Introduction to Database Systems CSE 414

Lecture 8: Datalog

Announcements

- HW3 posted (1 week)
  - Same dataset, more challenging queries
  - We have sent out all Azure codes if you filled out the form earlier
  - Make sure you use the cheapest tier
    - aka READ THE HW INSTRUCTIONS
  - You should first run on sqlite in any case!

Class Overview

- Unit 1: Intro
- Unit 2: Relational Data Models and Query Languages
  - Data models, SQL, Datalog, Relational Algebra
- Unit 3: Non-relational data
- Unit 4: RDMBS internals and query optimization
- Unit 5: Parallel query processing
- Unit 6: DBMS usability, conceptual design
- Unit 7: Transactions

What is Datalog?

- Another query language for relational model
  - Designed in the 80's
  - Simple, concise, elegant
  - Extends relational queries with *recursion*
- Today is a hot topic:
  - Souffle (we will use in HW4)
  - Eve http://witheve.com/
  - Differential datalog https://github.com/frankmcsherry/differential-dataflow
  - Beyond databases in many research projects: network protocols, static program analysis

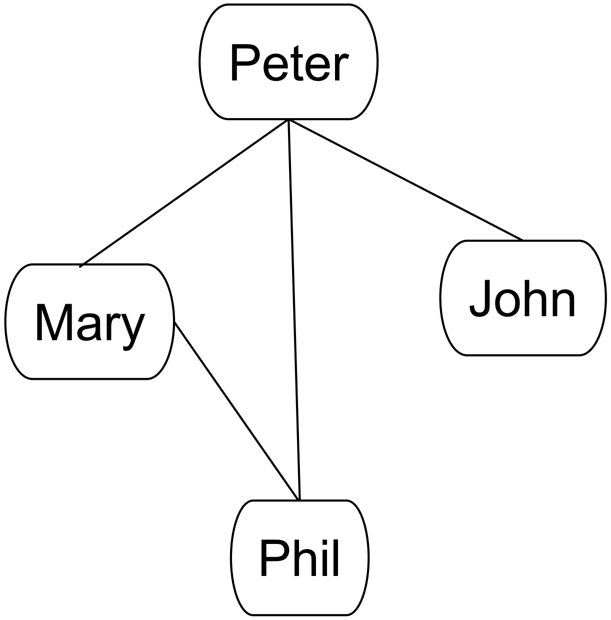
Soufflé

- Open-source implementation of Datalog DBMS
- Under active development
- Commercial implementations are available
  - More difficult to set up and use
- "sqlite" of Datalog
  - Set-based rather than bag-based

- Install in your VM
  - Run `sudo yum install souffle` in terminal
  - More details in upcoming HW4

Why bother with *yet* another relational query language?

Example: storing FB friends



As a graph

Or

Person1	Person2	is_friend
Peter	John	1
John	Mary	0
Mary	Phil	1
Phil	Peter	1
…	…	…

As a relation

We will learn the tradeoffs of different data models later this quarter

Compute your friends graph

p1	p2	isFriend
Peter	John	1
John	Mary	0
Mary	Phil	1
Phil	Peter	1
…	…	…

```
Friends(p1, p2, isFriend)
```

```
SELECT f.p2
FROM Friends as f
WHERE f.p1 = ‘me’ AND f.isFriend = 1
```

My own friends

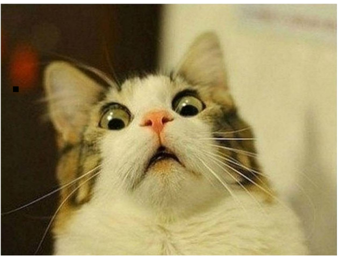
```
SELECT f1.p2
FROM Friends as f1,
     (SELECT f.p2
      FROM Friends as f
      WHERE f.p1 = ‘me’ AND
      f.isFriend = 1) as f2
WHERE f1.p1 = f2.p2 AND
      f1.isFriend = 1
```

My FoF

Datalog allows us to write *recursive queries* easily

My FoFoF… My FoFoFoF…

When does it end???



Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Schema

Datalog: Facts and Rules

Facts = tuples in the database

Rules = queries

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

Rules = queries

```
.decl Actor(id:number, fname:symbol, lname:symbol)
.decl Casts(id:number, mid:number)
.decl Movie(id:number, name:symbol, year:number)

Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Table declaration

Types in Souffle:
`number`
`symbol` (aka varchar)

Insert data

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

Find Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

SQL

```
SELECT name
FROM Movie
WHERE year = 1940
```

Find Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,'Douglas', 'Fowley').
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, 'A Night in Armour', 1910).
Movie(29000, 'Arizona', 1940).
Movie(29445, 'Ave Maria', 1940).
```

Rules = queries

id name year

```
Q1(y) :- Movie(x,y,z), z=1940.
```

Order of variable matters!

Find Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(iDontCare,y,z),
         z=1940.
```

Find Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(_,y,z), z=1940.
```

_ = “don’t care” variables

Find Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

```
Q2(f,l) :- Actor(z,f,l), Casts(z,x),
           Movie(x,y,1940).
```

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

```
Q2(f,l) :- Actor(z,f,l), Casts(z,x),
           Movie(x,y,1940).
```

Find Actors who acted in Movies made in 1940

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

Rules = queries

```
Q1(y) :- Movie(x,y,z), z=1940.
```

```
Q2(f,l) :- Actor(z,f,l), Casts(z,x),
           Movie(x,y,1940).
```

```
Q3(f,l) :- Actor(z,f,l), Casts(z,x1), Movie(x1,y1,1910),
                         Casts(z,x2), Movie(x2,y2,1940).
```

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

Rules = queries

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

```
Q1(y) :- Movie(x,y,z), z=1940.
```

```
Q2(f,l) :- Actor(z,f,l), Casts(z,x),
           Movie(x,y,1940).
```

```
Q3(f,l) :- Actor(z,f,l), Casts(z,x1), Movie(x1,y1,1910),
                         Casts(z,x2), Movie(x2,y2,1940).
```

both

Find Actors who acted in a Movie in 1940 and in one in 1910

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

Rules = queries

```
Actor(344759,‘Douglas’, ‘Fowley’).
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, ‘A Night in Armour’, 1910).
Movie(29000, ‘Arizona’, 1940).
Movie(29445, ‘Ave Maria’, 1940).
```

```
Q1(y) :- Movie(x,y,z), z=1940.
```

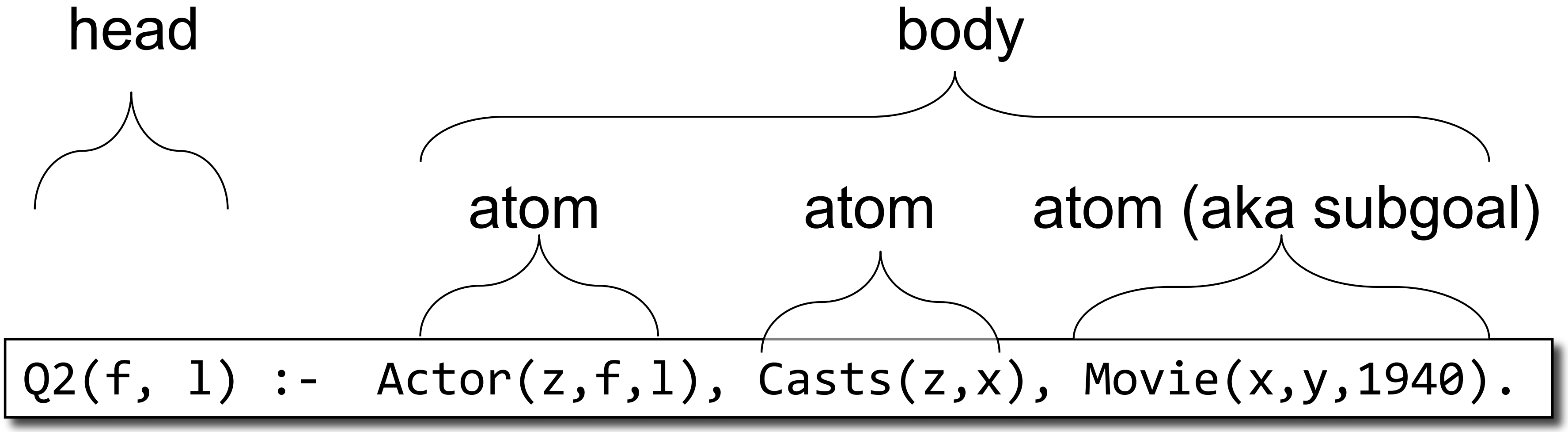
```
Q2(f,l) :- Actor(z,f,l), Casts(z,x),
           Movie(x,y,1940).
```

```
Q3(f,l) :- Actor(z,f,l), Casts(z,x1), Movie(x1,y1,1910),
                         Casts(z,x2), Movie(x2,y2,1940).
```

Extensional Database Predicates = EDB = Actor, Casts, Movie

Intensional Database Predicates = IDB = Q1, Q2, Q3

Datalog: Terminology



head

body

atom

atom

atom (aka subgoal)

```
Q2(f, l) :-  Actor(z,f,l), Casts(z,x), Movie(x,y,1940).
```

f, l = head variables

x,y,z = existential variables

More Datalog Terminology

```
Q(args) :- R1(args), R2(args), ...
```

- $R_i(args_i)$ called an *atom*, or a *relational predicate*
- $R_i(args_i)$ evaluates to true when relation R_i contains the tuple described by $args_i$.
  - Example: `Actor(344759, 'Douglas', 'Fowley')` is true
- In addition we can also have arithmetic predicates
  - Example: $z > 1940$.
- Book uses AND instead of ,

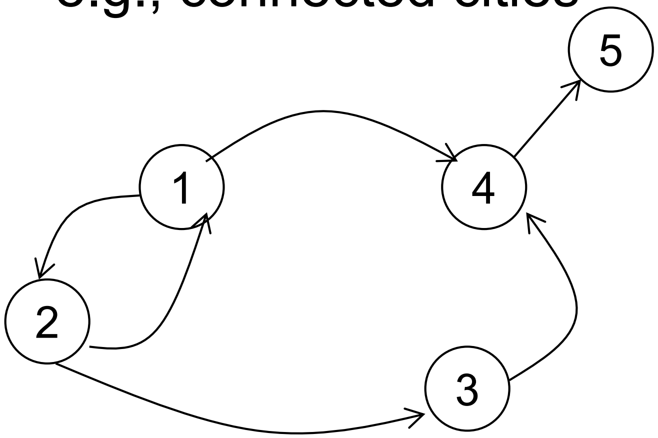
```
Q(args) :- R1(args) AND R2(args) ...
```

Datalog program

- A Datalog program consists of several rules
- Importantly, rules may be recursive!
  - Recall CSE 143!
- Usually there is one distinguished predicate that’s the output
- We will show an example first, then give the general semantics.

Example

R encodes a graph
e.g., connected cities

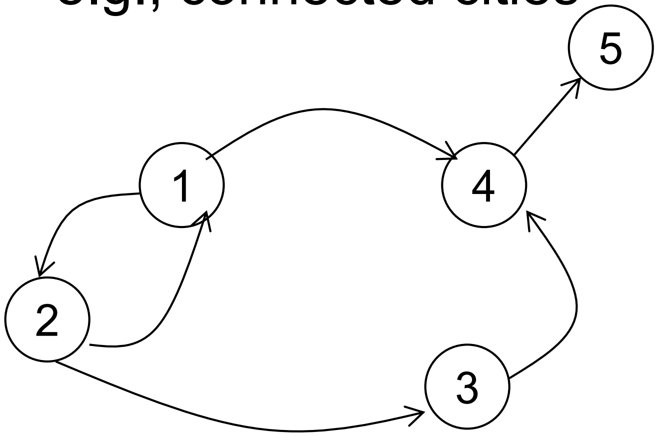


R=

1	2
2	1
2	3
1	4
3	4
4	5

Example

R encodes a graph
e.g., connected cities



R=

1	2
2	1
2	3
1	4
3	4
4	5

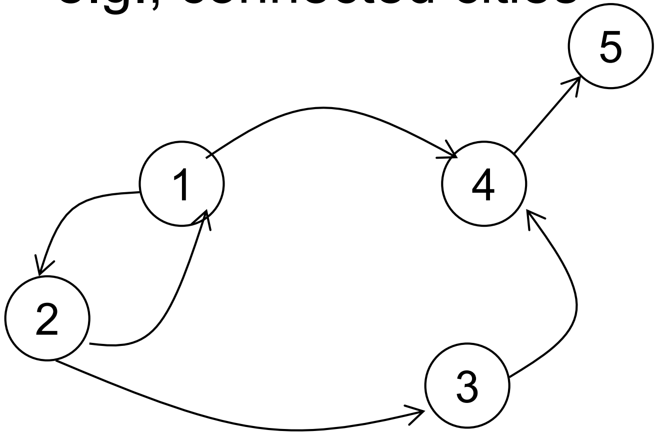
```
T(x,y) :- R(x,y).
T(x,y) :- R(x,z), T(z,y).
```

Multiple rules for the same IDB means OR

What does it compute?

Example

R encodes a graph
e.g., connected cities



T(x,y) :- R(x,y).
T(x,y) :- R(x,z), T(z,y).

What does it compute?

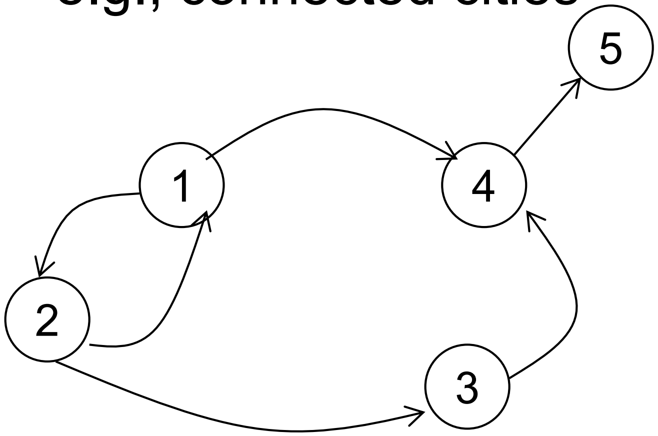
R=

1	2
2	1
2	3
1	4
3	4
4	5

Initially:
T is empty.

Example

R encodes a graph
e.g., connected cities



R=

1	2
2	1
2	3
1	4
3	4
4	5

Initially:

T is empty.

$T(x,y) \text{ :- } R(x,y).$

$T(\underset{2}{x},\underset{2}{y}) \text{ :- } R(\underset{2}{x},\underset{1}{z}), T(\underset{1}{z},\underset{2}{y}).$

What does it compute?

First iteration:

T =

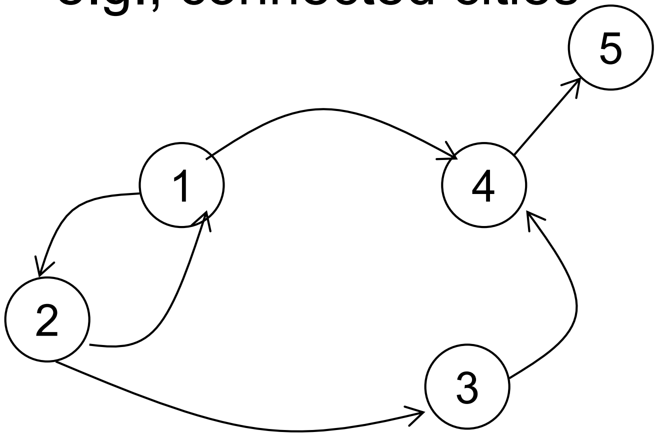
1	2
2	1
2	3
1	4
3	4
4	5

First rule generates this

Second rule generates nothing (because T is empty)

Example

R encodes a graph
e.g., connected cities



```
T(x,y) :- R(x,y).
T(x,y) :- R(x,z), T(z,y).
```

What does it compute?

R=

1	2
2	1
2	3
1	4
3	4
4	5

Initially:

T is empty.

First iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5

Second iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5
1	1
2	2
1	3
2	4
1	5
3	5

First rule generates this

Second rule generates this

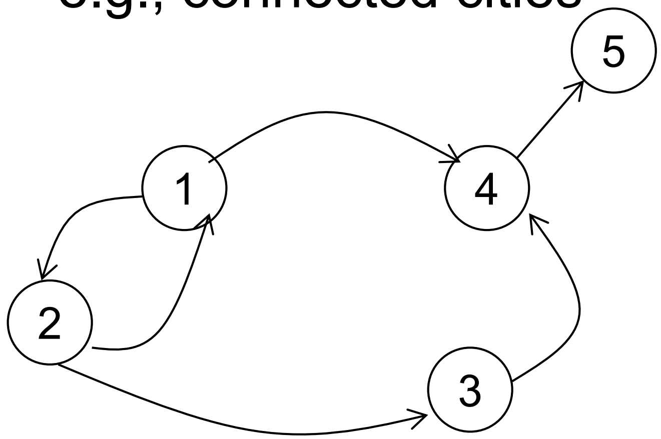
New facts

Example

T(x,y) :- R(x,y).
T(x,y) :- R(x,z), T(z,y).

What does it compute?

R encodes a graph
e.g., connected cities



R=

1	2
2	1
2	3
1	4
3	4
4	5

Initially:

T is empty.

First iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5

Second iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5
1	1
2	2
1	3
2	4
1	5
3	5

Third iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5
1	1
2	2
1	3
2	4
1	5
3	5
2	5

Both rules

First rule

Second rule

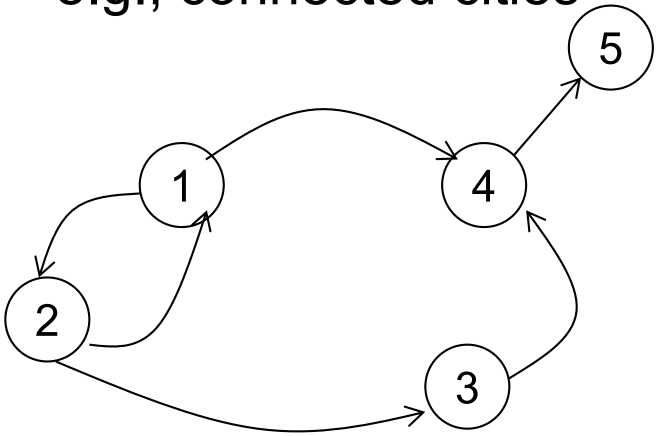
New fact

Example

```
T(x,y) :- R(x,y).
T(x,y) :- R(x,z), T(z,y).
```

What does it compute?

R encodes a graph
e.g., connected cities



R=

1	2
2	1
2	3
1	4
3	4
4	5

Initially:

T is empty.

First iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5

Second iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5
1	1
2	2
1	3
2	4
1	5
3	5

Third iteration:

T =

1	2
2	1
2	3
1	4
3	4
4	5
1	1
2	2
1	3
2	4
1	5
3	5
2	5

Fourth iteration

T =

(same)

No new facts. DONE