Ensuring Data Integrity Without Deferred Constraint Checking

Efficient Multiple Simultaneous Assignment of Relvars

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Multiple Simultaneous Assignment

Why?

1. Constraints that make sequential updates impossible.
2. Mutually dependent updates.
3. Performance.

Why Not Deferred Constraint Checking?

1. Transaction sees inconsistent database.
2. Deferred / immediate depends on DB design.
3. Semantic optimization using constraints.
4. User-defined operators loose orthogonality.

Mutually Dependent Updates

- Credit reference agency.
- 2 entities: credit history entries and credit reports.
- Creditor performs a credit check.
- Produces a credit report based on *previous* credit history.
- Creates a new history entry.
- History entry applies a penalty for a failed credit application.
- Amount of penalty depends on contents of *previous* credit reports.
- Credit report depends on *previous* credit history *and* credit history depends on outcome of *previous* reports.

Syntax

- V1 := Q1,… Vn := Qn;
- V1… Vn not necessarily unique.
- Syntactic sugar:
  - E.g. INSERT V Q is equivalent to V:= V UNION Q.

- Hugh Darwen, and C.J. Date, *Databases, Types, and the Relational Model: The Third Manifesto*. 3rd Ed. (USA: Pearson, 2006)

Naive Implementation

- Two sets of variables:
  - Program variables (e.g. `V`).
  - Temporaries (e.g. `V'`) (not used in the original program).
- Implement V1 := E1, V2 := E2, V3 := E3 as:

```
V1' := E1;  V2' := E2;  V3' := E3;
V1  := V1'; V2  := V2'; V3  := V3;
```

- Not efficient if `V1'` and `V1`, etc. have similar values.

Formal Semantics

$$\langle \mathtt{V} := \mathtt{E}, ACL \rangle, s \Rightarrow \langle replace(ACL, V, E) \rangle, s[V' \mapsto \mathrm{Exp}[\mathtt{E}]s]$$

$$\langle \mathtt{V} := \mathtt{E} \rangle, s \Rightarrow msa(s[V' \mapsto \mathrm{Exp}[\mathtt{E}]s])$$

$$msa(s) = \{V \mapsto x \mid declared(V, s) \wedge assign(V, s) = x\}$$

$$assign(V, s) = \begin{cases} s(V') & \text{if } V' \in \mathrm{dom}(s) \\ s(V) & \text{otherwise} \end{cases}$$

$$replace(, VR, ER) =$$

$$replace(\mathtt{V} := \mathtt{E}, ACL, VR, ER) = \begin{cases} \mathtt{V} := \mathtt{E}[ER/VR], ACL & \text{if } V = VR \\ \mathtt{V} := \mathtt{E}, replace(ACL, VR, ER) & \text{if } V <> VR \end{cases}$$

Related Problems

- Parallel Programming: Executing a program for Concurrent Read Exclusive Write (CREW) synchronous PRAM on a Von Neumann machine.
- Transaction Serialization: Finding a conflict-free schedule (but no guarantee that one exists!).

Optimization

1. Expansion
2. Conversion to Canonical Form
3. Query Rewrite
4. Dependency Graph Construction
5. Multi-Query Optimization
6. Cyclic Dependency Removal
7. Merge Integrity Constraint Checks
8. Transitive Dependency Removal
9. Code Generation

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10. Execution

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Canonical Form

- Already seen an example:
  - INSERT V Q $\rightarrow$ V := UNION{V, Q}
- Also, trivial things:
  - UNION{Q} $\rightarrow$ Q
- Expansion and conversion to canonical form are *abstractions*.
  - In practice the work is divided between the existing parsing and query rewrite steps.

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Updates

- Two types of updates: “in place” and not “in place”.
- “In place” updates are implemented using either overwriting or delta compression.
- Not “in place” updates are implemented using shadow copying.

Dependency Graphs

- A query *Q* is *independent of the update V:=E* iff Q ≡ Q[E/V].
- For queries Q1 and Q2, *Q1 contains Q2* iff Q1 ⊇ Q2.
- A labelled directed graph *G* = (*V*, *E,* cost) is a dependency graph for a multiple assignment V1:=Q1,… Vn:=Qn iff:

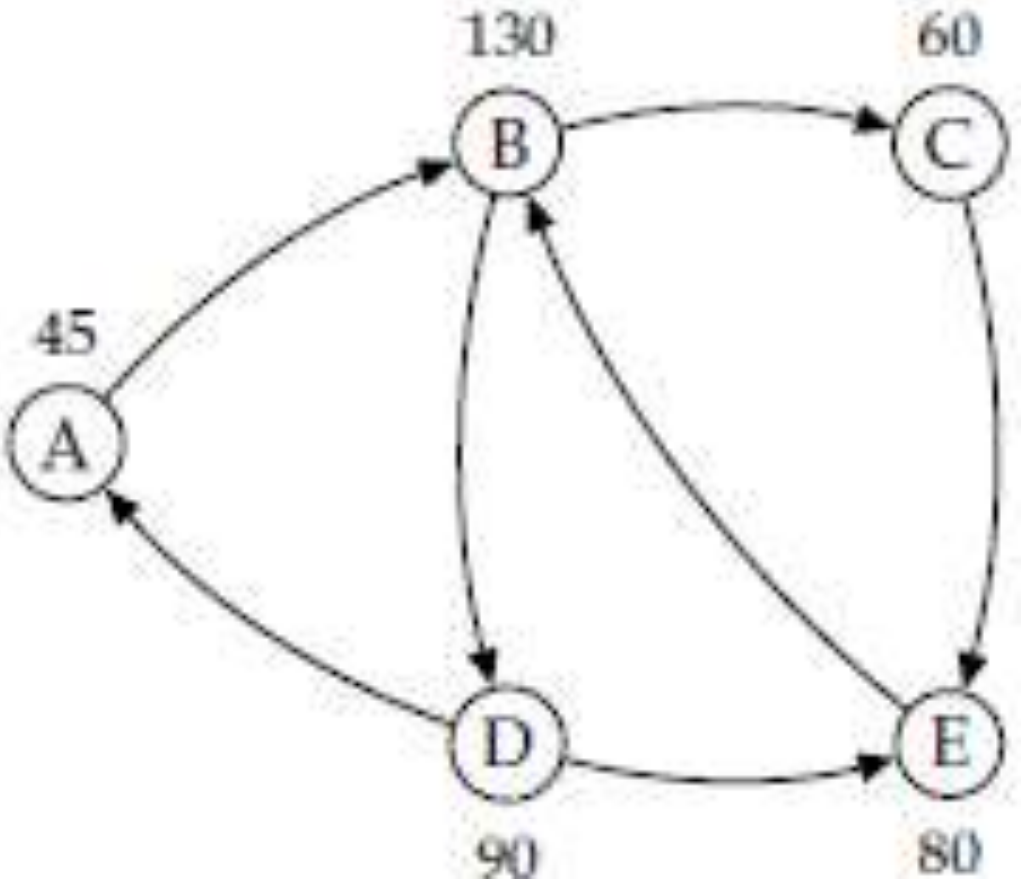
$$V = \{\mathrm{V1}, \ldots \mathrm{Vn}\}$$

$$E = \{v \rightarrow w \mid assigned(v, q) \wedge assigned(w, r) \wedge \neg(q \equiv q[r / w])$$

$$\mathrm{cost}(v) = \min(\mathrm{inplace}(v), \mathrm{notinplace}(v))$$

- *G* can contain loops.
- $v \rightarrow w$ means "*v* must be done before *w*".

Dependency Graphs



Independence Checking

- Need to show Qi $\subseteq$ Qi[Qj/Vj] and Qi[Qj/Vj] $\subseteq$ Qi (subject to integrity constraints).
- Carles Farre, Ernest Teniente, and Toni Urpi. (2005). Checking query containment with the CQC method. *Data and Knowledge Engineering, 53*(2), 163-223.
  - An automated method of performing proofs for query containment of Datalog queries with negation.
  - Tries to find a minimal database that violates containment.
  - Uses a tableau with 5 columns.

Farre et al. DATAK 53(2) 2005

- Search for a counterexample – a tuple in Qi MINUS Qi[Qj/Vi].

a b c d e

Goal	Conditions to Enforce	Example Database	Conditions to Maintain	Literals Used

- Expansion.
- Make database satisfy non-negated query clause ($a \rightarrow c,e$).
- Make negated query clause into a constraint ($a \rightarrow b$).
- Check a constraint ($b \rightarrow d,e$).
- Recheck a constraint ($d \rightarrow b$).

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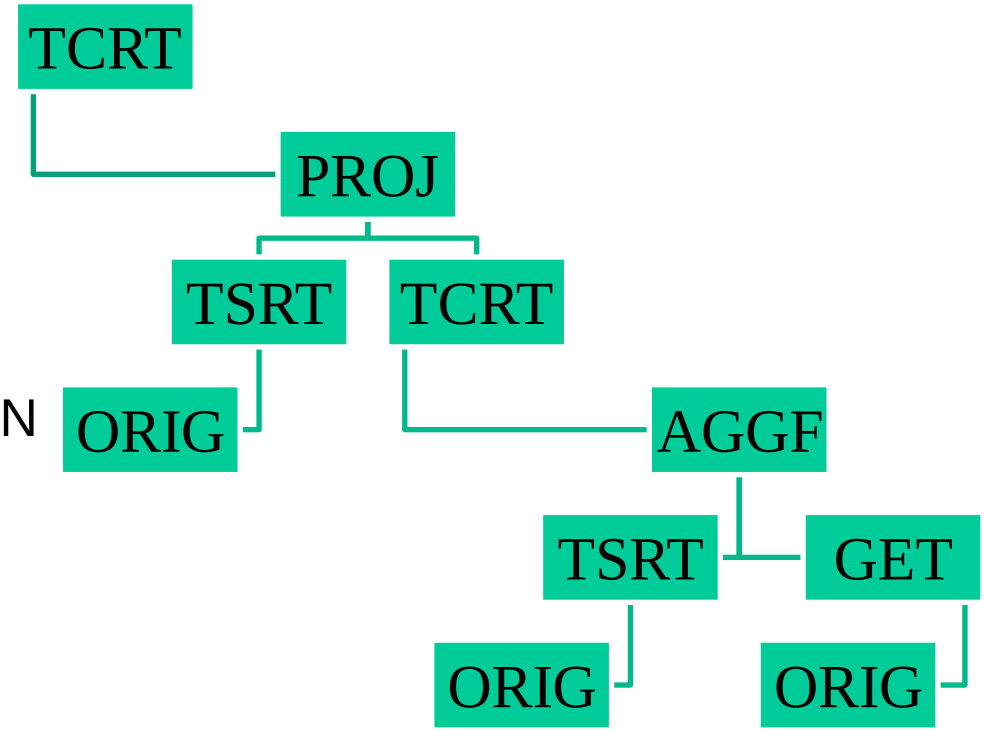
Plan Enumeration & Selection (Single Query)

```
SELECT
DISTINCT "S#"
FROM S
WHERE STATUS * 100 <
(SELECT N FROM
   (SELECT "S#", COUNT(*) AS N
      FROM SP
      GROUP BY "S#") AS SPA
   WHERE "S.S#" = "SPA.S#")
```



Multi-Query Optimization

- Identifies two or more equivalent subexpressions within one or more queries.
- Cost saving: (n-1) x evaluation cost.
- Costs *incurred*:
  - 1 x evaluation cost remains.
  - 1 x spooling result out.
  - n x reading result in.
- Problem is no longer compositional.
- Zhou, Freytag, Larson, and Lehner, 'Efficient Exploitation of Similar Subexpressions for Query Processing', *SIGMOD ’07.*

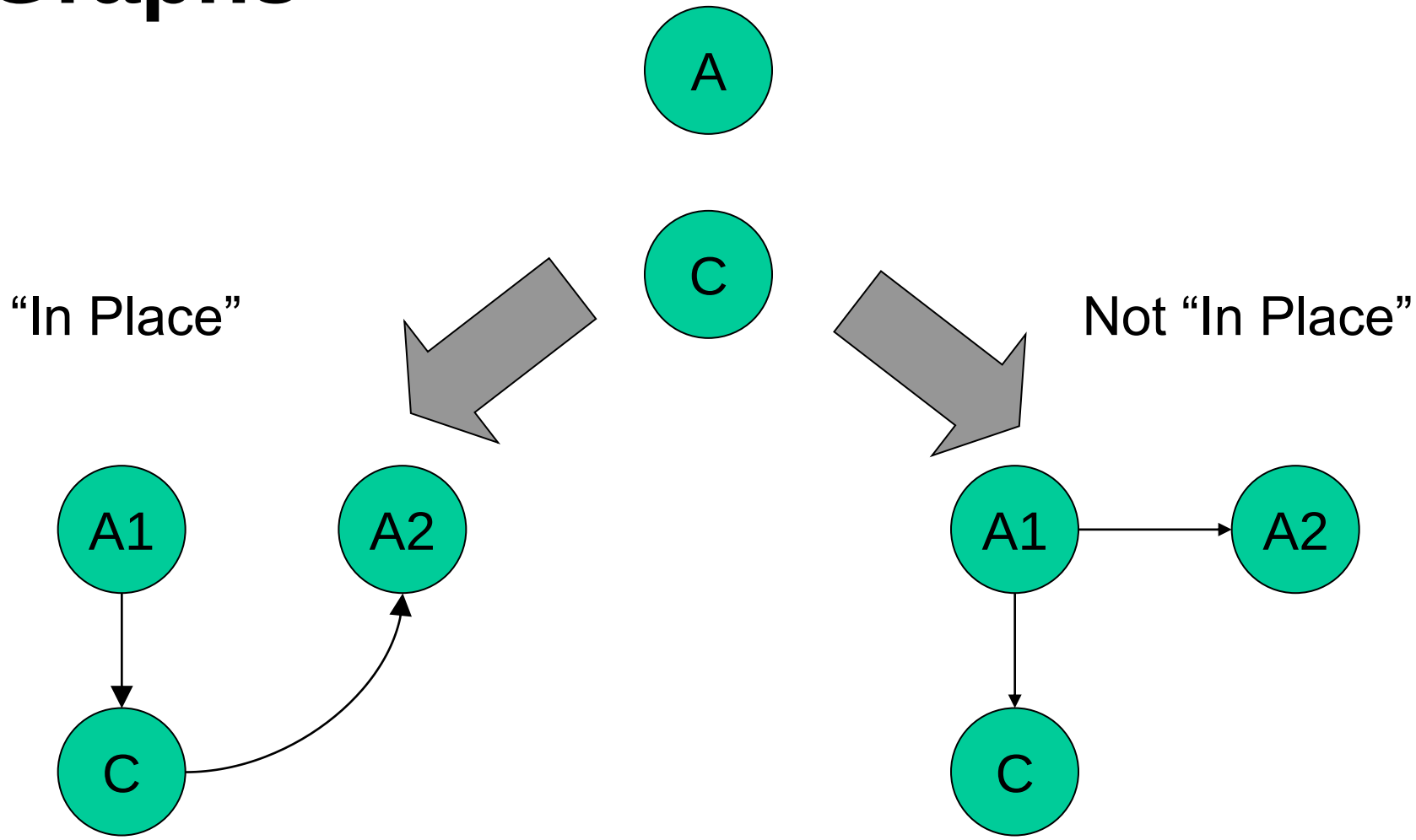
Approaches to MQO

- Find matching expressions by:
  - Textual match
  - Search parse tree
  - Graph representation
  - Most beneficial view
- Costing:
  - Delayed
  - Heuristic (best plans without MQO, greedy, A*, GA)

MQO (Zhou et al.)

1. Note the source relvars for each relational expression.
2. Generate candidate common subexpressions (CSEs).
   - Join compatible (with renaming).
   - Covering.
   - Merge similar CSEs.
   - Heuristics (no cheap CSEs, no CSEs with huge results, no large child CSEs).
3. Optimize with CSEs.
   - Delayed costing.
   - Optimize with different sets of CSEs enabled.

MQO & Extended Dependency Graphs



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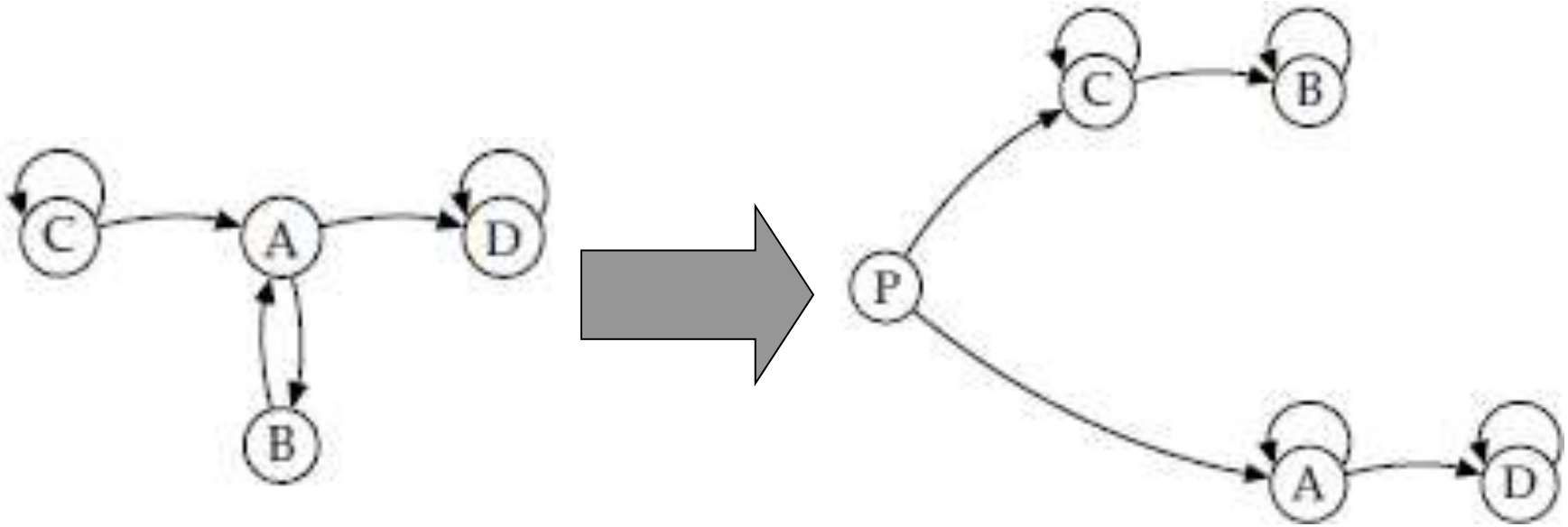
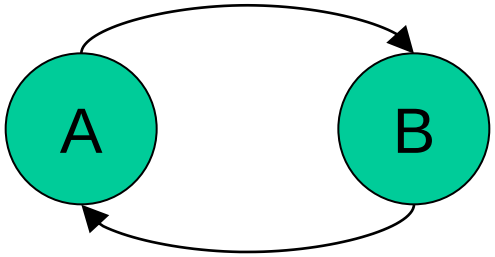
Cyclic Dependency Removal

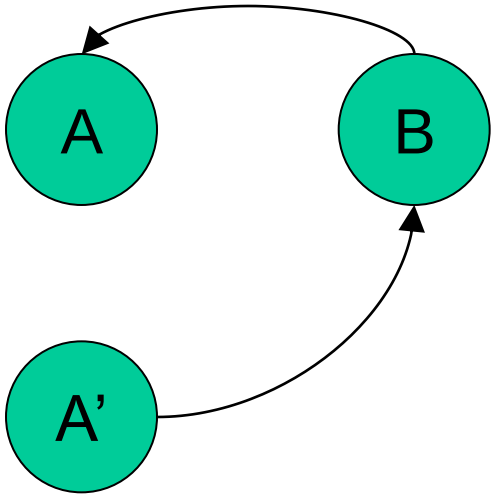
- 4 Methods:
  - Permutation
  - Vertex Splitting
  - Multi-Query Optimization
  - Multi-Query De-optimization

Permutation Method



Vertex Split Method





Minimum Feedback Vertex Set

- A *feedback vertex set* of a directed graph is a subset of its vertices containing at least one vertex for each directed cycle.
- The minimum feedback vertex set problem consists of finding a smallest cost feedback vertex set.
- Splitting a vertex that lies on many cycles could be advantageous.
- But not necessarily if the vertex has a high cost.
- Demetrescu, and Finocchi, 'Combinatorial Algorithms for Feedback Problems in Directed Graphs', *Information Processing Letters,* 86(3).

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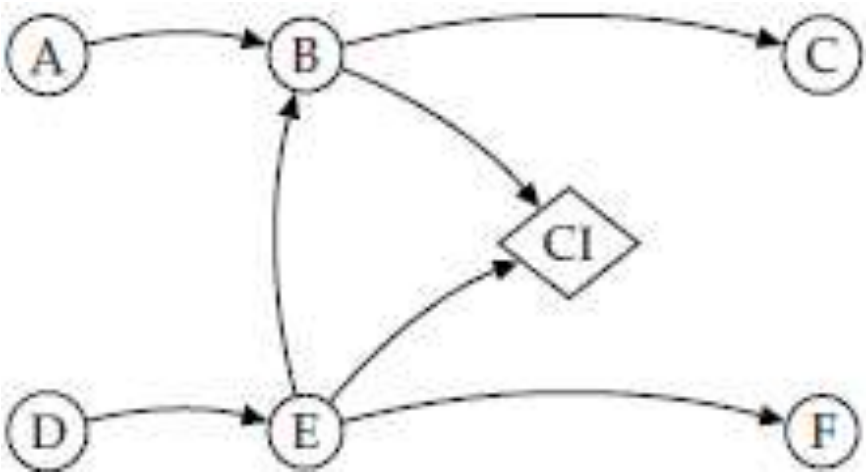
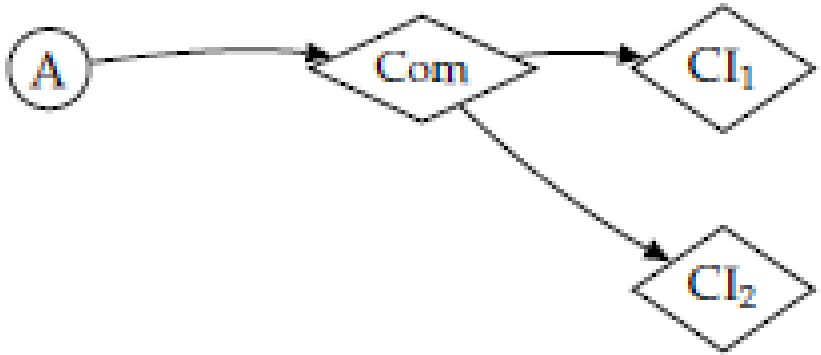
Merge Integrity Constraints





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Transitive Dependencies

- Clean up the dependency graph.
  - Important for a distributed DBMS.
- Uses Boolean matrix algebra.

$$E \wedge \neg\left(E^2 \cdot E^*\right)$$

- Same complexity as matrix multiplication.
- Kozen, *The Design and Analysis of Algorithms*, *Texts and Monographs in Computer Science* (New York: Springer, 1992), p.27,240.

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Execution

- Parallel execution
- Performing an assignment:
  - Like SQL MERGE with delete extension like MS SQL Server.
  - Implicit deletion
  - Delete-only assignments

Delta Compression

- Compact representation of old and new value.
- Used in DBMSs (Oracle, MS SQL Server, Firebird) for *multi-version concurrency control* (MVCC).
- Various methods, research papers…

Summary

- Multiple simultaneous assignment is a better alternative to deferred constraint checking.
- Challenging to implement. System must:
  - Identify dependencies (dependency graphs, query independent of update).
  - Exploit dependencies (MQO).
  - Handle mutual dependencies (permutation, delta compression, shadow copying).
  - Implement assignment!
  - Schedule parallel code.