Profiling Dataflow Systems on Multiple Abstraction Levels

Alexander Beischl, Timo Kersten, Maximilian Bandle

Jana Giceva, Thomas Neumann

Technische Universität München

beischl@in.tum.de

Compiling Dataflow Systems are Everywhere!

Dataflow systems in different areas

Machine- and deep learning

TensorFlow

PyTorch

Graph and stream-processing

Flink

Ligra

Big-data processing

Apache Spark™

Microsoft Naiad

Relational DBMS

Microsoft Hekaton

SAP HANA®

UMBRA

Profiling a Compiling Dataflow System

Trying to optimize the system

Query

```
df_sales.join(df_CPUs,
  col("df_sales.cpuID" ===
  col("df_CPUs.ID"), "inner")
```

Profiling a Compiling Dataflow System

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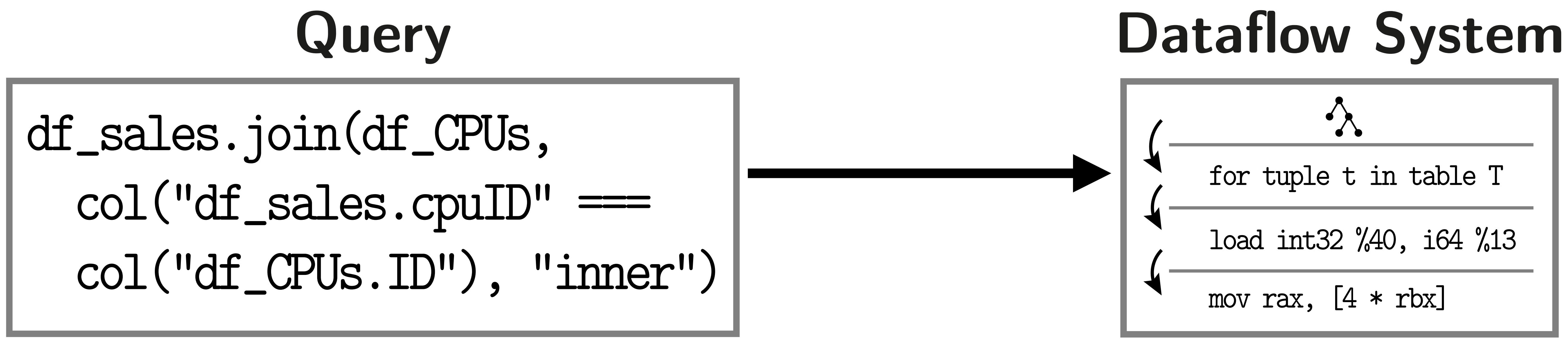

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Dataflow System

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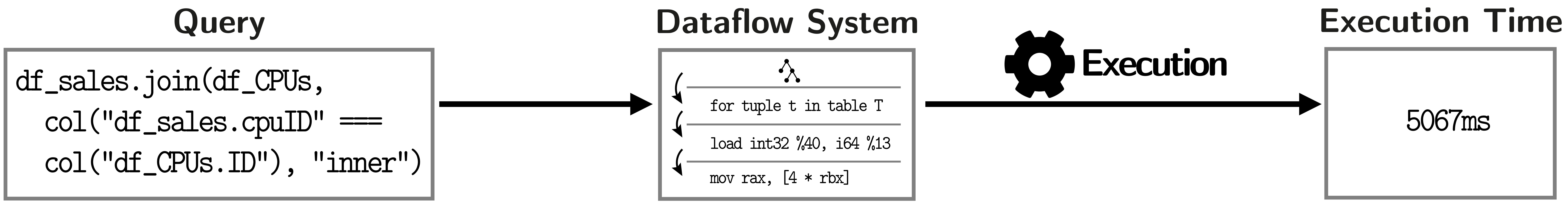

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Execution Time

5067ms

Profiling a Compiling Dataflow System

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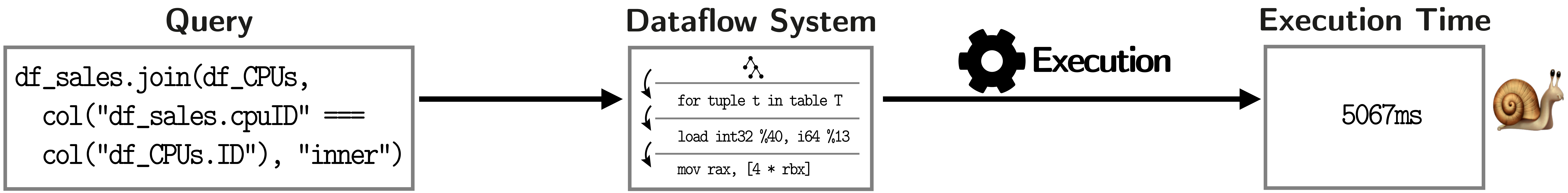

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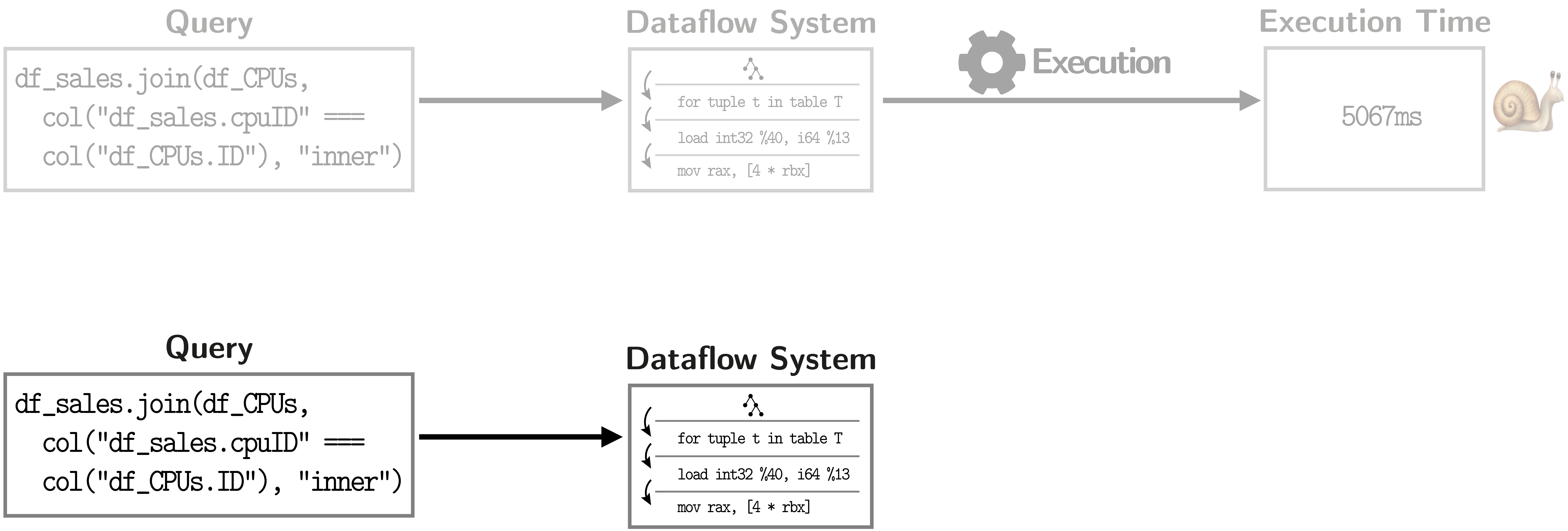

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Profiling a Compiling Dataflow System

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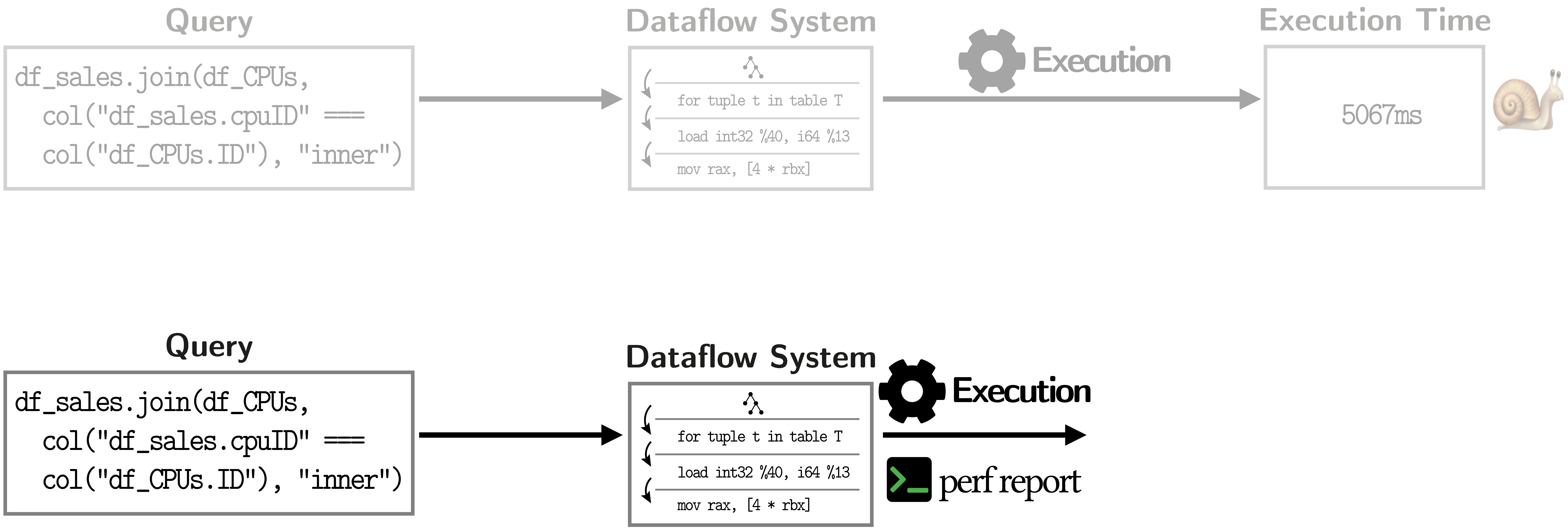

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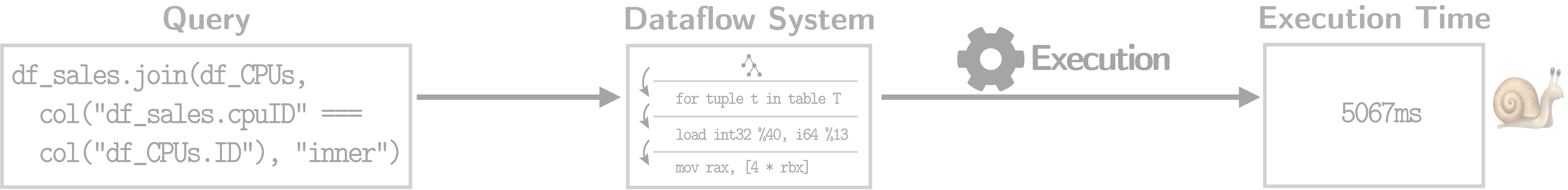
Execution

perf report

Profiling a Compiling Dataflow System

Trying to optimize the system



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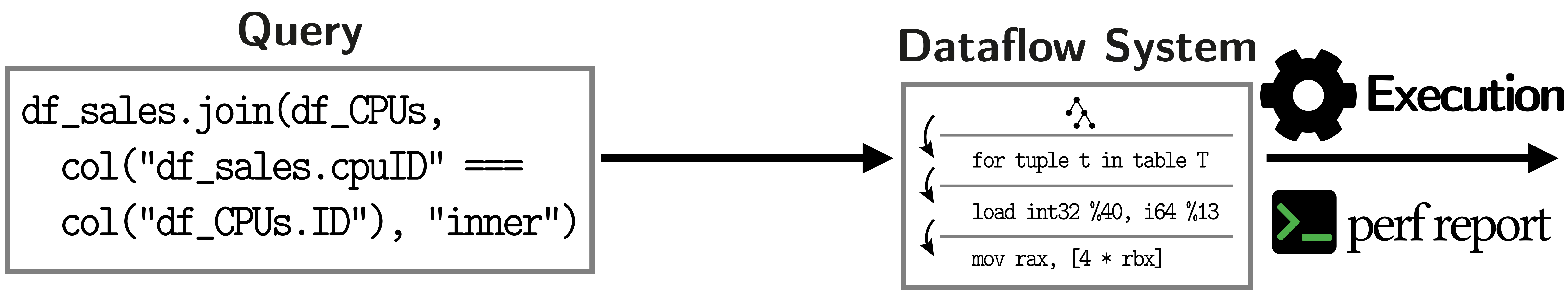

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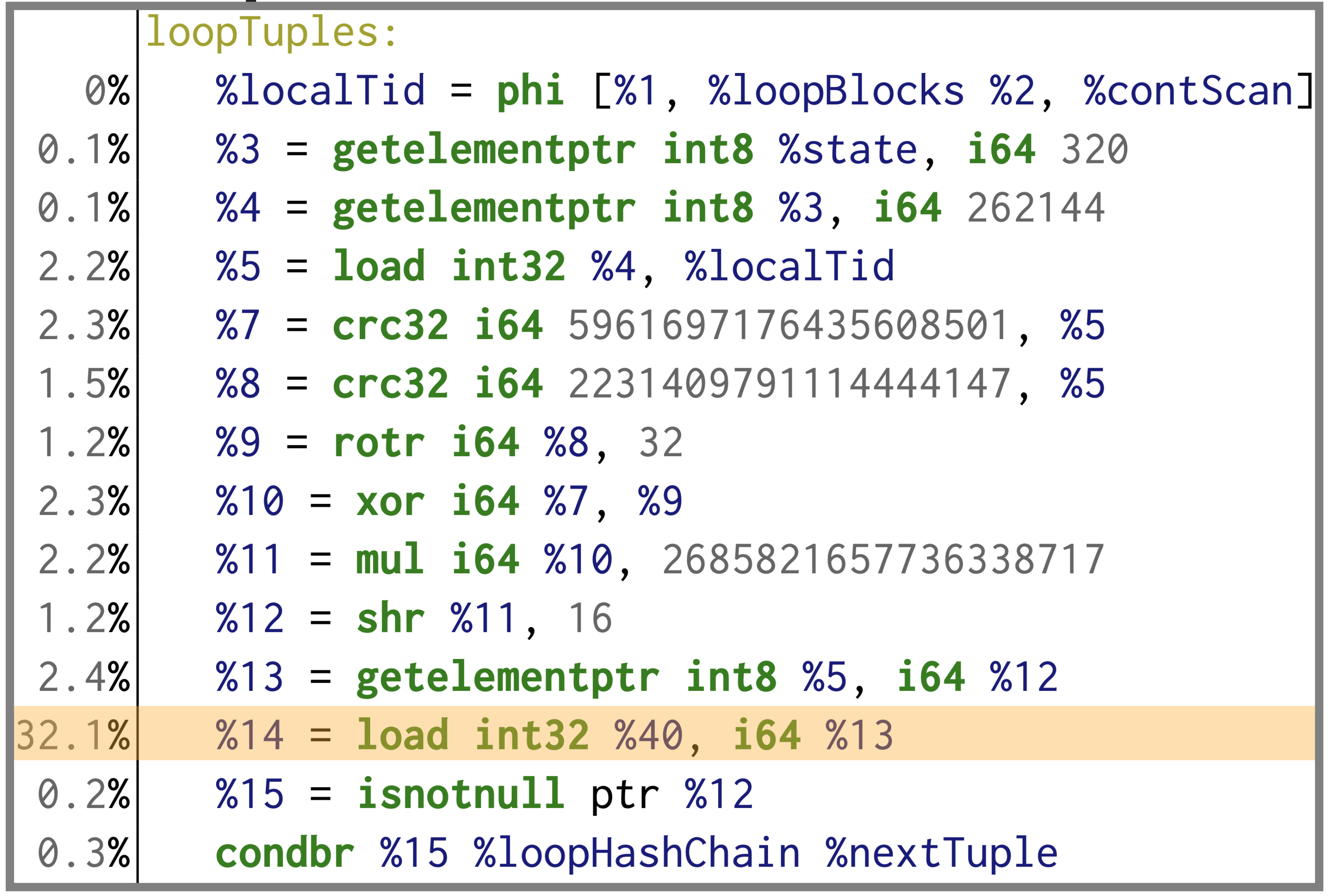
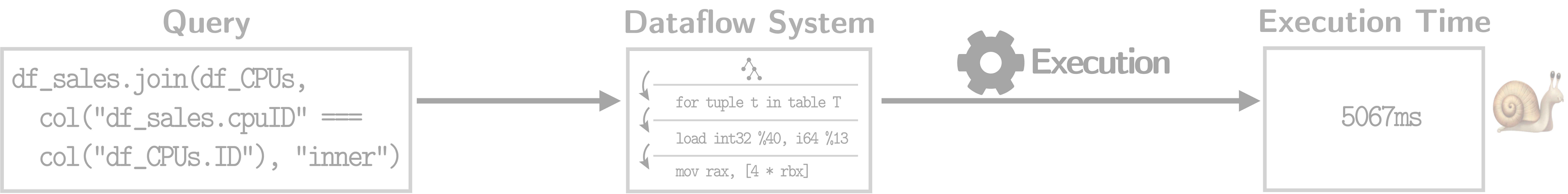
Perf report



```
      loopTuples:
   0%   %localTid = phi [%1, %loopBlocks %2, %contScan]
 0.1%   %3 = getelementptr int8 %state, i64 320
 0.1%   %4 = getelementptr int8 %3, i64 262144
 2.2%   %5 = load int32 %4, %localTid
 2.3%   %7 = crc32 i64 5961697176435608501, %5
 1.5%   %8 = crc32 i64 2231409791114444147, %5
 1.2%   %9 = rotr i64 %8, 32
 2.3%   %10 = xor i64 %7, %9
 2.2%   %11 = mul i64 %10, 2685821657736338717
 1.2%   %12 = shr %11, 16
 2.4%   %13 = getelementptr int8 %5, i64 %12
32.1%   %14 = load int32 %40, i64 %13
 0.2%   %15 = isnotnull ptr %12
 0.3%   condbr %15 %loopHashChain %nextTuple
```

Profiling a Compiling Dataflow System

Trying to optimize the system



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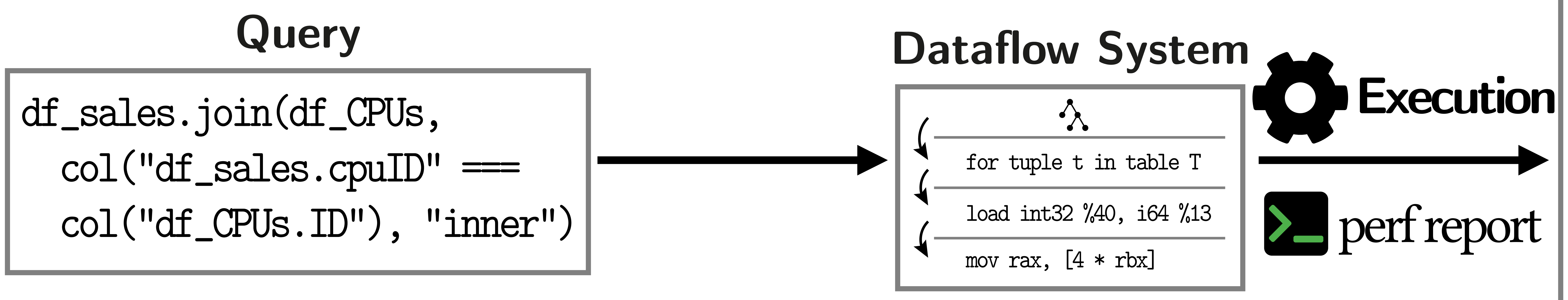

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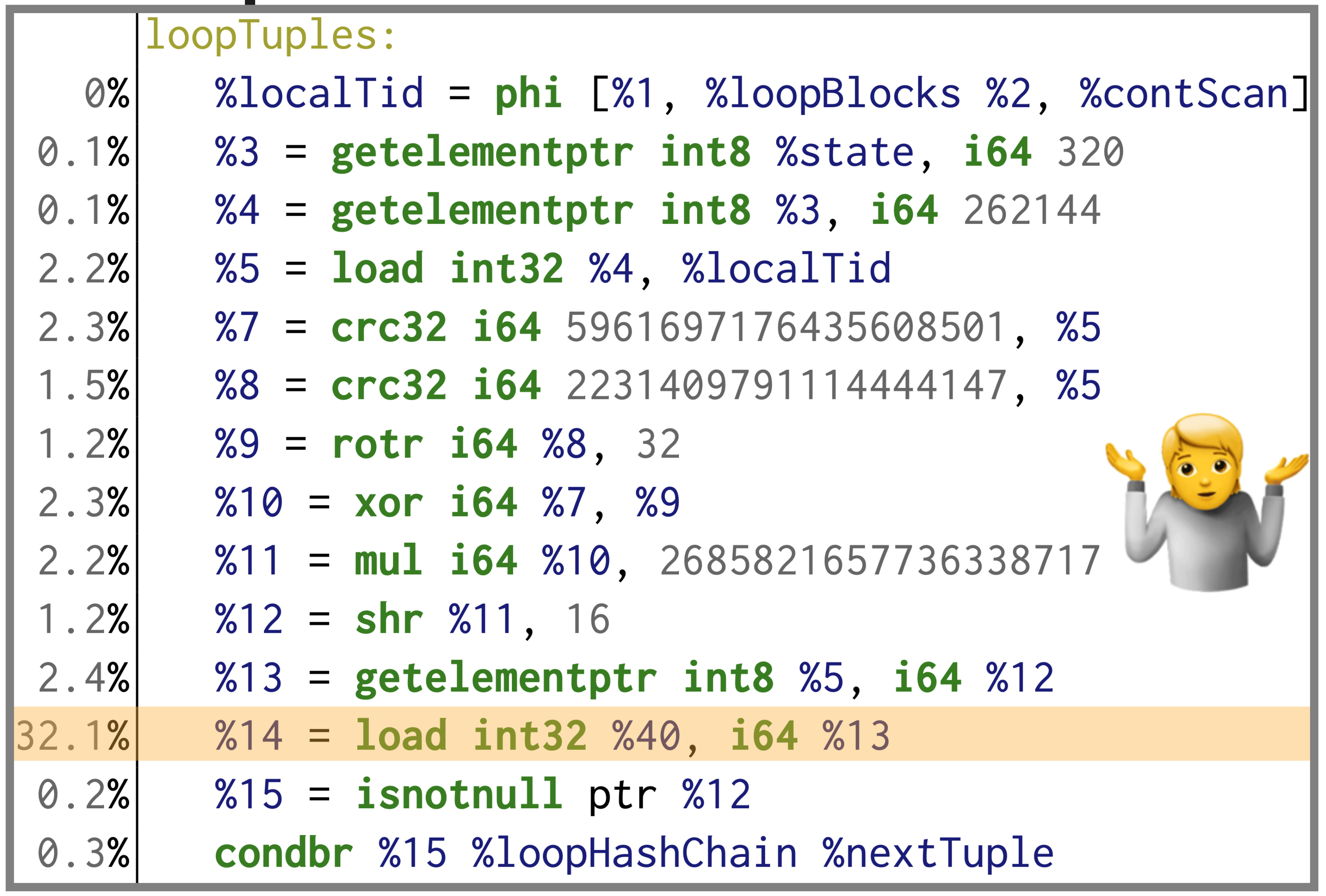

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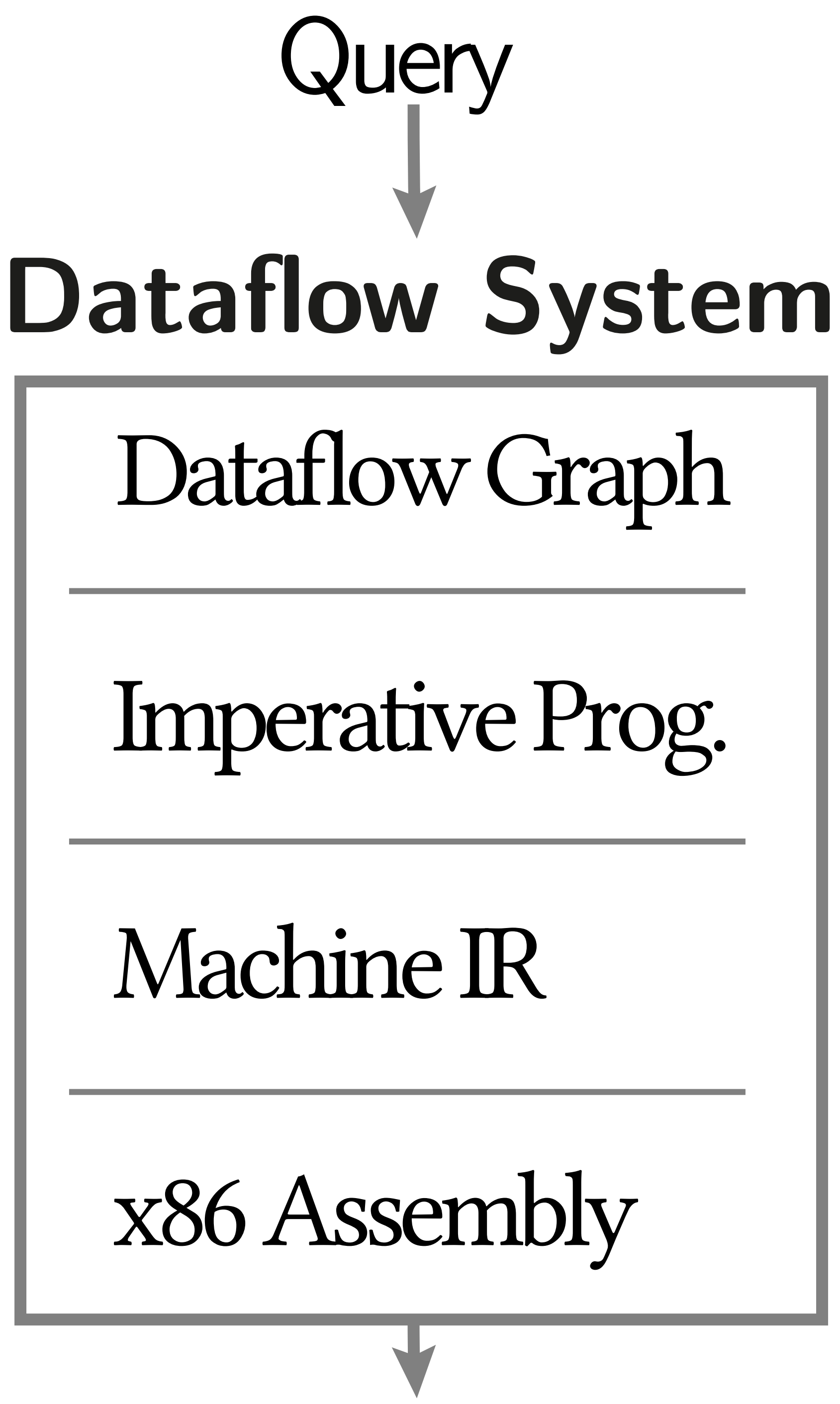
```

Why do we have this problem?

Identifying the gap



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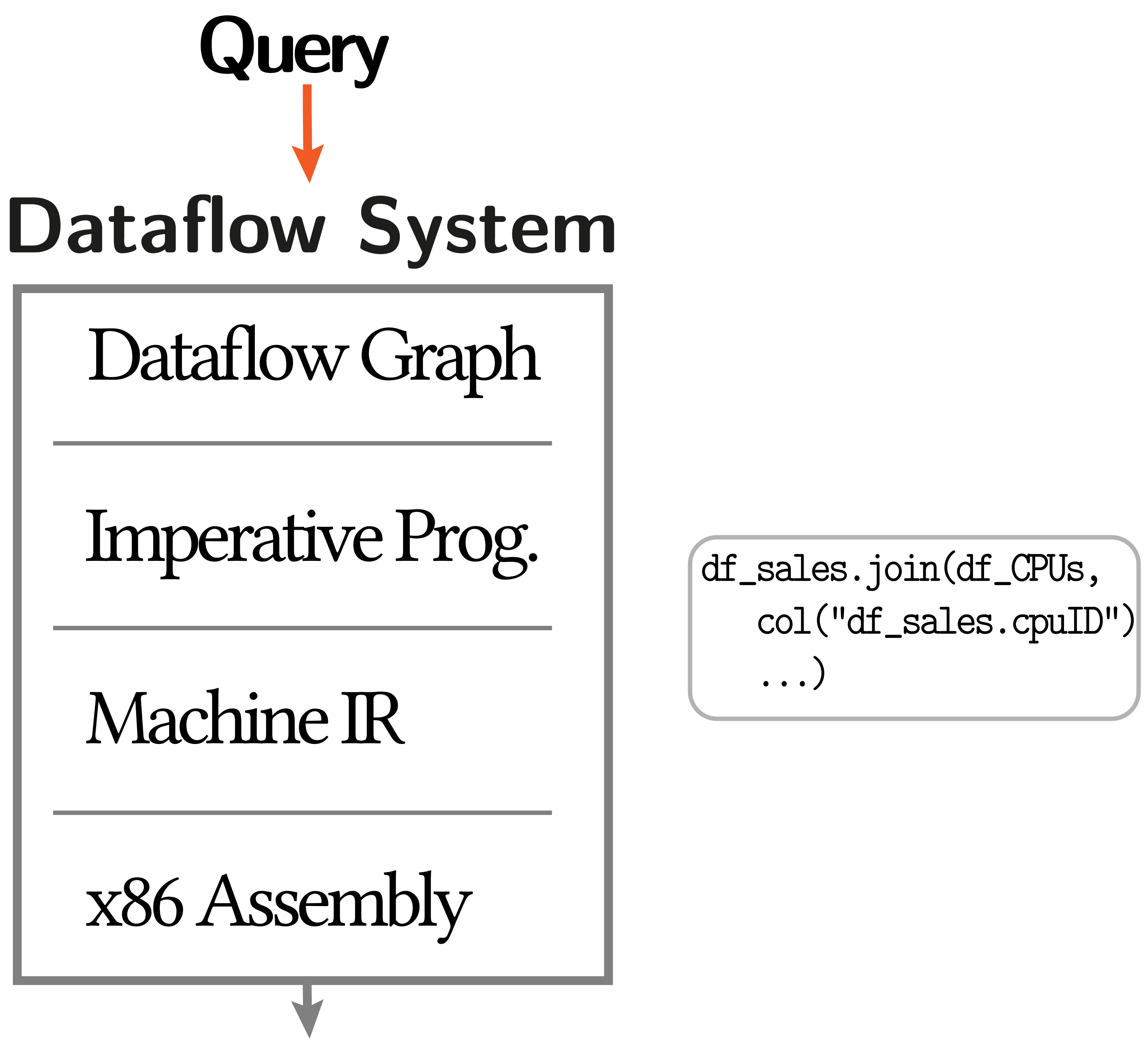

```
df_sales.join(df_CPUs,
   col("df_sales.cpuID")
   ...)
```

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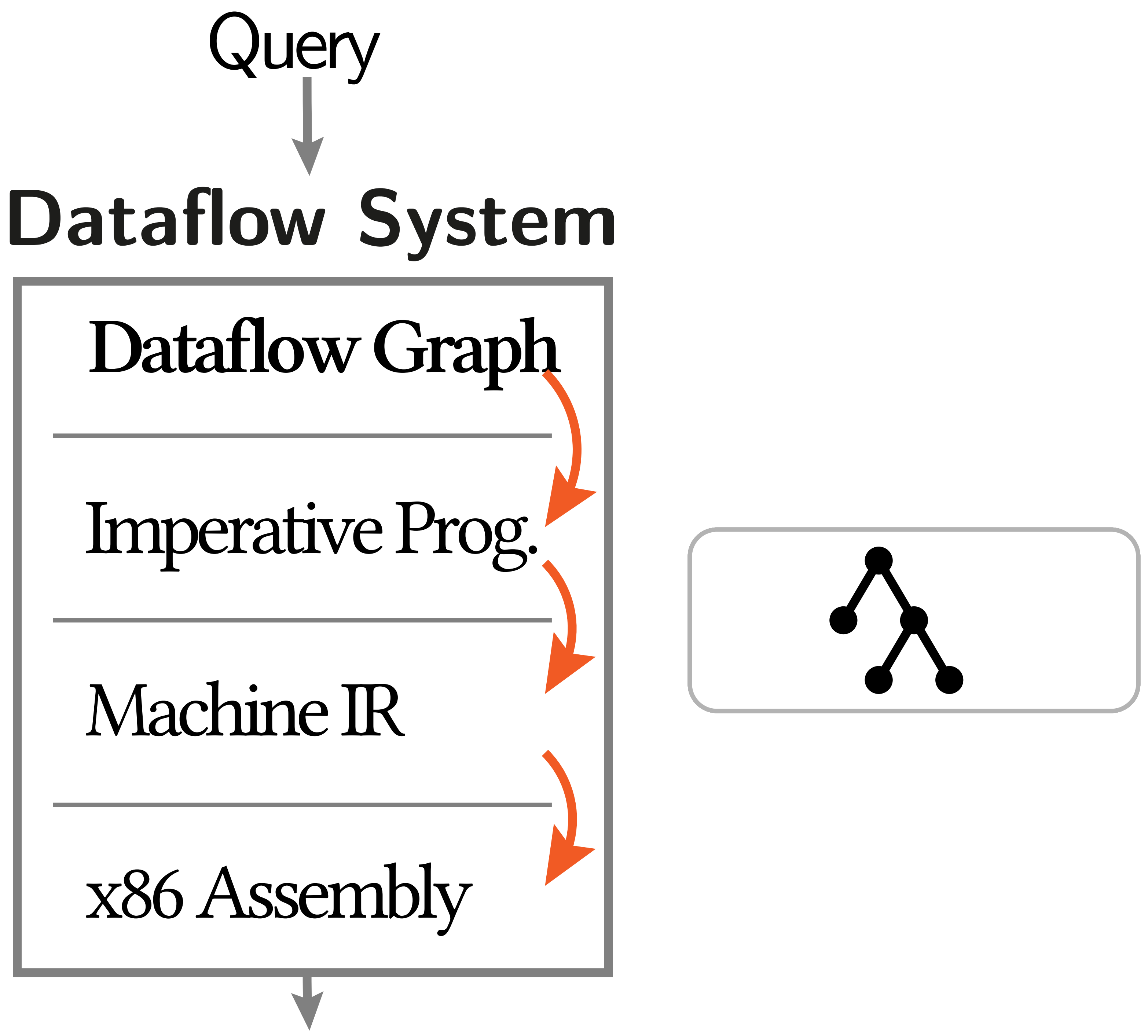
Identifying the gap



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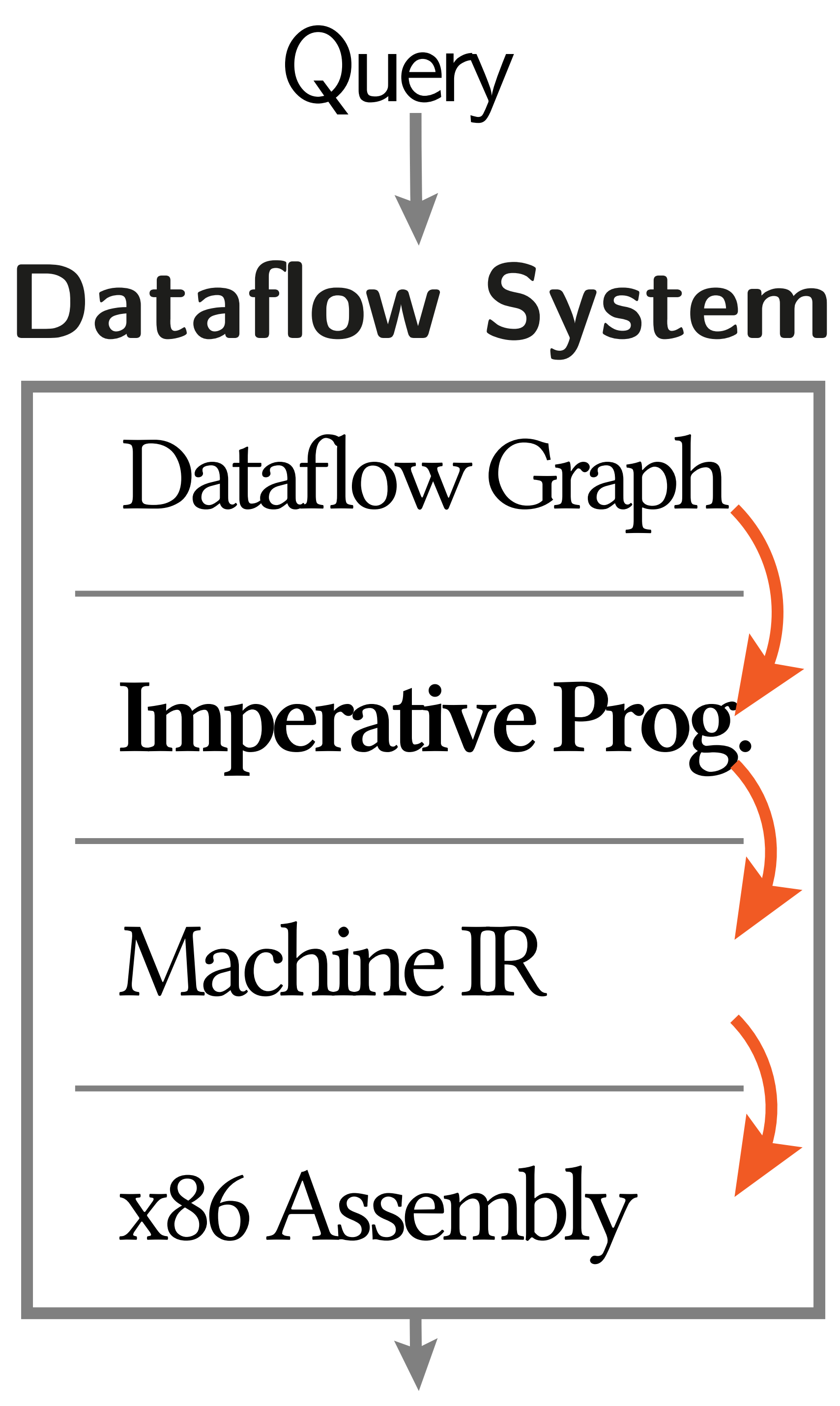

```
for tuple t in table T
  if t[1] > 5
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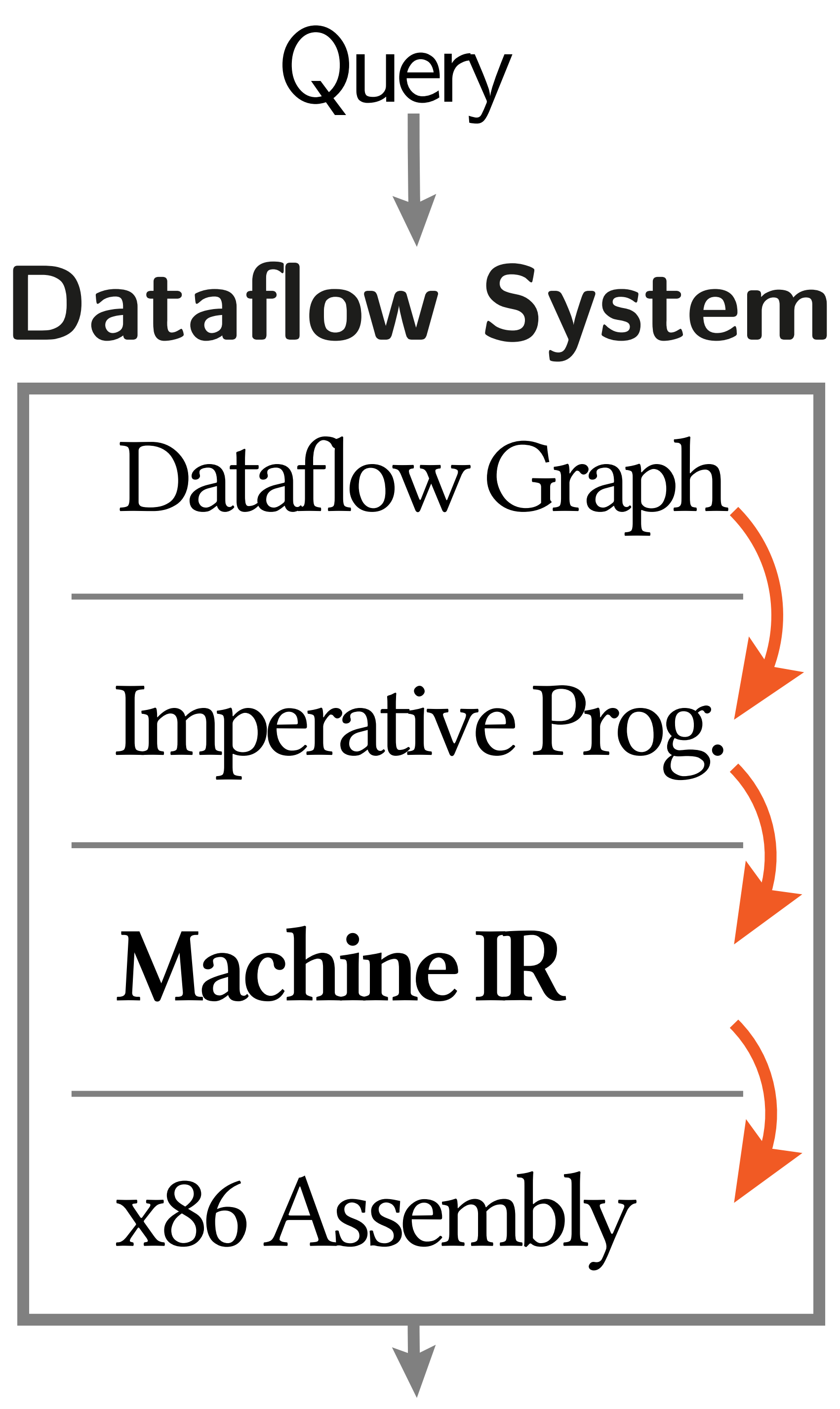

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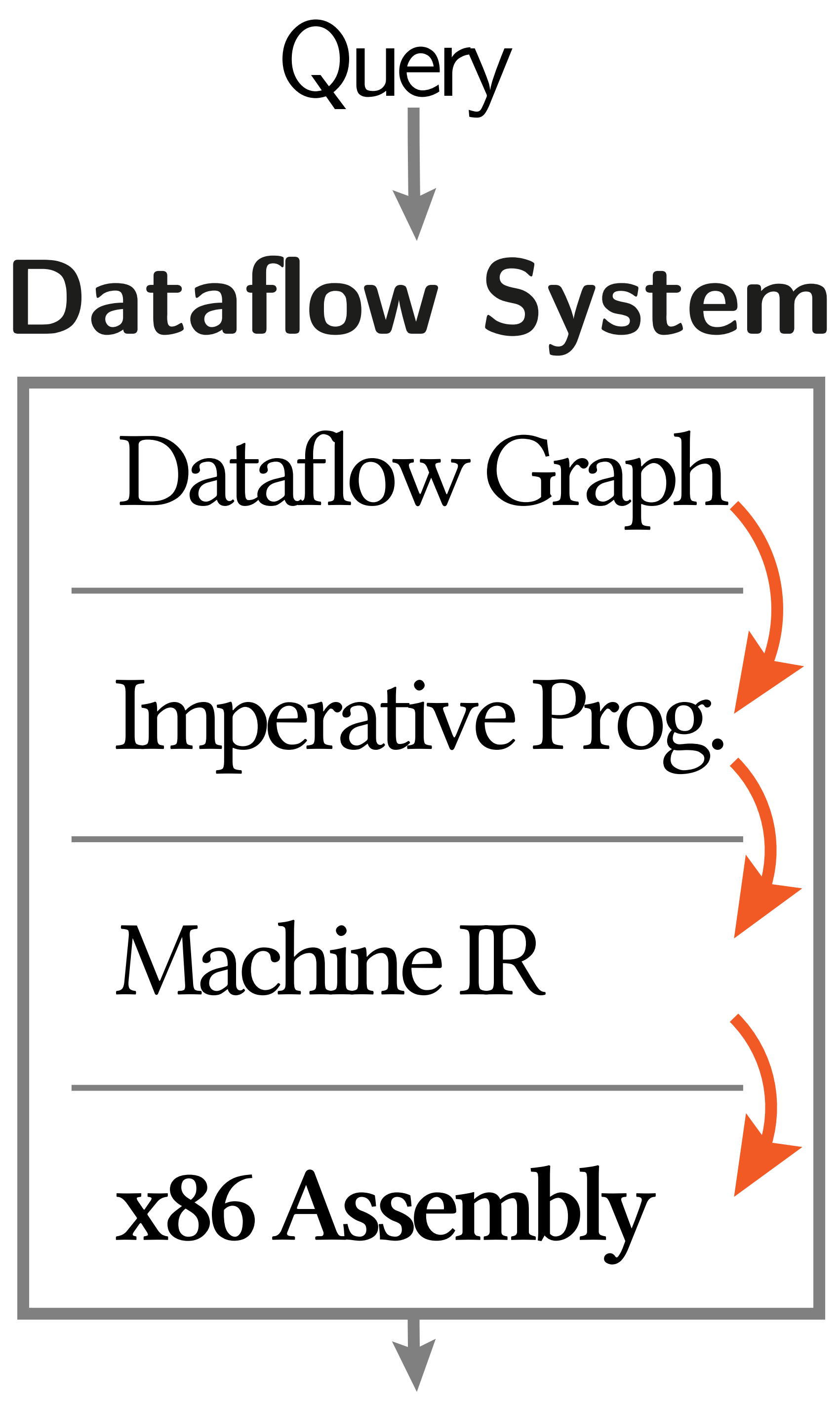

```
mov rax, [4 * rbx]
cmp rax, 0
je ...
```

Why do we have this problem?

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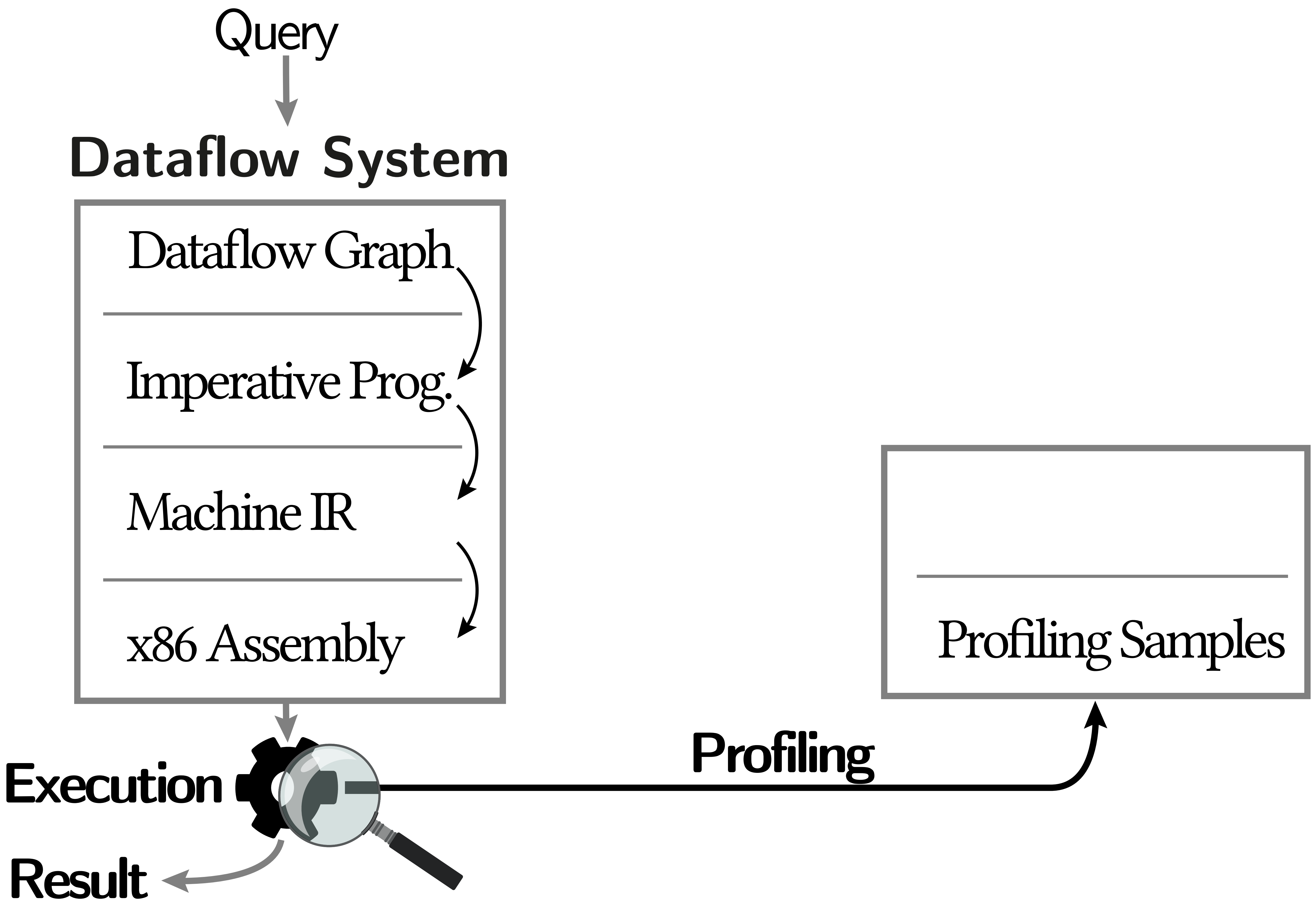

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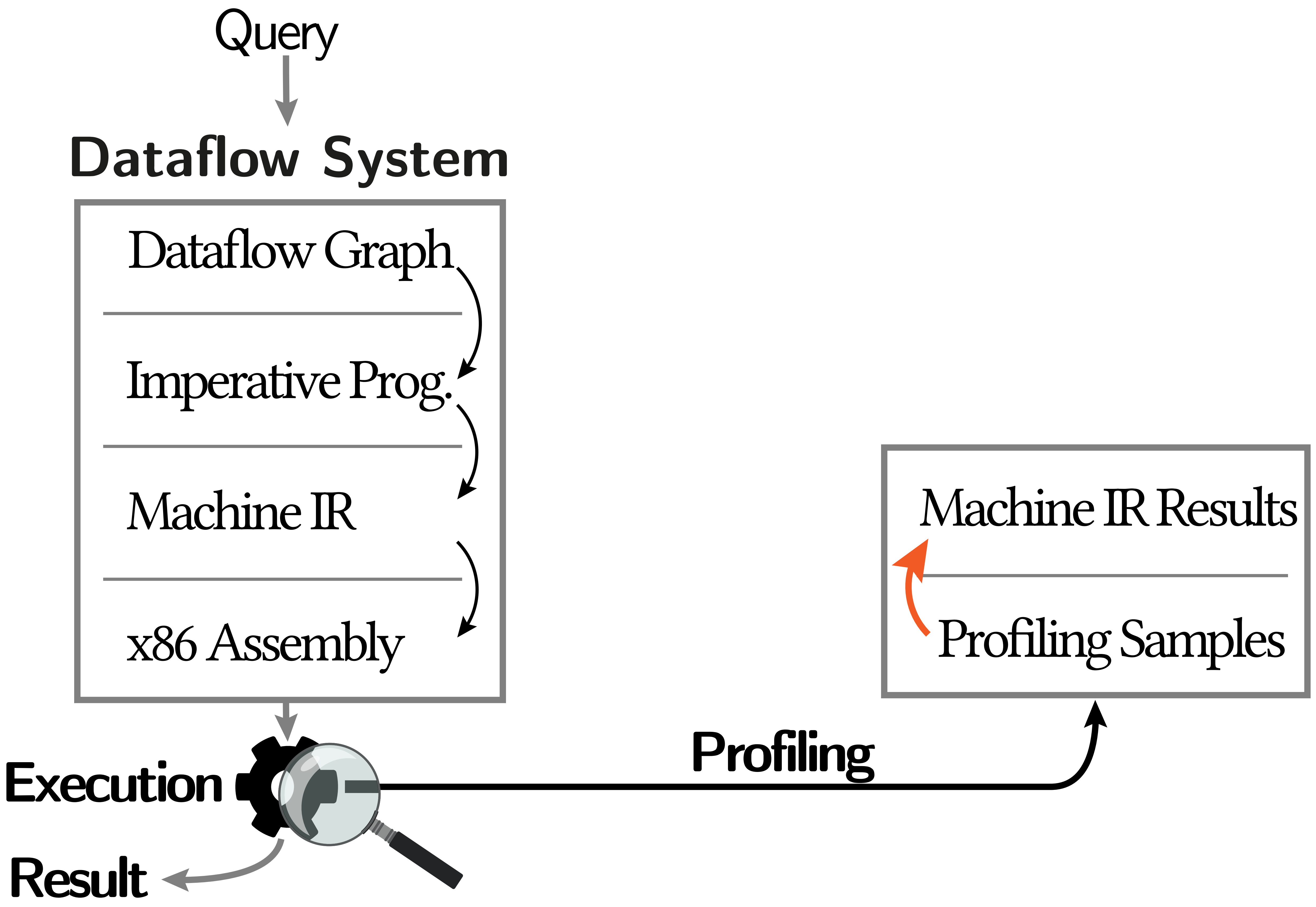

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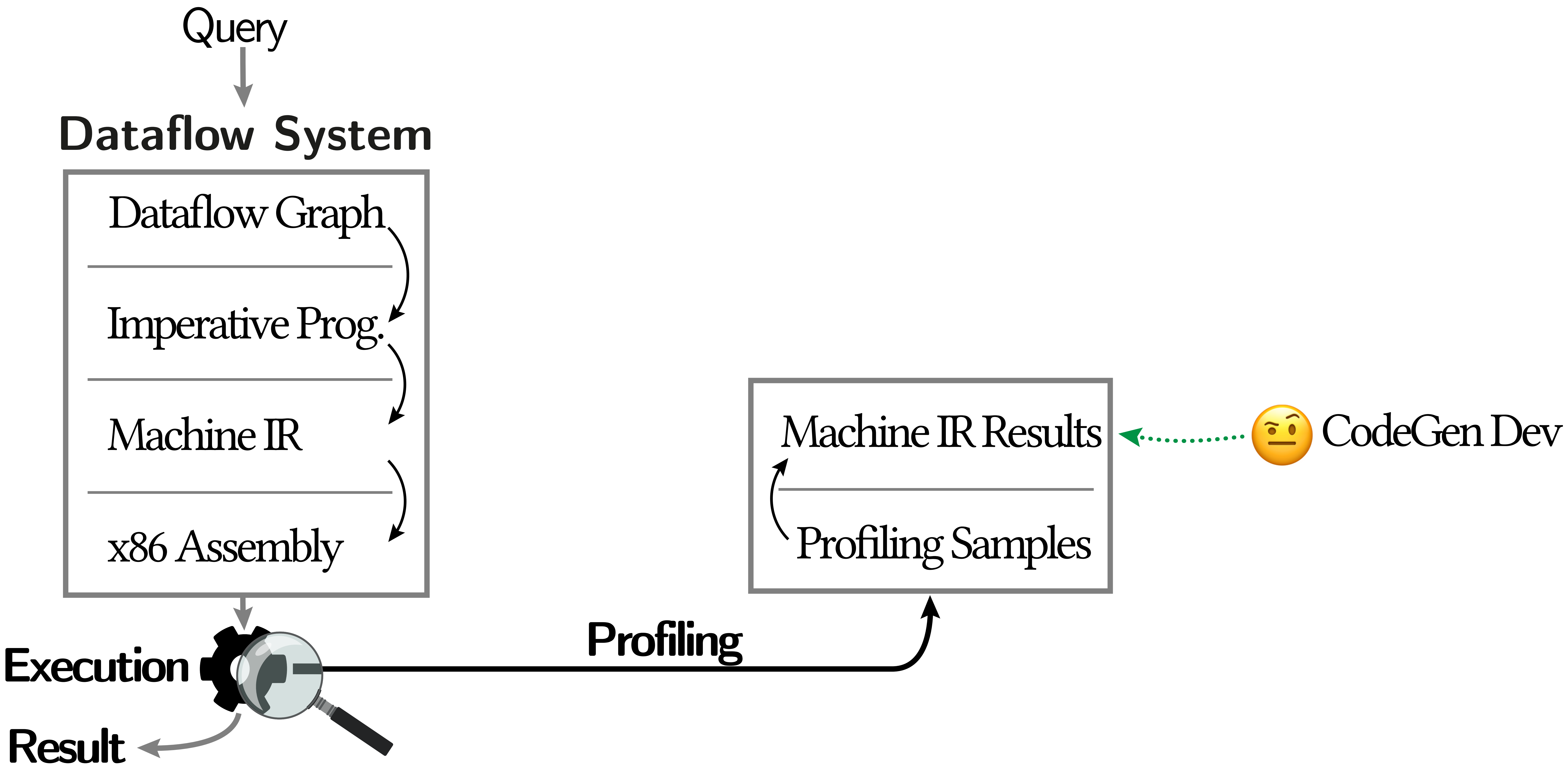


Query

Dataflow System

Dataflow Graph

Imperative Prog.

Machine IR

x86 Assembly

Execution

Result

Profiling

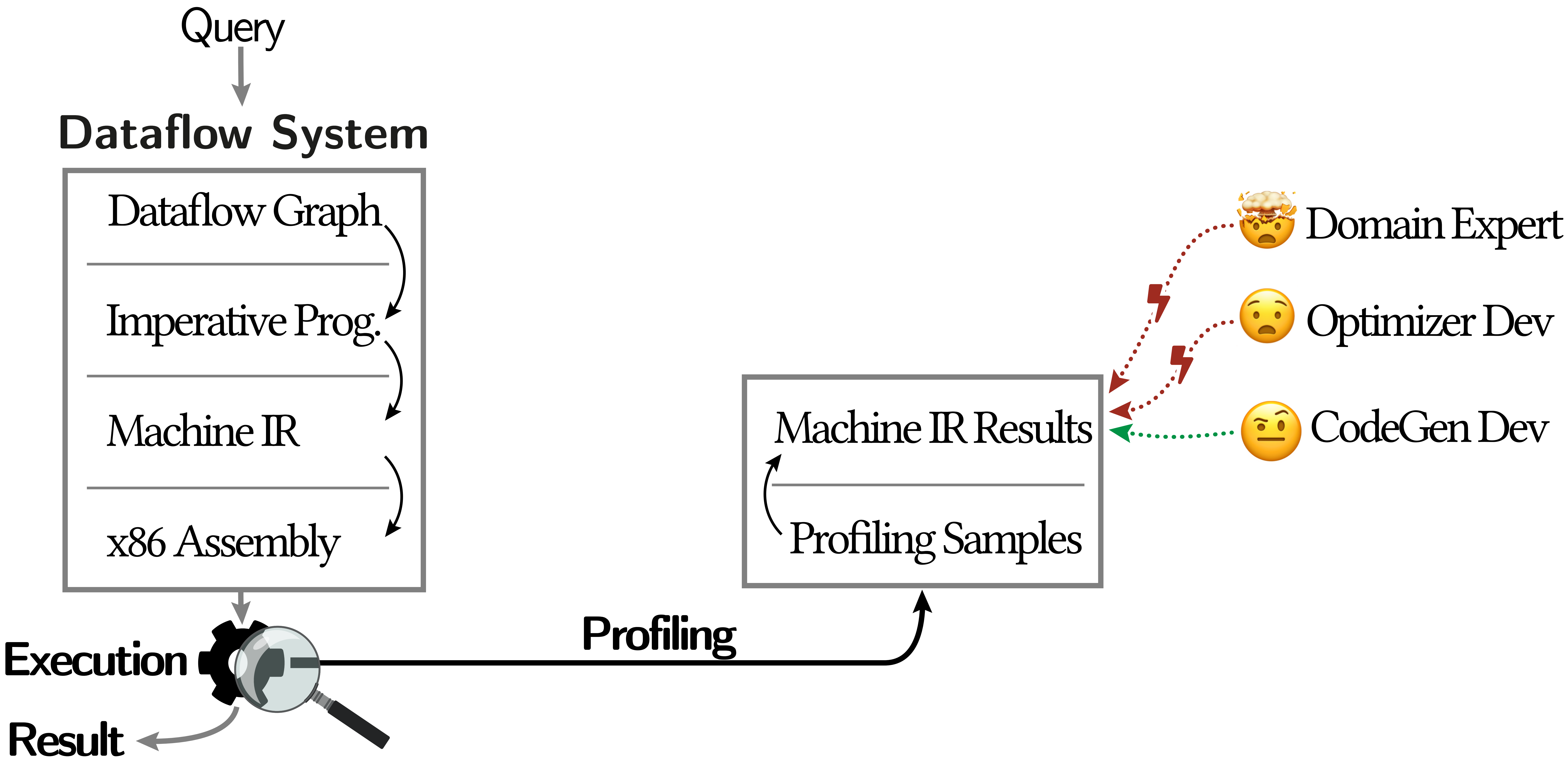
Machine IR Results

Profiling Samples

🤨 CodeGen Dev

Why do we have this problem?

Identifying the gap



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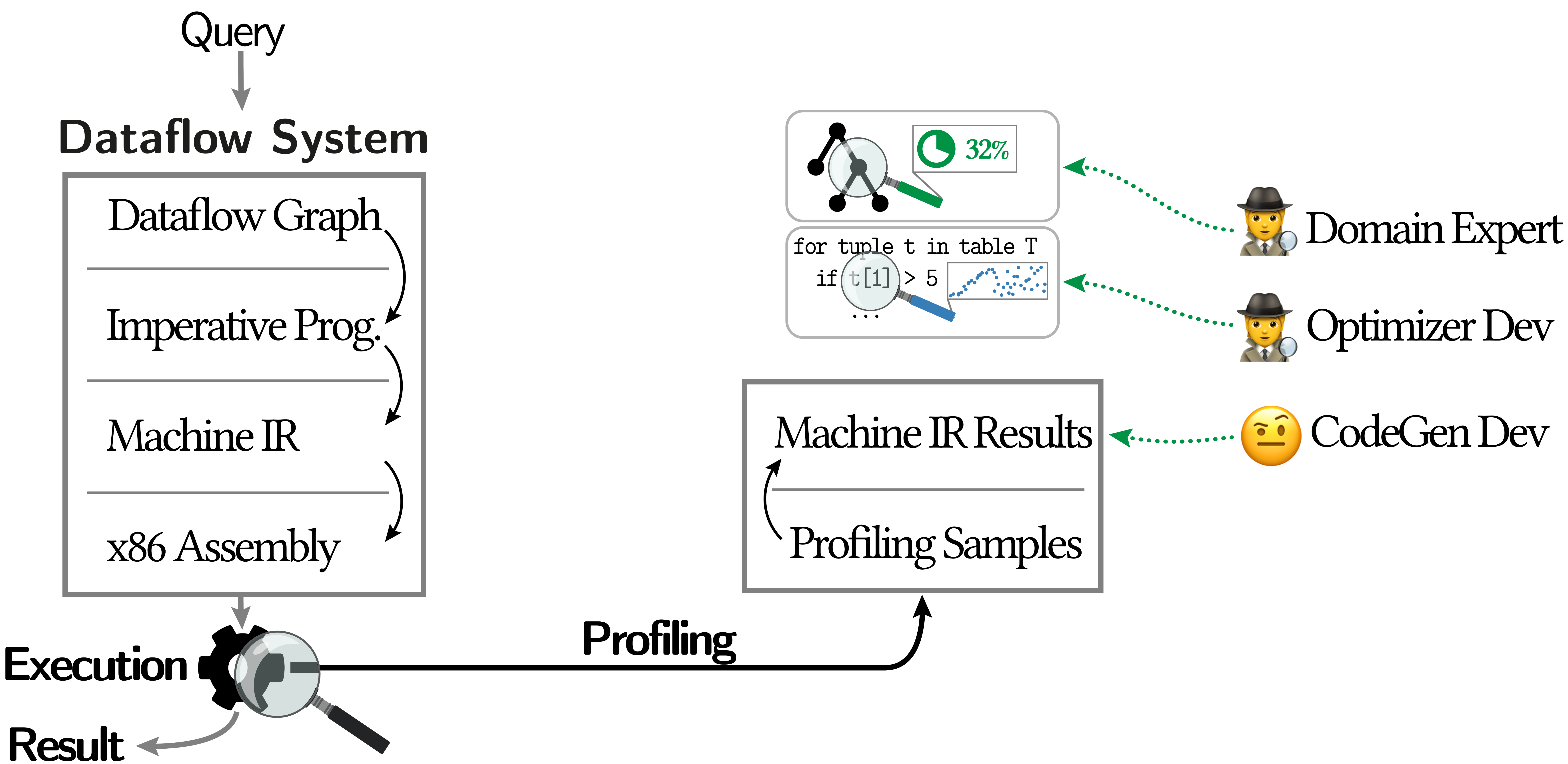

Query

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Profiling Samples

```
for tuple t in table T
  if t[1] > 5
    ...
```

Domain Expert

Optimizer Dev

CodeGen Dev

Why do we have this problem?

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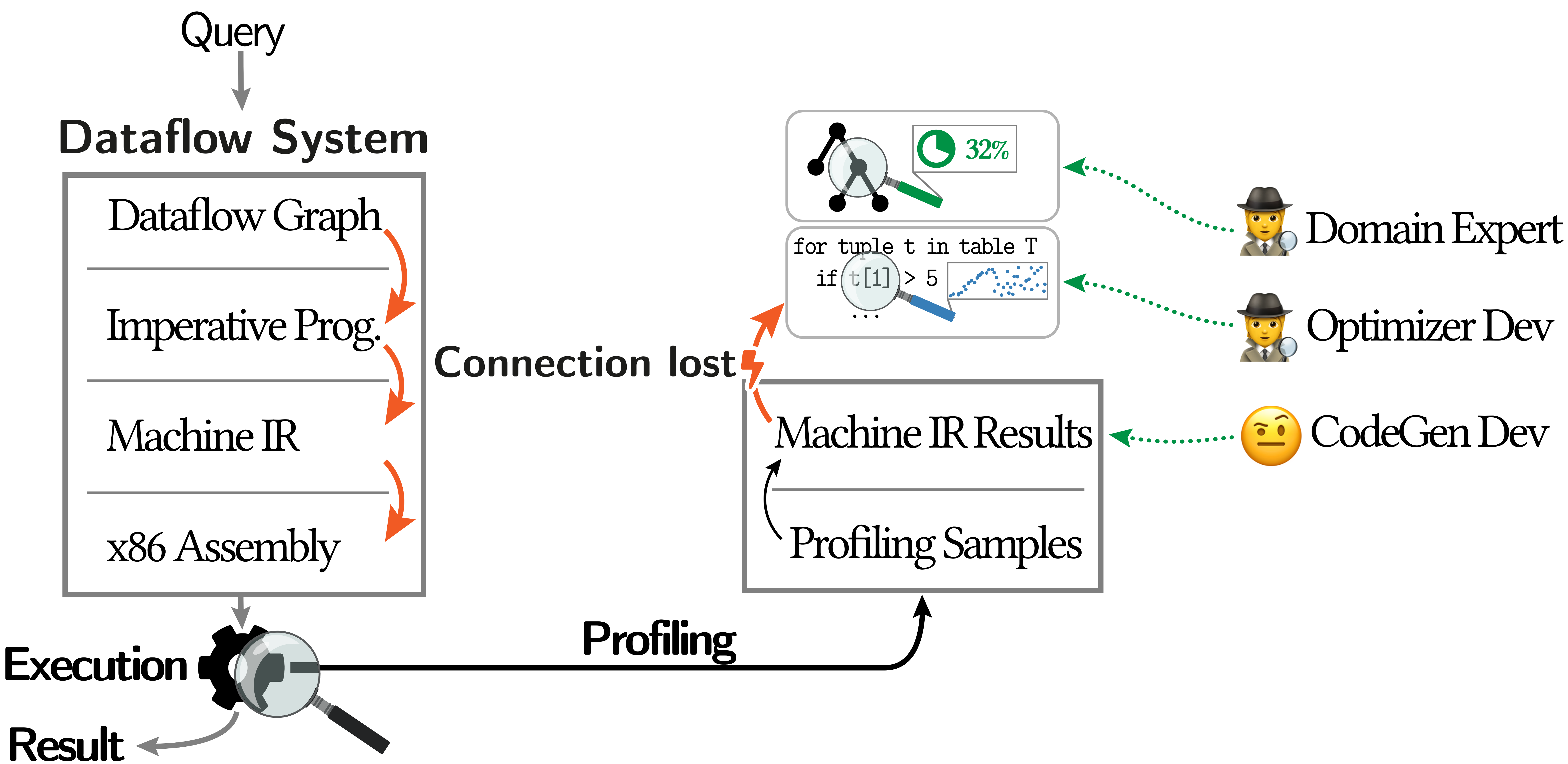

Query

Dataflow System

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Imperative Prog.

Machine IR

x86 Assembly

Connection lost

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Profiling Samples

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Domain Expert

Optimizer Dev

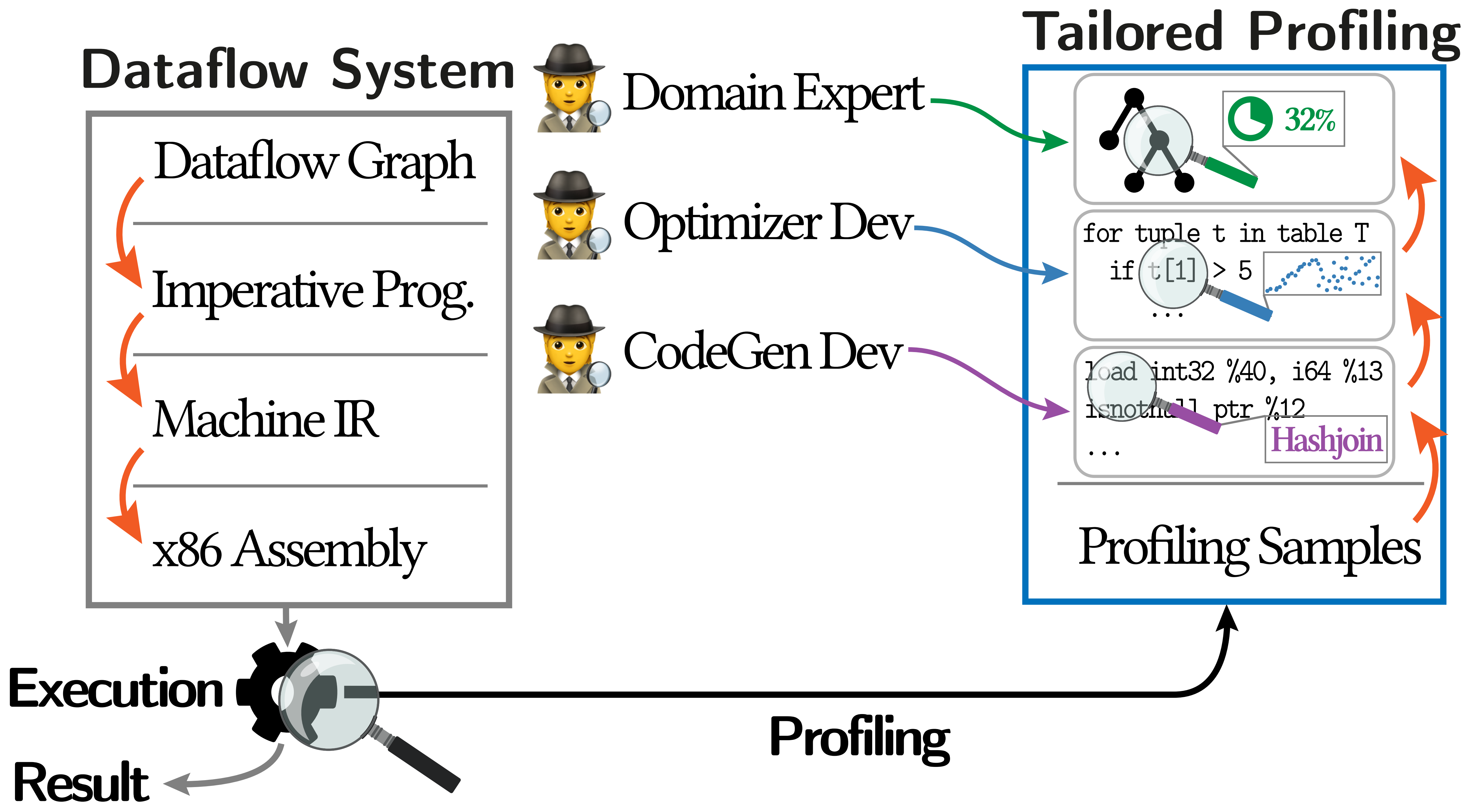
CodeGen Dev

Tailored Profiling

Closing the gap

- Track connection between components of all abstraction levels down to generated code
- Map profiling samples back to higher abstraction levels

- Ingredients
  - *Tagging Dictionary & Register Tagging*



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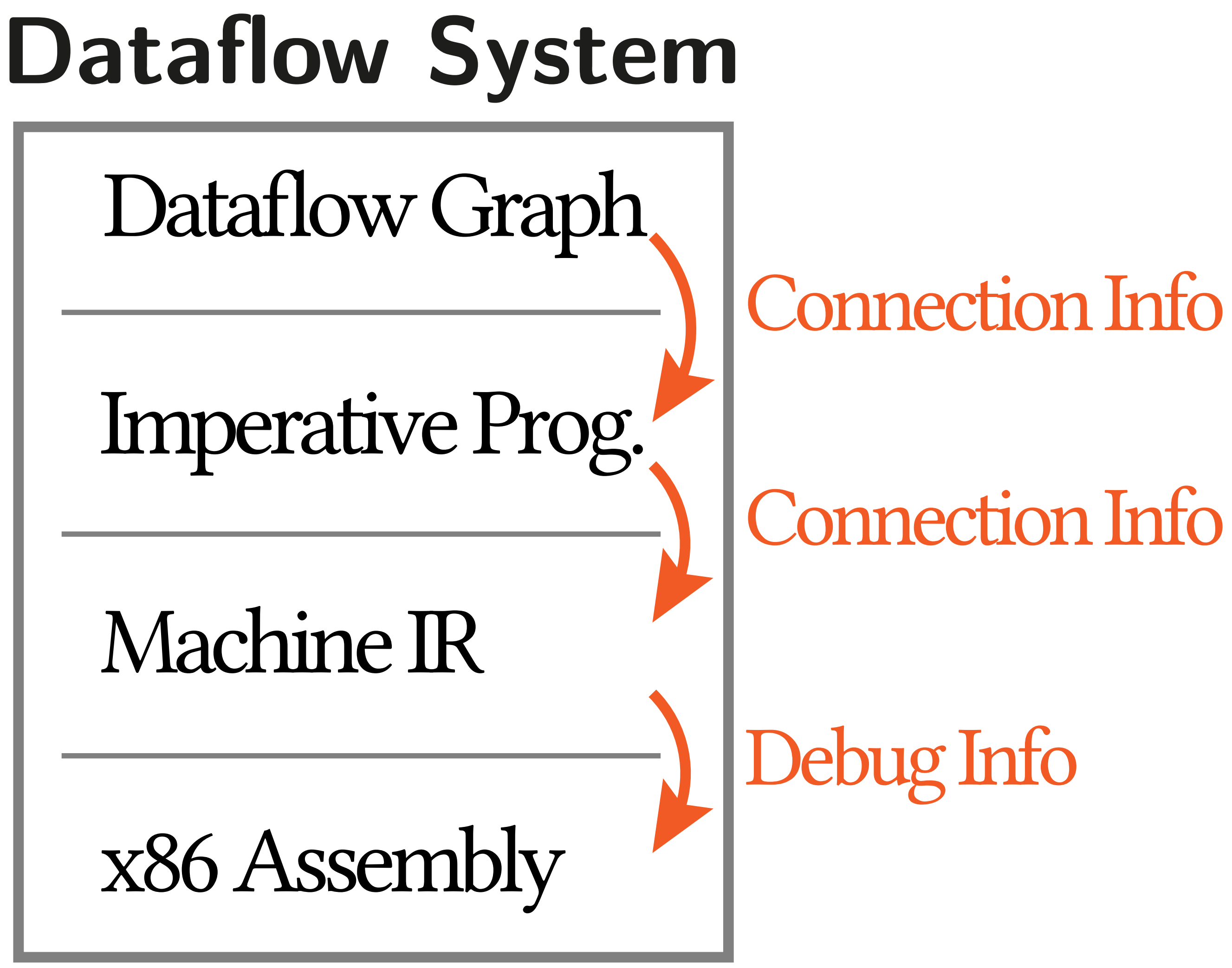
Tailored Profiling

Tagging Dictionary

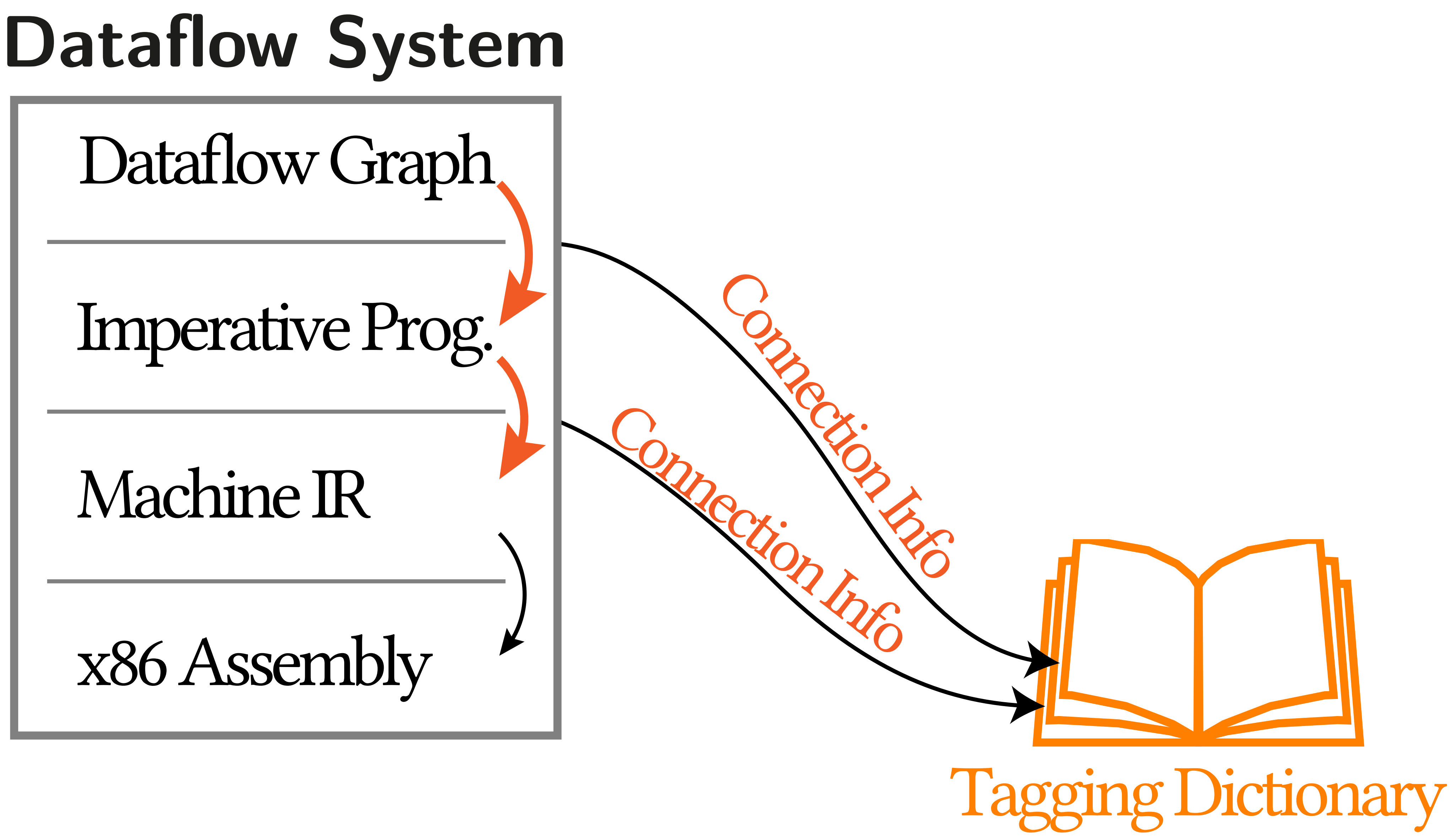
① *Connection tracking* of abstraction components for each lowering step (top-down)



Tailored Profiling

Tagging Dictionary

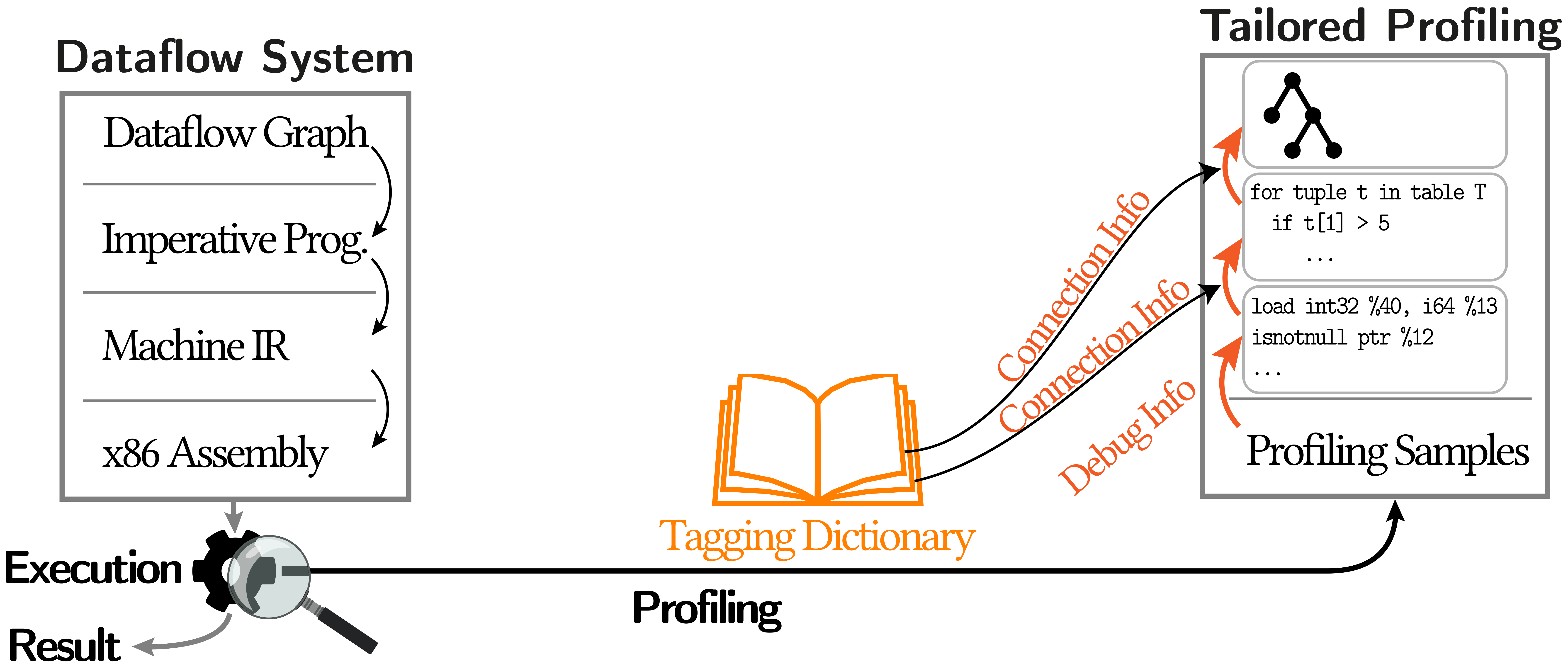
②Store mapping in the *Tagging Dictionary*



Tailored Profiling

Tagging Dictionary

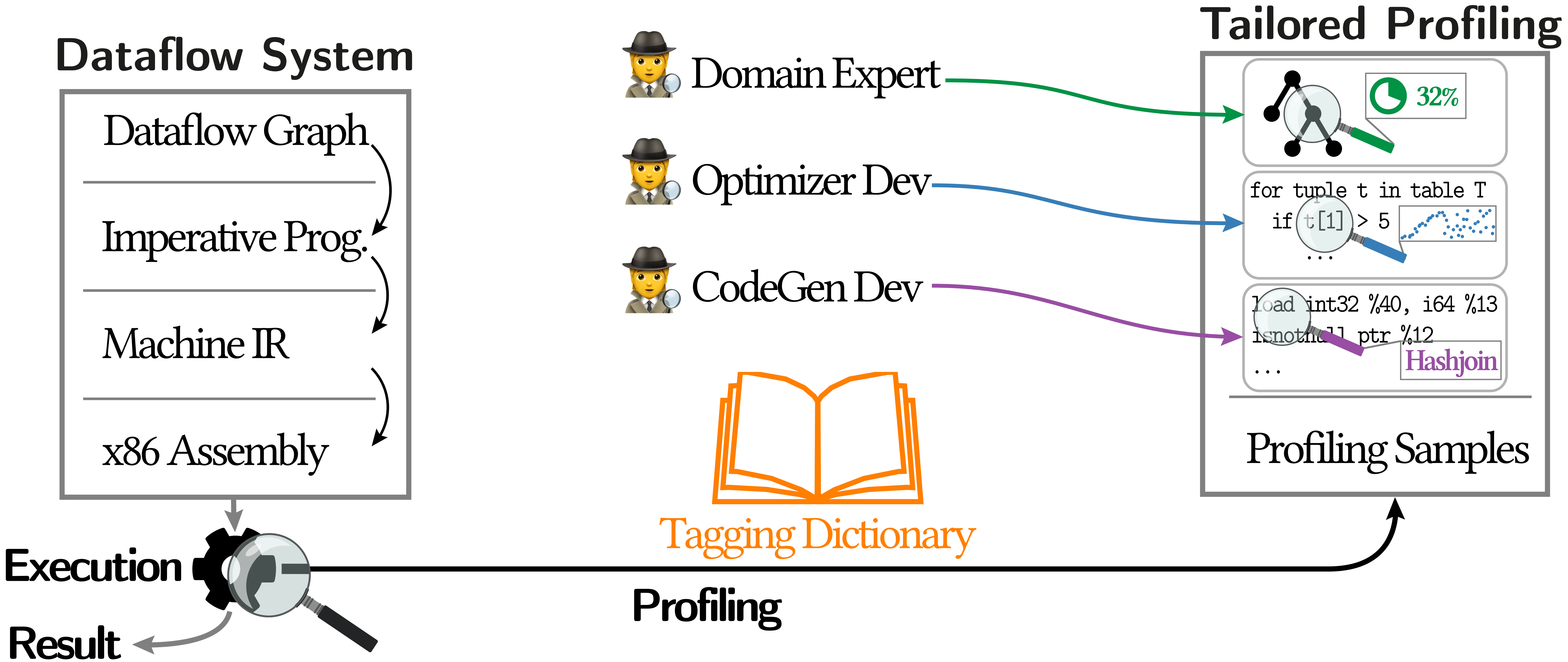
③ *Map* profiling results to each abstraction level's components (bottom-up)



Tailored Profiling

Tagging Dictionary

④ *Aggregate* the data for profiling results



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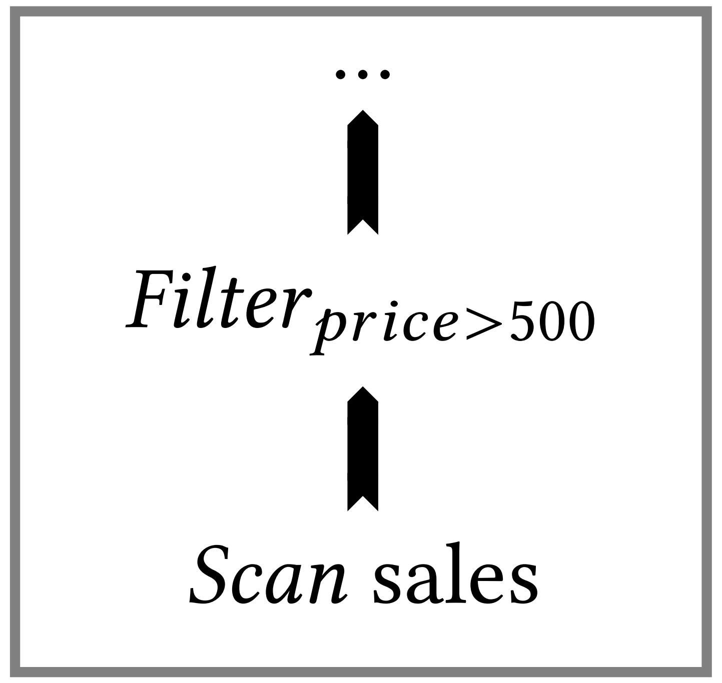
Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



...

$Filter_{price>500}$

$Scan$ sales

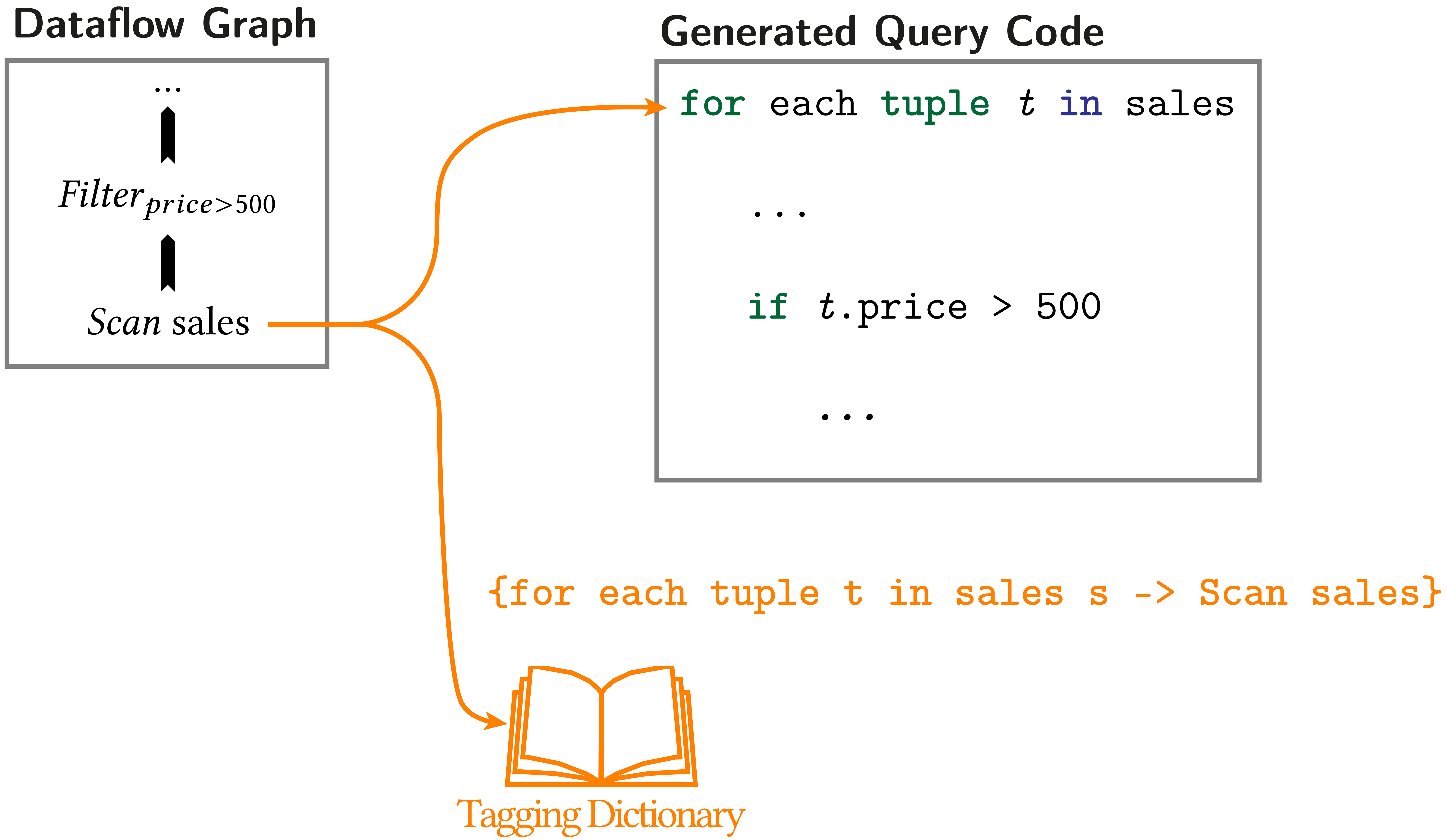
Generated Query Code

```
for each tuple t in sales
    ...
    if t.price > 500
        ...
```

Tagging Dictionary

Tailored Profiling

Tagging Dictionary and Register Tagging

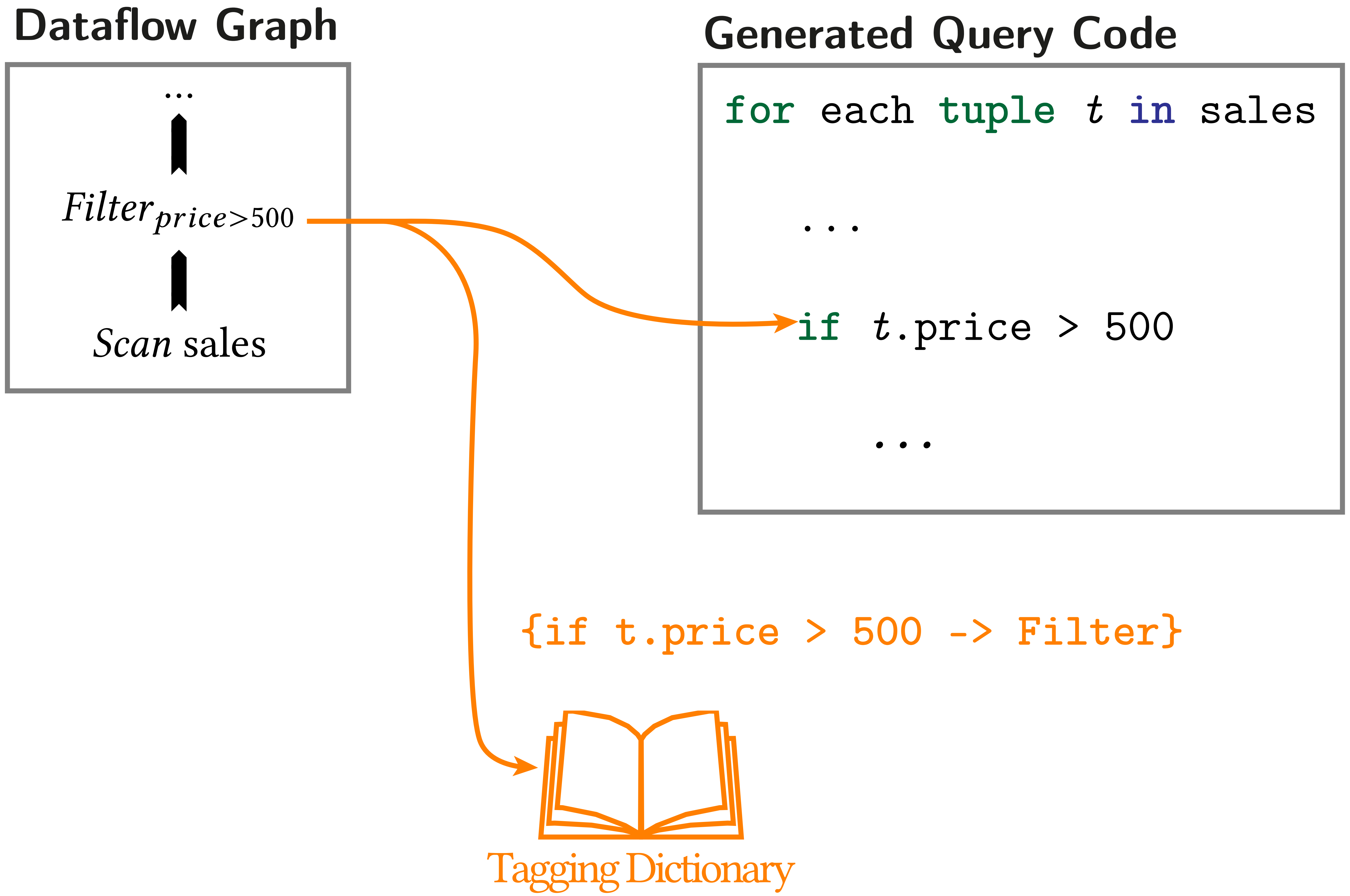


```
for each tuple t in sales
   ...
   if t.price > 500
      ...
```

{for each tuple t in sales s -> Scan sales}

Tailored Profiling

Tagging Dictionary and Register Tagging



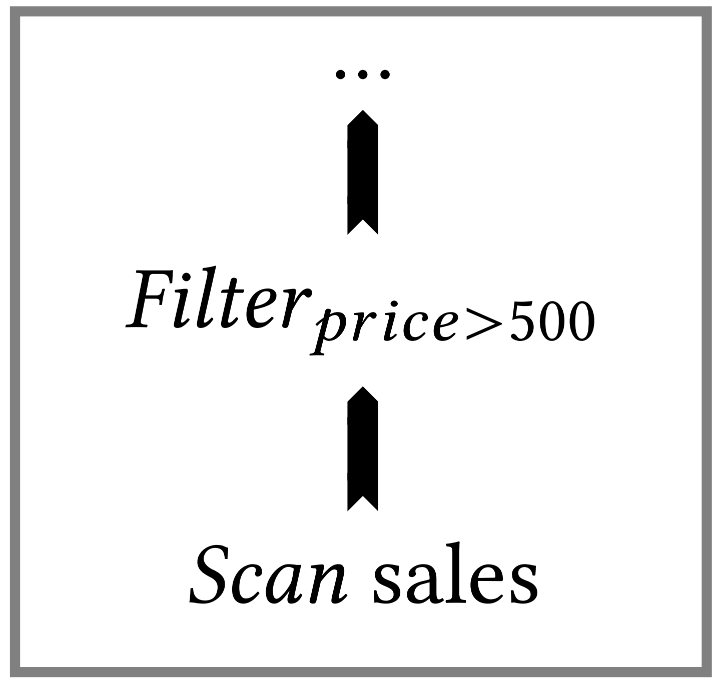
```
for each tuple t in sales

   ...

   if t.price > 500

      ...
```

```
{if t.price > 500 -> Filter}
```

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



Generated Query Code

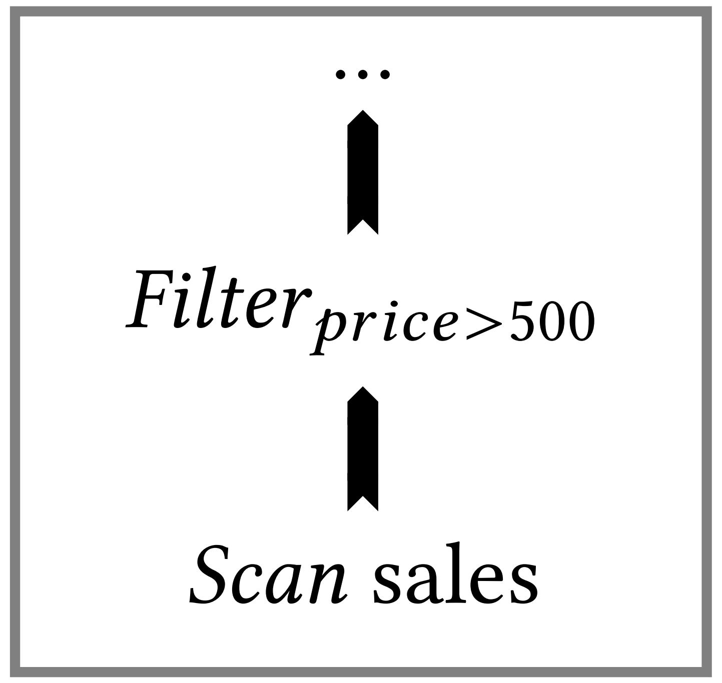
```
for each tuple t in sales
   call malloc(...)
   if t.price > 500
      call malloc(...)
```

Tagging Dictionary

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



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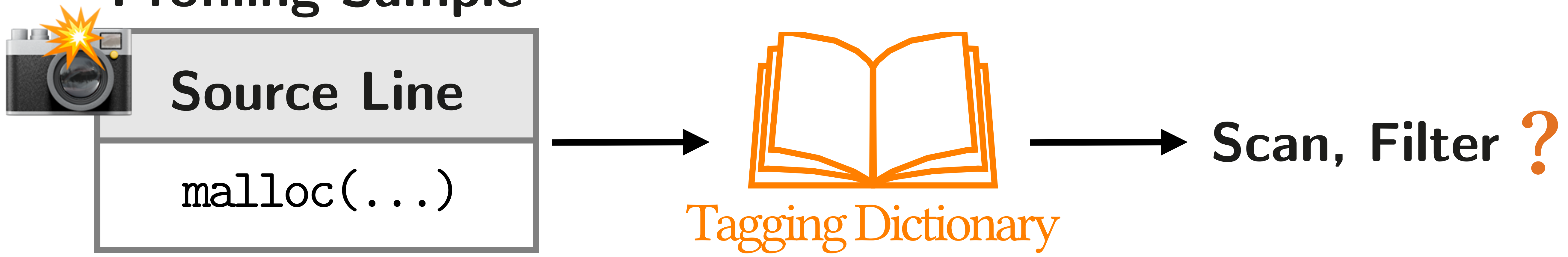
Profiling Sample

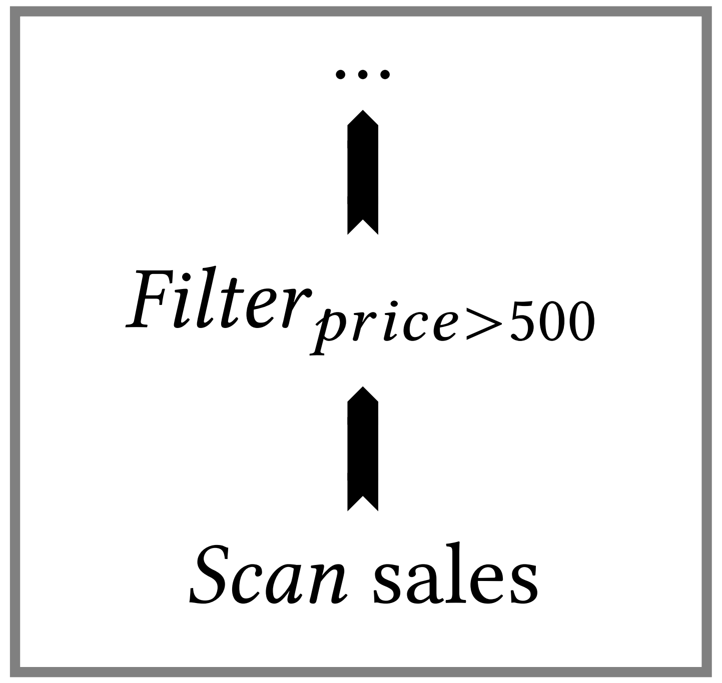


Source Line
malloc(...)

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



Generated Query Code

```
for each tuple t in sales
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```
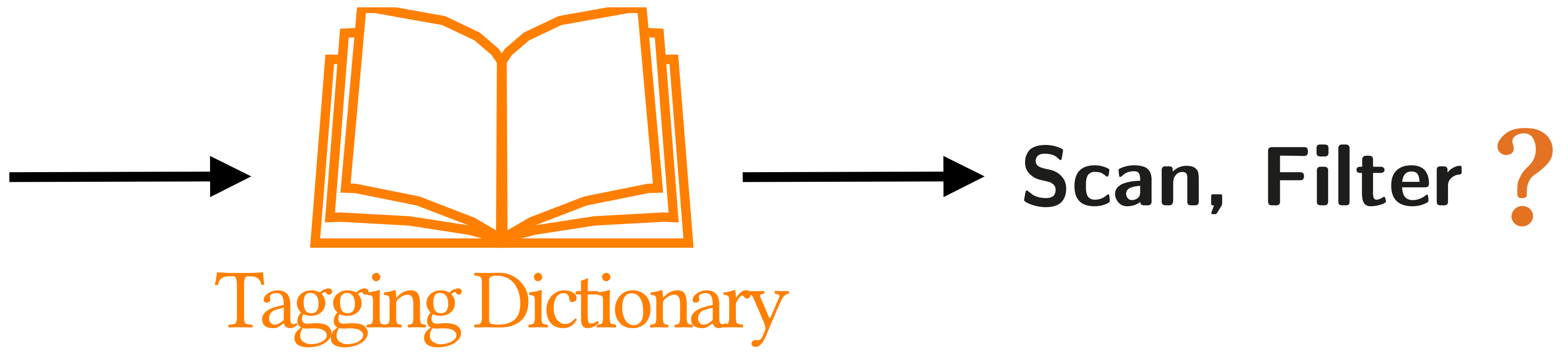

Call-Stack Sample

Recorded Call-Stack
malloc(...)
Scan: call malloc()
...

Profiling Sample

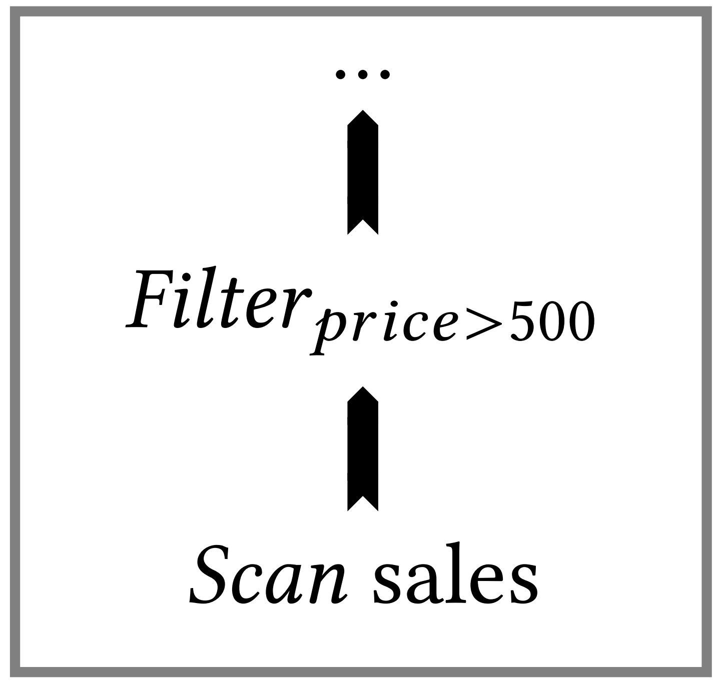
Source Line
malloc(...)



Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



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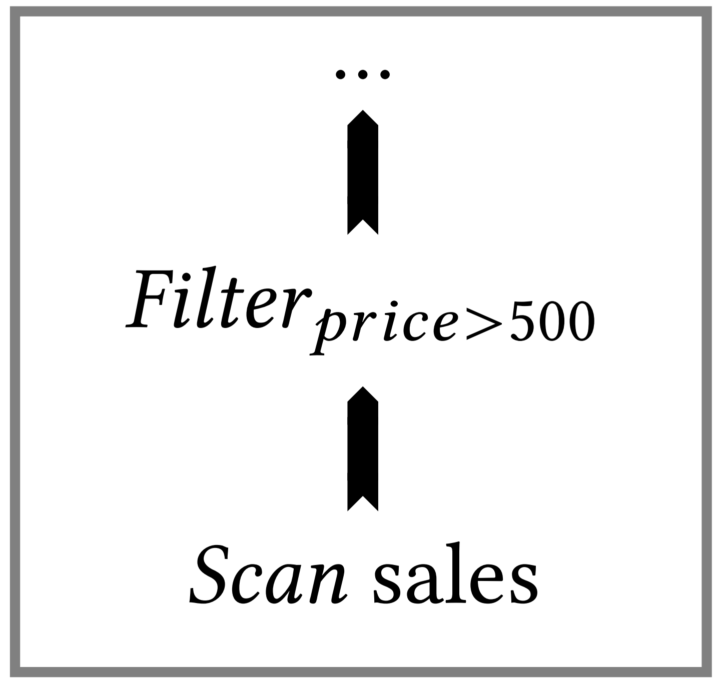
Machine Register

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



...

$Filter_{price>500}$

Scan sales

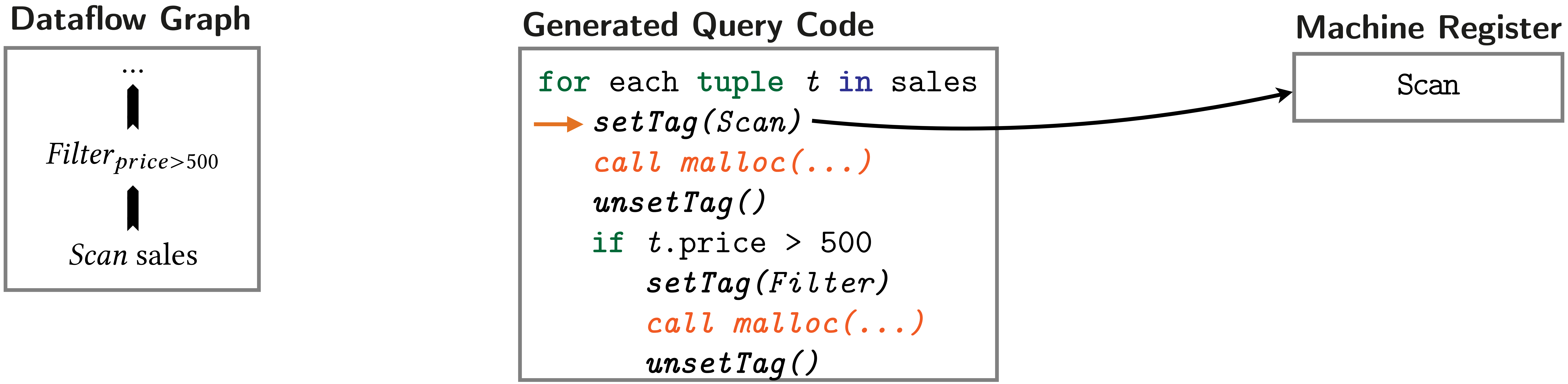
Generated Query Code

```
for each tuple t in sales
    setTag(Scan)
    call malloc(...)
    unsetTag()
    if t.price > 500
        setTag(Filter)
        call malloc(...)
        unsetTag()
```

Machine Register

Tailored Profiling

Tagging Dictionary and Register Tagging



Dataflow Graph

Generated Query Code

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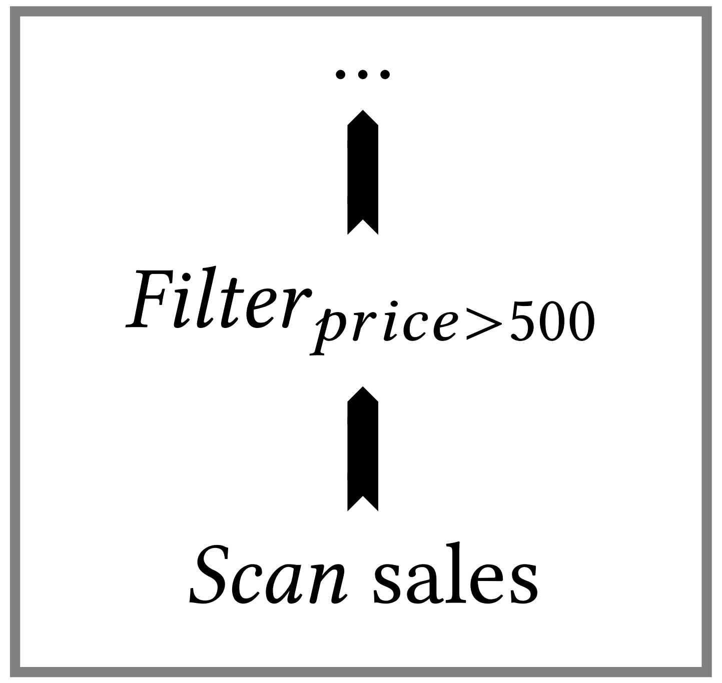
Machine Register

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



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Scan sales

Generated Query Code

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      setTag(Scan)
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          setTag(Filter)
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```

Machine Register

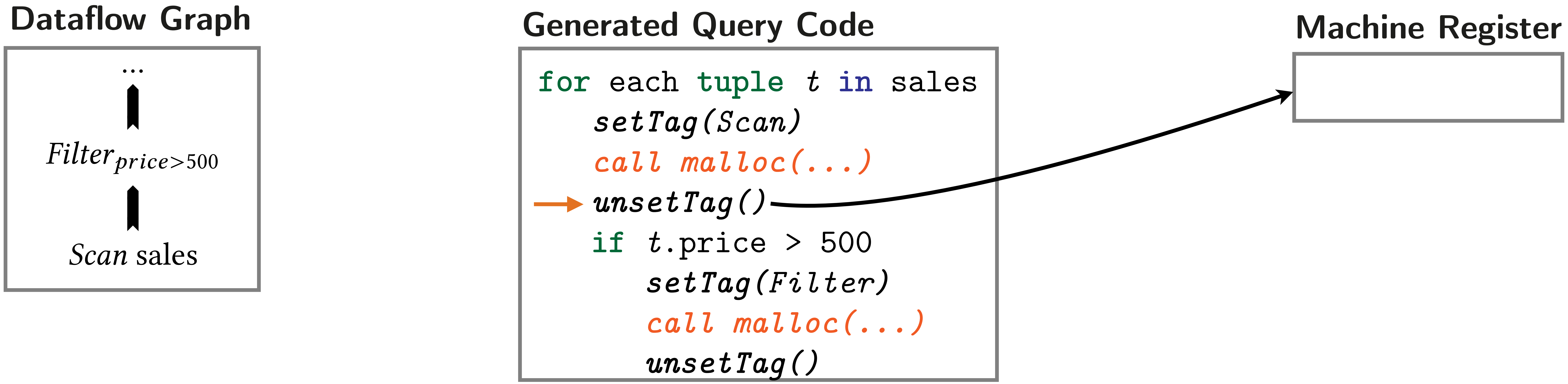
Scan

Profiling Sample

Source Line	Register Value
malloc(...)	Scan

Tailored Profiling

Tagging Dictionary and Register Tagging



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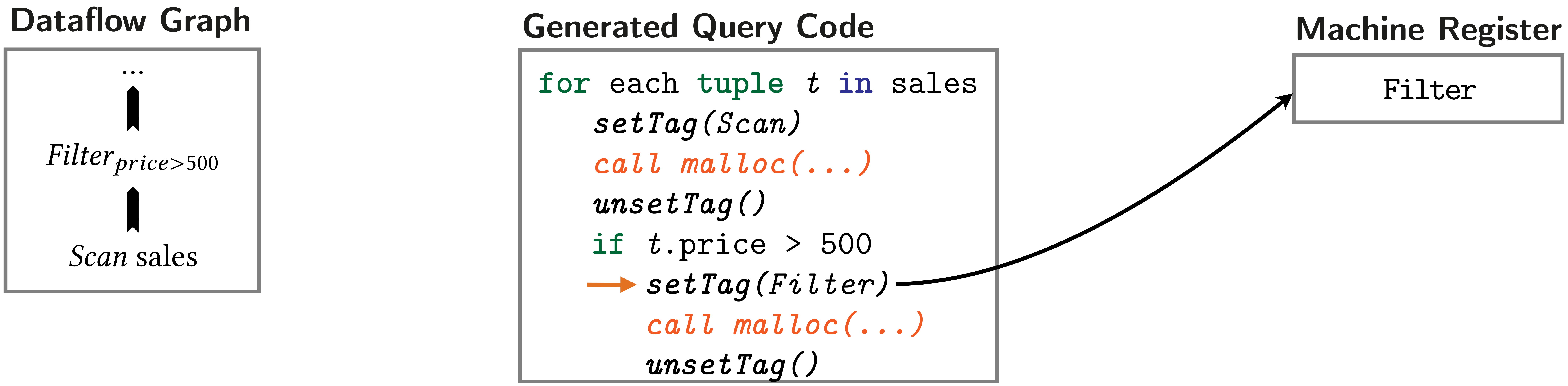
Tailored Profiling

Tagging Dictionary and Register Tagging



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       setTag(Filter)
       call malloc(...)
       unsetTag()
```
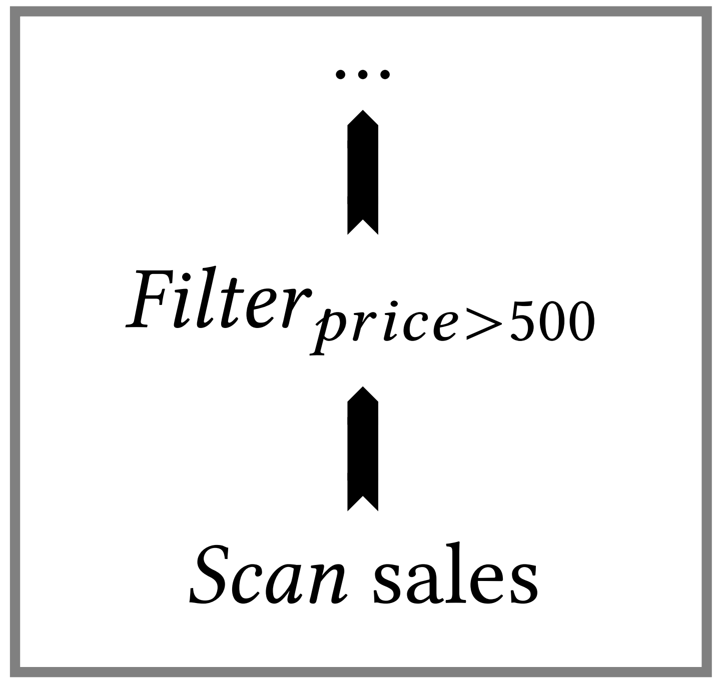

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph



Generated Query Code

```
for each tuple t in sales
    setTag(Scan)
    call malloc(...)
    unsetTag()
    if t.price > 500
        setTag(Filter)
    →   call malloc(...)
        unsetTag()
```

Machine Register

Filter

Profiling Sample

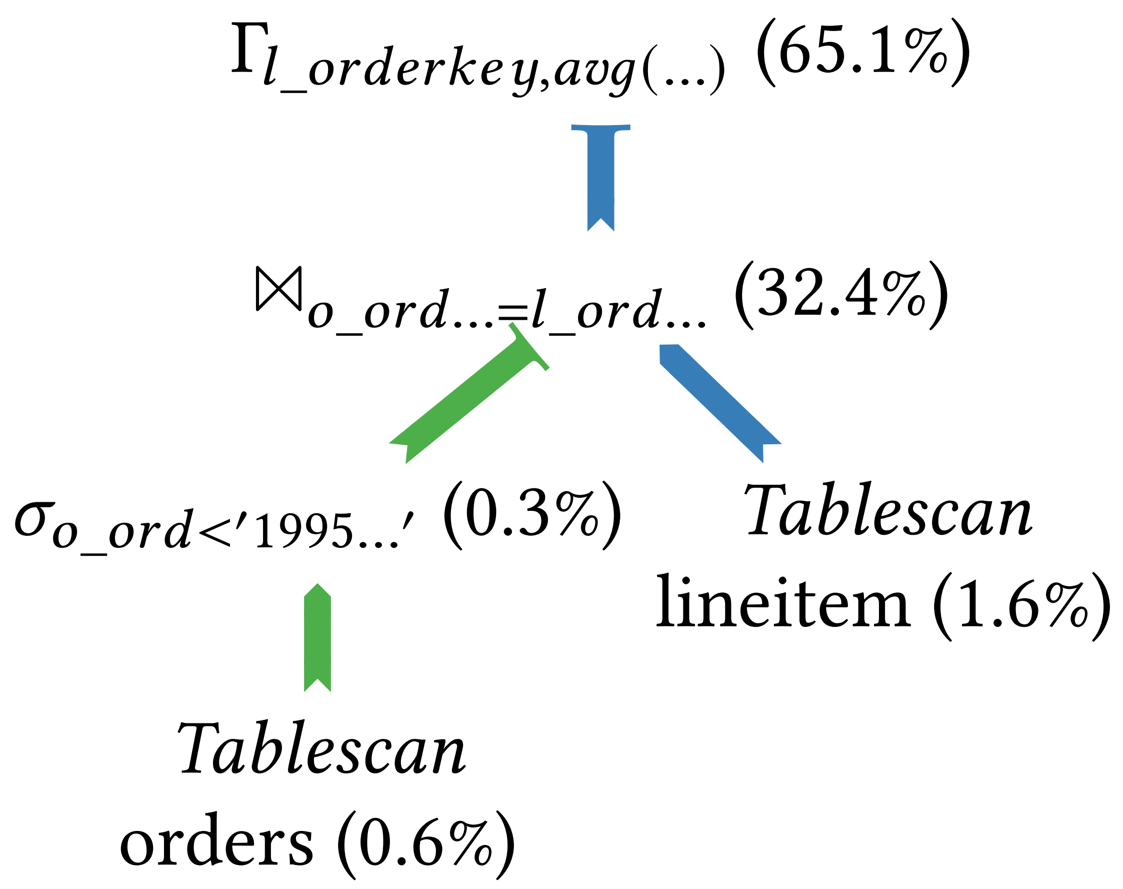
Source Line	Register Value
malloc(...)	Filter

Insights with Tailored Profiling

UMBRA

Insights with Tailored Profiling

UMBRA



$\Gamma_{l\_orderkey,avg(...)}$ (65.1%)

$\bowtie_{o\_ord...=l\_ord...}$ (32.4%)

$\sigma_{o\_ord<'1995...'}$ (0.3%)

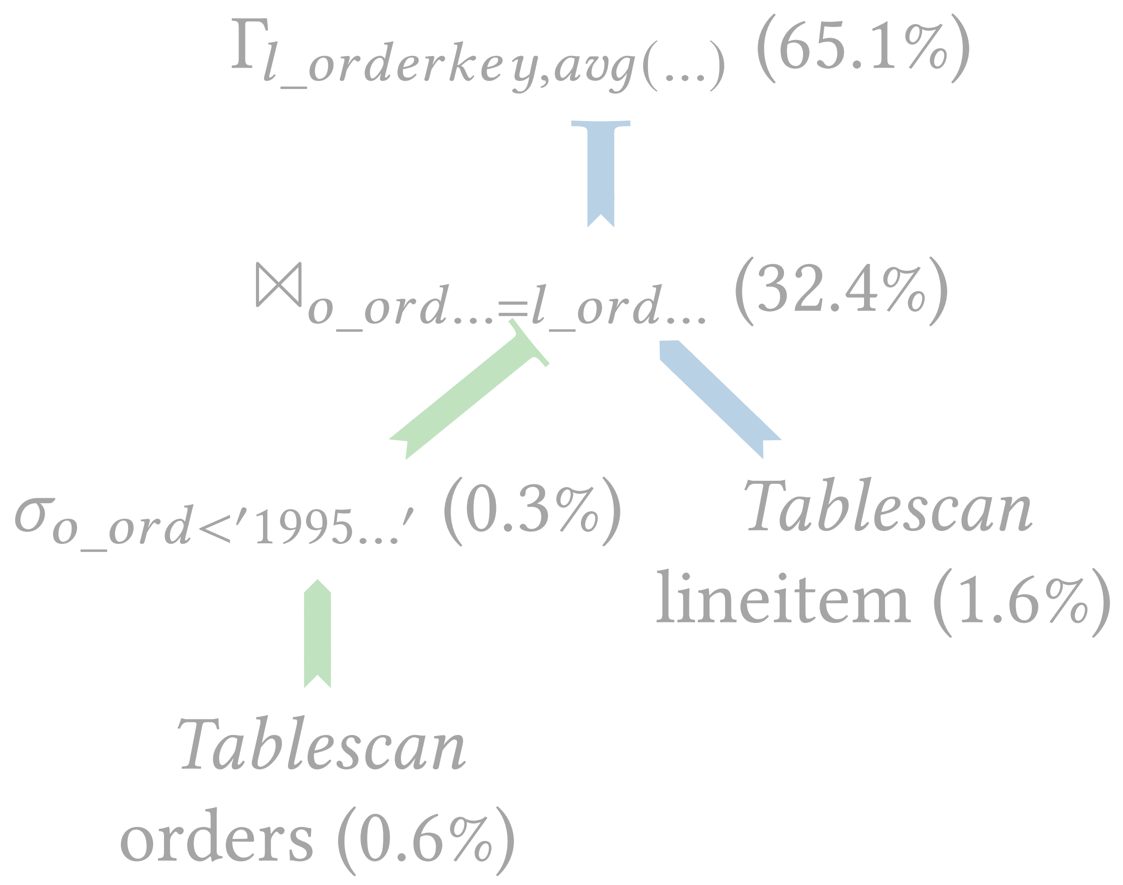
Tablescan lineitem (1.6%)

Tablescan orders (0.6%)

Time per operator

Insights with Tailored Profiling

UMBRA



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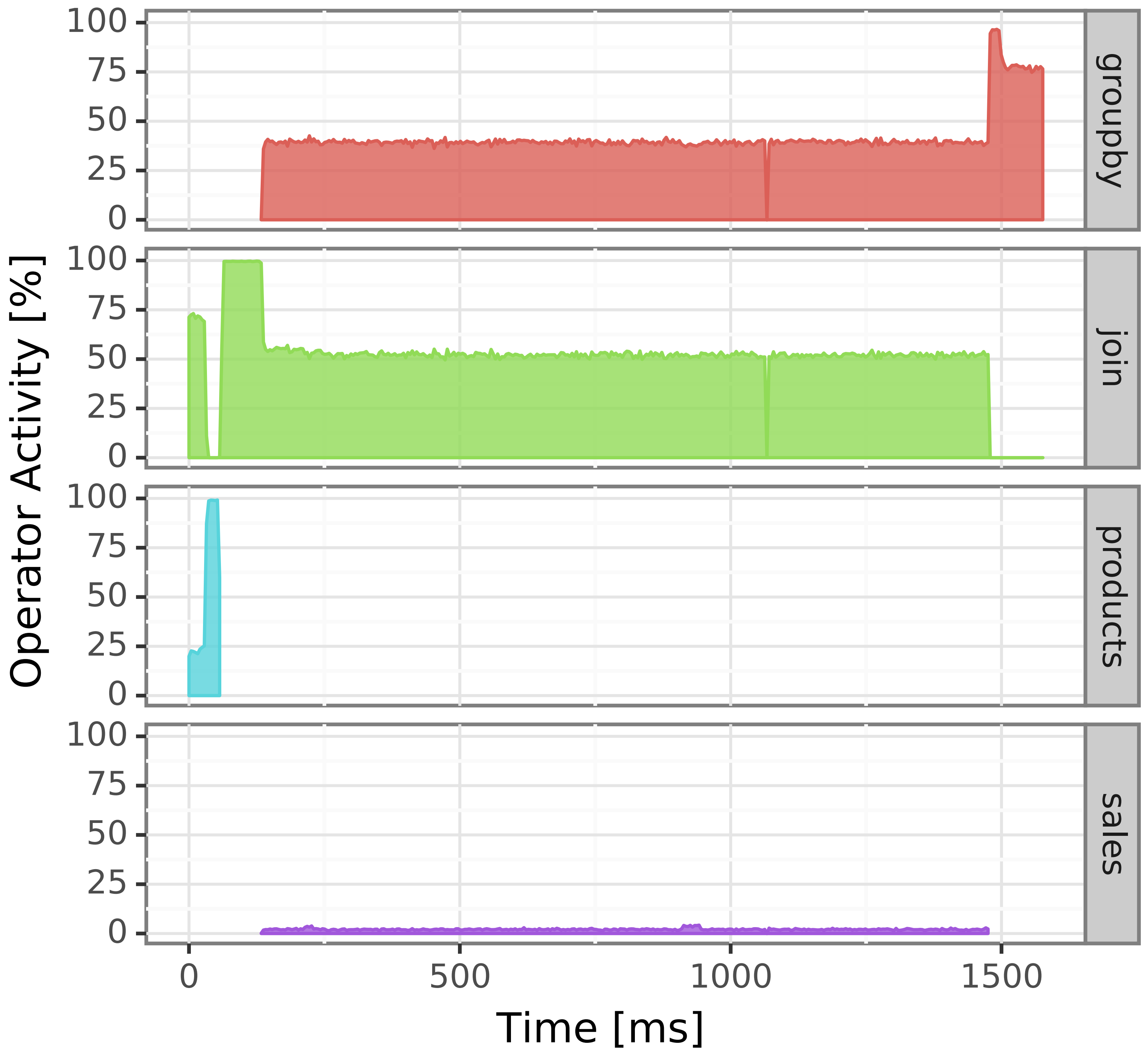
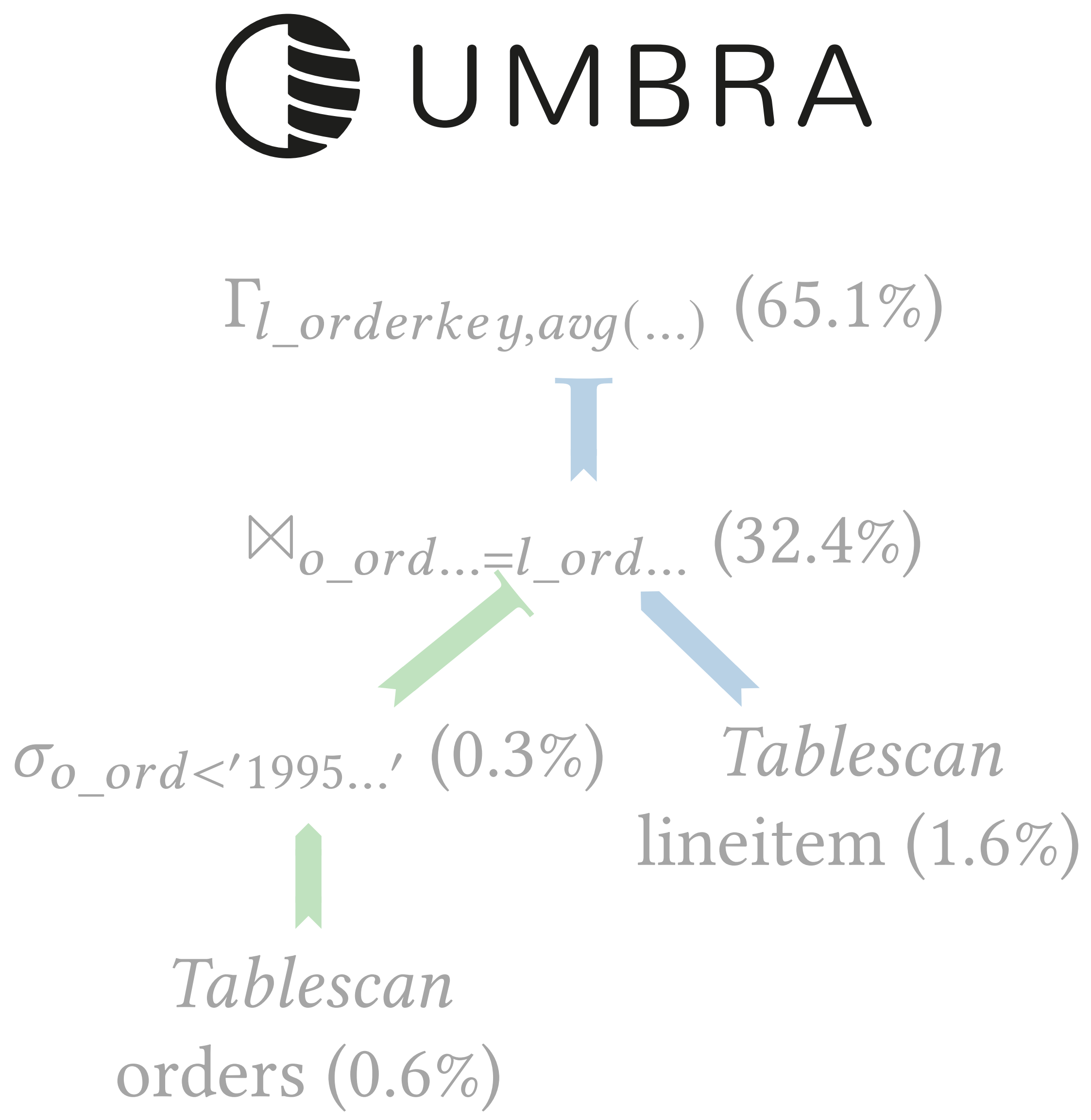


Time per operator

Context-aware profiling over time

Insights with Tailored Profiling



UMBRA

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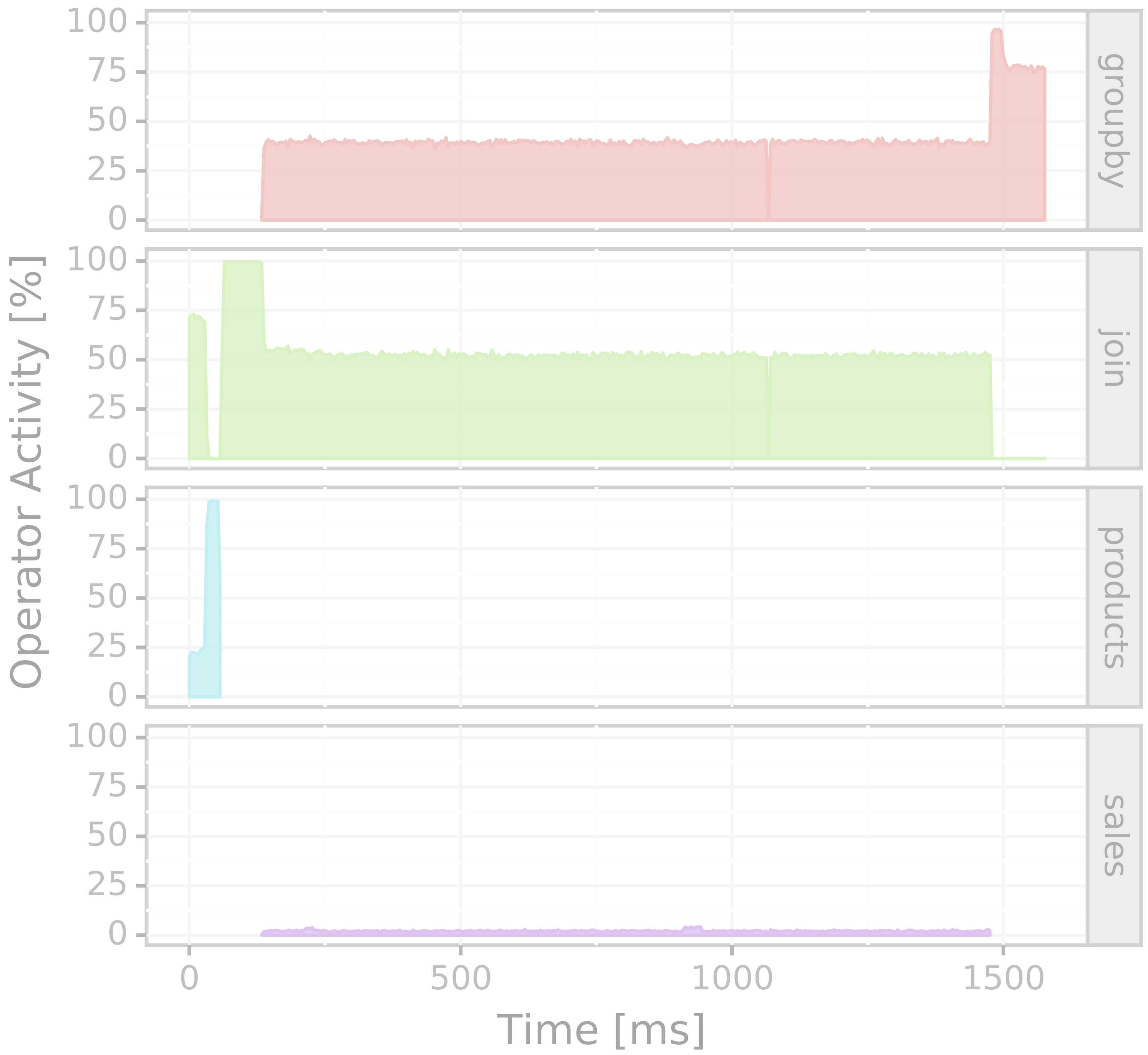
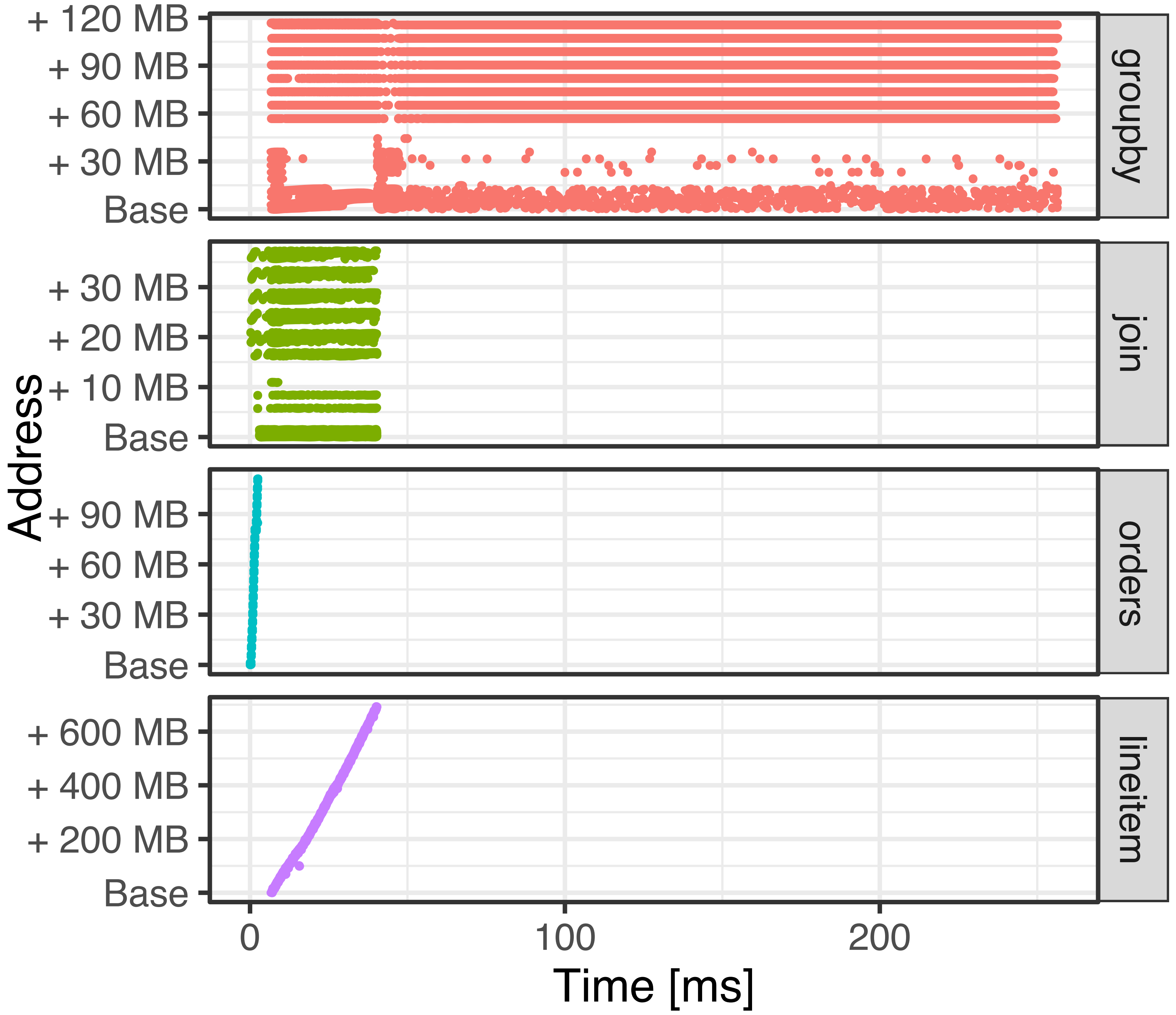


Context-aware profiling over time

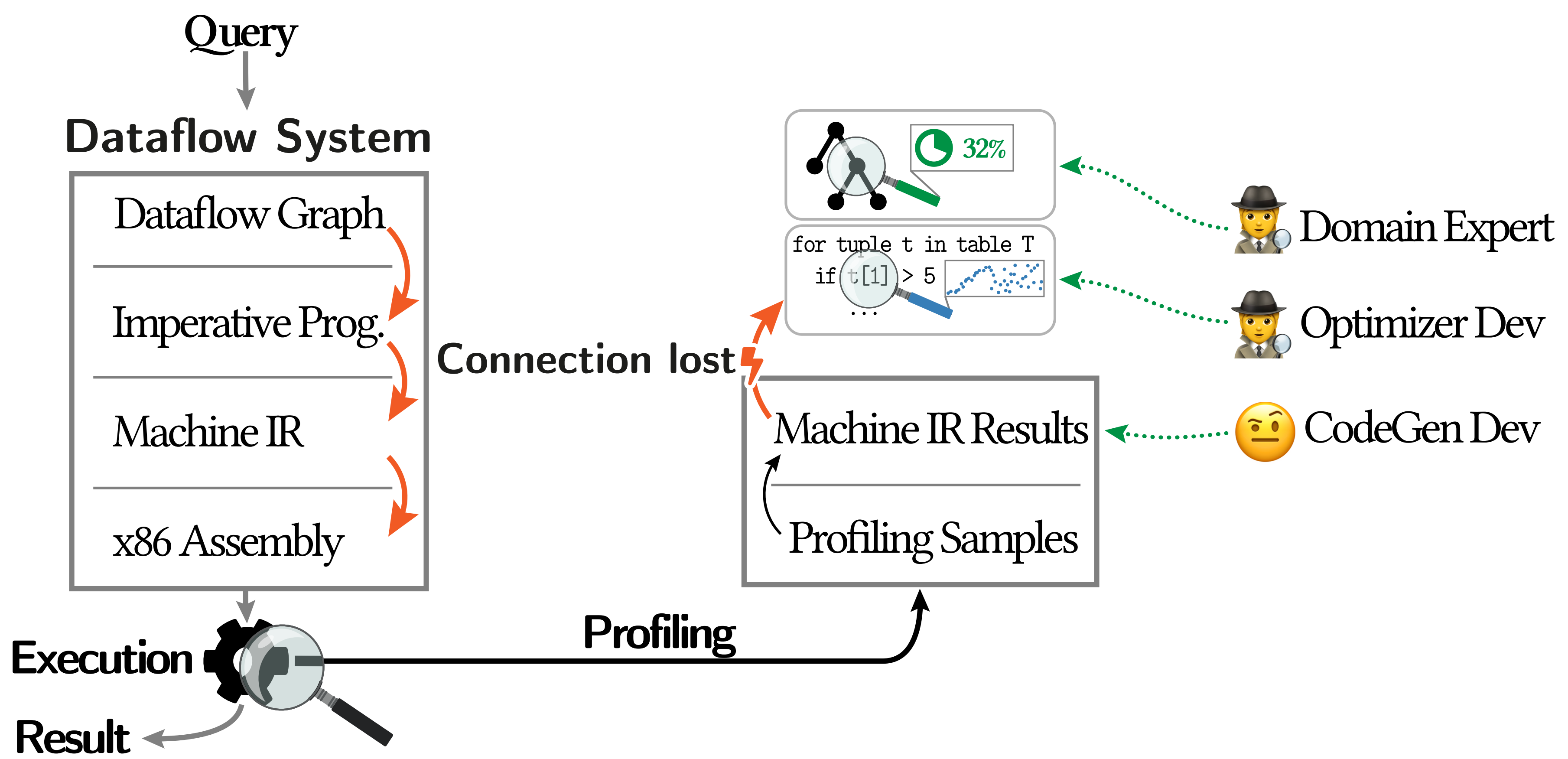


Memory access patterns

Impact of Tailored Profiling

Where can you apply it?

- Preserve connection information to close gap
- Profiling results on high abstraction levels

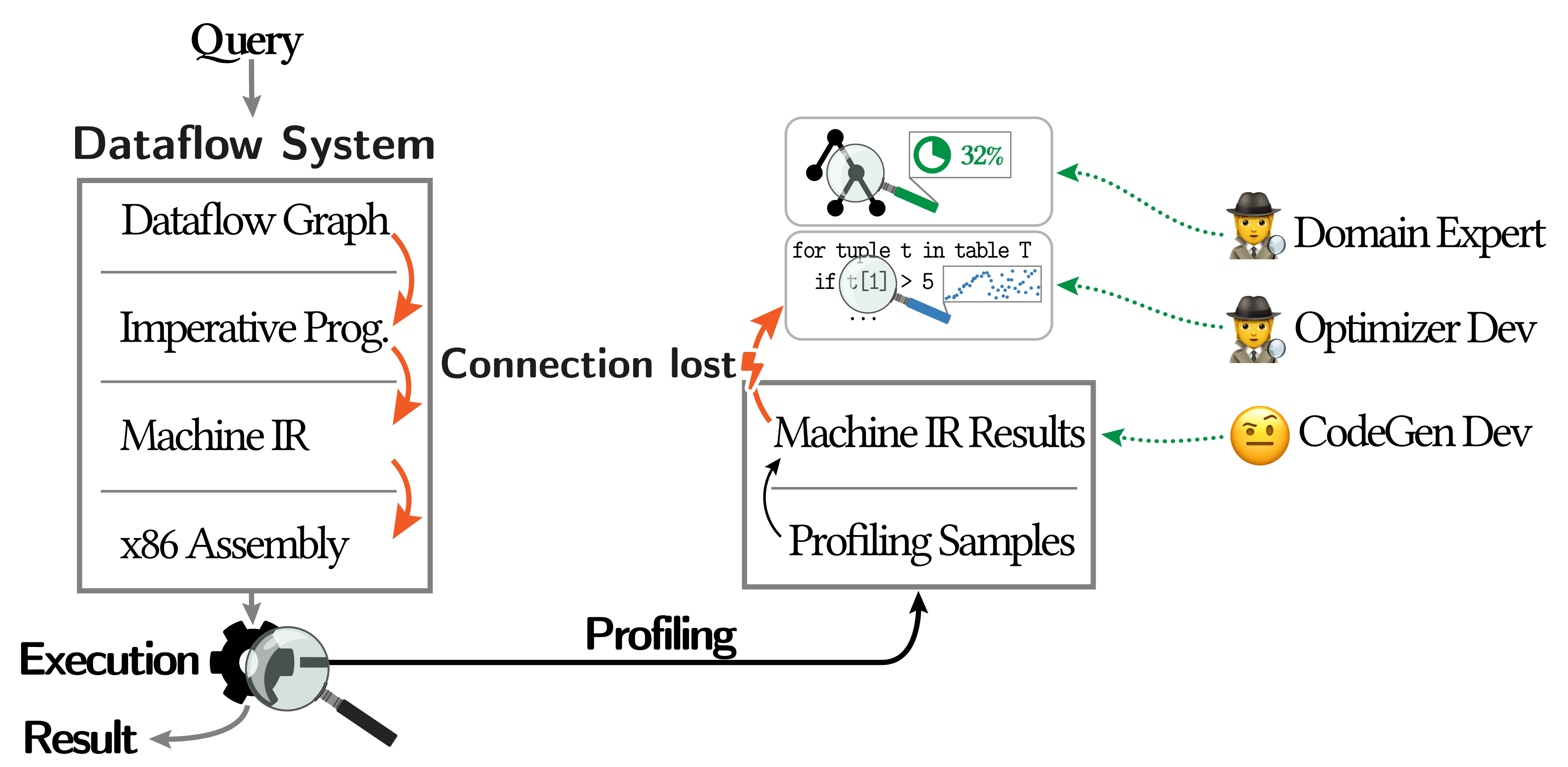


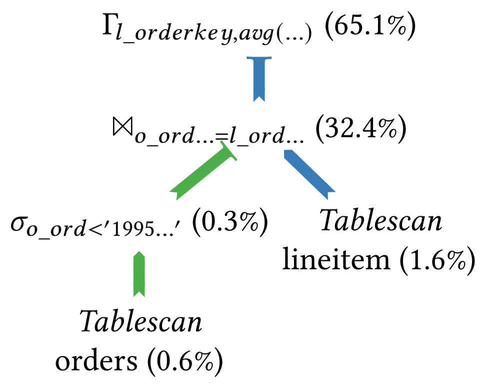
Impact of Tailored Profiling

Where can you apply it?

- Preserve connection information to close gap
- Profiling results on high abstraction levels

- Lightweight, high accuracy
- Easy to integrate
- Applicable to many systems

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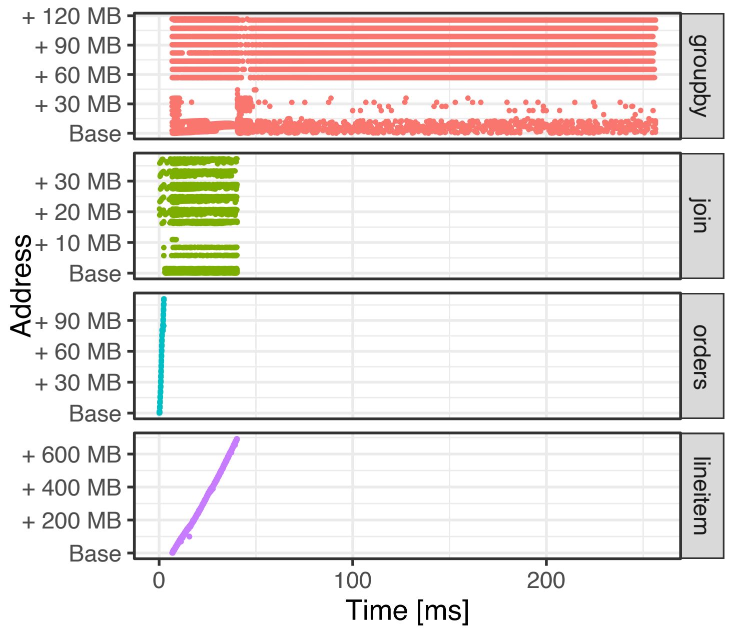
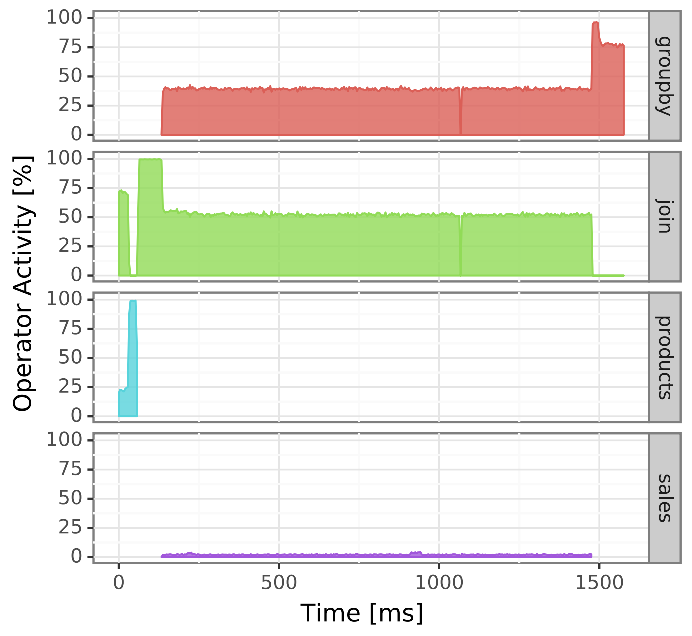




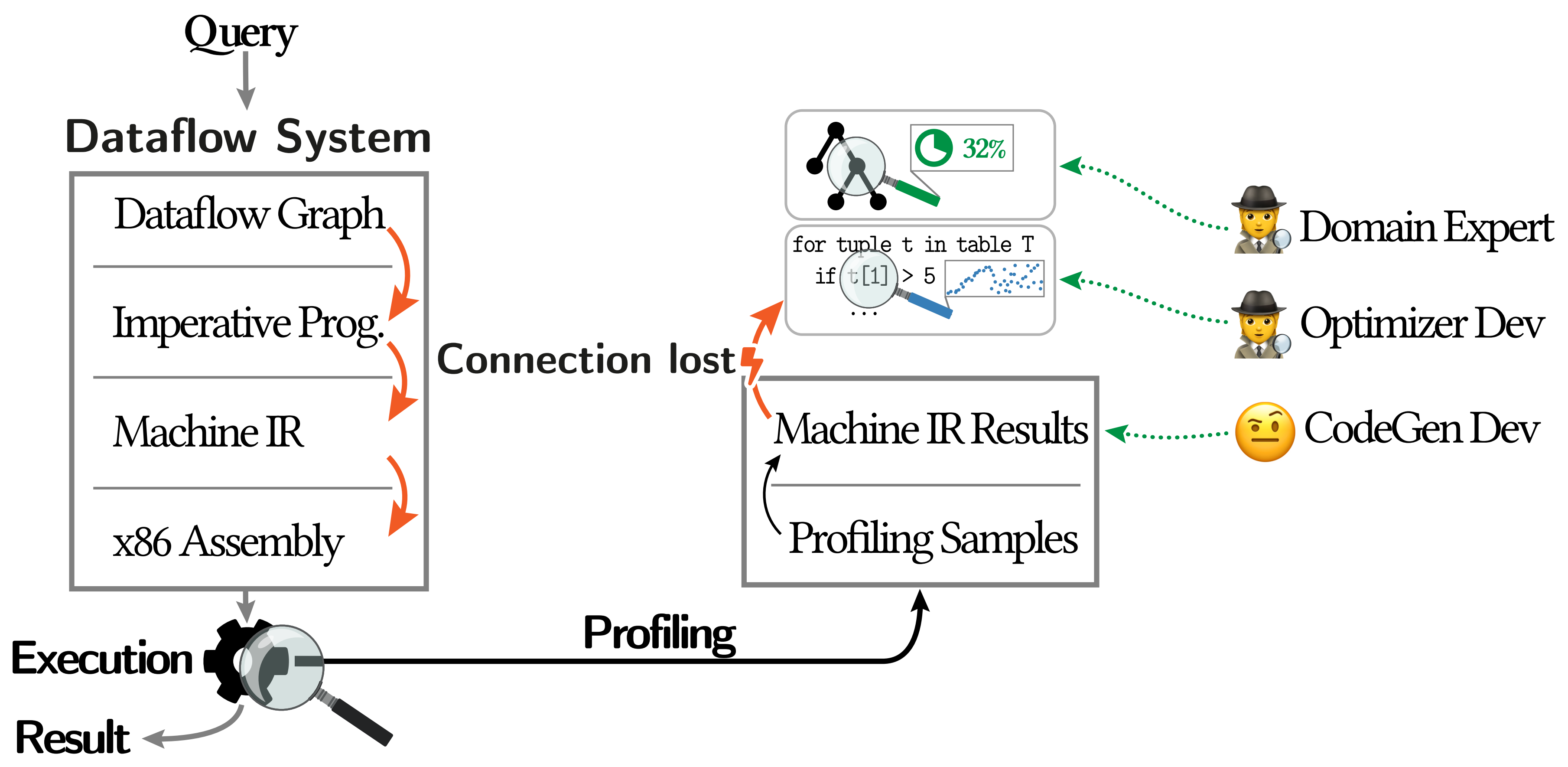
Impact of Tailored Profiling

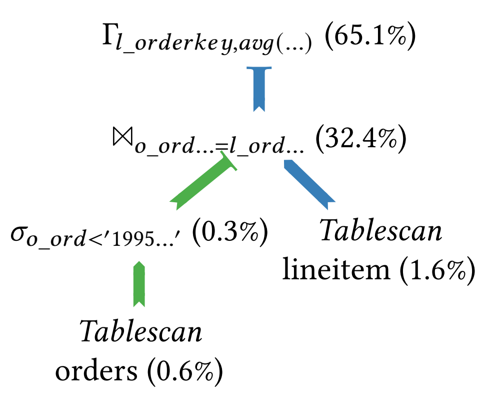
Where can you apply it?

- Preserve connection information to close gap
- Profiling results on high abstraction levels

- Lightweight, high accuracy
- Easy to integrate
- Applicable to many systems

- *Already supported:* profiling code on CPUs (multi-socket and multicore)
- *Future work:* heterogenous compute resources, distributed systems

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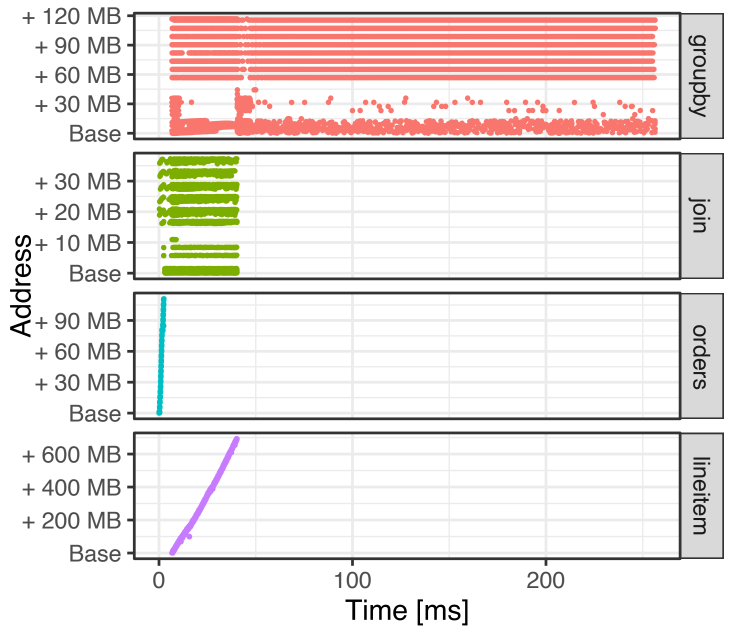

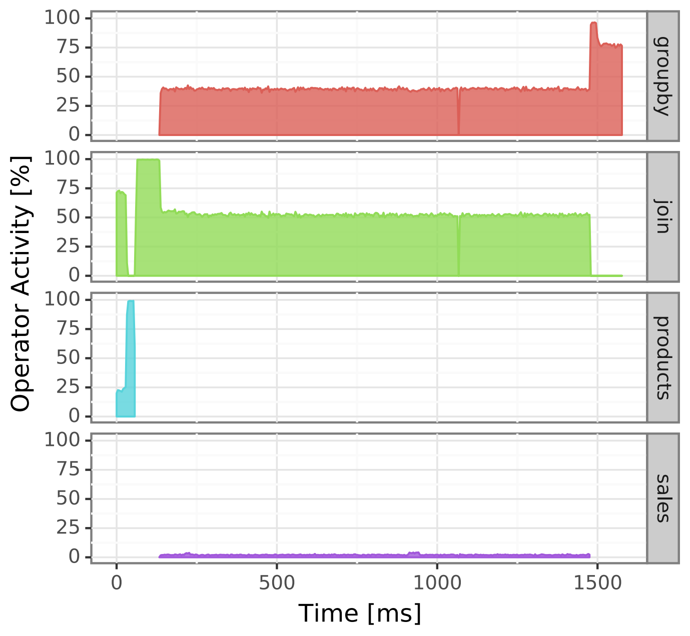

Thank you for watching!