Harvard University', 'Amazon Prime Video', 100)
('Harvard University', 'Spotify', 100)
('Harvard University', 'Hulu', 93)
('Massachusetts Institute of Technology', 'Spotify', 112)
('Massachusetts Institute of Technology', 'Amazon Prime Video', 104)
('Massachusetts Institute of Technology', 'Netflix', 103)
('Massachusetts Institute of Technology', 'Disney+', 93)
('Massachusetts Institute of Technology', 'Hulu', 93)
```

Initial Performance

Below is the performance of our query without any added indexes. Between each index, we made sure to drop the added index from the previous part, to ensure standardization between comparisons.

```
| -> Limit: 15 row(s)  (actual time=44.573..44.575 rows=15 loops=1)
    -> Sort: un.universityName, numUsers DESC, limit input to 15 row(s) per chunk  (actual time=44.572..44.574 rows=15 loops=1)
        -> Table scan on <temporary>  (actual time=0.002..0.005 rows=30 loops=1)
            -> Aggregate using temporary table  (actual time=44.503..44.508 rows=30 loops=1)
                -> Nested loop inner join  (cost=963.50 rows=400) (actual time=0.252..40.955 rows=3239 loops=1)
                    -> Nested loop inner join  (cost=823.50 rows=400) (actual time=0.246..38.364 rows=3239 loops=1)
                        -> Nested loop inner join  (cost=683.50 rows=400) (actual time=0.223..19.839 rows=3239 loops=1)
                            -> Nested loop inner join  (cost=543.50 rows=400) (actual time=0.171..16.376 rows=3239 loops=1)
                                -> Filter: (m.memberStatus = 'Accepted')  (cost=403.50 rows=400) (actual time=0.059..2.058 rows=3239 loops=1)
                                    -> Table scan on m  (cost=403.50 rows=4000) (actual time=0.056..1.349 rows=4000 loops=1)
                                -> Filter: (f.serviceName is not null)  (cost=0.25 rows=1) (actual time=0.004..0.004 rows=1 loops=3239)
                                    -> Single-row index lookup on f using PRIMARY (familyID=m.familyID)  (cost=0.25 rows=1) (actual time=0.004..0.004 rows=1 loops=3239)
                            -> Single-row index lookup on ss using PRIMARY (serviceName=f.serviceName)  (cost=0.25 rows=1) (actual time=0.001..0.001 rows=1 loops=3239)
                        -> Filter: (us.universityID is not null)  (cost=0.25 rows=1) (actual time=0.005..0.005 rows=1 loops=3239)
                            -> Single-row index lookup on us using PRIMARY (userID=m.memberID)  (cost=0.25 rows=1) (actual time=0.005..0.005 rows=1 loops=3239)
                    -> Single-row index lookup on un using PRIMARY (universityID=us.universityID)  (cost=0.25 rows=1) (actual time=0.001..0.001 rows=1 loops=3239)
 |
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-----------+
1 row in set (0.05 sec)
```
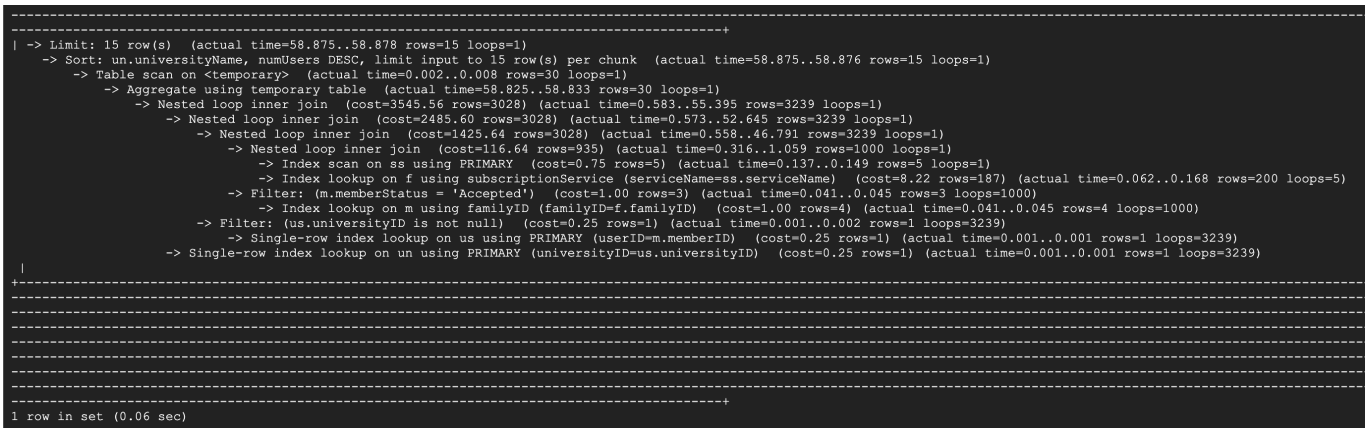

Index 1

For our first index design, we added an index on `Membership.memberStatus` because we filter on that column in the query.

```
alter table Membership add index memId(memberStatus);
```

The output of our analyze query follows:



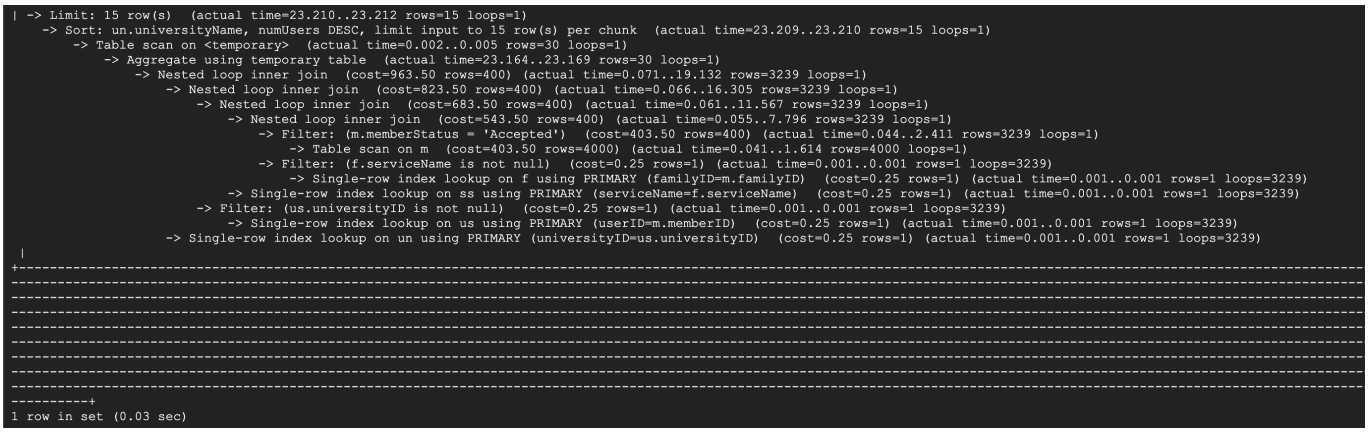
This time around, we find that the new index actually slows down both the individual runtime of our filtering step and the runtime of the overall query, so this would not be a good index to add to optimize our second query.

Index 2

For our second index design, we added an index on `Family.familyID` because it is used to join the `Family` table with the `Membership` table.

```
alter table Family add index famId(familyID);
```

The output of our analyze query follows:



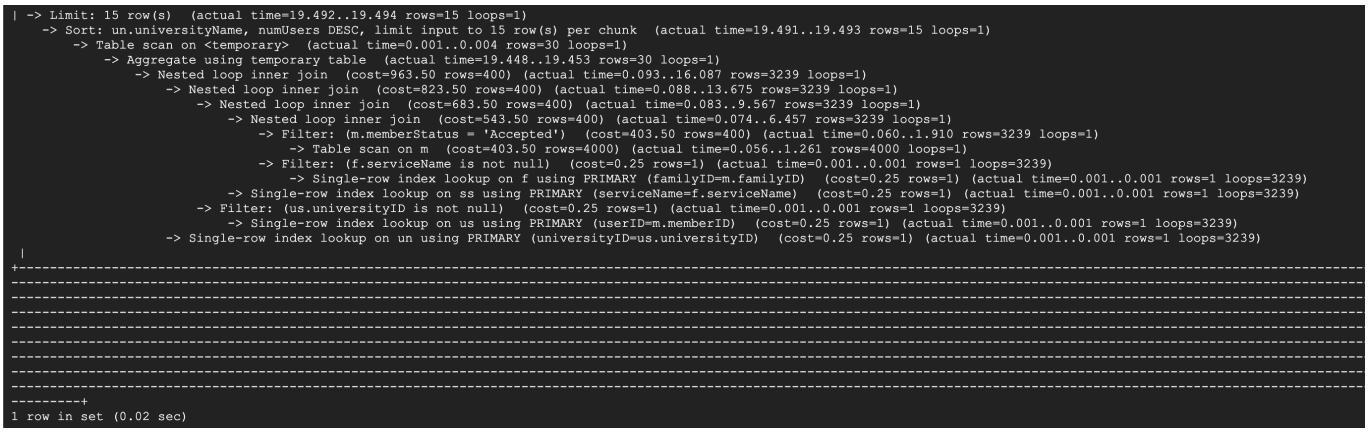
We find a significant improvement from using the new index. There is a cascaded speedup in the runtime of all of the nested inner joins, and a resulting speedup on the overall query as well, shown at the bottom.

Index 3

For our third index design, we tried a similar approach as the previous indexing step, adding an indexing to `Membership.memberID`, which is used in one of the inner joins.

```
alter table Membership add index memId(memberID);
```

The output of our analyze query follows:



We find an even bigger improvement by using the `memberID` index, again both in the several inner joins, and in the query as a whole, more than halving the runtime. As a result, we might next try to implement both indexes at once, to increase the speedup of the query even further, but this would need to be analyzed again to be sure.