Logical Query Languages

Motivation:

1. Logical rules extend more naturally to recursive queries than does relational algebra.
   - ✦ Used in SQL3 recursion.
2. Logical rules form the basis for many information-integration systems and applications.

Datalog Example

```
Likes(drinker, beer)
Sells(bar, beer, price)
Frequents(drinker, bar)

Happy(d) <-
    Frequents(d,bar) AND
    Likes(d,beer) AND
    Sells(bar,beer,p)
```

- Above is a *rule*.
- Left side = *head*.
- Right side = *body* = `AND` of *subgoals*.
- Head and subgoals are *atoms*.
  - ✦ Atom = *predicate* and arguments.
  - ✦ Predicate = relation name or arithmetic predicate, e.g. $<$.
  - ✦ Arguments are variables or constants.
- Subgoals (not head) may optionally be negated by `NOT`.

Meaning of Rules

Head is true of its arguments if there exist values for *local* variables (those in body, not in head) that make all of the subgoals true.

- If no negation or arithmetic comparisons, just natural join the subgoals and project onto the head variables.

Example

Above rule equivalent to `Happy(d)` $=$ $\pi_{drinker}(\texttt{Frequents} \bowtie \texttt{Likes} \bowtie \texttt{Sells})$

Evaluation of Rules

Two, dual, approaches:

1. *Variable-based*: Consider all possible assignments of values to variables. If all subgoals are true, add the head to the result relation.

2. *Tuple-based*: Consider all assignments of tuples to subgoals that make each subgoal true. If the variables are assigned consistent values, add the head to the result.

Example: Variable-Based Assignment

```
S(x,y) <- R(x,z) AND R(z,y)
    AND NOT R(x,y)
```

$R =$

A	B
1	2
2	3

- Only assignments that make first subgoal true:

  1. $x \rightarrow 1$, $z \rightarrow 2$.

  2. $x \rightarrow 2$, $z \rightarrow 3$.

- In case (1), $y \rightarrow 3$ makes second subgoal true. Since $(1, 3)$ is *not* in R, the third subgoal is also true.

  ✦ Thus, add $(x, y) = (1, 3)$ to relation S.

- In case (2), no value of y makes the second subgoal true. Thus, S =

A	B
1	3

Example: Tuple-Based Assignment

Trick: start with the positive (not negated), relational (not arithmetic) subgoals only.

```
S(x,y) <- R(x,z) AND R(z,y)
    AND NOT R(x,y)
```

$R =$

A	B
1	2
2	3

- Four assignments of tuples to subgoals:

$R(x,z)$	$R(z,y)$
$(1,2)$	$(1,2)$
$(1,2)$	$(2,3)$
$(2,3)$	$(1,2)$
$(2,3)$	$(2,3)$

- Only the second gives a consistent value to z.
- That assignment also makes `NOT R(x,y)` true.
- Thus, $(1,3)$ is the only tuple for the head.

Safety

A rule can make no sense if variables appear in funny ways.

Examples

- `S(x) <- R(y)`
- `S(x) <- NOT R(x)`
- `S(x) <- R(y) AND x < y`

In each of these cases, the result is infinite, even if the relation R is finite.

- To make sense as a database operation, we need to require three things of a variable x (= definition of *safety*). If x appears in either

  1. The head,
  2. A negated subgoal, or
  3. An arithmetic comparison,

  then x must also appear in a nonnegated, "ordinary" (relational) subgoal of the body.

- We insist that rules be safe, henceforth.

Datalog Programs

- A collection of rules is a *Datalog program.*
- Predicates/relations divide into two classes:
  - ✦ EDB = *extensional database* = relation stored in DB.
  - ✦ IDB = *intensional database* = relation defined by one or more rules.
- A predicate must be IDB or EDB, not both.
  - ✦ Thus, an IDB predicate can appear in the body or head of a rule; EDB only in the body.

Example

Convert the following SQL (Find the manufacturers of the beers Joe sells):

```
Beers(name, manf)
Sells(bar, beer, price)

SELECT manf
FROM Beers
WHERE name IN(
    SELECT beer
    FROM Sells
    WHERE bar = 'Joe''s Bar'
);
```

to a Datalog program.

```
JoeSells(b) <-
    Sells('Joe''s Bar', b, p)
Answer(m) <-
    JoeSells(b) AND Beers(b,m)
```

- Note: `Beers`, `Sells` = EDB; `JoeSells`, `Answer` = IDB.

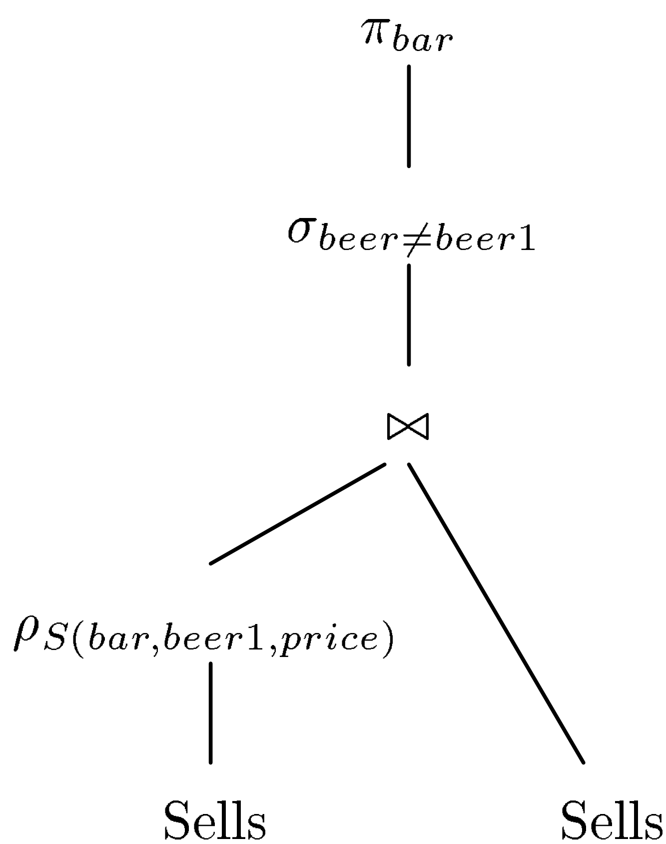
Expressive Power of Datalog

- Nonrecursive Datalog = relational algebra.
- Datalog simulates SQL select-from-where without aggregation and grouping.
- Recursive Datalog expresses queries that cannot be expressed in SQL.
- But none of these languages have full expressive power (*Turing completeness*).

Relational Algebra to Datalog

- Text has constructions for each of the operators of R.A.
    - ✦ Only hard part: selections with OR's and NOT's.
- Simulate a R.A. expression in Datalog by creating an IDB predicate for each interior node and using the constuction for the operator at that node.

Example: Find the bars that sell two different beers at the same price.




```
R1(bar,beer1,beer,price) <-
    Sells(bar,beer1,price) AND
    Sells(bar,beer,price);
R2(bar,beer1,beer,price) <-
    R1(bar,beer1,beer,price) AND
    beer1 <> beer;
Answer(bar) <-
    R2(bar,beer1,beer,price);
```

Datalog to Relational Algebra

- General rule is complex; the following often works for single rules:
  - ✦ Problems not handled: constant arguments and variables appearing twice in the same atom.
  - ✦ Can you provide the necessary fixes?

  1. Use ρ to create for each relational subgoal a relation whose schema is the variables of that subgoal.
  2. Handle negated subgoals by finding an expression for the finite set of all possible values for each of its variables (π a suitable column) and take their product. Then subtract.
  3. Natural join the relations from (1), (2).
  4. Get the effect of arithmetic comparisons with σ.
  5. Project onto head with π.

- Several rules for same predicate: use $\cup$.

Example

```
S(x,y) <- R(x,z) AND R(z,y)
    AND NOT R(x,y)
```

S1(x,y,z) := $\rho_{R1(x,z)}$(R) $\bowtie$ $\rho_{R2(z,y)}$(R);
S2(x,y) := π_x(S1) $\times$ π_y(S1);
S3(x,y) := S2 $-$ $\rho_{R3(x,y)}$(R);
S(x,y) := $\pi_{x,y}$(S1(x,y,z) $\bowtie$ S3(x,y));

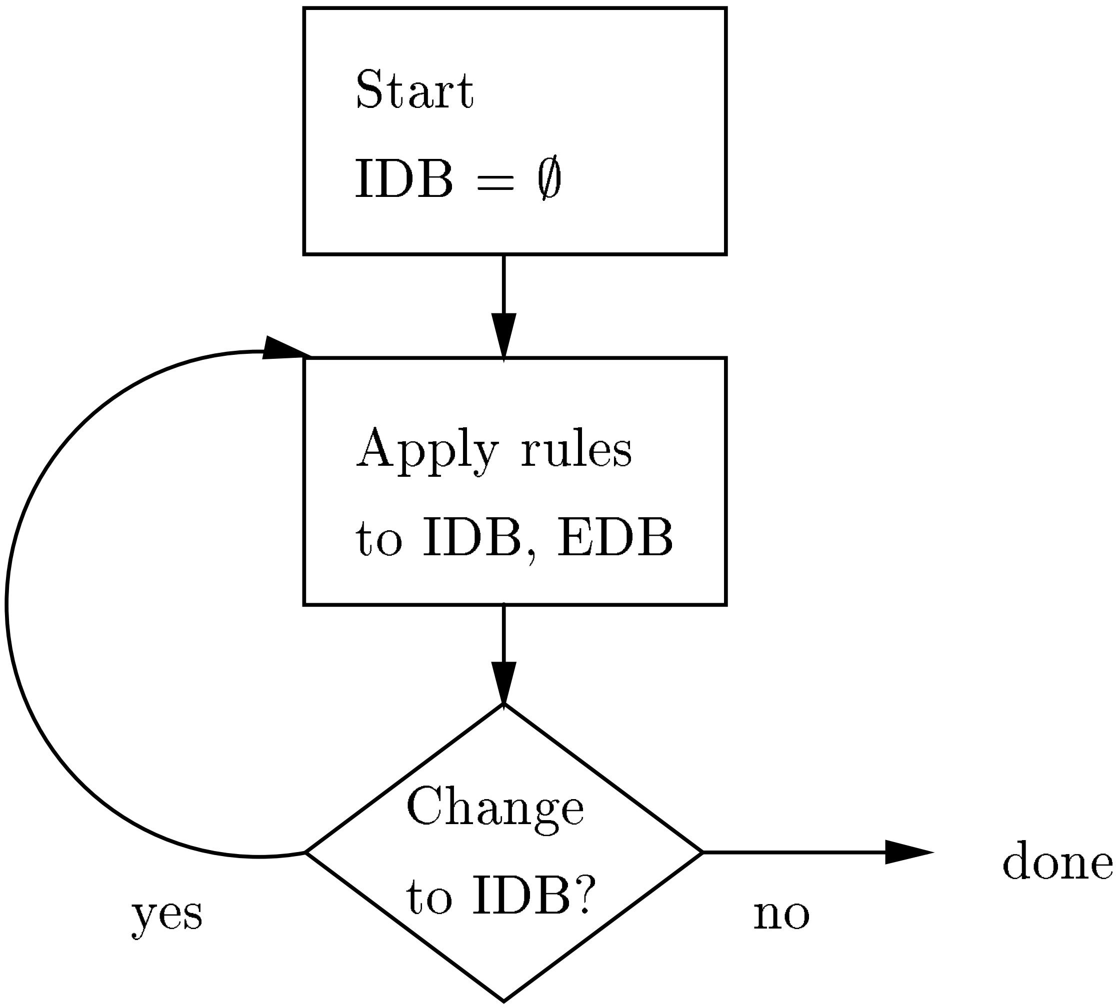
Recursion

- IDB predicate P *depends* on predicate Q if there is a rule with P in the head and Q in a subgoal.
- Draw a graph: nodes = IDB predicates, arc $P \rightarrow Q$ means P depends on Q.
- Cycles iff recursive.

Recursive Example

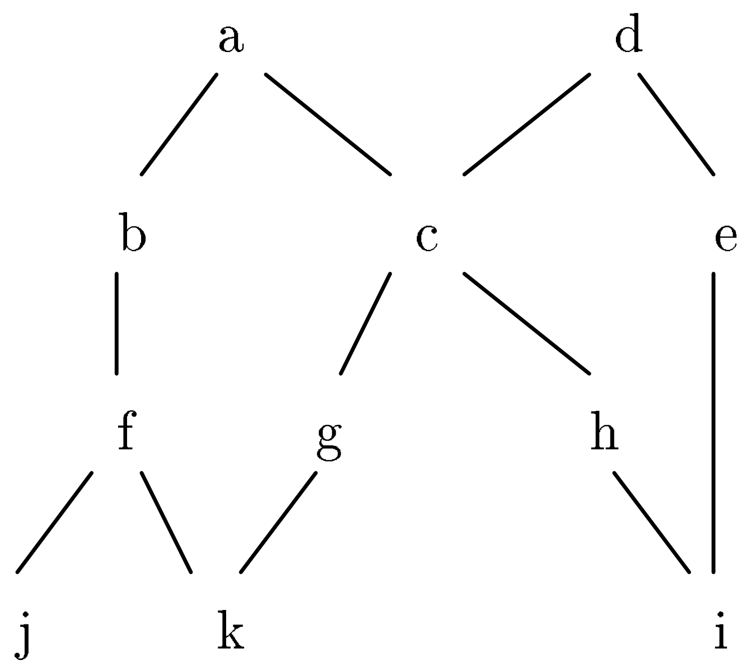
```
Sib(x,y) <- Par(x,p) AND Par(y,p)
    AND x <> y

Cousin(x,y) <- Sib(x,y)
Cousin(x,y) <- Par(x,xp)
    AND Par(y,yp)
    AND Cousin(xp,yp)
```

Iterative Fixed-Point Evaluates Recursive Rules



Example

EDB `Par` =



- Note, because of symmetry, `Sib` and `Cousin` facts appear in pairs, so we shall mention only (x, y) when both (x, y) and (y, x) are meant.

	`Sib`	`Cousin`
Initial	$\emptyset$	$\emptyset$
Round 1 add:	(b, c), (c, e) (g, h), (j, k)	$\emptyset$
Round 2 add:		(b, c), (c, e) (g, h), (j, k)
Round 3 add:		(f, g), (f, h) (g, i), (h, i) (i, k)
Round 4 add:		(k, k) (i, j)