Stop the Chase

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Motivation

The Chase Algorithm

- Central tool in many database areas, such as Semantic Query Optimization, Query Rewriting using Views, Data Integration ...
- Idea: given a database instance and a set of constraints, fix the constraint violations in the database instance

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Chase Termination

- The Chase Algorithm does not necessarily terminate
- Even worse: Chase termination is an undecidable problem in general, even for a fixed instance
- *Sufficient* conditions over the constraints exist, which guarantee Chase termination on every instance

Contributions and Outline

Novel Data-independent Chase Termination Conditions

- Apply to every database instance
- Generalize previous conditions, such as *Weak Acyclicity* and *Stratification*
- Allows us to guarantee Chase termination in more cases

Study of Data-dependent Chase Termination

- Static approach
- Dynamic approach

A Non-terminating Chase Sequence

Example

Consider a single predicate $E(src, dest)$ (storing graph edges), the database instance $\mathcal{I}$, and constraint α:

$$\mathcal{I} := \{E(a, b)\} \qquad \alpha := \forall x, y(E(x, y) \rightarrow \exists z(E(y, z))$$

The Chase Algorithm tries to fix constraint violations in $\mathcal{I}$:

$\{E(a, b)\}$
$\xrightarrow{\alpha} \{E(a, b), E(b, n_1)\}$, where n_1 is a fresh null value
$\xrightarrow{\alpha} \{E(a, b), E(b, n_1), E(n_1, n_2)\}$, where n_2 is a fresh null value
$\xrightarrow{\alpha} \{E(a, b), E(b, n_1), E(n_1, n_2), E(n_2, n_3)\}$, where n_3 is a fresh null value
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Source of Non-termination

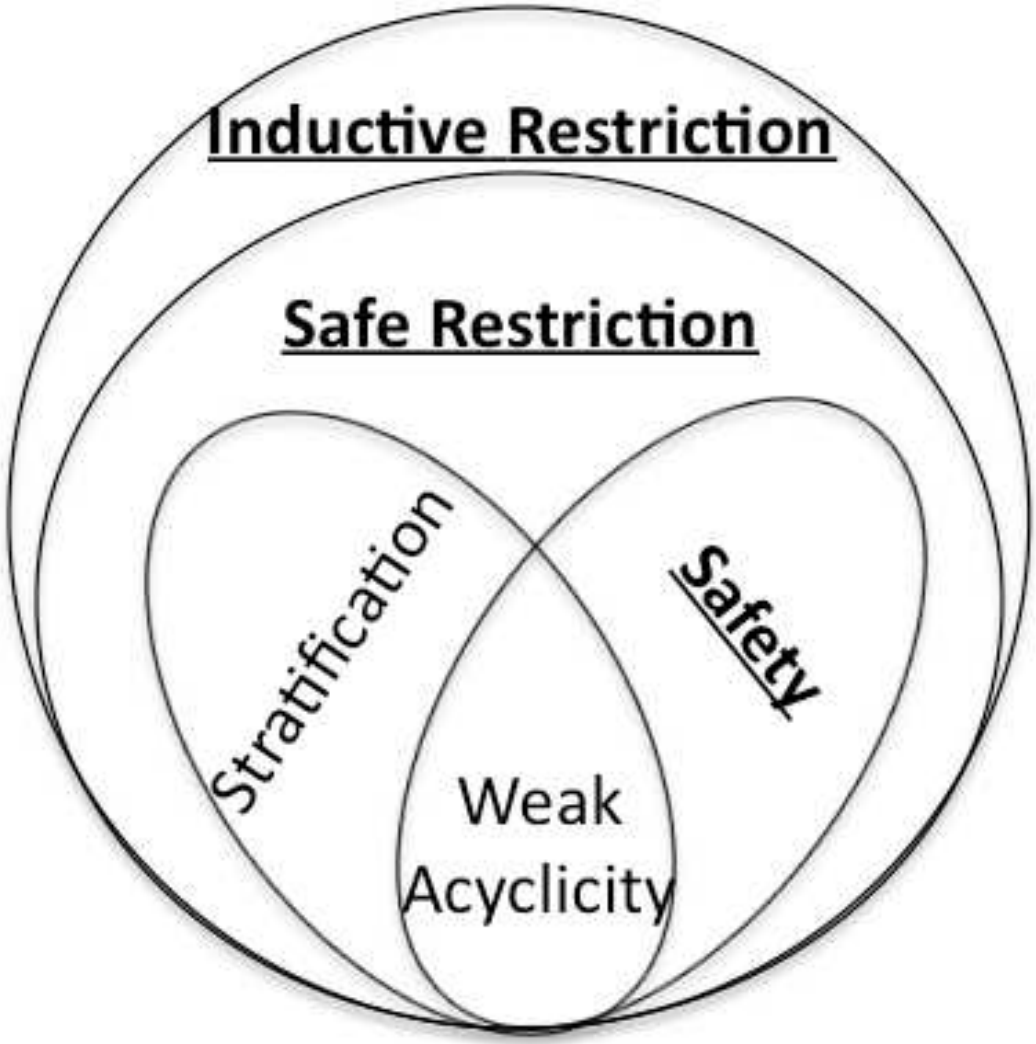
Cascading of fresh null values (here: created in position E^2).

Central Ideas

Estimating the Flow of Null Values

- Estimate positions where null values can be created in or copied to during the Chase run
- Supervise the flow of null values
- More fine-grained decomposition of the constraint set than in previous conditions

Survey of Results



The Limitations of Weak Acyclicity

Weak Acyclicity

- Construct the *dependency graph*, which tracks the flow of values
- Use "special edges" $\overset{*}{\longrightarrow}$ where fresh null values are created

$\forall x, y(E(x, y) \rightarrow \exists z\ E(y, z))$

Dependency graph:

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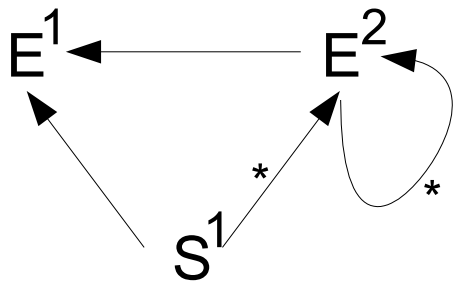

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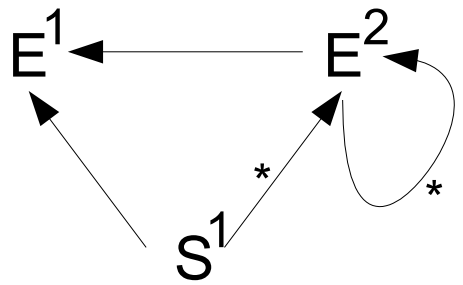

"Unnatural" Property of Weak Acyclicity

More literals in the body imply larger dependency graph.

Estimating Positions with Null Values

Estimating Positions That May Contain Null Values

- Borrow the notion of *affected positions* from [1]
- *Affected positions* are an overestimation of the positions where null values might be created in or copied to during Chase application

Reference

[1] *A. Cali, G. Gottlob, and M. Kifer.* Taming the Infinite Chase: Query Answering under Expressive Relational Constraints. KR 2008.

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Example

$\forall x, y(E(x, y) \rightarrow \exists z\ E(y, z)) \quad \rightarrow \quad$ Affected positions: $\{E^1, E^2\}$

$\forall x, y(S(y), E(x, y) \rightarrow \exists z\ E(y, z)) \quad \rightarrow \quad$ Affected positions: $\{E^2\}$

The Propagation Graph

Properties of the Propagation Graph

- Strict generalization of the Dependency Graph
- Takes affected positions into account

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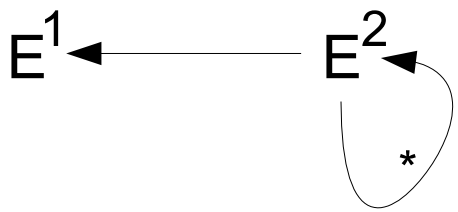

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Affected positions: $\{E^2\}$

Propagation graph:

The Safety Condition

Definition

A constraint set is called *safe* iff its propagation graph contains no cycle going through a special edge.

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Properties of *Safety*

- *Safety* guarantees Chase termination in polynomial-time data complexity
- It can be checked in polynomial time if a constraint set is *safe*
- *Safety* is strictly more general than *Weak Acyclicity*

Limitations of Stratification

- *Stratification* [2]: it suffices to assert *Weak Acyclicity* locally, for subsets of constraints that might cyclically fire each other

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Example

The following constraint set $\Sigma := \{\alpha_1, \alpha_2\}$ is neither *Weakly Acyclic*, nor *Safe*, nor *Stratified*.

α_1 : Special nodes have a cycle of length 2 through outgoing edges

$$\forall x, y(S(x), E(x, y) \rightarrow E(y, x))$$

α_2 : Special nodes have a cycle of length 3 through outgoing edges

$$\forall x, y(S(x), E(x, y) \rightarrow \exists z\ E(y, z), E(z, x))$$

Limitations of Stratification

Example (continued)

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Firing of Constraints

- Firing α_1 **cannot** cause α_1 to fire
- Firing α_2 **cannot** cause α_2 to fire

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Firing of Constraints

- Firing α_1 **can** cause α_2 to fire:

  $\{S(a), S(b), E(a, b), E(b, c), E(c, a)\}$
  $\xrightarrow{\alpha_1} \{S(a), S(b), E(a, b), E(b, c), E(c, a), \mathbf{E(b, a)}\}$
  $\xrightarrow{\alpha_2} \{S(a), S(b), E(a, b), E(b, c), E(c, a), E(b, a), \mathbf{E(a, n_1)}, \mathbf{E(n_1, b)}\}$
- Firing α_2 **can** cause α_1 to fire (similar)

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Firing of Constraints

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- Firing α_2 **can** cause α_1 to fire (similar)

$\rightarrow$ Constraints are cyclically connected, so *Stratification* does not apply

Decomposition of the Constraint Set

Observation

Not only cyclic firing, but also a cyclic passing of null values is necessary to obtain non-terminating Chase sequences.

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- Firing α_1 **cannot** cause α_2 to fire **s.t.** α_2 **copies some null values from its head to its body**, since S^1 does not contain null values

Safe Restriction

Refinement of Firing

- Ignore firing relation of (α_1,α_2) whenever the firing of α_2 (after firing α_1) cannot copy null values from its body to its head
- Allows for more fine-grained decomposition of the constraint set
- Check *Safety* condition for the decomposed sets

$\longrightarrow$ new Chase termination condition called *Safe Restriction*

Safe Restriction

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$\longrightarrow$ new Chase termination condition called *Safe Restriction*

Safe Restriction

- *Safe Restriction* guarantees Chase termination in polynomial time data complexity
- It can be checked by a coNP-algorithm if a constraint set is *safely restricted*
- *Safe Restriction* strictly generalizes *Stratification*

Inductive Restriction

α_1 : Every special node with an edge has a cycle of length 2

$\forall x, y(S(x), E(x, y) \rightarrow E(y, x))$

α_2 : Every special with and edge has a cycle of length 3

$\forall x, y(S(x), E(x, y) \rightarrow \exists z\ E(y, z), E(z, x))$

α_3 : There is at least one special node with outgoing edge

$\exists x, y\ S(x), E(x, y)$

Inductive Restriction

- Now a cyclic passing of null values between α_2 and α_1 becomes possible, because there might occur null values in S^1 now.
- Idea: inductive decomposition of the constraint set gives us a novel termination called *Inductive Restriction*, which further generalizes *Safe Restriction*

Data-dependent Chase Termination

Chase termination w.r.t. a fixed instance

- May overcome situations where no termination guarantees for the general case can be made
- Given a constraint set Σ and a database instance $\mathcal{I}$, we propose two complementary approaches
  - Static approach
  - Dynamic approach

Static Approach

Idea

- Try to exclude constraints from the constraint set that will never fire when chasing the instance under consideration
- Check if data-independent termination condition (i.e., *Inductive Restriction*) holds for this subset of relevant constraints

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Challenge

- Fundamental result: it is an undecidable problem if a constraint fires when chasing a fixed instance
- Techniques to overestimate the constraint set that may be used during the Chase on the instance

Dynamic Approach

Monitoring Chase Execution

- Maintain a data structure (called *monitor graph*) that tracks the repeated introduction of fresh null values
- Fix a repetition treshold k and abort the Chase run if k is exceeded: in such a case, no termination guarantees can be made

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- Maintain a data structure (called *monitor graph*) that tracks the repeated introduction of fresh null values
- Fix a repetition treshold k and abort the Chase run if k is exceeded: in such a case, no termination guarantees can be made

Properties of the Monitoring Approach

- **Guarantee:** infinite Chase sequences will always be detected, independent from the size of the repetition threshold
- **Natural condition:** the monitor graph accounts for situations that may well cause non-termination
- **Pay-as-you-go approach:** the repetition threshold can be chosen following a pay-as-you-go approach: The higher the threshold, the more terminating Chase sequences will be recognized

Conclusion

Data-independent Chase Termination

- Estimation of the positions that may contain null values and tracking the flow of null values allwos us to improve existing sufficient termination conditions
  - *Safety* (checkable in polynomial time)
  - *Safe Restriction* and *Inductive Restriction* (checkable by a coNP-algorithm)

Data-dependent Chase Termination

- First results on Chase termination for fixed instances
  - Static approach: exclude irrelevant constraints
  - Dynamic approach: monitor Chase at runtime

Thank You for Your Attention!

Any questions?