



Migrating Monolithic Applications to Microservices with CARGO



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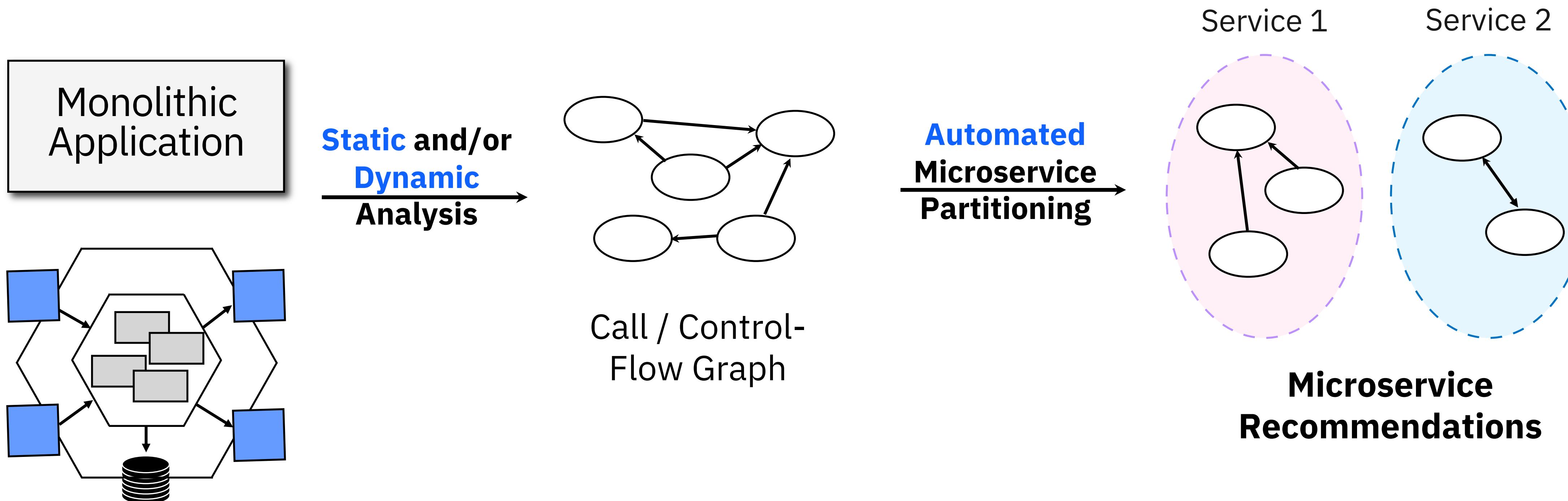


Baishakhi Ray
Columbia University



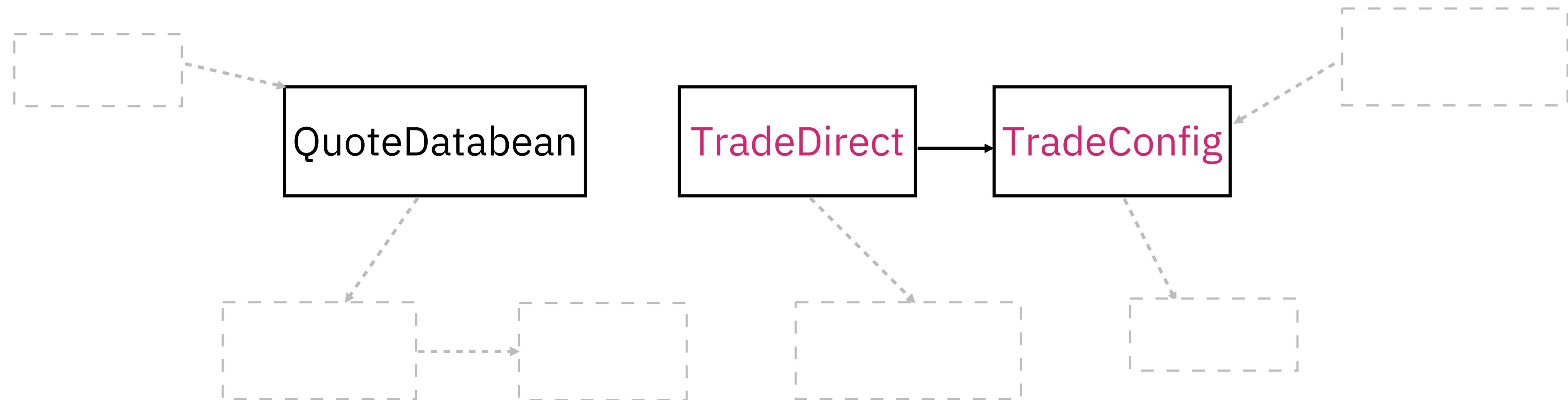
Rahul Krishna
IBM Research

Automated monolith decomposition tools



The Problem

A real example from a benchmark application,
DAYTRADER. This is a portion of a **call-graph**, and
there is a *call edge* between the classes
TradeDirect and **TradeConfig**.



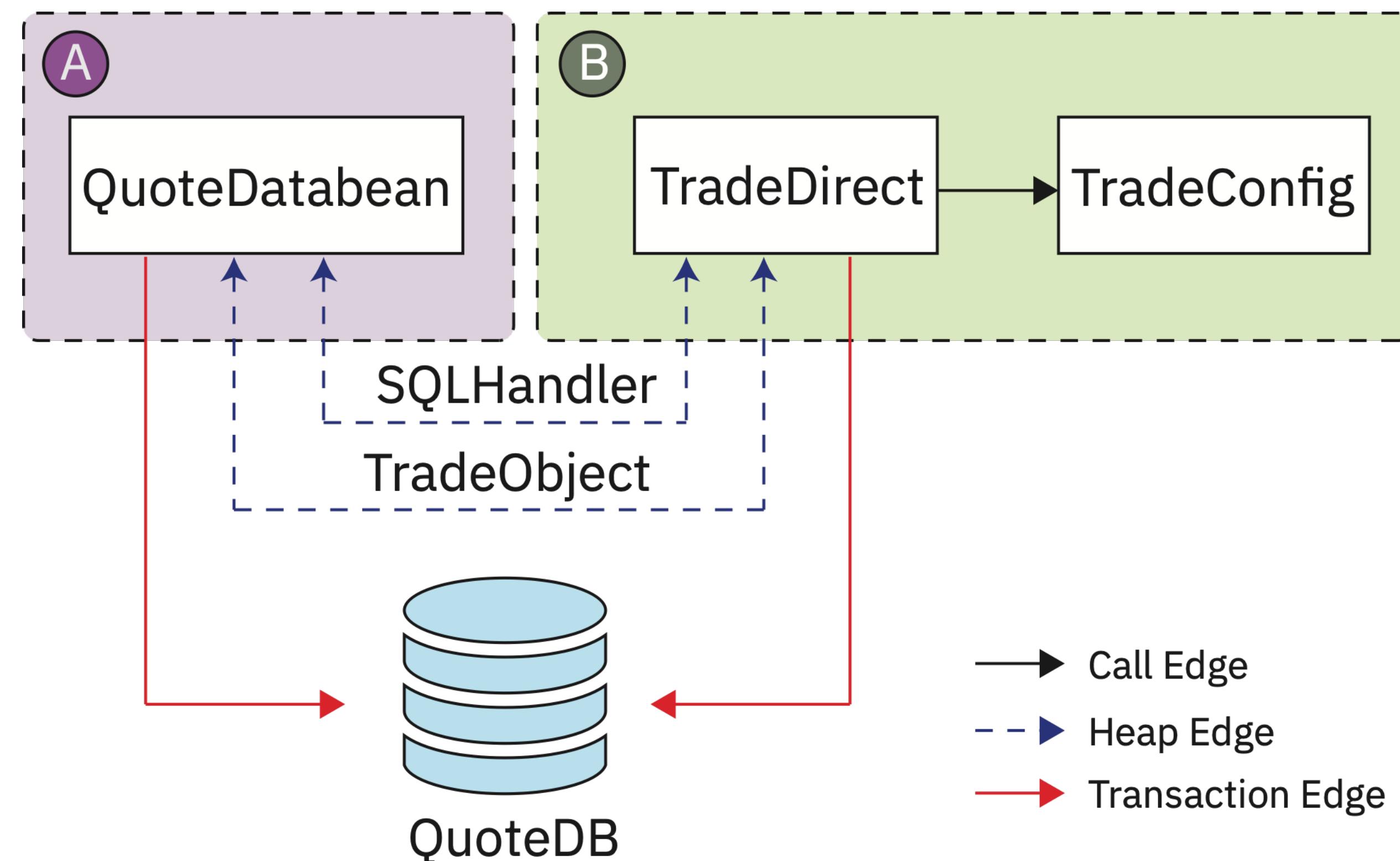
The Problem

In this commonly recommended partitioning,
QuoteDatabasean and **TradeDirect** lie in different partitions.



The Problem

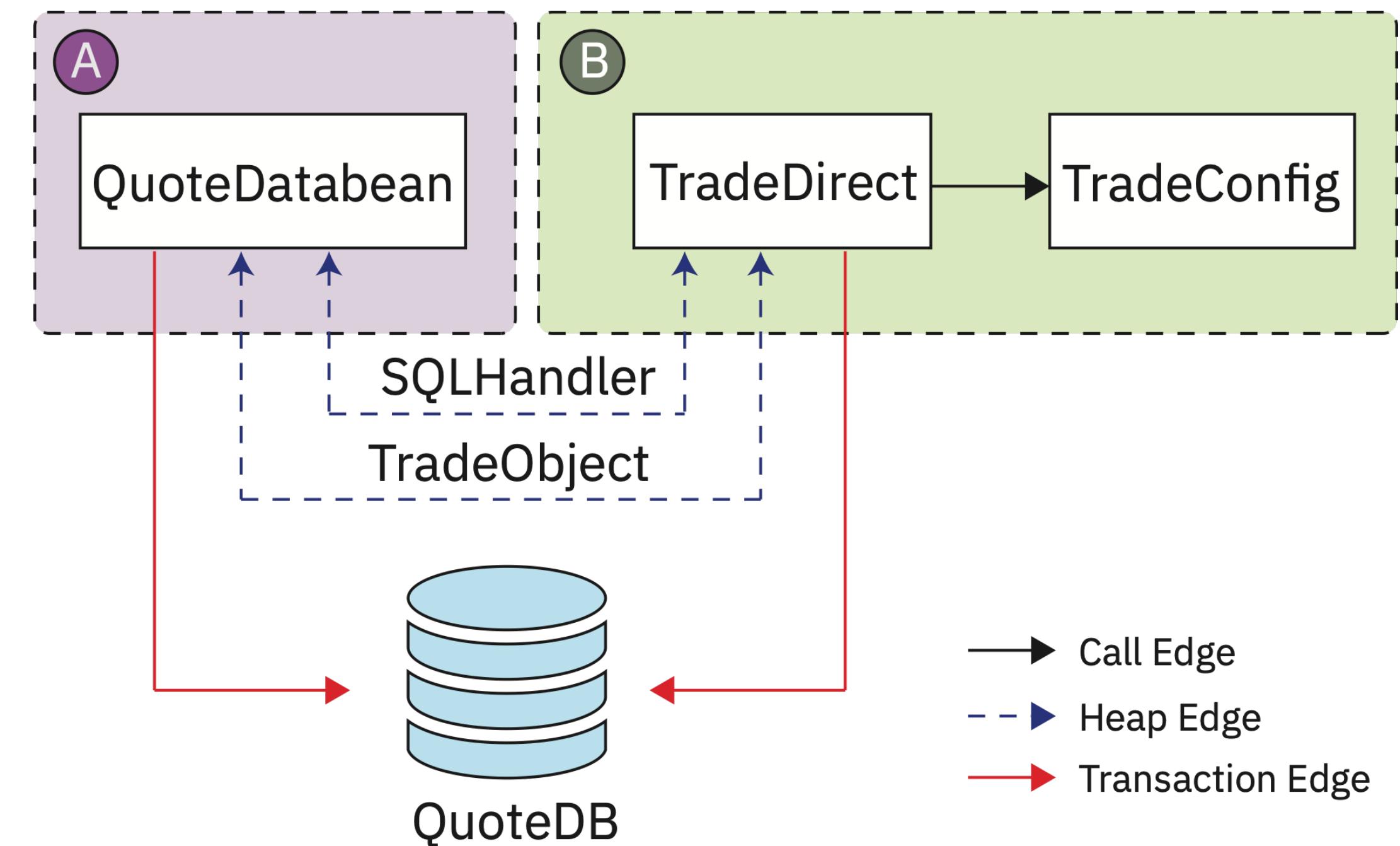
But if we look beyond the call graph, we find this...



The Problem

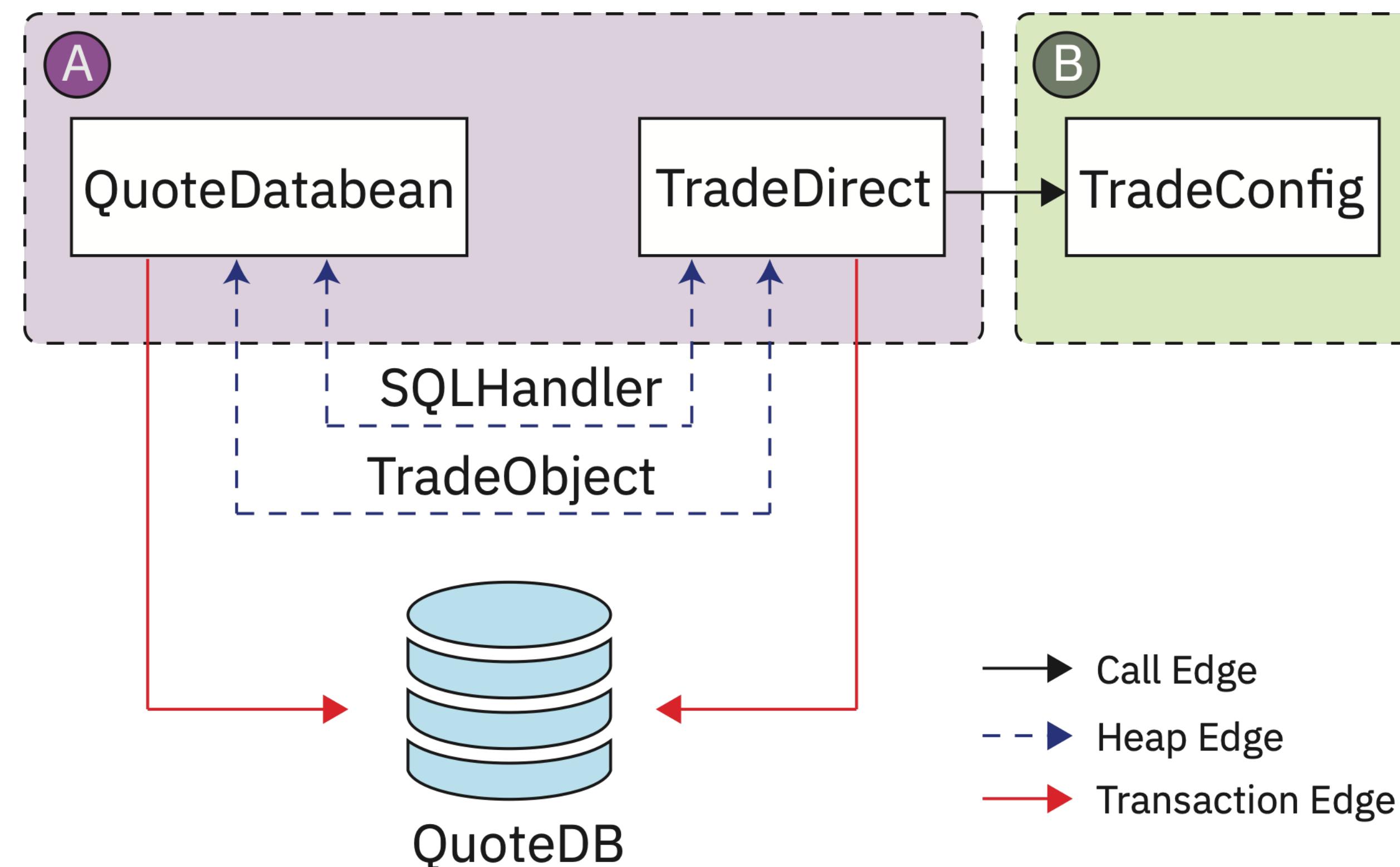
Implementing this partitioning scheme can be challenging...

- 1. Distributed monolith:** The two classes **QuoteDatabean** and **TradeConfig** are tightly coupled (access shared heap objects)
- 2. Distributed transaction:** **QuoteDatabean** and **TradeConfig** write to the same DB.



The Problem

In reality, `QuoteDatabasean` and `TradeDirect` are tightly coupled!
Our algorithm, CARGO, groups them in the same partition



How do we get better partitions?

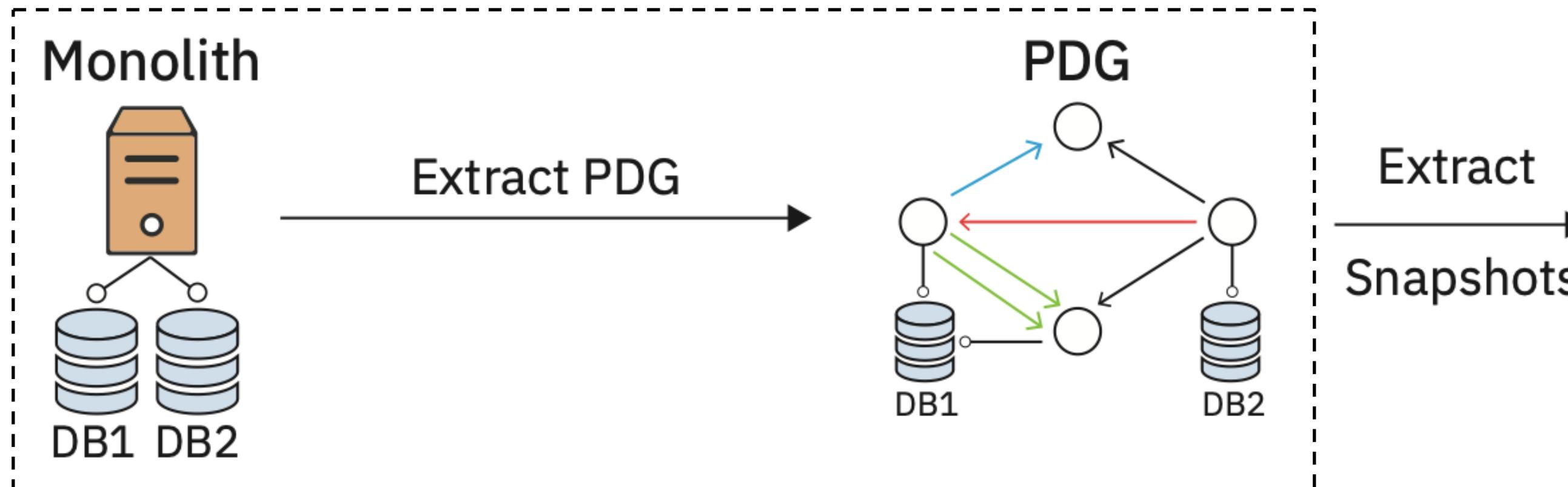
Our algorithm CARGO, uses the following key ideas:

- 1 **Complete and precise static analysis:** Capture many types of dependencies between classes and build a program dependency graph (PDG)
- 2 **Explicitly model transactions:** Database transactions are added as edges in the PDG.
- 3 **Detect communities in the PDG:** We present a novel community detection algorithm to assign partitions to nodes in the PDG.

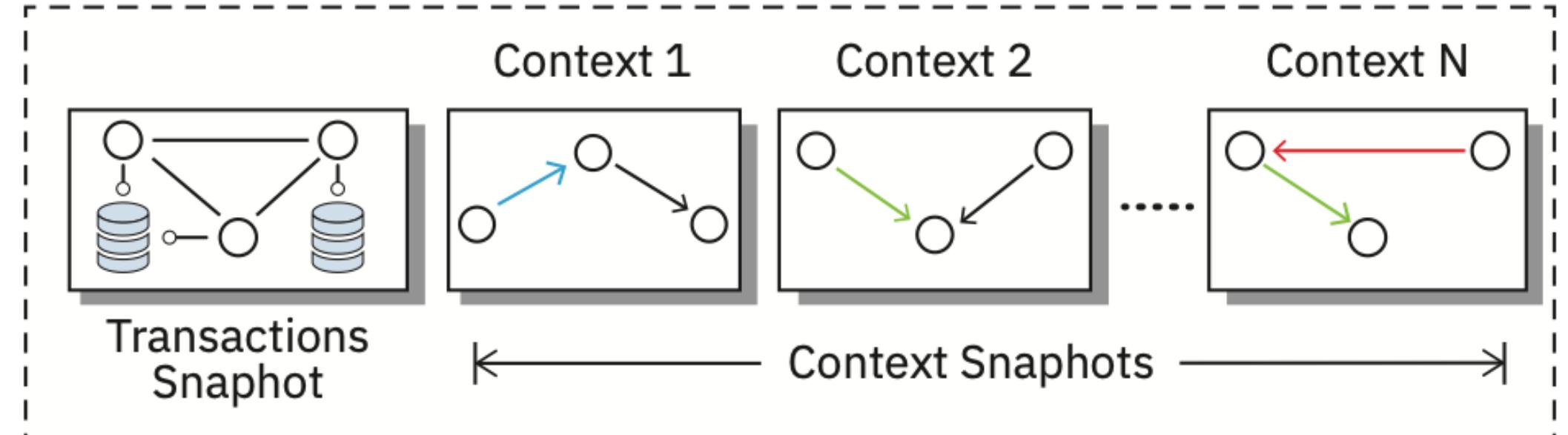
CARGO

CARGO: Overview

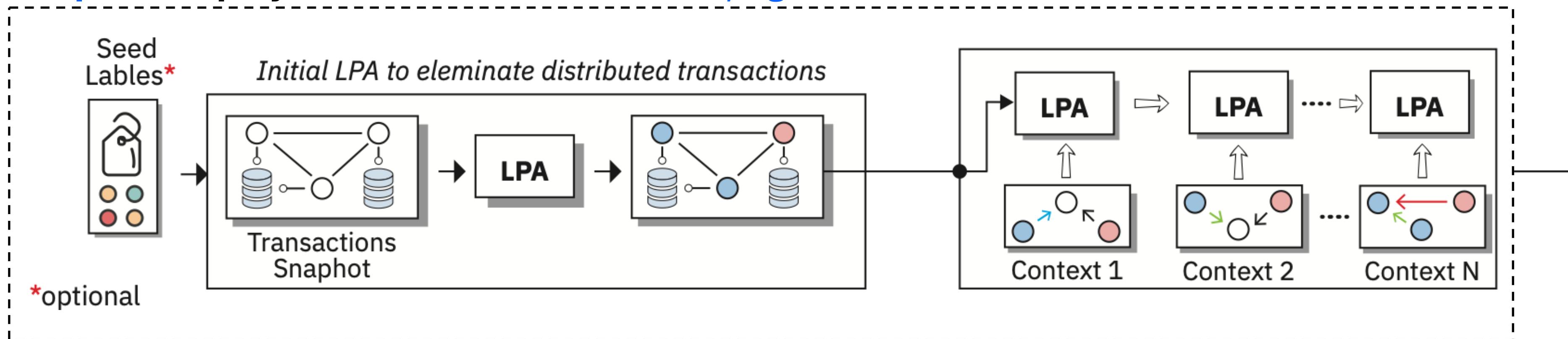
Step I: Build *context-sensitive program dependency graph*



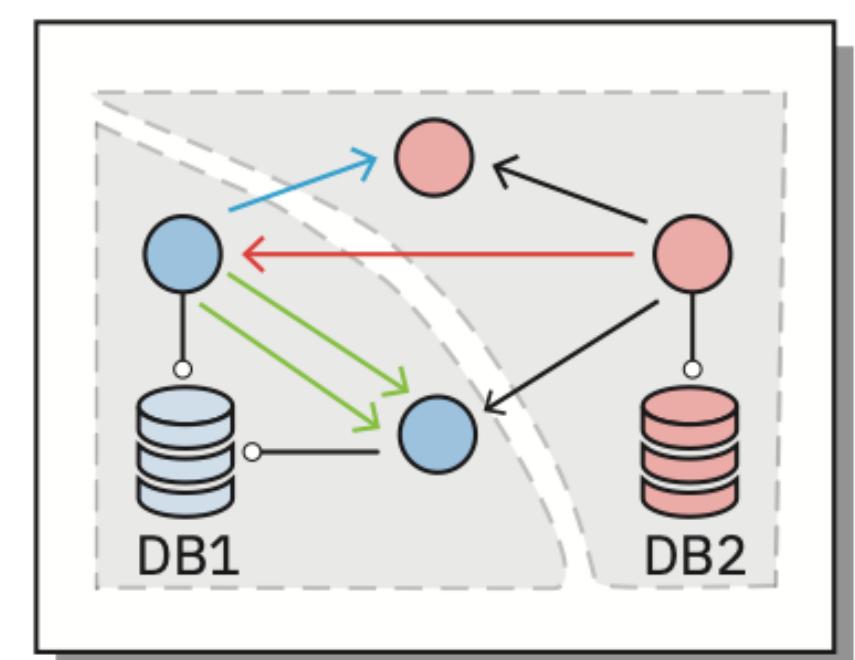
Step II: Extract *context snapshots*



Step III: Deploy *Context-sensitive Label Propagation*



Microservice Boundaries



Step I: Context Sensitive PDG

Extract a Context-sensitive Program Dependency Graph



Context-Sensitivity

```
1 void main(Object[] args) {  
2     A a1 = new A();  
3     Object v1 = a1.foo(new Object());  
4  
5     A a2 = new A();  
6     Object v2 = a2.foo(new Object());  
7 }
```

```
1 class A {  
2     Object foo(Object v) {  
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```

```
1 class B {  
2     Object bar(Object v) {  
3         . . .  
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5 }
```

Context-Sensitivity

Context-insensitive Analysis

main()

```
1 void main(Object[] args) {  
2     A a1 = new A(); // A/1  
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7 }
```

Context-sensitive Analysis

$[\Phi, \Phi]$

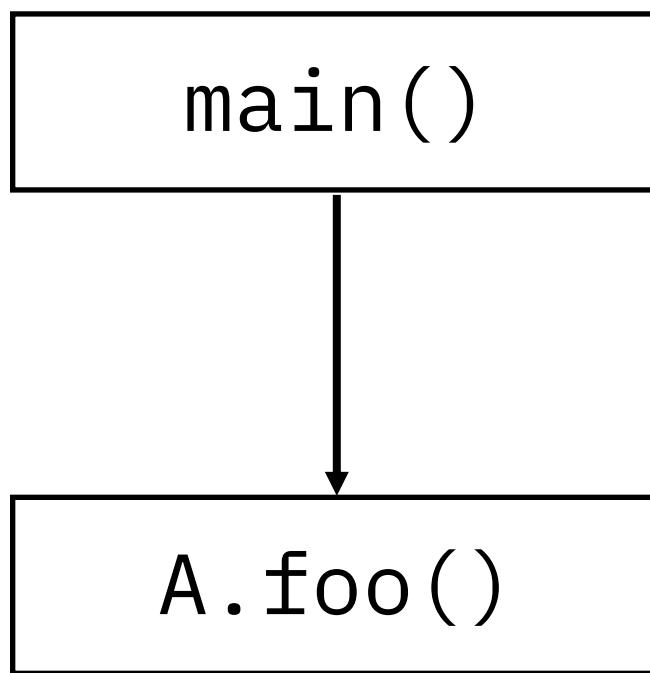
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Context-Sensitivity

Context-insensitive Analysis

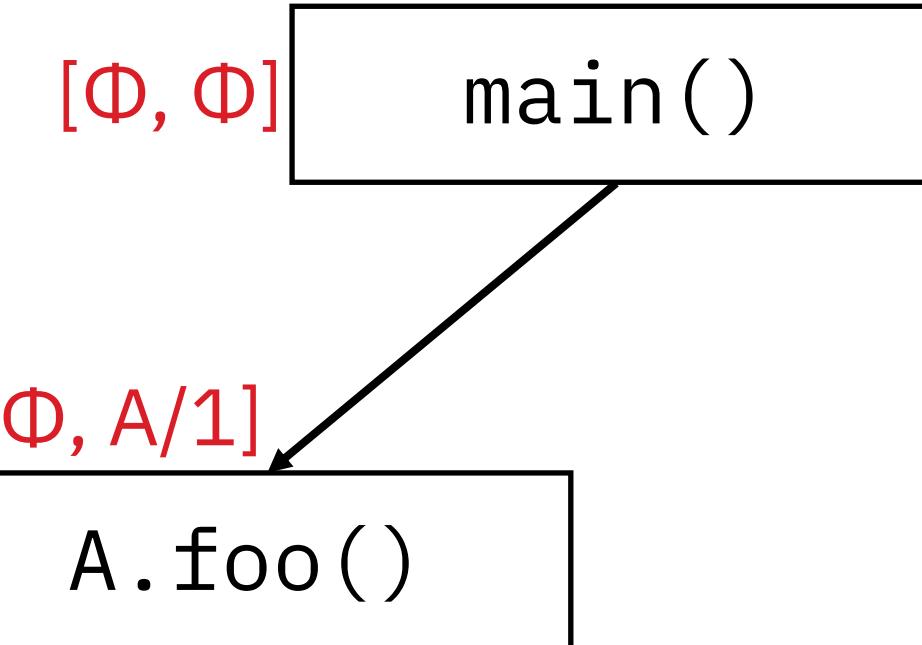


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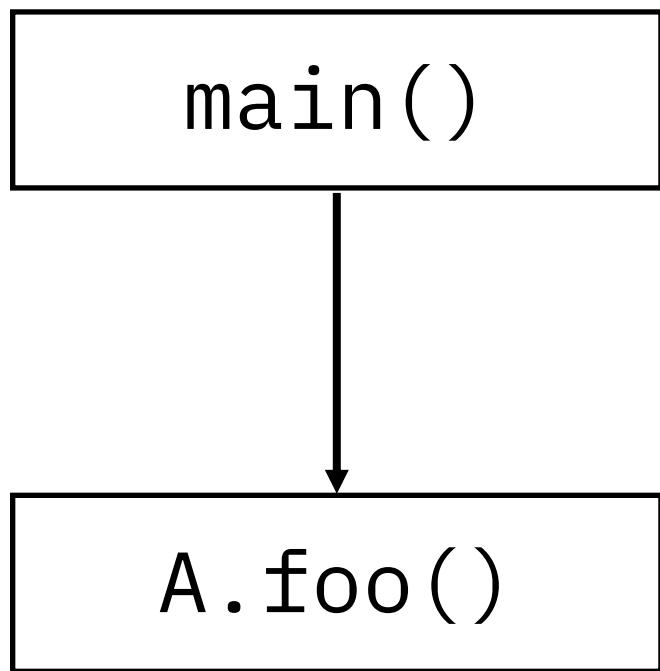
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Context-sensitive Analysis



Context-Sensitivity

Context-insensitive Analysis

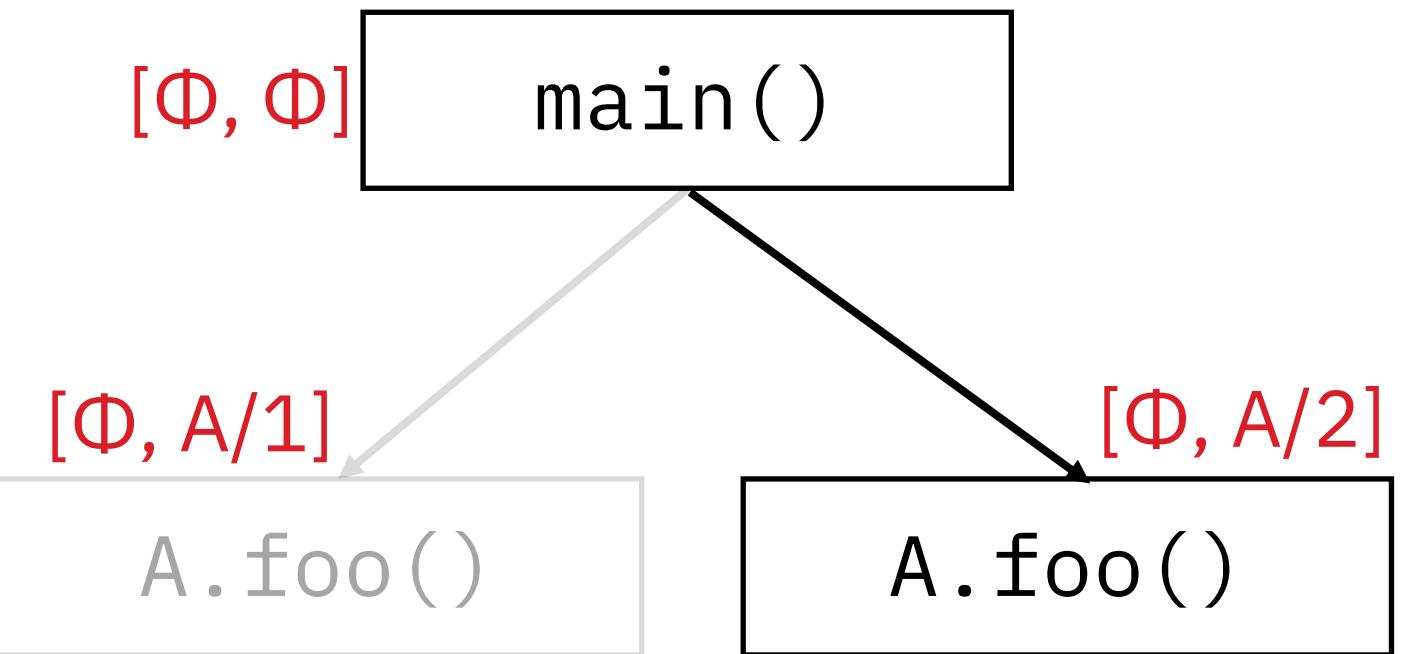


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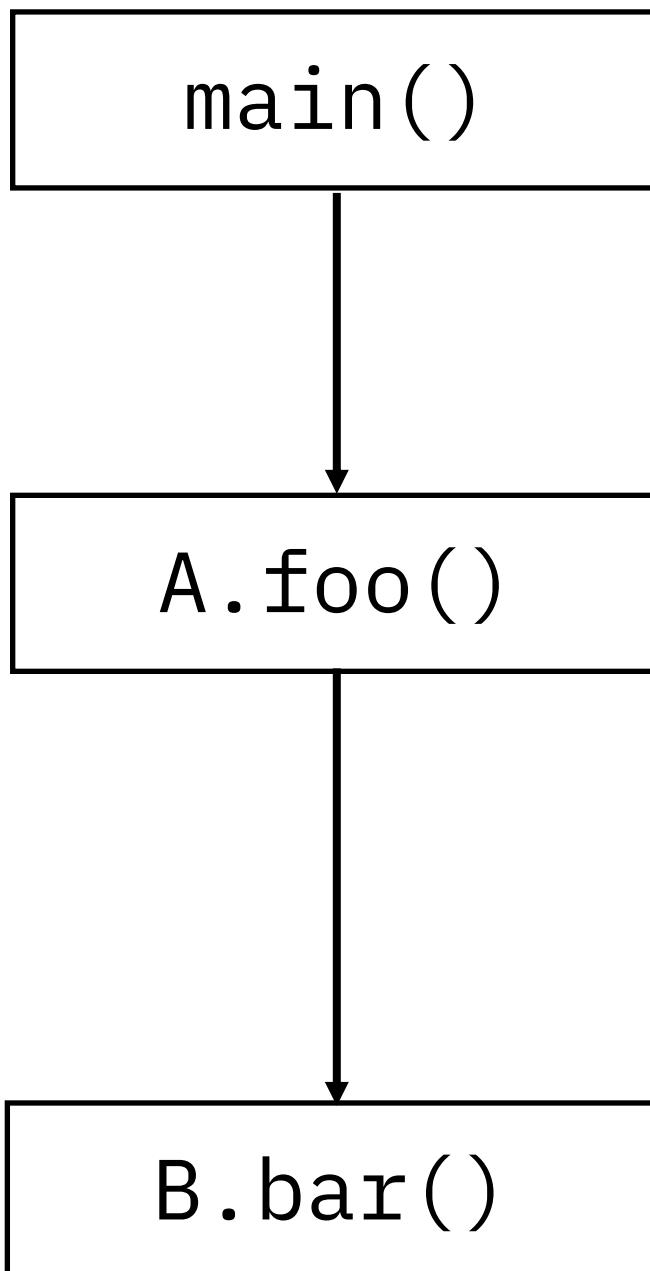
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Context-sensitive Analysis



Context-Sensitivity

Context-insensitive Analysis



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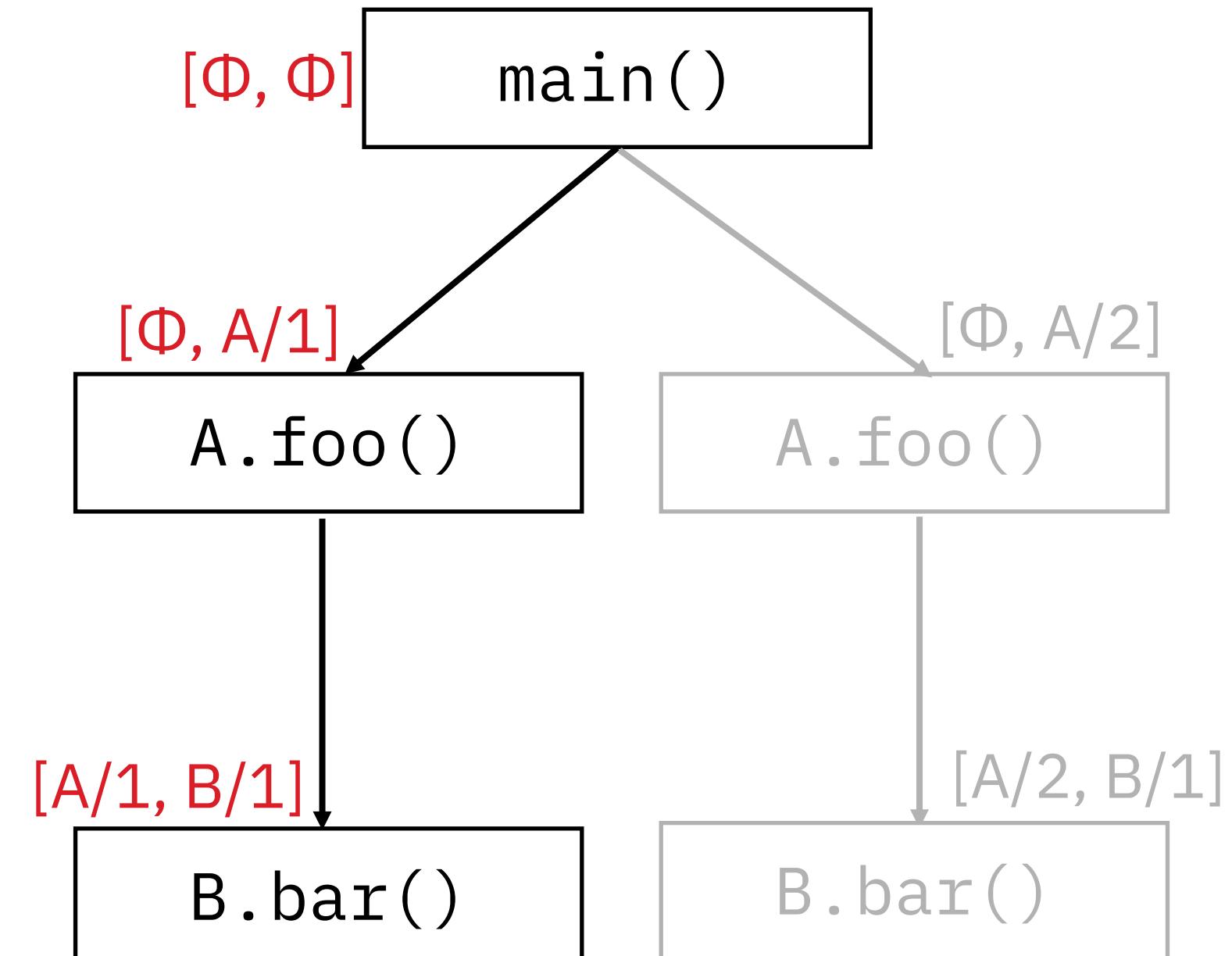


```
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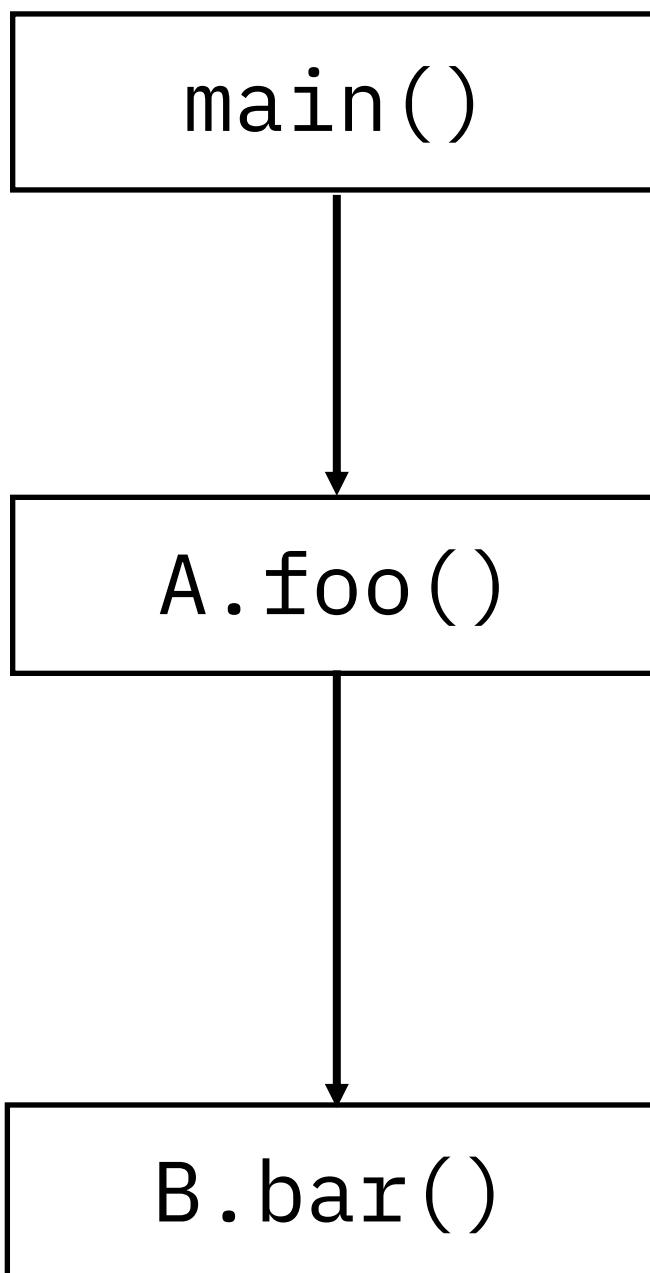
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Context-sensitive Analysis



Context-Sensitivity

Context-insensitive Analysis

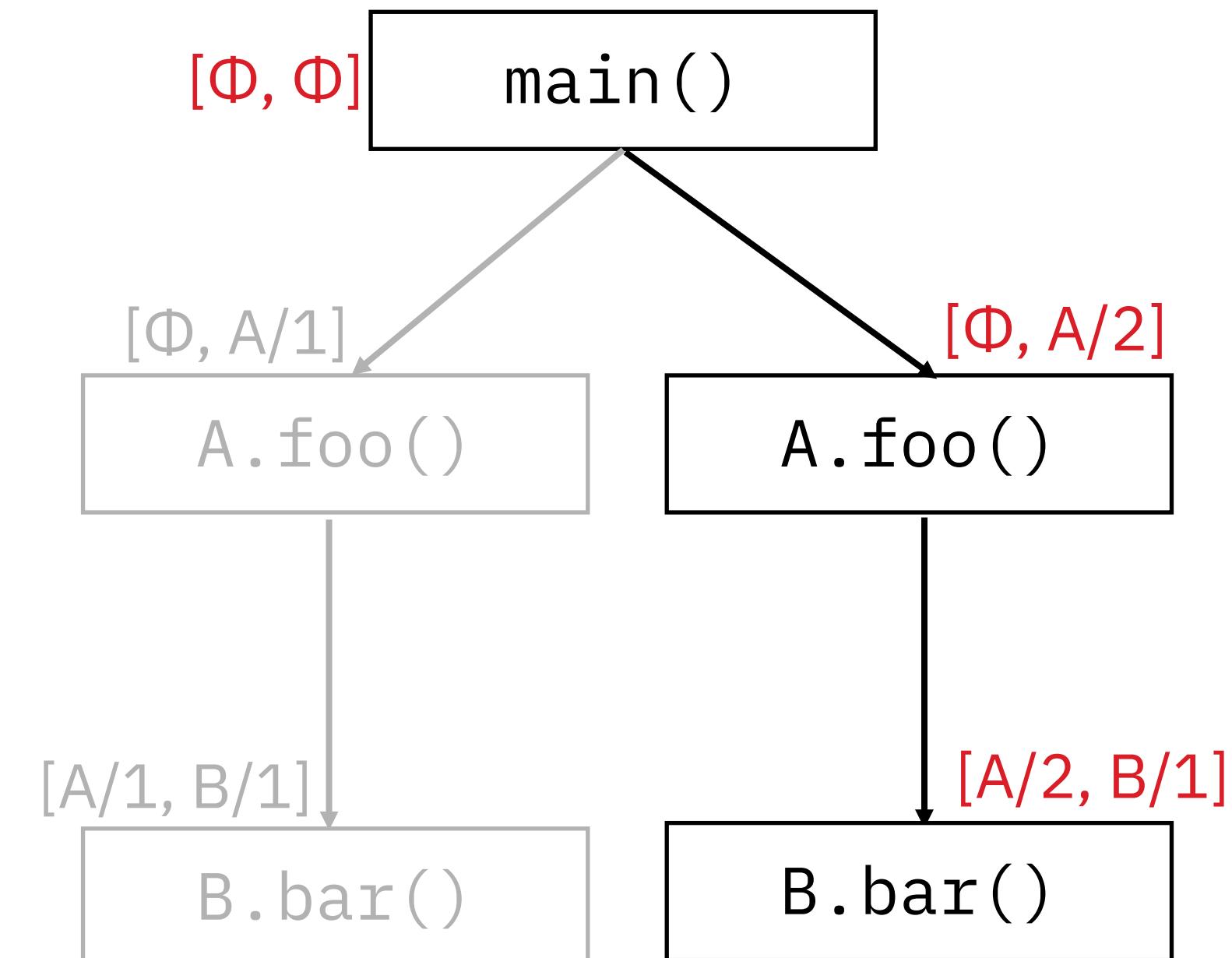


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Context-sensitive Analysis



Building a Program Dependency Graph

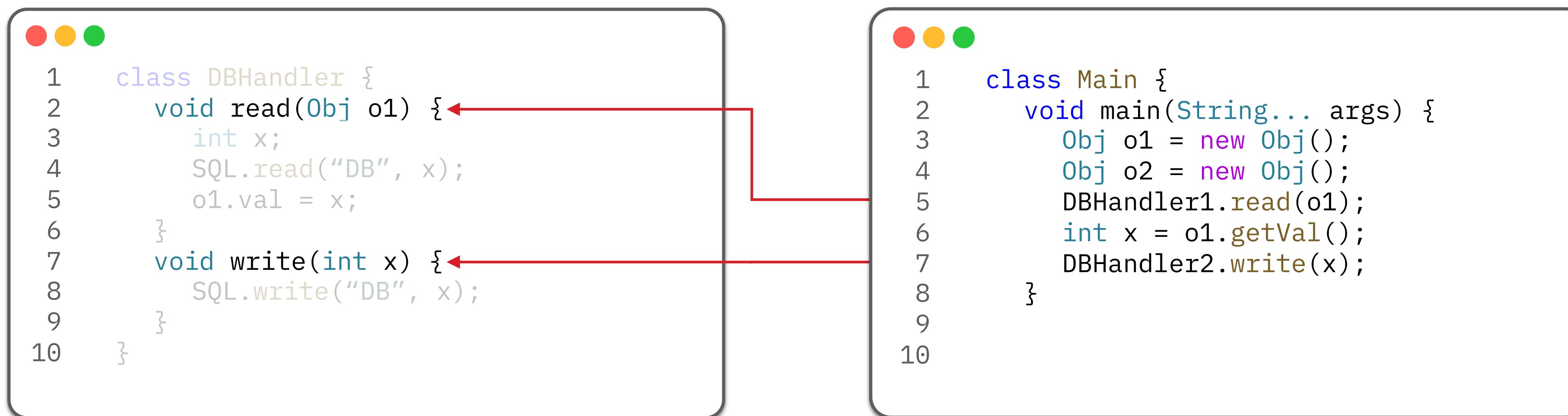


```
1  class DBHandler {  
2      void read(Obj o1) {  
3          int x;  
4          SQL.read("DB", x);  
5          o1.val = x;  
6      }  
7      void write(int x) {  
8          SQL.write("DB", x);  
9      }  
10 }
```



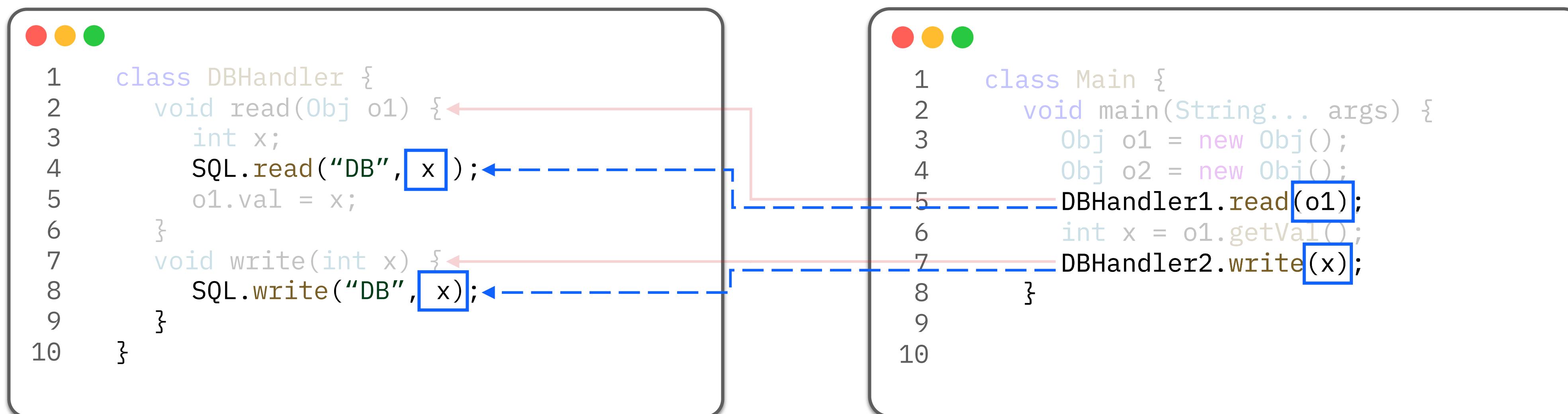
```
1  class Main {  
2      void main(String... args) {  
3          Obj o1 = new Obj();  
4          Obj o2 = new Obj();  
5          DBHandler1.read(o1);  
6          int x = o1.getVal();  
7          DBHandler2.write(x);  
8      }  
9  
10 }
```

Building a Program Dependency Graph



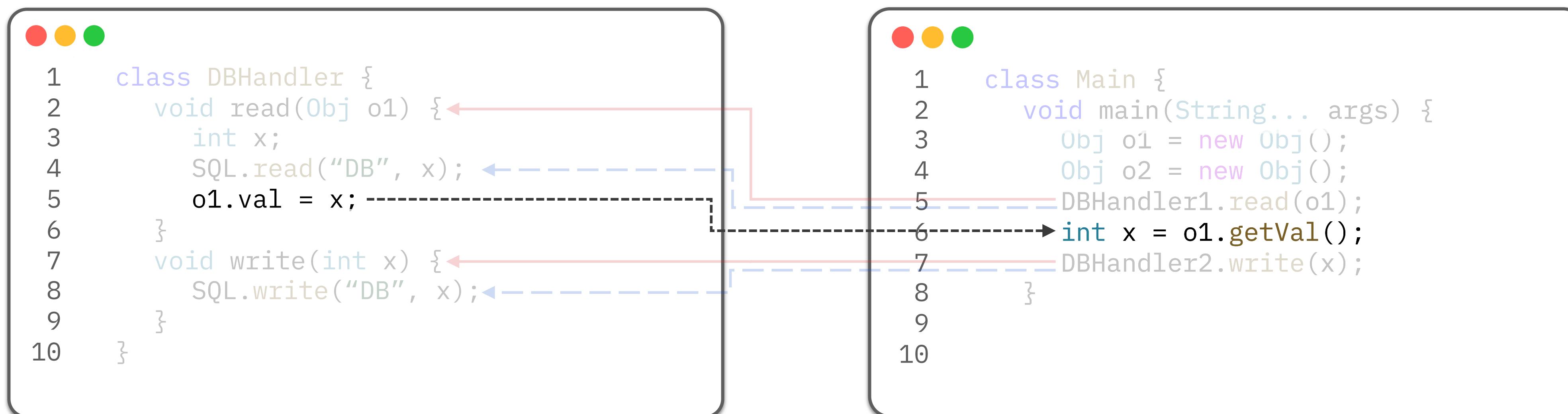
→ Call-return dependency

Building a Program Dependency Graph



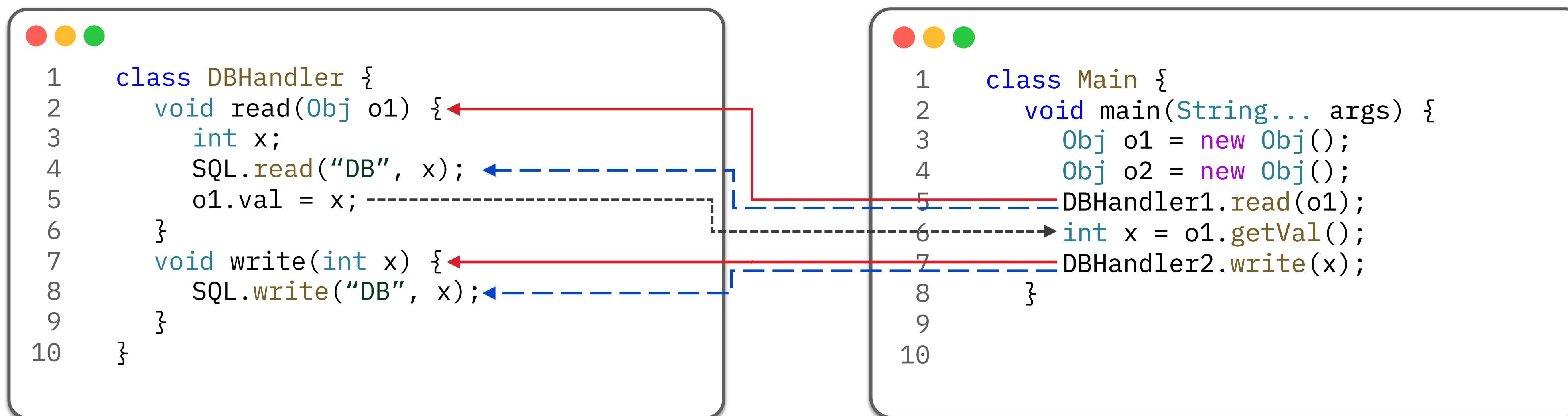
→ Call-return dependency
→ Dataflow dependency

Building a Program Dependency Graph



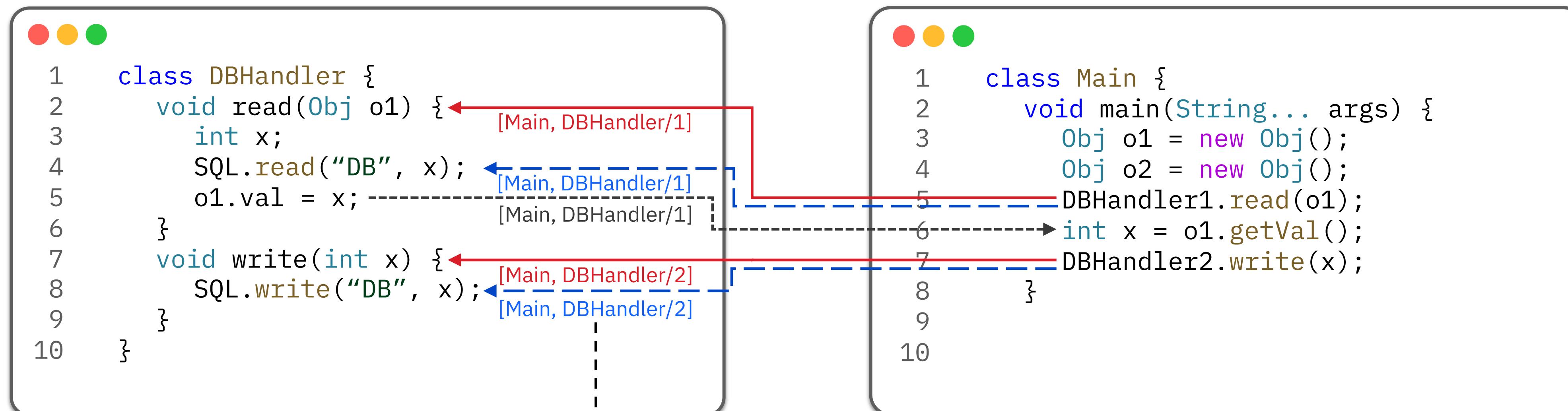
- Call-return dependency
- Dataflow dependency
- Heap dependency

Building a Program Dependency Graph



- Call-return dependency
- Dataflow dependency
- Heap dependency

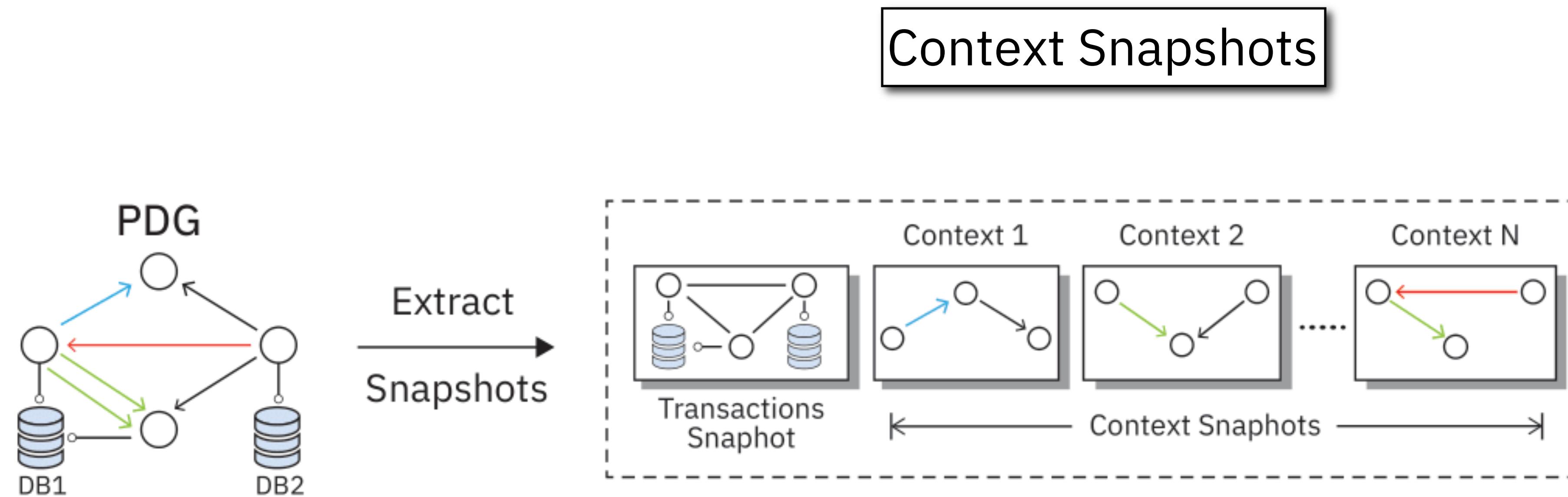
Building a Program Dependency Graph



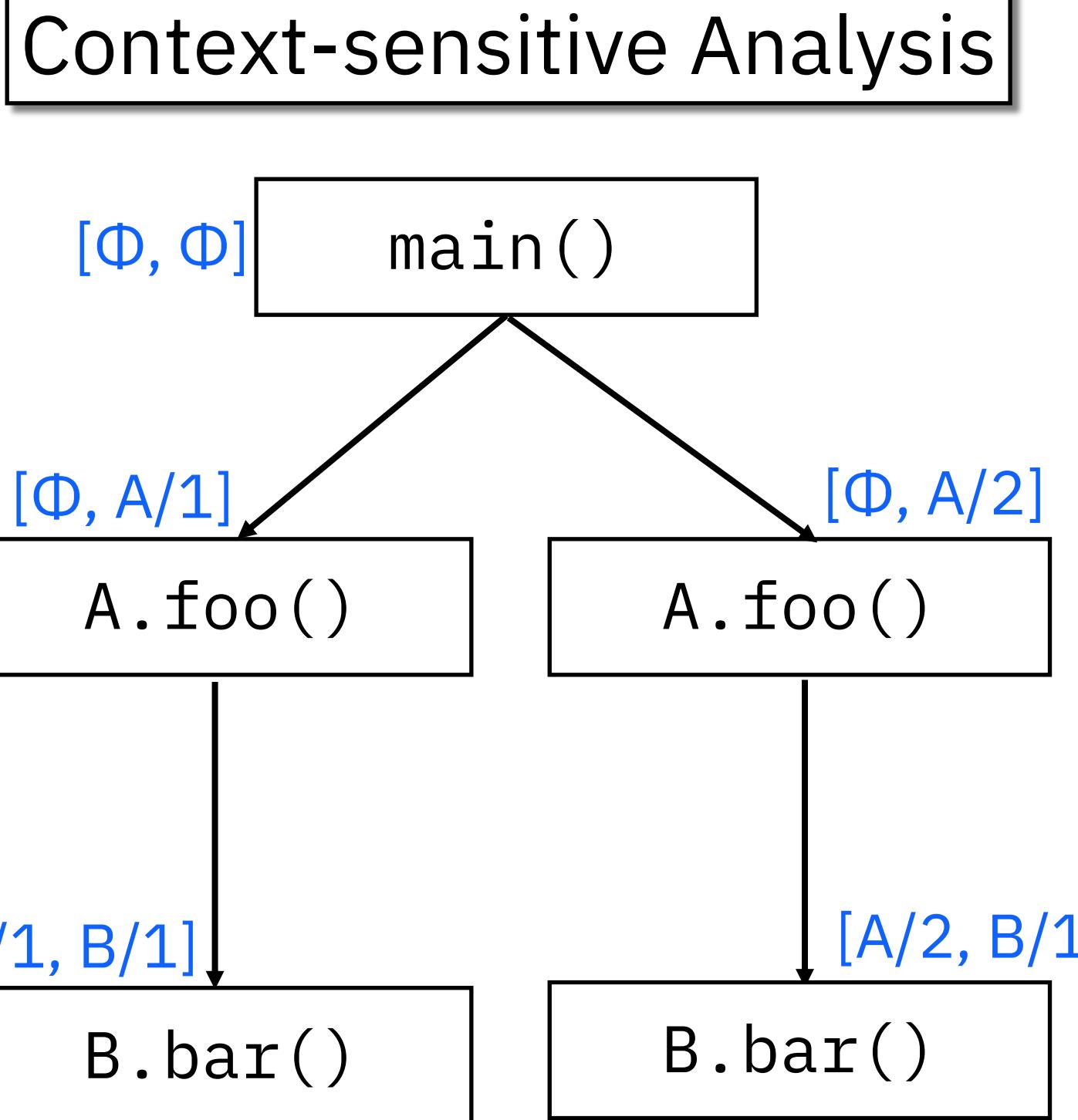
Each edge is qualified by context-information

- Call-return dependency
- Dataflow dependency
- Heap dependency

Step II: Isolating Context Snapshots



Recap: Context-sensitive Analysis

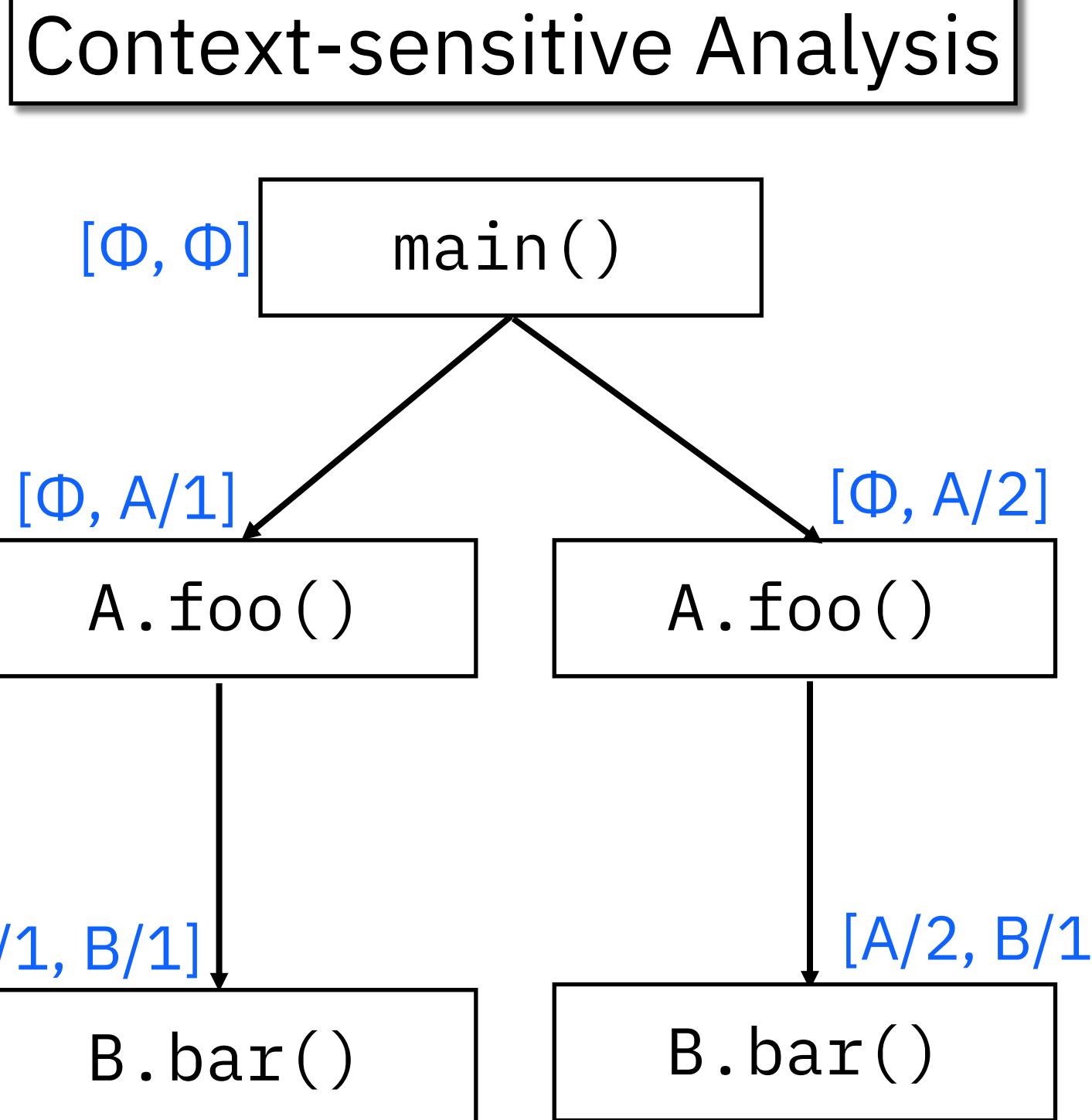


1 void main(Object[] args) {
2 A a1 = new A();
3 Object v1 = a1.foo(new Object());
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1 class B {
2 Object bar(Object v) {
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4 }
5 }

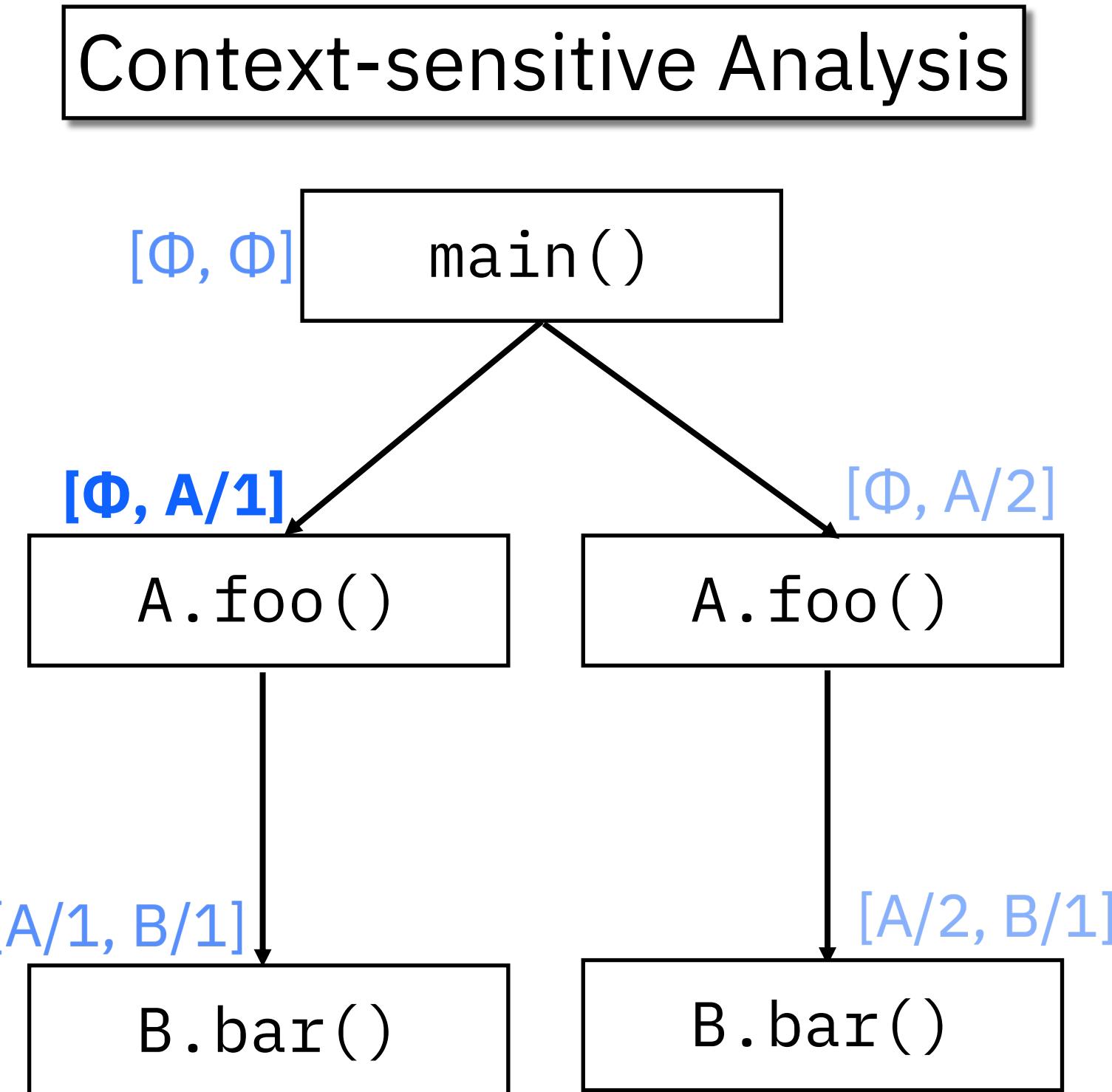
Context Snapshots



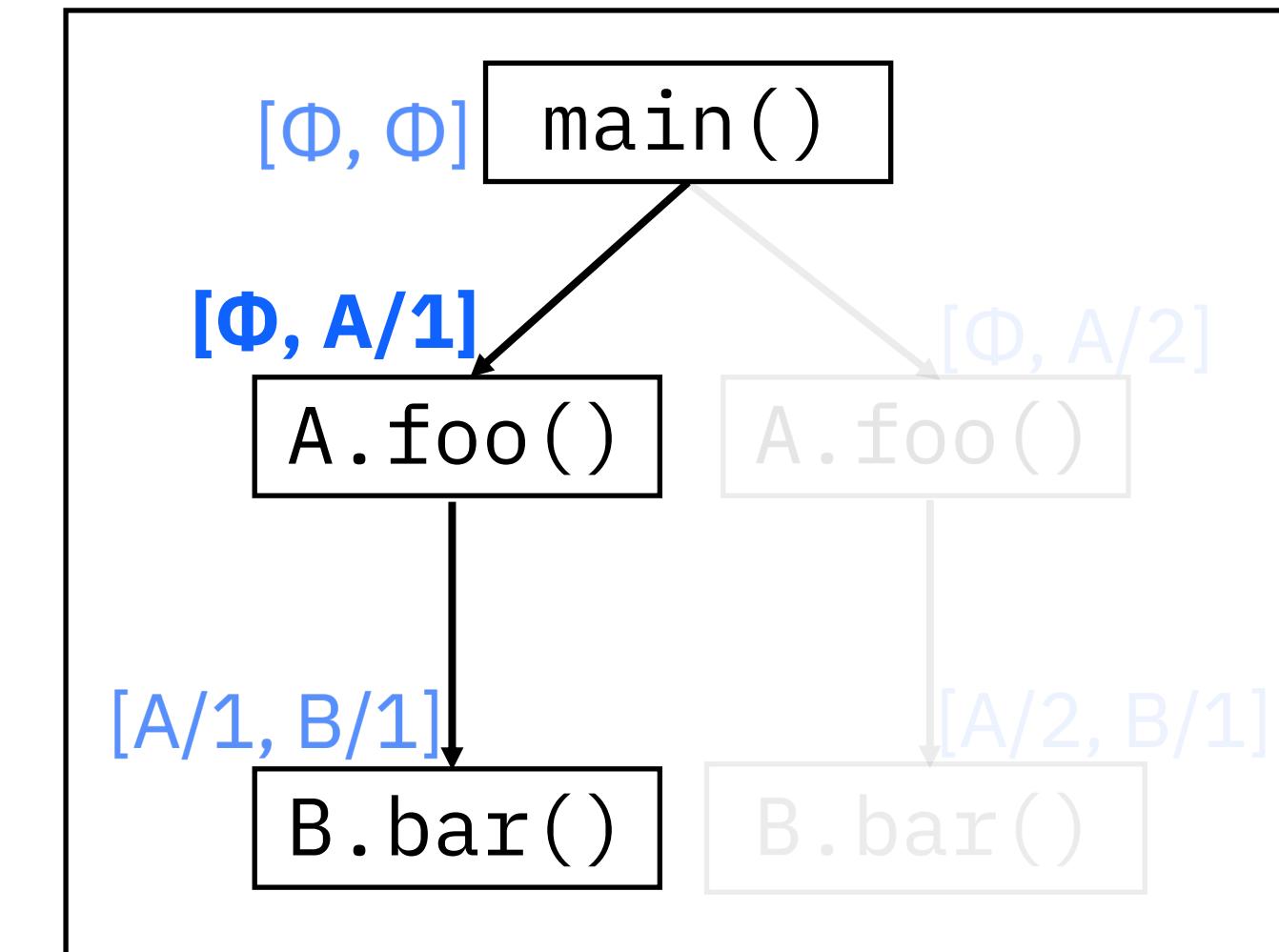
The context-sensitive PDG is a superposition of all possible contexts.

At any time, $A.\text{foo}()$ and $B.\text{bar}()$ can exist in any one context *but not both simultaneously*.

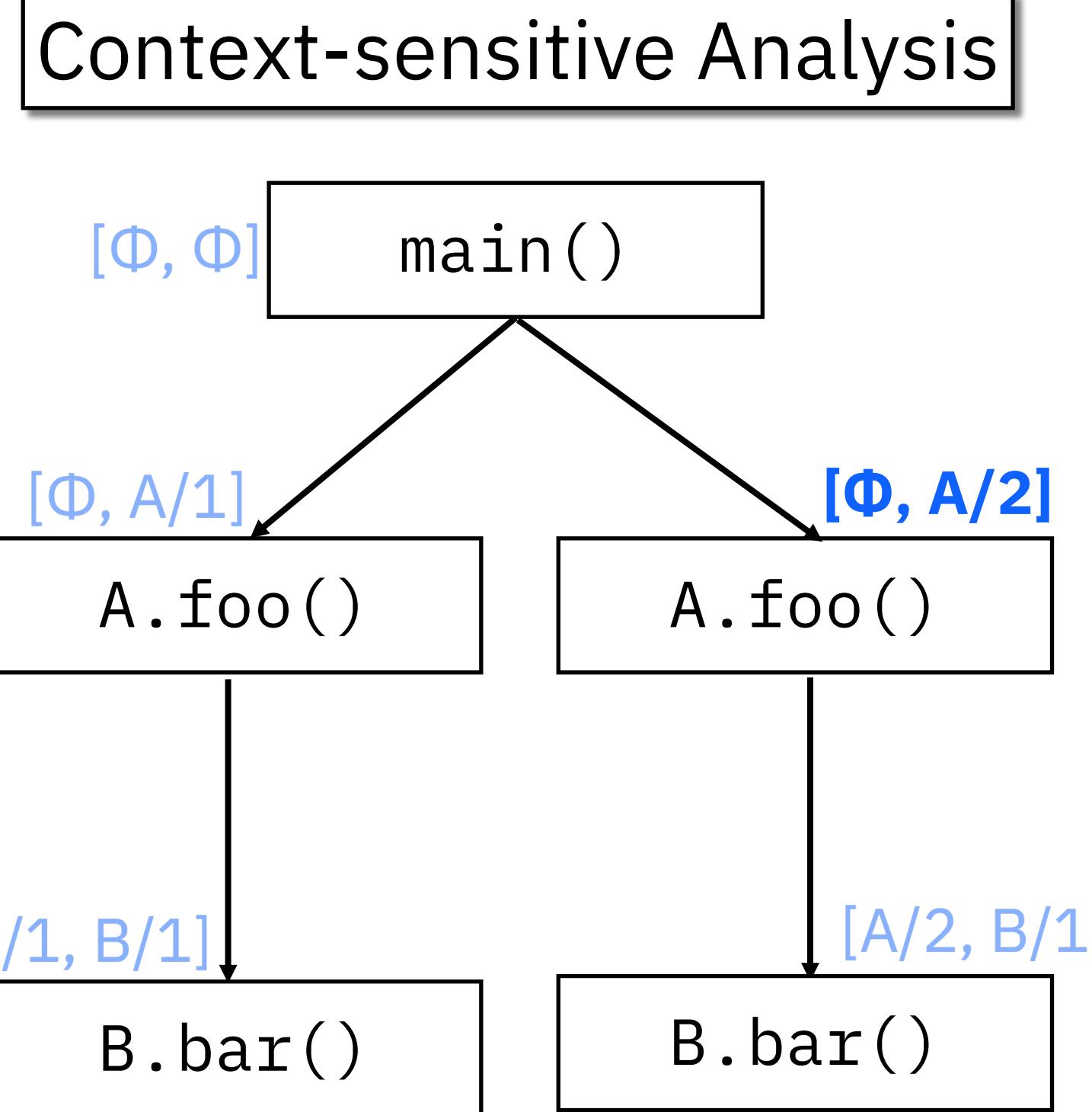
Context Snapshots



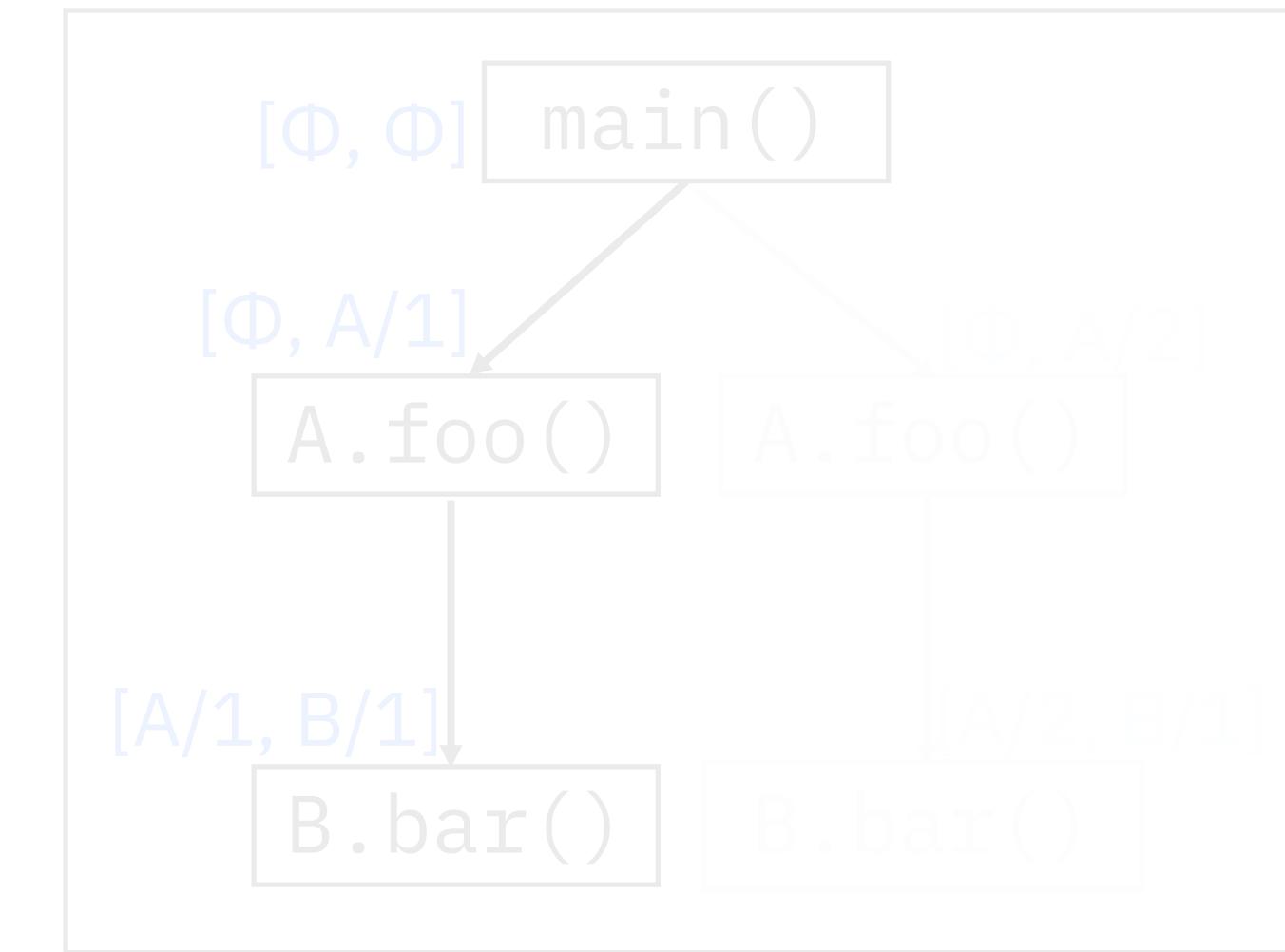
1



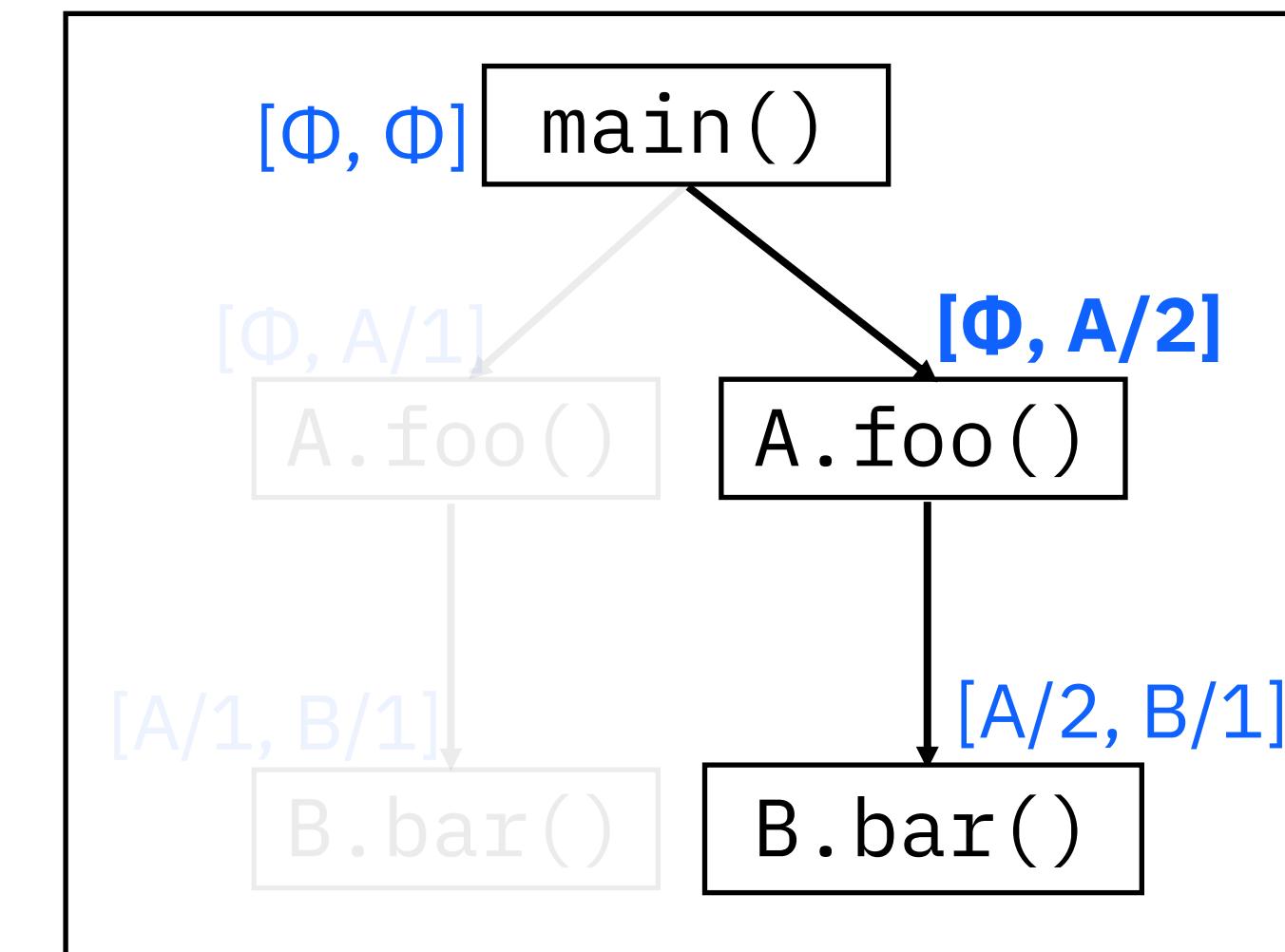
Context Snapshots



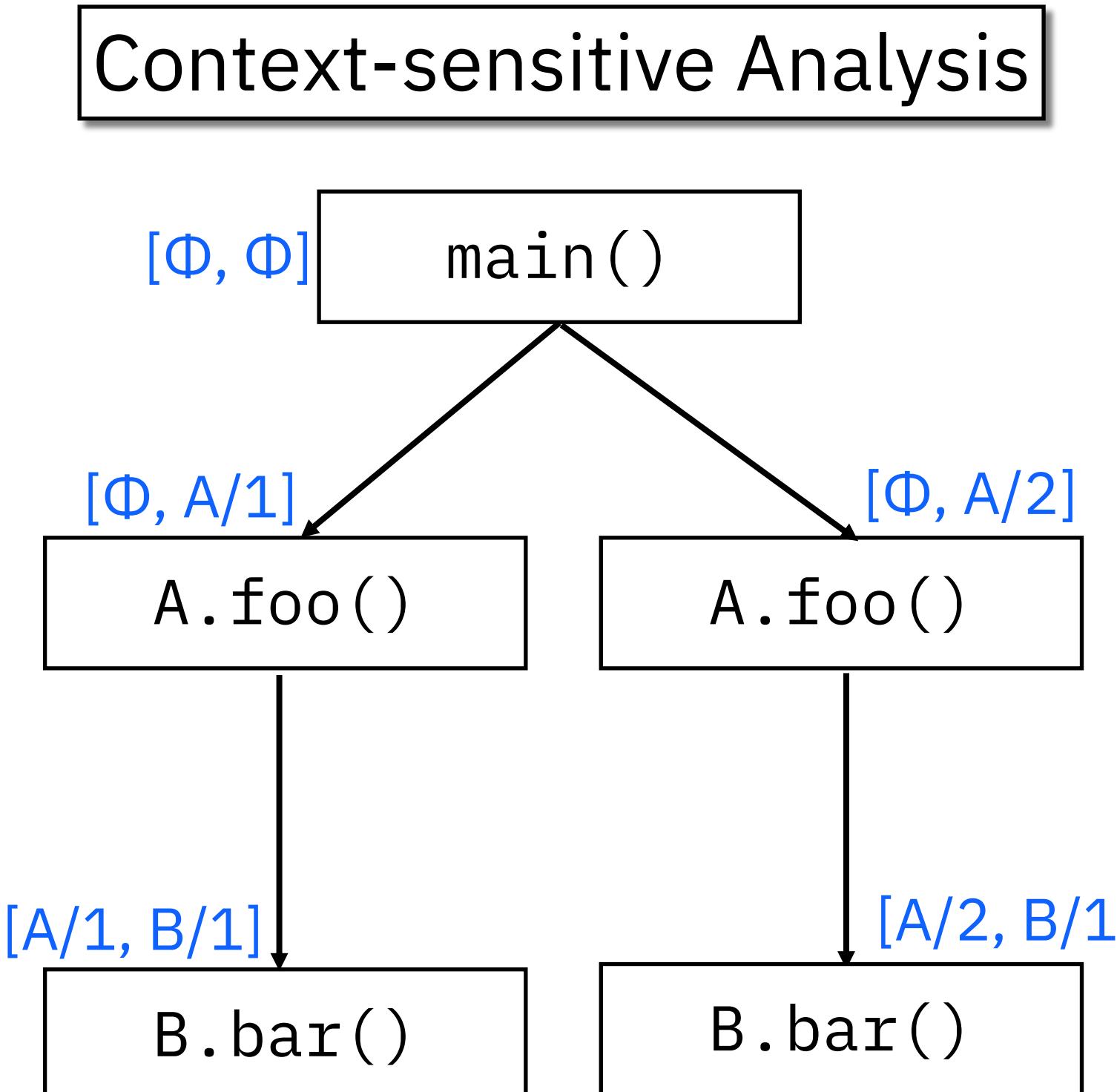
28



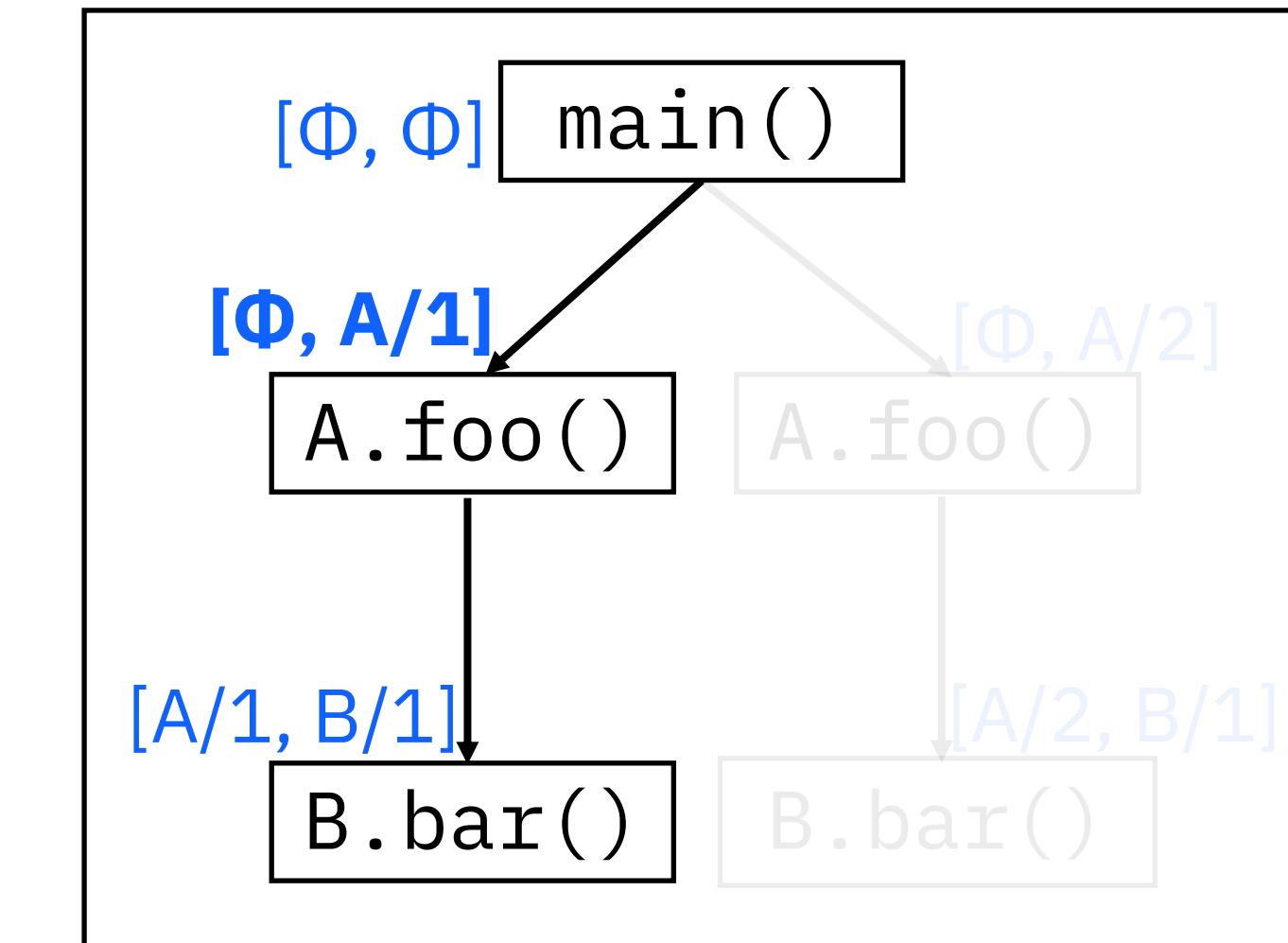
2



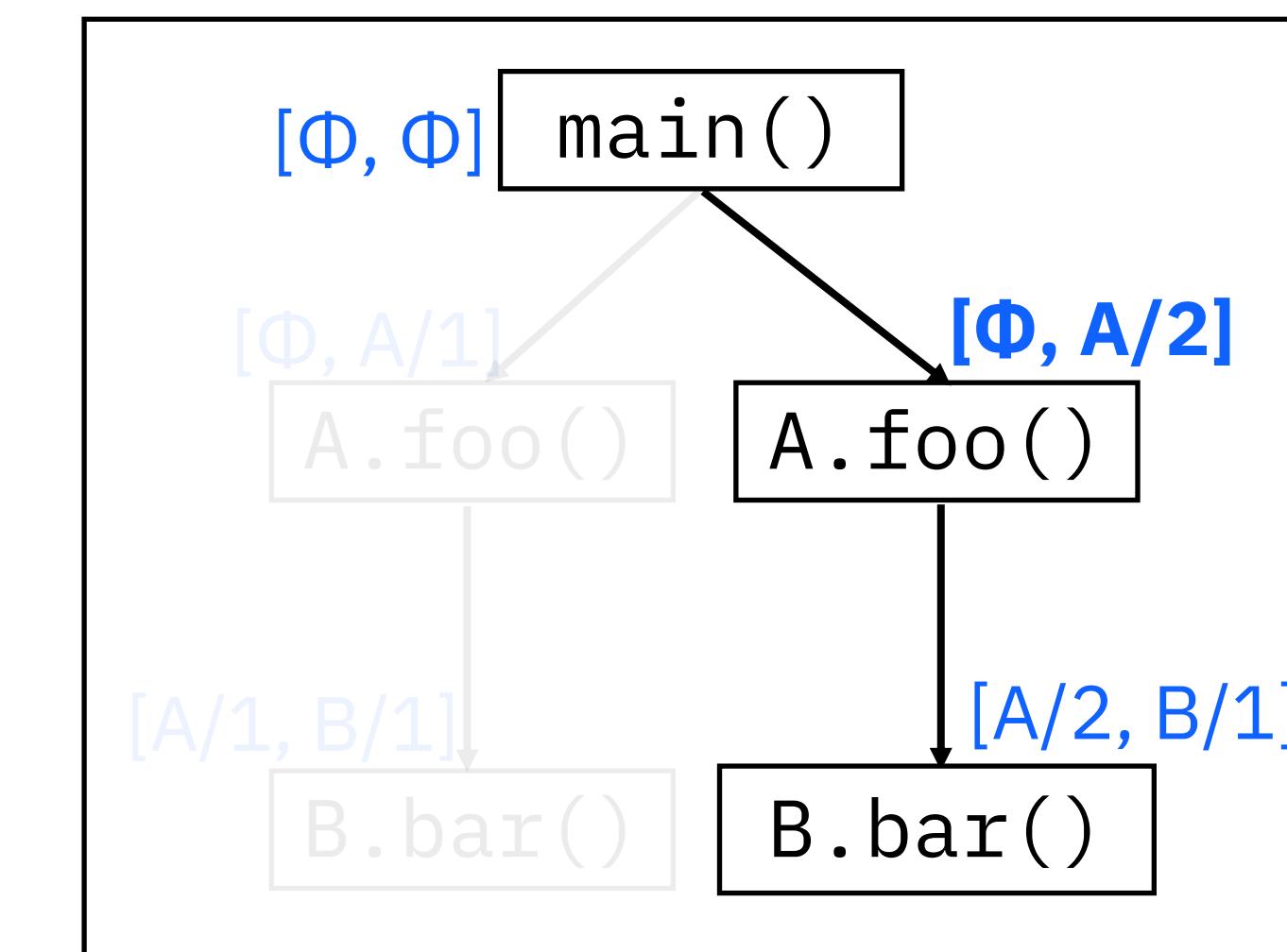
Context Snapshots



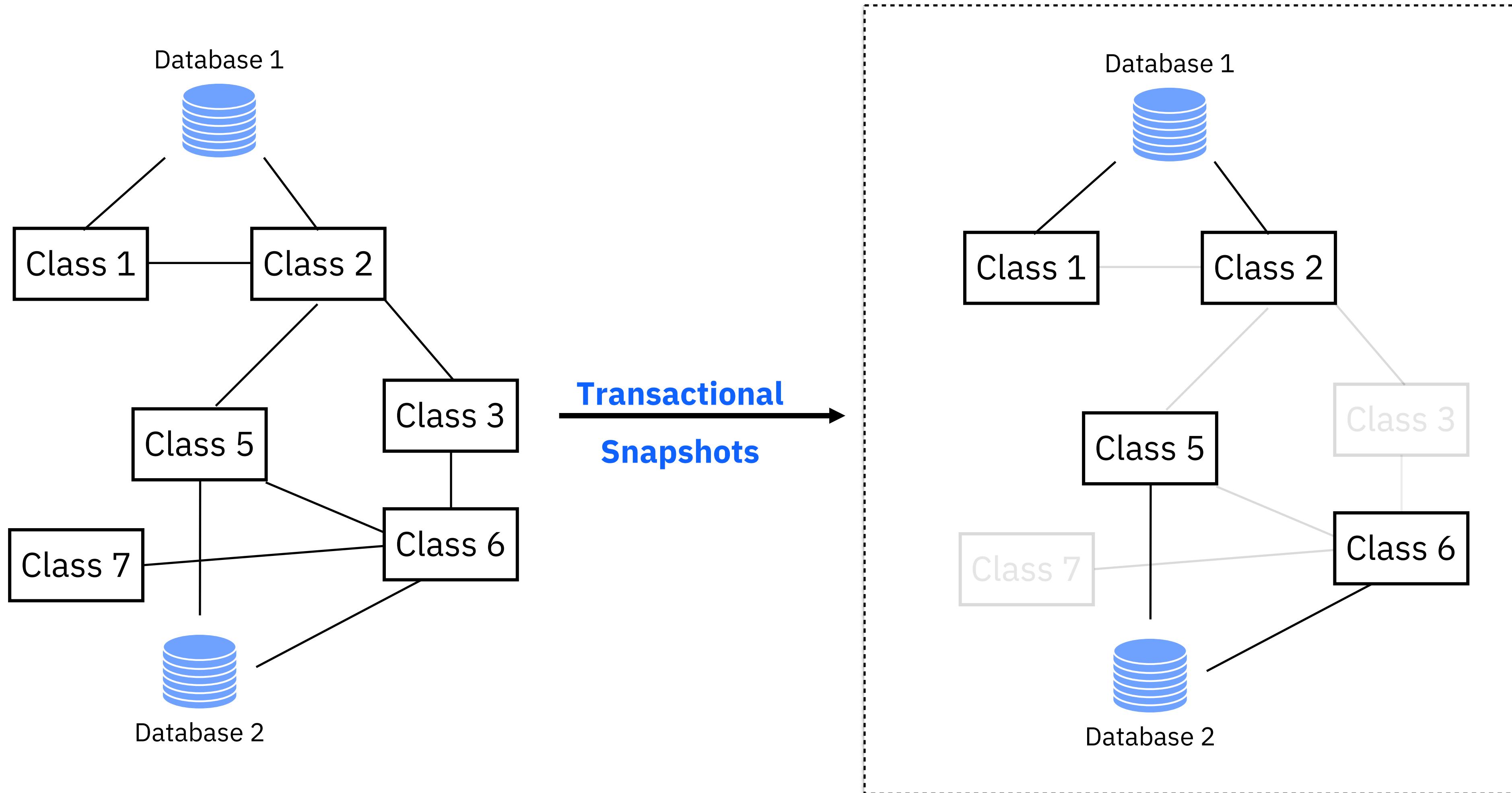
1



2



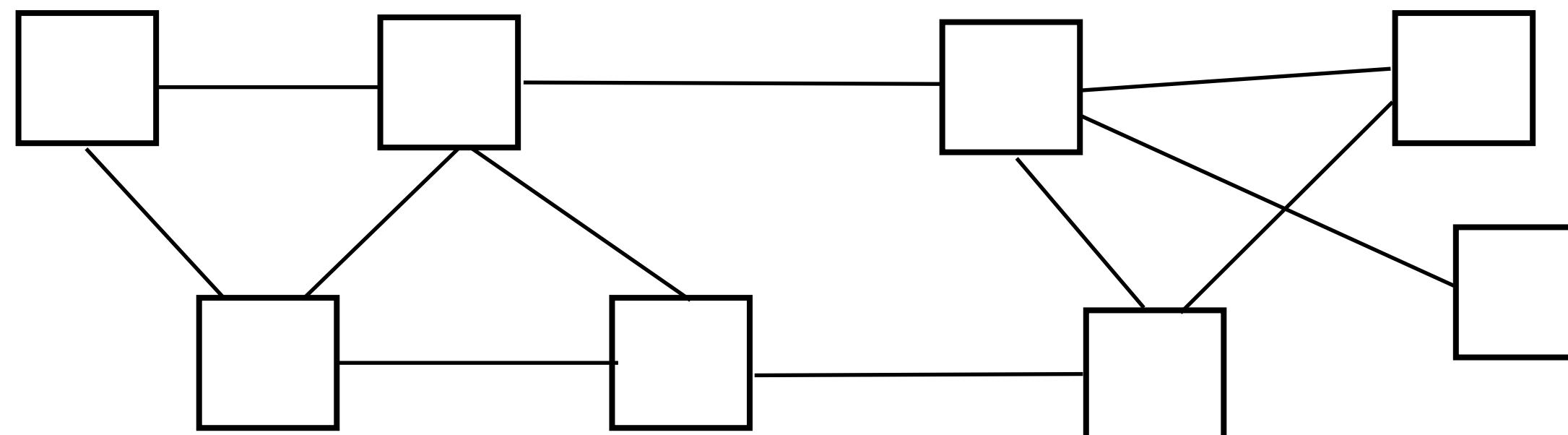
Transactional Snapshot



Step III: Context-Sensitive Label Propagation

Context-sensitive Label Propagation

Label propagation is an algorithm to detect communities of nodes in a graph

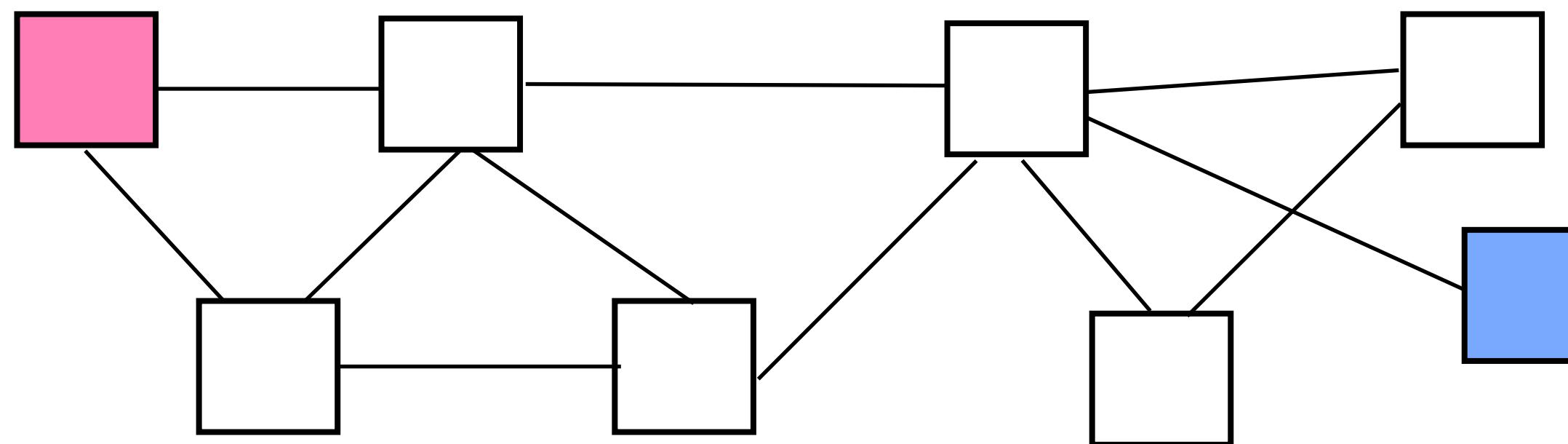


Label Propagation Algorithm

Initial State

We start with some **initial assignment** of labels to nodes

Magenta and Blue are the two categories of label

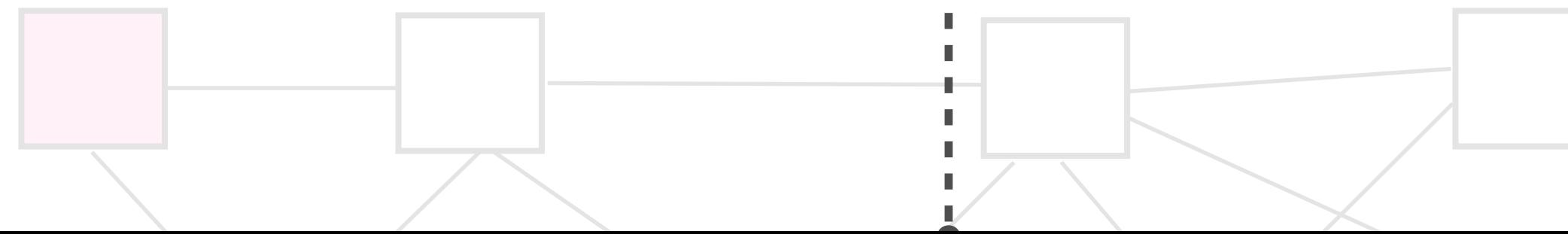


Label Propagation Algorithm

Initial State

We start with some initial assignment of labels to nodes

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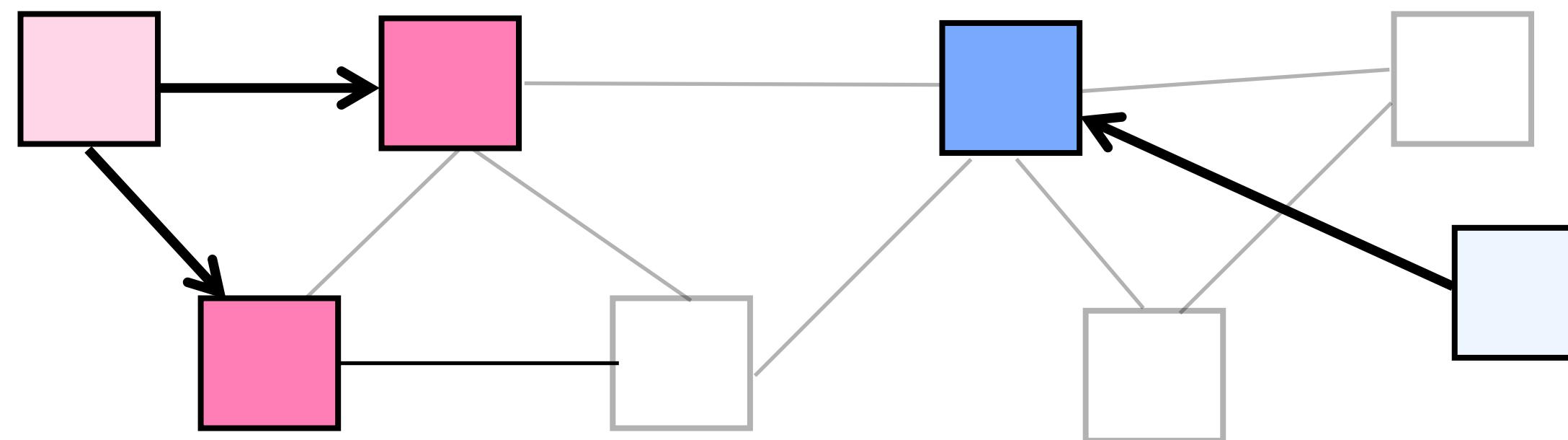


- a) Random (unsupervised)
- b) From the output of another algorithm (semi-supervised)

Label Propagation Algorithm

Pass 1

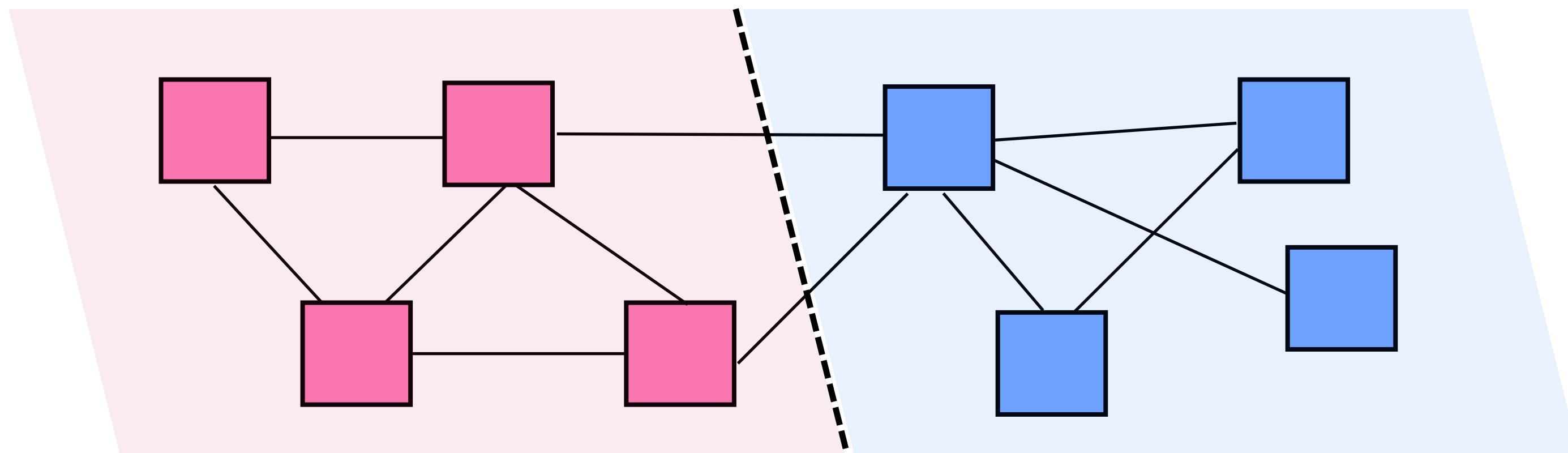
Each node is assigned the majority label of its neighbors



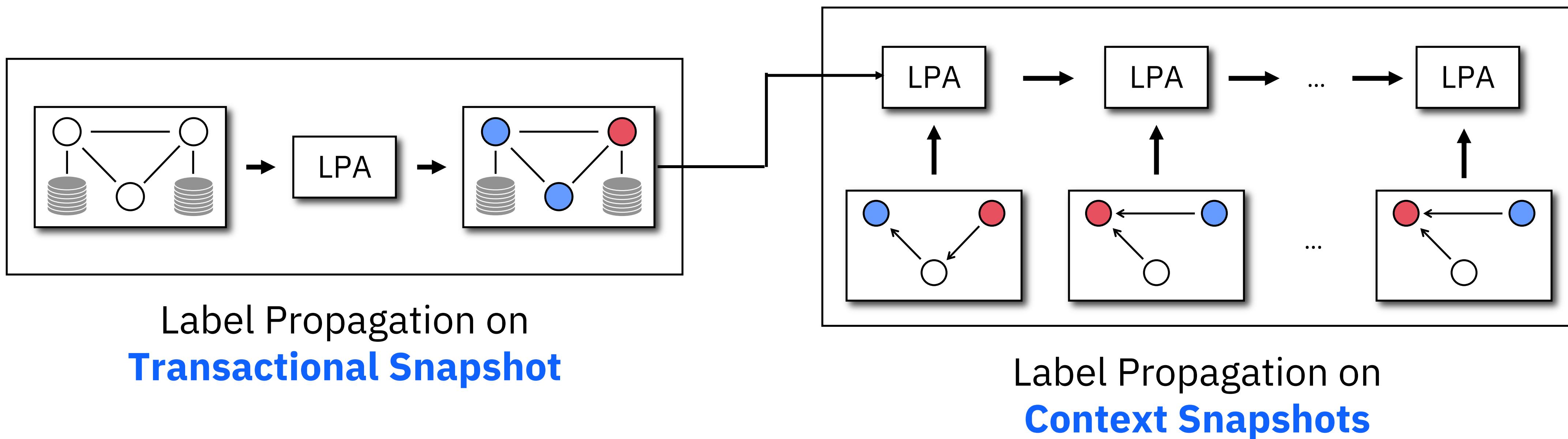
Label Propagation Algorithm

Final

Repeat until convergence (no more node updates)

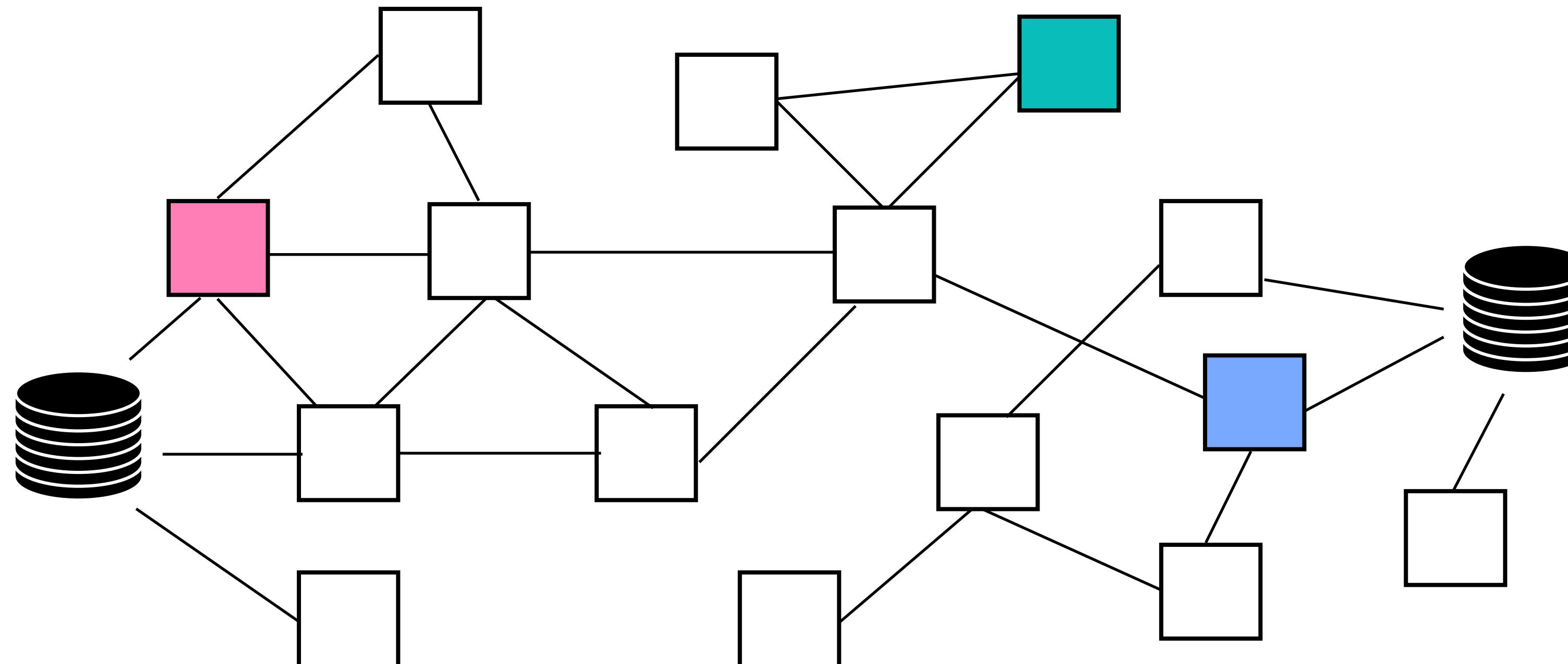


Context-sensitive Label Propagation



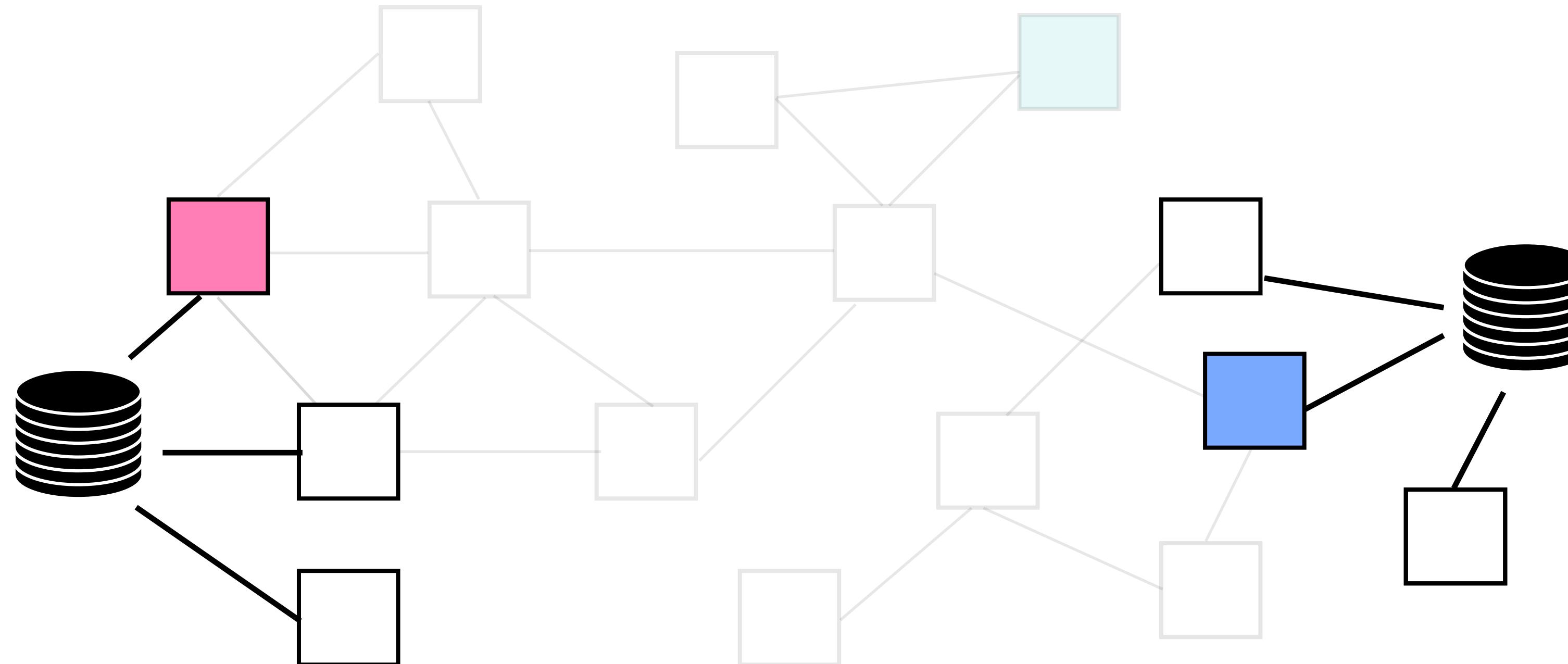
Context-sensitive Label Propagation

Initialize labels



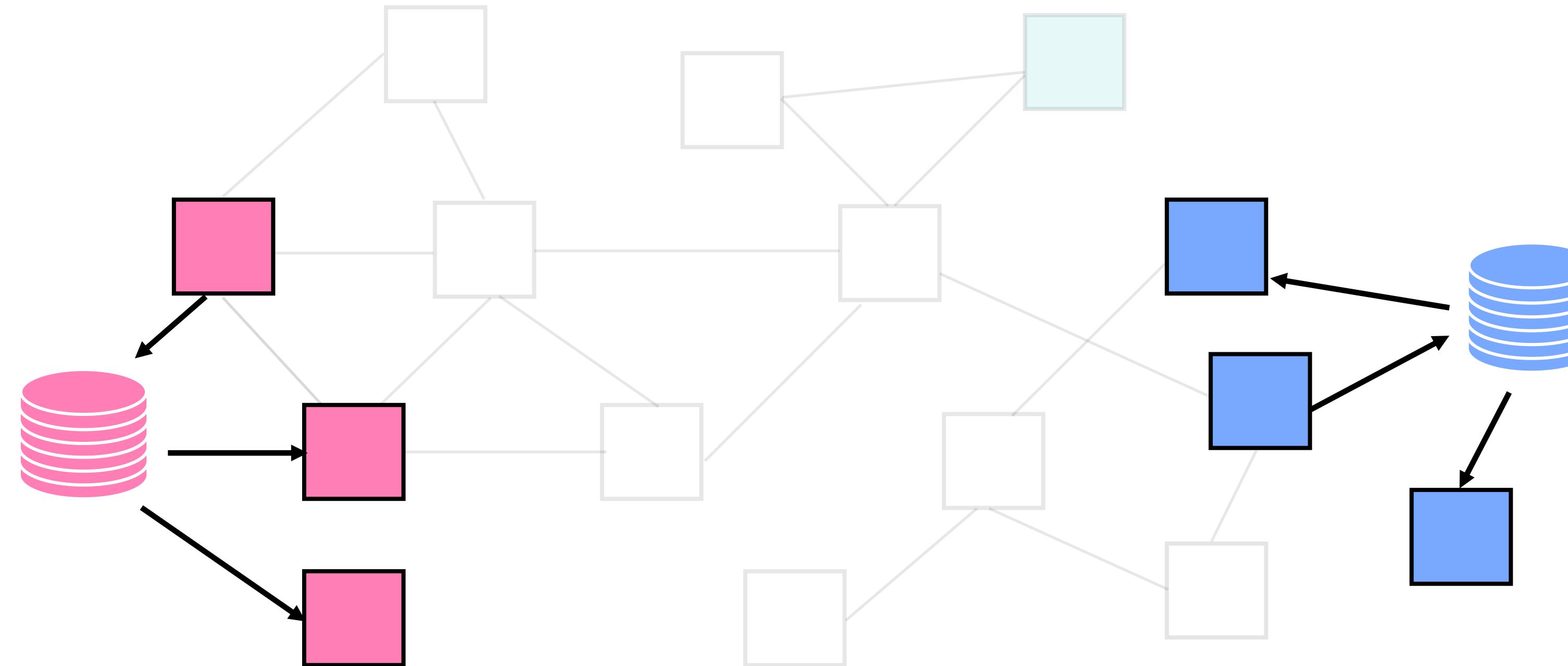
Context-sensitive Label Propagation

Transactional Snapshot



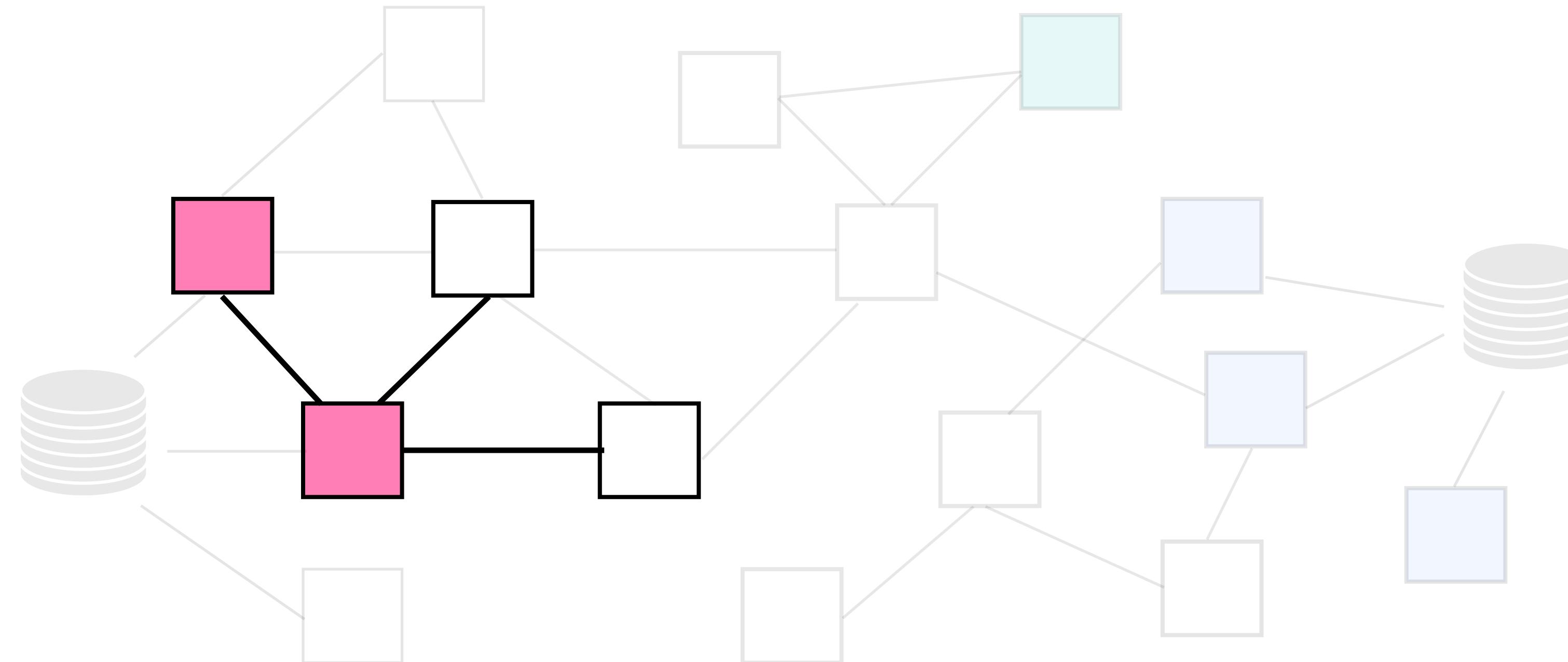
Context-sensitive Label Propagation

Propagate Labels



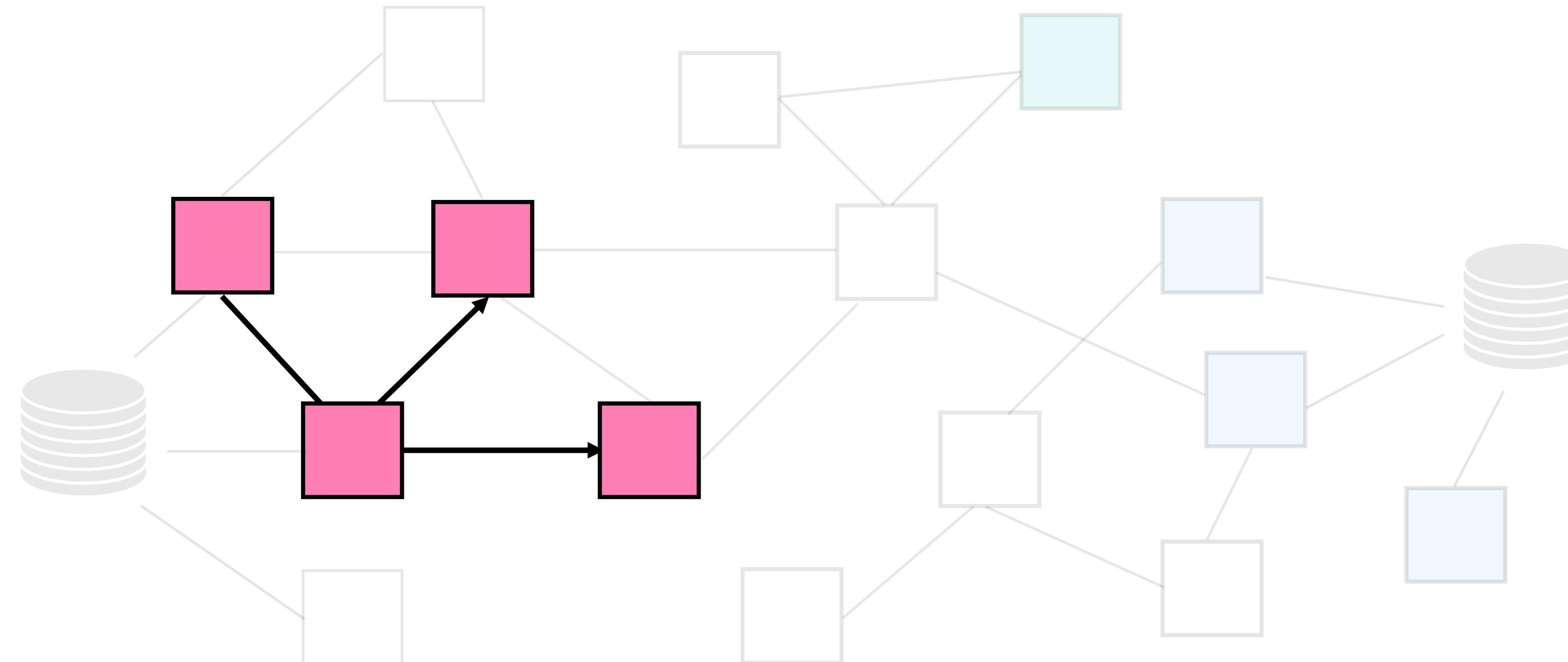
Context-sensitive Label Propagation

Context Snapshot 1



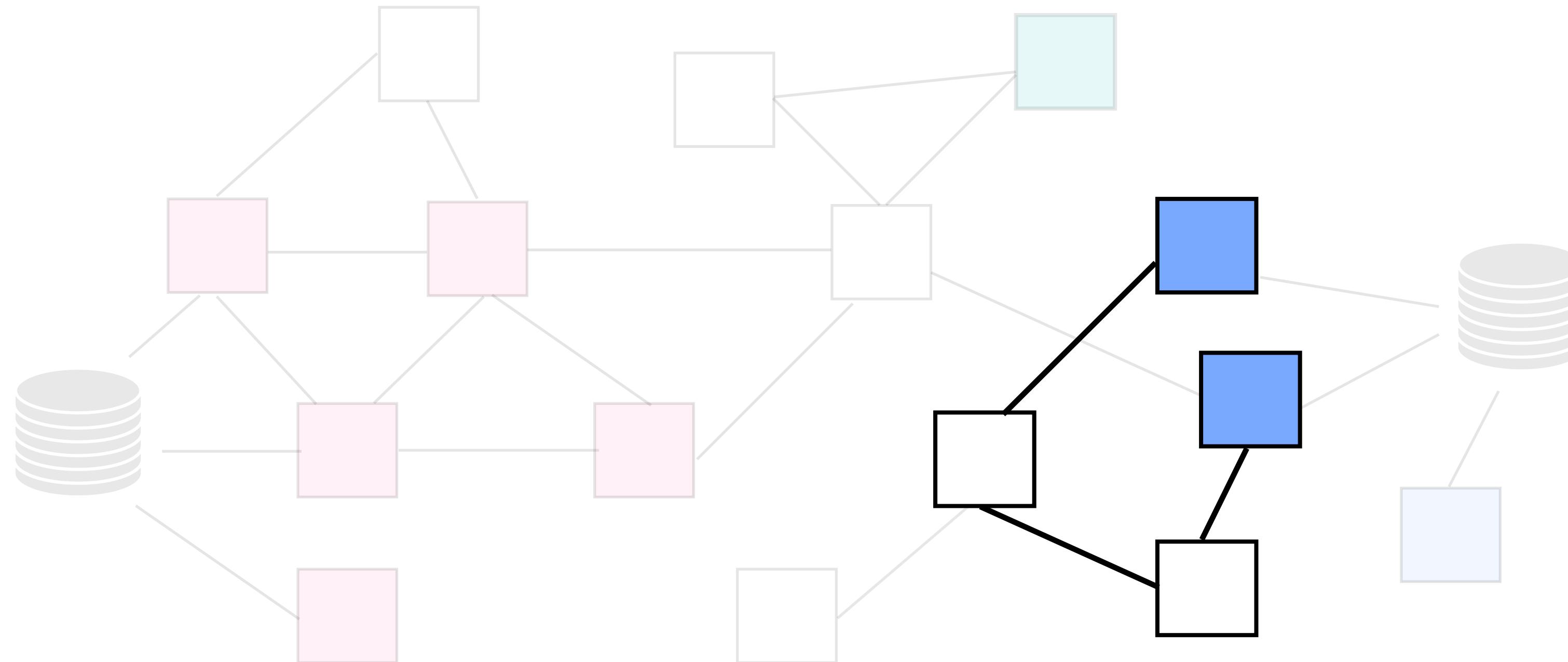
Context-sensitive Label Propagation

Propagate Labels



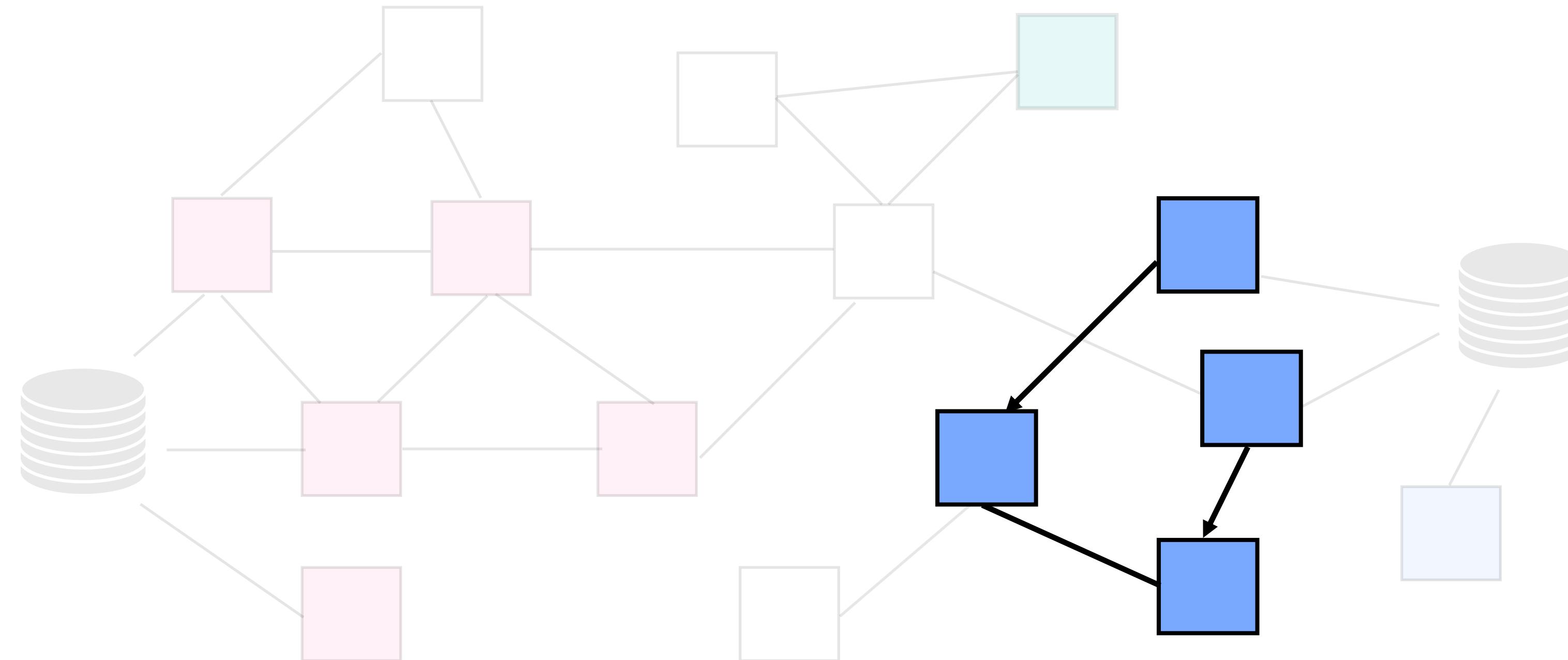
Context-sensitive Label Propagation

Context Snapshot 2



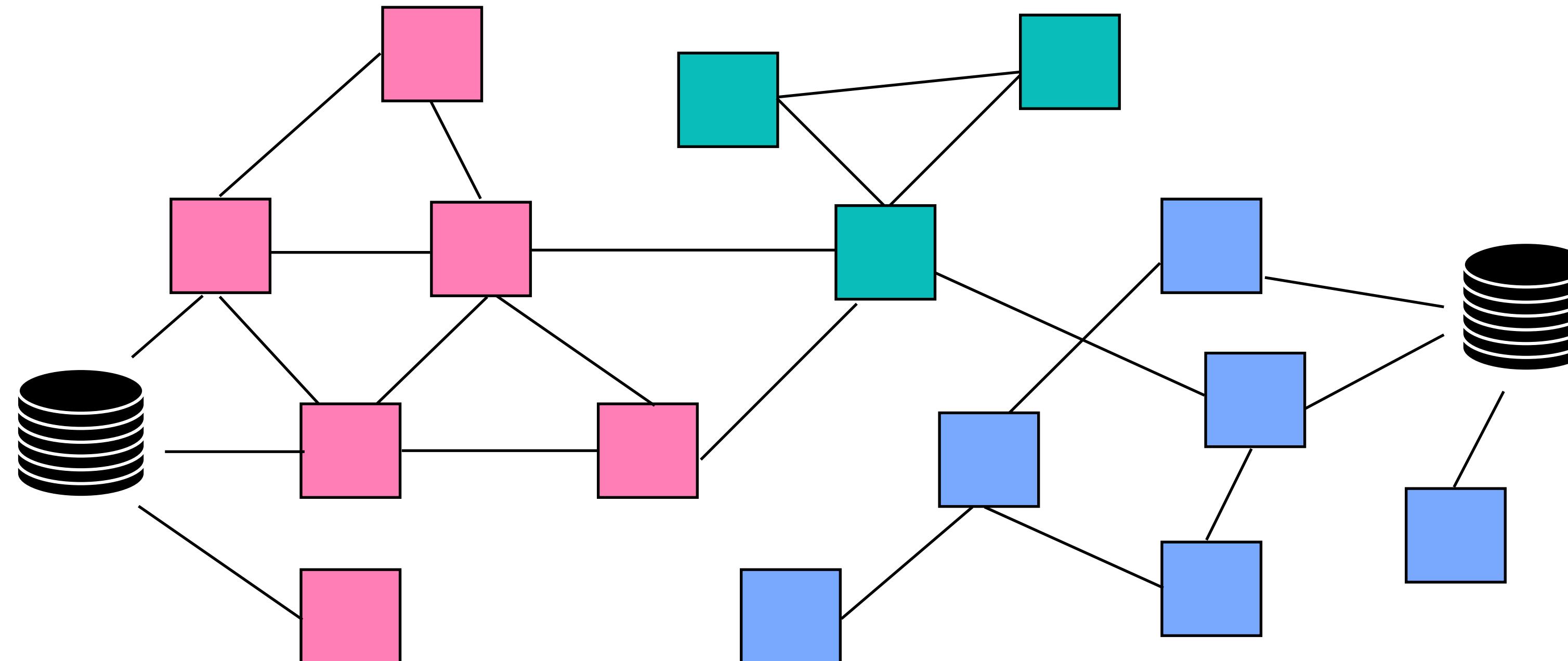
Context-sensitive Label Propagation

Propagate Labels



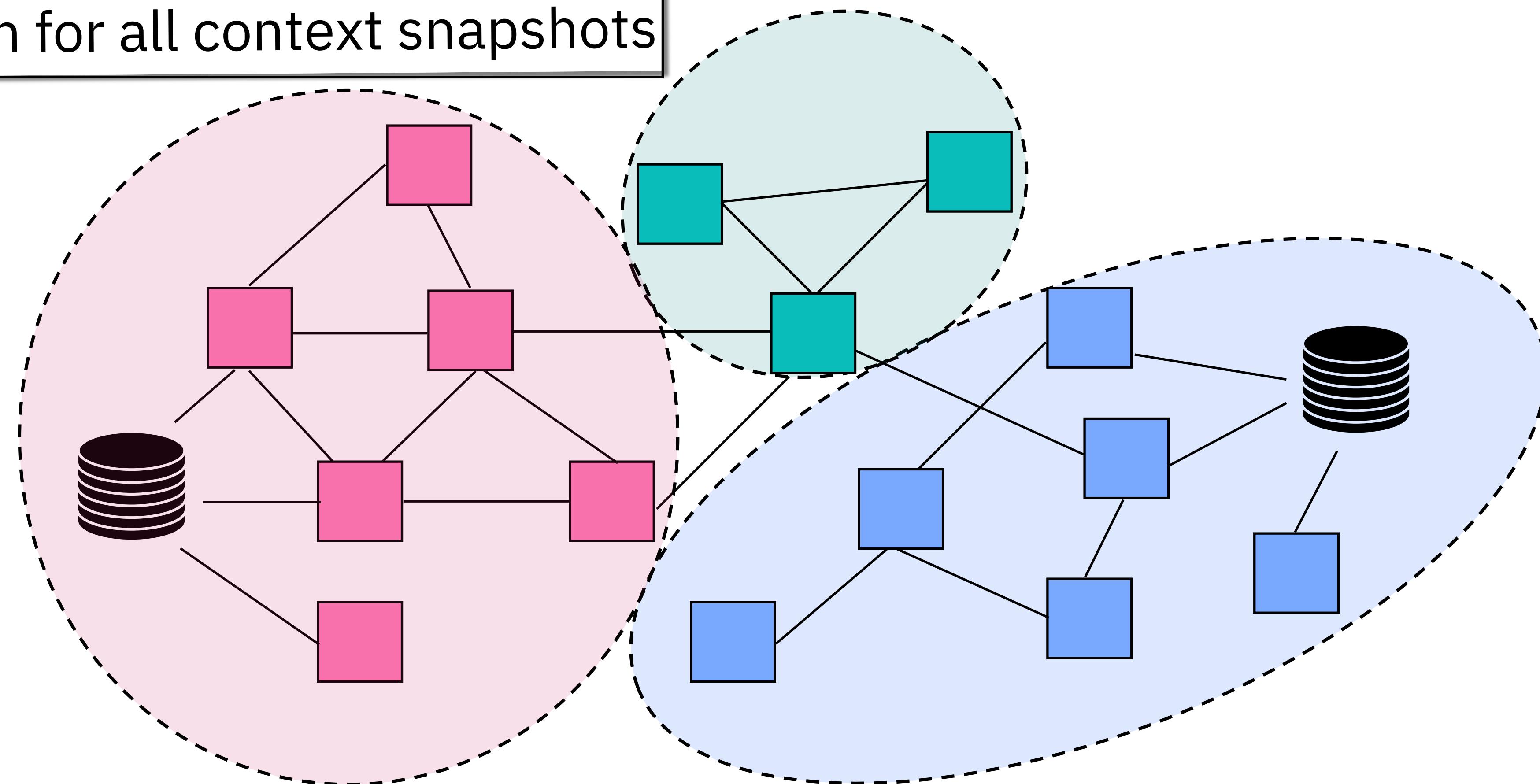
Context-sensitive Label Propagation

And so on for all context snapshots



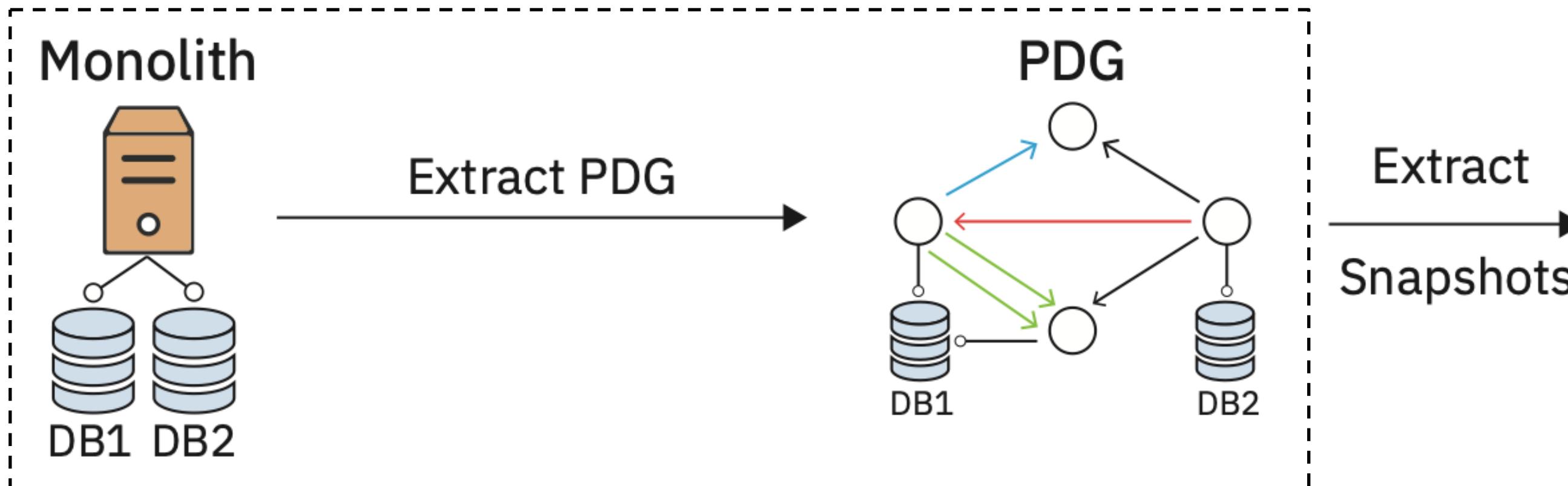
Context-sensitive Label Propagation

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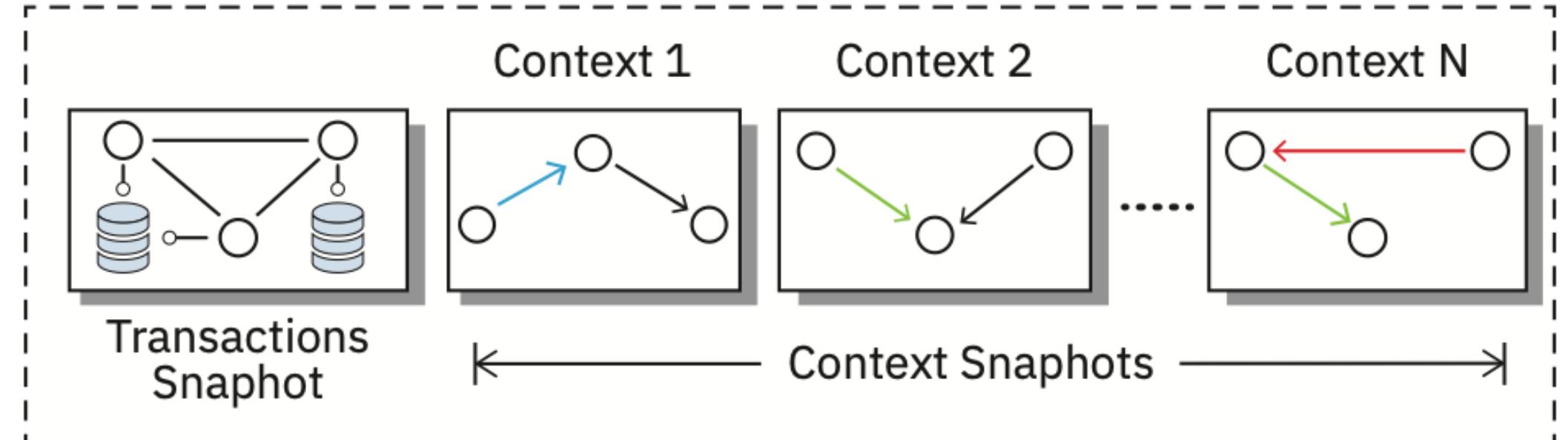


CARGO: Summary

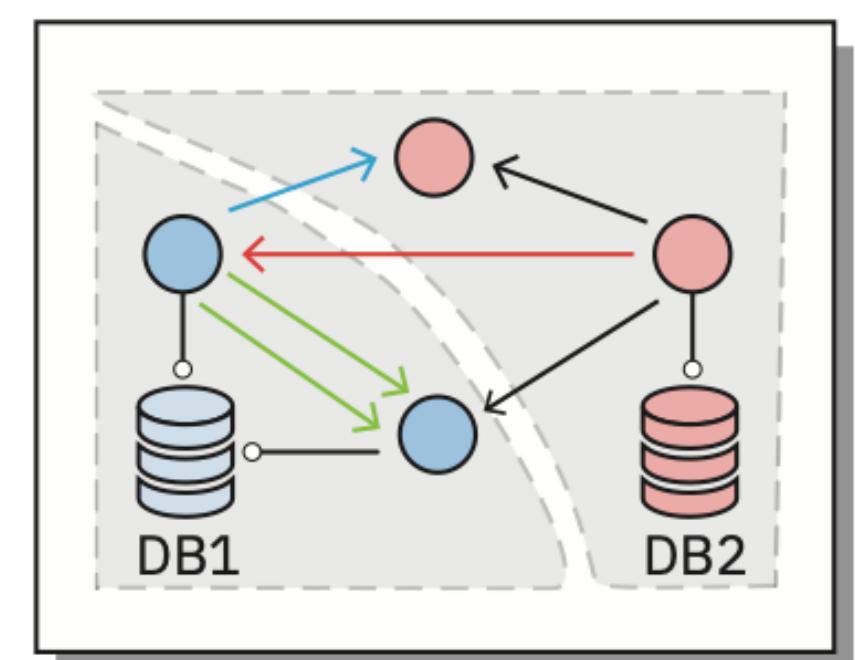
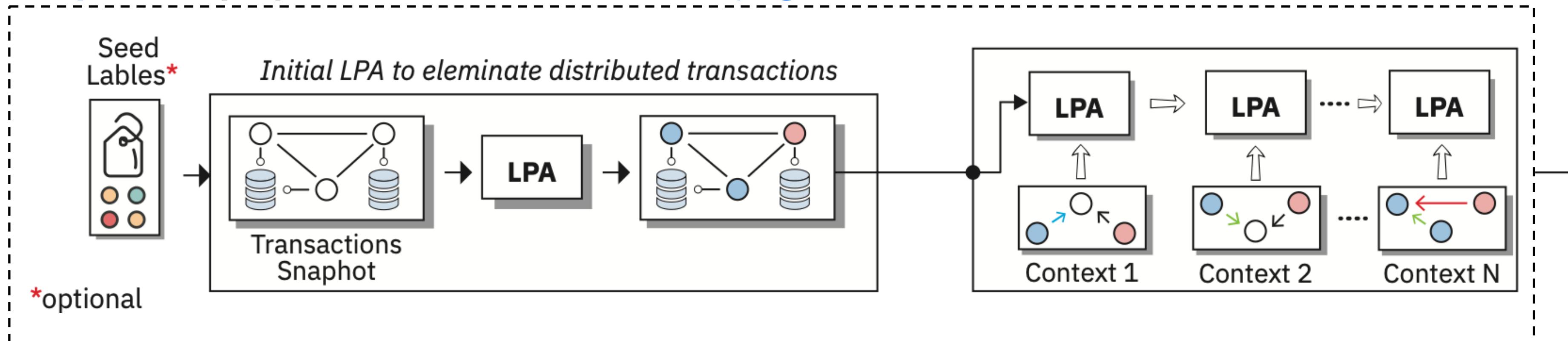
Step I: Build *context-sensitive program dependency graph*



Step II: Extract *context snapshots*



Step III: Deploy *Context-sensitive Label Propagation*



Evaluation

Evaluation Setup - Benchmark Applications

Application	Description	Java Framework	# Classes	# SQL Tables
Daytrader	Trading application	Java EE 8, Websphere	109	6
Plants	Online plant shopping	Java EE 7, Websphere	33	.
AcmeAir	Website of a fictitious airline	Openliberty, Websphere eXtreme	66	.
JPetStore	Online pet supply store	Spring, Springboot	37	.
Proprietary1	Proprietary app	.	82	.

Evaluation Setup - Baseline Approaches

Approach	Summary
Mono2Micro*	Dynamic call traces and hierarchical clustering.
CoGCN	A Graph Neural Network and K-Means on a static call graph
FoSCI	Genetic Search-based algorithm on dynamic execution traces
MEM	A Minimum-Spanning Tree based Clustering Algorithm on a graph. Edit-history and semantics are used to define coupling

* Enterprise scale decomposition tool

Evaluation Setup - “refining” partitions

CARGO can be used to **refine** the partitions produced by other approaches.

□ Denoted by “**++**” suffix.

E.g., *Mono2Micro⁺⁺* denotes running CARGO with *initial partition labels* produced by *Mono2Micro*.

Original Approach	Refined with CARGO
Mono2Micro	Mono2Micro ⁺⁺
CoGCN	CoGCN ⁺⁺
FoSCI	FoSCI ⁺⁺
MEM	MEM ⁺⁺

Research Questions

RQ-1 Effectiveness in remediating distributed transactions

RQ-2 Latency and Throughput improvements resulting from refined microservice partitions

RQ-3 Quality of microservice partition architectural metrics

RQ-1 Distributed database transactions



To minimize distributed transactions, we would like, to the extent possible, for each database table to be **accessed from one microservice partition only**

Evaluation

- Use **Transactional Purity (TXP)** to measure the tendency of a database table to be accessed by multiple microservices

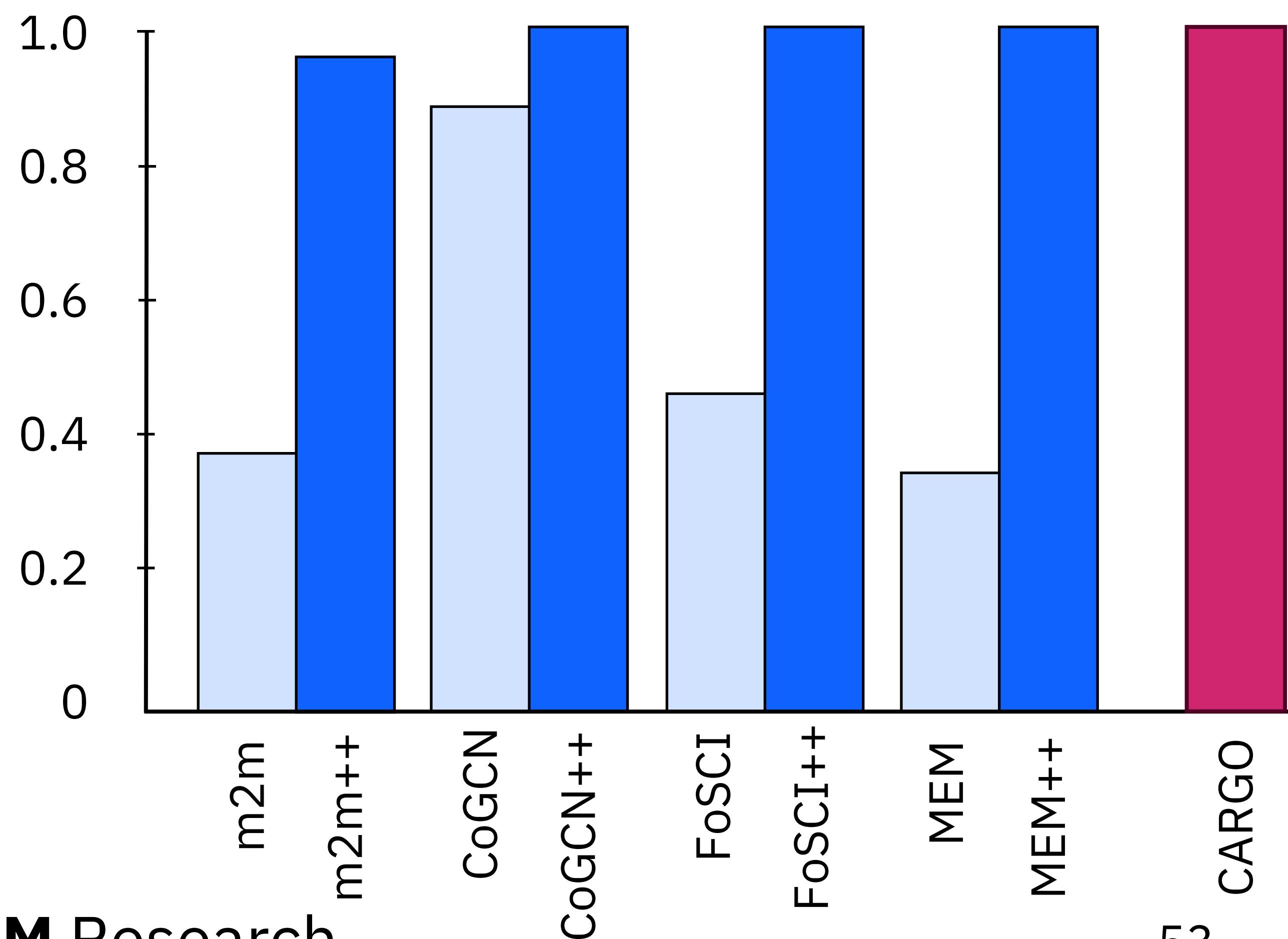
Entropy

$$TXP = 1 - \sum_{i=0}^K p_i \cdot \log \left[\frac{1}{p_i} \right]$$

- Lower purity indicates accesses from more microservices
- Higher purity indicates accesses from less microservices

RQ-1 Distributed database transactions

Daytrader



Summary

- For each of the 4 baselines, the refined partitions have higher transactional purity.
- FoSCI++ and MEM++ have transactional purity of 1.0, (i.e., no distributed transactions after repartitioning).
- CARGO (unsupervised) natively achieves transactional purity of 1.0

++ implies refinement with CARGO

Research Questions

RQ-1 Effectiveness in remediating distributed transactions

RQ-2 Latency and Throughput improvements resulting from refined microservice partitions

RQ-3 Quality of microservice partition architectural metrics

RQ-2 Runtime Performance Improvements



Minimizing distributed transactions can offer significant runtime benefits in terms of reduced latency and improved throughput.

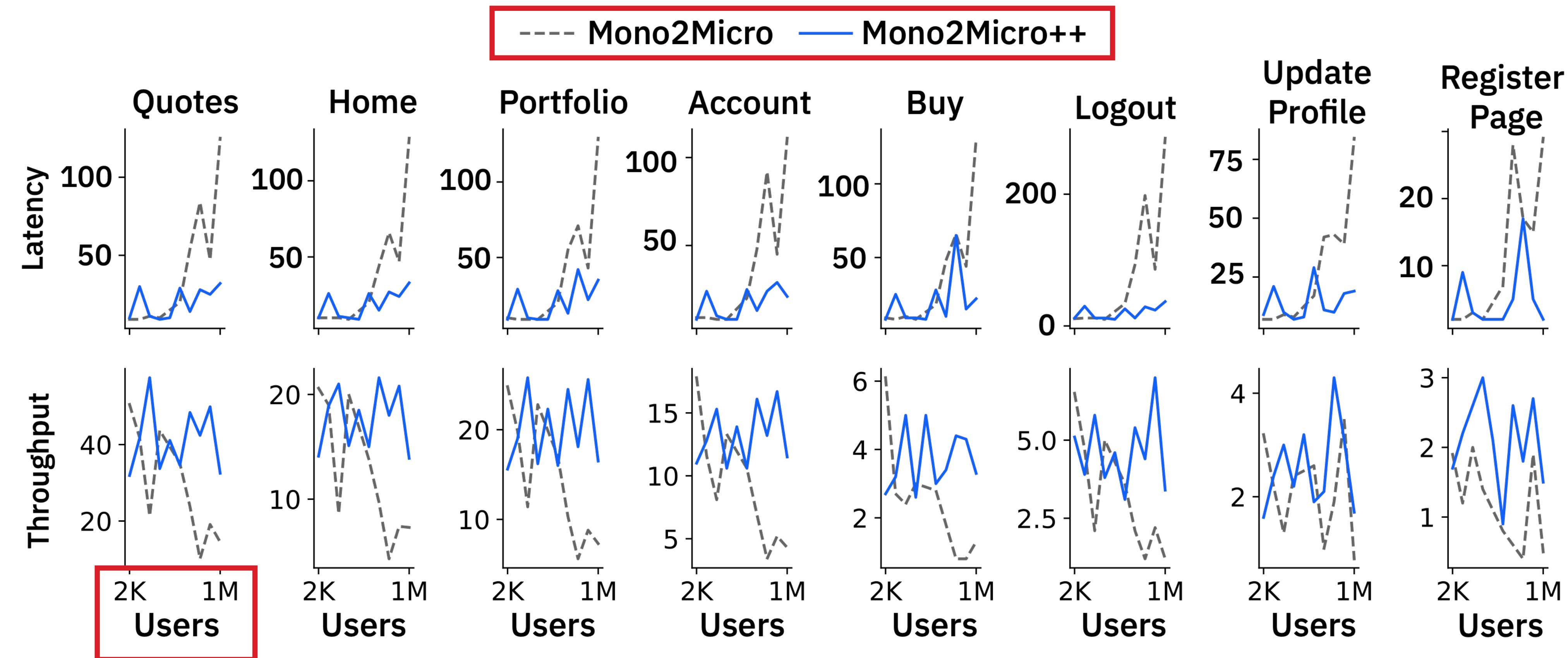
Evaluation

- Deploy two variants of the applications:
 1. Application with original partitioning (Mono2Micro)¹
 2. Application with partitions refined with CARGO (aka. Mono2Micro++)²
- Compare two runtime performance metrics:
 1. Latency: Time between reception and completion of a request (milliseconds)
 2. Throughput: Number of successful requests honored per unit time (requests/second)

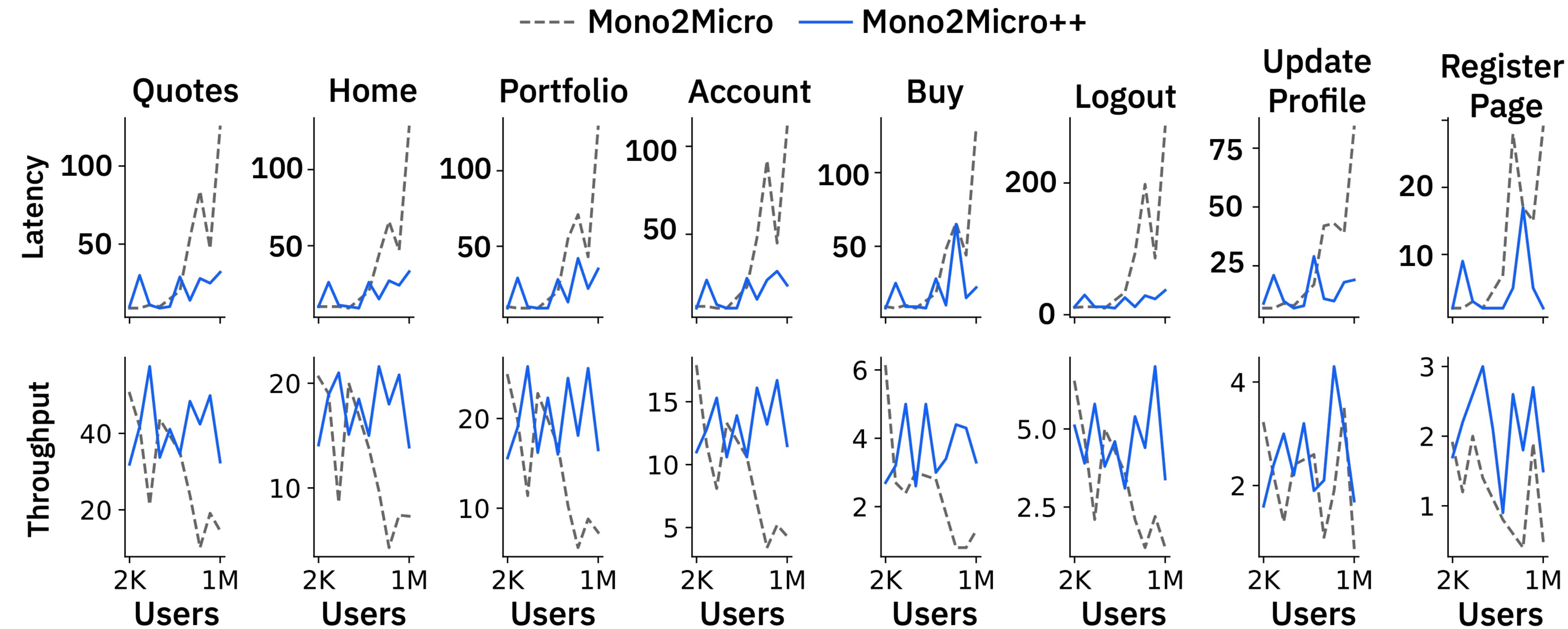
¹ https://github.com/vikramnitin9/tackle-data-gravity-insights/tree/main/RQ2/daytrader_apps/daytrader_cargo

² https://github.com/vikramnitin9/tackle-data-gravity-insights/tree/main/RQ2/daytrader_apps/daytrader_monomicro

RQ-2 Runtime Performance Improvements



RQ-2 Runtime Performance Improvements



Significant improvements in latency and throughput. Repartitioned application has [11% lower latency](#) and [120% higher throughput](#) on average across use cases compare to the original deployment.

Research Questions

RQ-1 Effectiveness in remediating distributed transactions

RQ-2 Latency and Throughput improvements resulting from refined microservice partitions

RQ-3 Quality of microservice partition architectural metrics

RQ-3 Partitions and their Architectural Quality

METRIC	DESCRIPTION
Coupling ∇	Average Coupling among partitions
Cohesion Δ	Average cohesion within a partition
BCP ∇	Purity of Business use cases per partition.
ICP ∇	Inter-partition call volume

∇ Lower is better Δ Higher is better

RQ-3 Partitions and their Architectural Quality

	Coupling ▽			Cohesion △		
	MONO2MICRO	MONO2MICRO++	CARGO	COGCN	COGCN++	CARGO
DAYTRADER	0.78	0.02	0.01	0.37	0.61	0.71
PLANTS	0.31	0.04	0.05	0.39	0.46	0.6*
ACMEAIR	0.58	0.04	0.03	0.21	0.32	0.96
JPETSTORE	0.77	0.03	0.03	0.20	0.24	0.94
PROPRIETARY	0.42	0.03	0.04	0.69	0.73	0.75*
WIN/TIE/Loss	5/0/0			5/0/0		

CARGO improves the partitioning quality (reduced coupling and increased cohesion) of other approaches and works equally well in unsupervised mode.

*Mono2Micro++ performs slightly better than CARGO

RQ-3 Partitions and their Architectural Quality

	BCP ▽		
	MONO2MICRO	MONO2MICRO++	CARGO
DAYTRADER	2.31	2.57	1.31
PLANTS	1.68	2.20	1.79
ACMEAIR	1.29	1.48	1.75
JPETSTORE	2.25	2.35	2.87
PROPRIETARY	1.53	1.23	1.55
WIN/TIE/Loss	0/0/5		

CARGO performs poorly on BCP. The definition of BCP depends heavily on the quality of the generated business use cases, which Mono2Micro has access to but we do not.

Summary

- ❑ Existing automated approaches miss key code and/or transactional dependencies
- ❑ We present CARGO, which uses (a) precise static analysis, (b) explicit modeling of database transactions, and (c) a novel community detection algorithm
- ❑ Compared to existing approaches, CARGO (a) reduces distributed transactions, (b) achieves better latency and throughput, (c) achieves better performance on architectural metrics