Introduction to Relational Database Systems

Datenbanksysteme 1 (INF 3131)

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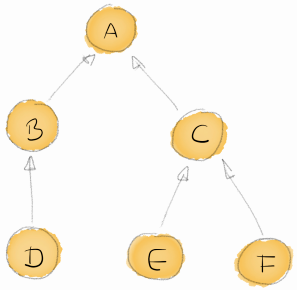
Limits of the Relational Algebra

- RA is **not a full-fledged programming language** by design:
  1. The **evaluation of any RA query will terminate**, regardless of the size/contents of the input relations.
     (“*RA does not loop forever*”)
  2. The **evaluation of any RA query will use a restricted amount of time and space only**.
     (“*RA can be evaluated efficiently*”)
     - An RA query that produces intermediate result relations of arity k can be evaluated in $O(|D|^k)$ (where $|D|$ denotes the database size).
     - ⚠ A problem like “*Compute all tuple subsets of relation* R” thus is inexpressible in RA.
- Yet, there are a number of common, not too-far-fetched types of complex query problems that we would like a DBMS to compute.
  - $\Rightarrow$ Need **a query construct beyond RA** to tackle such problems.

Recursive Queries

- Recall the relational representation of **tree-shaped** data structures:



tree

node	parent
A	□
B	A
C	A
D	B
E	C
F	C

- Typical and useful **tree queries** are out of reach for RA:

1. *"Find all nodes under subtree root* `C`*."*
2. *"Find all nodes on the path from node* `D` *to the root."*

Recursive Queries

Find all nodes under subtree root ⟨*root*⟩

tree

node	parent
A	□
B	A
C	A
D	B
E	C
F	C

```
r := { (root:⟨root⟩) } # r will hold the result
t := r
while t ≠ ∅ do
   t := π[root←node](t ⋈[root = parent] tree)
   r := r ⊎ t
end

return π[node←root](r) # “cosmetics”
```

A Recursive Query Template

- The recursion pattern we have just seen turns out to be quite generally useful. Abstract over specific query parts to obtain a **iterative/recursive query template**:

```
iterate(q, r):
        t := r
        while t ≠ ∅ do
          t := q(t)
          r := r ⊎ t
        end
        return r
```

```
recurse(q, r):
        if r ≠ ∅ then
          return r ⊎ recurse(q, q(r))
        else
          return ∅
        end
```

SQL: Recursive Queries

- This iterative RA query template also is available in modern SQL dialects (since the SQL:1999 standard), expressed in terms of a **recursive common table expression**:

`WITH RECURSIVE` (Recursive Common Table Expression)

```
WITH RECURSIVE
  ⟨query_name⟩[ ( ⟨column_name⟩ [, …] ) ] AS (
    ⟨non-recursive SFW⟩       -- base case
      UNION ALL
    ⟨recursive SFW⟩           -- may refer to ⟨query_name⟩
)
⟨final SFW⟩                   -- may refer to ⟨query_name⟩
```

- ⚠ In the ⟨recursive SFW⟩ block of a CTE, the following SQL constructs are ruled out:
  - `OUTER JOIN`s, subqueries referring to `⟨query_name⟩`, `GROUP BY`, aggregate functions, `ORDER BY`, `LIMIT`/`OFFSET`.

SQL: Recursive Queries

```
WITH RECURSIVE
  ⟨query_name⟩[ ( ⟨column_name⟩ [, …] ) ] AS (
    ⟨non-recursive SFW⟩       -- base case
      UNION ALL
    ⟨recursive SFW⟩           -- may refer to ⟨query_name⟩
)
⟨final SFW⟩                   -- may refer to ⟨query_name⟩
```

- Semantics:

```
r := ⟨non-recursive SFW⟩
t := r
while t ≠ ∅ do
   t := ⟨recursive SFW⟩(t)
   r := r ⊎ t   # ⊎: bag union
end
return ⟨final SFW⟩(r)
```

SQL: Recursive Queries (Set Semantics)

```
WITH RECURSIVE
  ⟨query_name⟩[ ( ⟨column_name⟩ [, …] ) ] AS (
    ⟨non-recursive SFW⟩
      UNION [ DISTINCT ]      -- no UNION ALL: set semantics
    ⟨recursive SFW⟩
)
⟨final SFW⟩
```

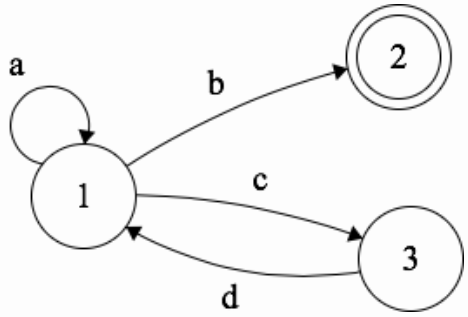
- Set semantics
  (avoids to add tuples to intermediate result *r* that have already been seen):

```
r := ⟨non-recursive SFW⟩
t := r
while t ≠ ∅ do
   t := DISTINCT(⟨recursive SFW⟩(t)) \ r
   r := r ⊎ t   # ⊎: disjoint union
end
return ⟨final SFW⟩(r)
```

SQL: Recursive Queries

Example: Run a Deterministic Finite State Automaton (DFA)

1. Encode the transition table of a DFA as a regular relational table.
2. Formulate a recursive common table expression that consumes/matches on character of input in each iteration.

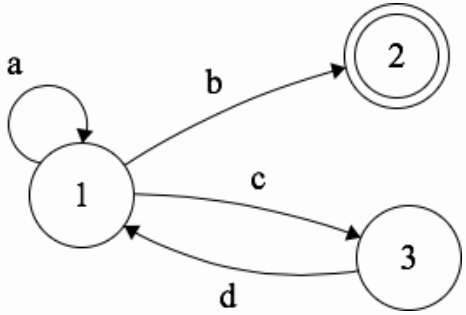


DFA for regular expression `(a|cd)*b`, start state ①

- Note:
  - PostgreSQL:
    Extract first `n` characters of string `s`: `left(s,n)`; all but first character: `right(s,-1)`.

SQL: Recursive Queries

Example: Run a Deterministic Finite State Automaton (DFA)



`fsm`

source	trans	target	final
1	a	1	false
1	b	2	false
1	c	3	false
2	ε_T	□	true
3	d	1	false

- Column `final`: Is the source state of this DFA edge an accepting state?
- **Quiz:** What would be the correct key for table `fsm`?

SQL: Recursive Queries

Example: Iteratively Collapse Adjacent Time Tntervals

calendar

appointment	start	stop
meeting	11:30	12:00
lunch	12:00	13:00
biking	18:30	□

attendees

appointment	person
meeting	Alex
meeting	Bert
meeting	Cora
lunch	Bert
lunch	Drew

- Recall that `calendar` ⋈ `attendees` can answer the "*Who is busy at at what times?*" question but that we end up with unpleasant **adjacent time intervals** (see `Bert`).
- Can we collapse/merge adjacent time intervals?

SQL: Recursive Queries

Example: Iteratively Collapse Adjacent Time Tntervals

busy

appointment	start	stop	person	
meeting	11:30:00	12:00:00	Alex	
meeting	11:30:00	12:00:00	Cora	
meeting	11:30:00	12:00:00	Bert	⚠
lunch	12:00:00	13:00:00	Bert	⚠
lunch	12:00:00	13:00:00	Drew	

- Helpful PostgreSQL built-in types and operators:
  - `tsrange(t1,t2)`: Construct the time range with start time `t1`, end time `t2`
  - `r1 -|- r2`: Are time ranges `r1`, `r2` directly adjacent?
  - `r1 @> r2`: Does time range `r1` cover `r2`? (also true for `r1 = r2`)
  - `least(x,y)`, `greatest(x,y)`: return the minimum/maximum of `x`, `y`