Applied Databases

Lecture 8
SQL and Beyond

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Outline

1. More on Aggregates
2. Joins
3. Limits of SQL

From Last Lecture

MySQL is NULL allowed for a primary key attribute?

```
mysql> CREATE TABLE T (a INT PRIMARY KEY, b INT);
mysql> INSERT INTO T VALUES(NULL,1);
ERROR 1048 (23000): Column 'a' cannot be null
mysql>
```

From Last Lecture

Sqlite3

```
sqlite> CREATE TABLE T (a INT PRIMARY KEY, b INT);
sqlite> INSERT INTO T VALUES(1,1);
sqlite> INSERT INTO T VALUES(NULL,1);
sqlite> INSERT INTO T VALUES(NULL,2);
sqlite> SELECT * FROM T;
1|1
|1
|2
sqlite> SELECT a FROM T;


1
sqlite> SELECT DISTINCT a FROM T;

1
sqlite>
```

1. More on Aggregates

```
> SELECT * FROM T;
+------+------+------+
| a1   | a2   | a3   |
+------+------+------+
| a    |    1 |    5 |
| a    |    1 |    2 |
| a    |    2 |    2 |
| a    |    2 |    3 |
+------+------+------+
> SELECT a1, AVG(a3) FROM T GROUP BY a1;

??
```

1. More on Aggregates

```
> SELECT * FROM T;
+------+------+------+
| a1   | a2   | a3   |
+------+------+------+
| a    |    1 |    5 |
| a    |    1 |    2 |
| a    |    2 |    2 |
| a    |    2 |    3 |
+------+------+------+
> SELECT a1, AVG(a3) FROM T GROUP BY a1;
```

(1) take all a3-values and compute average: (5 + 2 + 2 + 3) / 4 = **3**

(2) only (a1,a3) are relevant, so, we project onto (a1,a3) to get

```
+------+------+
| a1   | a3   |
+------+------+
| a    |    5 |
| a    |    2 |
| a    |    3 |
+------+------+
```

average now: (5 + 2 + 3) / 3 = **10 / 3**

1. More on Aggregates

```
> SELECT * FROM T;
+------+------+------+
| a1   | a2   | a3   |
+------+------+------+
| a    |    1 |    5 |
| a    |    1 |    2 |
| a    |    2 |    2 |
| a    |    2 |    3 |
+------+------+------+
> SELECT a1, AVG(a3) FROM T GROUP BY a1;
+------+---------+
| a1   | AVG(a3) |
+------+---------+
| a    |  3.0000 |
+------+---------+
```

→ SQL keeps duplicates

→ thus, solution (1)

1. More on Aggregates

```
> SELECT * FROM T;
+------+------+------+
| a1   | a2   | a3   |
+------+------+------+
| a    |    1 |    5 |
| a    |    1 |    2 |
| a    |    2 |    2 |
| a    |    2 |    3 |
+------+------+------+
> SELECT COUNT(a3) FROM T;
+-----------+
| COUNT(a3) |
+-----------+
|         4 |
+-----------+
> SELECT COUNT(DISTINCT a3) FROM T;
+--------------------+
| COUNT(DISTINCT a3) |
+--------------------+
|                  3 |
+--------------------+
> SELECT SUM(a3) FROM T;
+---------+
| SUM(a3) |
+---------+
|      12 |
+---------+
```

```
> SELECT SUM(DISTINCT a3) FROM T;
+------------------+
| SUM(DISTINCT a3) |
+------------------+
|               10 |
+------------------+


> SELECT MIN(a3) FROM T;

> SELECT MIN(DISTINCT a3) FROM T;
```

Selection Based on Aggregates

```
SELECT     list, of, attributes
FROM       list of tables
WHERE      conditions
GROUP BY   list of attributes
ORDER BY   attribute ASC | DESC
```

cannot contain Aggregates!

Selection Based on Aggregates

```
SELECT     list, of, attributes
FROM       list of tables
WHERE      conditions
GROUP BY   list of attributes
ORDER BY   attribute ASC | DESC
HAVING     AGGREGATE(attribute) operator value
```

→ find directors and average length of their movies, provided they made at least one movie that is longer than 2 hours

```
SELECT   director, AVG(length) FROM Movies
GROUP BY director
HAVING MAX(length) > 120;
```

Selection Based on Aggregates

```
SELECT     list, of, attributes
FROM       list of tables
WHERE      conditions
GROUP BY   list of attributes
ORDER BY   attribute ASC | DESC
HAVING     AGGREGATE(attribute) operator value
```

→ find directors and average length of their movies, provided they made at least one movie that is longer than 2 hours

```
SELECT   director, AVG(length) FROM Movies
GROUP BY director
HAVING MAX(length) > 120;
```

could be a nested query
(e.g., selecting another aggregate!)

Selection Based on Aggregates

- Find movies that are shorter than some currently playing movie:

```
SELECT M.Title
FROM Movies M
WHERE M.length < (SELECT MAX(M1.length)
                  FROM Movies M1, Schedule S
                  WHERE M1.title=S.title)
```

or

```
SELECT M.Title
FROM Movies M
WHERE M.length < ANY(SELECT M1.length
                     FROM Movies M1, Schedule S
                     WHERE M1.title=S.title)
```

Selection Based on Aggregates

- `<value> <condition> ANY ( <query> )`
  is true if for some `<value1>` in the result of `<query>`,
  `<value> <condition> <value1>` is true.

- For example,

  $5 < \texttt{ANY}(\emptyset)$ is false;

  $5 < \texttt{ANY}(\{1, 2, 3, 4\}$ is false;

  $5 < \texttt{ANY}(\{1, 2, 3, 4, 5, 6\}$ is true.

Selection Based on Aggregates

- `<value>  <condition>  ALL ( <query> )` is true if either:
  - `<query>` evaluates to the empty set, or
  - for every `<value1>` in the result of `<query>`, `<value>  <condition>  <value1>` is true.
- For example,

  $5 > \texttt{ALL}(\emptyset)$ is true;

  $5 > \texttt{ALL}(\{1, 2, 3\}$ is true;

  $5 > \texttt{ALL}(\{1, 2, 3, 4, 5, 6\}$ is false.

2. Joins

2. Joins

What is special about databases?

→ transaction processing (data is safe, multi-user support)
→ SQL

What is special about SQL?

→ mature standard
→ widely adopted & used in industry
→ expressiveness and efficiency
  (*) all queries terminate
  (*) data complexity is polynomial time

What is the most important (and expensive) SQL operation?

→ the JOIN

2. Joins

→ for each author, find the number of papers he/she wrote

paper_id author_id (aid)

```
1;1
2;2
3;3
3;4
4;5
5;6
6;7
7;8
7;9
8;10
8;11
9;12
10;13
10;14
10;15
```

WrittenBy table

```
1;Sanjeev Saxena
2;Hans-Ulrich Simon
3;Nathan Goodman
4;Oded Shmueli
5;Norbert Blum
6;Arnold Schonhage
7;Juha Honkala
8;Chua-Huang Huang
9;Christian Lengauer
10;Alain Finkel
11;Annie Choquet
12;Joachim Biskup
13;Symeon Bozapalidis
.
```

Author table

→ naively, takes **quadratic time**:

for each author,
go through WrittenBy table,
and count
his/her number of occurrences.

2. Joins

→ the simplest join is just the Cartesian product.
→ its size is quadratic!

```
SELECT * FROM Numbers;
+------+
| a    |
+------+
|    1 |
|    2 |
|    3 |
|    4 |
+------+
```

```
SELECT * FROM Numbers JOIN Numbers N2;
+------+------+
| a    | a    |
+------+------+
|    1 |    1 |
|    2 |    1 |
|    3 |    1 |
|    4 |    1 |
|    1 |    2 |
|    2 |    2 |
|    3 |    2 |
|    4 |    2 |
|    1 |    3 |
|    2 |    3 |
|    3 |    3 |
|    4 |    3 |
|    1 |    4 |
|    2 |    4 |
|    3 |    4 |
|    4 |    4 |
+------+------+
```

2. Joins

→ the simplest join is just the Cartesian product.
→ its size is quadratic!

```
SELECT * FROM Numbers;
+-------+
| a     |
+-------+
|     1 |
|     2 |
|     3 |
|     4 |
+-------+
```

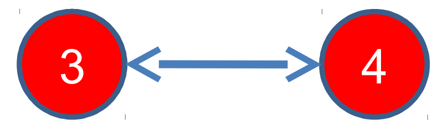
```
SELECT * FROM Numbers, Numbers N2;
+------+------+
| a    | a    |
+------+------+
|    1 |    1 |
|    2 |    1 |
|    3 |    1 |
|    4 |    1 |
|    1 |    2 |
|    2 |    2 |
|    3 |    2 |
|    4 |    2 |
|    1 |    3 |
|    2 |    3 |
|    3 |    3 |
|    4 |    3 |
|    1 |    4 |
|    2 |    4 |
|    3 |    4 |
|    4 |    4 |
+------+------+
```

Co-Author Graph

```
1;1
2;2
3;3
3;4
4;5
5;6
6;7
7;8
7;9
8;10
8;11
9;12
10;13
10;14
10;15
```

```
1;Sanjeev Saxena
2;Hans-Ulrich Simon
3;Nathan Goodman
4;Oded Shmueli
5;Norbert Blum
6;Arnold Schonhage
7;Juha Honkala
8;Chua-Huang Huang
9;Christian Lengauer
10;Alain Finkel
11;Annie Choquet
12;Joachim Biskup
13;Symeon Bozapalidis
.
.
.
```

coauthors



aid	cid
.	
.	
3	4
4	3
.	
.	

CA table =
Co-Author relationship

How can we produce this table?

Co-Author Graph

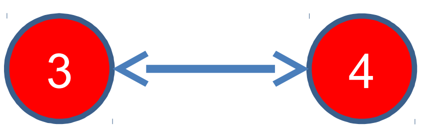
```
1;1
2;2
3;3
3;4
4;5
5;6
6;7
7;8
7;9
8;10
8;11
9;12
10;13
10;14
10;15
```

join

```
1;1
2;2
3;3
3;4
4;5
5;6
6;7
7;8
7;9
8;10
8;11
9;12
10;13
10;14
10;15
```

using (pid)

```
SELECT * FROM
WrittenBy w1 JOIN WrittenBy w2
USING (pid);
+------+------+------+
| pid  | aid  | aid  |
+------+------+------+
|    1 |    1 |    1 |
|    2 |    2 |    2 |
|    3 |    3 |    3 |
|    3 |    4 |    3 |
|    3 |    3 |    4 |
|    3 |    4 |    4 |
|    4 |    5 |    5 |
```



aid	cid
. .	
3	4
4	3
. .	

CA table =
Co-Author relationship

Co-Author Graph

→ exclude self-relations

```
SELECT W1.aid,W2.aid FROM
WrittenBy W1 JOIN WrittenBy W2
USING (pid)
WHERE W1.aid <> W2.aid;
+------+------+
| aid  | aid  |
+------+------+
|    4 |    3 |
|    3 |    4 |
|    9 |    8 |
|    8 |    9 |
|   11 |   10 |
|   10 |   11 |
```

```
SELECT * FROM
WrittenBy W1 JOIN WrittenBy W2
USING (pid);
+------+------+------+
| pid  | aid  | aid  |
+------+------+------+
|    1 |    1 |    1 |
|    2 |    2 |    2 |
|    3 |    3 |    3 |
|    3 |    4 |    3 |
|    3 |    3 |    4 |
|    3 |    4 |    4 |
|    4 |    5 |    5 |
```

Correctly produces the Co-Author Graph!

2. Natural Joins

```
Table1 JOIN Table2 USING (c1, c2, …, cN)
```

→ order depends on implementation. (MySQL)

→ joins all tuples of Table1 and Table2 which *agree* on their c1,..,cN values

→ result table has columns c1,..,cN, followed by the columns of Table1 that are not in { c1,..,cN } followed by the columns of Table2 that are not in { c1,..,cN }

```
SELECT * FROM T1;
+------+------+------+------+
| a    | b    | c    | d    |
+------+------+------+------+
|    1 |    2 |    3 |    1 |
|    4 |    5 |    6 |    2 |
+------+------+------+------+
SELECT * FROM T2;
+------+------+
| d    | e    |
+------+------+
|    1 |    1 |
|    1 |    2 |
|    2 |    4 |
|    2 |    7 |
+------+------+
```

```
SELECT * FROM T1 JOIN T2 USING (d);
+------+------+------+------+------+
| d    | a    | b    | c    | e    |
+------+------+------+------+------+
|    1 |    1 |    2 |    3 |    1 |
|    1 |    1 |    2 |    3 |    2 |
|    2 |    4 |    5 |    6 |    4 |
|    2 |    4 |    5 |    6 |    7 |
+------+------+------+------+------+
```

2. Joins

```
T1 JOIN T2 ON (T1.c1=T2.d1 AND T1.c2<=T2.d2 OR NOT( … ))
```

→ joins all tuples of Table1 and Table2 which *satisfy* join condition

→ result table has all columns of Table1
followed by all columns of Table2

```
SELECT * FROM T1 JOIN T2 ON (T1.d=T2.d);
+------+------+------+------+------+------+
| a    | b    | c    | d    | d    | e    |
+------+------+------+------+------+------+
|    1 |    2 |    3 |    1 |    1 |    1 |
|    1 |    2 |    3 |    1 |    1 |    2 |
|    4 |    5 |    6 |    2 |    2 |    4 |
|    4 |    5 |    6 |    2 |    2 |    7 |
+------+------+------+------+------+------+
```

duplicate d-column

2. Joins

→ joins are quite powerful!
→ E.g. simulate **GROUP BY** through a join:

```
SELECT * FROM T;
+------+
| a    |
+------+
|    1 |
|    1 |
|    2 |
|    2 |
|    2 |
|    3 |
+------+
```

```
SELECT a,COUNT(a) FROM T GROUP BY a;
+------+----------+
| a    | COUNT(a) |
+------+----------+
|    1 |        2 |
|    2 |        3 |
|    3 |        1 |
+------+----------+
```

```
SELECT DISTINCT T1.a, (SELECT COUNT(T2.a)
    FROM T T2 WHERE T2.a=T1.a) AS Count
FROM T T1;
+------+-------+
| a    | Count |
+------+-------+
|    1 |     2 |
|    2 |     3 |
|    3 |     1 |
+------+-------+
```

2. Joins

→ joins are quite powerful!
→ E.g. simulate **GROUP BY** through a join:

```
SELECT * FROM T;
+-------+
| a     |
+-------+
|     1 |
|     1 |
|     2 |
|     2 |
|     2 |
|     3 |
+-------+
```

→ why is it a join?
→ can you rewrite the query to use **JOIN** keyword?

```
SELECT DISTINCT T1.a, (SELECT COUNT(T2.a)
    FROM T T2 WHERE T2.a=T1.a) AS Count
FROM T T1;
+-------+-------+
| a     | Count |
+-------+-------+
|     1 |     2 |
|     2 |     3 |
|     3 |     1 |
+-------+-------+
```

2. Joins

→ joins are quite powerful!
→ E.g. simulate **GROUP BY** through a join:

```
SELECT * FROM T;
+-------+
| a     |
+-------+
|     1 |
|     1 |
|     2 |
|     2 |
|     2 |
|     3 |
+-------+
```

→ similarly, you can avoid **HAVING** by the use of a JOIN

→ do you see how ?

```
SELECT DISTINCT T1.a, (SELECT COUNT(T2.a)
    FROM T T2 WHERE T2.a=T1.a) AS Count
FROM T T1;
+------+-------+
| a    | Count |
+------+-------+
|    1 |     2 |
|    2 |     3 |
|    3 |     1 |
+------+-------+
```

Outer Joins

```
SELECT * FROM Author;
+-----+------+
| aid | name |
+-----+------+
|   1 | ab   |
|   2 | cd   |
|   3 | ef   |
+-----+------+
SELECT * FROM Book;
+-----+------+
| bid | aid  |
+-----+------+
|   1 |    1 |
|   2 |    1 |
|   3 |    3 |
+-----+------+
```

```
SELECT * FROM Book JOIN Author USING (aid);
+------+-----+------+
| aid  | bid | name |
+------+-----+------+
|    1 |   1 | ab   |
|    1 |   2 | ab   |
|    3 |   3 | ef   |
+------+-----+------+
```

Author “2” not listed,
because he/she not in the Book-table.

Outer Joins

```
SELECT * FROM Author;
+-----+------+
| aid | name |
+-----+------+
|   1 | ab   |
|   2 | cd   |
|   3 | ef   |
+-----+------+
SELECT * FROM Book;
+-----+------+
| bid | aid  |
+-----+------+
|   1 |    1 |
|   2 |    1 |
|   3 |    3 |
+-----+------+
```

```
SELECT * FROM Book JOIN Author USING (aid);
+------+-----+------+
| aid  | bid | name |
+------+-----+------+
|    1 |   1 | ab   |
|    1 |   2 | ab   |
|    3 |   3 | ef   |
+------+-----+------+
```

```
SELECT * FROM Book RIGHT OUTER JOIN
              Author USING (aid);
+-----+------+------+
| aid | name | bid  |
+-----+------+------+
|   1 | ab   |    1 |
|   1 | ab   |    2 |
|   2 | cd   | NULL |
|   3 | ef   |    3 |
+-----+------+------+
```

Outer Joins

```
SELECT * FROM Author;
+-----+------+
| aid | name |
+-----+------+
|   1 | ab   |
|   2 | cd   |
|   3 | ef   |
+-----+------+
SELECT * FROM Book;
+-----+------+
| bid | aid  |
+-----+------+
|   1 |    1 |
|   2 |    1 |
|   3 |    3 |
+-----+------+
```

```
SELECT * FROM Book RIGHT OUTER JOIN
             Author USING (aid);
+-----+------+------+
| aid | name | bid  |
+-----+------+------+
|   1 | ab   |    1 |
|   1 | ab   |    2 |
|   2 | cd   | NULL |
|   3 | ef   |    3 |
+-----+------+------+
```

```
SELECT aid,count(bid) AS n_books
FROM Book RIGHT OUTER JOIN
   Author USING (aid)
GROUP BY aid;
+-----+---------+
| aid | n_books |
+-----+---------+
|   1 |       2 |
|   2 |       0 |
|   3 |       1 |
+-----+---------+
```

Outer Joins

```
mysql> SELECT * FROM T;
+------+
| a    |
+------+
|    1 |
|    2 |
|    3 |
| NULL |
+------+
```

```
mysql> SELECT * FROM T, T t2;
+------+------+
| a    | a    |
+------+------+
|    1 |    1 |
|    2 |    1 |
|    3 |    1 |
| NULL |    1 |
|    1 |    2 |
|    2 |    2 |
|    3 |    2 |
| NULL |    2 |
|    1 |    3 |
|    2 |    3 |
|    3 |    3 |
| NULL |    3 |
|    1 | NULL |
|    2 | NULL |
|    3 | NULL |
| NULL | NULL |
+------+------+
16 rows in set (0.00 sec)
```

```
mysql> SELECT t1.a,COUNT(t2.a)
         FROM T t1, T t2 GROUP BY a;
+------+-------------+
| a    | count(t2.a) |
+------+-------------+
| NULL |           3 |
|    1 |           3 |
|    2 |           3 |
|    3 |           3 |
+------+-------------+
```

Not counted

Outer Joins

```
mysql> SELECT * FROM T;
+-------+
| a     |
+-------+
|     1 |
|     2 |
|     3 |
| NULL  |
+-------+
```

```
mysql> SELECT * FROM T JOIN T t2 USING (a);
+-------+
| a     |
+-------+
|     1 |
|     2 |
|     3 |
+-------+
3 rows in set (0.02 sec)
```

Outer Joins

```
Table1 RIGHT OUTER JOIN Table2 USING / ON ...
```

→ joins all tuples of Table1 with Table2 satisfying join condition, plus all remaining tuples from Table2 (the RIGHT)

→ result tuples of the second type above have **NULL-values** in the columns coming from Table1.

Outer Joins

```
Table1 RIGHT OUTER JOIN Table2 USING / ON ...
```

→ joins all tuples of Table1 with Table2 satisfying join condition, plus all remaining tuples from Table2 (the RIGHT)

→ result tuples of the second type above have **NULL-values** in the columns coming from Table1.

```
Table1 LEFT OUTER JOIN Table2 USING / ON ...
```

→ joins all tuples of Table1 with Table2 satisfying join condition, plus all remaining tuples from Table1 (the LEFT)

→ result tuples of the second type above have **NULL-values** in the columns coming from Table2.

Outer Joins

```
SELECT * FROM Part;
+---------+---------+
| part_id | supp_id |
+---------+---------+
| P1      | S1      |
| P2      | S2      |
| P3      | NULL    |
| P4      | NULL    |
+---------+---------+

SELECT * from Supplier;
+---------+-------------+
| supp_id | supp_name   |
+---------+-------------+
| S1      | Supplier#1 |
| S2      | Supplier#2 |
| S3      | Supplier#3 |
+---------+-------------+
```

Join on all common attributes

```
SELECT * FROM Part NATURAL JOIN Supplier;
+---------+---------+-------------+
| supp_id | part_id | supp_name   |
+---------+---------+-------------+
| S1      | P1      | Supplier#1 |
| S2      | P2      | Supplier#2 |
+---------+---------+-------------+
```

Left Outer Join

```
SELECT * FROM Part;
+---------+---------+
| part_id | supp_id |
+---------+---------+
| P1      | S1      |
| P2      | S2      |
| P3      | NULL    |
| P4      | NULL    |
+---------+---------+

SELECT * from Supplier;
+---------+-------------+
| supp_id | supp_name   |
+---------+-------------+
| S1      | Supplier#1 |
| S2      | Supplier#2 |
| S3      | Supplier#3 |
+---------+-------------+
```

```
SELECT part_id,supp_name FROM
Part NATURAL LEFT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| P3      | NULL        |
| P4      | NULL        |
+---------+-------------+
```

Right Outer Join

```
SELECT * FROM Part;
+---------+---------+
| part_id | supp_id |
+---------+---------+
| P1      | S1      |
| P2      | S2      |
| P3      | NULL    |
| P4      | NULL    |
+---------+---------+

SELECT * from Supplier;
+---------+-------------+
| supp_id | supp_name   |
+---------+-------------+
| S1      | Supplier#1 |
| S2      | Supplier#2 |
| S3      | Supplier#3 |
+---------+-------------+
```

```
SELECT part_id,supp_name FROM
Part NATURAL LEFT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| P3      | NULL        |
| P4      | NULL        |
+---------+-------------+
```

```
SELECT part_id,supp_name FROM
Part NATURAL RIGHT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| NULL    | Supplier#3 |
+---------+-------------+
```

Full Outer Join

```
SELECT * FROM Part;
+---------+---------+
| part_id | supp_id |
+---------+---------+
| P1      | S1      |
| P2      | S2      |
| P3      | NULL    |
| P4      | NULL    |
+---------+---------+

SELECT * from Supplier;
+---------+-------------+
| supp_id | supp_name   |
+---------+-------------+
| S1      | Supplier#1  |
| S2      | Supplier#2  |
| S3      | Supplier#3  |
+---------+-------------+
```

```
Part NATURAL LEFT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1  |
| P2      | Supplier#2  |
| P3      | NULL        |
| P4      | NULL        |
+---------+-------------+
```

```
Part NATURAL RIGHT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1  |
| P2      | Supplier#2  |
| NULL    | Supplier#3  |
+---------+-------------+
```

```
Part NATURAL FULL OUTER JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1  |
| P2      | Supplier#2  |
| P3      | NULL        |
| P4      | NULL        |
| NULL    | Supplier#3  |
+---------+-------------+
```

Full Outer Join

```
SELECT * FROM Part;
+---------+---------+
| part_id | supp_id |
+---------+---------+
| P1      | S1      |
| P2      | S2      |
| P3      | NULL    |
| P4      | NULL    |
+---------+---------+

SELECT * from Supplier;
+---------+-------------+
| supp_id | supp_name   |
+---------+-------------+
| S1      | Supplier#1 |
| S2      | Supplier#2 |
| S3      | Supplier#3 |
+---------+-------------+
```

- → no full outer join in **mysql**
- → write a query that does full outer join

```
Part NATURAL LEFT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| P3      | NULL        |
| P4      | NULL        |
+---------+-------------+
```

```
Part NATURAL RIGHT JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| NULL    | Supplier#3 |
+---------+-------------+
```

```
Part NATURAL FULL OUTER JOIN Supplier;
+---------+-------------+
| part_id | supp_name   |
+---------+-------------+
| P1      | Supplier#1 |
| P2      | Supplier#2 |
| P3      | NULL        |
| P4      | NULL        |
| NULL    | Supplier#3 |
+---------+-------------+
```

2. Joins

→ outer joins can be useful to efficiently implement other queries!

→ efficiency of joins?
(*) nested loop
(*) sort merge
(*) hash join

→ intermediate result sizes can be HUGE

→ query performance often depends on how you write the query!
(difficult problem)

→ create indexes on all columns on which you join!

Sort Merge Join

already sorted

```
1;1
2;2
3;3
3;4
4;5
5;6
6;7
7;8
7;9
8;10
8;11
9;12
10;13
10;14
10;15
```

sort

```
1;1
57;1
1089;1
49018;1
2;2
3784;2
992;2
3;3
10193;3
.
.
.
```

```
1;Sanjeev Saxena
2;Hans-Ulrich Simon
3;Nathan Goodman
4;Oded Shmueli
5;Norbert Blum
6;Arnold Schonhage
7;Juha Honkala
8;Chua-Huang Huang
9;Christian Lengauer
10;Alain Finkel
11;Annie Choquet
12;Joachim Biskup
13;Symeon Bozapalidis
.
```

pick up join results in
one top-down traversal on both tables

Sort Merge Join

→ a **B-tree index** is nothing else but a SORTED search-tree that behaves well on disk

→ even having such sorted **B-tree indexes**, efficient join processing remains a tremendous challenge

E.g. **in which order** to apply joins?

(SELECT … FROM ..) JOIN (SELECT … FROM ..) JOIN
(SELECT …)

Smallest result?

→ histograms & approximations!

Sort Order

→ can cause the query to run

few seconds, or a day ...

→ absolutely crucial to determine good join order!

(SELECT … FROM ..) JOIN (SELECT … FROM ..) JOIN
(SELECT …)

Smallest result?

→ histograms & approximations!

3. Limits of SQL

In a graph, determine if two given nodes A,B are connected.

3. Limits of SQL

aid	cid
.	
.	
3	4
4	3
.	
.	

table CA

In a graph, determine if two given nodes A,B are connected.

What we can do in SQL:

1) determine all nodes at distance 1 from A:

(SELECT cid FROM CA WHERE aid=A) =CA0

2) apply to this set of nodes the same query

SELECT cid FROM CA WHERE aid IN CA0 – { A } =CA1

This determines all nodes at distance two.

3) SELECT …. aid IN CA1 – CA0;

→ after **k** such queries we have nodes at distance **k**.

3. Limits of SQL

On the given Co-Author Graph CA (1.6 million nodes, 6.7 million edges):

→ for ONE AUTHOR feasalbe: takes ca 5 minutes (on a laptop)

But, find distance for EVERY PAIR OF AUTHORS
is infeasible.

1.6 million authors.
1.6 * 1.6 million numbers to compute. Storage: **2.5 TB**

(probably >>1 year to compute)

```
SELECT 1.0*COUNT(*)/(2* (SELECT COUNT(distinct aid) from CA));
4.37035511508065
```

3. Limits of SQL

→ distance for EVERY PAIR OF AUTHORS

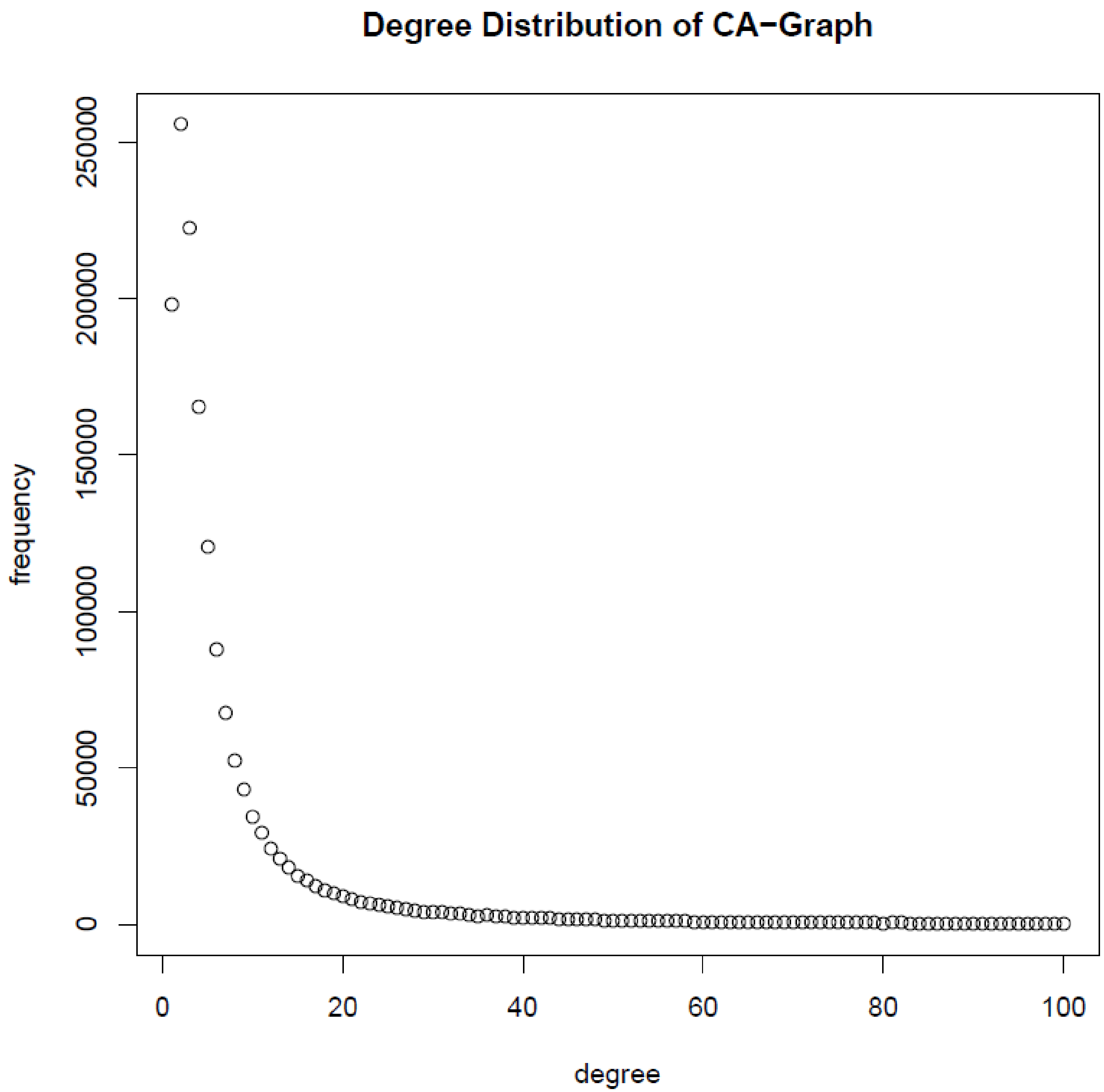
→ is between 0 and 17

Degree Distribution?
→ follows a POWER LAW! (such as Zipf Distribution!)

Average?

Mean / mode?

Power Law



node degree (= number of outgoing edges) was computed for all nodes.

→ formulate a SQL query (over CA) that does this!

Power Law

$y = ax^{b}$

$\log(y) = \log(a) + b \log(x)$

$y = \log(a) + bX$

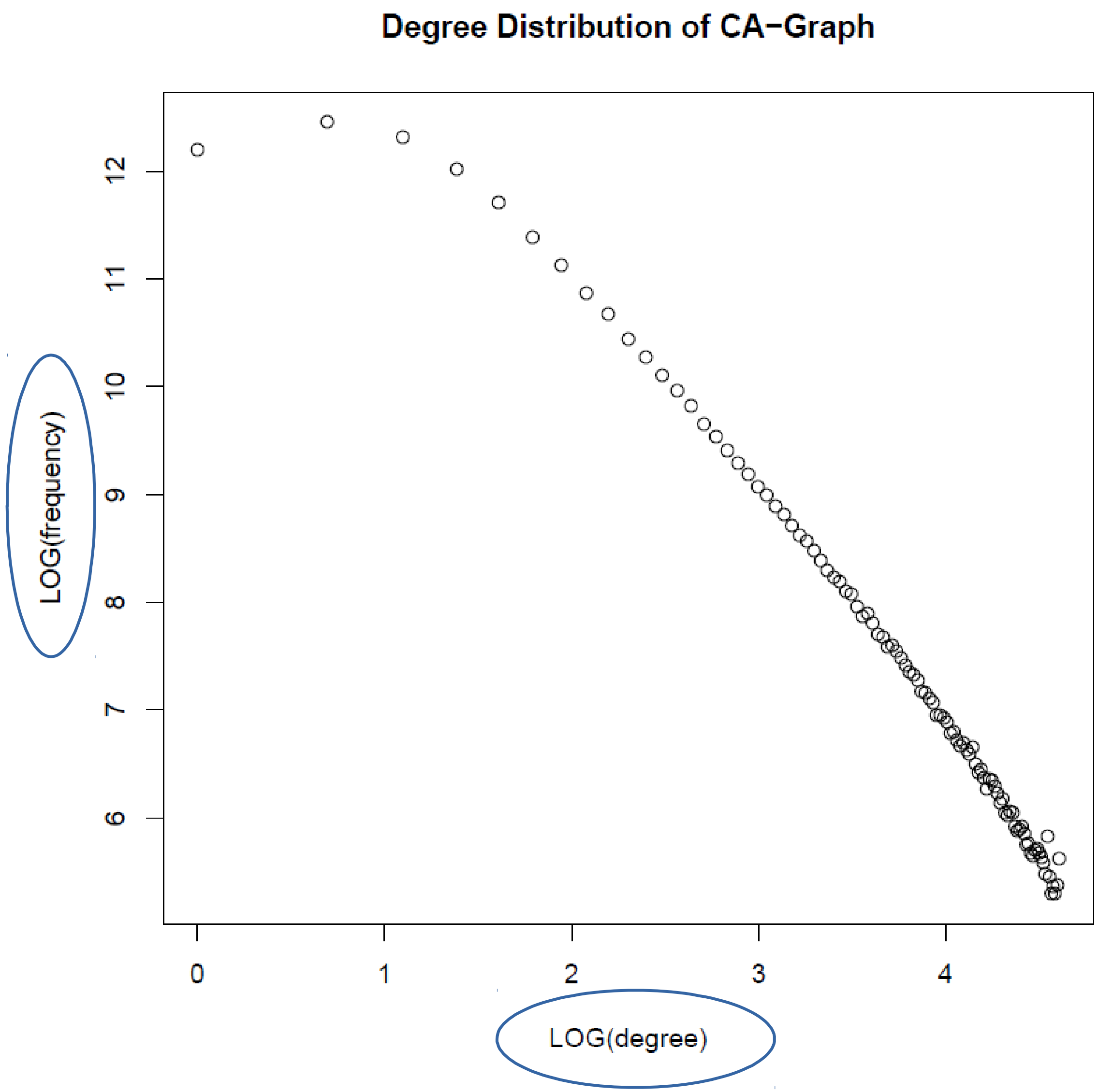
a line

e.g., typical Zipf could be:

N
N/2
N/3
N/4
N/5
N/6
.
.
.

($a = 1$, $b = -1$)

Power Law

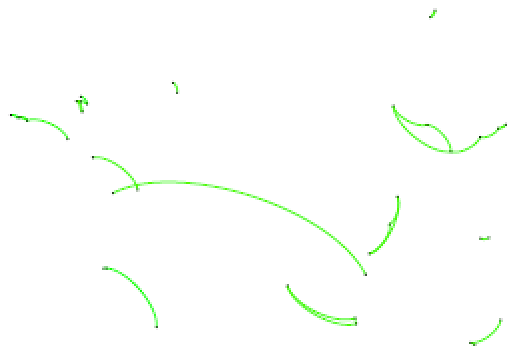

Degree Distribution of CA−Graph
12
11
10
9
8
7
6
LOG(frequency)
0
1
2
3
4
LOG(degree)

Dynamics of the Co-Author Graph

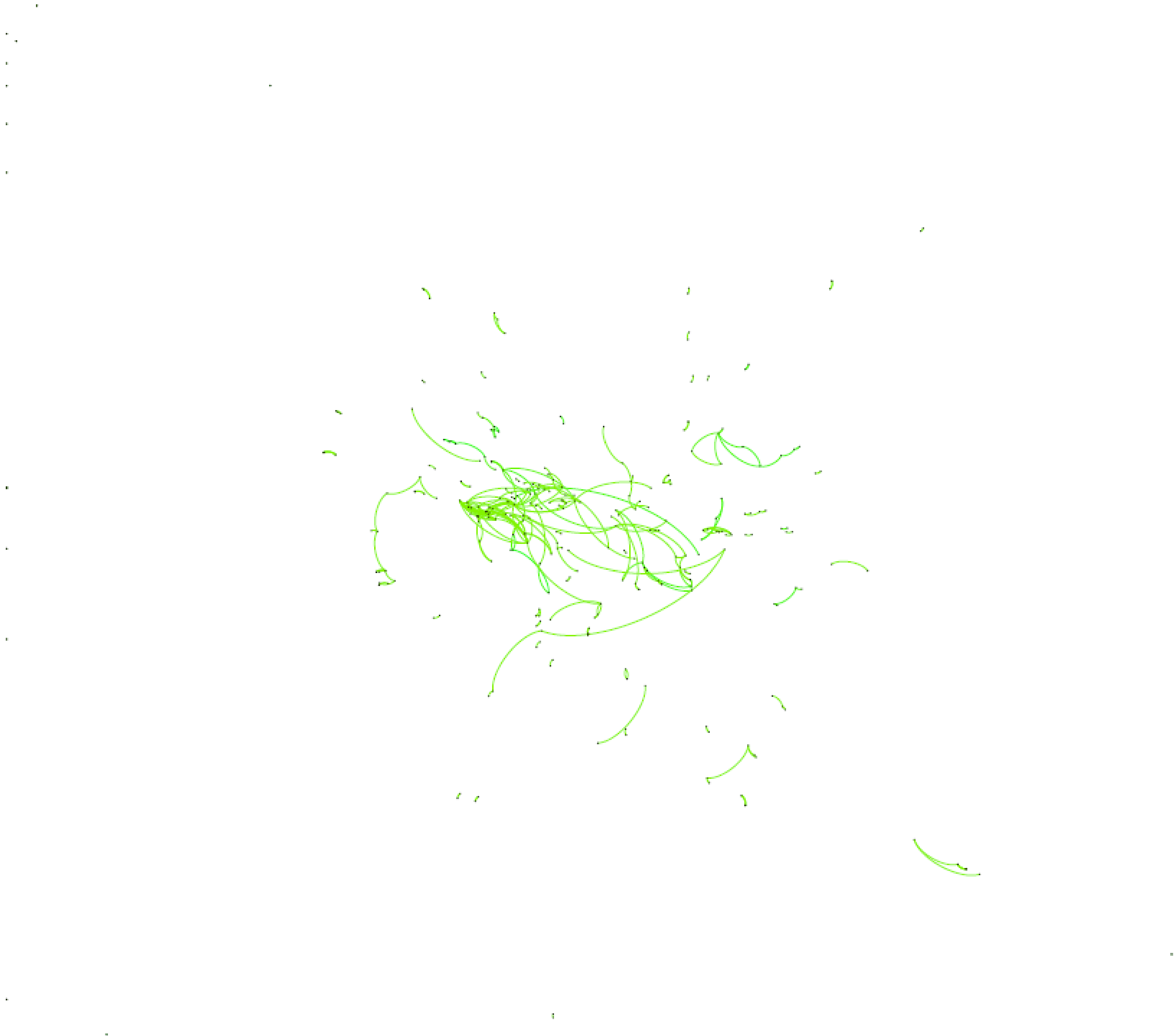
```
SELECT DISTINCT W1.aid, W2.aid
FROM Paper P, WrittenBy W1 join WrittenBy W2 on W1.pid=W2.pid
WHERE W1.aid<>W2.aid AND
P.pid=W1.pid and P.year<=1955;
```

1955 version of CoAuthor Graph
1960
1965
.
.
.
1995

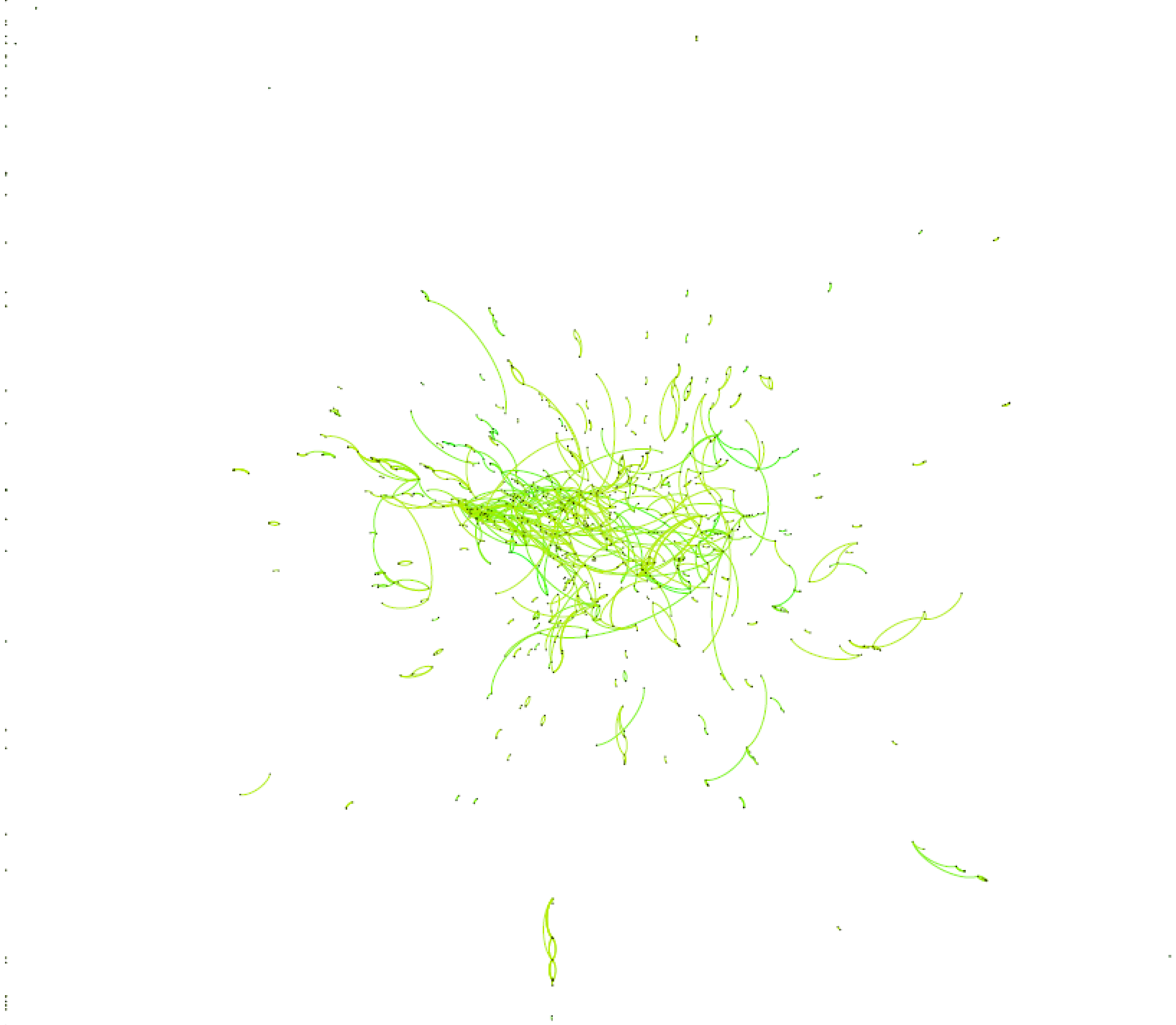
1955



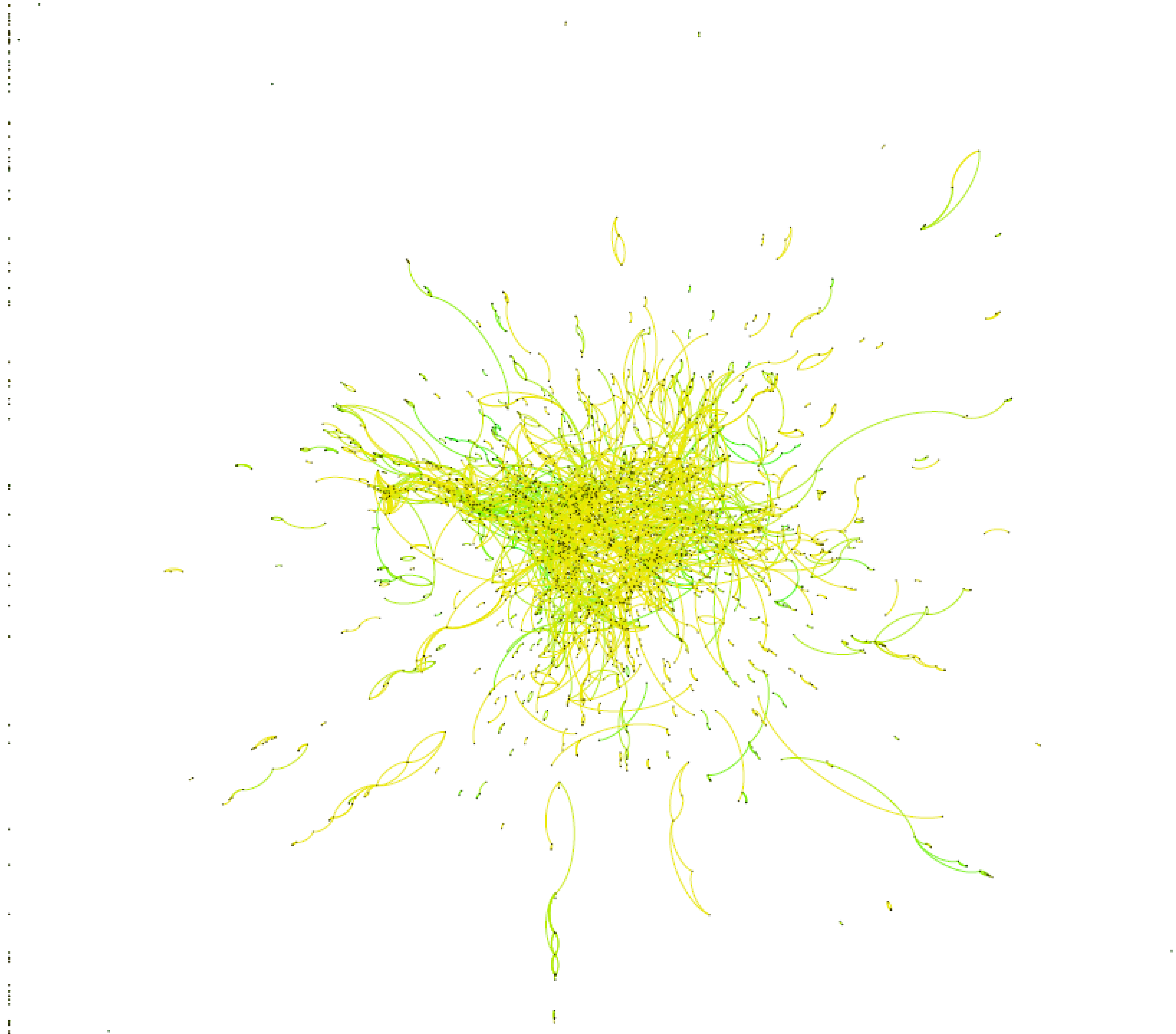
1960



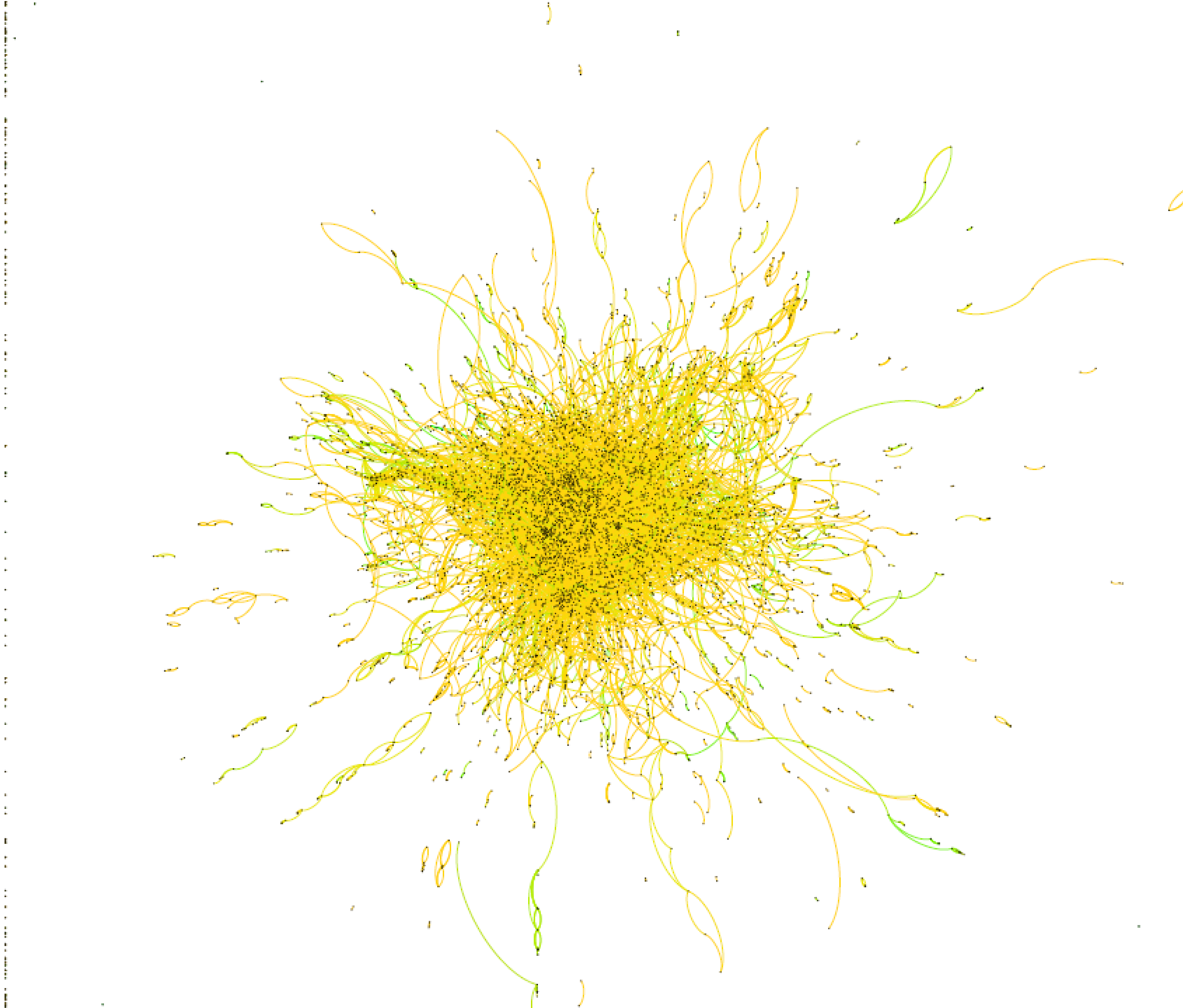
1965



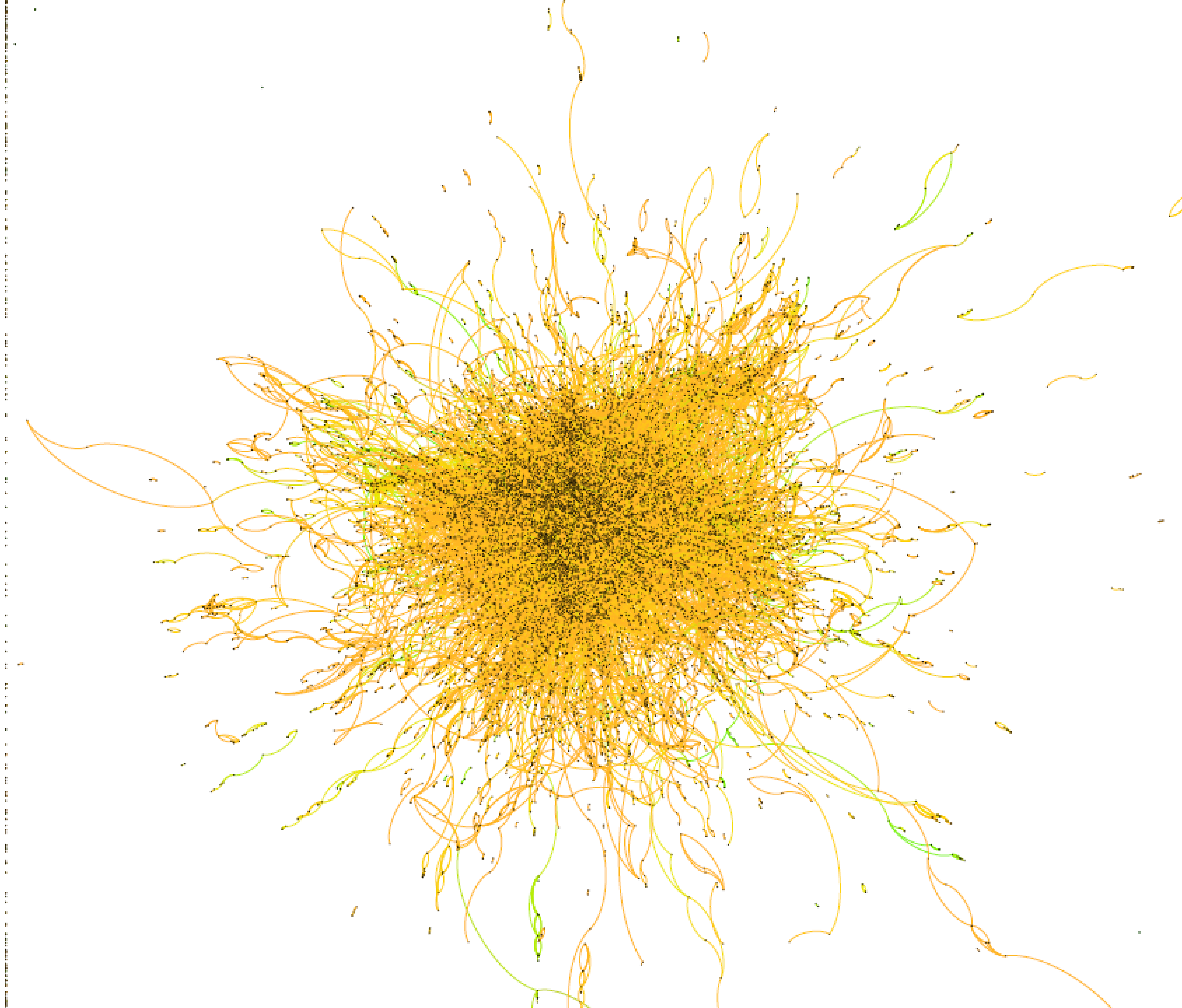
1970



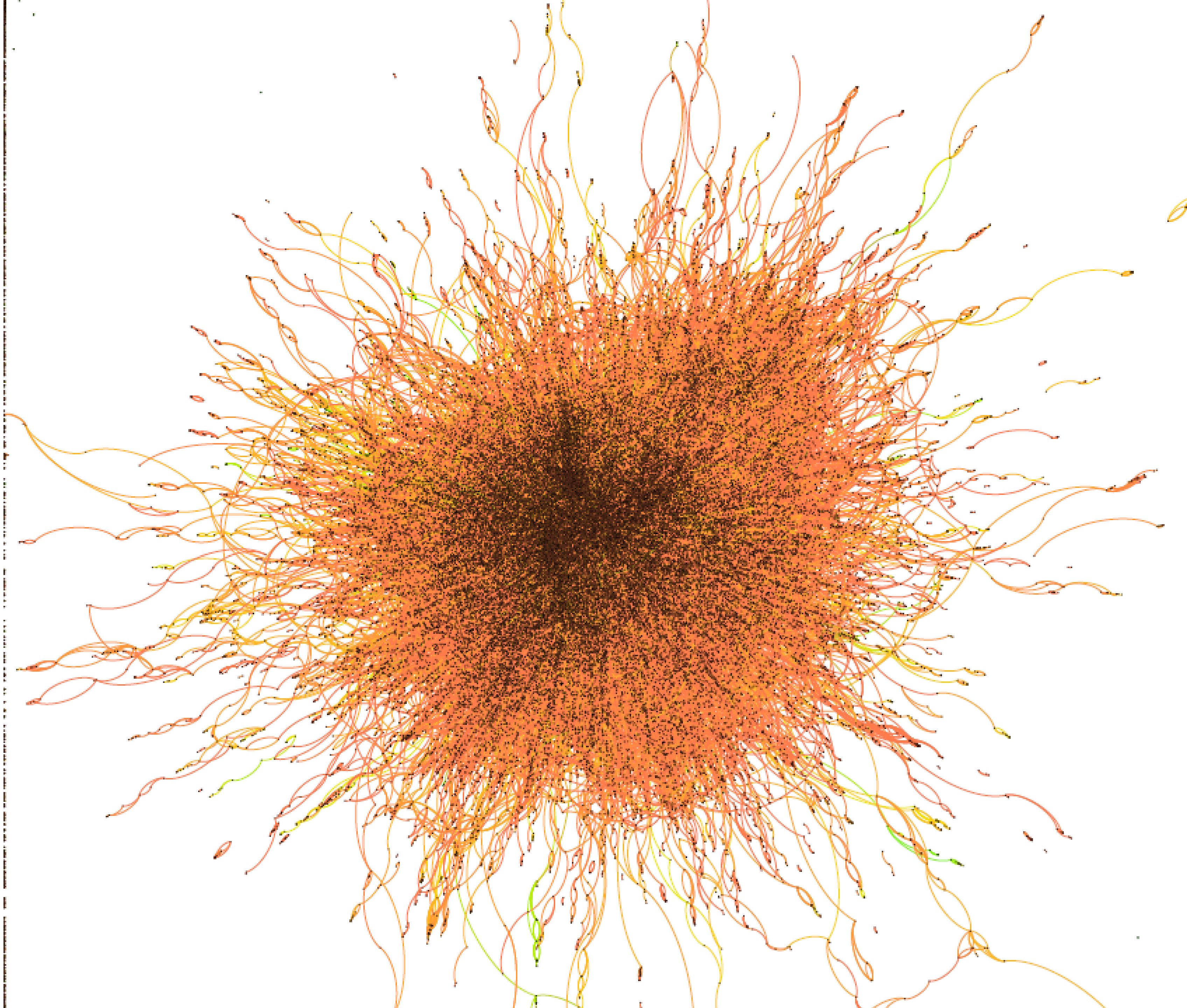
1975



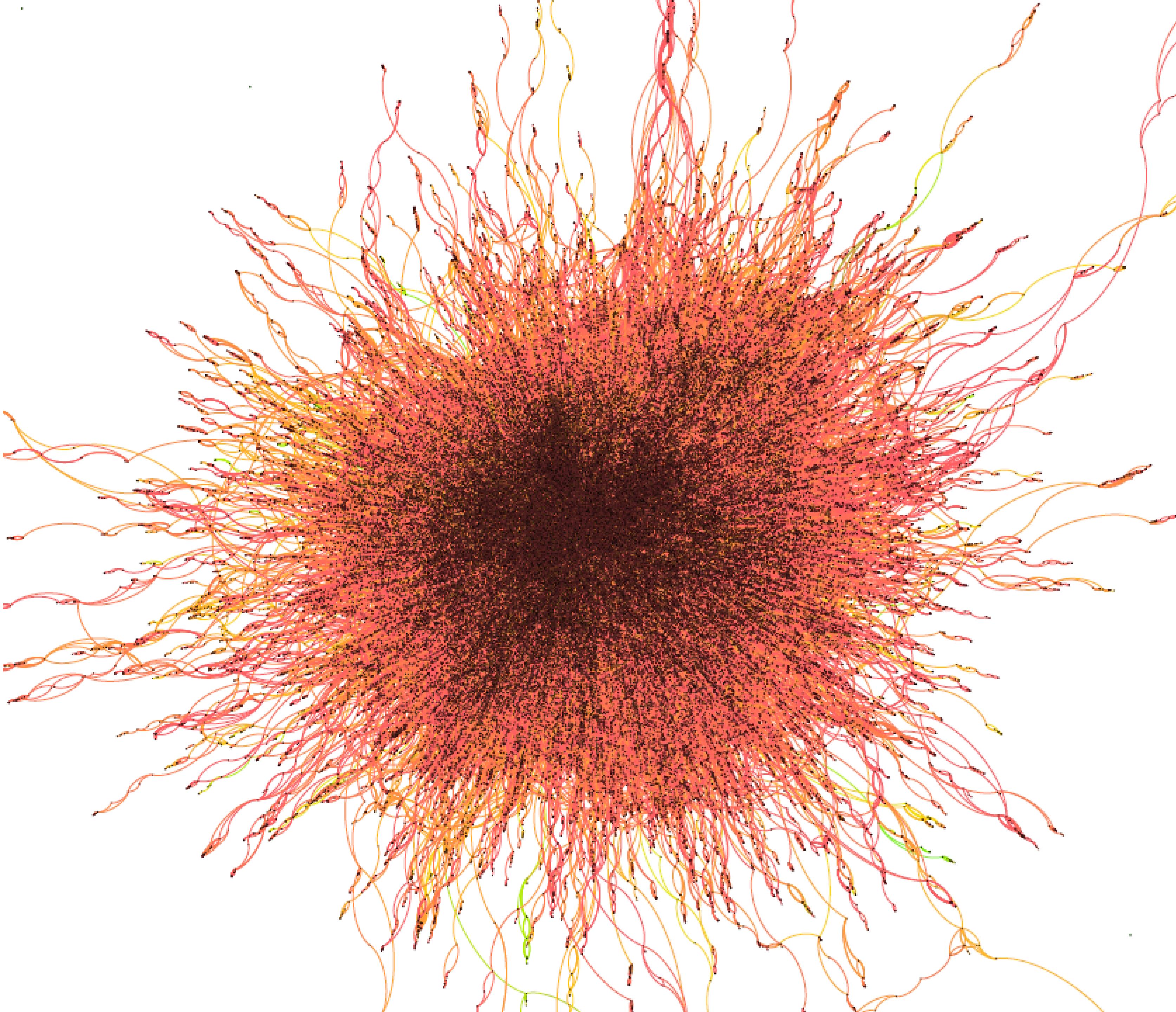
1980



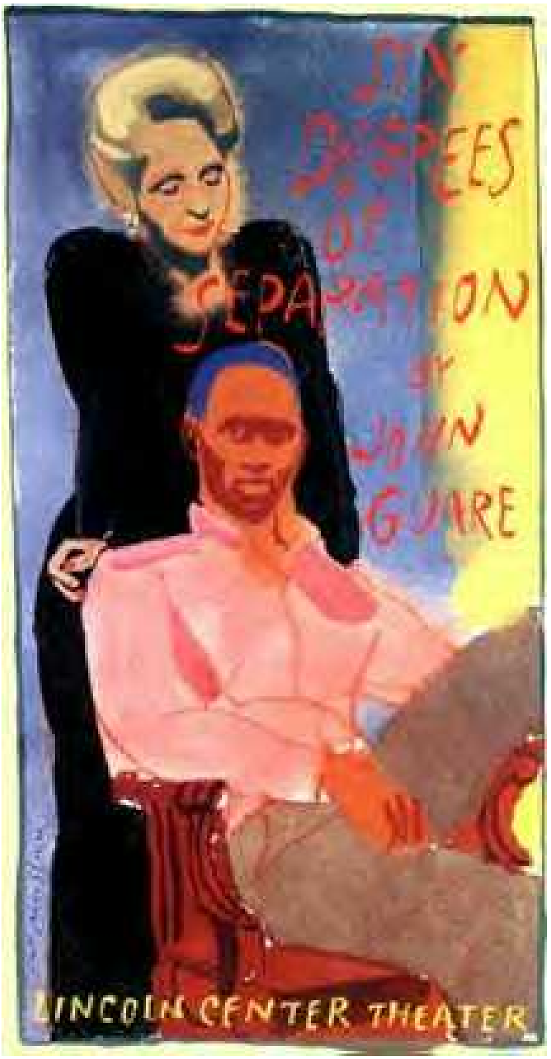
1990



1995



Small World



"I read somewhere that everybody on this planet is separated by only six other people. Six degrees of separation. Between us and everybody else on this planet. The president of the United States. A gondolier in Venice. Fill in the names. I find that A) tremendously comforting that we're so close and B) like Chinese water torture that we're so close. Because you have to find the right six people to make the connection. It's not just big names. It's anyone. A native in a rain forest. A Tierra del Fuegan. An Eskimo. I am bound to everyone on this planet by a trail of six people. It's a profound thought. How Paul found us. How to find the man whose son he pretends to be. Or perhaps is his son, although I doubt it. How every person is a new door, opening up into other worlds. Six degrees of separation between me and everyone else on this planet. But to find the right six people."

John Guare

Step-Wise-Reachable-Nodes (SWRN)

```
INSERT INTO Auth
(SELECT A.aid FROM Acopy A ORDER BY RANDOM() LIMIT 1)


DELETE FROM CA1;
INSERT INTO CA1 SELECT DISTINCT C.cid FROM CA C, CA0 D
WHERE D.aid=C.aid AND C.cid NOT IN (SELECT E.aid FROM CA0 E);

INSERT INTO Adist SELECT Auth.aid,Counter.i,COUNT(C.cid)
FROM Auth,Counter, CA1 C;

INSERT INTO CA0 SELECT * FROM CA1;
UPDATE Counter SET i=(SELECT Counter.i+1 FROM Counter);
```

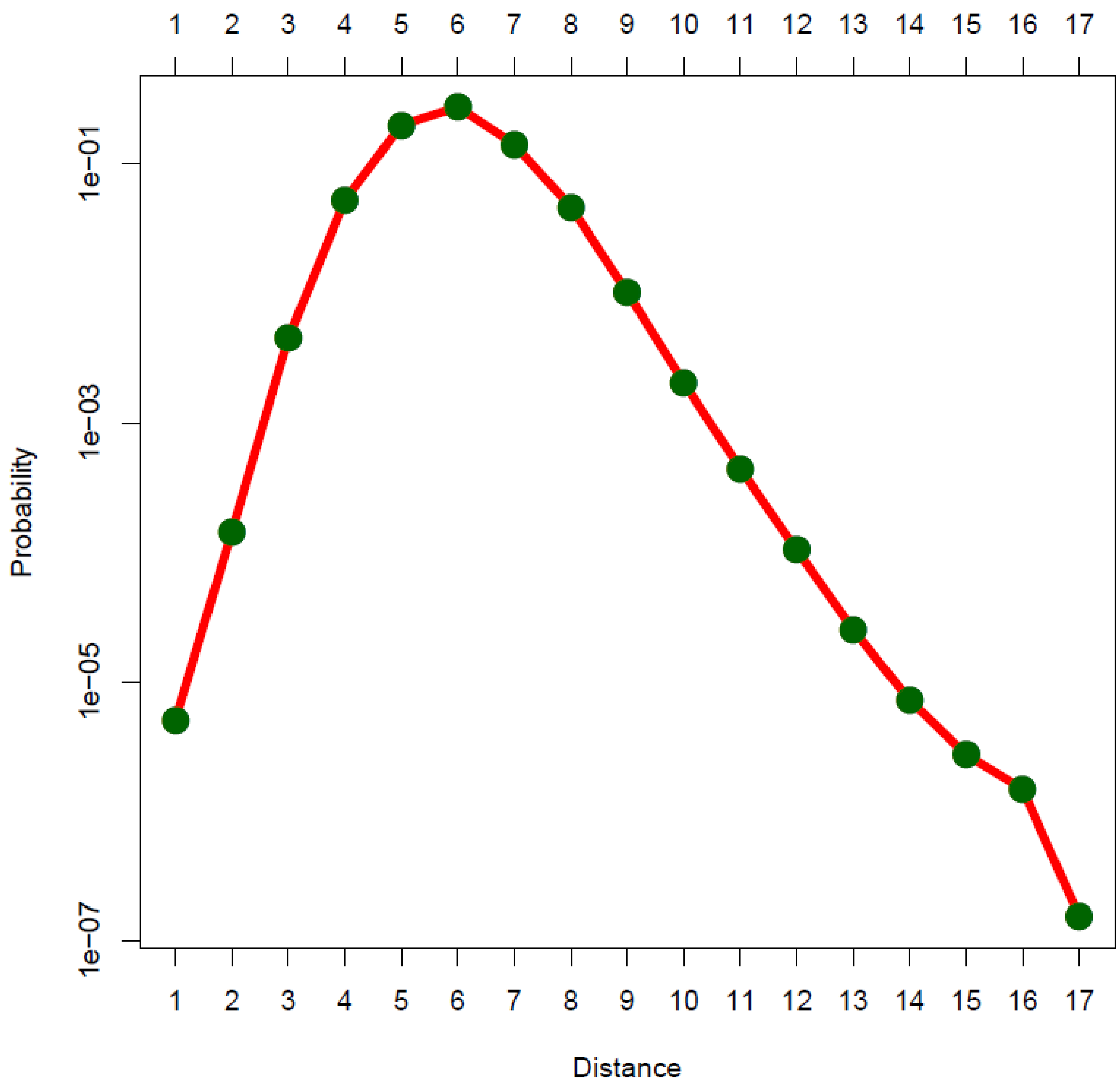
repeat until CA1 becomes empty

at most 17-times
(longest distance in the graph)

Adist table

```
1513 | 1 | 65
1513 | 2 | 1,599
1513 | 3 | 37,748
1513 | 4 | 407,839
1513 | 5 | 665,405
1513 | 6 | 223,957
1513 | 7 | 4,3758
1513 | 8 | 8,684
1513 | 9 | 1904
.
       13| 11
```

Degrees of Separation in the DPLP Co-Author Graph



→ obtained by running SWRN (≤17) on a random sample of **50 nodes**.

→ what "confidence" does the sample give?

DPLP Co-Author Graph

```
$ Rscript.exe do_stats.R
Distance Frequency Distribution -- Summary:
    mean   median     mode      var       sd
5.941985 6.000000 6.000000 1.256740 1.121044
Coverage of largest component (in %): [1] 73.0216
Percentage reached after 5 hops (in that component): [1] 35.10105
Percentage reached after 6 hops (in that component): [1] 72.53906
```

END
Lecture 8