How to Stay CALM While Seeing What is not There?

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Introduction

- Cloud-computing: Setting with asynchronous communication via messages which can be arbitrarily delayed but not lost
- CALM-conjecture: No coordination = Monotonicity

[Hellerstein, 2010]

(CALM = Consistency And Logical Monotonicity)

Monotonicity

Definition

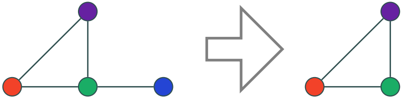
A query Q is monotone if $Q(\mathbf{I}) \subseteq Q(\mathbf{I} \cup \mathbf{J})$ for all database instances $\mathbf{I}$ and $\mathbf{J}$.

Notation

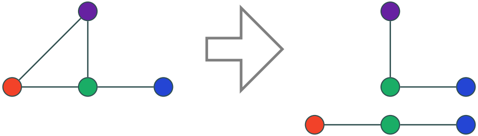
$\mathcal{M}$: class of monotone queries

Example

- Q_Δ: Select triangles in a graph $\in \mathcal{M}$



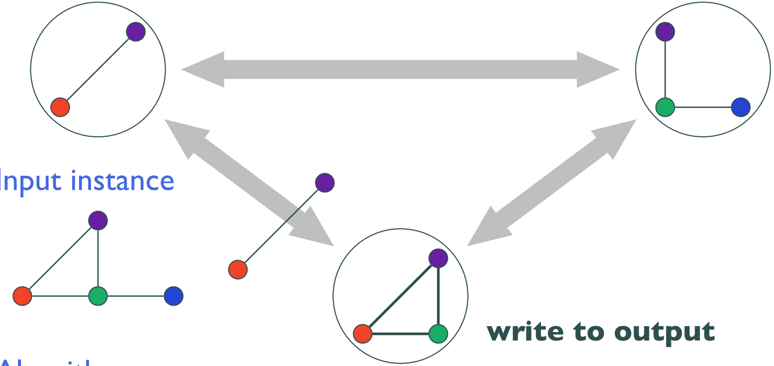
- $Q_<$: Select open triangles in a graph $\notin \mathcal{M}$



CALM by Example

Q_Δ: select all triangles $\in \mathcal{M}$

Input instance



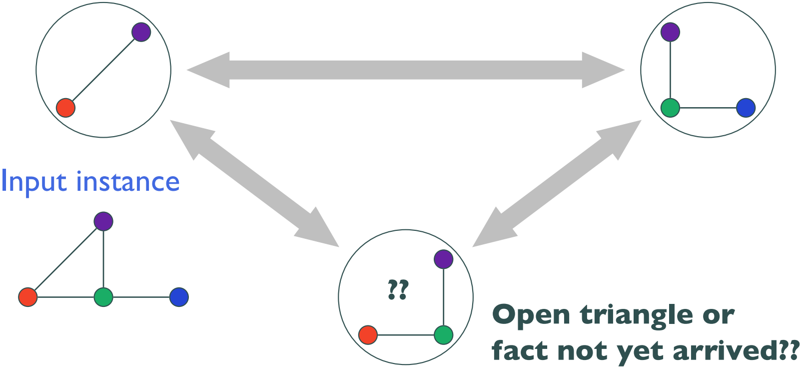
Algorithm

- broadcast all data
- periodically output local triangles

No coordination + Eventually consistent

CALM by Example

$Q_{<}$: select all open triangles $\notin \mathcal{M}$



Requires global coordination

CALM-conjecture

CALM-conjecture

No-coordination = Monotonicity

[Hellerstein, 2010]

- [Ameloot, Neven, Van den Bussche, 2011]: TRUE
  - for a setting where nodes have **no** information about the distribution of facts
- [Zinn, Green, Ludäscher, 2012]: FALSE
  - for settings where nodes **have** information about the distribution of facts
- **TRUE when also refining montonicity**

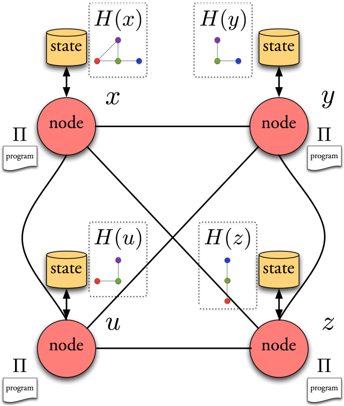
Overview

1. CALM
2. CALM Revision 1
3. CALM Revision 2

Relational Transducer Networks

[Ameloot, Neven, Van den Bussche, 2011]

- Network $\mathcal{N} = \{x, y, u, z\}$
- Transducer Π
- messages can be arbitrarily delayed but never get lost



Semantics defined in terms of runs over a transition system

Relational Transducer Networks

[Ameloot, Neven, Van den Bussche, 2011]

Definition

A transducer Π computes a query Q if

- for all networks $\mathcal{N}$, ← Network independent
- for all databases $\mathbf{I}$, Data distribution independent
- for all horizontal distributions H, and
- for every run of Π,

$$out(\Pi) = Q(\mathbf{I}).$$

Consistency requirement

Coordination-free Algorithms

[Ameloot, Neven, Van den Bussche, 2011]

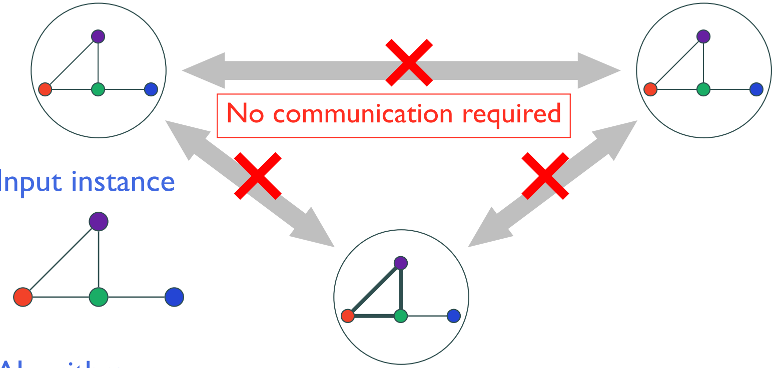
Definition

Π is coordination-free if for all inputs $\mathbf{I}$ there is a distribution on which Π computes $Q(\mathbf{I})$ without having to do communication.

Goal: separate data-communication from coordination-communication

Example: Ideal Distribution

Q_Δ: select all triangles



Input instance

Algorithm

- (broadcast all data)
- periodically output local triangles

CALM-conjecture

[Ameloot, Neven, Van den Bussche, 2011]

A query has a coordination-free and eventually consistent execution strategy
iff
the query is monotone

⇓

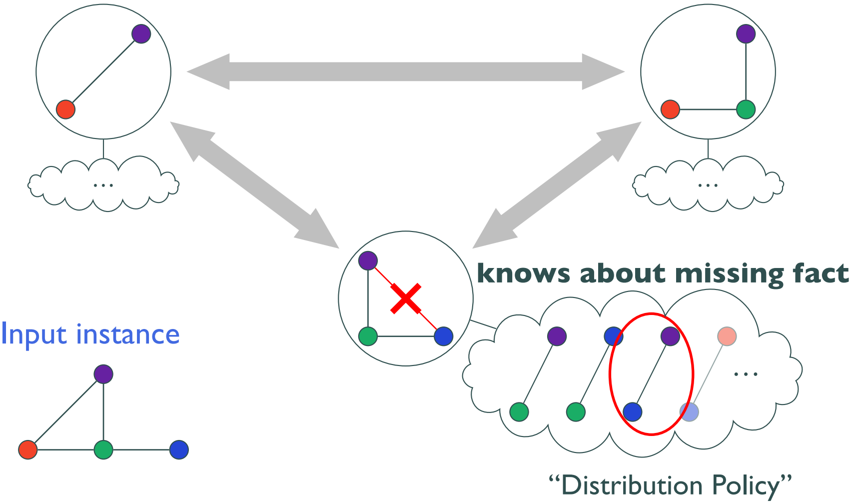
Theorem
$\mathcal{F}_0 = \mathcal{M}$

Definition
$\mathcal{F}_0$ = set of queries which are distributedly computed by coordination-free transducers

Overview

1. CALM
2. CALM Revision 1
3. CALM Revision 2

Policy-aware Transducers



Policy-aware Transducers

[Zinn, Green, Ludäscher, 2012]

Definition
A distribution policy $\mathbf{P}$ for σ and $\mathcal{N}$ is a total function from $facts(\sigma)$ to the power set of $\mathcal{N}$.

Definition
A policy-aware transducer is a transducer with access to $\mathbf{P}$ restricted to its active domain

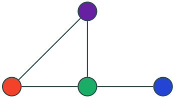
Definition
$\mathcal{F}_1 =$ set of queries which are distributedly computed by policy-aware coordination-free transducers

Domain-distinct-monotonicity

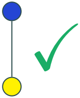
Definition

A fact **f** is domain distinct from instance $\mathbf{I}$ when $adom(\mathbf{f}) \not\subseteq adom(\mathbf{I})$.

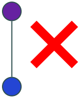
Example



$\mathbf{I}$



f



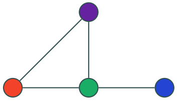
f′

Domain-distinct-monotonicity

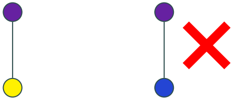
Definition

An instance $\mathbf{J}$ is domain distinct from instance $\mathbf{I}$ when every fact $\mathbf{f} \in \mathbf{J}$ is domain distinct from $\mathbf{I}$.

Example



$\mathbf{I}$



$\mathbf{J}$

Domain-distinct-monotonicity

Definition

A query Q is domain-distinct-monotone if $Q(\mathbf{I}) \subseteq Q(\mathbf{I} \cup \mathbf{J})$ for all $\mathbf{I}$ and $\mathbf{J}$ for which $\mathbf{J}$ is domain distinct from $\mathbf{I}$.

Notation

$\mathcal{M}_{distinct}$: *class of domain-distinct-monotone queries*

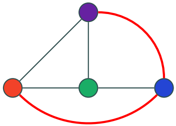
Remark

$\mathcal{M}_{distinct}$: *class of queries preserved under extensions*

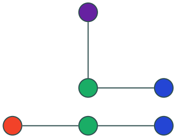
Domain-distinct-monotonicity

Example

Select open triangles in graph $\in \mathcal{M}_{distinct}$.



$\mathbf{I}$



$Q(\mathbf{I})$

Not domain-distinct from $\mathbf{I}$

Revised CALM-conjecture

A query has a coordination-free and eventually consistent execution strategy under distribution policies

iff

the query is domain-distinct-monotone

Theorem

$$\mathcal{F}_1 = \mathcal{M}_{distinct}$$

Definition

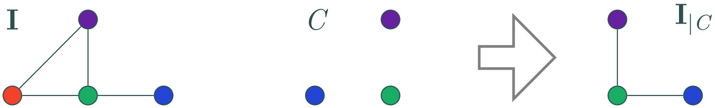
$\mathcal{F}_1 =$ set of queries which are distributedly computed by policy-aware coordination-free transducers

Proof of $\mathcal{M}_{distinct} \subseteq \mathcal{F}_1$

- Monotonicity: $Q(\mathbf{J}) \subseteq Q(\mathbf{I})$ for every $\mathbf{J} \subseteq \mathbf{I}$
- Domain-distinct-monotonicity:

Let $\mathbf{I}$ be an instance, $C \subseteq adom(\mathbf{I})$.

Induced instance: $\mathbf{I}_{|C} = \{\mathbf{f} \in \mathbf{I} \mid adom(\mathbf{f}) \subseteq C\}$



By domain-distinct-monotonicity: $Q(\mathbf{I}_{|C}) \subseteq Q(\mathbf{I})$

Proof of $\mathcal{M}_{distinct} \subseteq \mathcal{F}_1$

- $\mathcal{F}_1$ setting:

  Let $\mathbf{I}$ be an instance, $C \subseteq adom(\mathbf{I})$.

  C is complete at node x when x knows for every fact **f** with $adom(\mathbf{f}) \subseteq C$ whether $\mathbf{f} \in \mathbf{I}$ or $\mathbf{f} \notin \mathbf{I}$.

  complete set = instance based on complete C
  = induced instance of $\mathbf{I}$ based on C

Algorithm

- broadcast all present and deduced absent facts
- Evaluate query on complete sets

Overview

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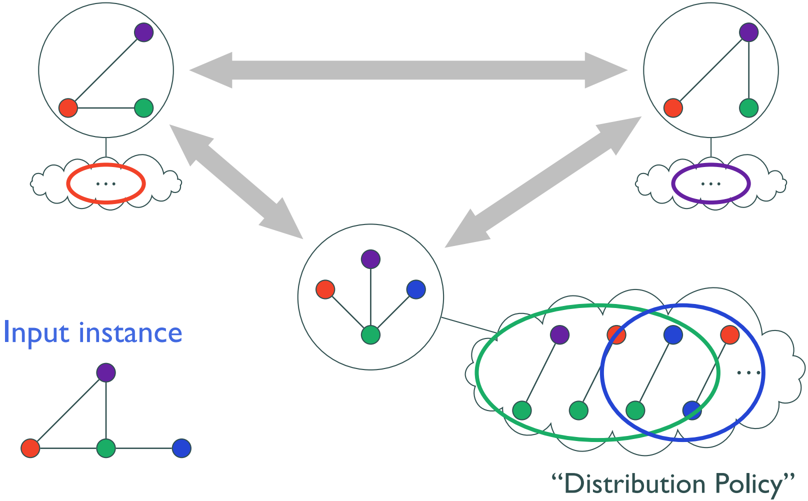
Domain-guided Policies



Domain-guided Policies

[Zinn, Green, Ludäscher, 2012]

Definition

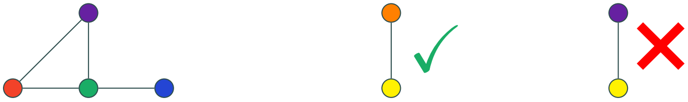
$\mathcal{F}_2 =$ queries which are distributedly computed under domain-guided distribution policies by policy-aware coordination-free transducers.

Domain-disjoint-monotonicity

Definition

An instance $\mathbf{J}$ is domain disjoint from instance $\mathbf{I}$ when $adom(\mathbf{I}) \cap adom(\mathbf{J}) = \emptyset$.

Example



$\mathbf{I}$ $\mathbf{J}$ $\mathbf{J}'$

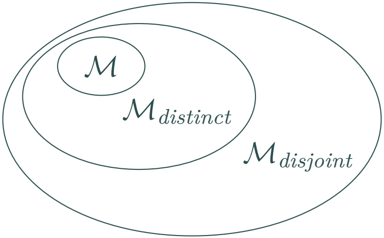
Domain-disjoint-monotonicity

Definition

A query Q is domain-disjoint-monotone if $Q(\mathbf{I}) \subseteq Q(\mathbf{I} \cup \mathbf{J})$ for all $\mathbf{I}$ and $\mathbf{J}$ for which $\mathbf{J}$ is domain disjoint from $\mathbf{I}$.

Notation

$\mathcal{M}_{disjoint}$: *class of domain-disjoint-monotone queries*



Revised CALM-conjecture

A query has a coordination-free and eventually consistent execution strategy under domain-guided distribution policies

iff

the query is domain-disjoint-monotone

Theorem

$$\mathcal{F}_2 = \mathcal{M}_{disjoint}$$

Definition

$\mathcal{F}_2 =$ queries which are distributedly computed under domain-guided distribution policies by policy-aware coordination-free transducers.

Summary

$\mathcal{F}_0$	$=$	$\mathcal{M}$	$=$	wILOG($\neq$)	$\supsetneq$	Datalog($\neq$)
$\subsetneq$		$\subsetneq$		$\subsetneq$		$\subsetneq$
$\mathcal{F}_1$	$=$	$\mathcal{M}_{distinct}$	$=$	SP-wILOG	$\supsetneq$	SP-Datalog
$\subsetneq$		$\subsetneq$		$\subsetneq$		$\subsetneq$
$\mathcal{F}_2$	$=$	$\mathcal{M}_{disjoint}$	$=$	semicon-wILOG$^{\neg}$	$\supsetneq$	semicon-Datalog$^{\neg}$
Coordination freeness		Monotonicity		Datalog + value invention		Datalog

References

Tom J Ameloot, B. K., Frank Neven and Daniel Zinn. *Weaker Forms of Monotonicity for Declarative Networking: a more fine-grained answer to the CALM-conjecture*. In **PODS** 2014.