Profiling Dataflow Systems on Multiple Abstraction Levels

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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")
```

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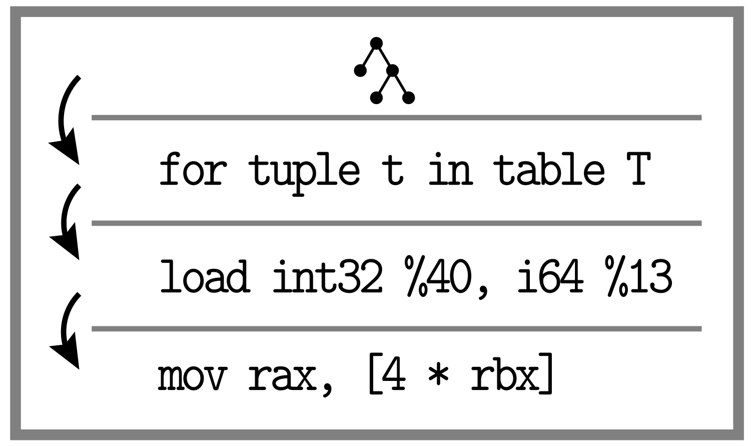
Dataflow System



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Profiling a Compiling Dataflow System

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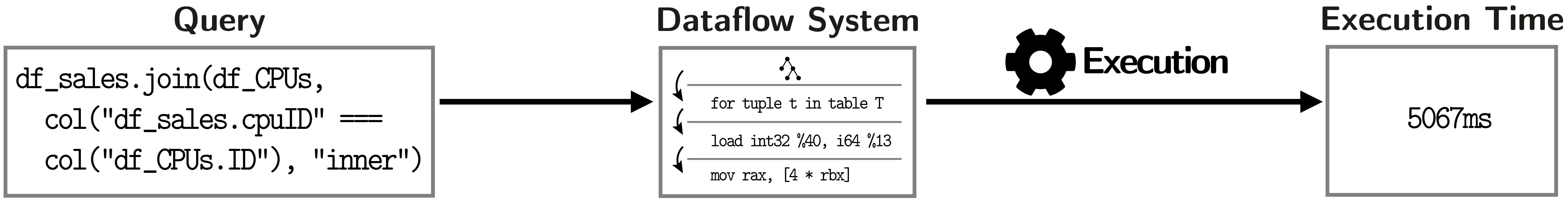

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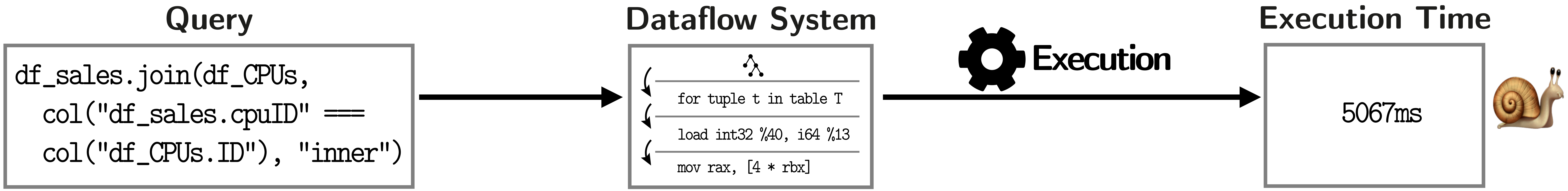

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Trying to optimize the system

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df_sales.join(df_CPUs,
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```

Dataflow System

```
for tuple t in table T
load int32 %40, i64 %13
mov rax, [4 * rbx]
```

Execution

Execution Time

5067ms

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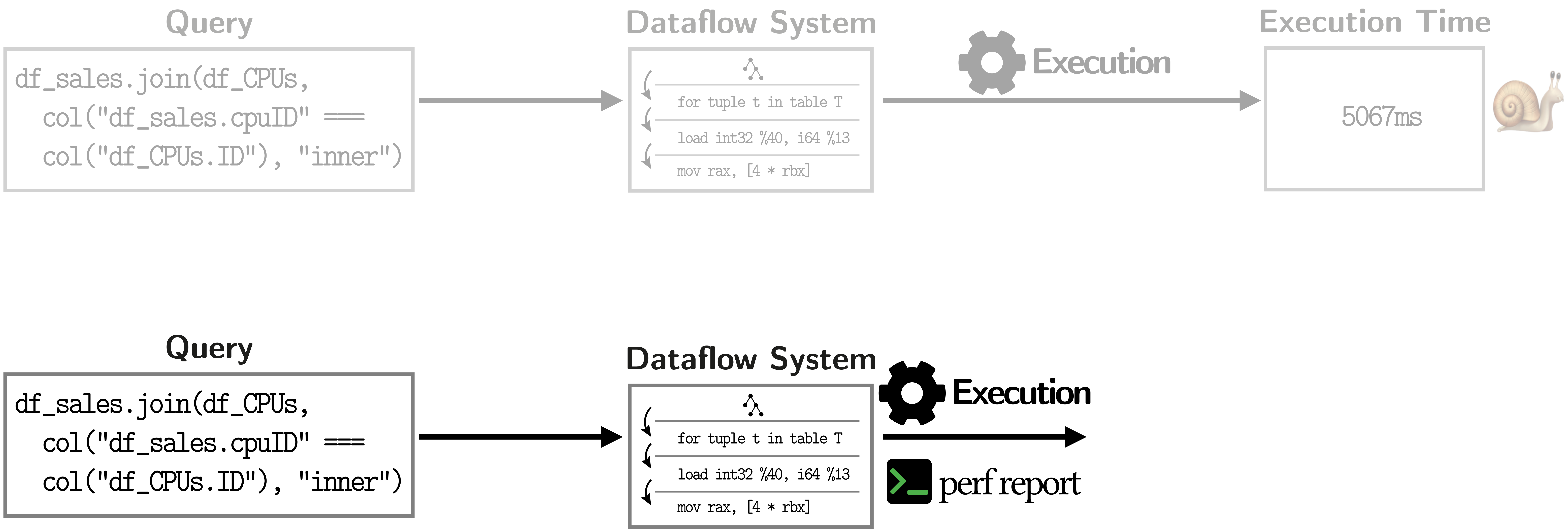

Profiling a Compiling Dataflow System

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Execution

perf report

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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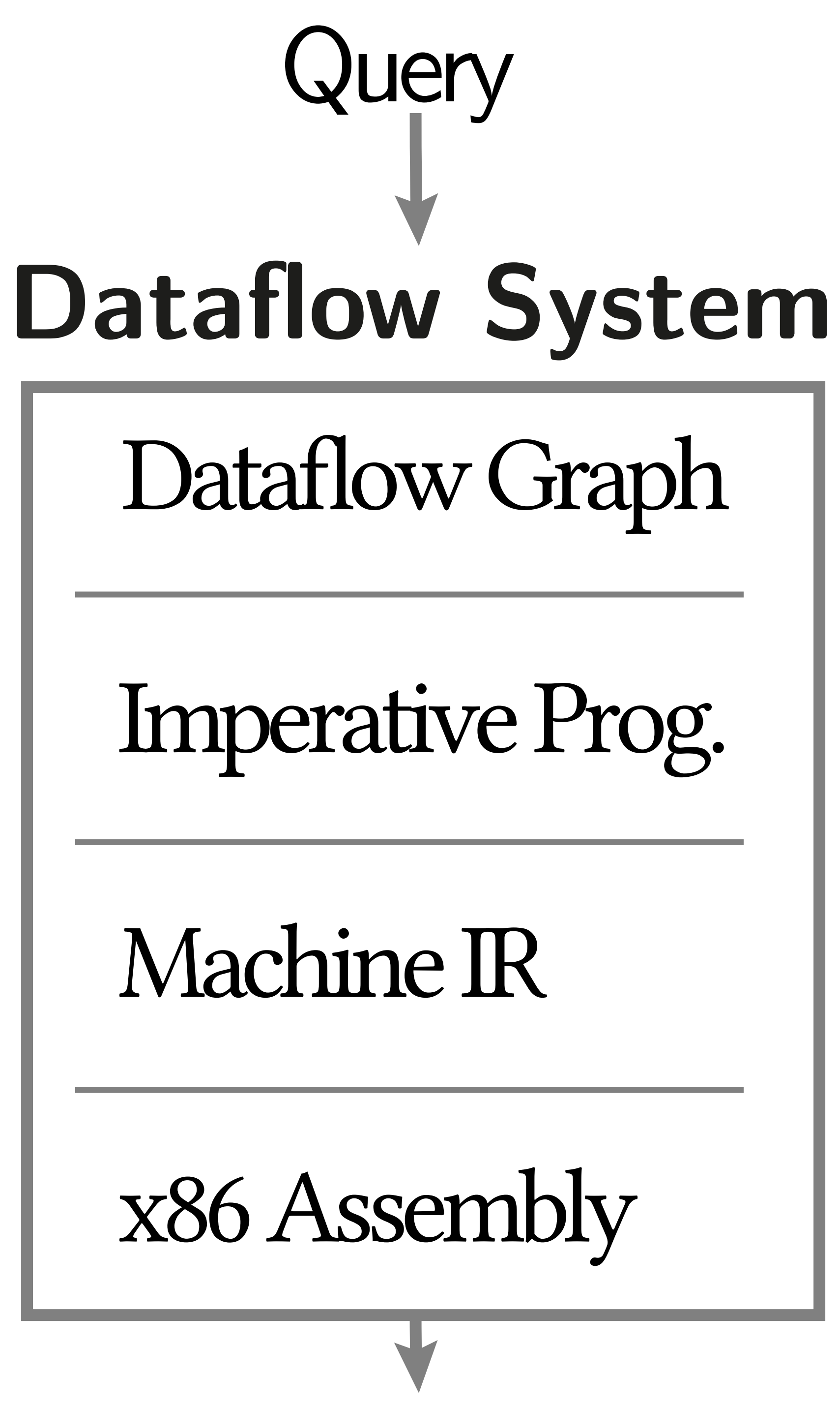
Why do we have this problem?

Identifying the gap



Why do we have this problem?

Identifying the gap

Query

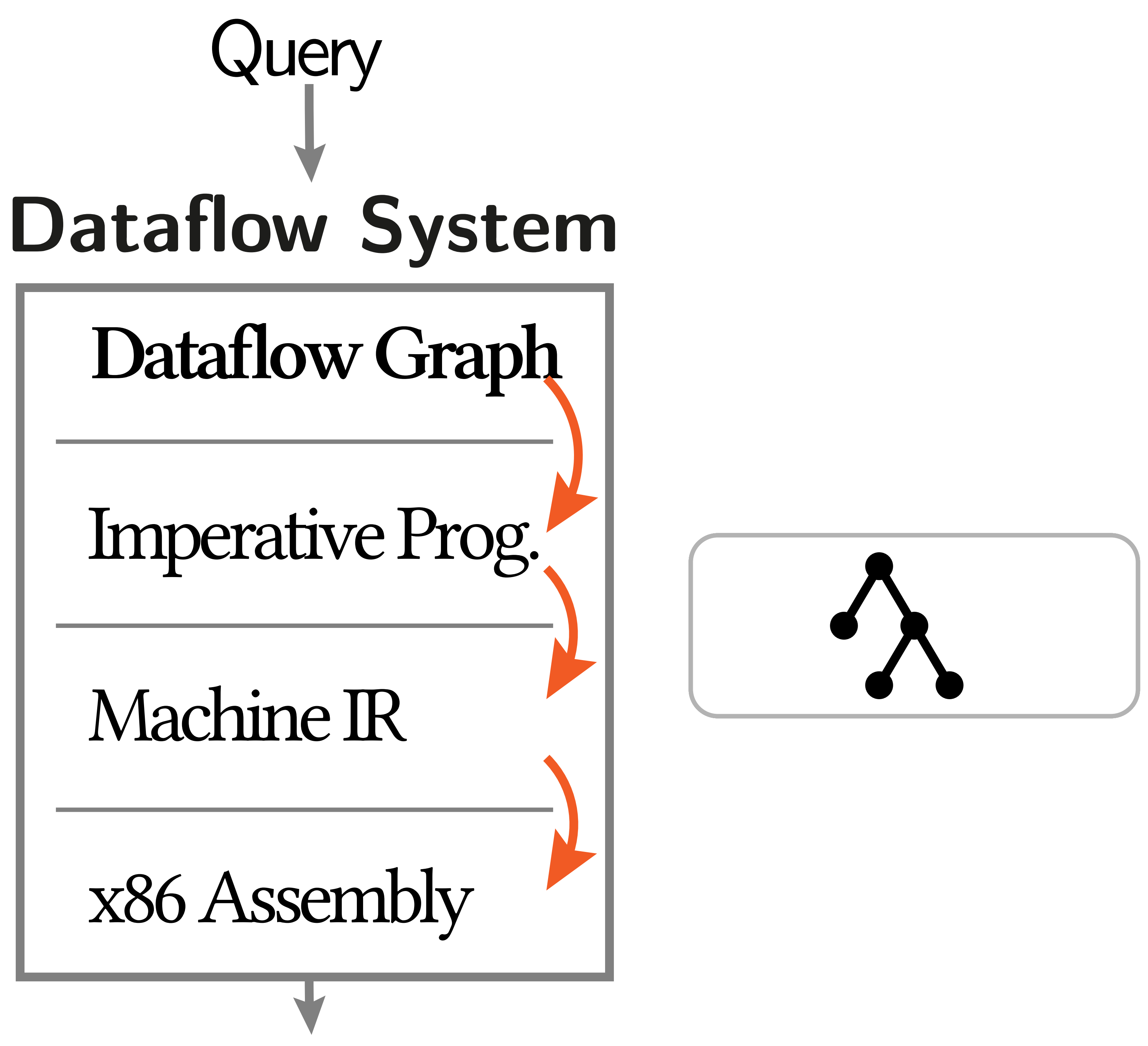
Dataflow System

Dataflow Graph
Imperative Prog.
Machine IR
x86 Assembly

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

Why do we have this problem?

Identifying the gap



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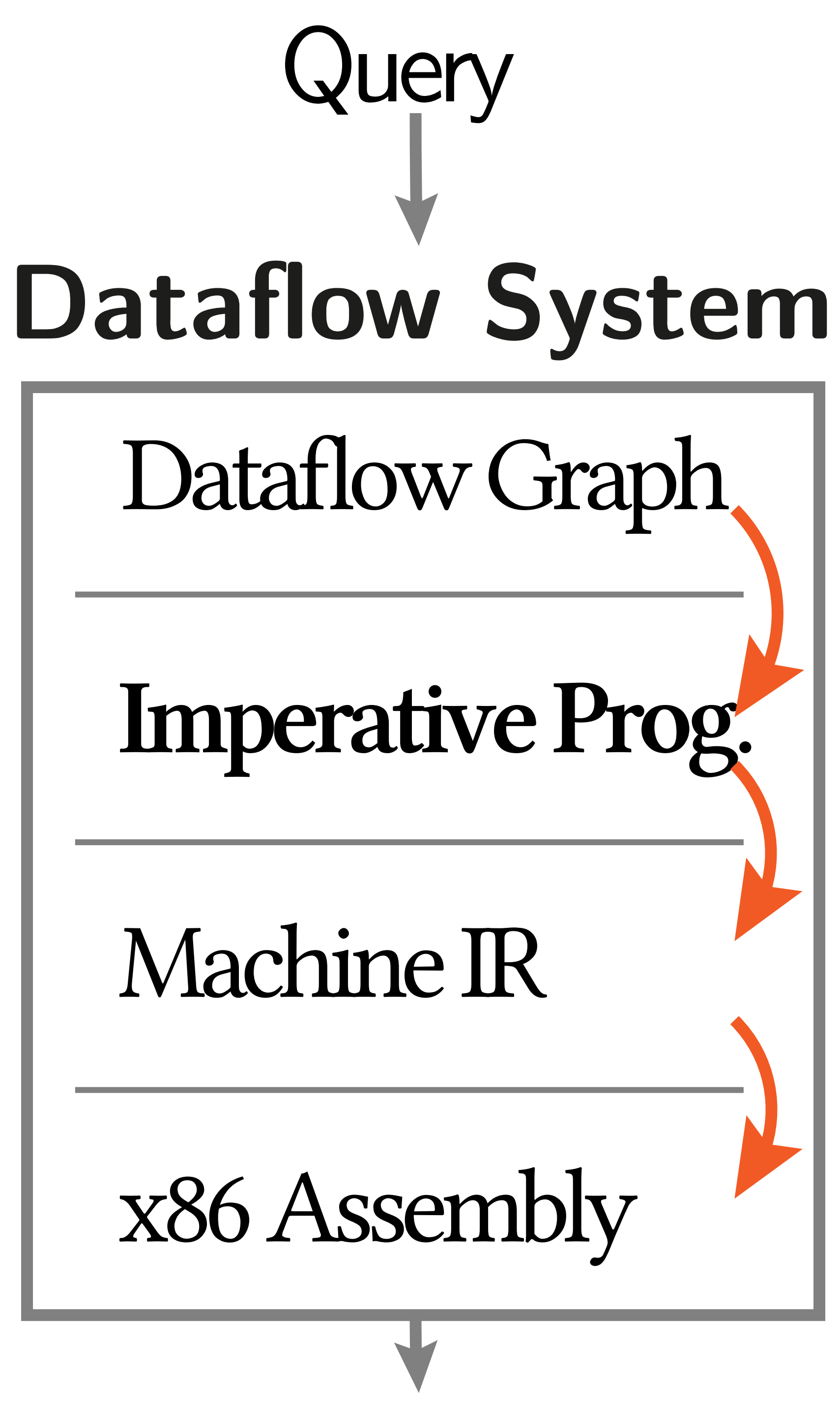
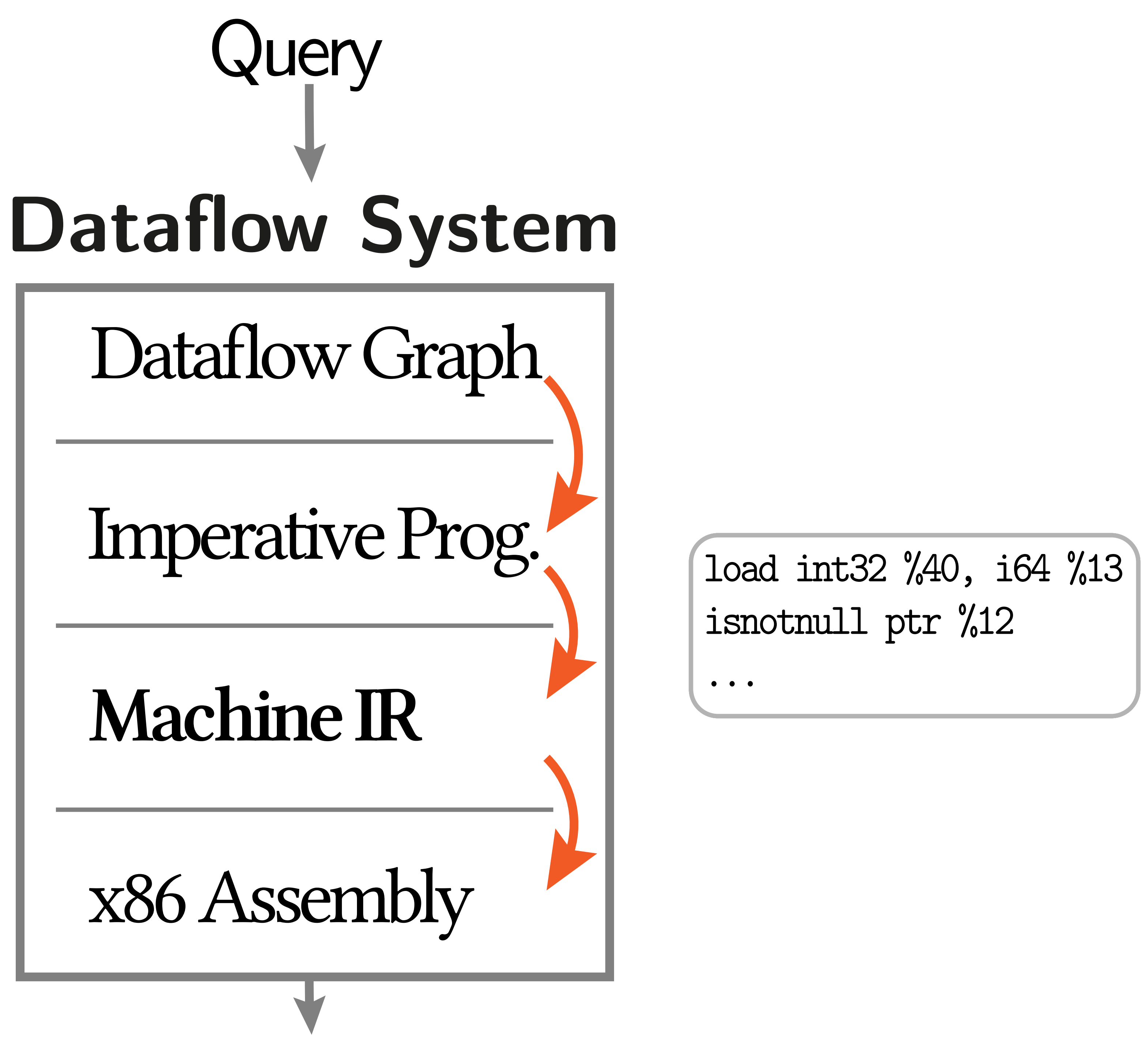



```
for tuple t in table T
  if t[1] > 5
    ...
```

Why do we have this problem?

Identifying the gap



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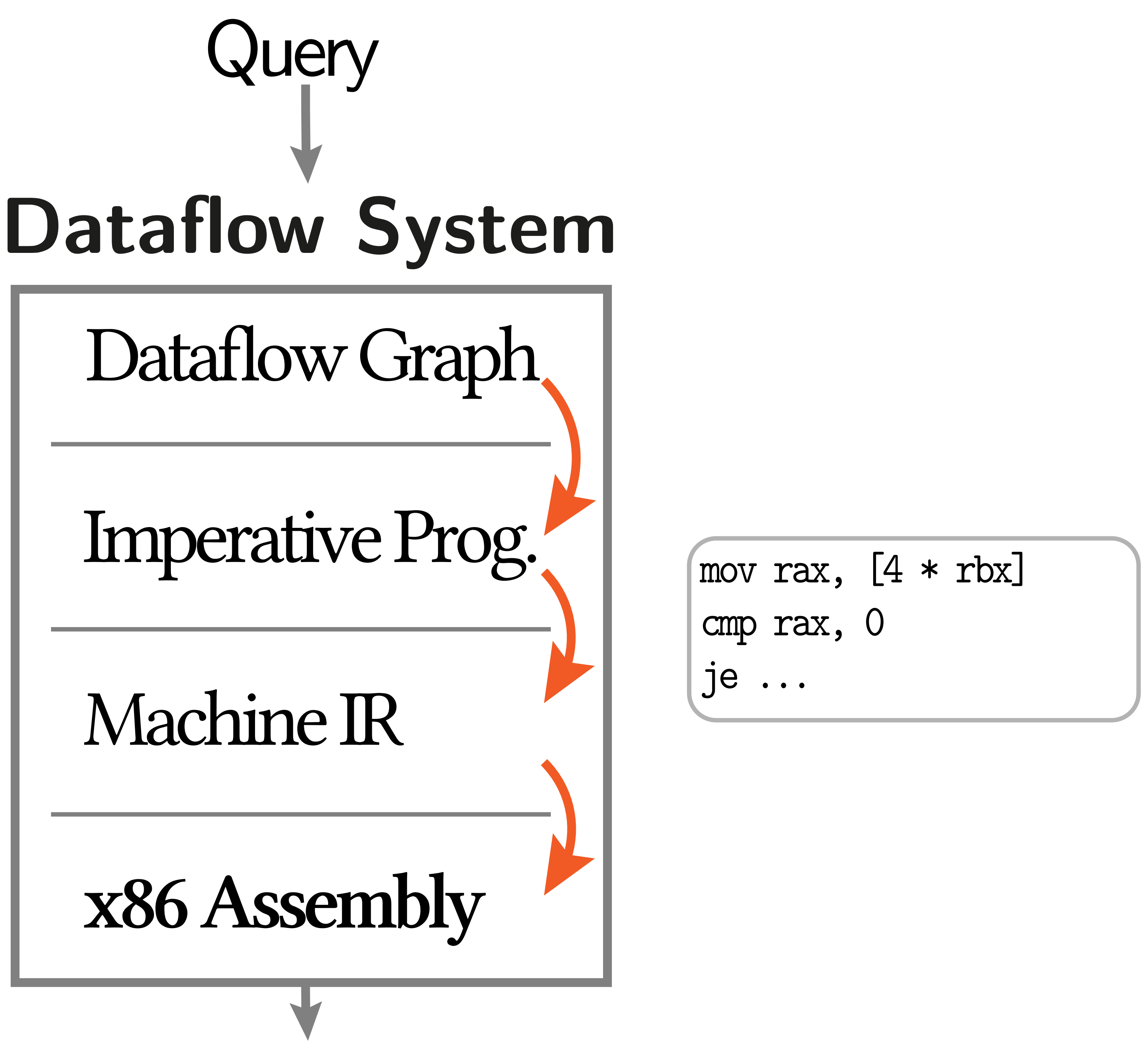

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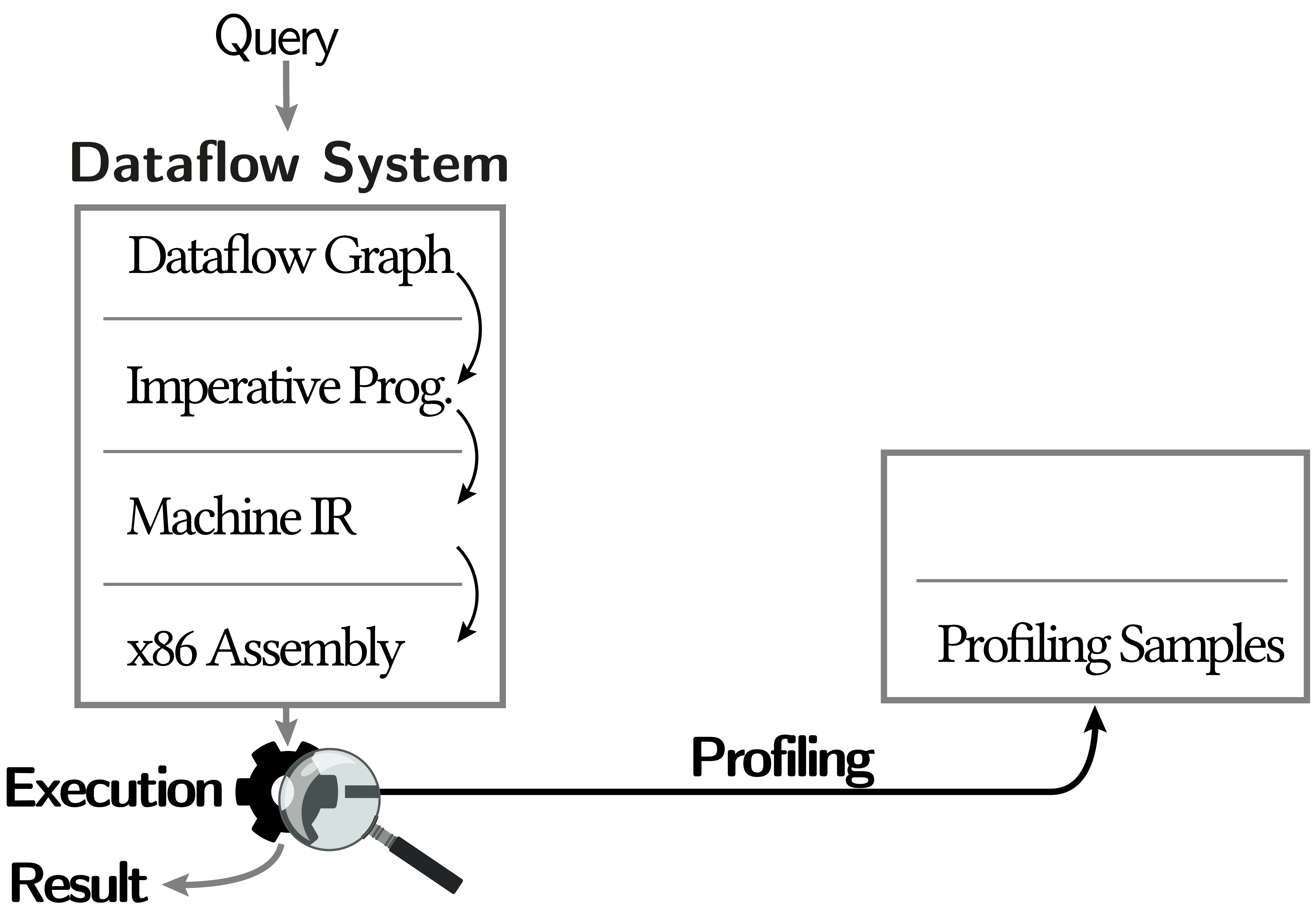

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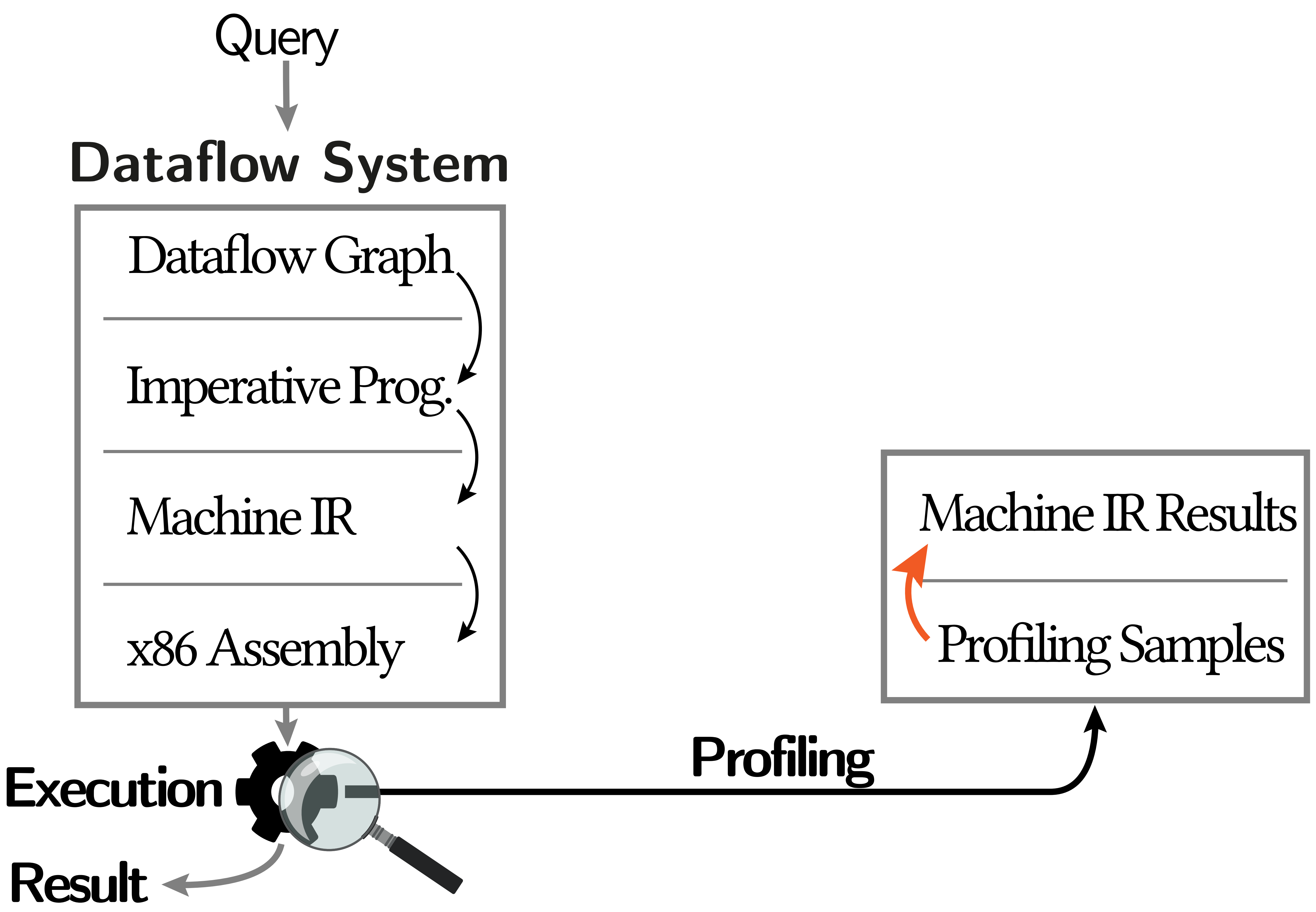

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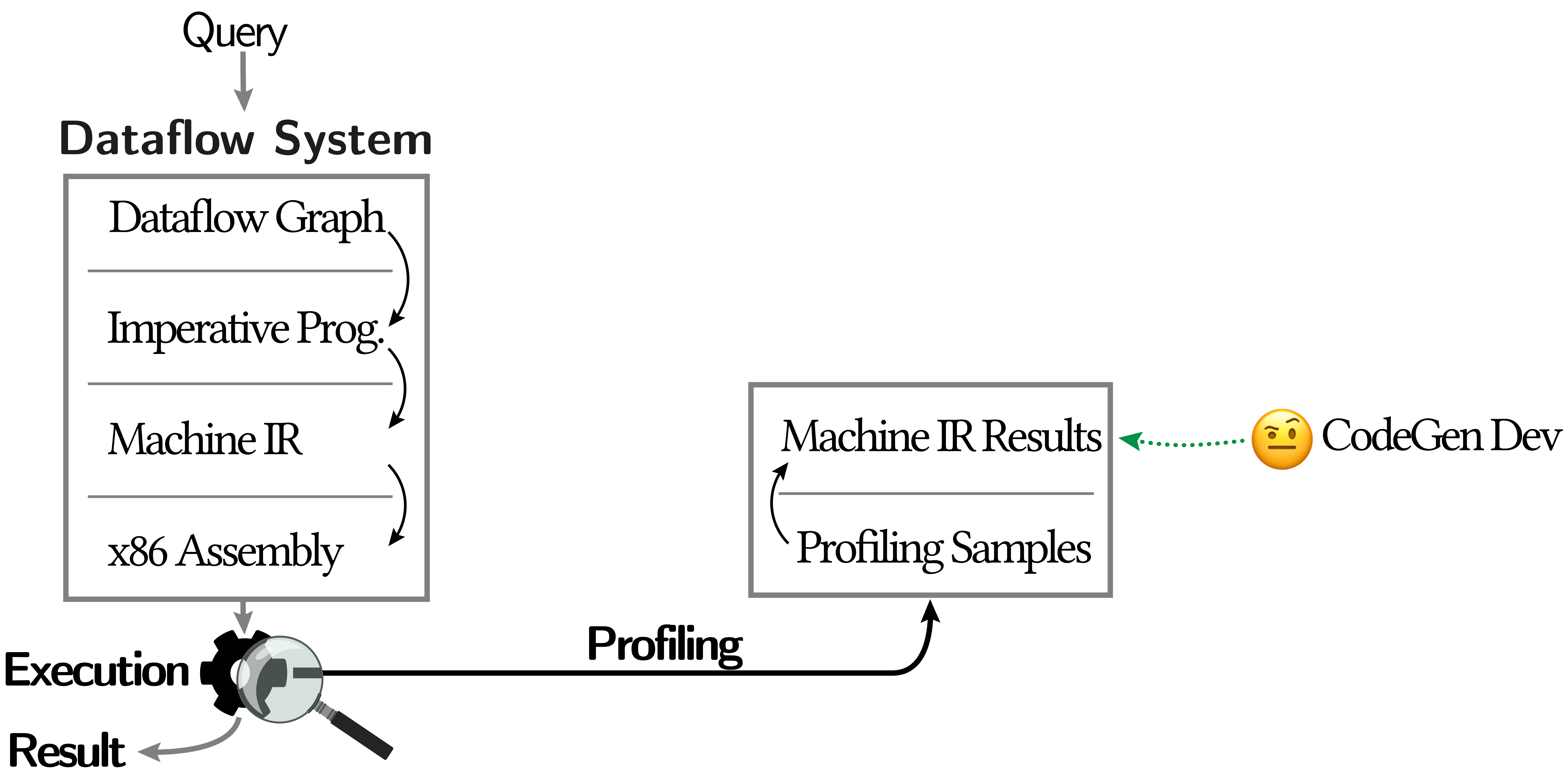

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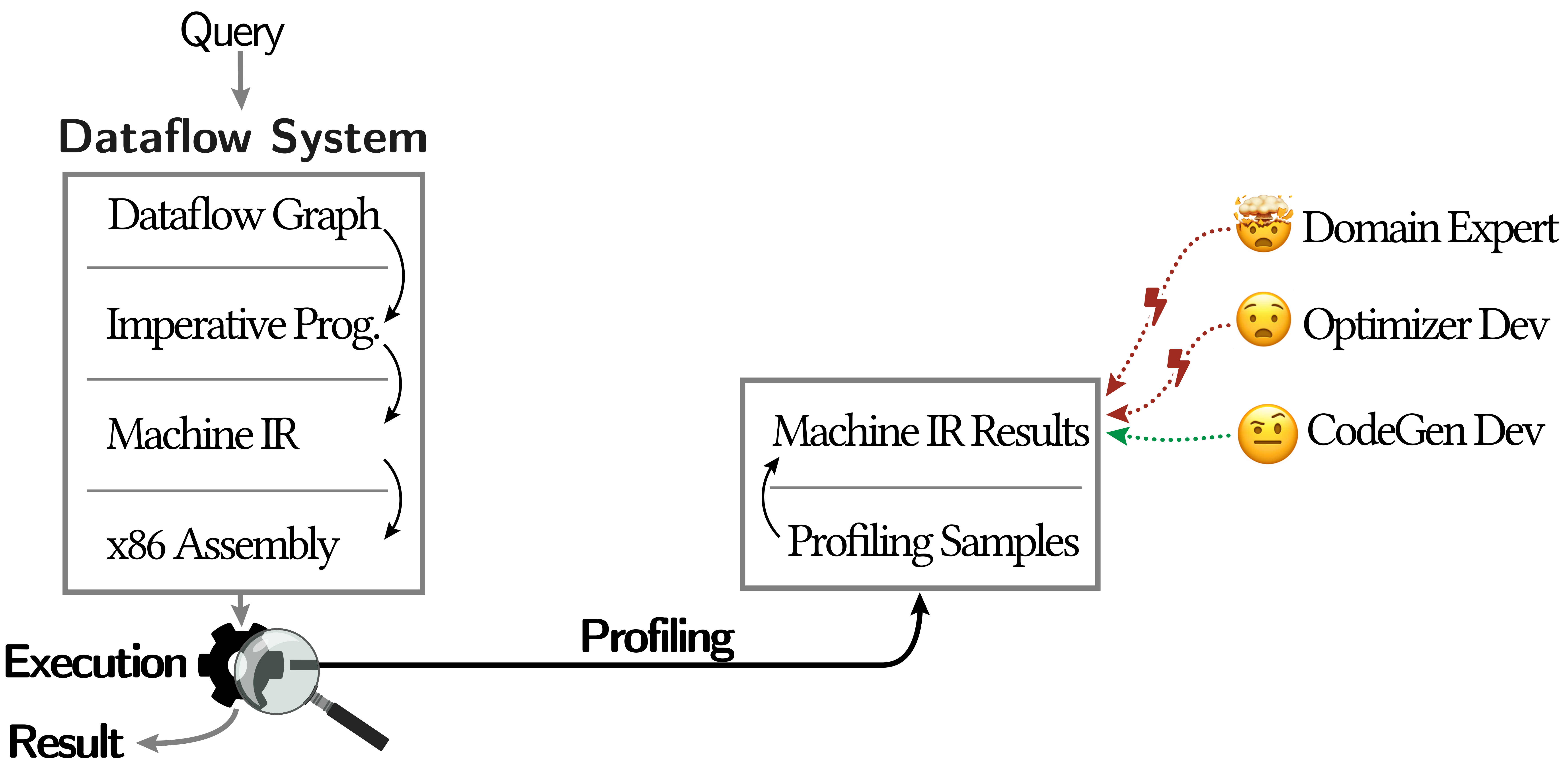

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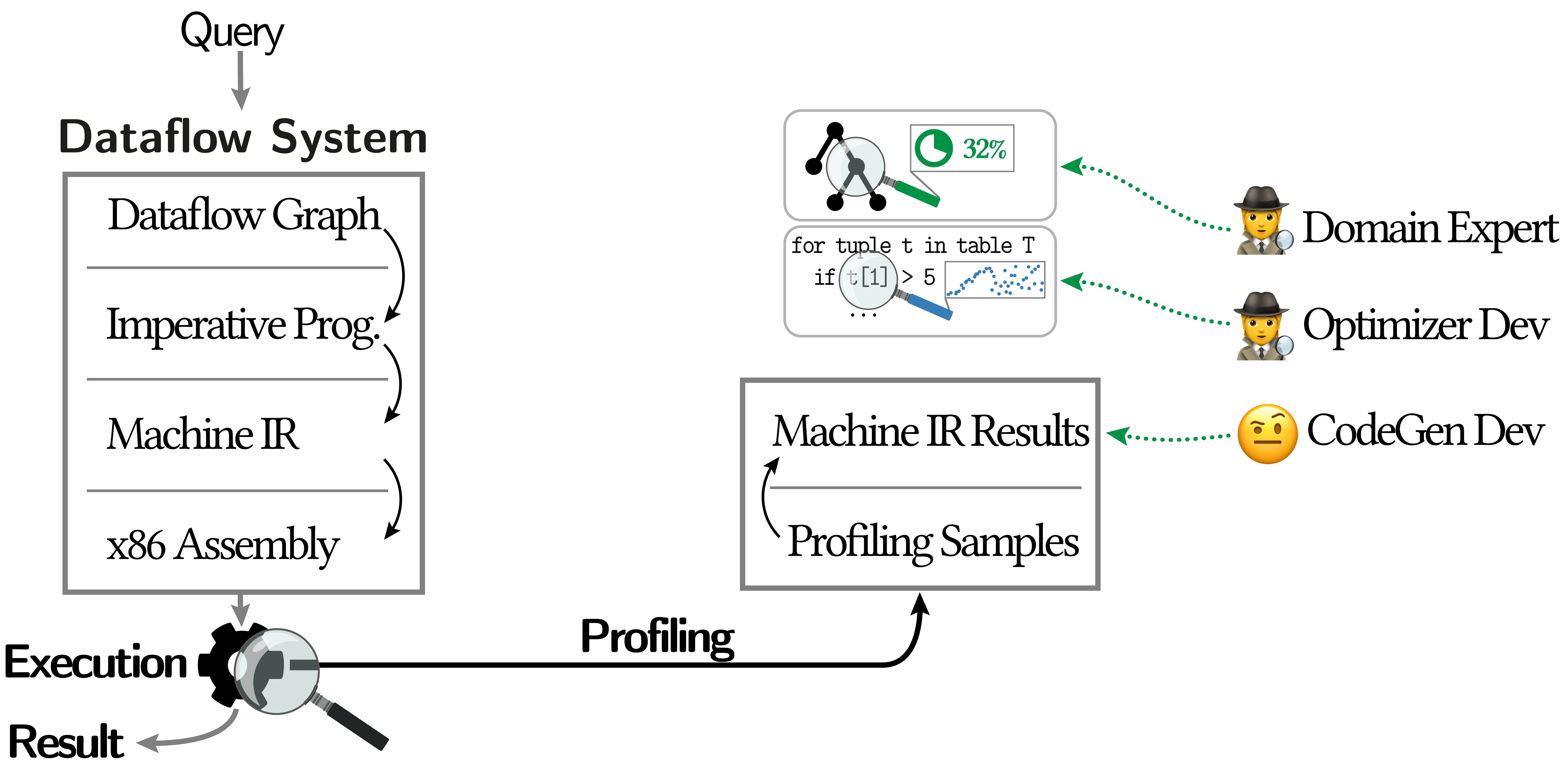

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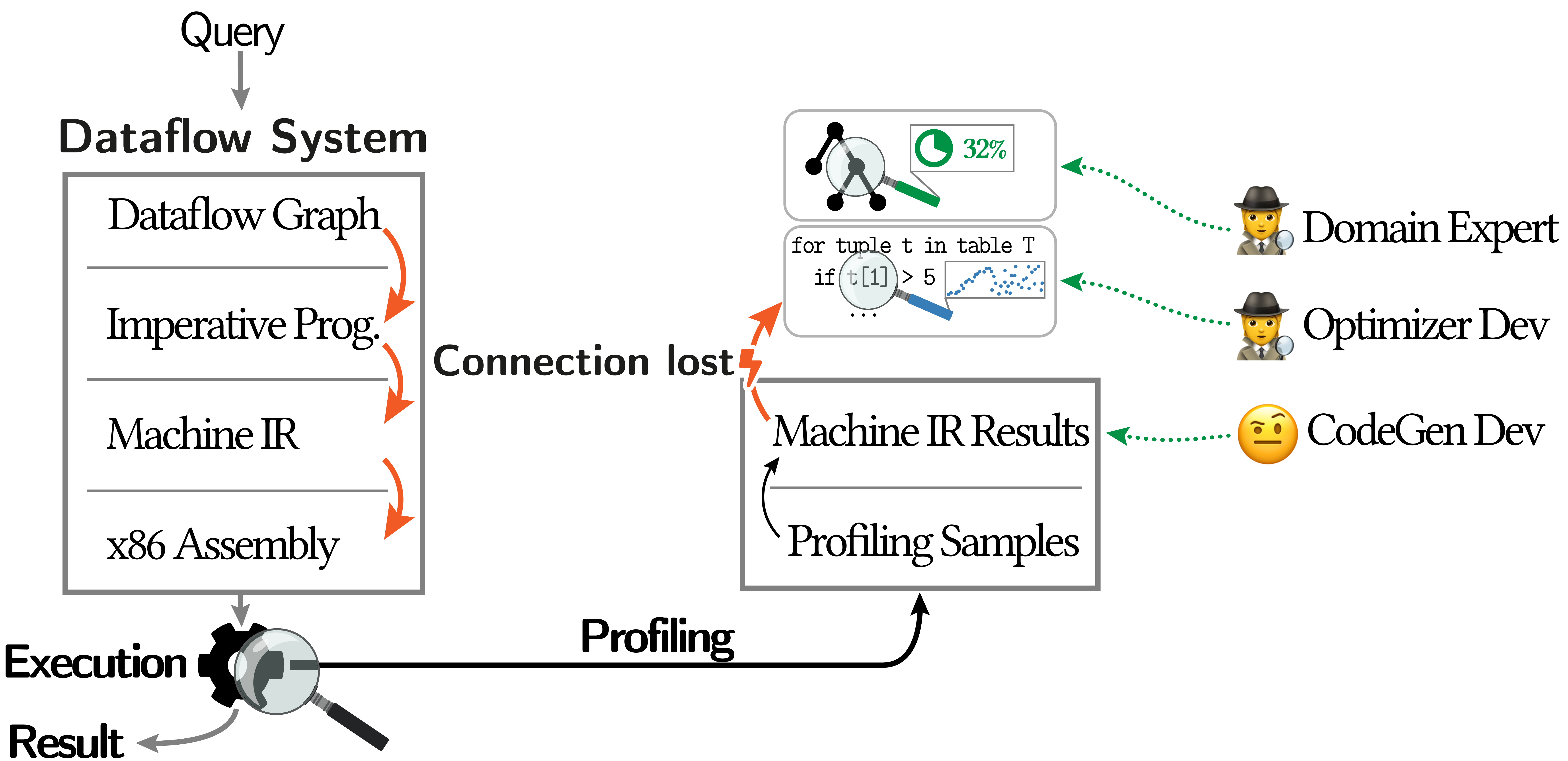
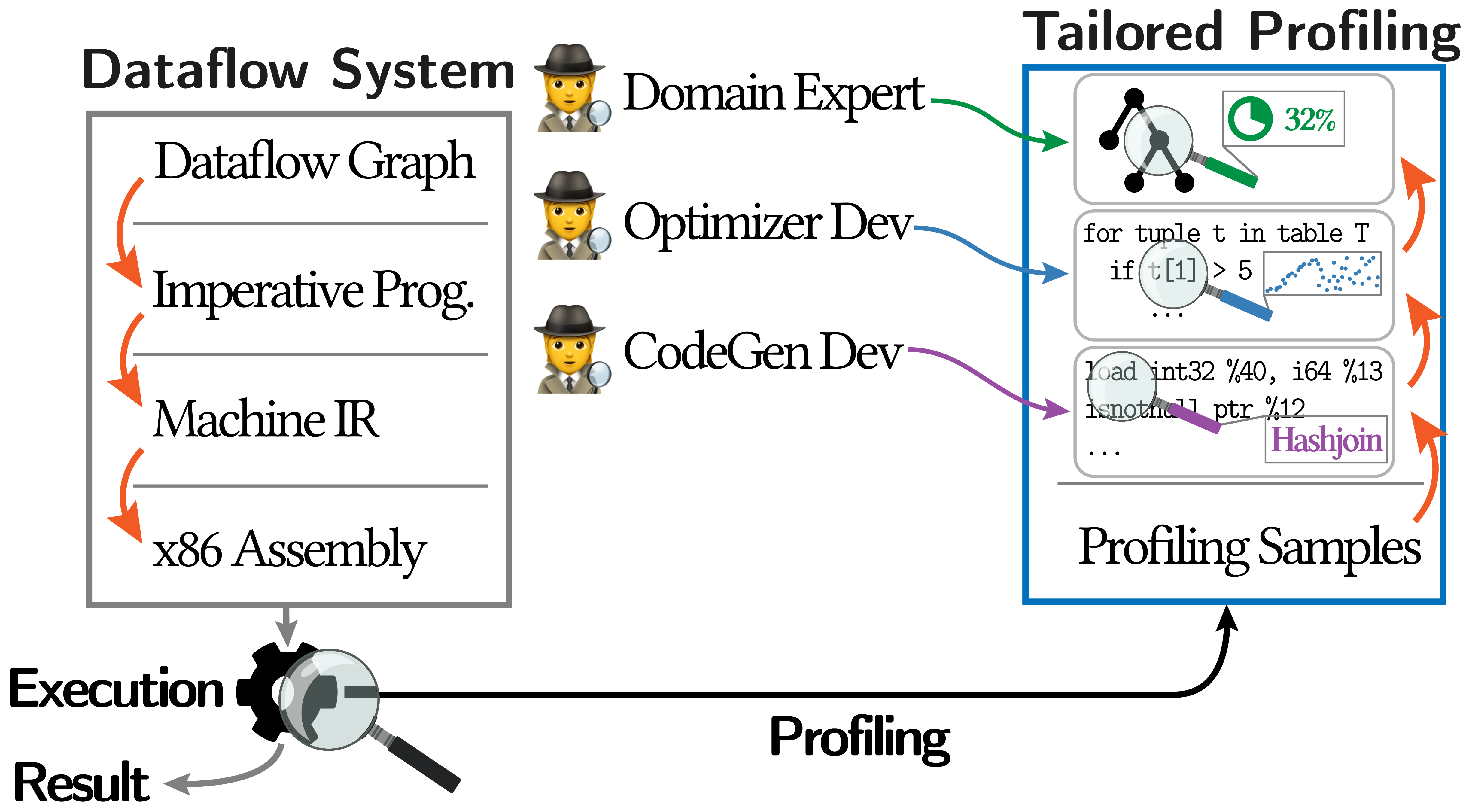


Tailored Profiling

Closing the gap

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

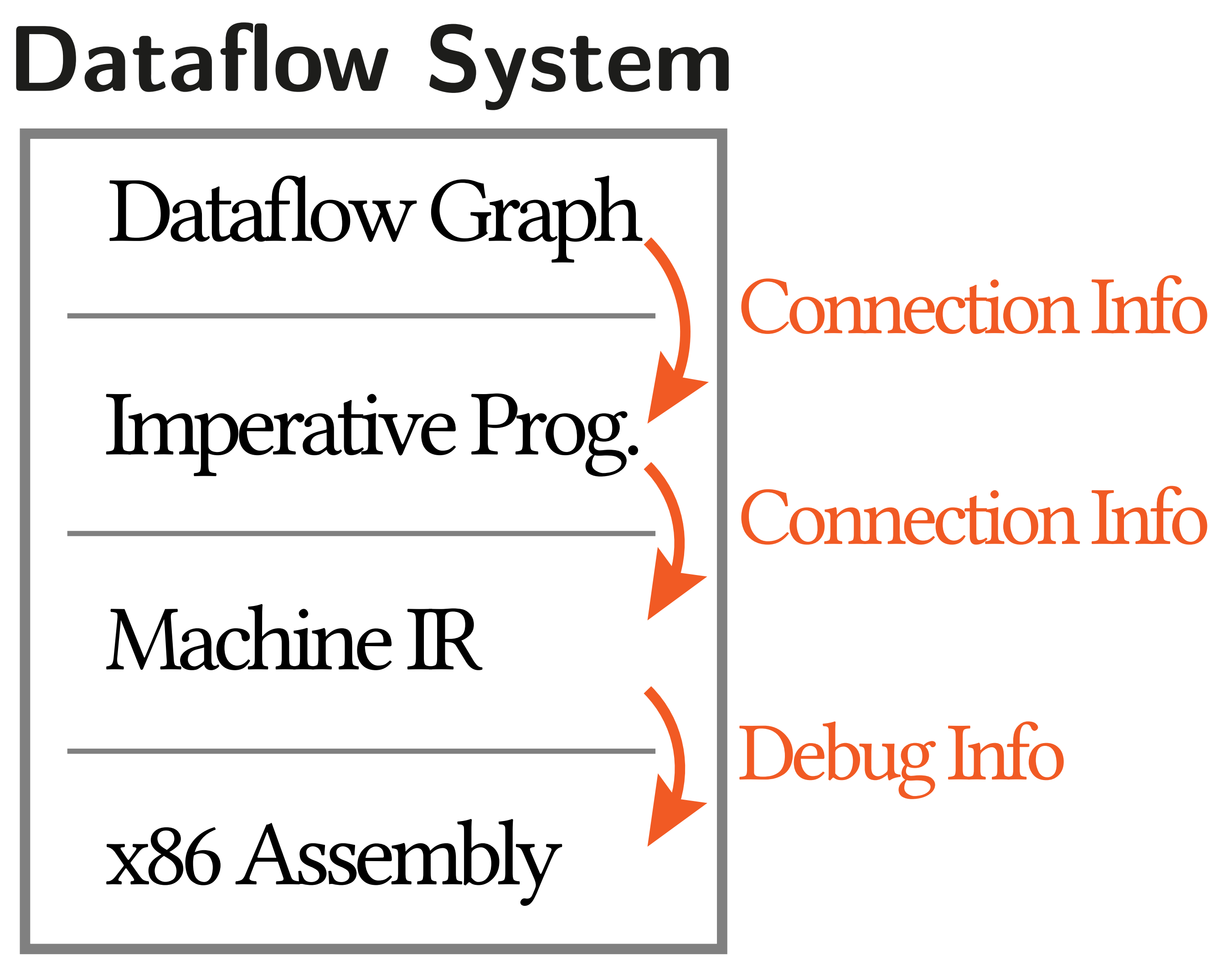
- Ingredients
  - *Tagging Dictionary & Register Tagging*



Tailored Profiling

Tagging Dictionary

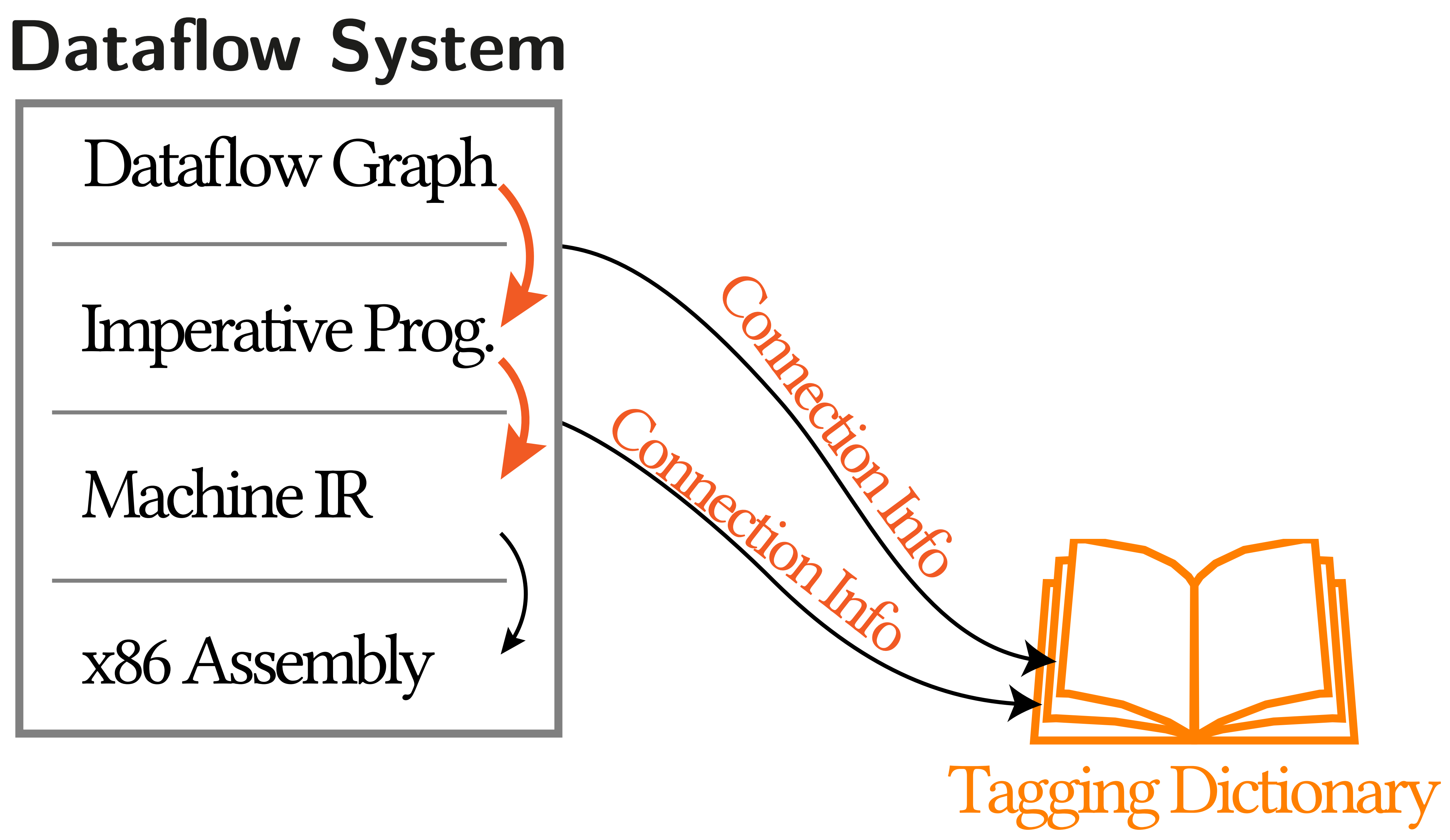
① *Connection tracking* of abstraction components for each lowering step (top-down)



Tailored Profiling

Tagging Dictionary

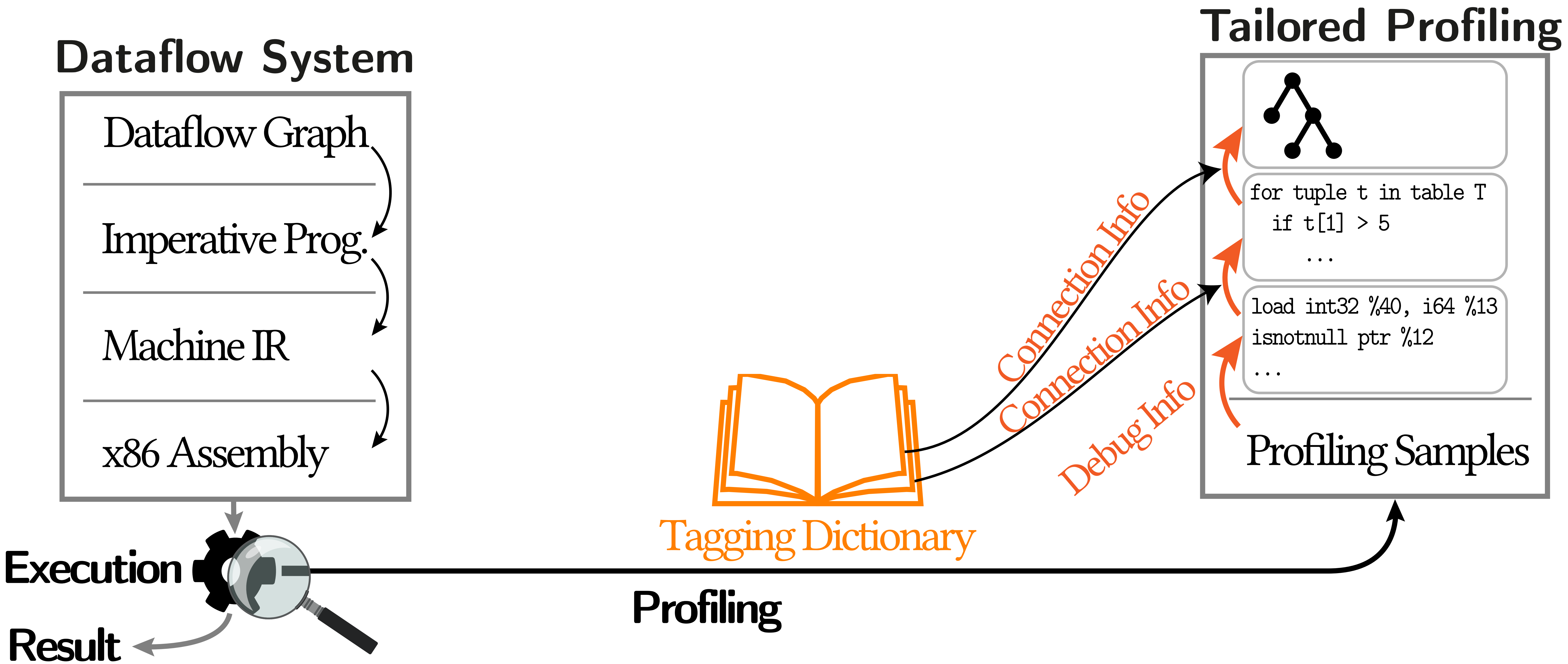
② Store mapping in the *Tagging Dictionary*



Tailored Profiling

Tagging Dictionary

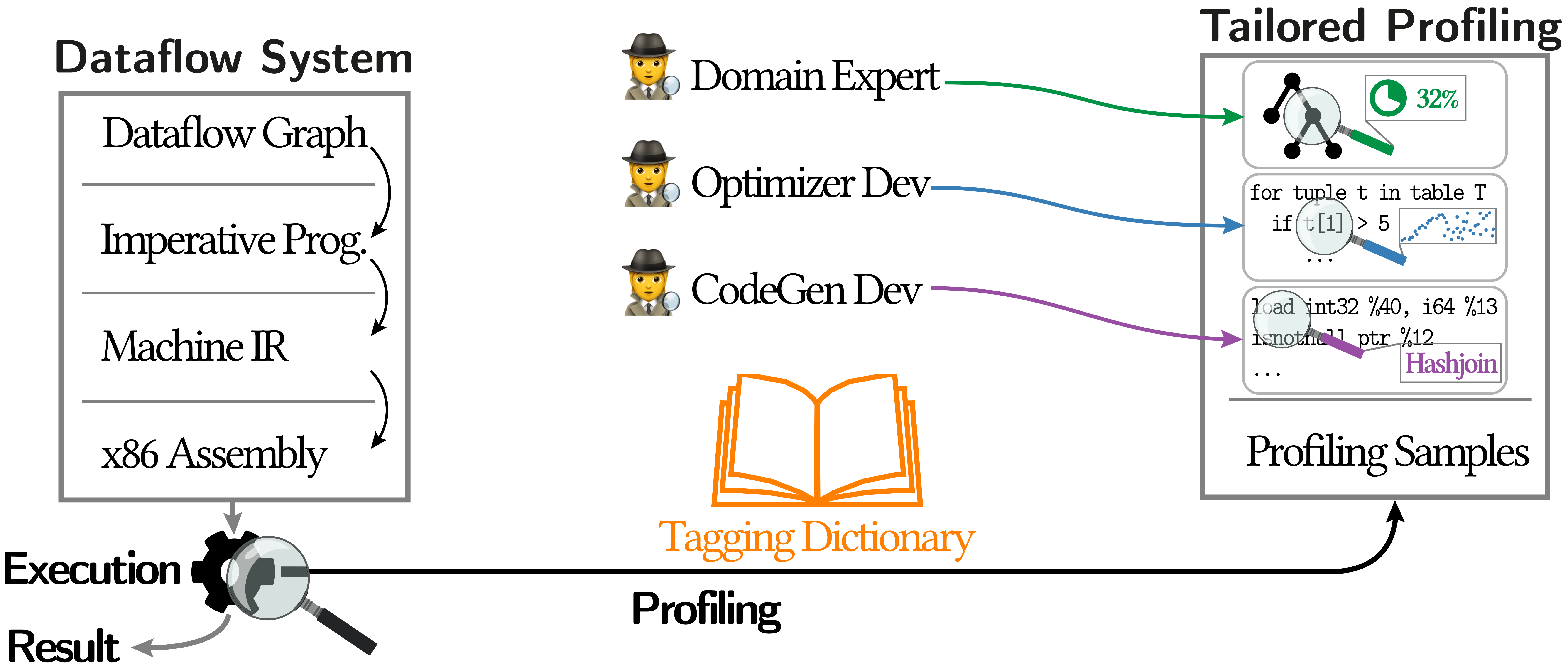
③ *Map* profiling results to each abstraction level's components (bottom-up)



Tailored Profiling

Tagging Dictionary

④ *Aggregate* the data for profiling results



Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

…

$Filter_{price>500}$

Scan sales

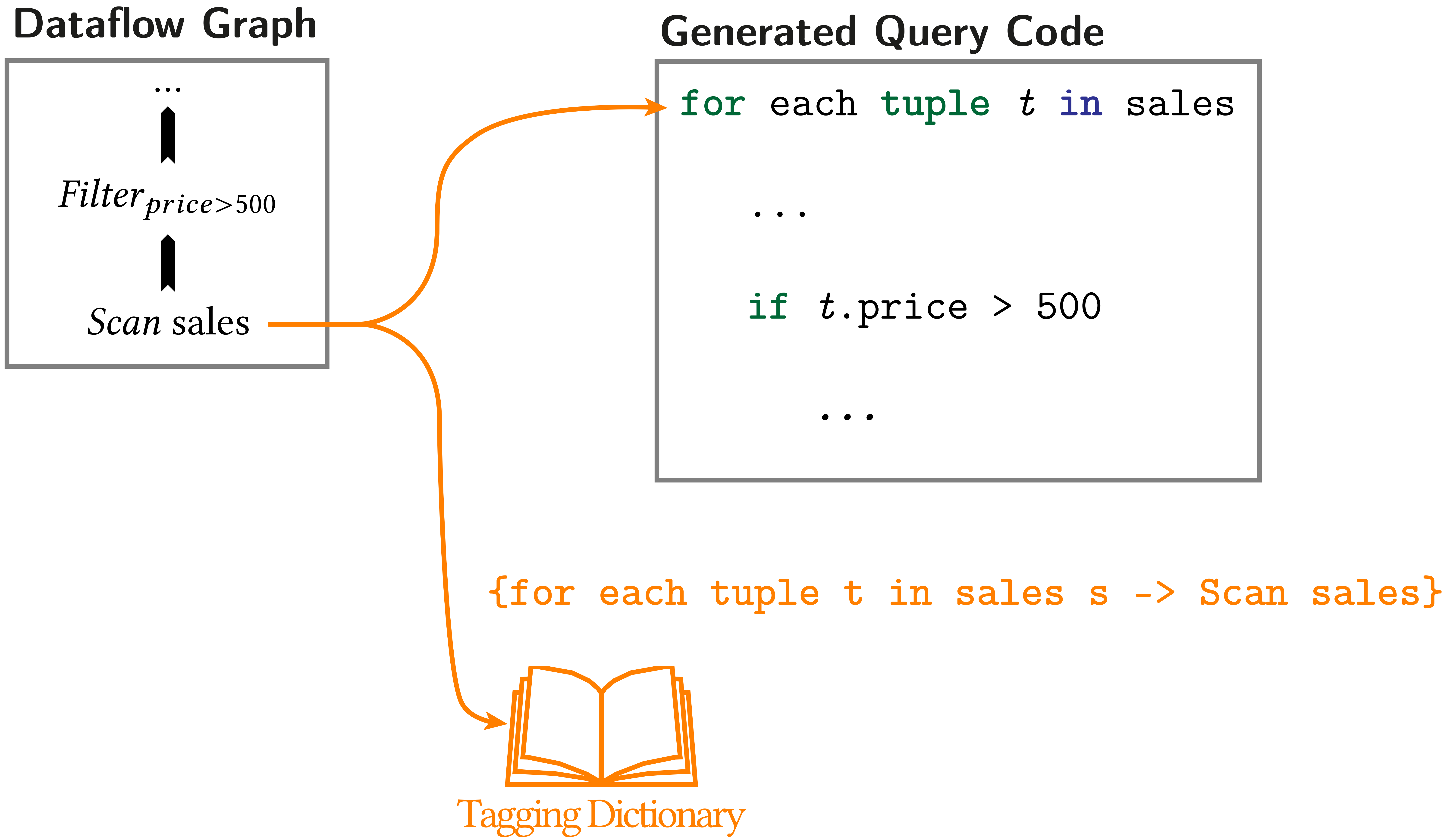
Generated Query Code

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

Tagging Dictionary

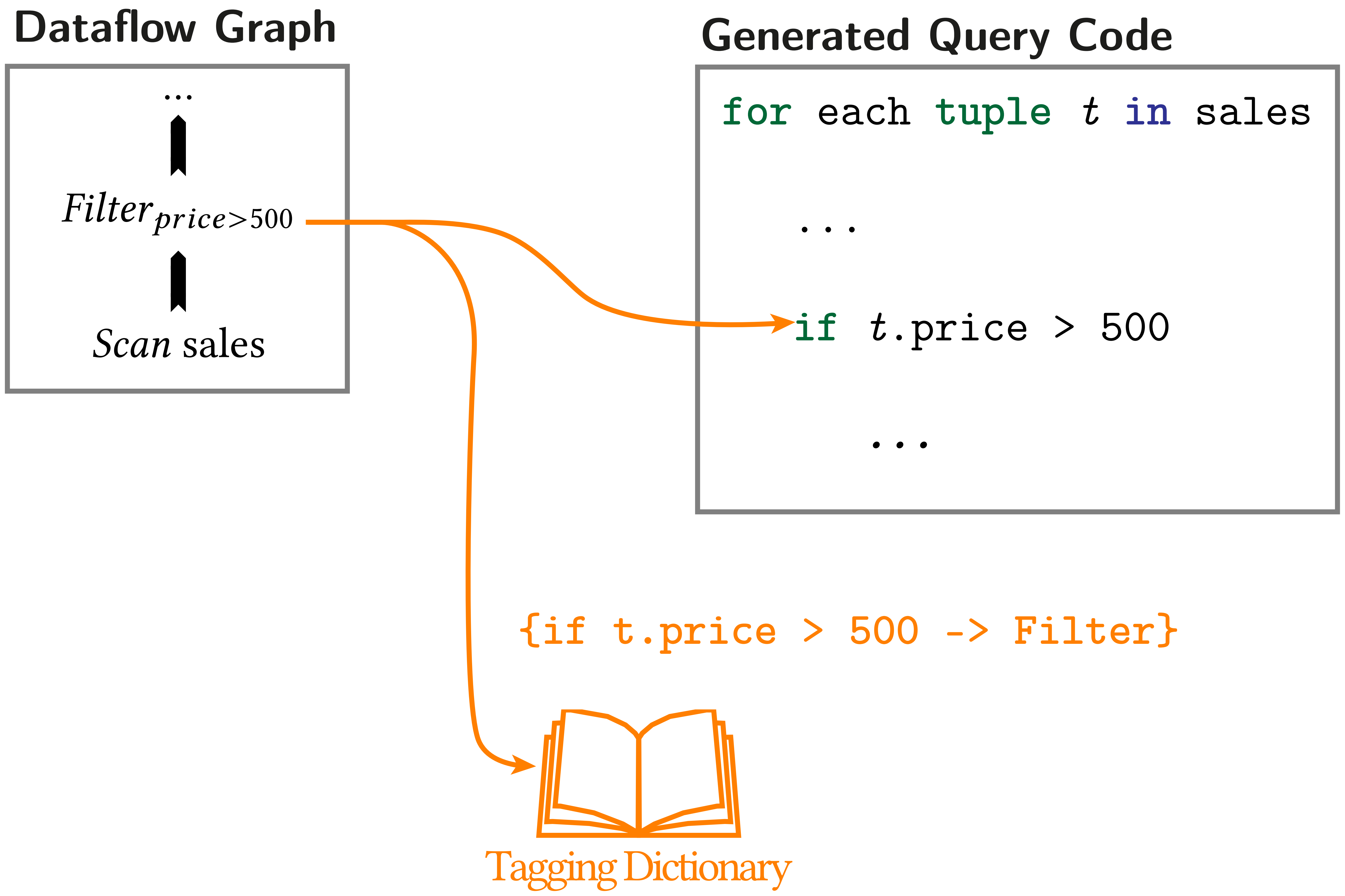
Tailored Profiling

Tagging Dictionary and Register Tagging



Tailored Profiling

Tagging Dictionary and Register Tagging



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Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

…

↑

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↑

Scan sales

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

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Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

…

$\uparrow$

$Filter_{price>500}$

$\uparrow$

Scan sales

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Profiling Sample

Source Line
malloc(...)

→

Tagging Dictionary

→ Scan, Filter ?

Tailored Profiling

Tagging Dictionary and Register Tagging

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```

Call-Stack Sample

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

Profiling Sample

Source Line
malloc(...)

→ Tagging Dictionary → Scan, Filter ?

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

...

↑

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↑

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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

Scan

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Tailored Profiling

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Dataflow Graph

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Machine Register

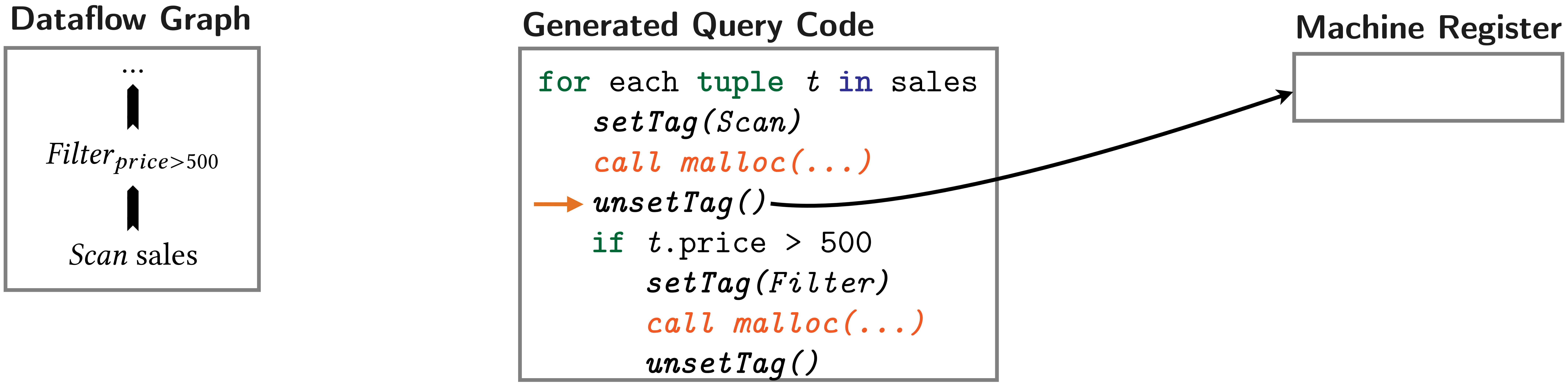
Scan

Profiling Sample

Source Line	Register Value
malloc(...)	Scan

Tailored Profiling

Tagging Dictionary and Register Tagging



Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

...

$Filter_{price>500}$

$Scan$ sales

Generated Query Code

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Machine Register

Filter

Tailored Profiling

Tagging Dictionary and Register Tagging

Dataflow Graph

$$\ldots$$
$$\uparrow$$
$$\mathit{Filter}_{price>500}$$
$$\uparrow$$
$$\mathit{Scan}\ \text{sales}$$

Generated Query Code

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Machine Register

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Profiling Sample

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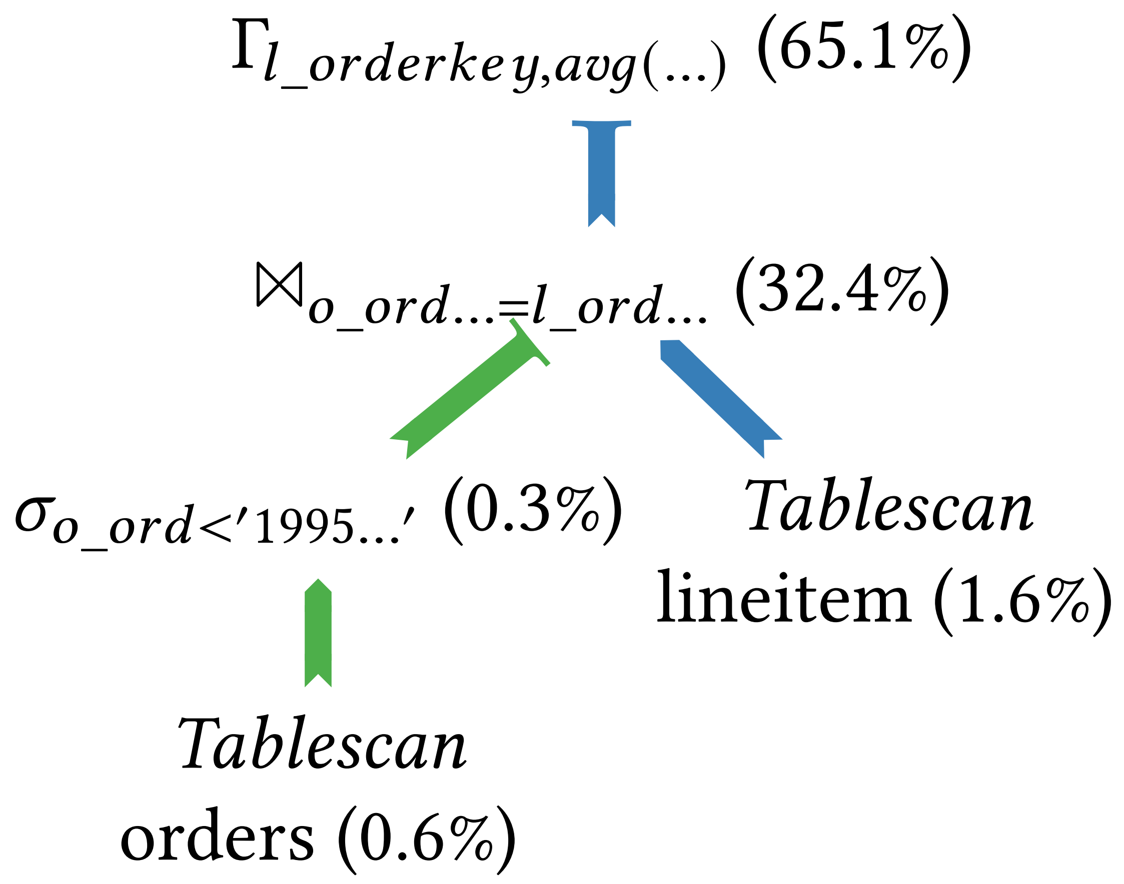
malloc(...)	Filter

Insights with Tailored Profiling

UMBRA

Insights with Tailored Profiling

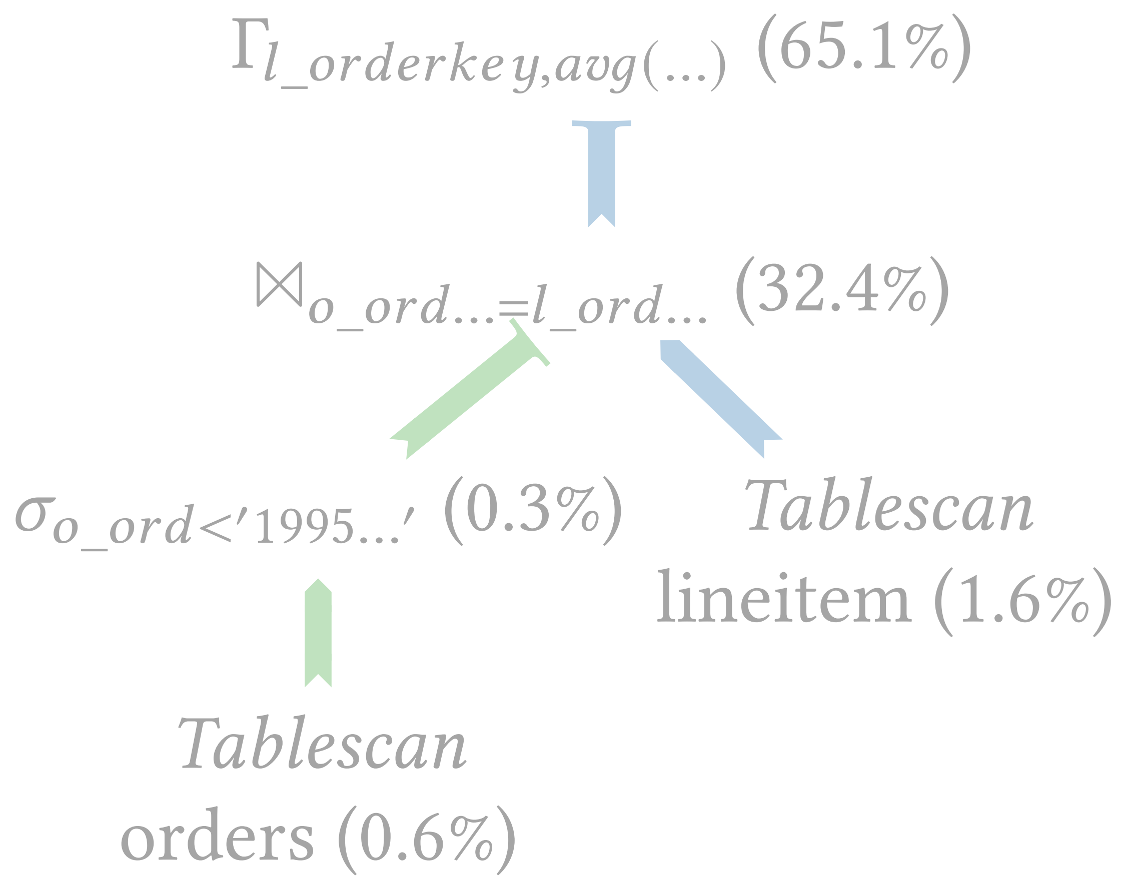
UMBRA

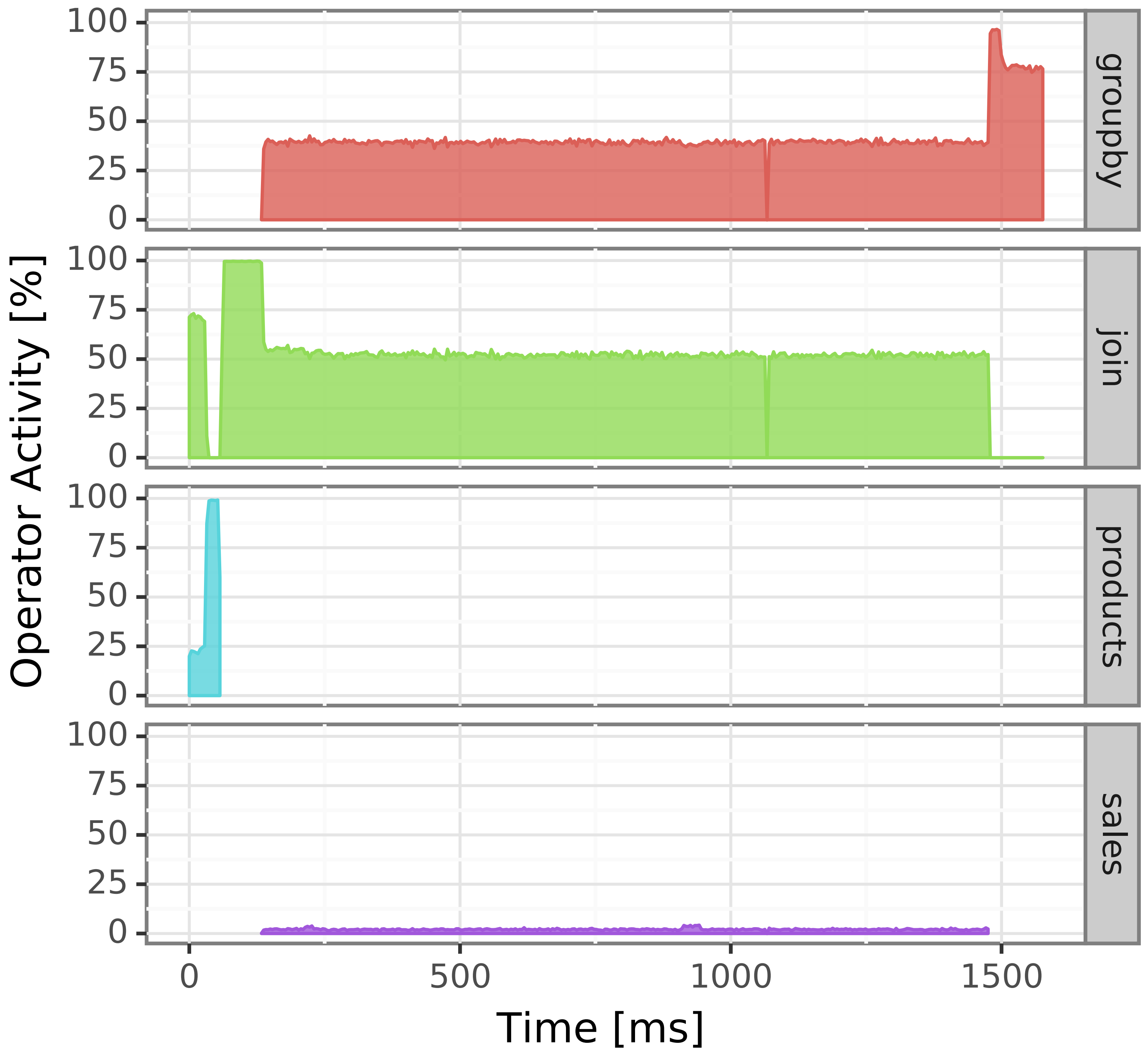


Time per operator

Insights with Tailored Profiling

UMBRA

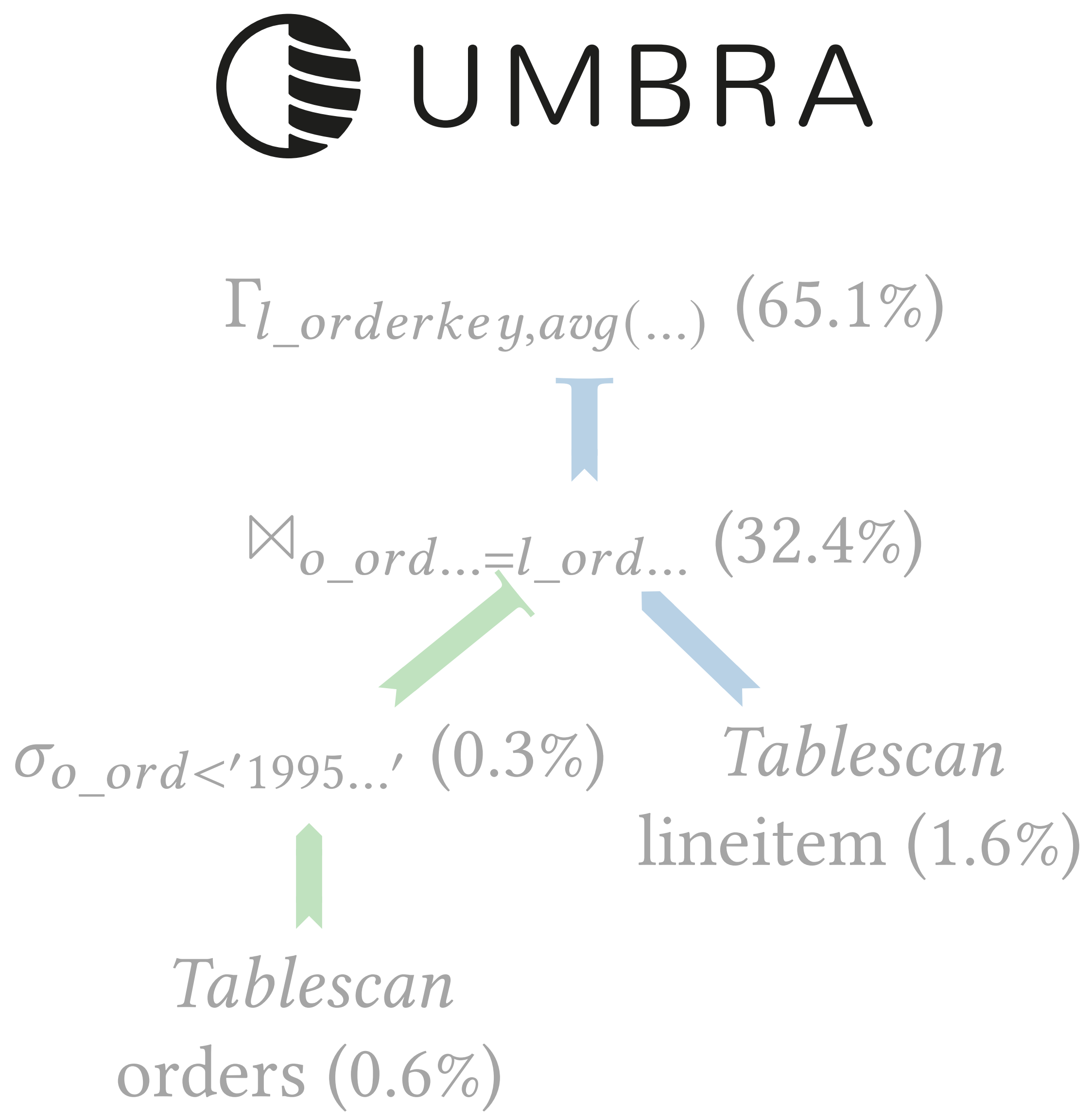


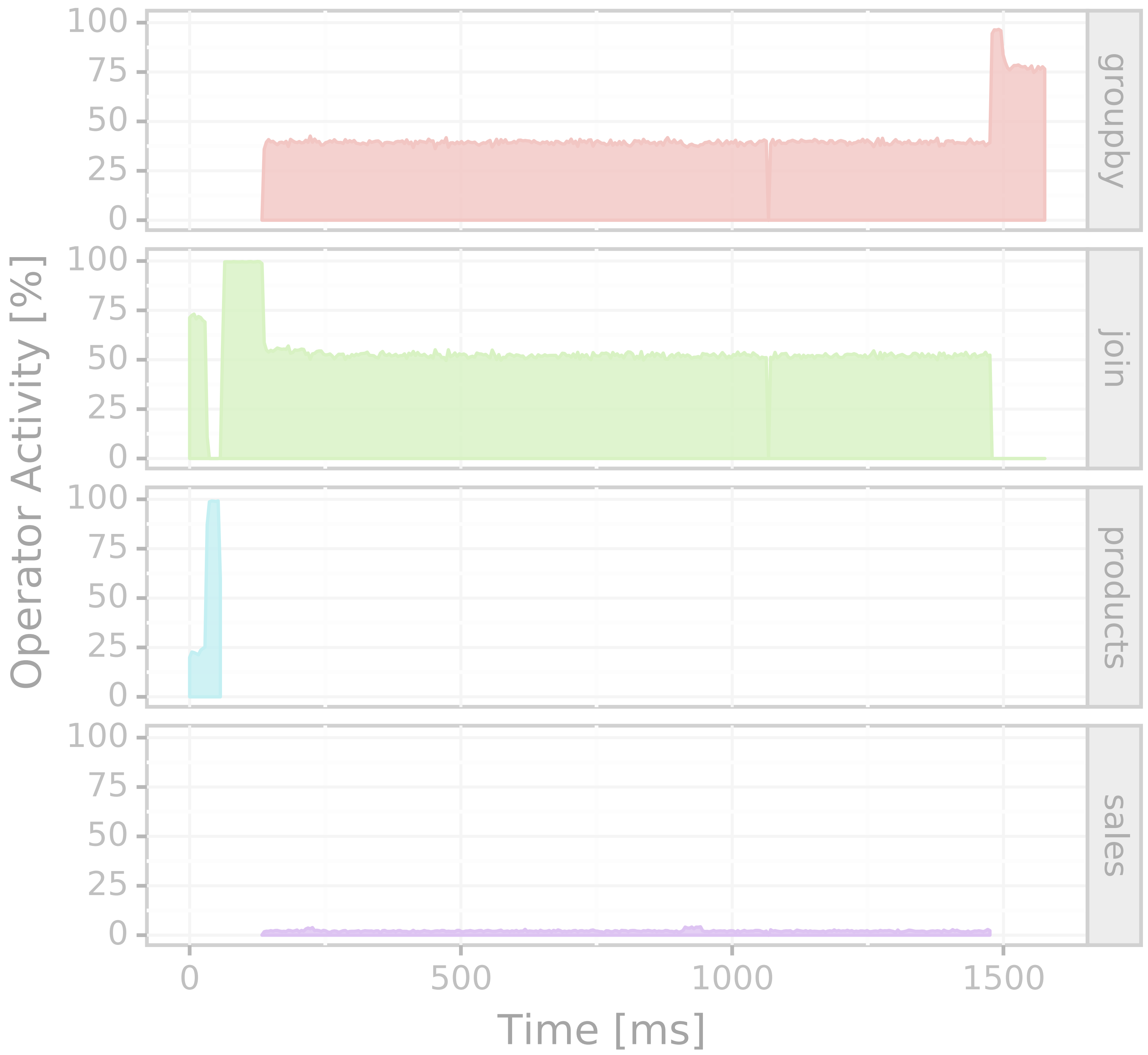


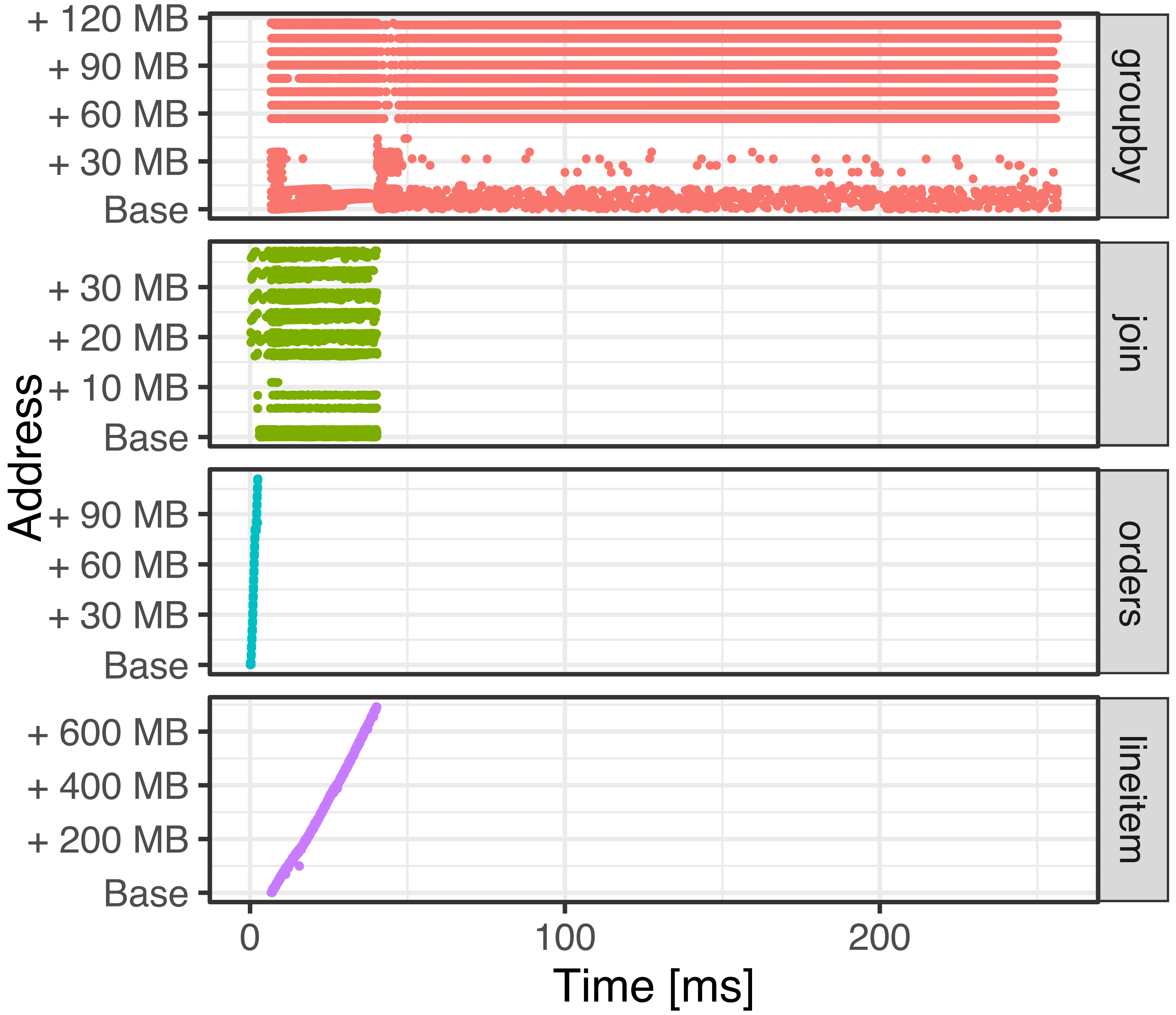
Time per operator

Context-aware profiling over time

Insights with Tailored Profiling







Time per operator

Context-aware profiling over time

Memory access patterns

Overhead and Integration Effort

Is it worth it?

Overhead and Integration Effort

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- Little implementation effort

Component	Lines Added
Code Gen.	56
Sample Processing	1176
Visualizations	510

Overhead and Integration Effort

Is it worth it?

- Little implementation effort
- High accuracy

Component	Lines Added
Code Gen.	56
Sample Processing	1176
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Attributed Samples	98 %

Overhead and Integration Effort

Is it worth it?

- Little implementation effort
- High accuracy
- Lightweight
  - Small query execution overhead
    - Tagging Dictionary: populated at compile time
    - Register Tagging: 3%
- Cheaper than call-stack sampling

Component	Lines Added
Code Gen.	56
Sample Processing	1176
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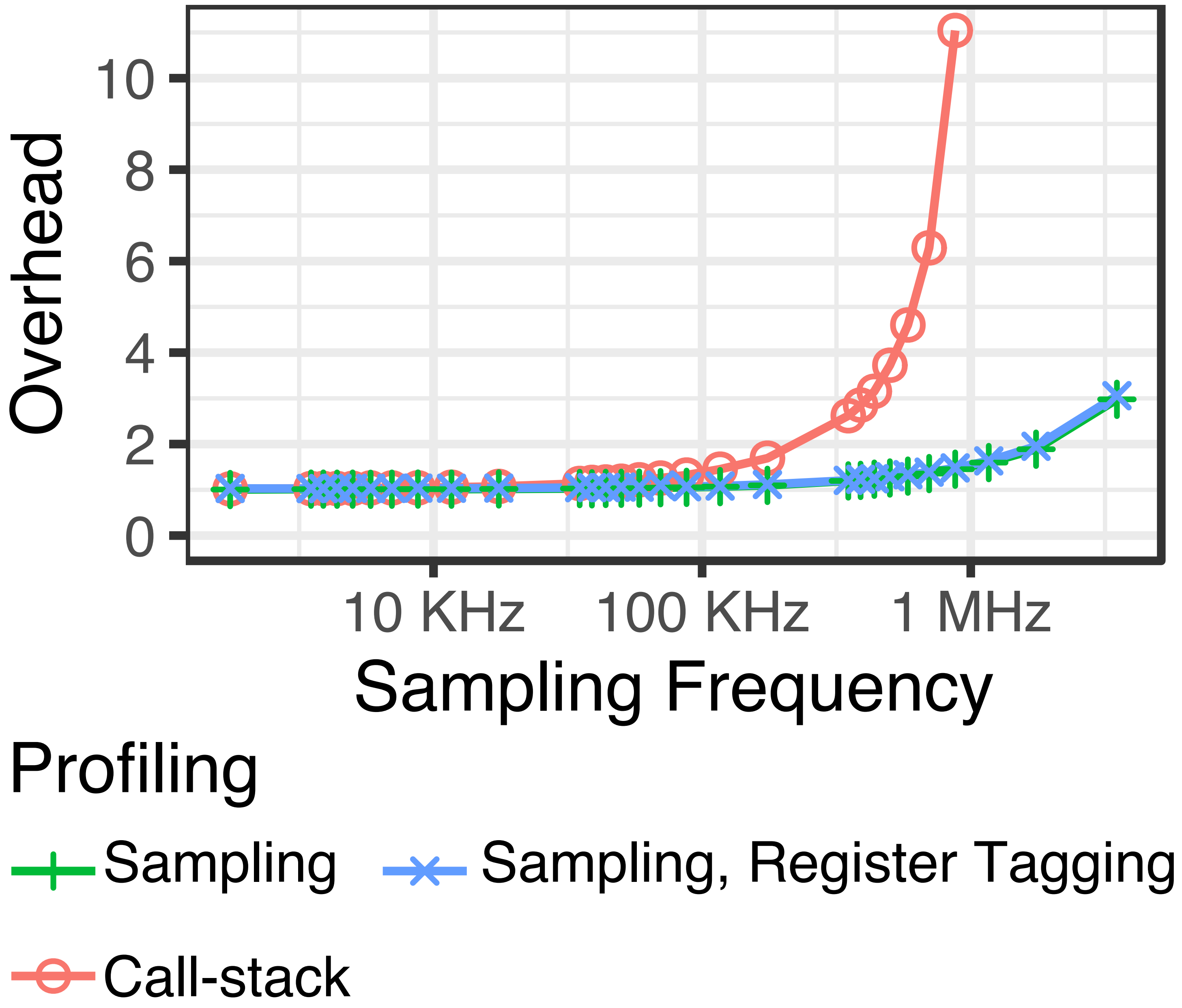
Attributed Samples	98 %



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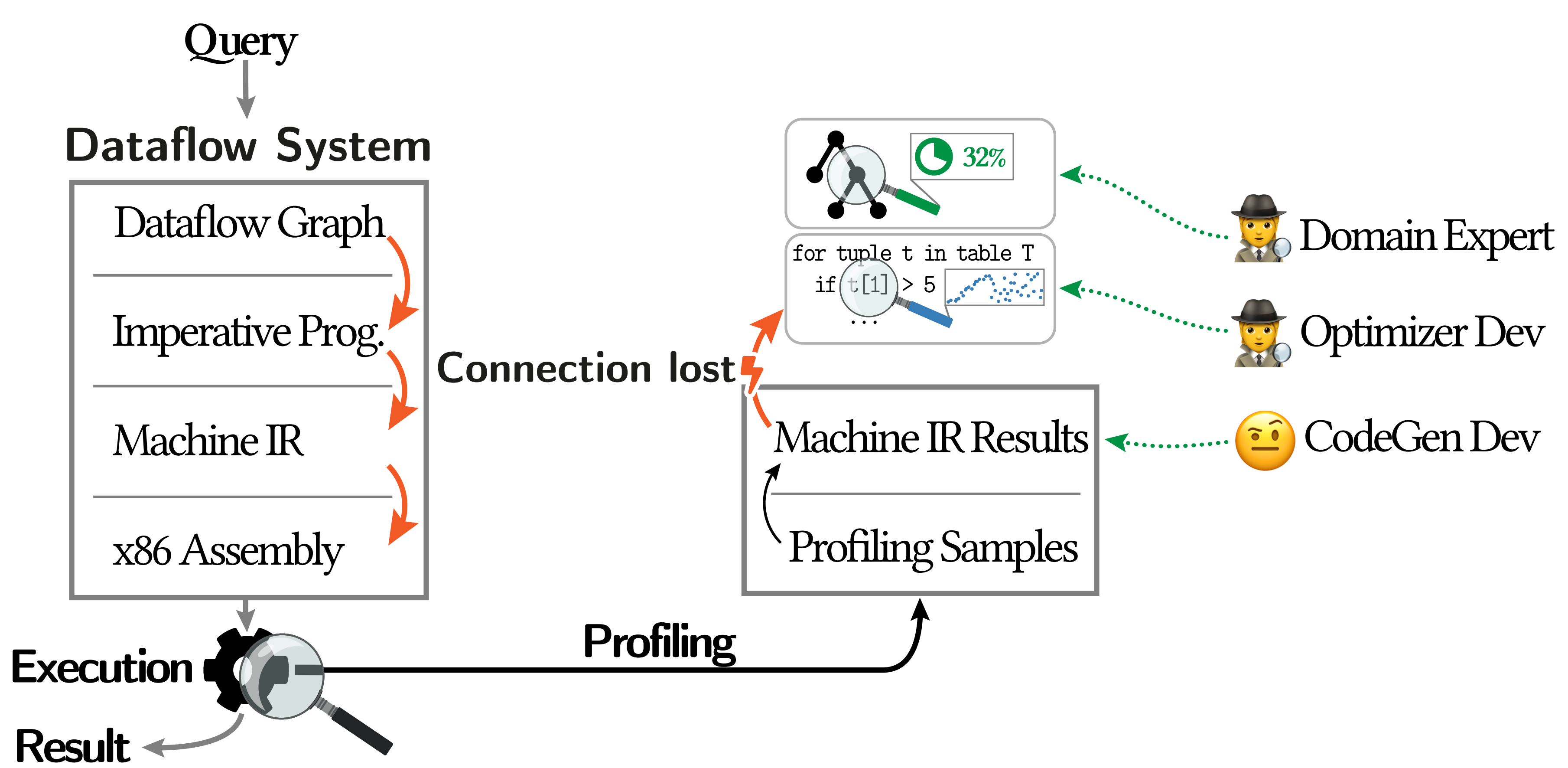
Impact of Tailored Profiling

Where can you apply it?

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



Impact of Tailored Profiling

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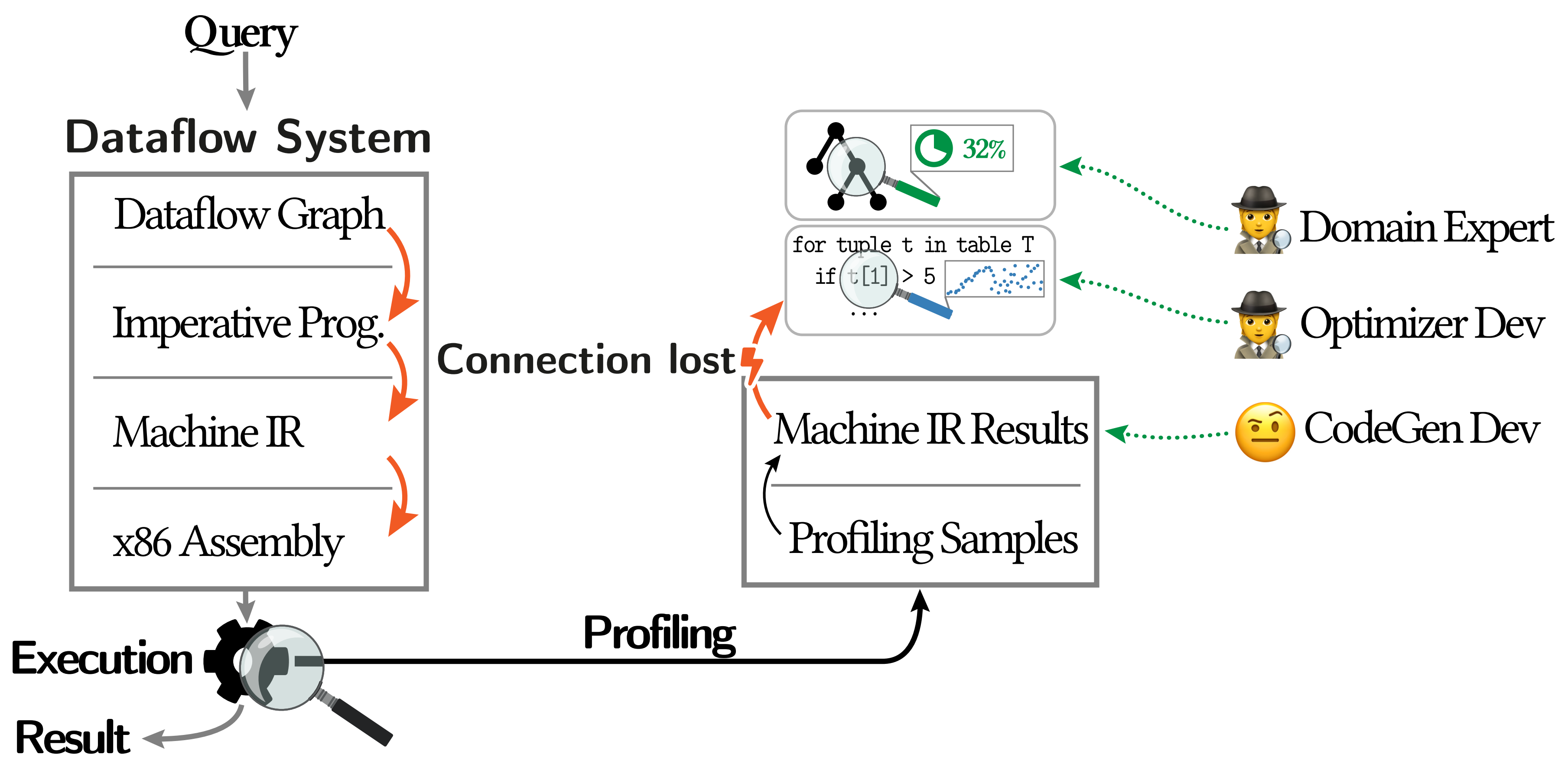
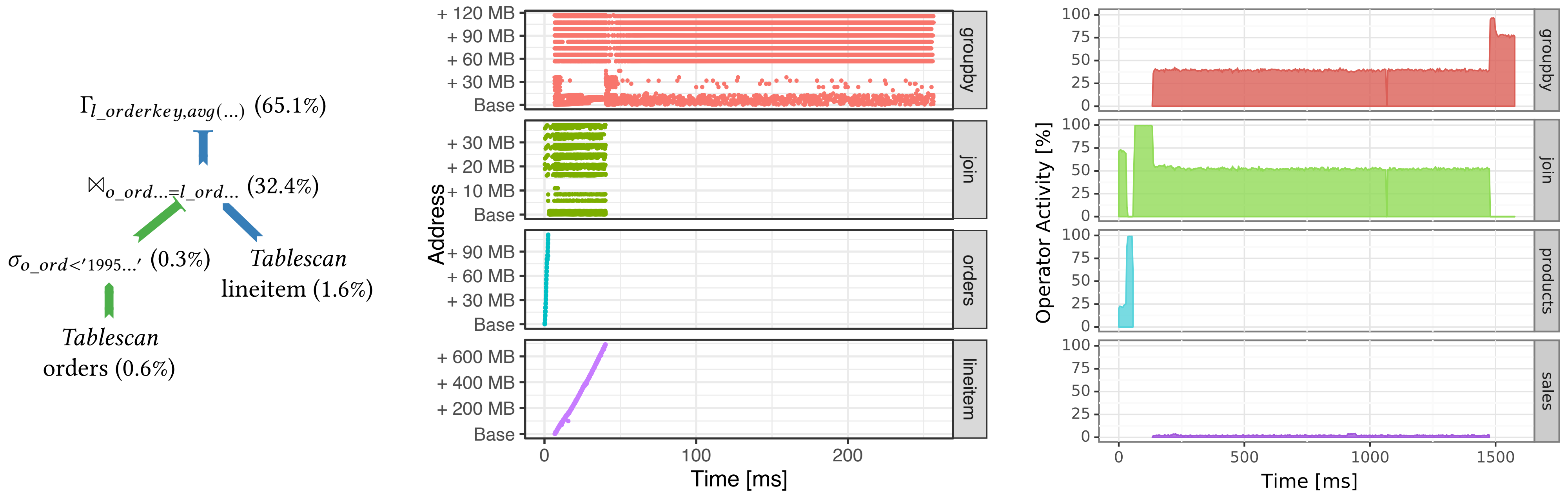
- Easy to integrate
- Applicable to many systems





Impact of Tailored Profiling

Where can you apply it?

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- Lightweight, high accuracy
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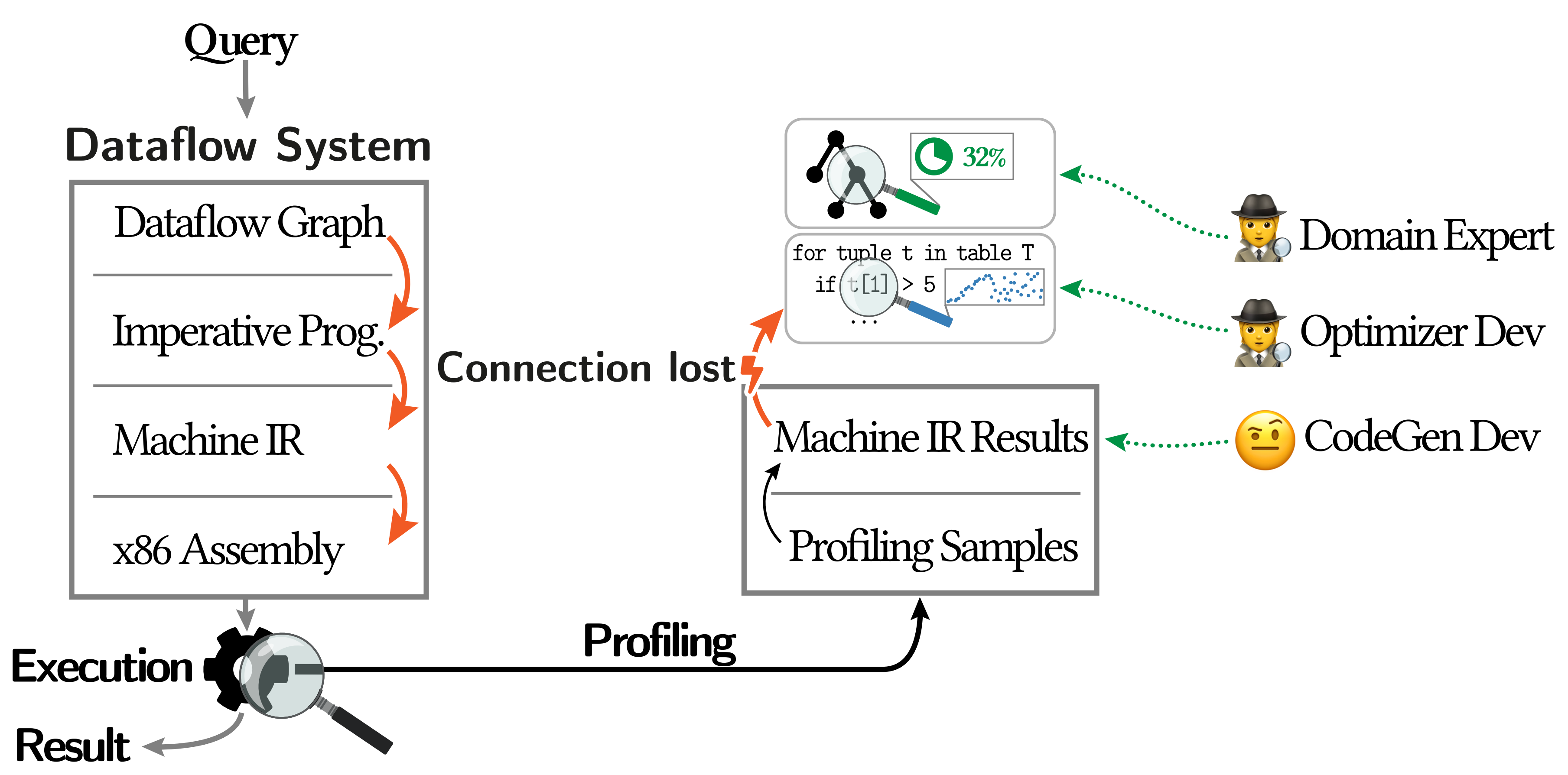
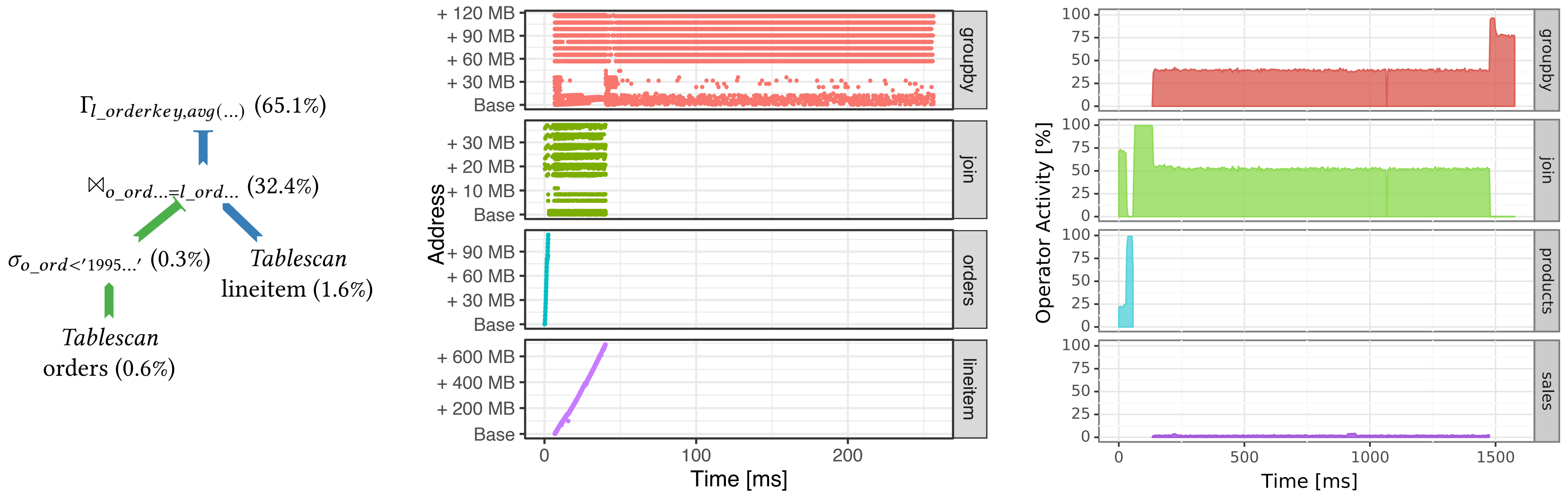
- Applicable to many systems

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





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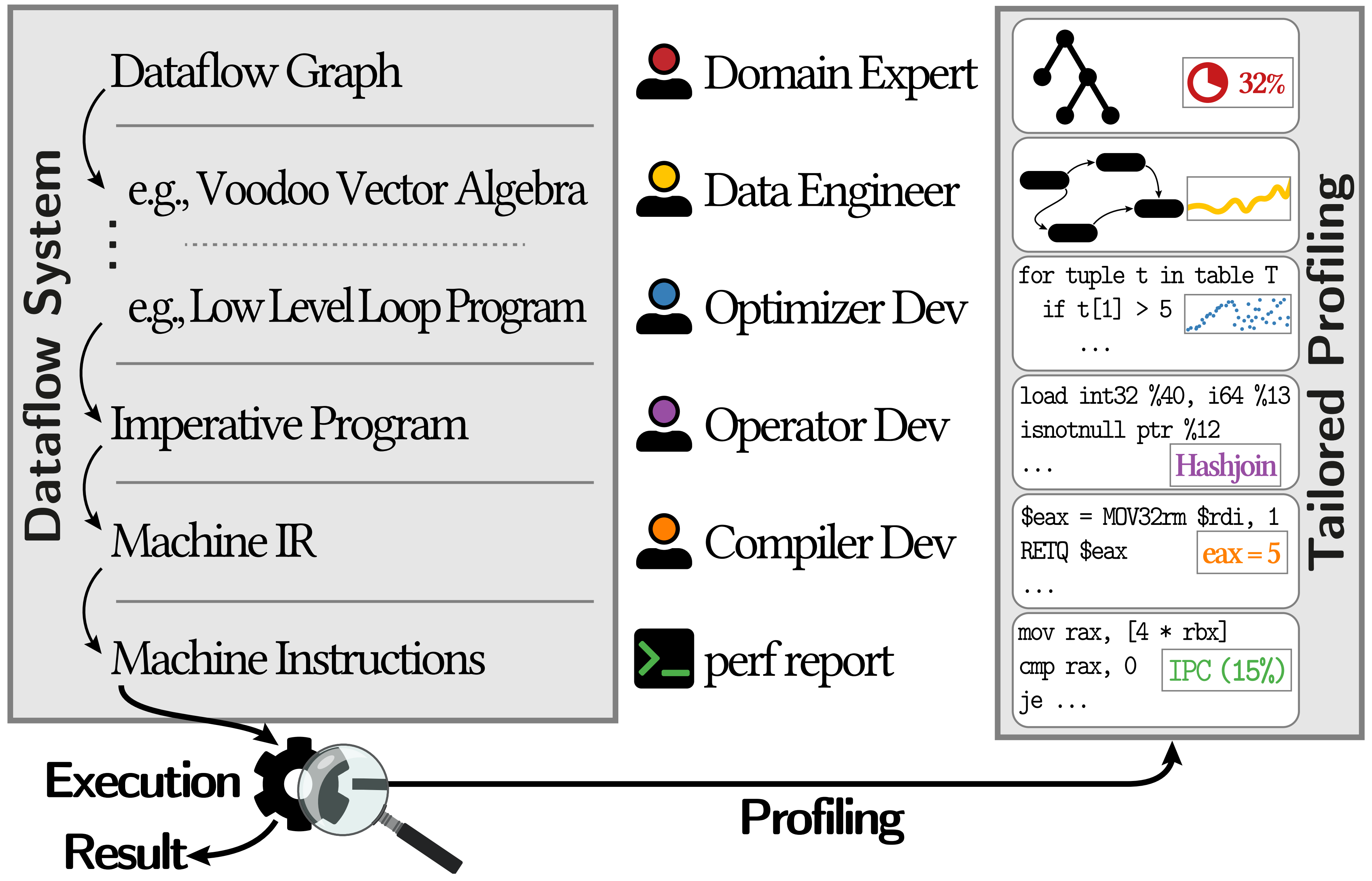
What else can be found in the Paper

- Technical and implementation details
  - Tagging Dictionary for multiple abstraction levels
  - Register Tagging and call-stack sampling
  - Supported optimizations



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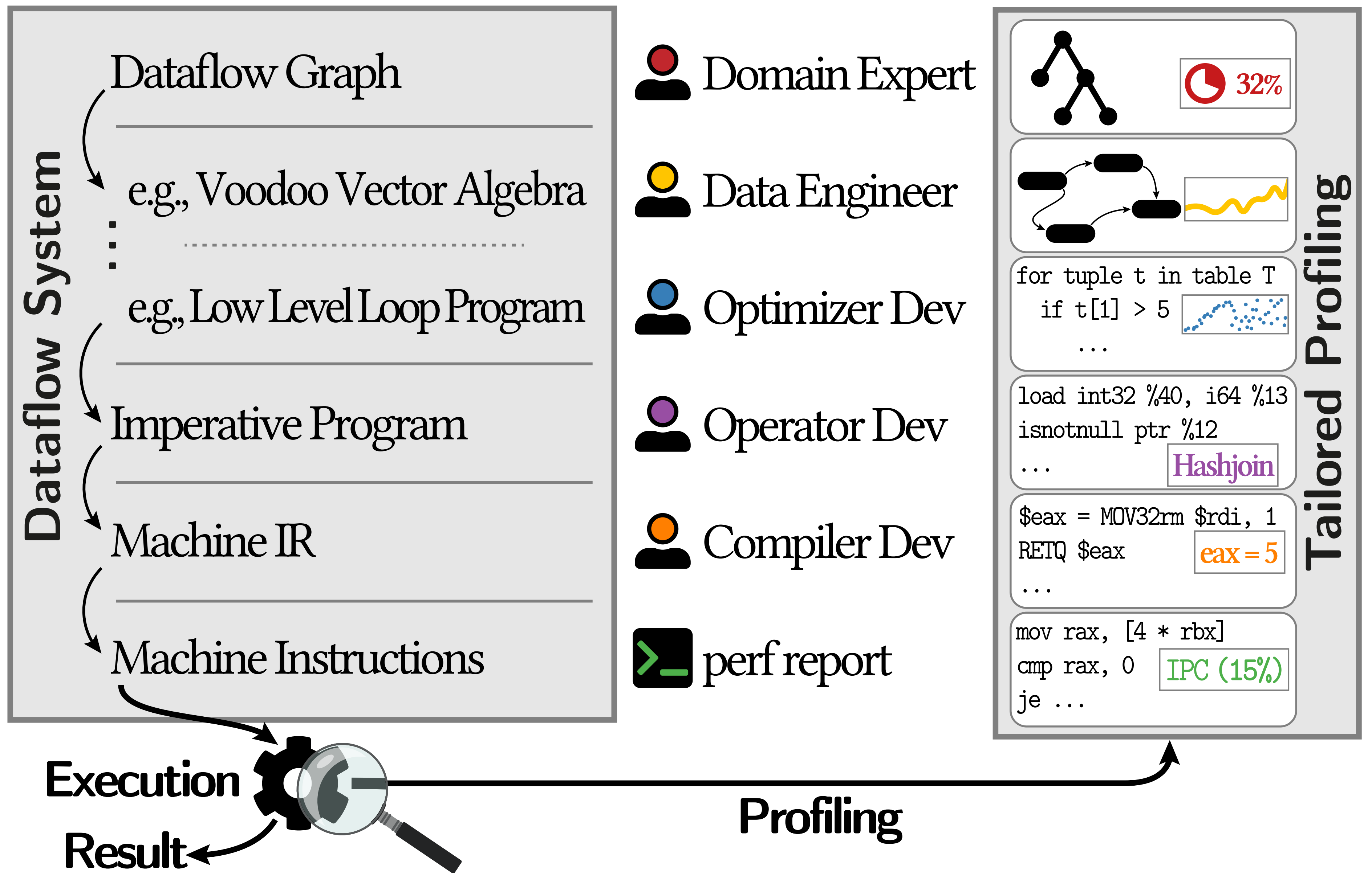
- Integration details for our compiling DBMS Umbra



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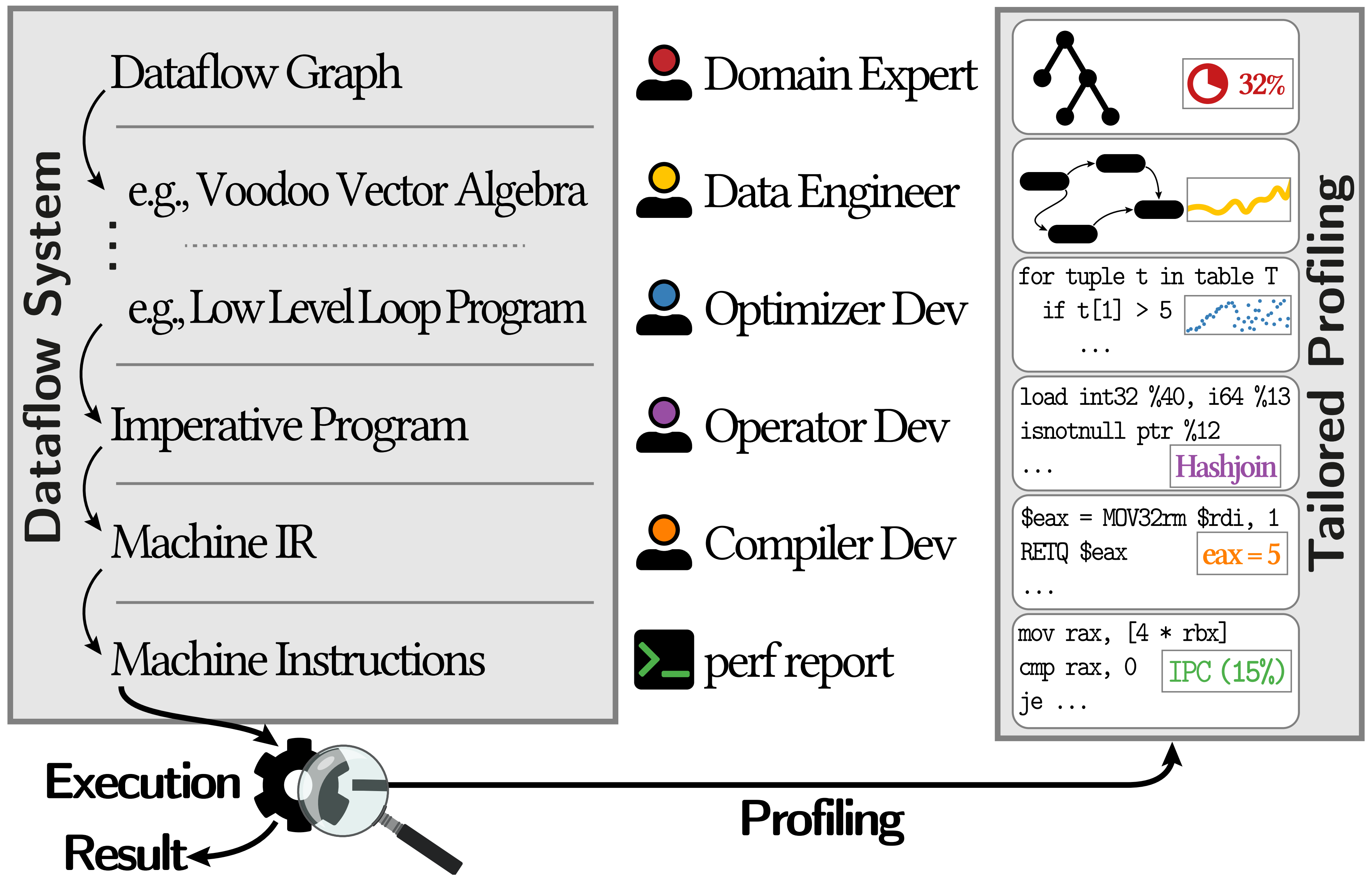
  - Register Tagging and call-stack sampling
  - Supported optimizations
- Integration details for our compiling DBMS Umbra
- More detailed evaluation, runtime overhead and use cases



Thank you for watching!

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