Repurposing Scala's **Pattern Matching** for Deeply Embedded **DSLs**

Tomas Mikula

Feb 19th, 2025

> scalac

Functional World

… in other words …

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Write DSL programs using **Scala**-embedded syntax

```
f(a) switch {
  case Foo(Bar(b) ** baz) =>
    doStuff(b ** baz)
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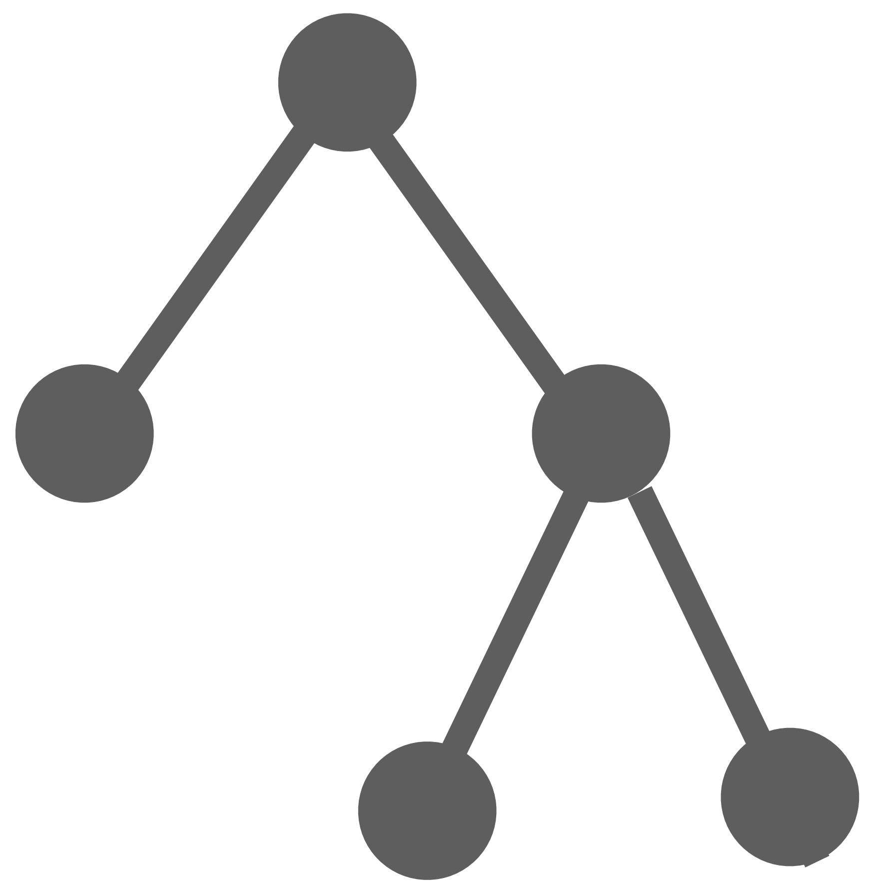
(your *custom* data structure)



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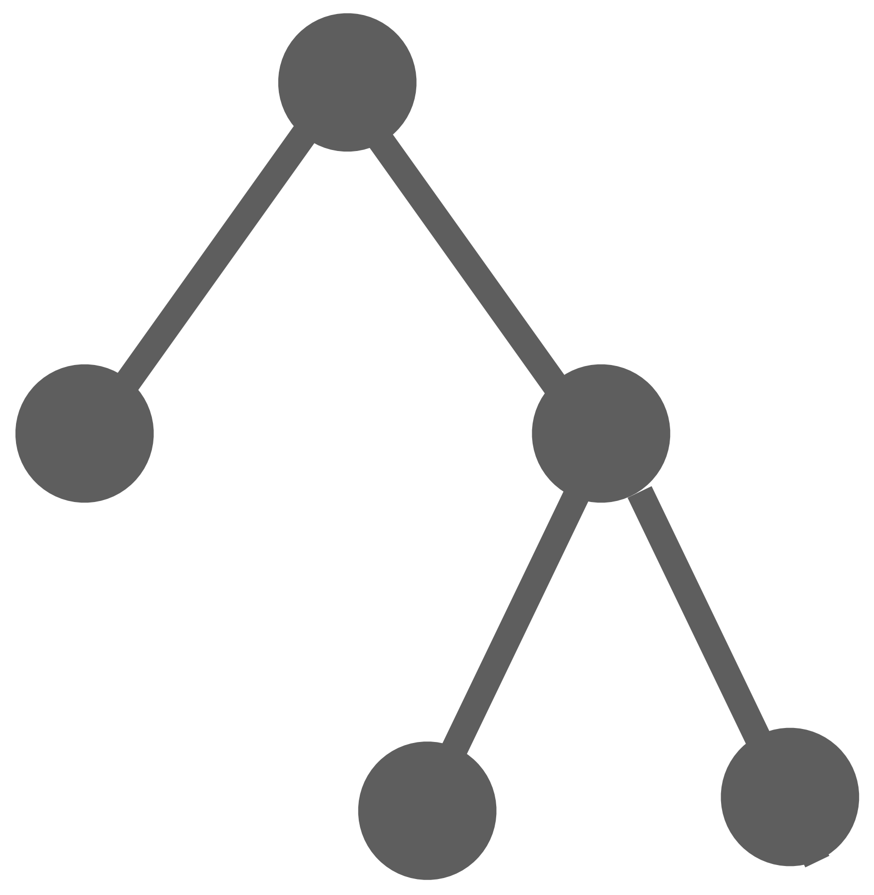

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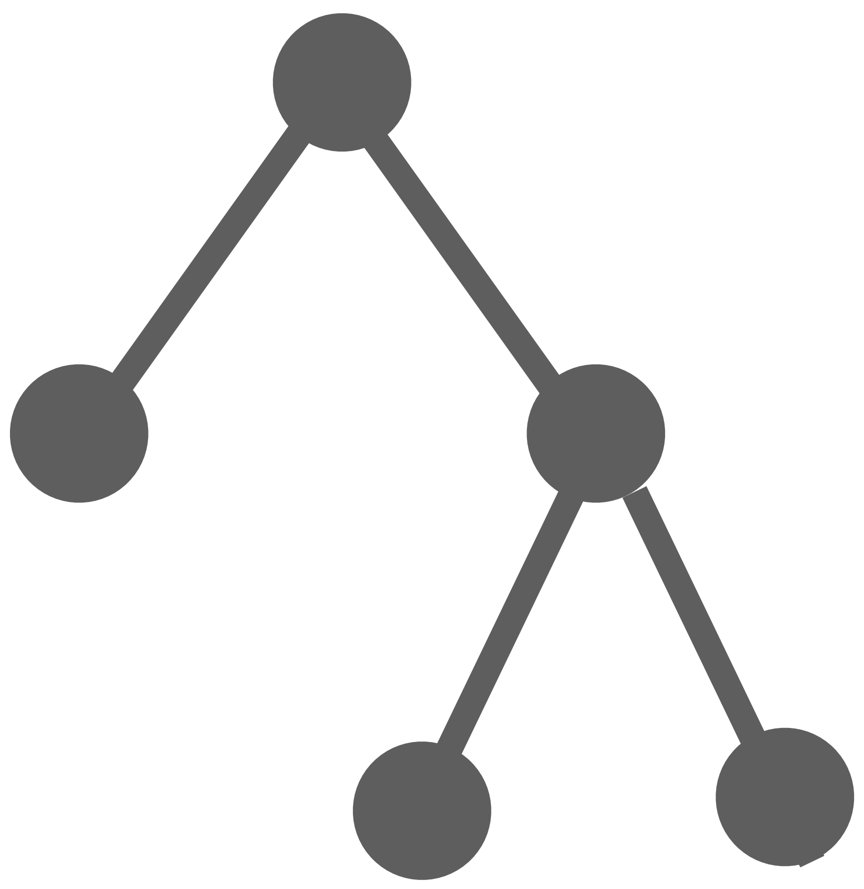

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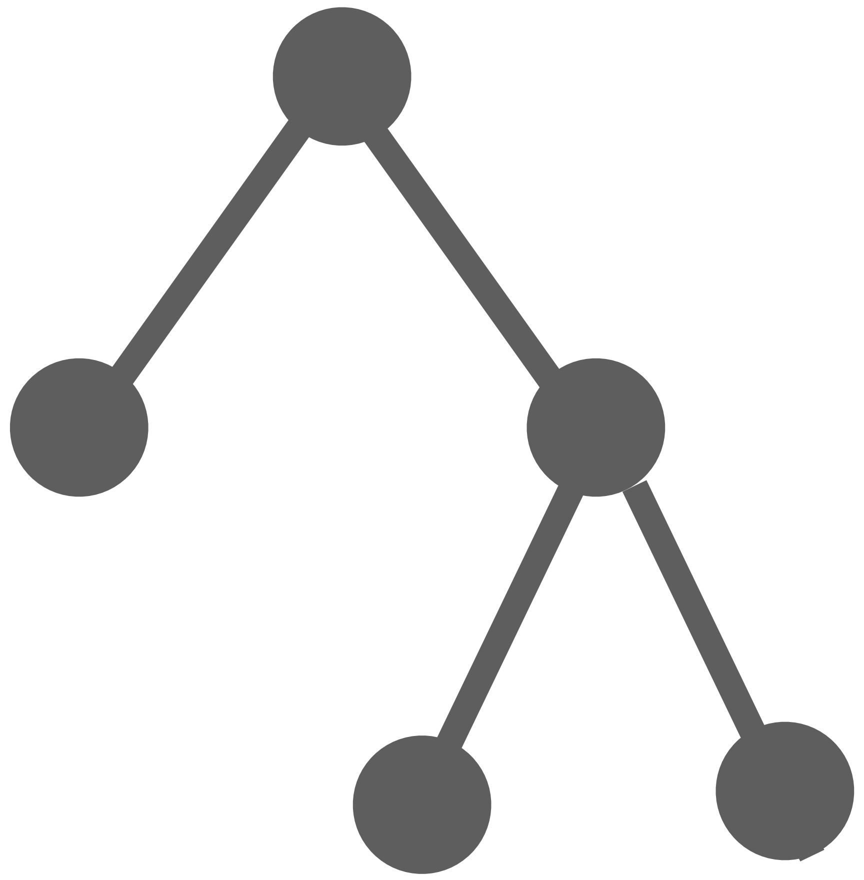

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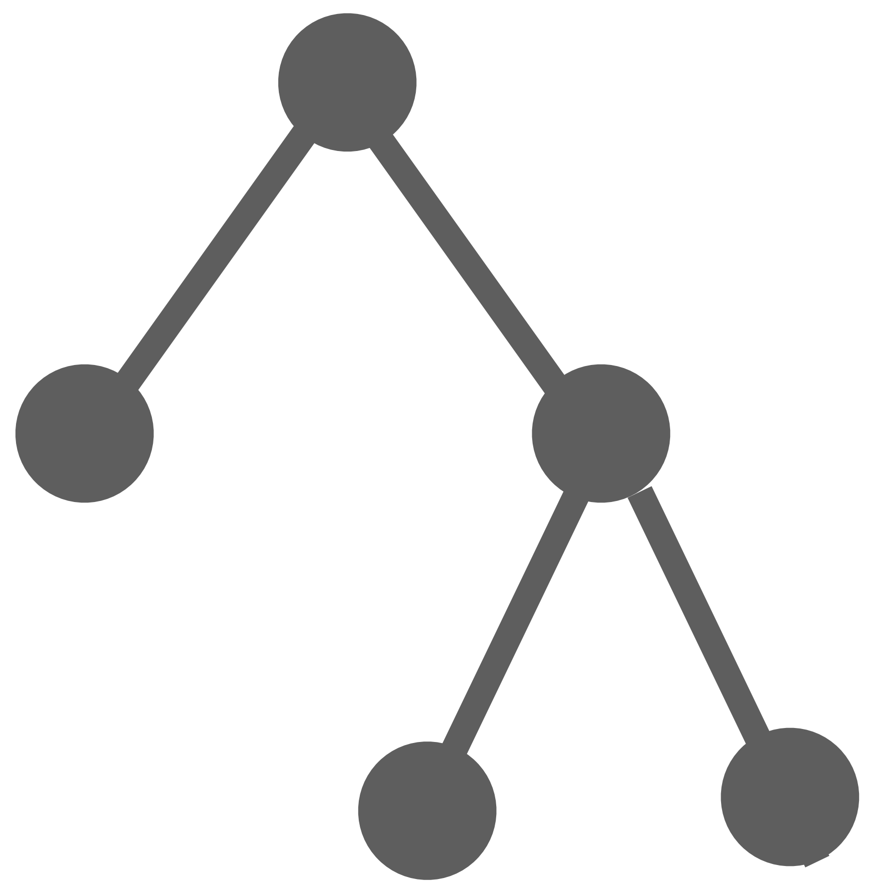

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“DIY Scala Virtualized” (sort of)

Why, oh Why?

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Why **reified** intermediate representation?

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Freedom of interpretation. (Visualization, Simulation, …)

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Use case coming in a minute.

Aspects of a deeply-embedded DSL

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Domain

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Syntax

Aspects of a deeply-embedded DSL

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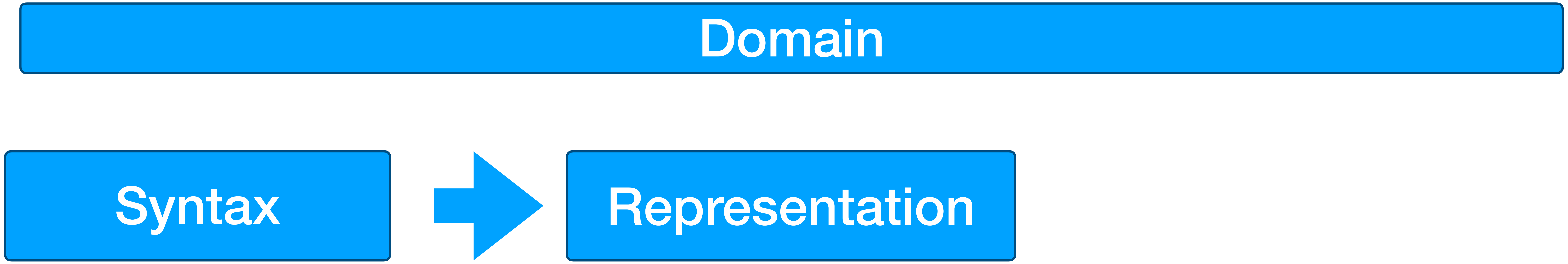
Syntax

What we write

Aspects of a deeply-embedded DSL



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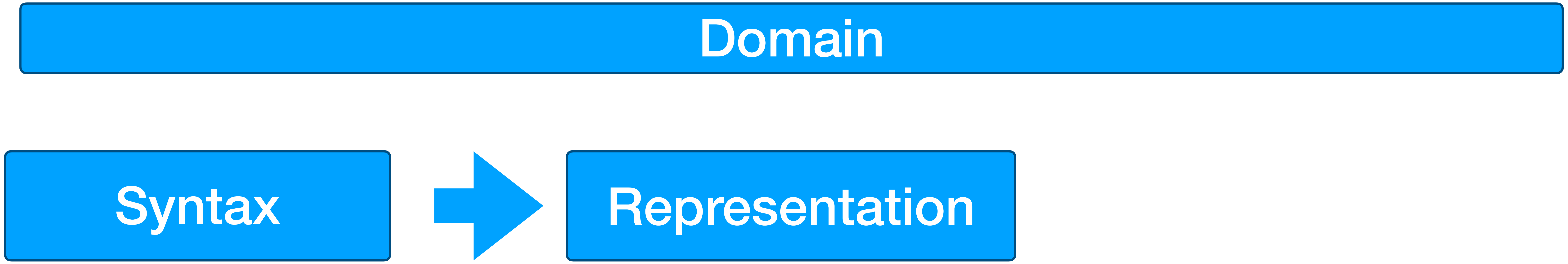

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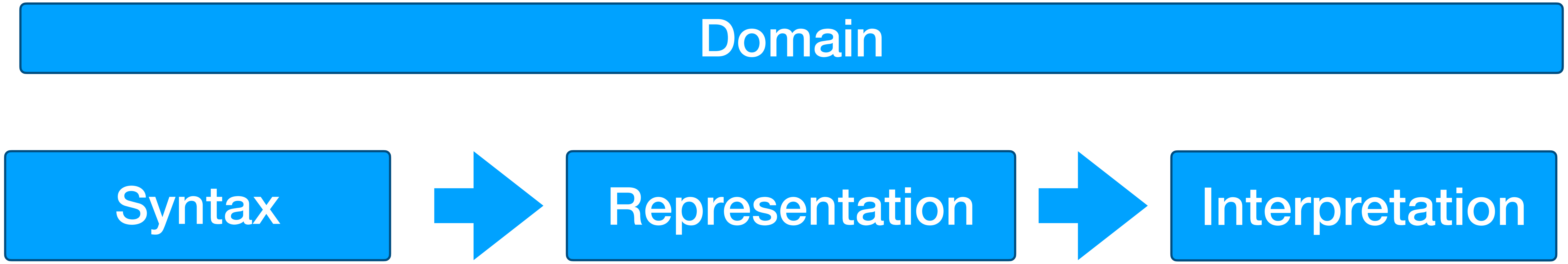

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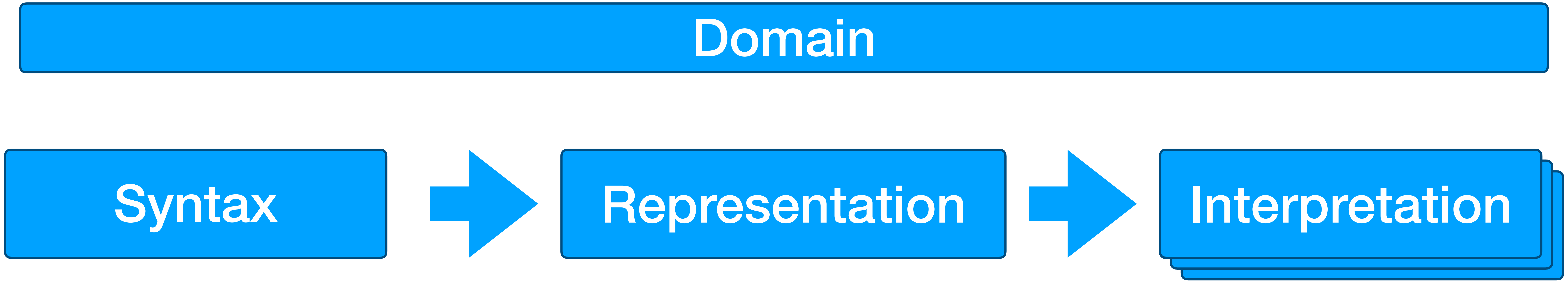

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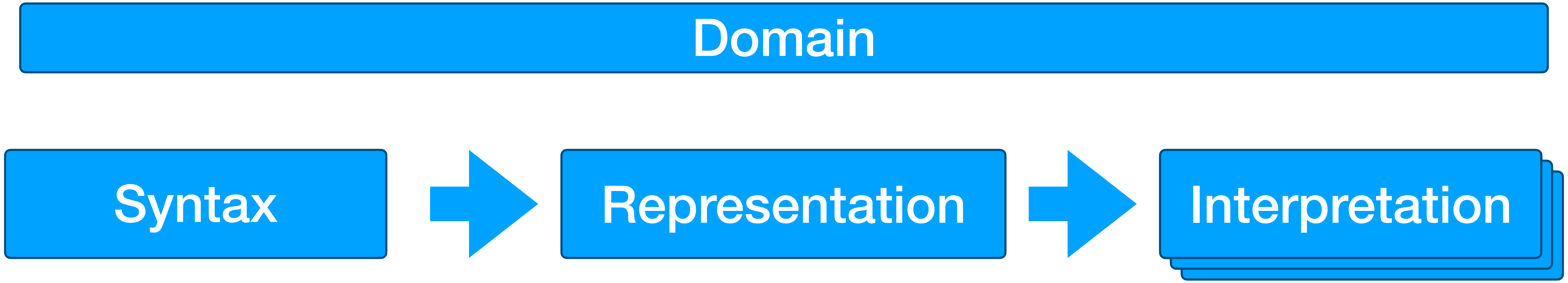
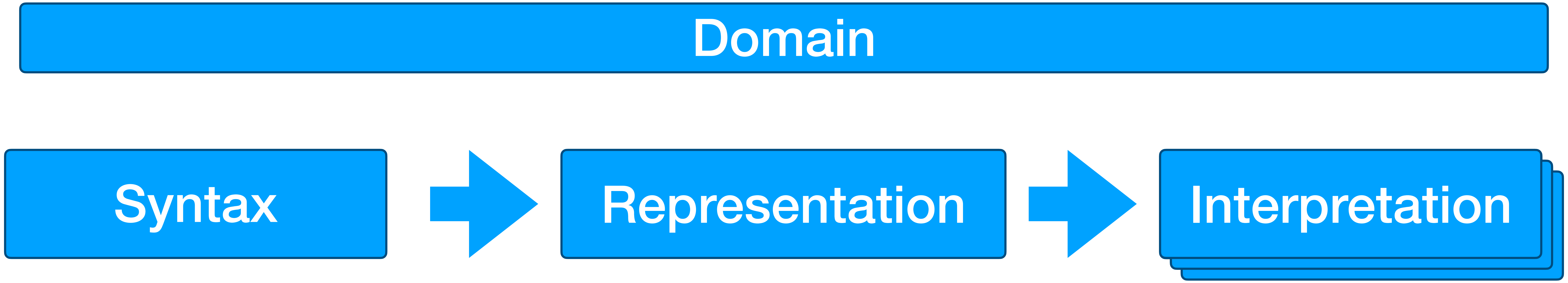


What we write

What we prefer to operate on

- Run

Aspects of a deeply-embedded DSL



What we write

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- Run
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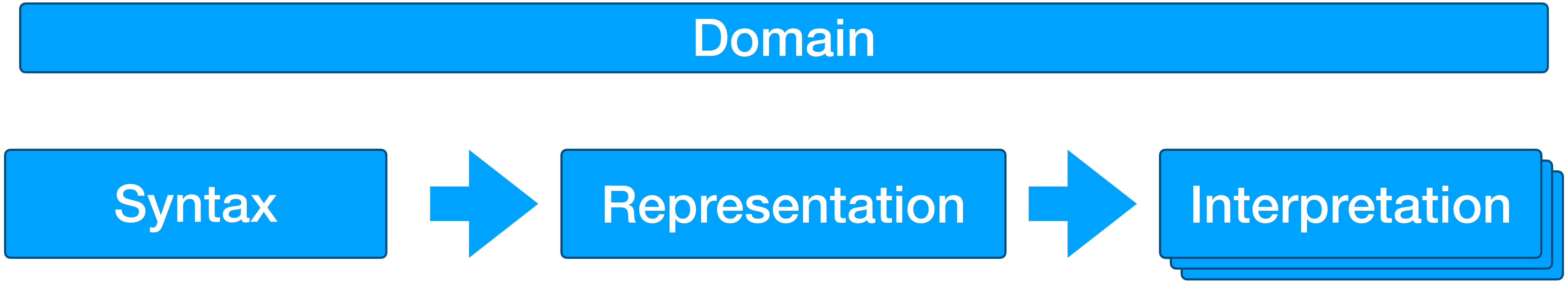

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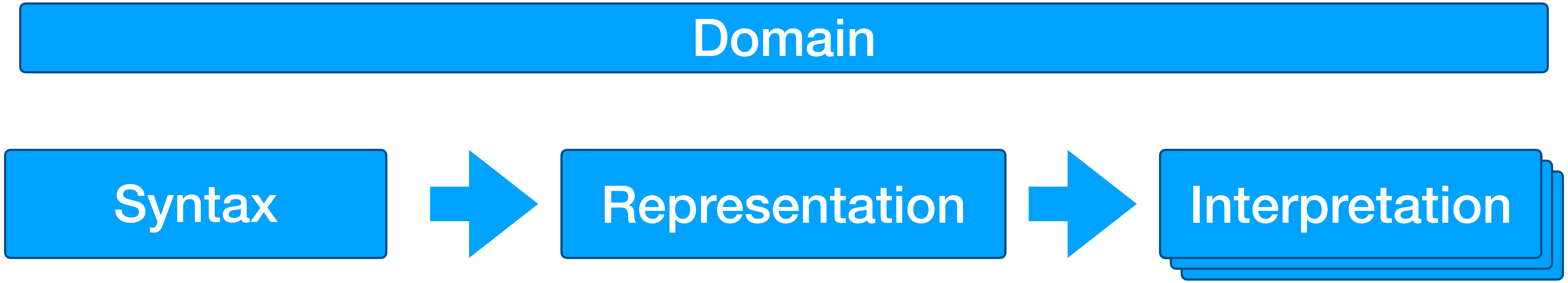

What we write

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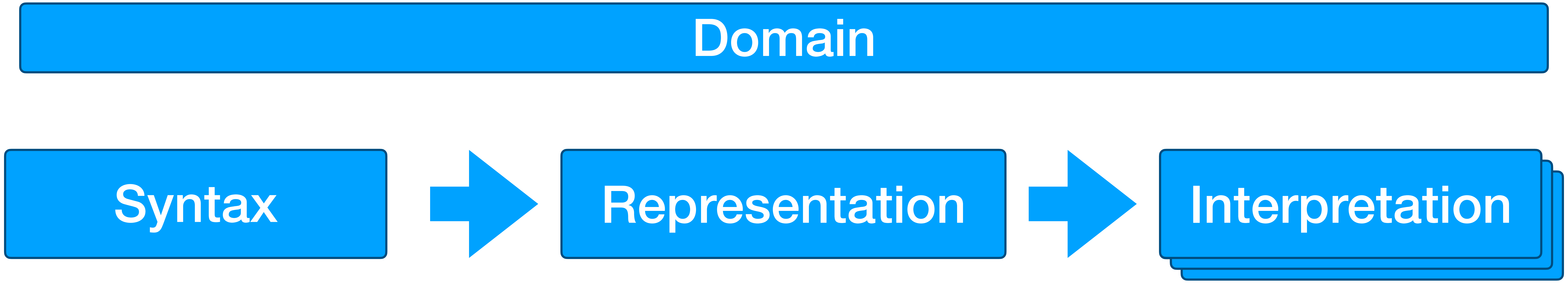

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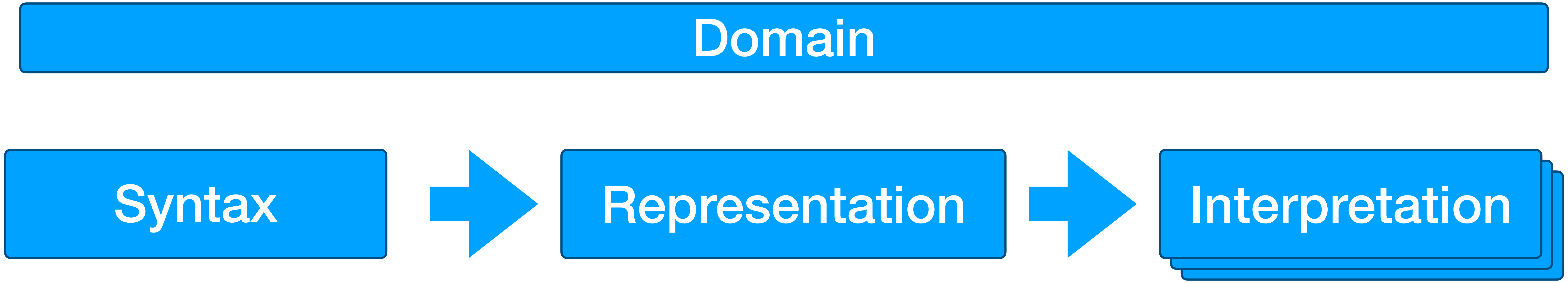

What we write

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Aspects of a deeply-embedded DSL

Domain

Syntax → Representation → Interpretation

What we write

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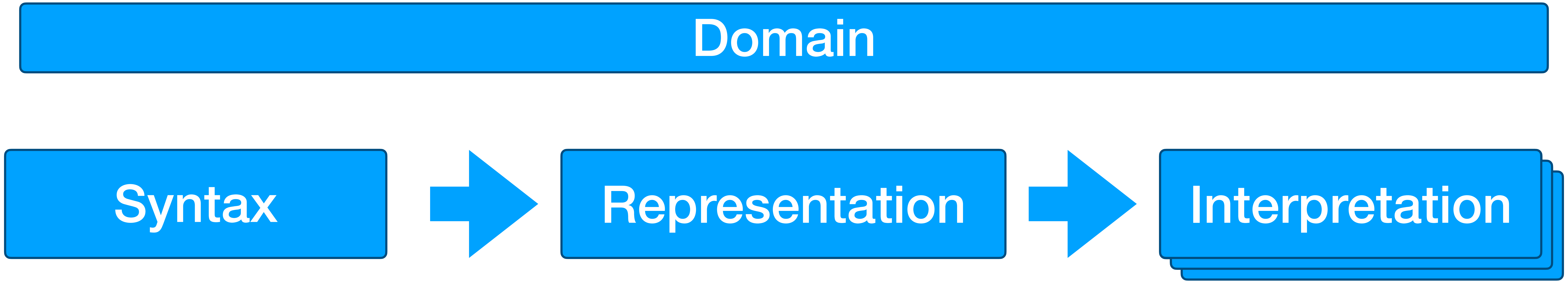

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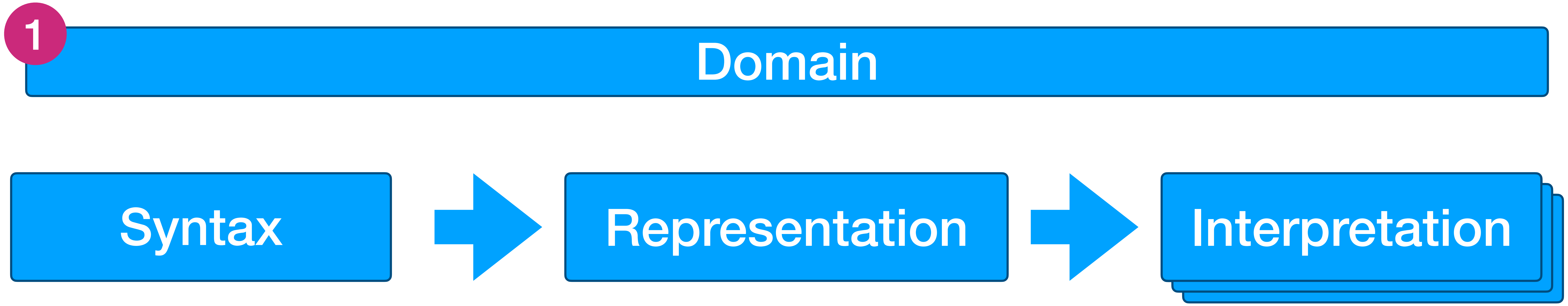

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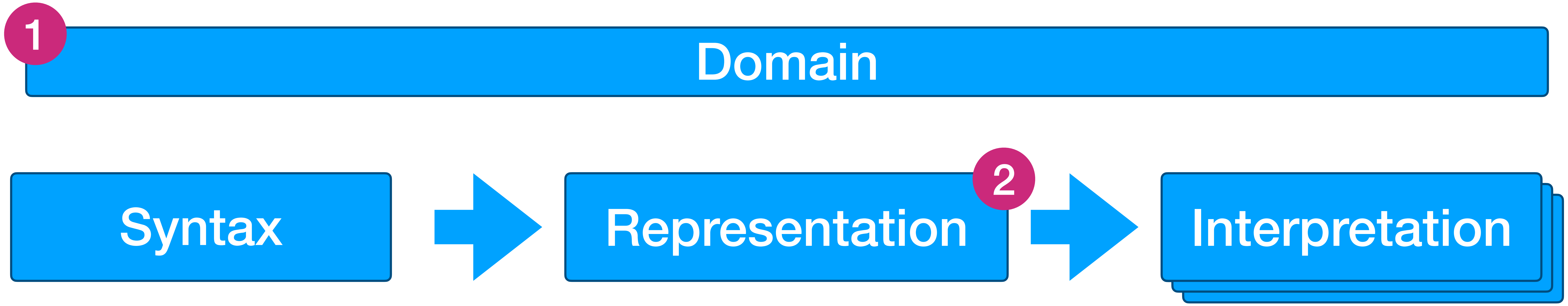

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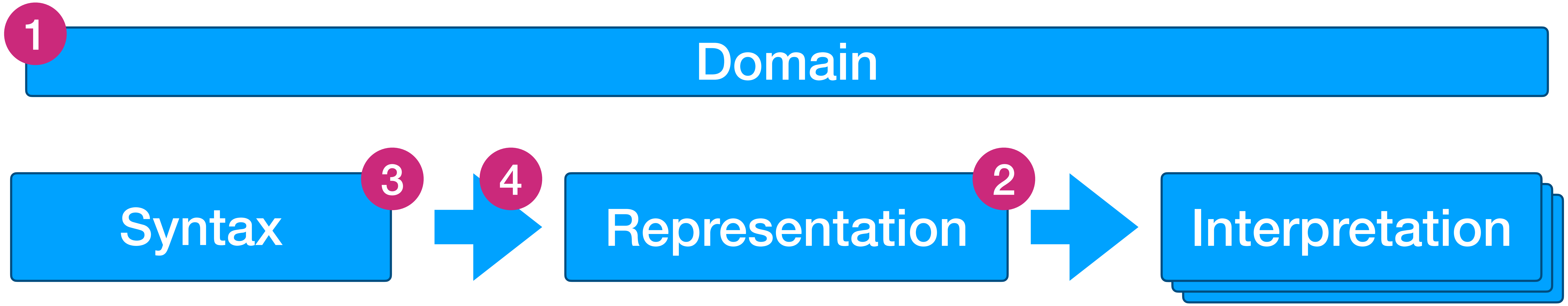

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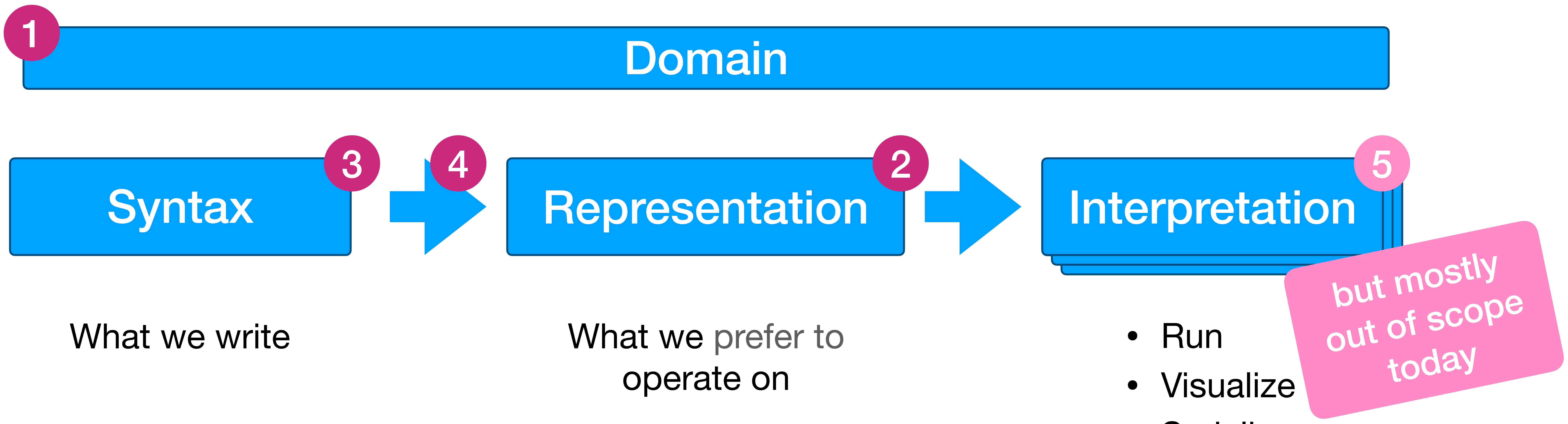

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Domain: Workflows

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“A fault-oblivious stateful function that orchestrates activities.”

— *cadenceworkflow.io*

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  - **without explicit database**

Example: Equipment Request

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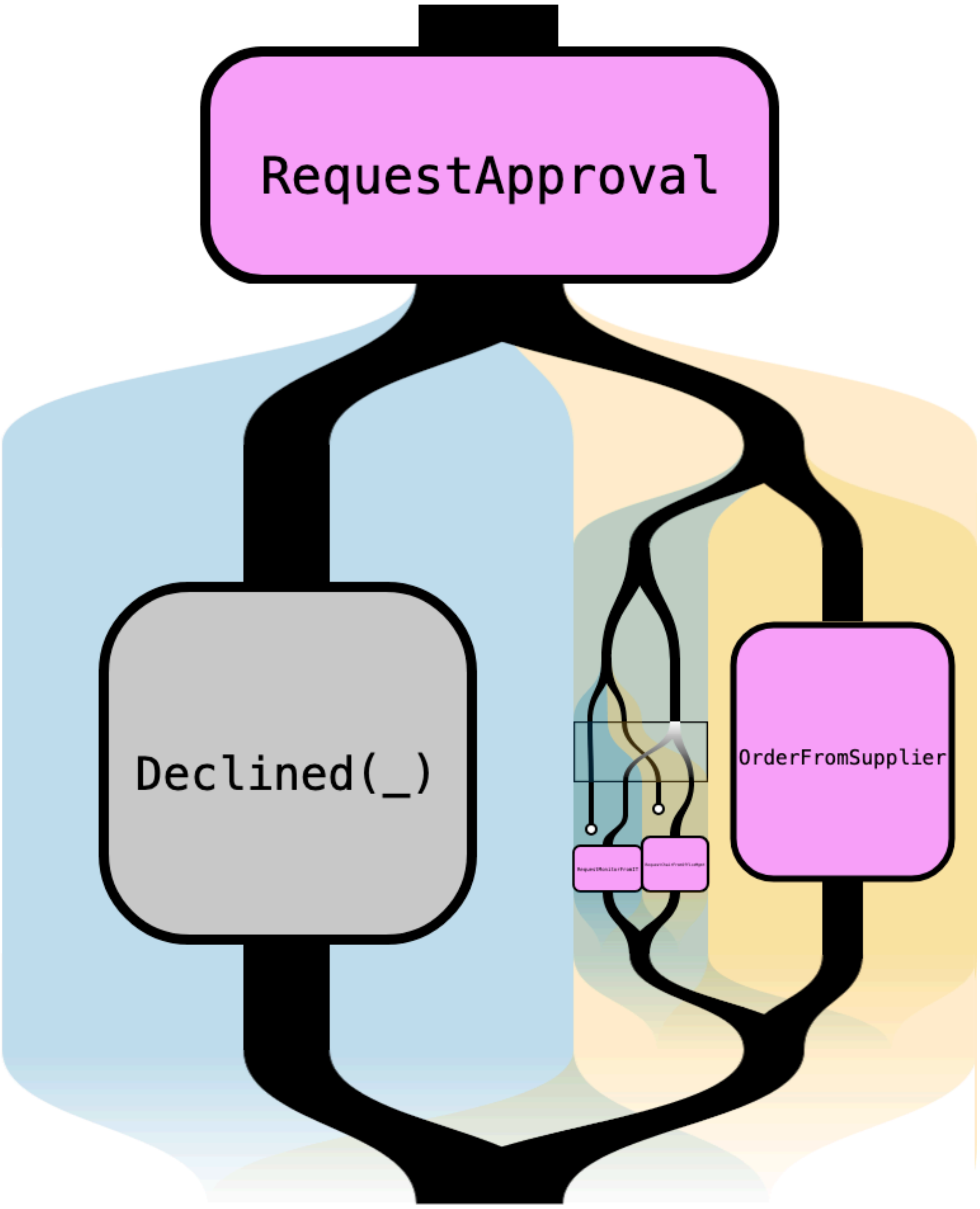

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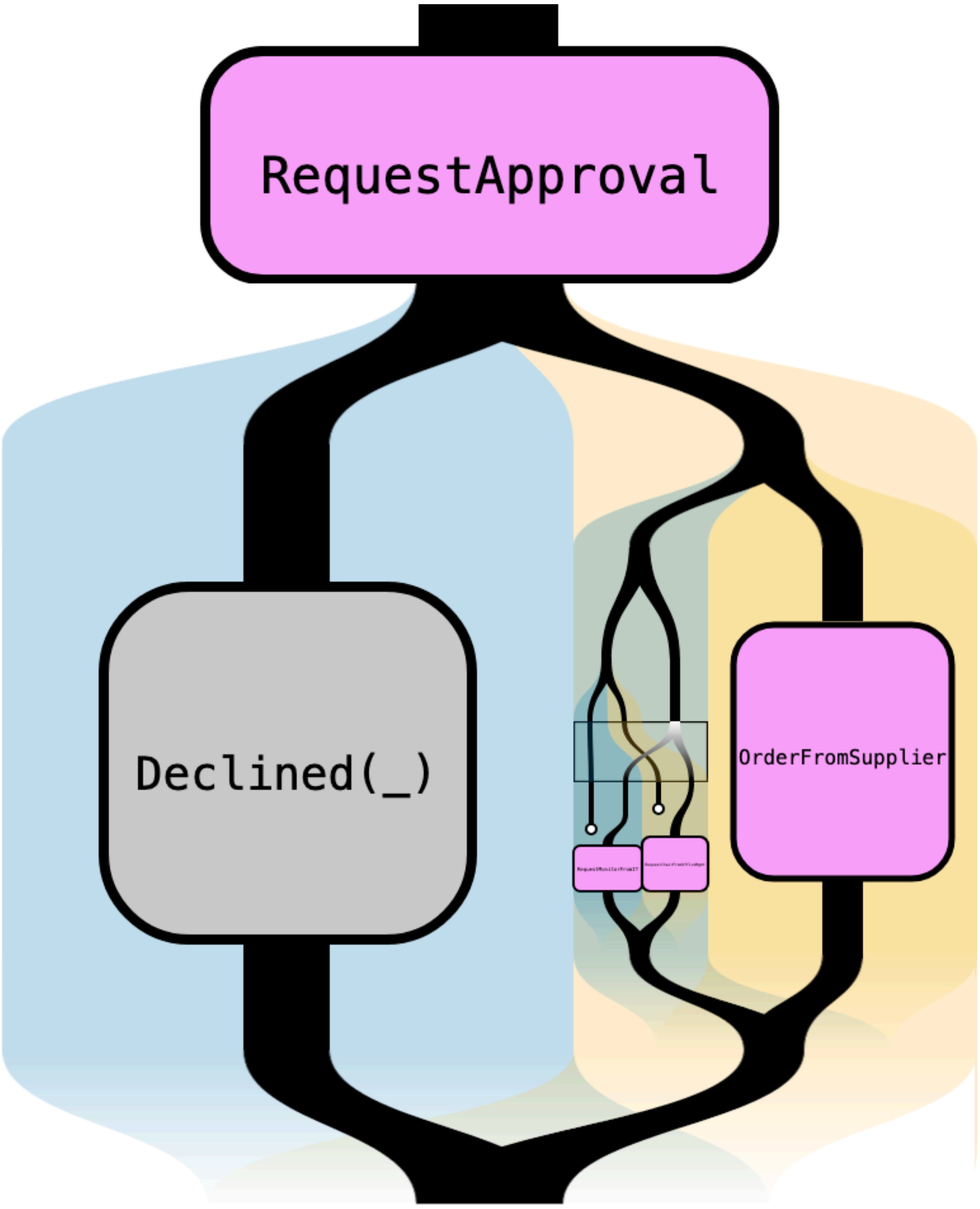

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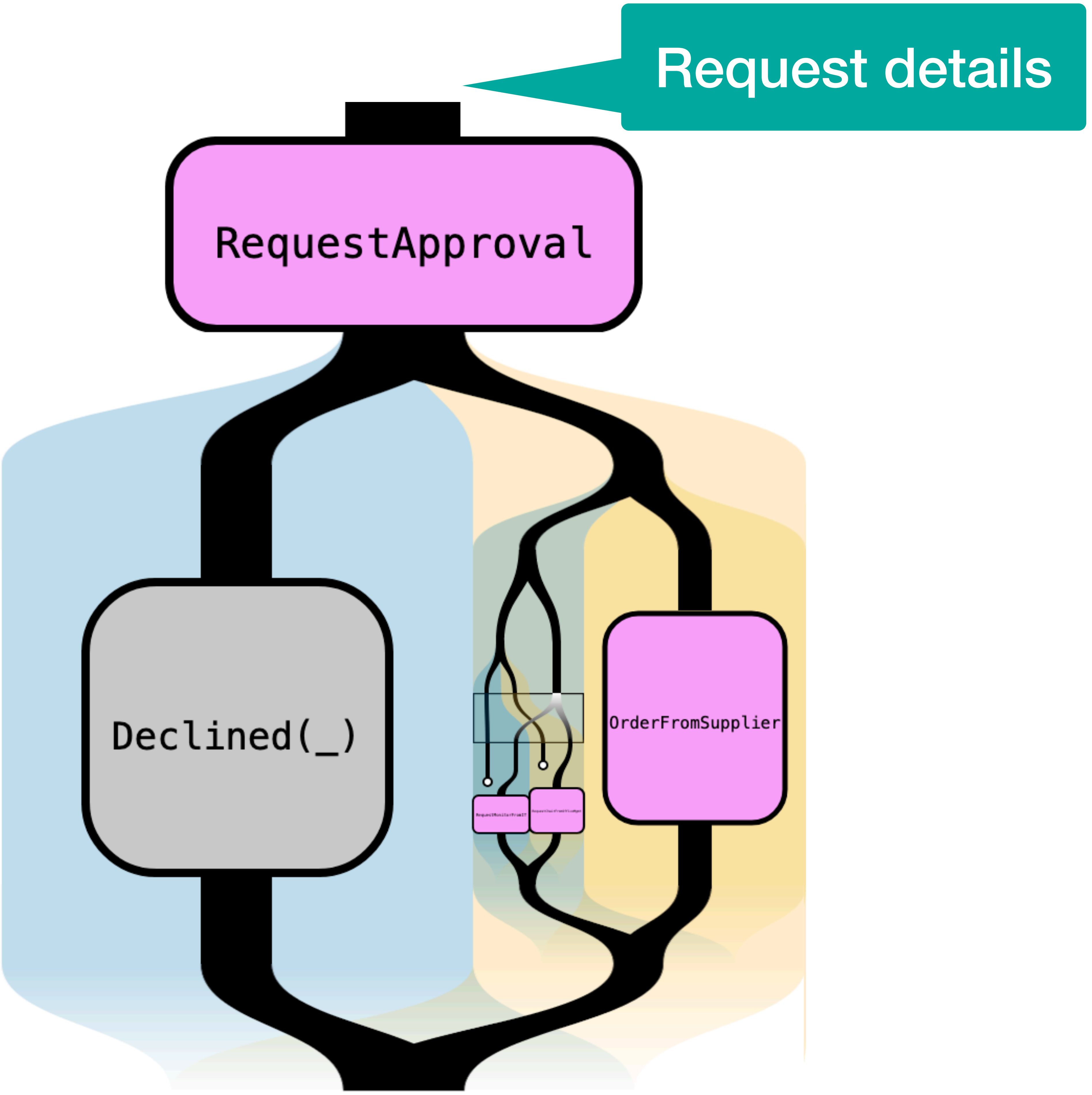

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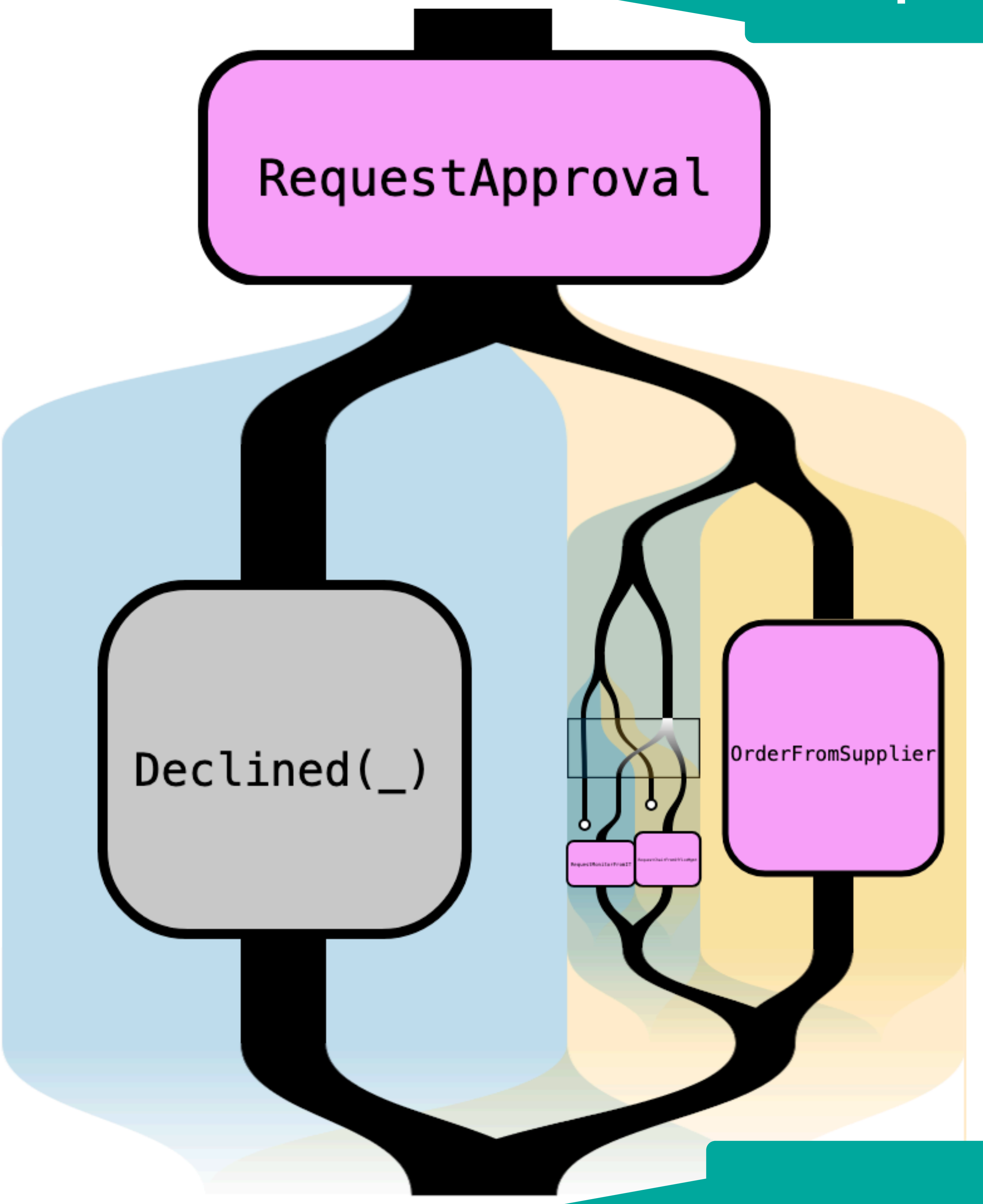

Result
(declined, fulfilled, failure)

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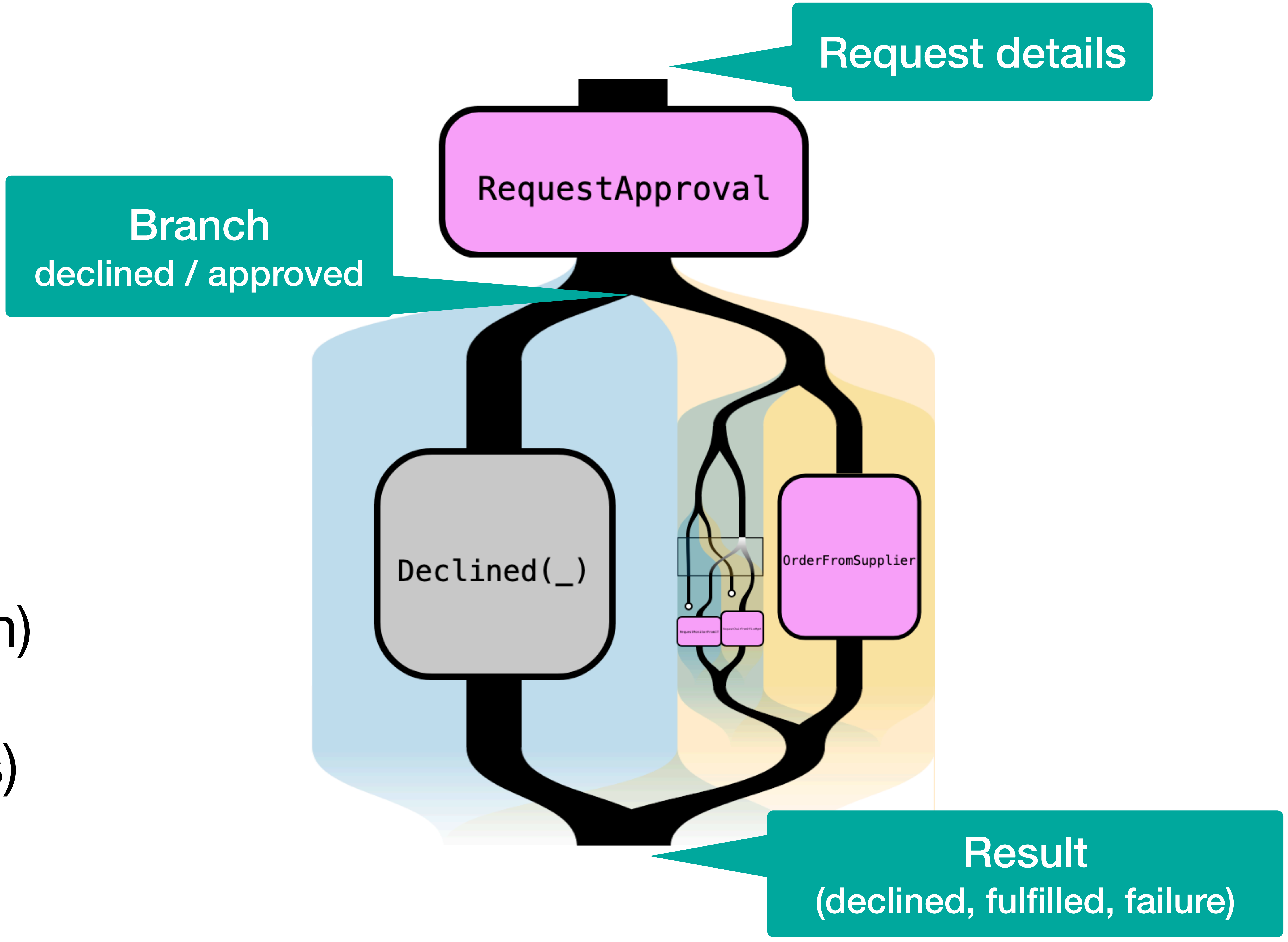

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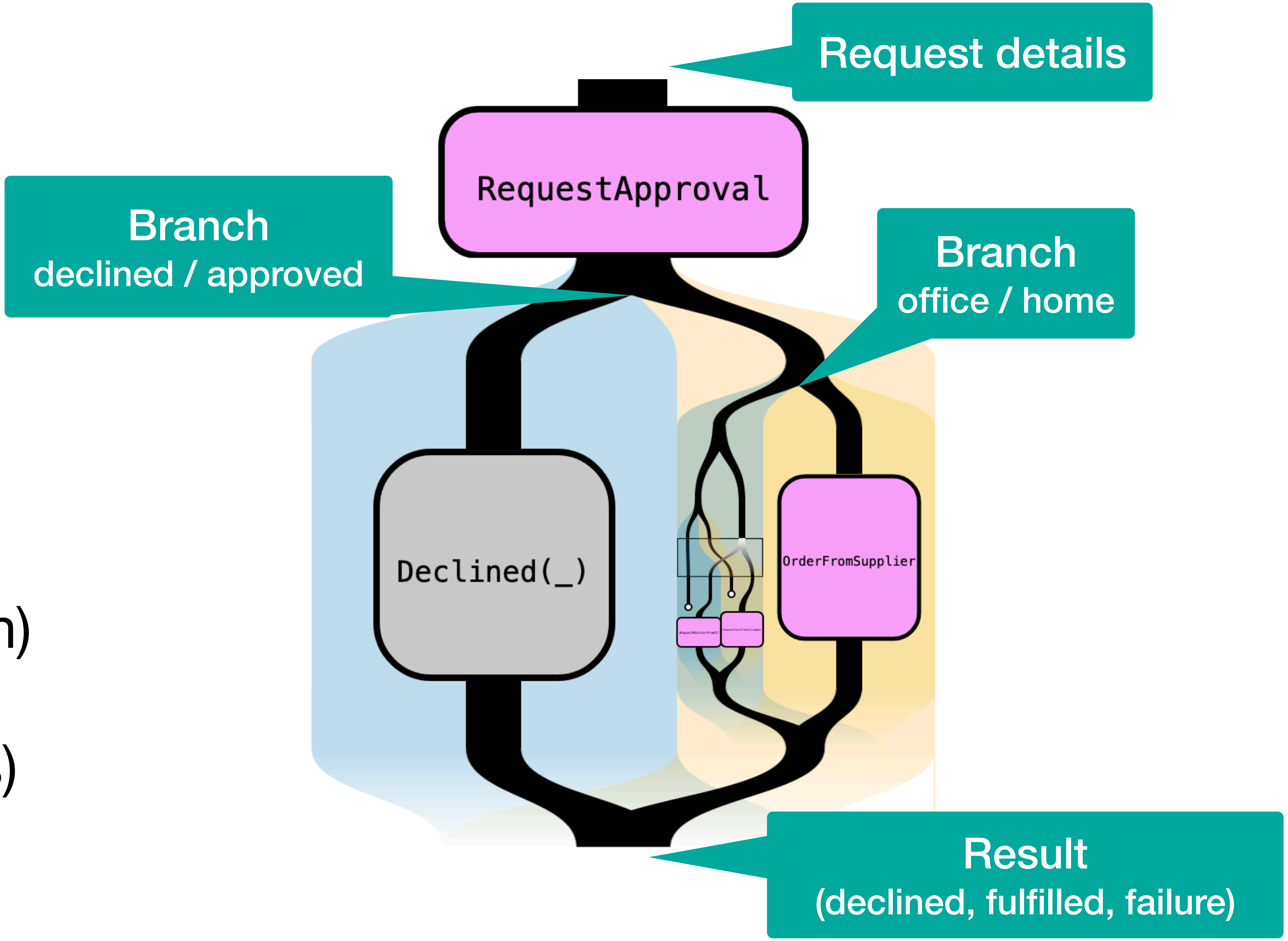

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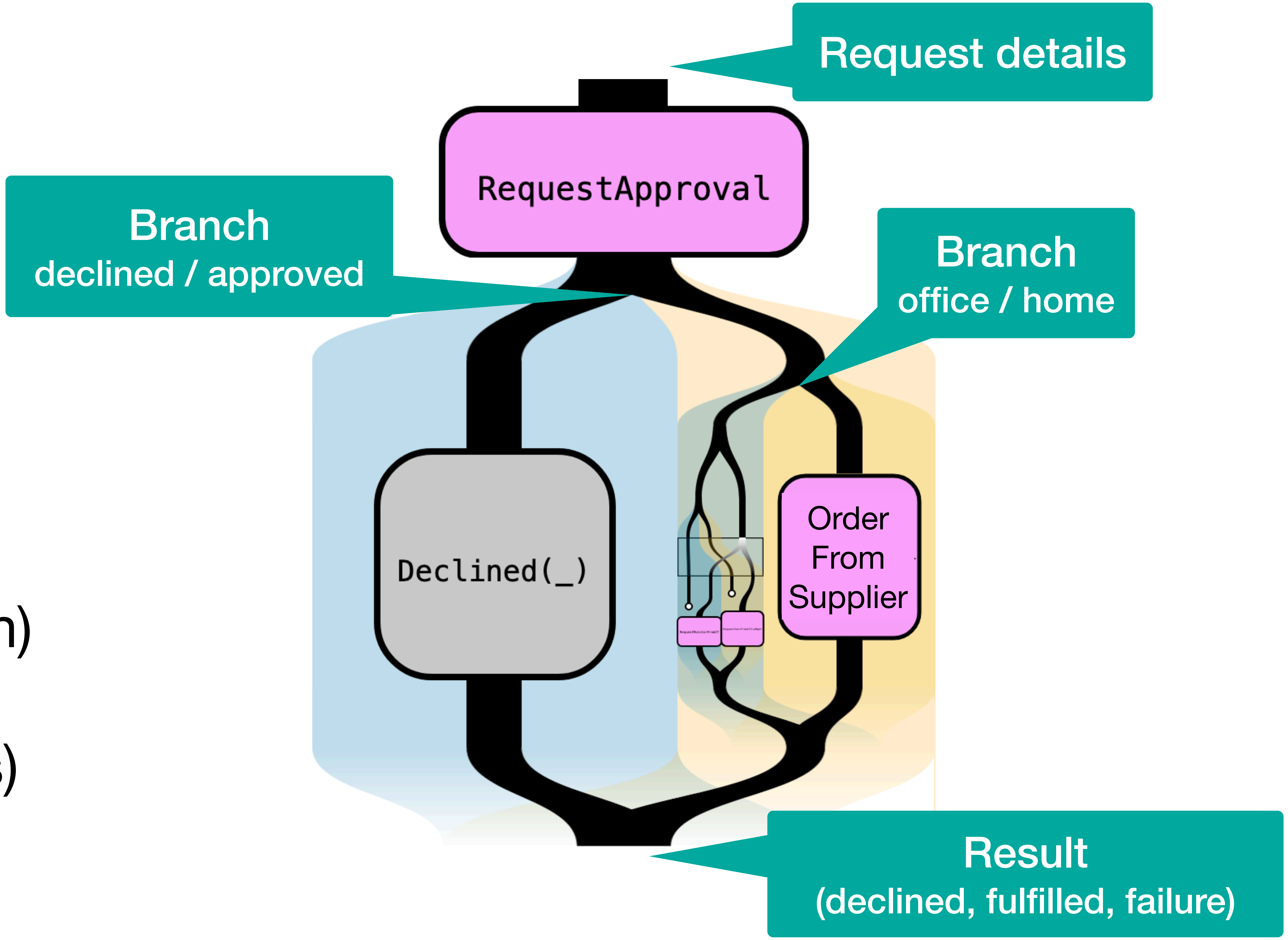

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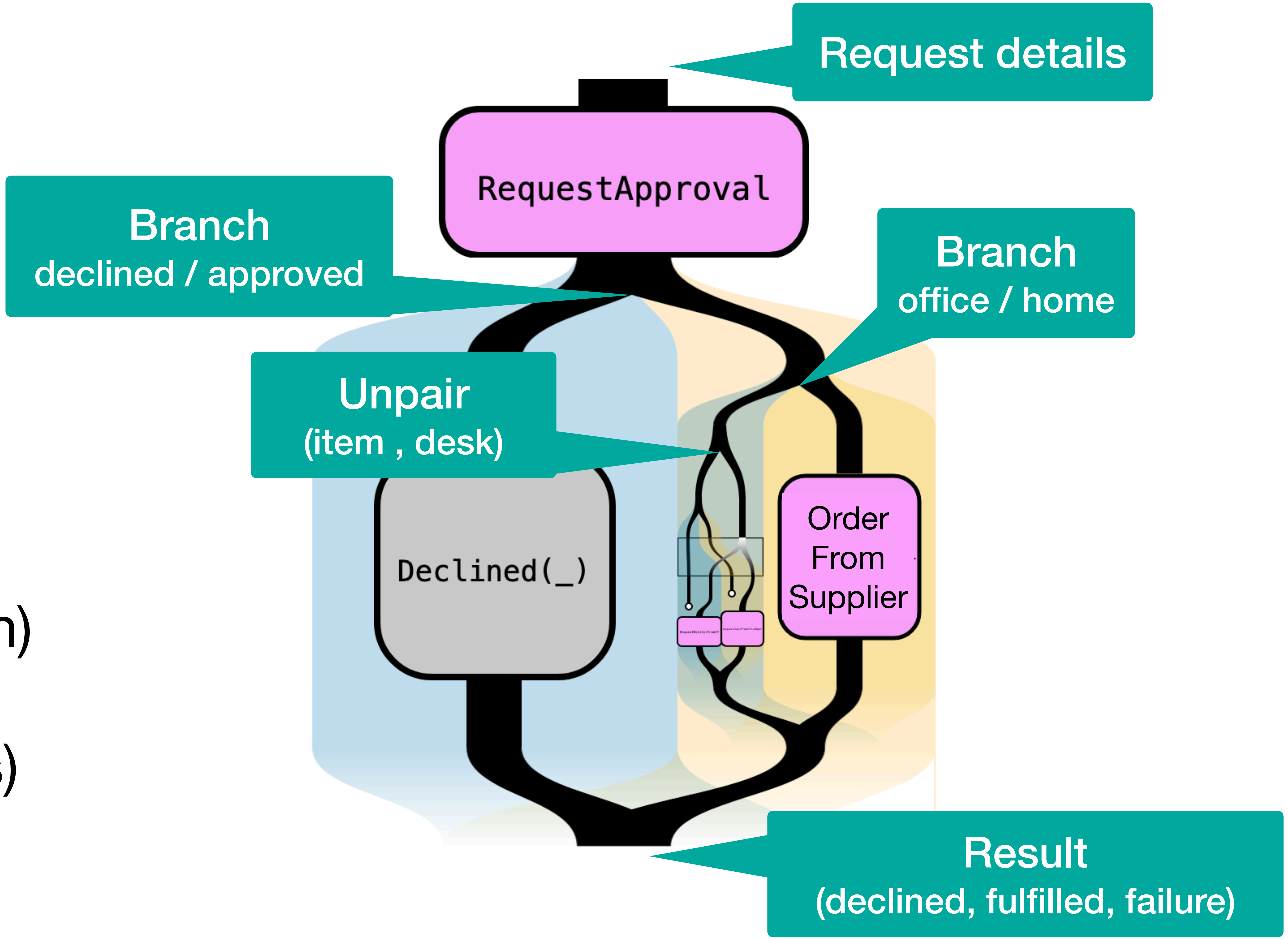

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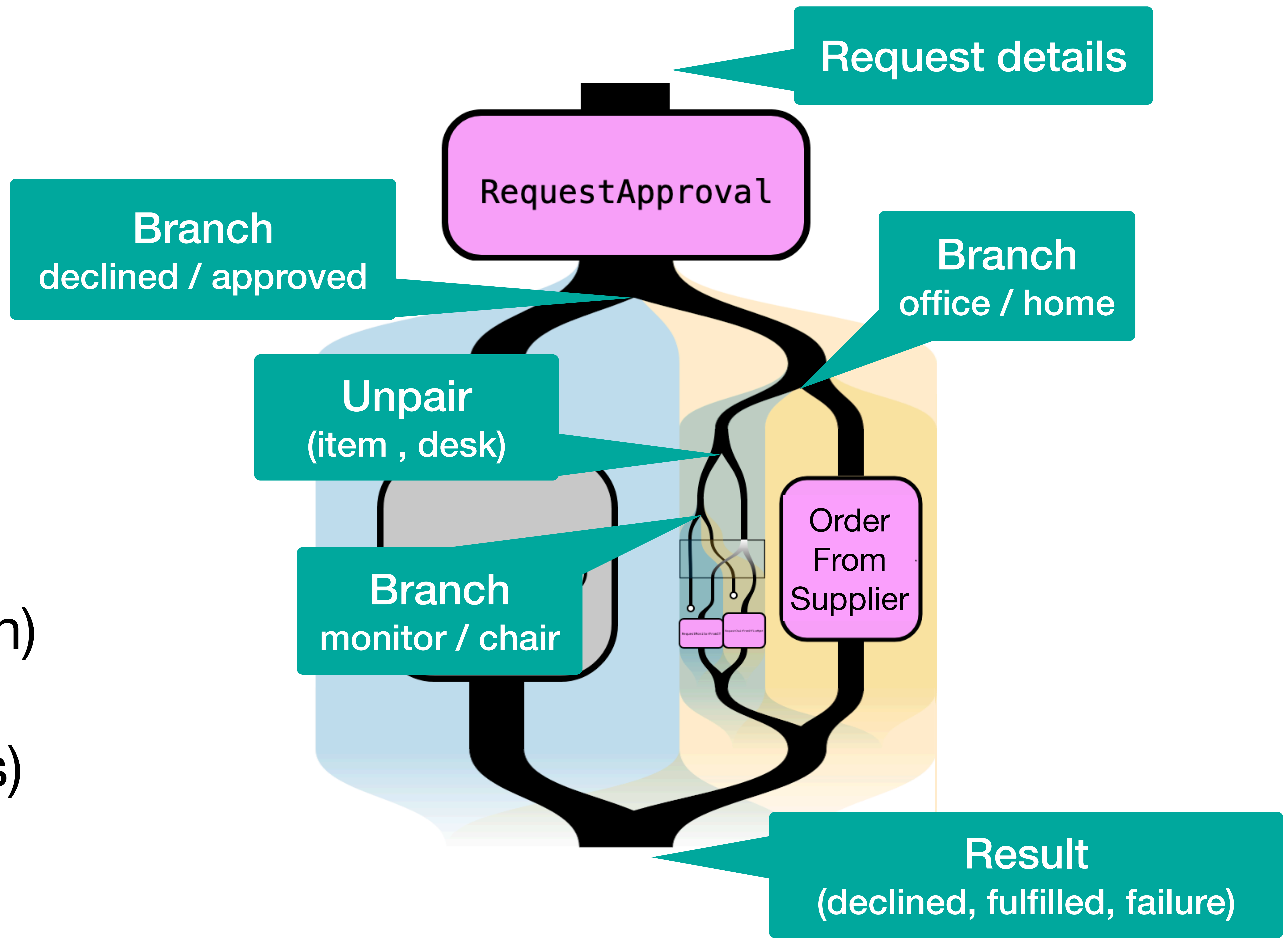

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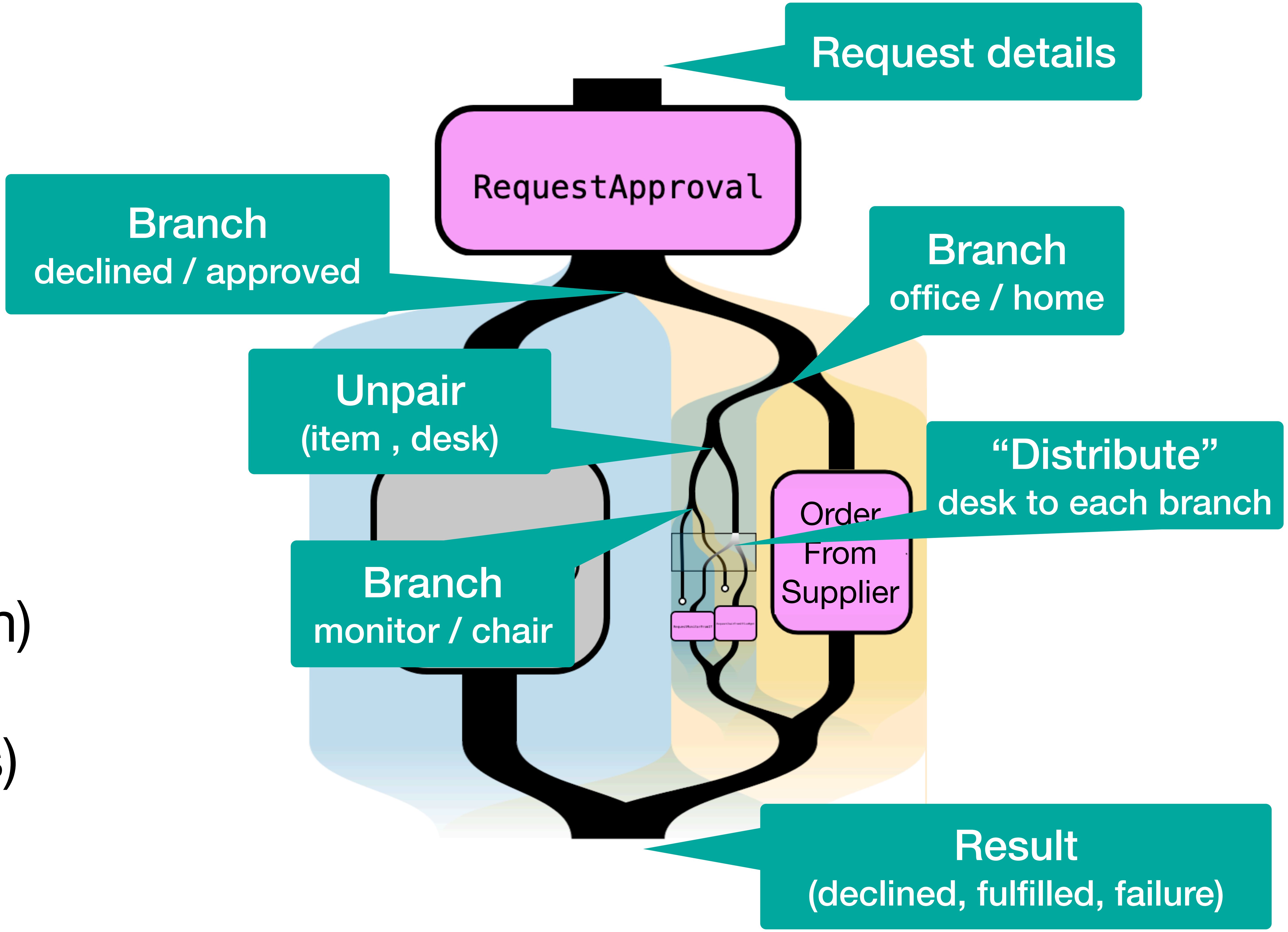

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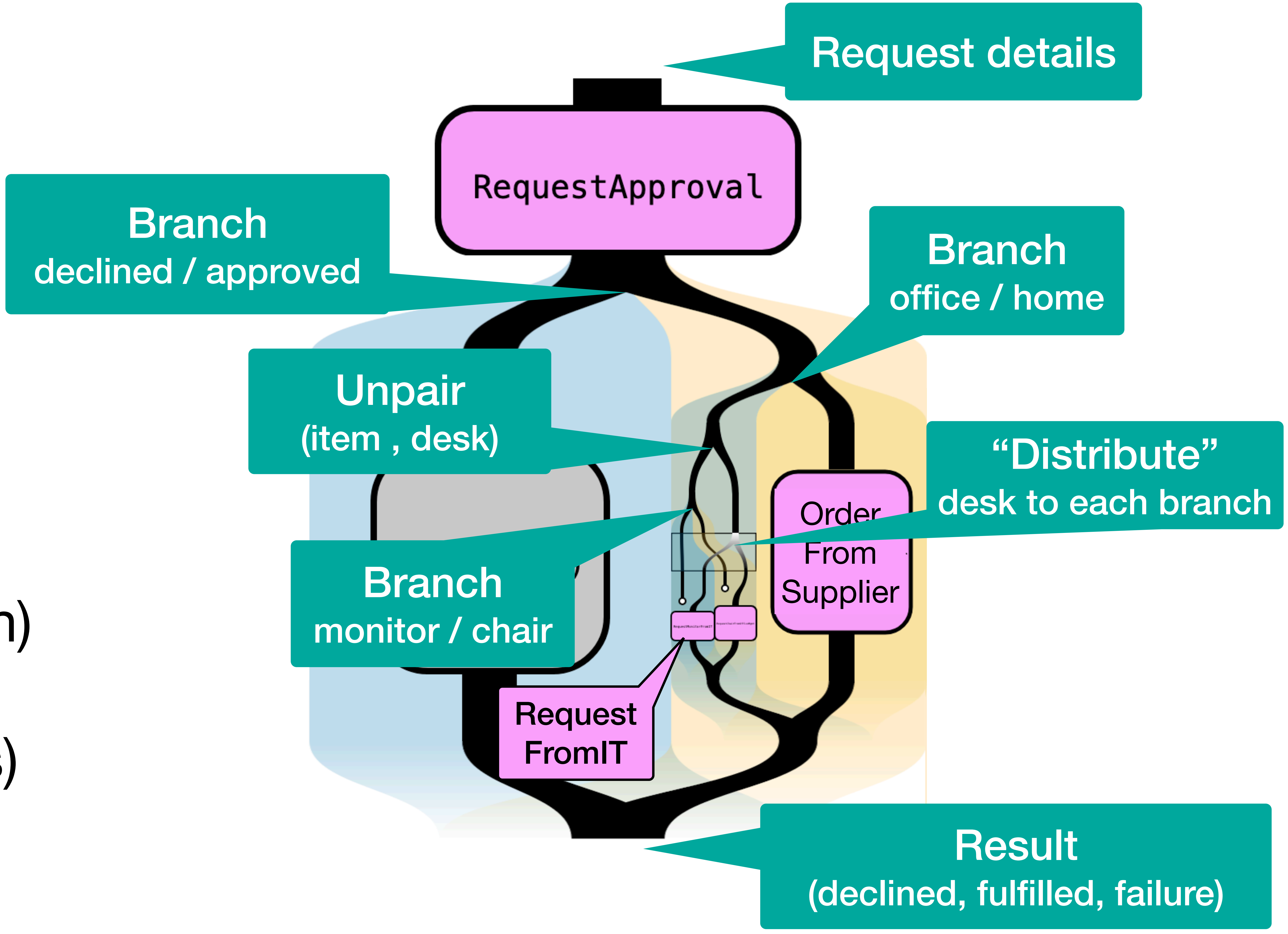

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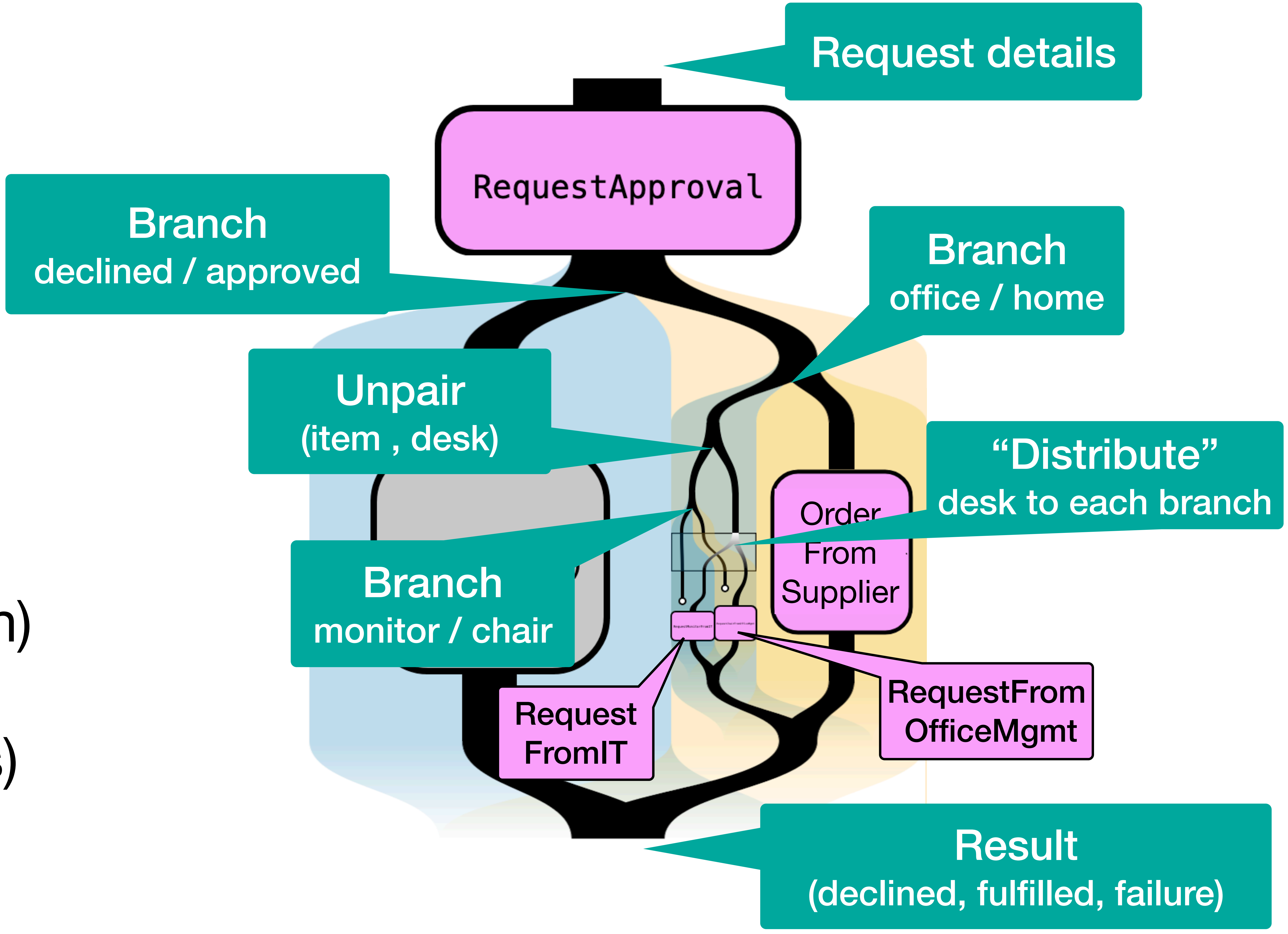

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  - *without rewriting* existing workflows

What Do Others Do?

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- User-defined **functions**
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What Do Do?

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  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
- **Durable** execution
  - **Serializable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
- **Migration path**
  - to potential External DSL, Graphical Editor
  - *without rewriting* existing workflows

What Do Temporal Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
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What Do Temporal Cadence Do?

- Expressive **control flow**
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- User-defined **data types**
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  - **Serializable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
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  - *without rewriting* existing workflows

What Do Temporal Cadence restate Do?

- Expressive **control flow**
    - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
- **Durable** execution
    - **Serializable** state
- **Alternative interpretations**
    - Visualization, Simulation, …
- **Migration path**
    - to potential External DSL, Graphical Editor
    - *without rewriting* existing workflows

What Do Temporal Cadence restate GOLEM Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
- **Durable** execution
  - **Serializable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
- **Migration path**
  - to potential External DSL, Graphical Editor
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What Do Temporal / Cadence / restate / GOLEM / Workflows4s Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
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What Do Temporal, Cadence, restate, GOLEM, Workflows4s Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
- **Durable** execution
  - **Serializable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
- **Migration path**
  - to potential External DSL, Graphical Editor
  - *without rewriting* existing workflows

What Do Temporal Cadence restate GOLEM Workflows4s Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
- **Durable** execution
  - **Serializable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
- **Migration path**
  - to potential External DSL, Graphical Editor
  - *without rewriting* existing workflows

Just use the **host language**

What Do Temporal, Cadence, restate, GOLEM, Workflows4s Do?

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- User-defined **functions**
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Just use the **host language**

- **Durable** execution
  - ~~**Serializable** state~~ **Recoverable** state
- **Alternative interpretations**
  - Visualization, Simulation, …
- **Migration path**
  - to potential External DSL, Graphical Editor
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What Do Temporal Cadence restate GOLEM Workflows4s Do?

- Expressive **control flow**
  - Branching, Loops, Concurrency
- User-defined **functions**
- User-defined **data types**
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Just use the **host language**

& **event sourcing**

- log result of each activity
- **recovery:** restart,
  but use recorded activity results

What Do Temporal Cadence restate GOLEM Workflows4s Do?

- Expressive **control flow**
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What Do Temporal, Cadence, restate, GOLEM, Workflows4s Do?

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Just use the **host language**

& **event sourcing**

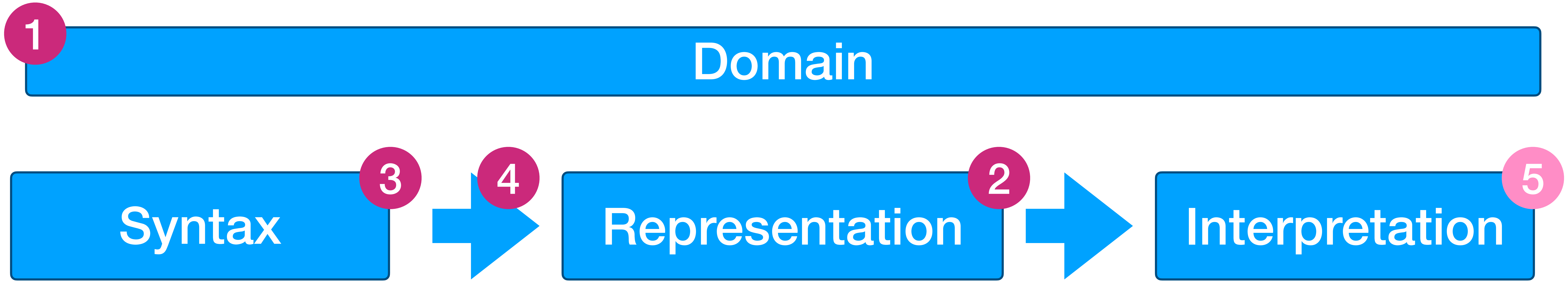
- log result of each activity
- **recovery:** restart,
  but use recorded activity results

Off-limits

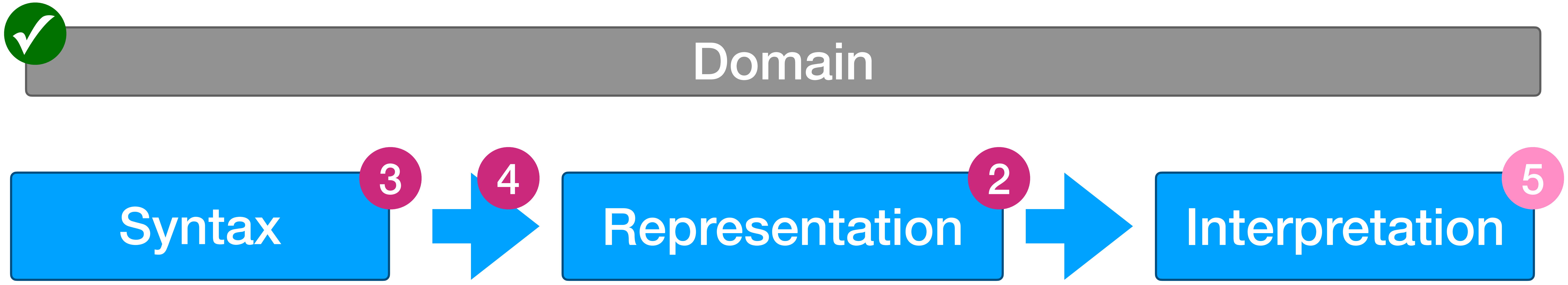
Not in control of representation.

There's only a single interpretation
of the host language: running it.

Agenda



Agenda



Roles

Roles

Language
Developer

design & implement
the Workflow DSL

Roles




This is you!

Language
Developer

design & implement
the Workflow DSL

Roles

```
import libretto.lambda.Lambdas
object Flow:
  val lambdas: Lambdas[Flow, **, …] =
    Lambdas[Flow, **, …](...)
  opaque type Expr[A] = lambdas.Expr[A]
  def apply[A, B](
    f: Expr[A] => Expr[B],
  ): Flow[A, B] =
    lambdas.delambdify(..., f)
```

This is you!

Language Developer

design & implement the Workflow DSL

Roles

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This is you!

Workflow Developer

create workflows *using* the DSL

Language Developer

design & implement the Workflow DSL

Roles

```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
    case ForOffice(Chair(_) ** deskLoc) =>
      requestChairFromOfficeMgmt(deskLoc)
    case WorkFromHome(item ** address) =>
      orderFromSupplier(item ** address)
  }
}
```

Workflow Developer

create workflows *using* the DSL

```
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Workflow User

Business person

Workflow Developer

create workflows *using* the DSL

This is you!

Language Developer

design & implement the Workflow DSL

Roles

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```

This is you!

Workflow User	Workflow Developer	Language Developer	Library Code
Business person	create workflows *using* the DSL	design & implement the Workflow DSL	reusable bits from libretto-lambda

Roles

```
Flow { req =>
  req switch {
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  val lambdas: Lambdas[Flow, **, …] =
    Lambdas[Flow, **, …](...)
  opaque type Expr[A] = lambdas.Expr[A]
  def apply[A, B](
    f: Expr[A] => Expr[B],
  ): Flow[A, B] =
    lambdas.delambdify(..., f)
```

```
// approximately
def delambdify[A, B](
  f: Expr[A] => Expr[B]
): Flow[A, B] | ... =
  val a : Expr[A] = Var(freshId())
  val b  : Expr[B] = f(a)
  eliminate(a, from = b)
```

Workflow User

Business person

Workflow Developer

create workflows *using* the DSL

This is you!

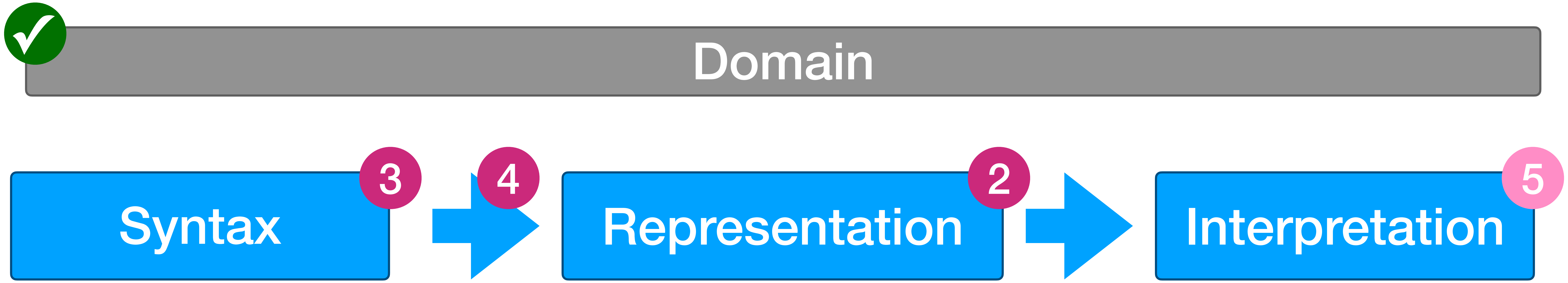
Language Developer

design & implement the Workflow DSL

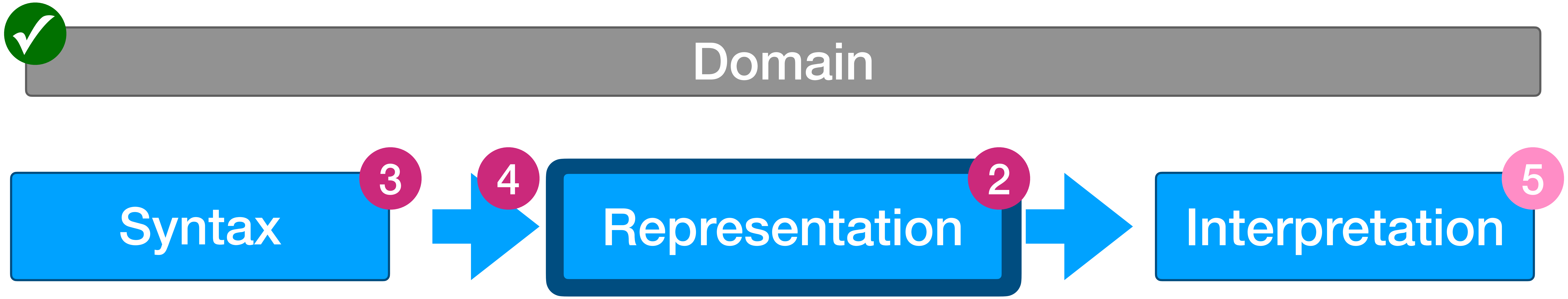
Library Code

reusable bits from libretto-lambda

Agenda



Agenda



Representing (eDSL) Programs

Choosing a Suitable Data Structure *(“AST”)*

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

```
enum Expr[A]:
  case IntConstant(i: Int)                        extends Expr[Int]
  case Plus(l: Expr[Int], r: Expr[Int]) extends Expr[Int]
  ...
```

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

straightforward

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Representing (eDSL) Programs

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  ...
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straightforward

until you need functions

Representing (eDSL) Programs

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  ...
```

straightforward

until you need functions

Gain-of-functions crossroads

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

```scala
enum Expr[A]:
  case IntConstant(i: Int)                      extends Expr[Int]
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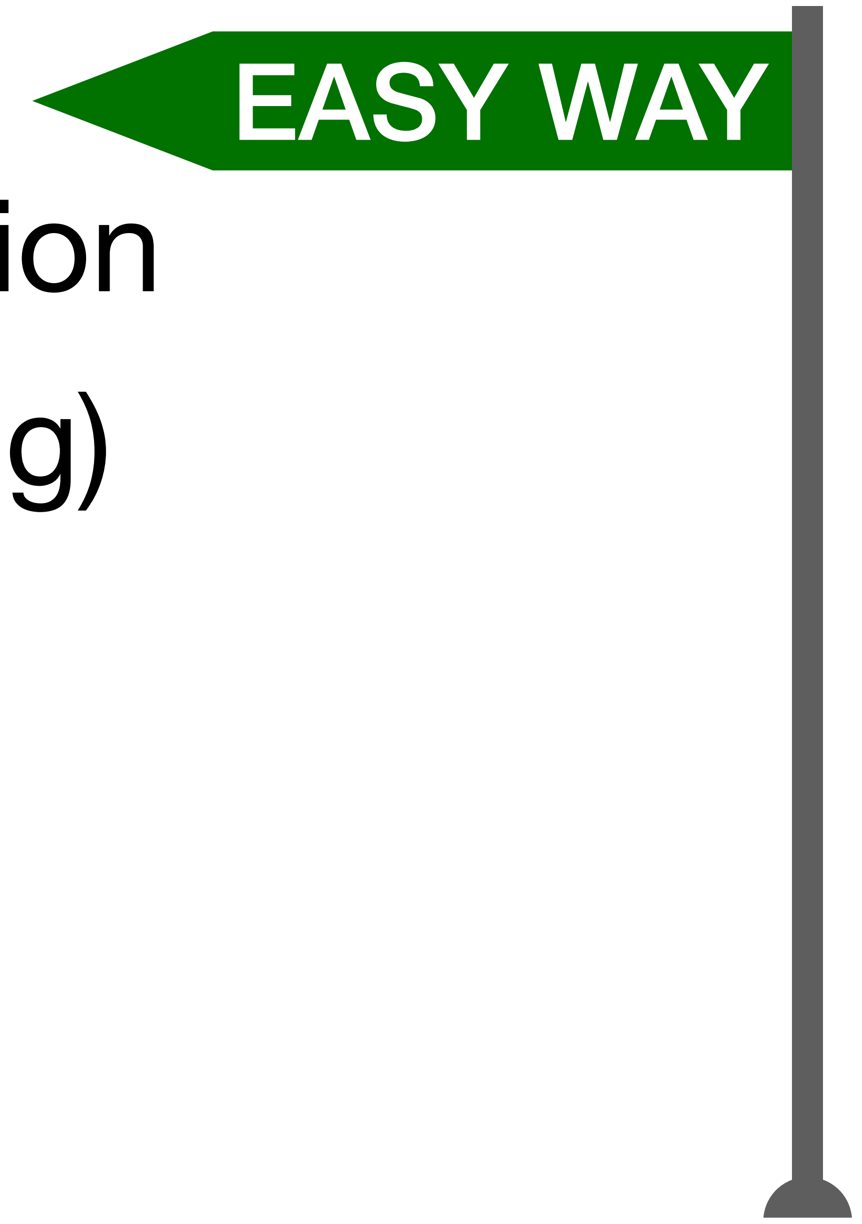
  ...
```

straightforward

until you need functions

Gain-of-functions crossroads



Just use a Scala function

(***"shallow"*** embedding)

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

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```

straightforward

until you need functions

Gain-of-functions crossroads

EASY WAY

Just use a Scala function

(***"shallow"*** embedding)

```
case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
  extends Expr[B]
```

Representing (eDSL) Programs

Choosing a Suitable Data Structure (*"AST"*)

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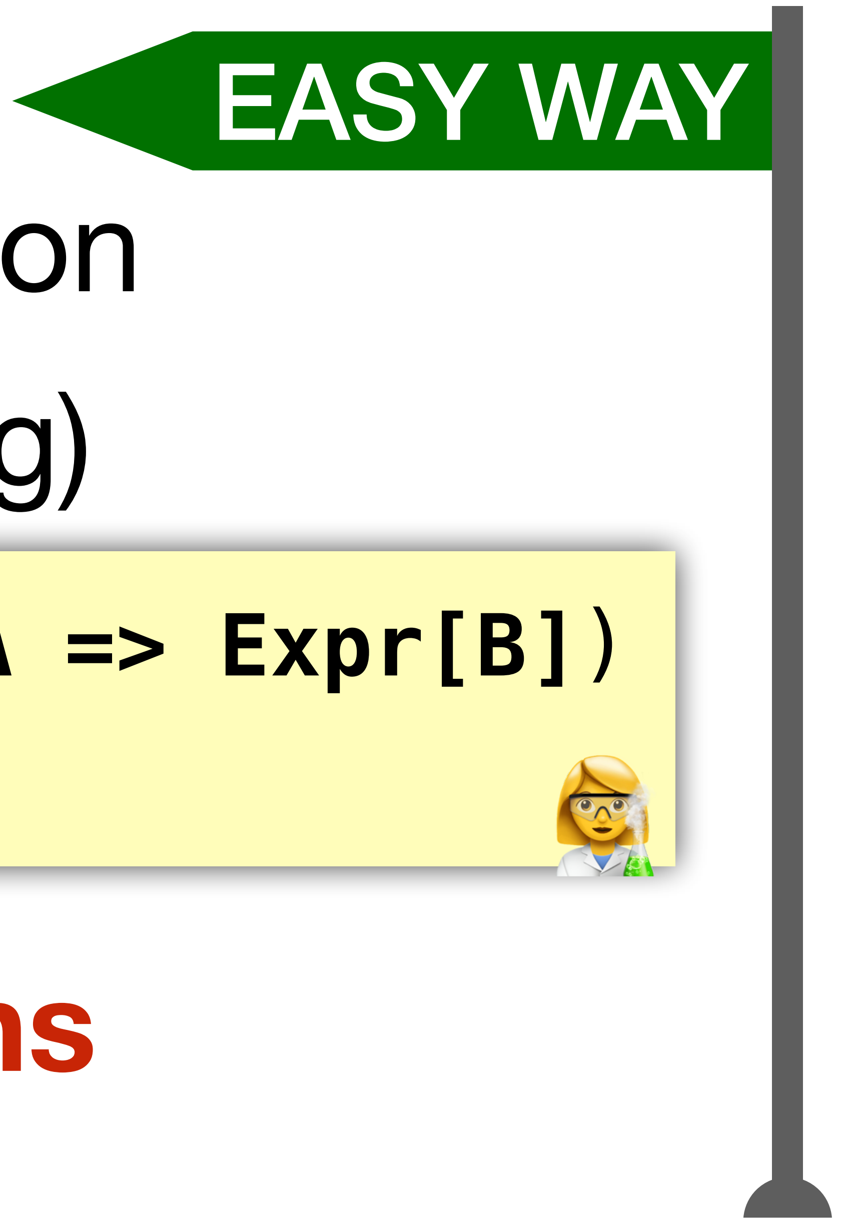
straightforward

until you need functions

Gain-of-functions crossroads



Just use a Scala function

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```
case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
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no alternative interpretations

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

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  case IntConstant(i: Int)                    extends Expr[Int]
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straightforward

until you need functions

Gain-of-functions crossroads

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```
case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
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no alternative interpretations

DEAD END

Representing (eDSL) Programs

Choosing a Suitable Data Structure (*“AST”*)

straightforward

until you need functions

```
enum Expr[A]:
  case IntConstant(i: Int)                      extends Expr[Int]
  case Plus(l: Expr[Int], r: Expr[Int]) extends Expr[Int]
  ...
```

Gain-of-functions crossroads

EASY WAY | RIGHT WAY

Just use a Scala function

(***“shallow”*** embedding)

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case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
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no alternative interpretations

DEAD END

deviantart.com/fernandesvincent

Functions as Data

(***“deep”*** embedding)

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

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enum Expr[A]:
  case IntConstant(i: Int)                    extends Expr[Int]
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straightforward

until you need functions

Gain-of-functions crossroads

Just use a Scala function

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case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
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no alternative interpretations

deviantart.com/fernandesvincent

Functions as Data

(***"deep"*** embedding)

- no Scala functions inside

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

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straightforward

until you need functions

Gain-of-functions crossroads

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(***"shallow"*** embedding)

```
case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
  extends Expr[B]
```

no alternative interpretations

DEAD END

deviantart.com/fernandesvincent

Functions as Data

(***"deep"*** embedding)

- no Scala functions inside
- fully introspectable

Representing (eDSL) Programs

Choosing a Suitable Data Structure (*"AST"*)

straightforward

until you need functions

```
enum Expr[A]:
  case IntConstant(i: Int)                      extends Expr[Int]
  case Plus(l: Expr[Int], r: Expr[Int]) extends Expr[Int]
  ...
```

Gain-of-functions crossroads

EASY WAY | RIGHT WAY

Just use a Scala function

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case FlatMap[A, B](a: Expr[A], f: A => Expr[B])
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no alternative interpretations

DEAD END

deviantart.com/fernandesvincent

Functions as Data

(***"deep"*** embedding)

- no Scala functions inside
- fully introspectable
- *we* are **in control**

Representing (eDSL) Programs

Choosing a Suitable Data Structure *("AST")*

straightforward

until you need functions

```
enum Expr[A]:
  case IntConstant(i: Int)                  extends Expr[Int]
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Gain-of-functions crossroads

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deviantart.com/fernandesvincent

Functions as Data

(***"deep"*** embedding)

- no Scala functions inside
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- *we* are **in control**

Representing Functions

Representing Functions

Representing Functions

Expression-centric

Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])     extends Expr[Int]
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])      extends Expr[Int]
  case Var[A](name: String)                  extends Expr[A]
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])      extends Expr[Int]
  case Var[A](name: String)                  extends Expr[A]
  case Lam[A,B](a: Var[A], b: Expr[B])       extends Expr[A ⇒ B]
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])      extends Expr[Int]
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  case App[A,B](f: Expr[A ⇒ B], a: Expr[A]) extends Expr[B]
```

```
x ⇒ f(x) + g(x)
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])     extends Expr[Int]
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  case App[A,B](f: Expr[A ⇒ B], a: Expr[A]) extends Expr[B]
```

```
val f, g: Expr[Int ⇒ Int] = ???
```

```
x ⇒ f(x) + g(x)
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Representing Functions

Expression-centric

```
enum Expr[A]:
  case Plus(l: Expr[Int], r: Expr[Int])      extends Expr[Int]
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```

```
val f, g: Expr[Int ⇒ Int] = ???
```

```
x ⇒ f(x) + g(x)
```

```
Lam(
  Var("x"),
  Plus(
    App(f, Var("x")),
    App(g, Var("x"))
  )
): Expr[Int ⇒ Int]
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  Plus(Expr[Int], Expr[Int]): Expr[Int]
  Var(String)               : Expr[A]
  Lam(Var[A], Expr[B])      : Expr[A ⇒ B]
  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
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Representing Functions

Expression-centric

Function-centric
(Point-free)

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enum Expr[A]:
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```

```
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Lam(
  Var("x"),
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): Expr[Int ⇒ Int]
```

```
enum Flow[A,B]:
```

Representing Functions

Expression-centric

```
enum Expr[A]:
  Plus(Expr[Int], Expr[Int]): Expr[Int]
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  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
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```

```
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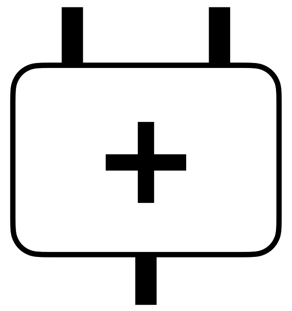
```

```
Lam(
  Var("x"),
  Plus(
    App(f, Var("x")),
    App(g, Var("x"))
  )
): Expr[Int ⇒ Int]
```

Function-centric
(Point-free)

```
enum Flow[A,B]:
  case Plus()
    extends Flow[(Int, Int), Int]
```



Representing Functions

Expression-centric

```
enum Expr[A]:
  Plus(Expr[Int], Expr[Int]): Expr[Int]
  Var(String)               : Expr[A]
  Lam(Var[A], Expr[B])      : Expr[A ⇒ B]
  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
```

```
val f, g: Expr[Int ⇒ Int] = ???
```

```
x ⇒ f(x)
```

```
Lam(
  Var("x"),
  Plus(
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```

Function-centric
(Point-free)

```
enum Flow[A,B]:
  case Plus()
    extends Flow[(Int, Int), Int]
  case Dup[A]()
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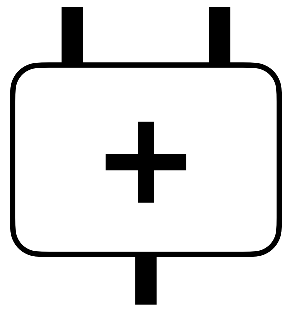

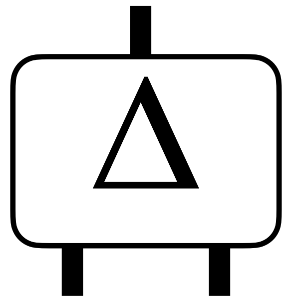

Representing Functions

Expression-centric

```
enum Expr[A]:
  Plus(Expr[Int], Expr[Int]): Expr[Int]
  Var(String)               : Expr[A]
  Lam(Var[A], Expr[B])      : Expr[A ⇒ B]
  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
```

```
val f, g: Expr[Int ⇒ Int] = ???
```

```
x ⇒ f(x)
```

```
Lam(
  Var("x"),
  Plus(
    App(f, Var("x")),
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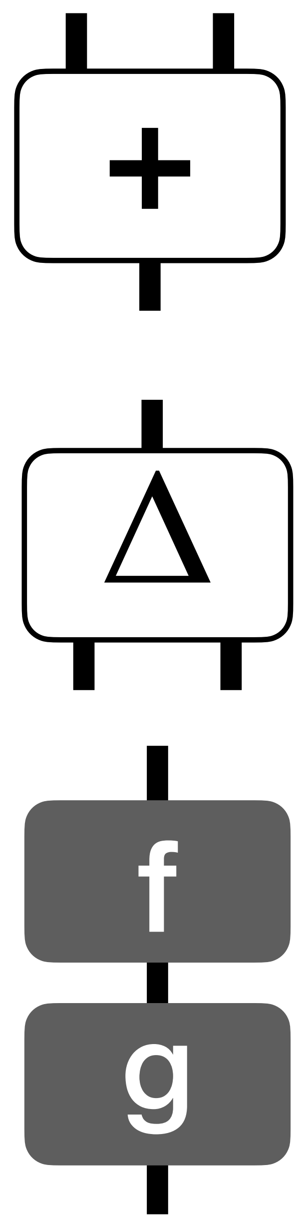
  )
): Expr[Int ⇒ Int]
```

Function-centric
(Point-free)

```
enum Flow[A,B]:
  case Plus()
    extends Flow[(Int, Int), Int]
  case Dup[A]()
    extends Flow[A, (A, A)]
  case AndThen[A,B,C](
    f: Flow[A,B],
    g: Flow[B,C]
  ) extends Flow[A,C]
```



Representing Functions

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Function-centric

(Point-free)

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  case Plus()
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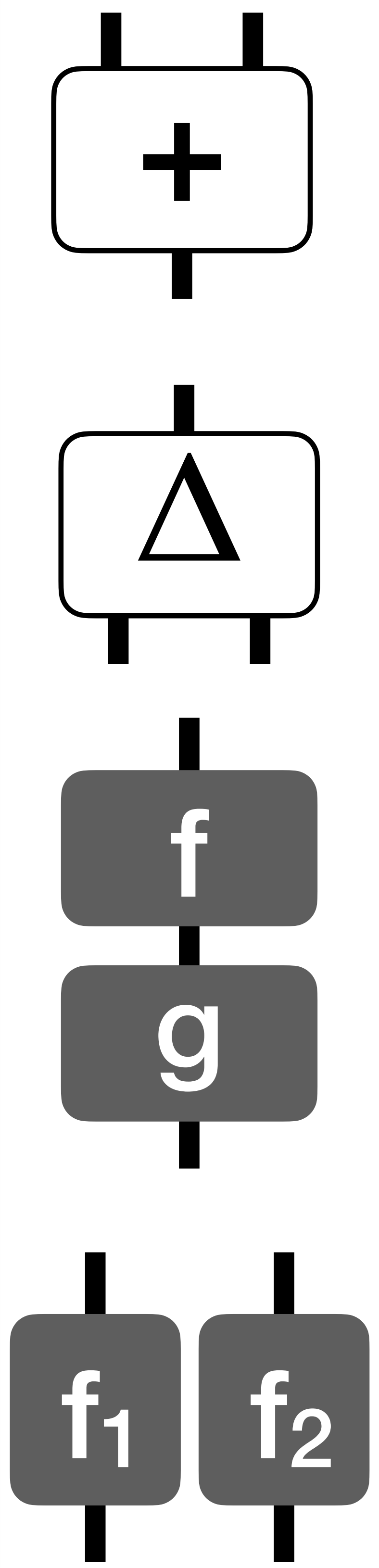
  case AndThen[A,B,C](
    f: Flow[A,B],
    g: Flow[B,C]
  ) extends Flow[A,C]
  case Par[A1, A2, B1, B2](
    f1: Flow[A1, B1],
    f2: Flow[A2, B2]
  ) extends Flow[(A1, A2), (B1, B2)]
```



Representing Functions

Expression-centric

Function-centric
(Point-free)

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  Lam(Var[A], Expr[B])      : Expr[A ⇒ B]
  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
```

```
enum Flow[A,B]:
  Plus(): Flow[(Int,Int), Int]
  Dup() : Flow[A, (A,A)]
  AndThen(Flow[A,B], Flow[B,C]): Flow[A,C]
  Par(Flow[A₁,B₁], Flow[A₂,B₂])
   : Flow[(A₁,A₂), (B₁,B₂)]
```

```
val f, g: Expr[Int ⇒ Int] = ???
```

```
x ⇒ f(x) + g(x)
```

```
Lam(
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Representing Functions

Expression-centric

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```

Function-centric

(Point-free)

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val f, g: Expr[Int ⇒ Int] = ???
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Representing Functions

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Function-centric

(Point-free)

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Representing Functions

Expression-centric

Function-centric
(Point-free)

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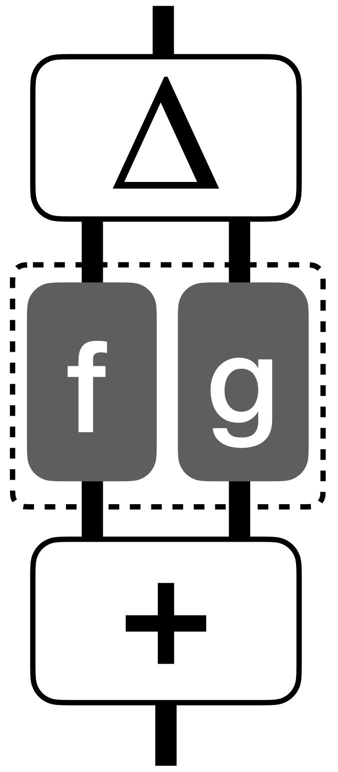

Representing Functions

Expression-centric

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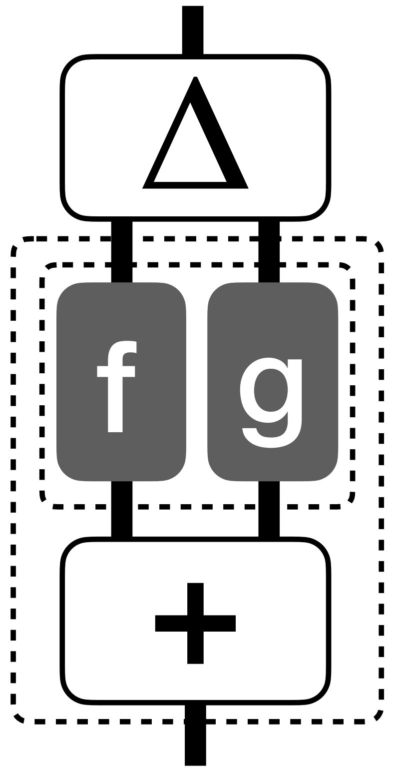

Representing Functions

Expression-centric

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  App(Expr[A ⇒ B], Expr[A]) : Expr[B]
```

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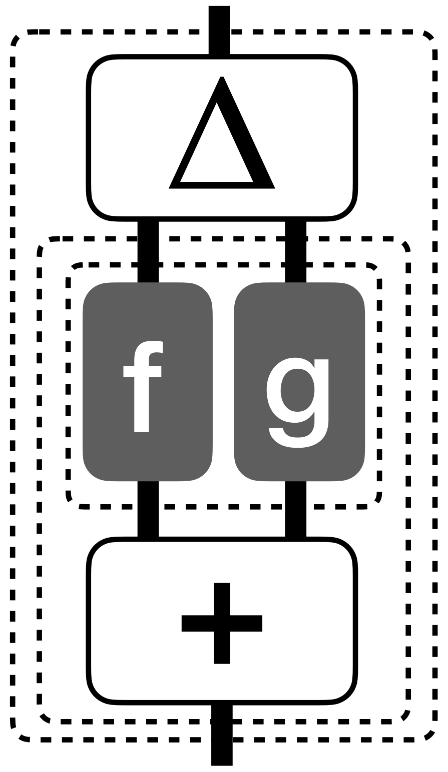

Expression centric vs. Function centric

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- close to syntax
- few primitives

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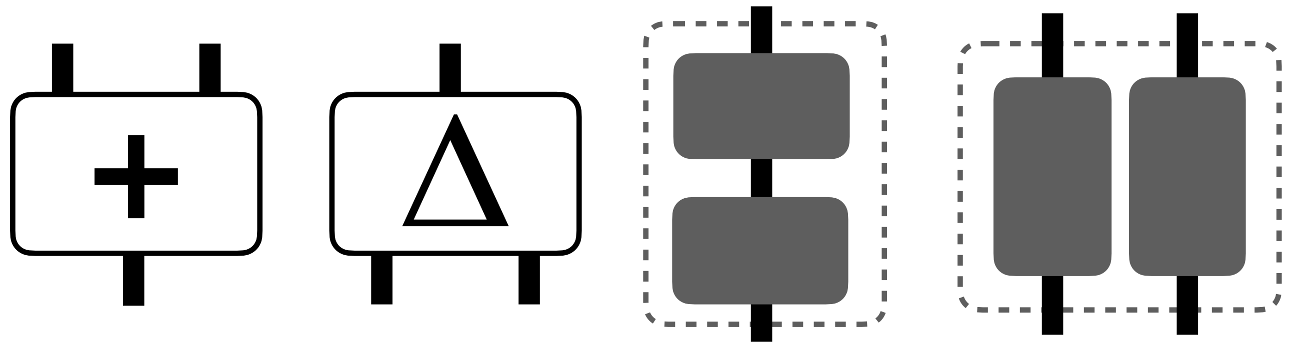

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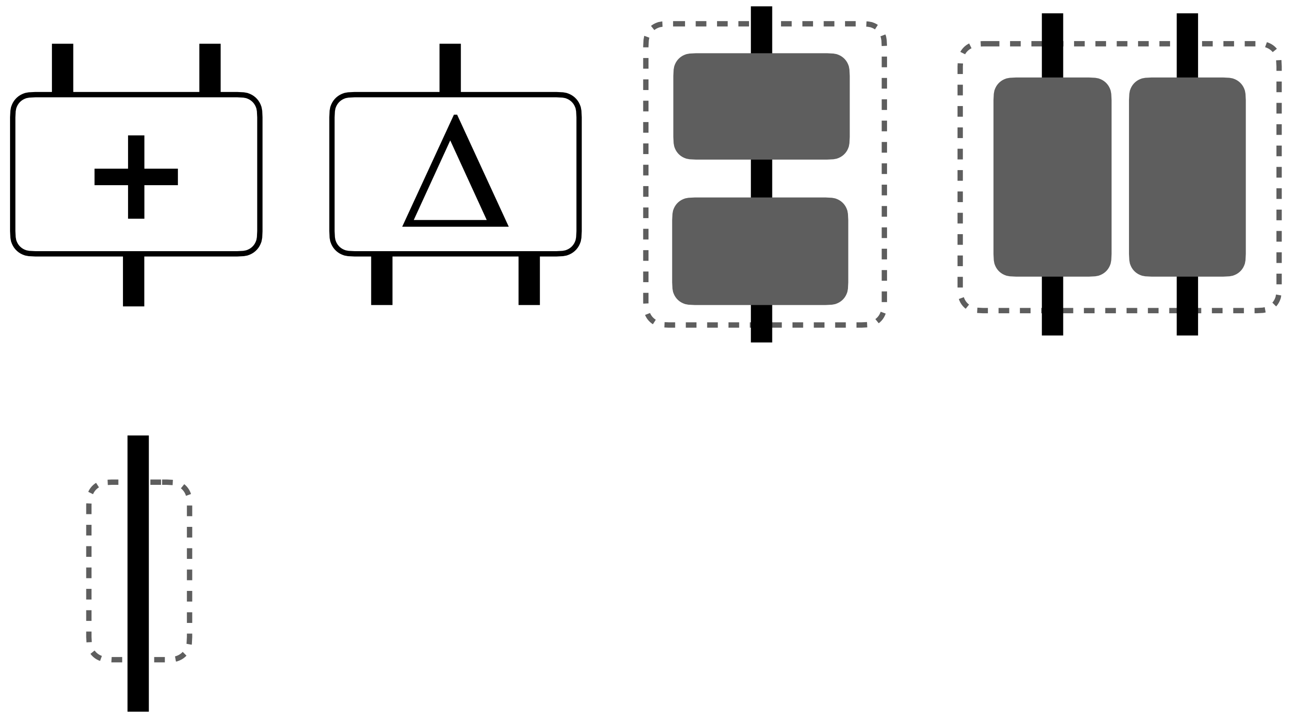

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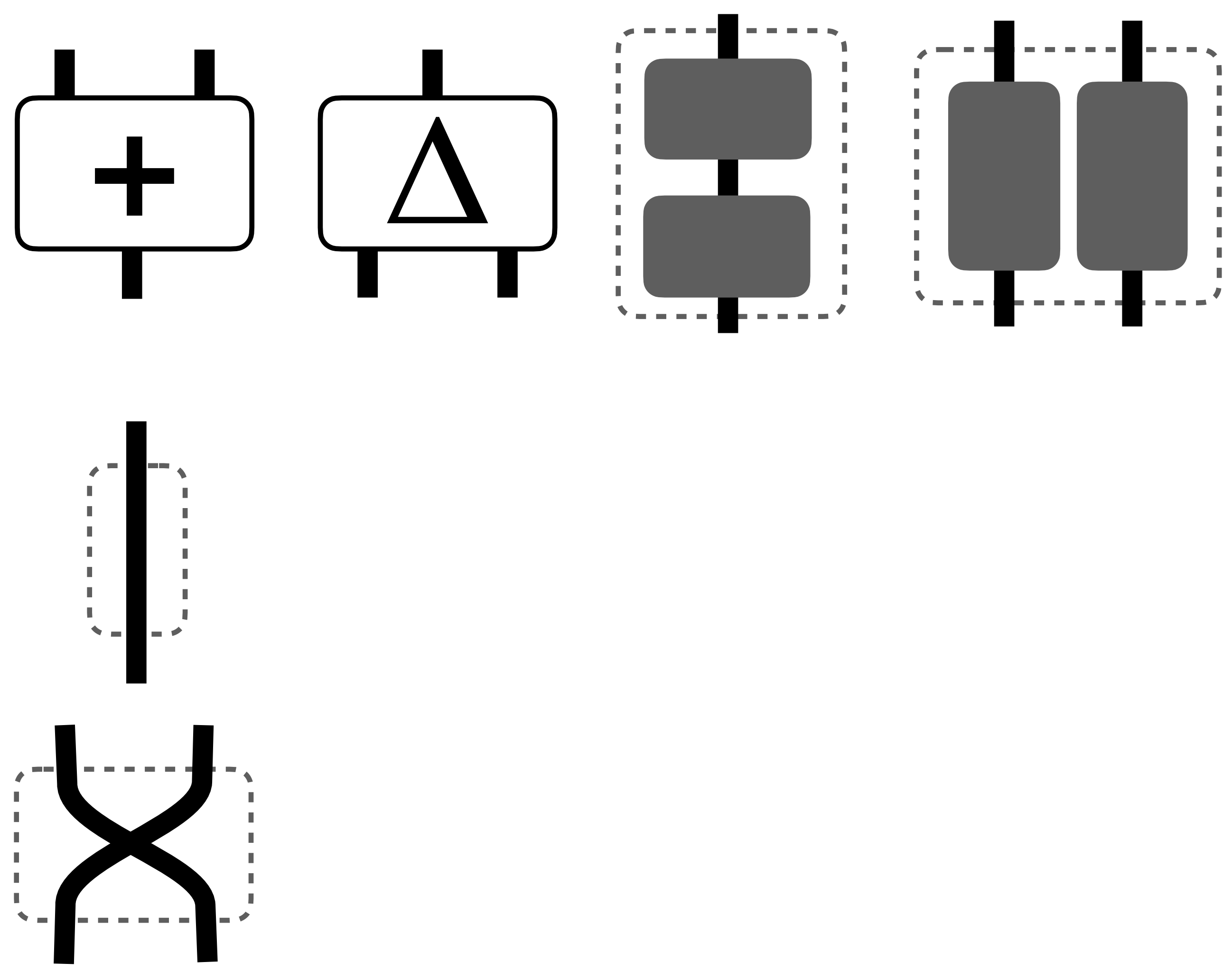

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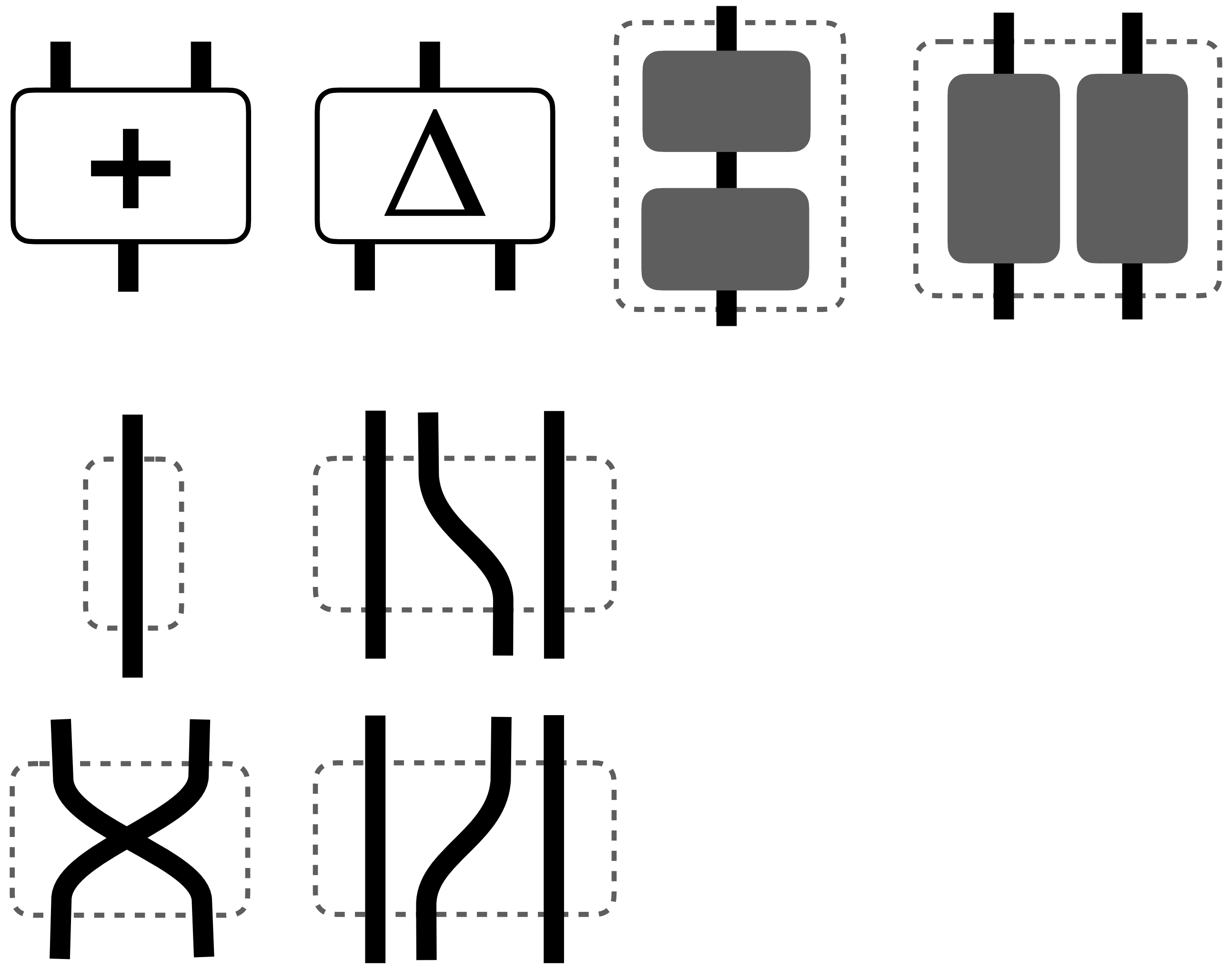

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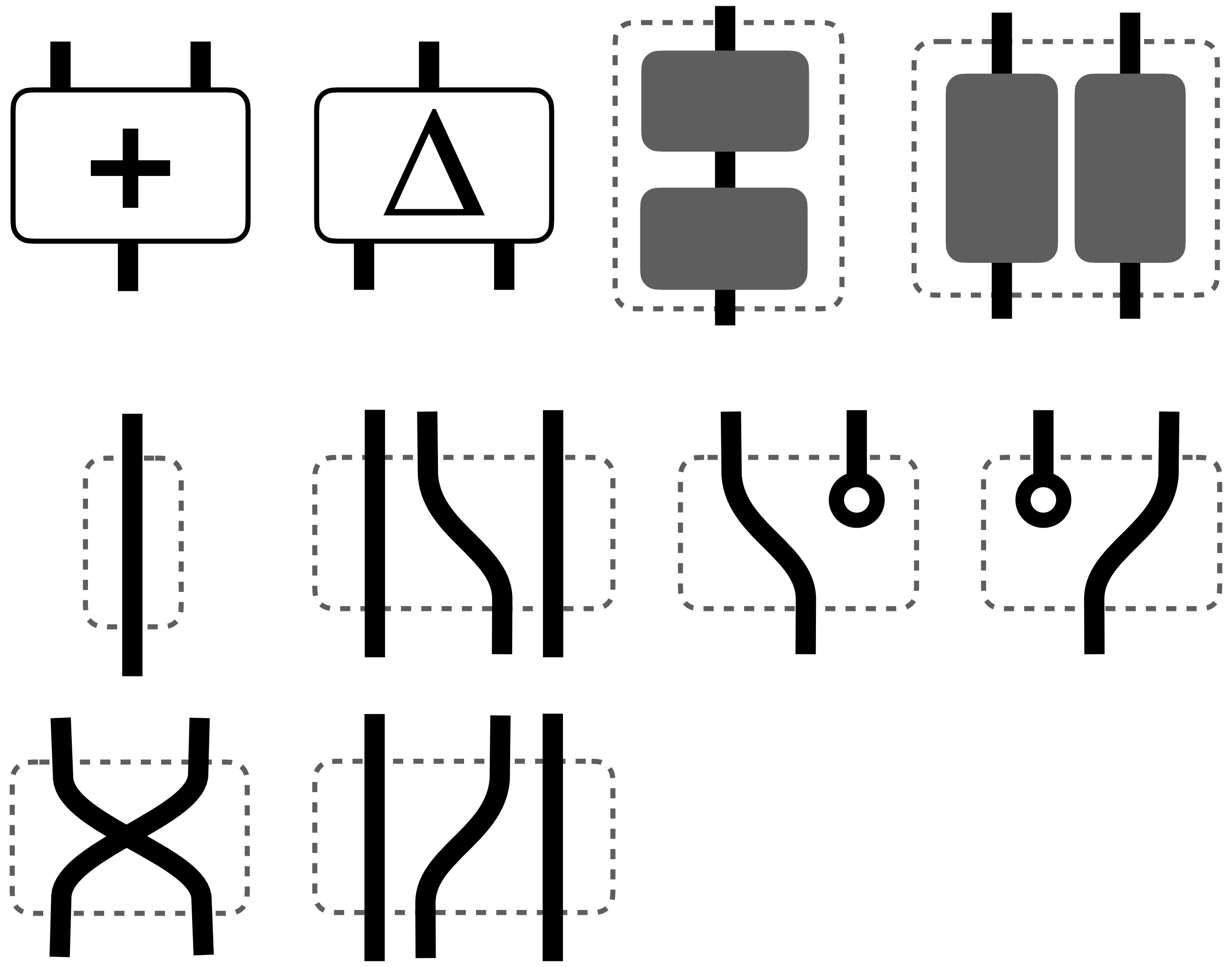

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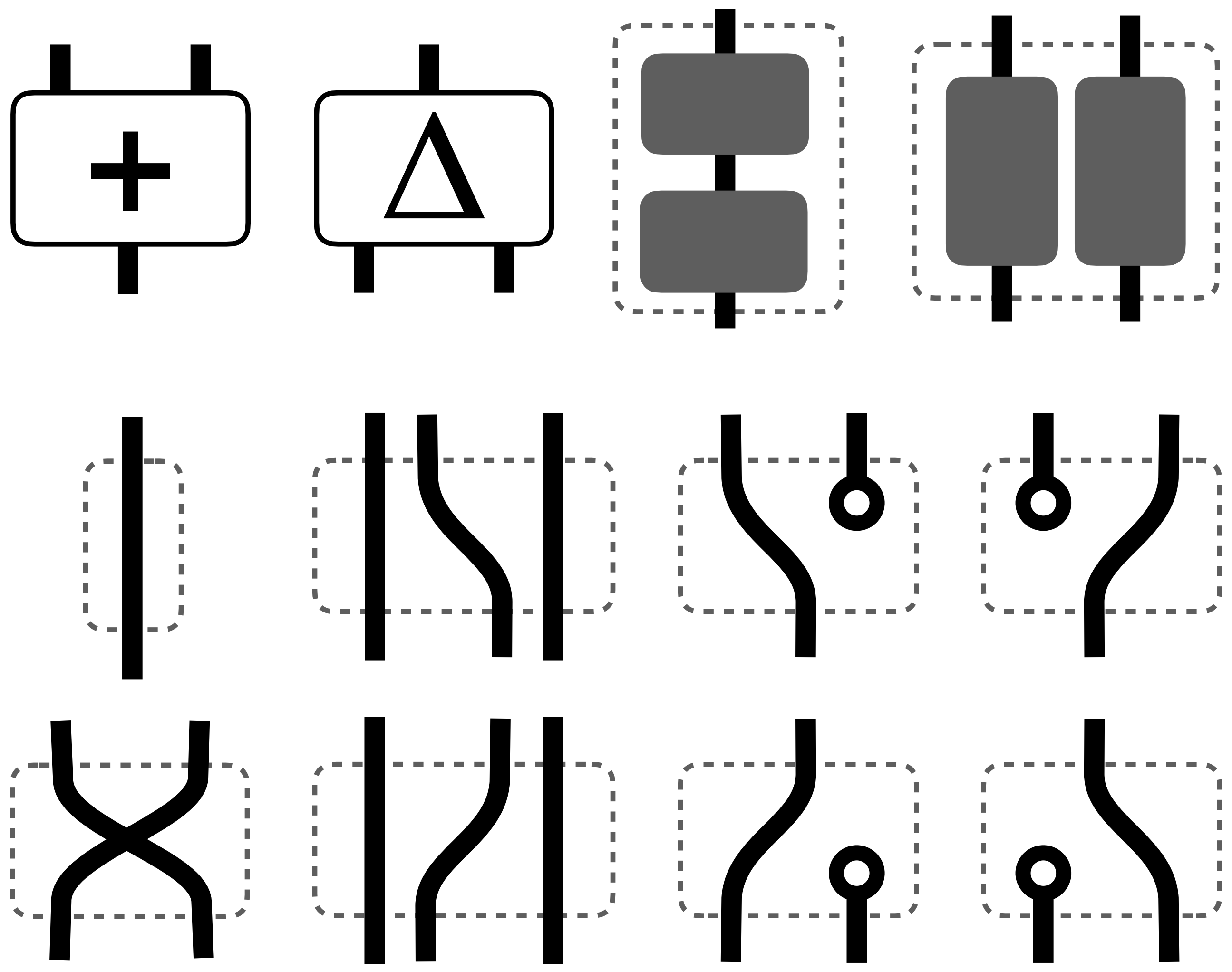

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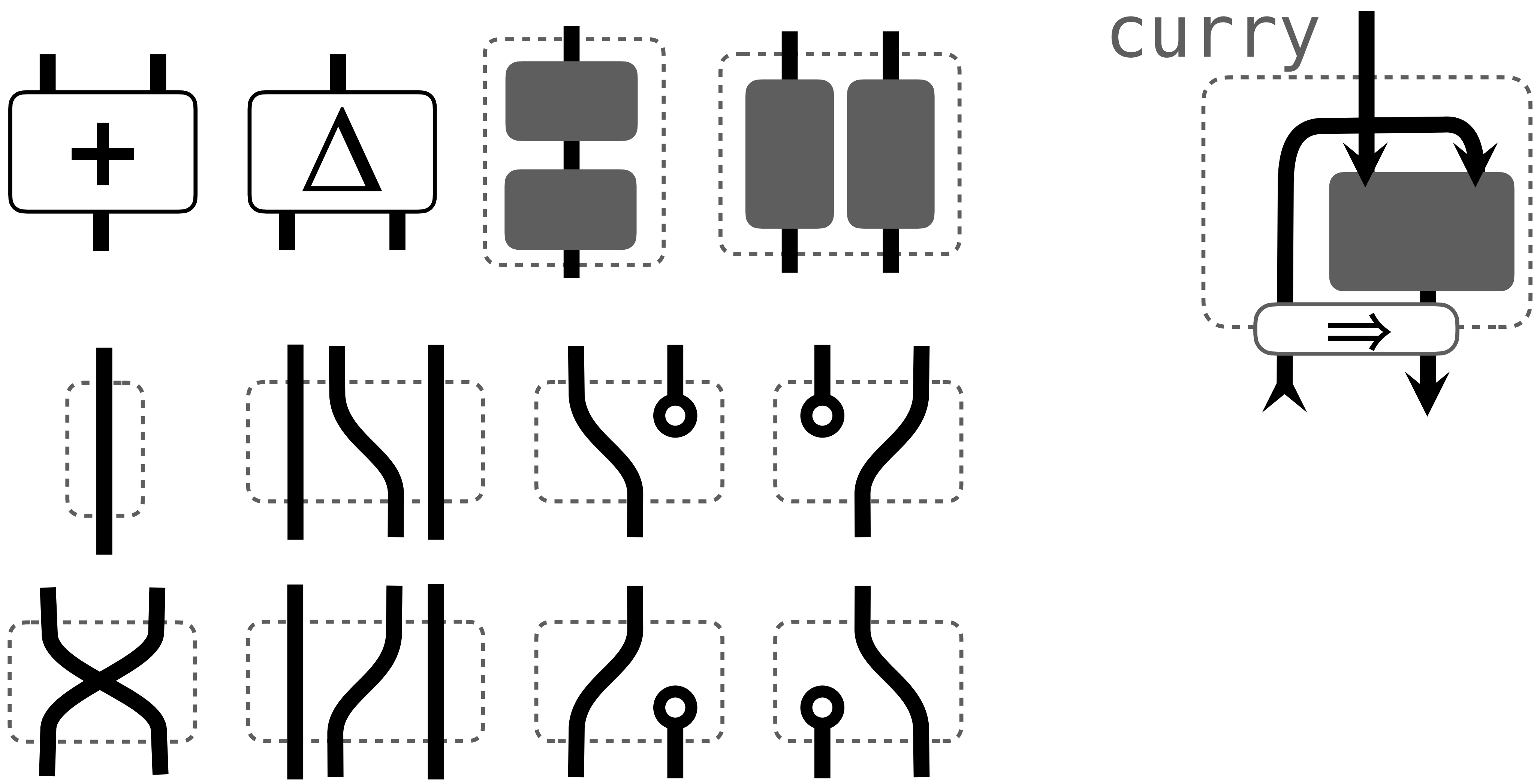

Expression centric vs. Function centric

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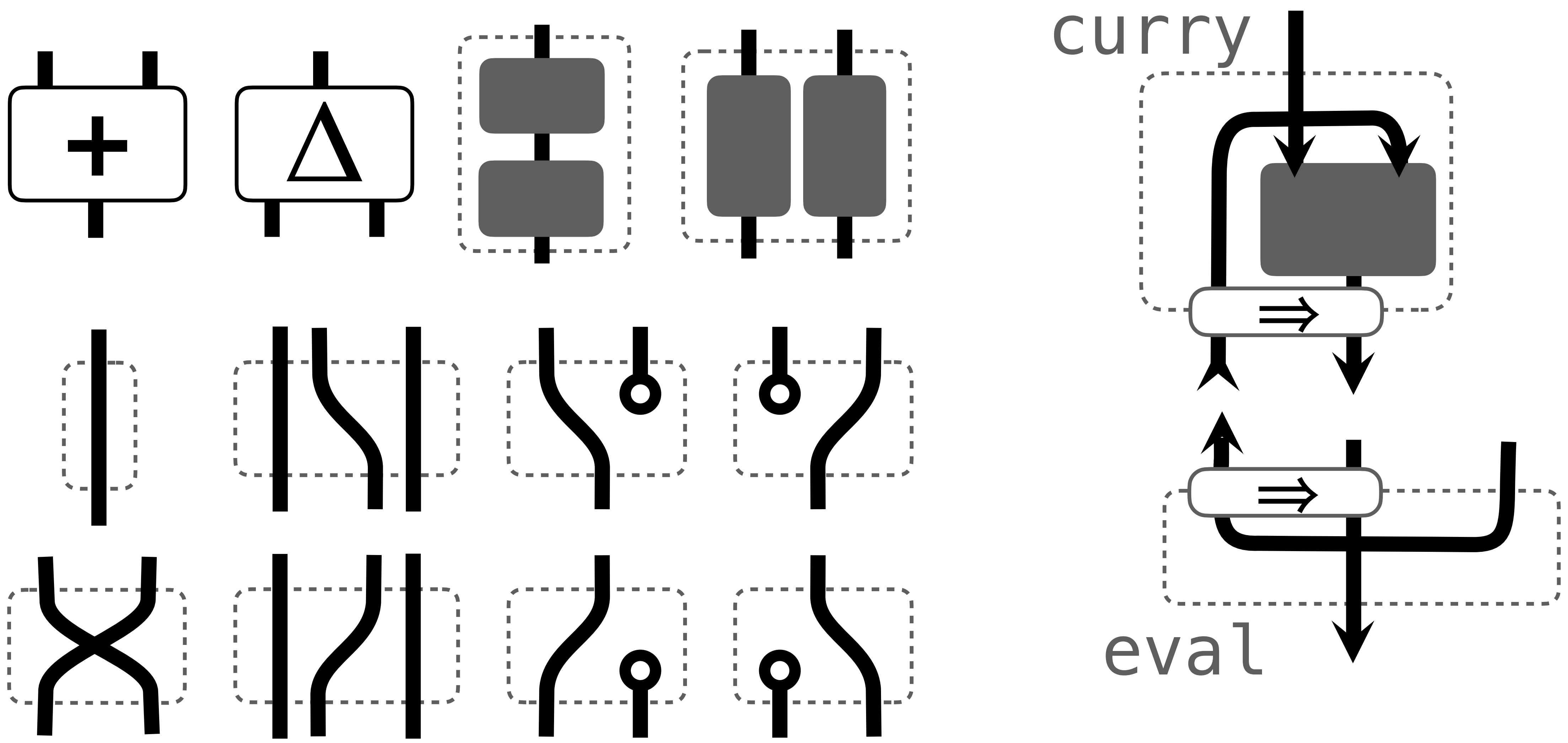

Expression centric vs. Function centric

```scala
val f, g: Expr[Int ⇒ Int] = ???
```

```scala
x ⇒ f(x) + g(x)
```

```scala
val f, g: Flow[Int, Int] = ???
```

- close to syntax
- few primitives
- concise

```scala
Lam(
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Expression centric vs. Function centric

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- close to syntax
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  AndThen(
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  )
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```

- needs translation
- many primitives
- verbose

Expression centric vs. Function centric

```
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```
x ⇒ f(x) + g(x)
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```
val f, g: Flow[Int, Int] = ???
```

- close to syntax
- few primitives
- concise
- ~ λ-calculus

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- close to syntax
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  - pairs before HOFs; don't have to have HOFs
  - linearity by *taking away* non-linear ops

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THIS WAY

Values as Functions

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case Const[A](value: A) extends Flow[Unit, A]
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enum Value[A]:
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  case Pair[A, B](
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  ) extends Value[(A, B)]
  ...
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```
Found:    Thread
Required: Value[A]
```

Best Practice:

Don’t Reuse Scala Types as Domain Types

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Introduce new domain types for common concepts

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Scala	Domain (Workflows)
`(A, B)`	`A ** B`
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`Unit`	`One`

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    f2: Flow[A2, B2]
  ) extends Flow[A1 ** A2, B1 ** B2]
  case Const[A](value: Value[A]) extends Flow[One, A]
  ...
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Domain-level Enums

(a.k.a. sum types, tagged unions, variant types, coproduct types)

Domain-level **Enums**

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- Looking for domain-level analog of

```
enum Request:
  case ForOffice   (what: Equipment, desk: DeskLocation)
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- Aiming for

```
type Request = Enum
  [ "ForOffice"     :: (Equipment ** DeskLocation)
  || "WorkFromHome" :: (Equipment ** DeliveryAddress)
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Domain-level **Enums**

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Domain-level **Enums**

```
sealed trait **[A, B]
sealed trait Enum[Cases]
sealed trait ||[A, B]
sealed trait ::[Name, Type]
```

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What can we ***do*** with it?

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What do we *need* to ***do*** with it?

Create Requests
from input data

```scala
Flow[Equipment ** DeskLocation,    Request]
Flow[Equipment ** DeliveryAddress, Request]
```

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```
Flow[Equipment ** DeskLocation,    B]
Flow[Equipment ** DeliveryAddress, B]
```

by providing a handler for each case

⇒

Handle Requests

```
Flow[Request, B]
```

Domain-level **Enums**

What:

Create Requests

```
Flow[Equipment ** DeskLocation,    Request]
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```

Handle Requests

```
Flow[Equipment ** DeskLocation,    B]
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```

$\Rightarrow$

```
Flow[Request, B]
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What:

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⇒

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How: Capture the intent, in a type-safe manner.

Domain-level **Enums**

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Handle Requests

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Flow[Equipment ** DeliveryAddress, B]
```

⇒

```
Flow[Request, B]
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How: Capture the intent, in a type-safe manner.

```
// create
case class Inject[N, A, Cases](ev: Member[N, A, Cases]) extends Flow[A, Enum[Cases]]
// handle
case class Handle[Cases, B]   (hs: Handlers[Cases, B])  extends Flow[Enum[Cases], B]
```

Producing **Enums**

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Producing **Enums**

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```
case class Inject[N, A, Cases](ev: Member[N, A, Cases]) extends Flow[A, Enum[Cases]]
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Producing **Enums**

```
type Cases =
  ( "ForOffice"    :: (Equipment ** DeskLocation)
  || "WorkFromHome" :: (Equipment ** DeliveryAddress)
  )
type Request = Enum[Cases]
```

```
case class Inject[N, A, Cases](ev: Member[N, A, Cases]) extends Flow[A, Enum[Cases]]
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Producing Enums

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  || "WorkFromHome" :: (Equipment ** DeliveryAddress)
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```
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                                            : Flow[Equipment ** DeskLocation, Enum[Cases]]
Inject["WorkFromHome", Equipment ** DeliveryAddress, Cases](???)
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What we wanted

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Producing **Enums**

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                                    : Flow[Equipment ** DeskLocation,    Request]
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                                : Flow[Equipment ** DeskLocation,     Request]
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Evidence that N :: A is one of Cases (📗)

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Member[“ForOffice", Equipment ** DeskLocation,    Cases] ✔
Member[“Foo",       Equipment ** DeskLocation,    Cases]
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case class Inject[N, A, Cases](ev: Member[N, A, Cases]) extends Flow[A, Enum[Cases]]
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unrepresentable

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Consuming Enums

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case class Handle[Cases, B](hs: Handlers[Cases, B]) extends Flow[Enum[Cases], B]
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```
type Cases = "x" :: Tuna || "y" :: Cod
```

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collection of handlers, one for each case (📗)

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type Cases = "x" :: Tuna || "y" :: Cod
```

```
Handle[Cases, B] =
```

```
Enum[ "x" :: Tuna || "y" :: Cod ]
```

B

Consuming **Enums**

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type Cases = “x” :: Tuna  ||  “y” :: Cod
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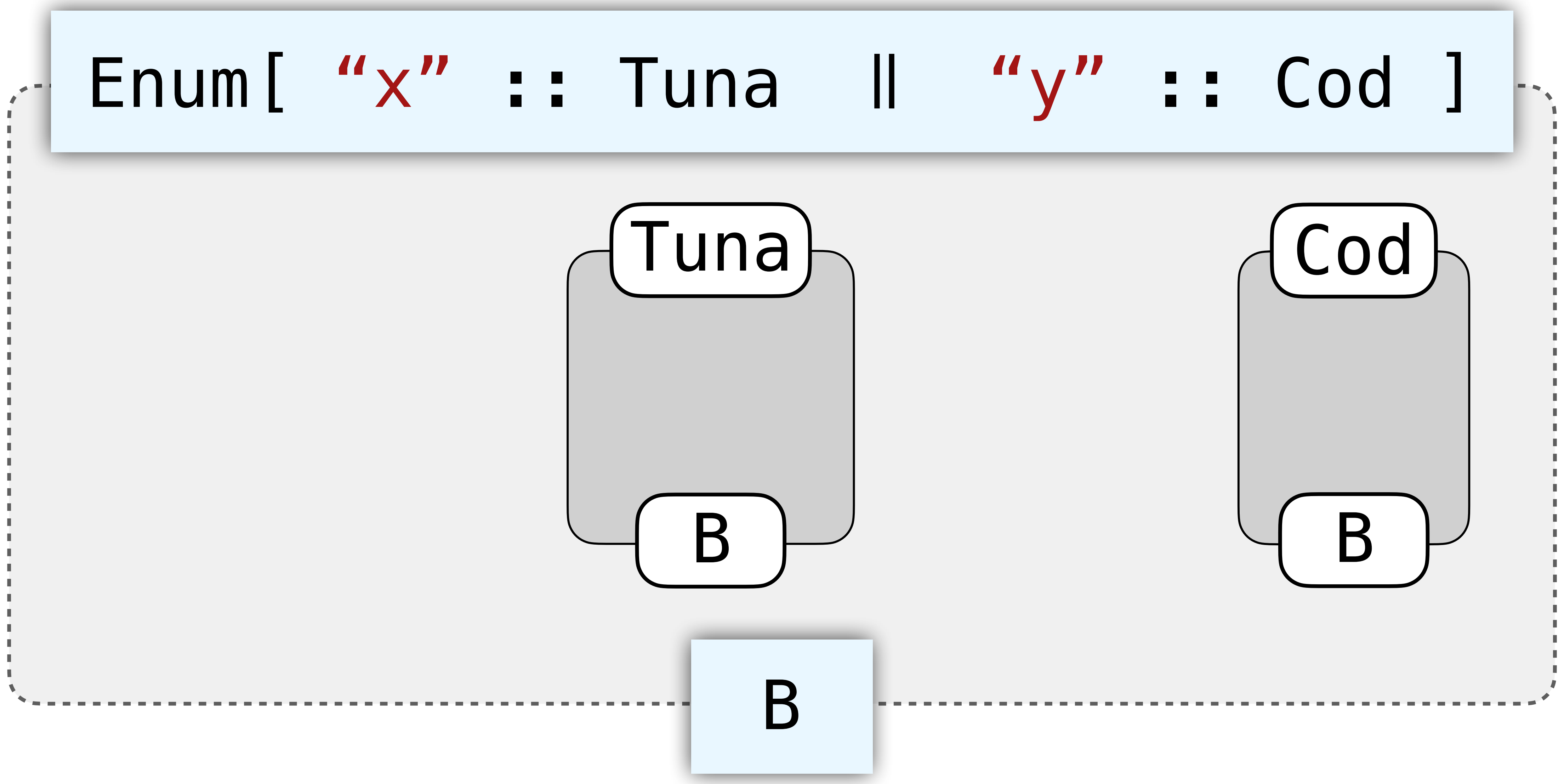

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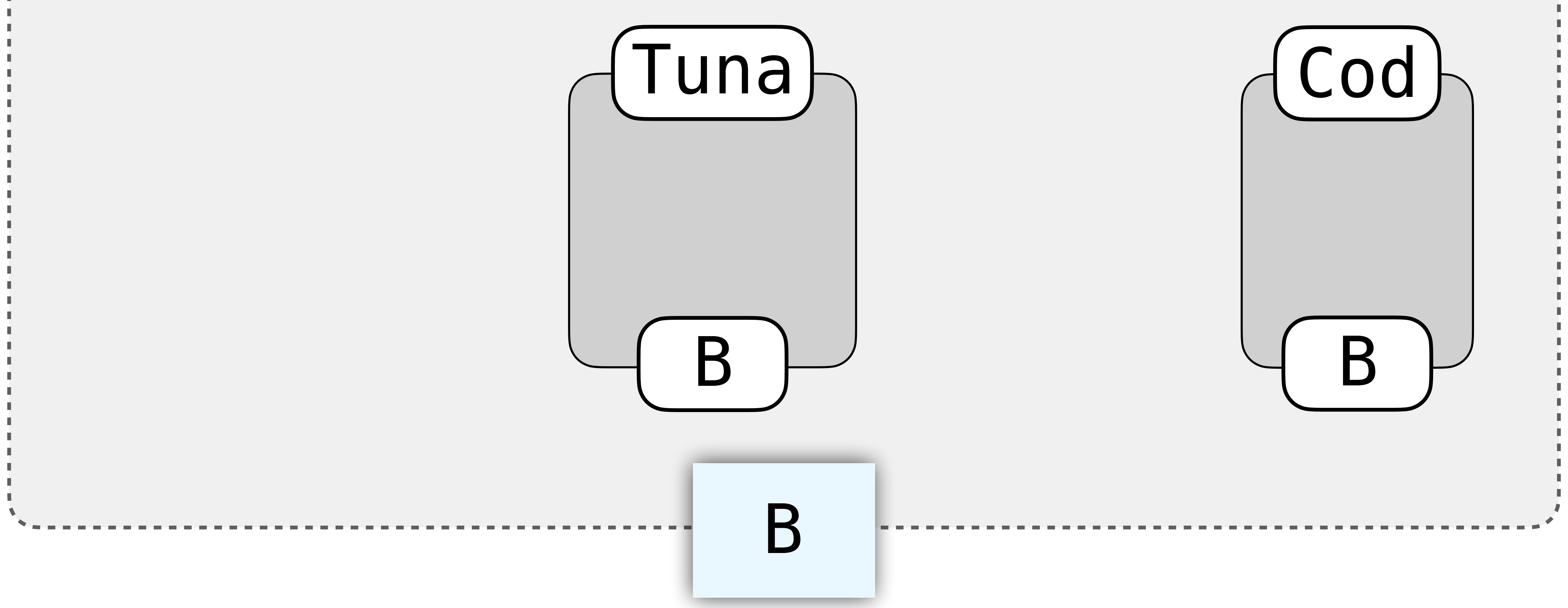

non-exhaustive handlers *unrepresentable*

Consuming **Enum** and a **Side Dish**

(needed to support pattern matching with **capture**)

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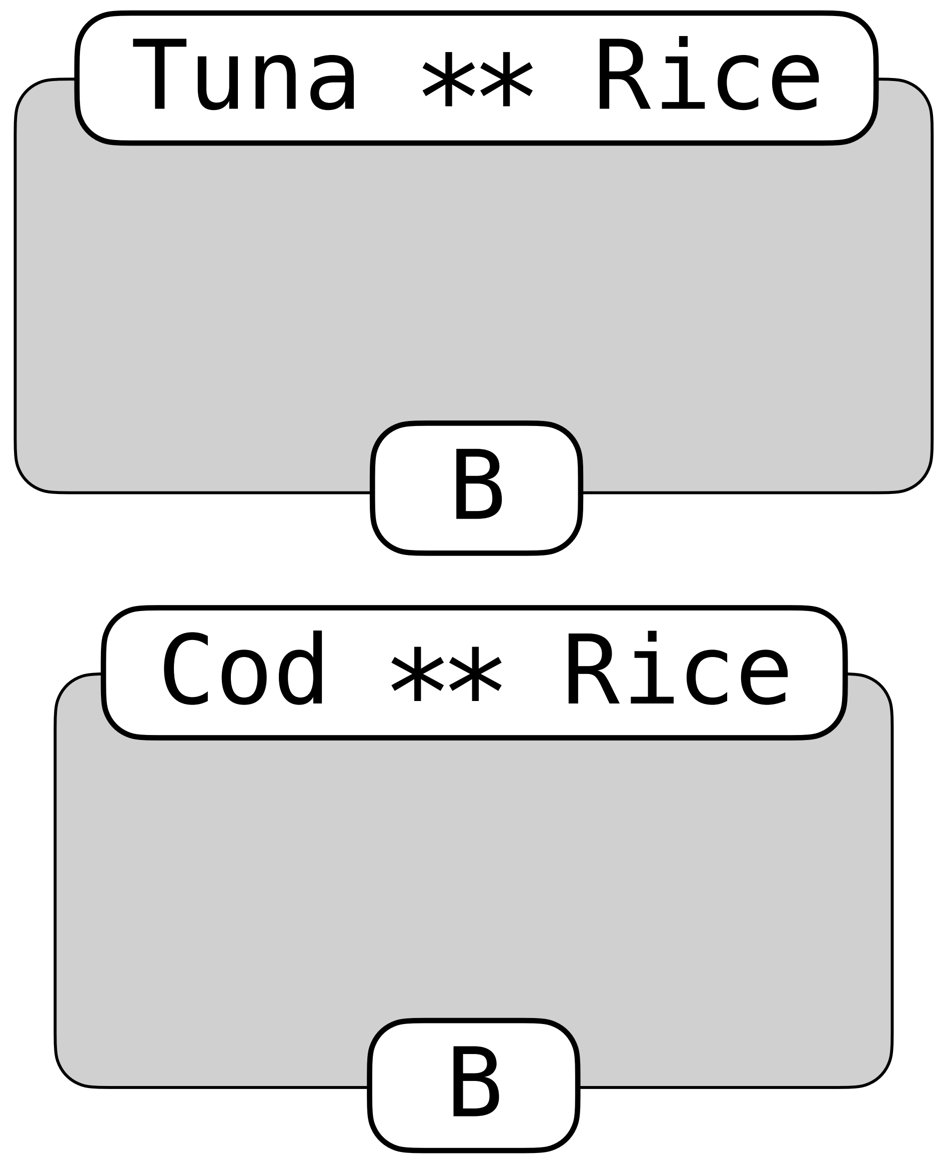

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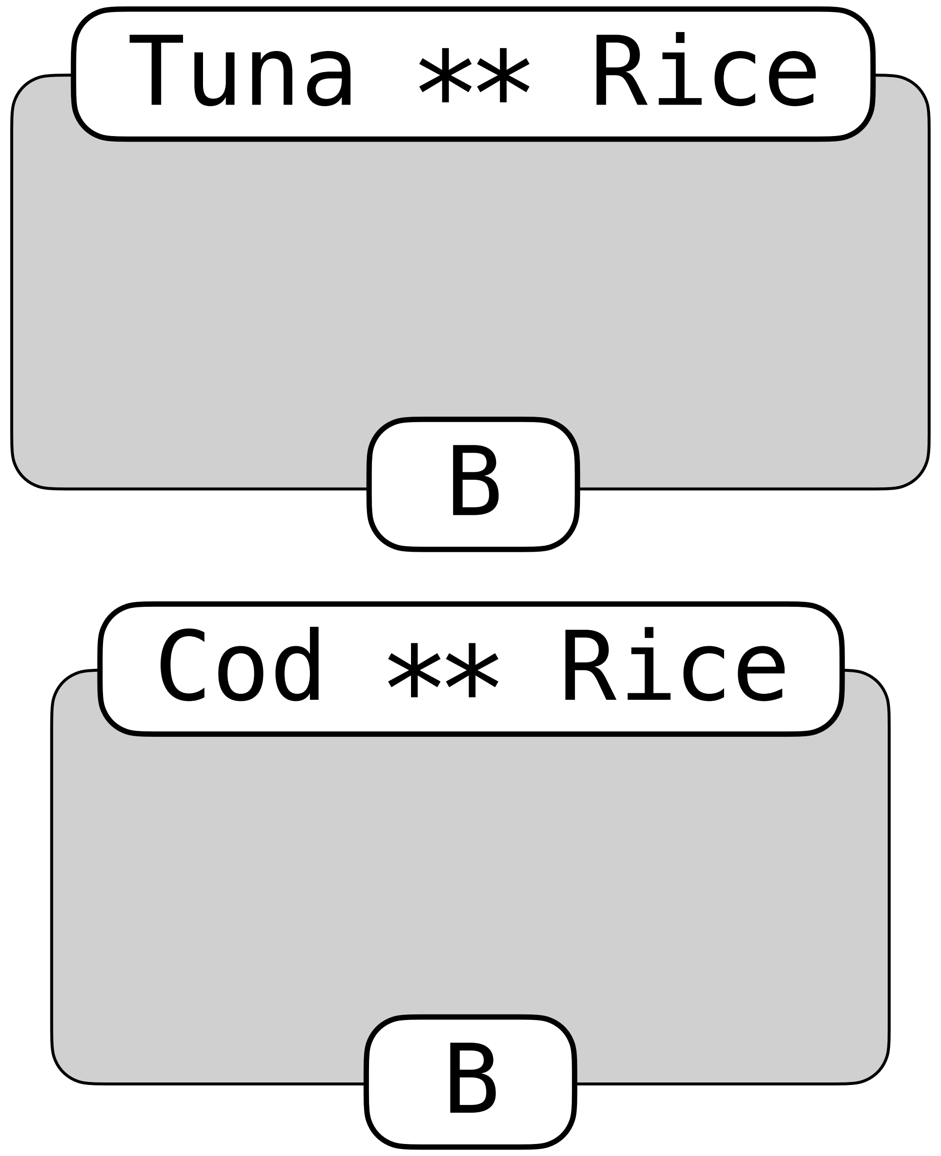

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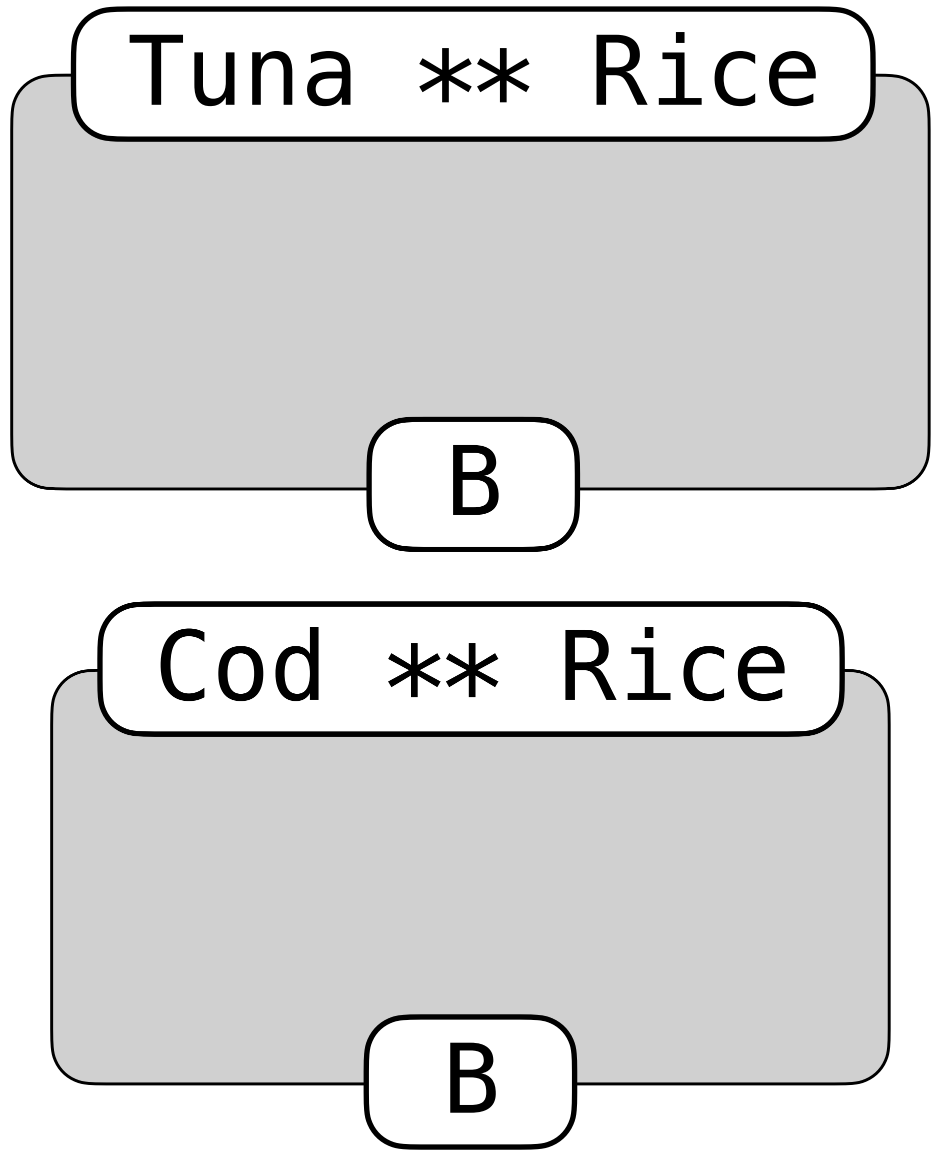

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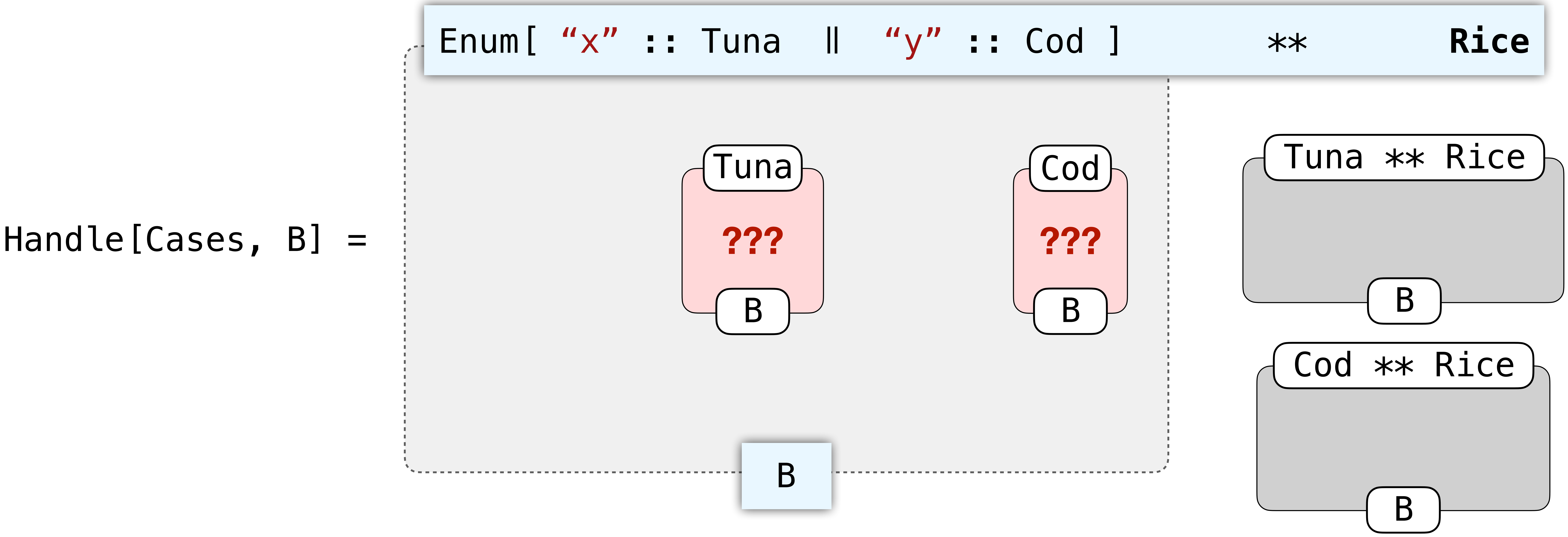

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Enum[ "x" :: Tuna  ||  "y" :: Cod ]        **        Rice
```

```
Enum[ "x" :: (Tuna ** Rice)  ||  "y" :: (Cod ** Rice) ]
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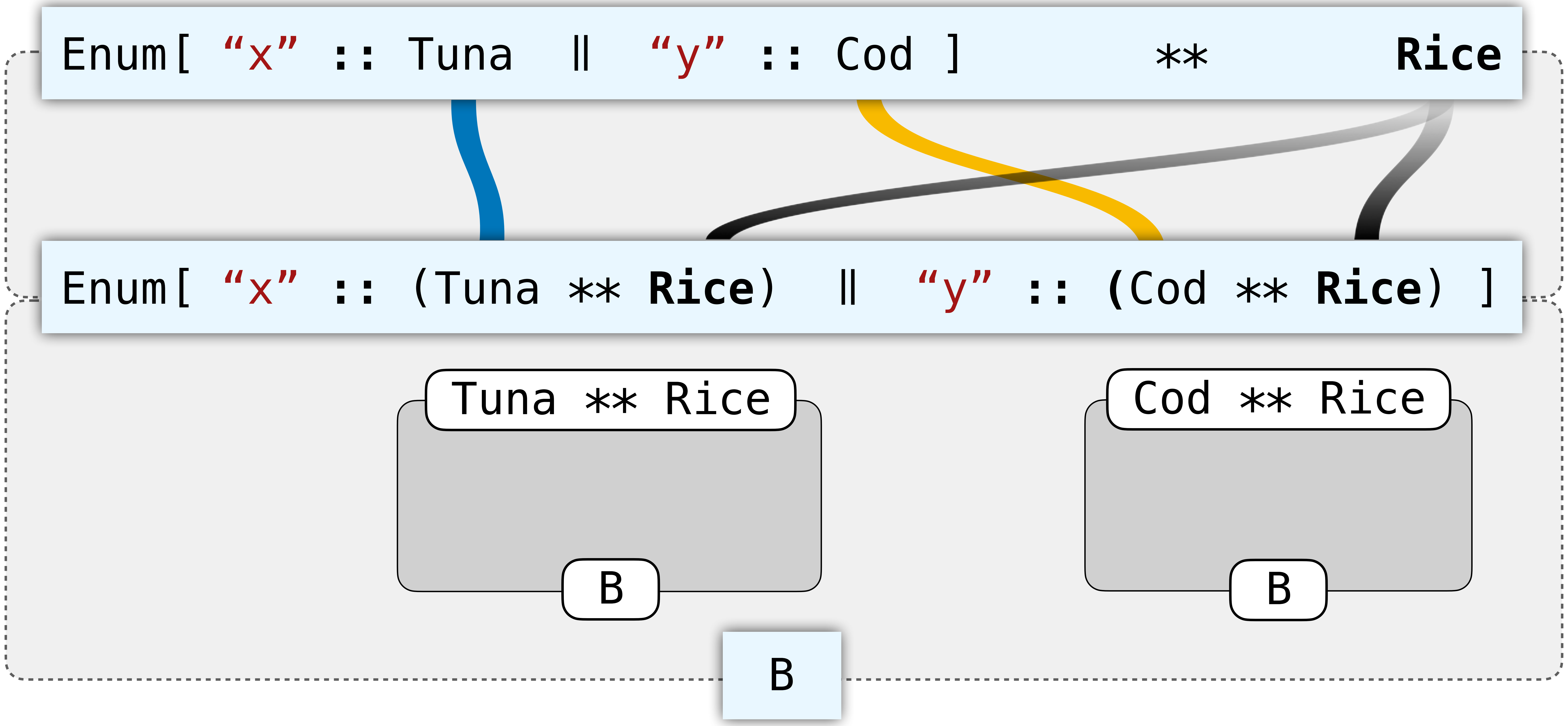

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case class Handle[Cases, B](hs: Handlers[Cases, B]) extends Flow[Enum[Cases], B]
```
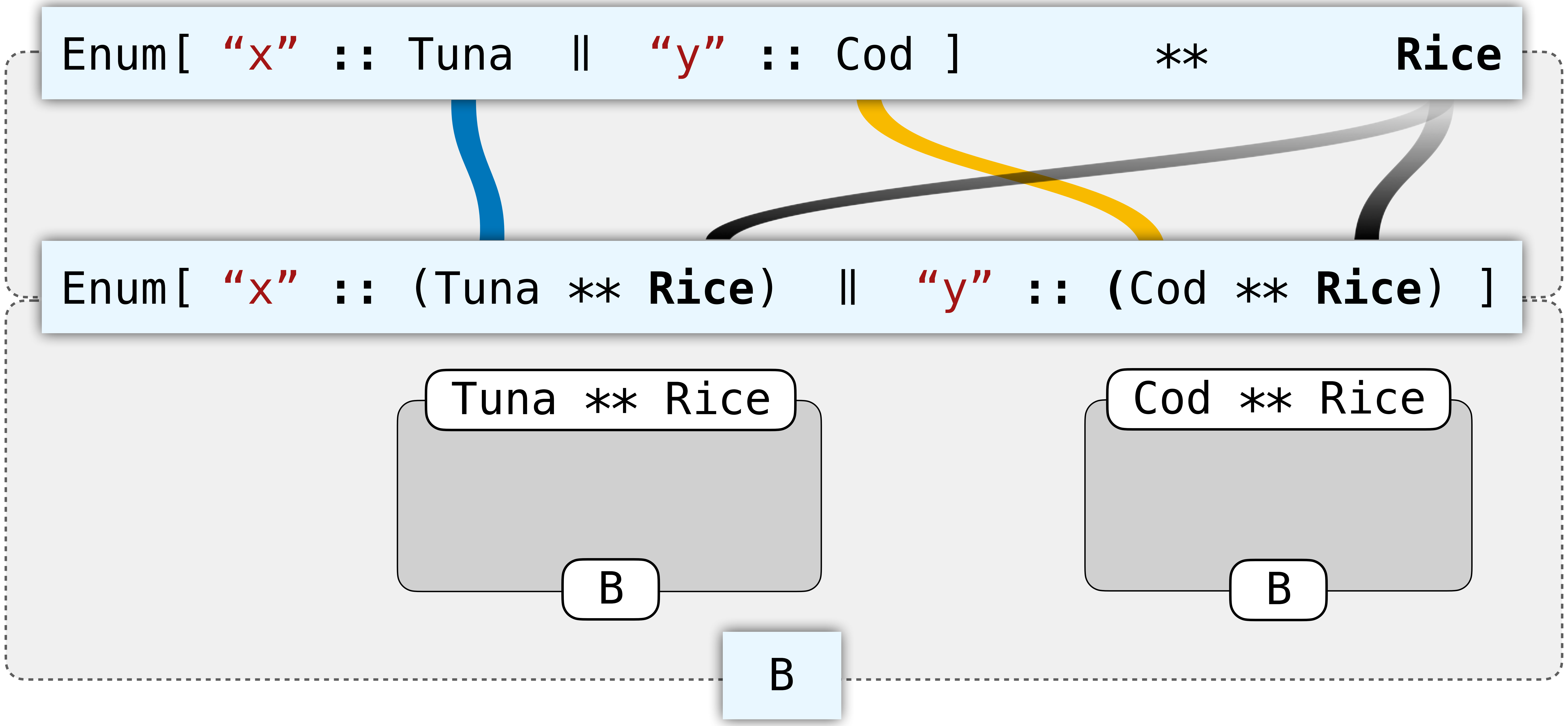

```
DistributeRL[
  Rice,
  Cases,
  Cases¹
]
```

=



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```
DistributeRL[
  Rice,
  Cases,          =   Enum[ "x" :: Tuna  ||  "y" :: Cod ]       **        Rice
  Cases¹
]                     Enum[ "x" :: (Tuna ** Rice)  ||  "y" :: (Cod ** Rice) ]
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- **idea: just capture the intent**

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  Rice,
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  Cases¹
]                 =   Enum[ “x” :: Tuna  ‖  “y” :: Cod ]      **      Rice

                      Enum[ “x” :: (Tuna ** Rice)  ‖  “y” :: (Cod ** Rice) ]
```

```
case class DistributeRL[R, Cases, Cases¹](
  [ ... evidence that Cases¹ is the result
        of distributing R into Cases ... ]
) extends Flow[Enum[Cases] ** R, Enum[Cases¹]]
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- **idea: just capture the intent**

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case class Handle[Cases, B](hs: Handlers[Cases, B]) extends Flow[Enum[Cases], B]
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DistributeRL[
  Rice,
  Cases,
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]                =

Enum[ “x” :: Tuna  ||  “y” :: Cod ]        **        Rice

Enum[ “x” :: (Tuna ** Rice)  ||  “y” :: (Cod ** Rice) ]
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- **idea: just capture the intent**
- completely type-safe

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Problem: What if I cannot consume Tuna/Cod without Rice

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  Rice,
  Cases,
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]                =   Enum[ “x” :: Tuna  ||  “y” :: Cod ]        **        Rice

                     Enum[ “x” :: (Tuna ** Rice)  ||  “y” :: (Cod ** Rice) ]
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```
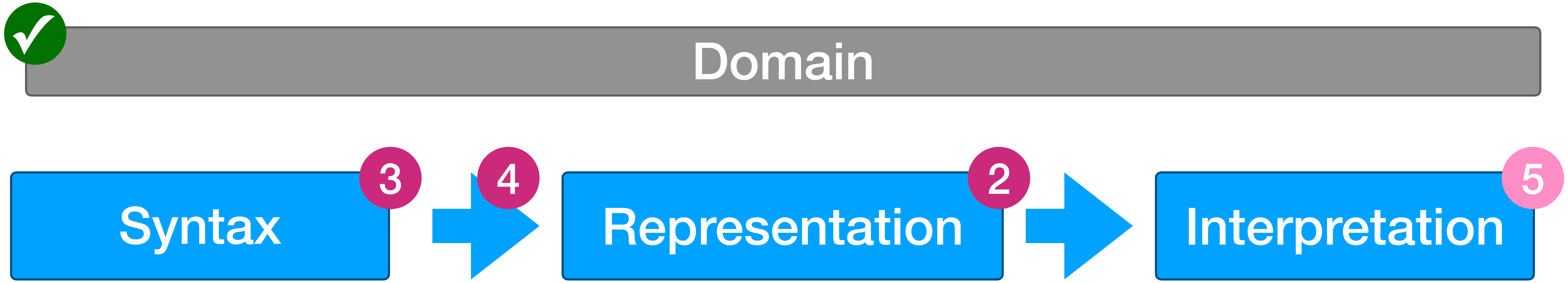
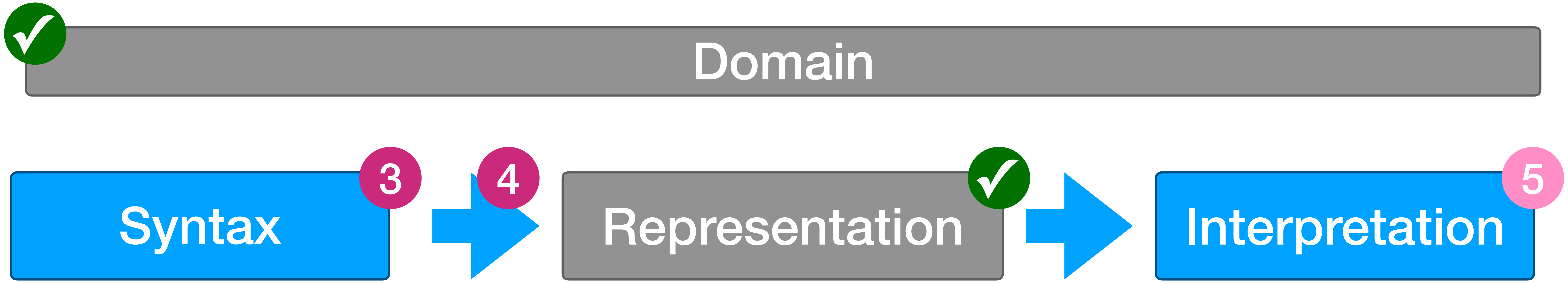

- **idea: just capture the intent**
- completely type-safe
- works for any number of cases

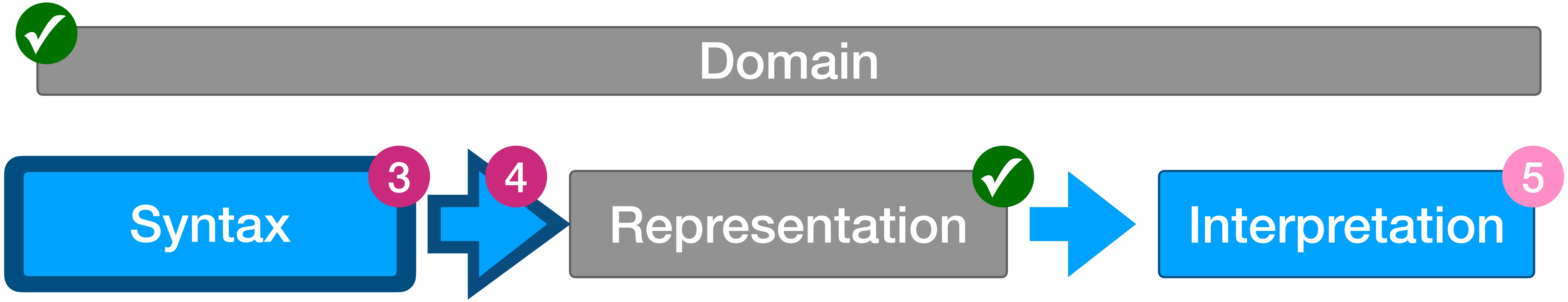
Agenda



Agenda



Agenda



Why any special Syntax?

Why not construct instances of `Flow[A,B]` directly?

Why any special Syntax?

Why not construct instances of `Flow[A,B]` directly?

```
AndThen(
  Peel(),
  Either(
    AndThen(
      Extract(),
      AndThen(
        AndThen(
          AndThen(
            Par(Peel(), Id()),
            AndThen(
              AndThen(Swap(), DistributeLR()),
              Either(
                AndThen(Swap(), InjectL()),
                AndThen(Swap(), InjectR())
              )
            )
          ),
          Either(
            AndThen(
              AndThen(
                AndThen(Par(Extract(), Id()), Inject(Single(Monitor))),
                InjectL()
              ),
              Unpeel()
            ),
            Inject(InLast(Chair))
          )
        ),
        AndThen(
          Peel(),
          Either(
            AndThen(
              Extract(),
              AndThen(
                Par(Id(), Ext(RequestMonitorFromIT)),
                Prj2()
              )
            ),
            AndThen(
              Par(
                Id(),
                Ext(RequestChairFromOfficeMgmt)
              ),
              Prj2()
            )
          )
        )
      )
    ),
    Ext(OrderFromSupplier)
  )
)
```

Why any special Syntax?

Why not construct instances of `Flow[A,B]` directly?

```
AndThen(
  Peel(),
  Either(
    AndThen(
      Extract(),
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            Par(Peel(), Id()),
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              AndThen(Swap(), DistributeLR()),
              Either(
                AndThen(Swap(), InjectL()),
                AndThen(Swap(), InjectR())
              )
            )
          ),
          Either(
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              AndThen(
                AndThen(Par(Extract(), Id()), Inject(Single(Monitor))),
                InjectL()
              ),
              Unpeel()
            ),
            Inject(InLast(Chair))
          )
        ),
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          Peel(),
          Either(
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              Extract(),
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                Prj2()
              )
            ),
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              Par(
                Id(),
                Ext(RequestChairFromOfficeMgmt)
              ),
              Prj2()
            )
          )
        )
      )
    ),
    Ext(OrderFromSupplier)
  )
)
```

Can we get back variables and expressions?

Desired Syntax

```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
    case ForOffice(Chair(_) ** deskLoc) =>
      requestChairFromOfficeMgmt(deskLoc)
    case WorkFromHome(item ** address) =>
      orderFromSupplier(item ** address)
  }
}
```

- Lambdas
- Variables
- Pattern-matching
- Expressions

Desired Syntax

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Flow { req =>
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  }
}
```

- Lambdas
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  }
}
```

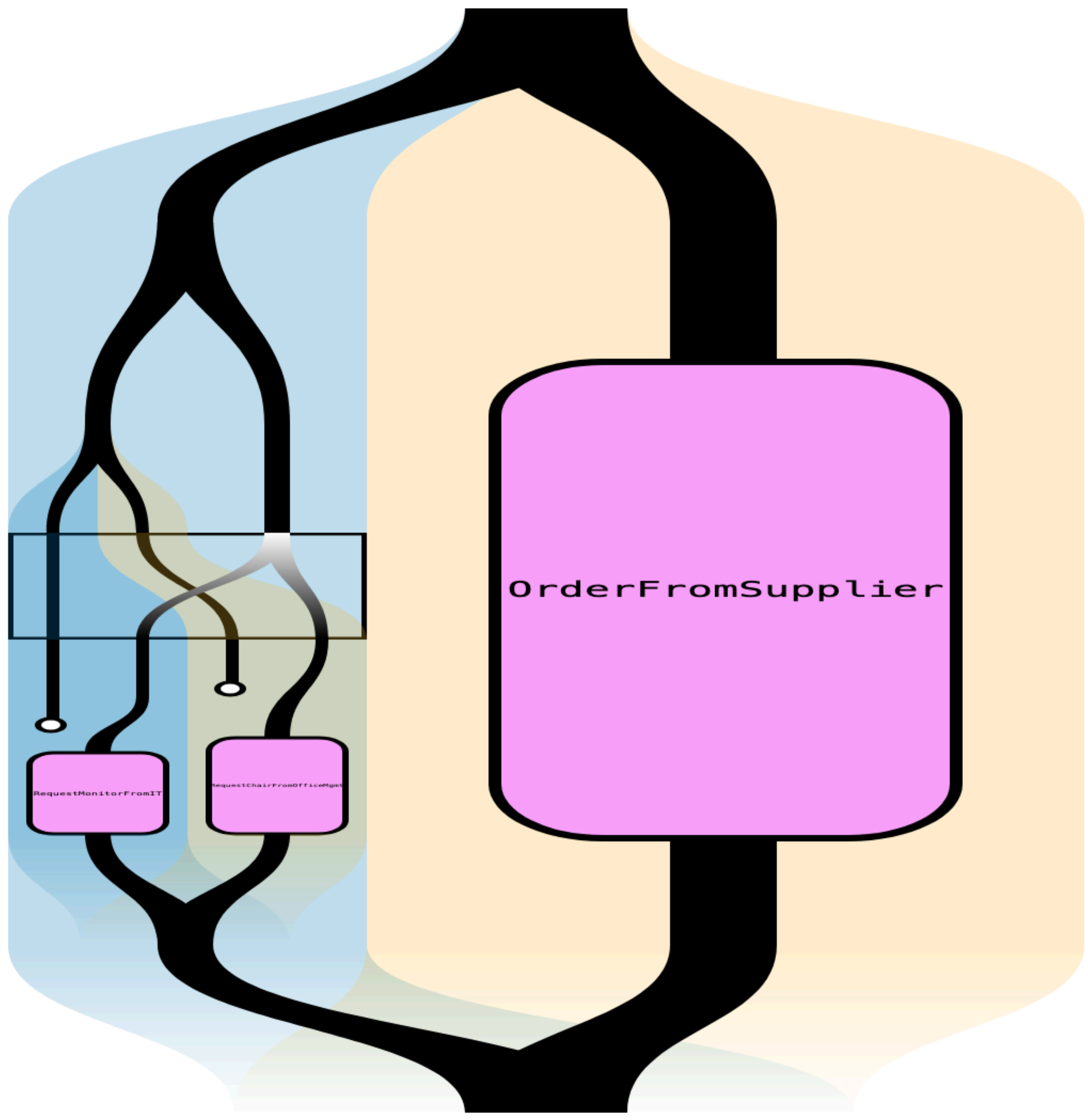

Let’s Break It Down

```
Flow { req =>
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```

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Flow { req =>
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  }
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```

1. What does **`Flow`** do?

Let’s Break It Down

```
Flow { req =>                                              🧑‍💻
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
    case ForOffice(Chair(_) ** deskLoc) =>
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      orderFromSupplier(item ** address)
  }
}
```

1. What does **`Flow`** do?
2. What does **`switch`** do?

Let's Break It Down

```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
    case ForOffice(Chair(_) ** deskLoc) =>
      requestChairFromOfficeMgmt(deskLoc)
    case WorkFromHome(item ** address) =>
      orderFromSupplier(item ** address)
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}
```

1. What does **`Flow`** do?
2. What does **`switch`** do?
3. What do the **extractors** do? (`ForOffice`, `Monitor`, ...)

Let’s Break It Down

```
Flow { req =>
  req switch {
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1. What does **`Flow`** do? 👈
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Flow *"Compiles"* Scala Functions

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Flow { req =>

  ???

}
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- Takes a *Scala* function

Flow *"Compiles"* Scala Functions

```scala
Flow { req =>

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} : Flow[Request, Result]
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  - **without** Scala functions

Flow *“Compiles”* Scala Functions

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Flow { (req: Expr[Request]) => 👨‍💻

  ??? : Expr[Result]

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- Takes a *Scala* function
  - **on auxiliary expressions**

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object Flow:




  def apply[A, B](
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  ): Flow[A, B] =
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```

Flow *“Compiles”* Scala Functions

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import libretto.lambda.Lambdas

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    f: Expr[A] => Expr[B],
  ): Flow[A, B] =
    lambdas.delambdify(..., f)
    // ... and handle errors ...
```

Flow *"Compiles"* Scala Functions

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Peek into `libretto-lambda`

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```
enum Expr[A]: // approximately
```

📗

Peek into `libretto-lambda`

```
enum Expr[A]: // approximately
  case Var(id: Object)
```

- variables

Peek into `libretto-lambda`

```
enum Expr[A]: // approximately
  case Var(id: Object)
  case Zip[A, B](
    a: Expr[A],
    b: Expr[B]
  ) extends Expr[A ** B]
```

- variables
- forming pairs

Peek into `libretto-lambda`

```
enum Expr[A]: // approximately
  case Var(id: Object)
  case Zip[A, B](
    a: Expr[A],
    b: Expr[B]
  ) extends Expr[A ** B]

  case Prj1[A, B](e: Expr[A ** B]) extends Expr[A]
  case Prj2[A, B](e: Expr[A ** B]) extends Expr[B]
```

- variables
- forming pairs
- accessing pairs

Peek into `libretto-lambda`

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enum Expr[A]: // approximately
  case Var(id: Object)
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  case Map[A, B](
    a: Expr[A],
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  ) extends Expr[B]
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- variables
- forming pairs
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- applying an *already compiled* `Flow`

Peek into `libretto-lambda`

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- variables
- forming pairs
- accessing pairs
- applying an *already compiled* `Flow`
- **no** lambda abstraction (immediately delambdified)

Peek into libretto-lambda

```scala
// approximately
def delambdify[A, B](
  f: Expr[A] => Expr[B]
): Flow[A, B] | ... =
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Peek into `libretto-lambda`

```
// approximately 📗
def delambdify[A, B](
  f: Expr[A] => Expr[B]
): Flow[A, B] | ... =
  val 🍅 : Expr[A] = Var(freshId())
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Peek into `libretto-lambda`

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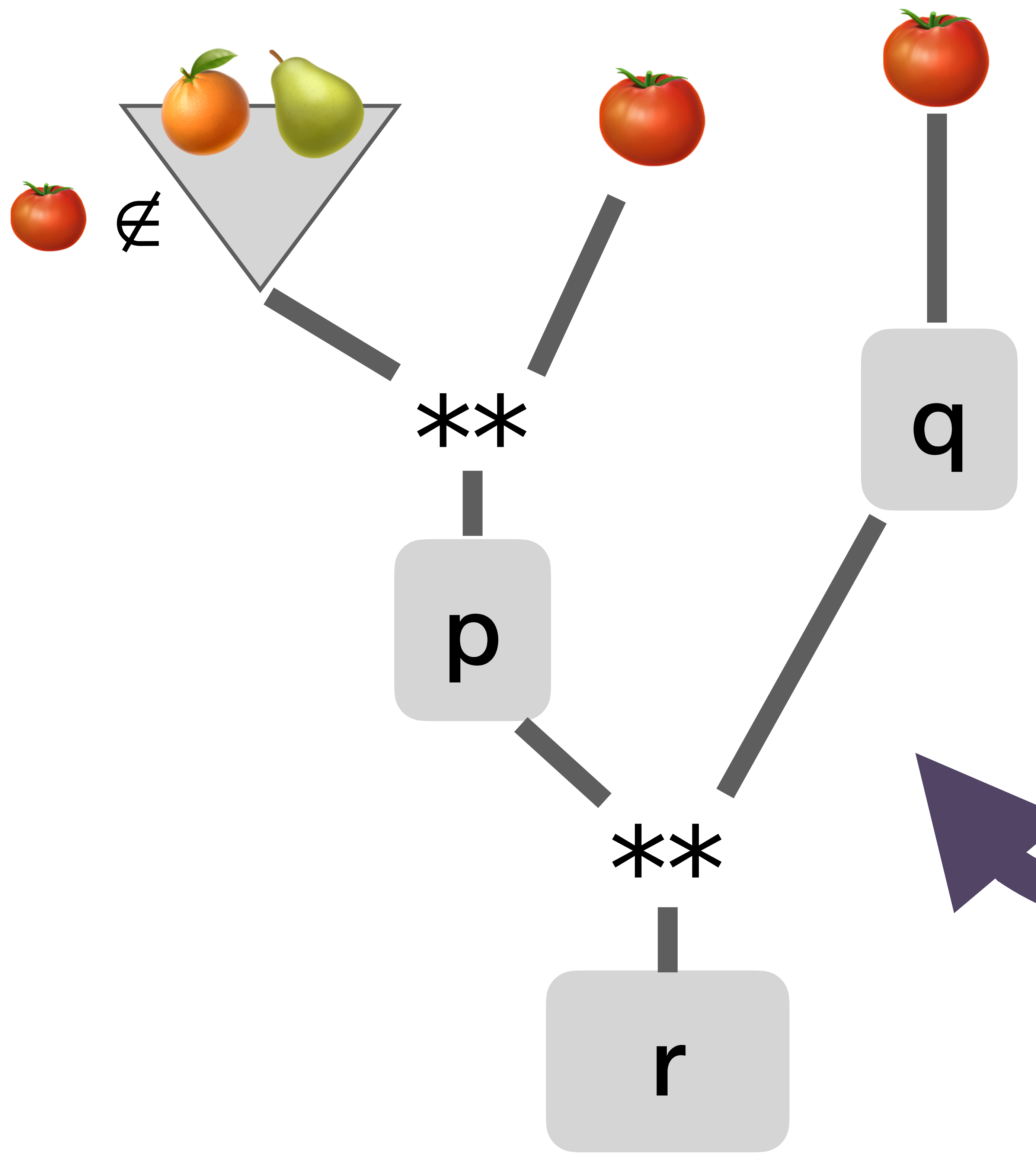


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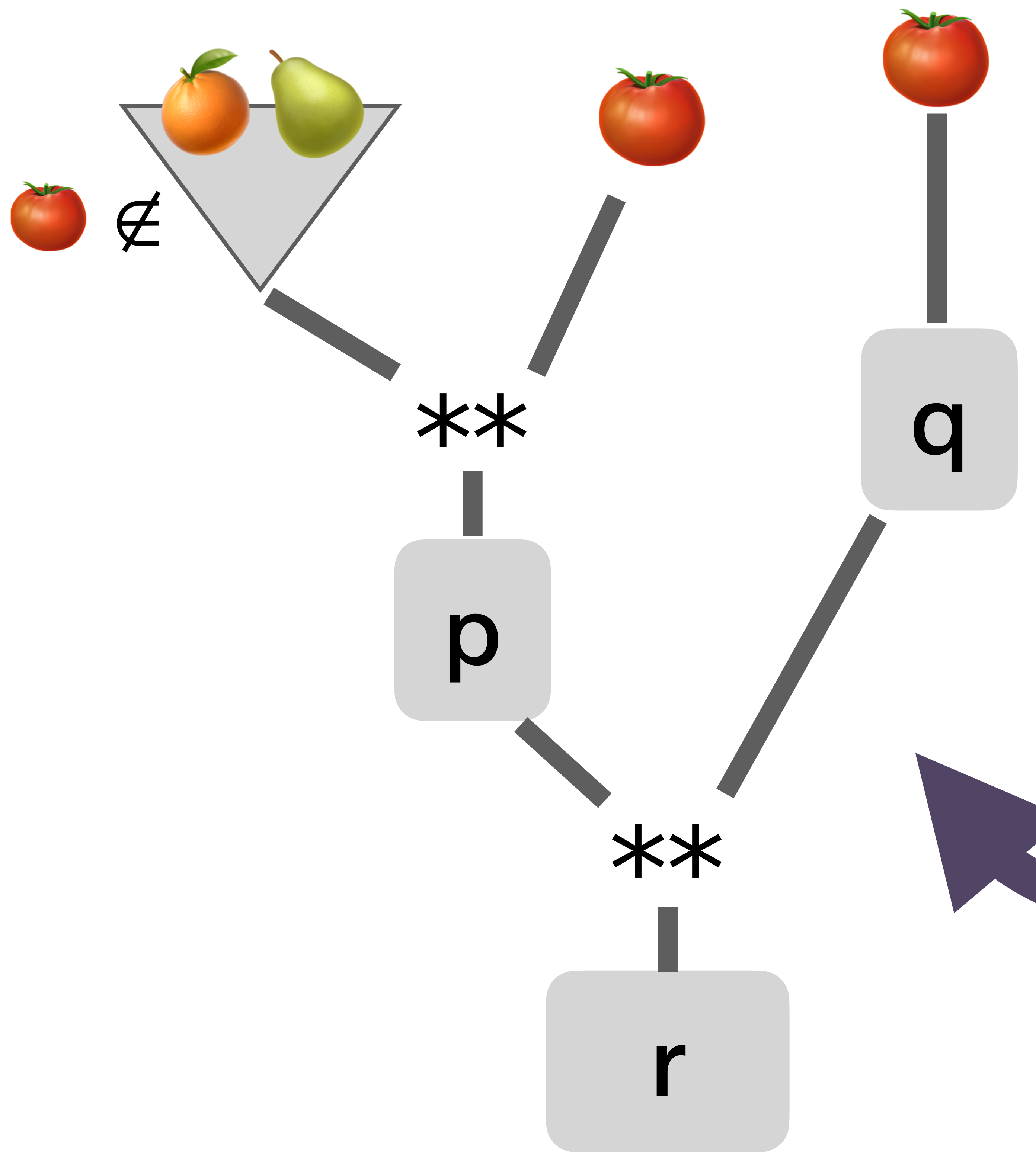


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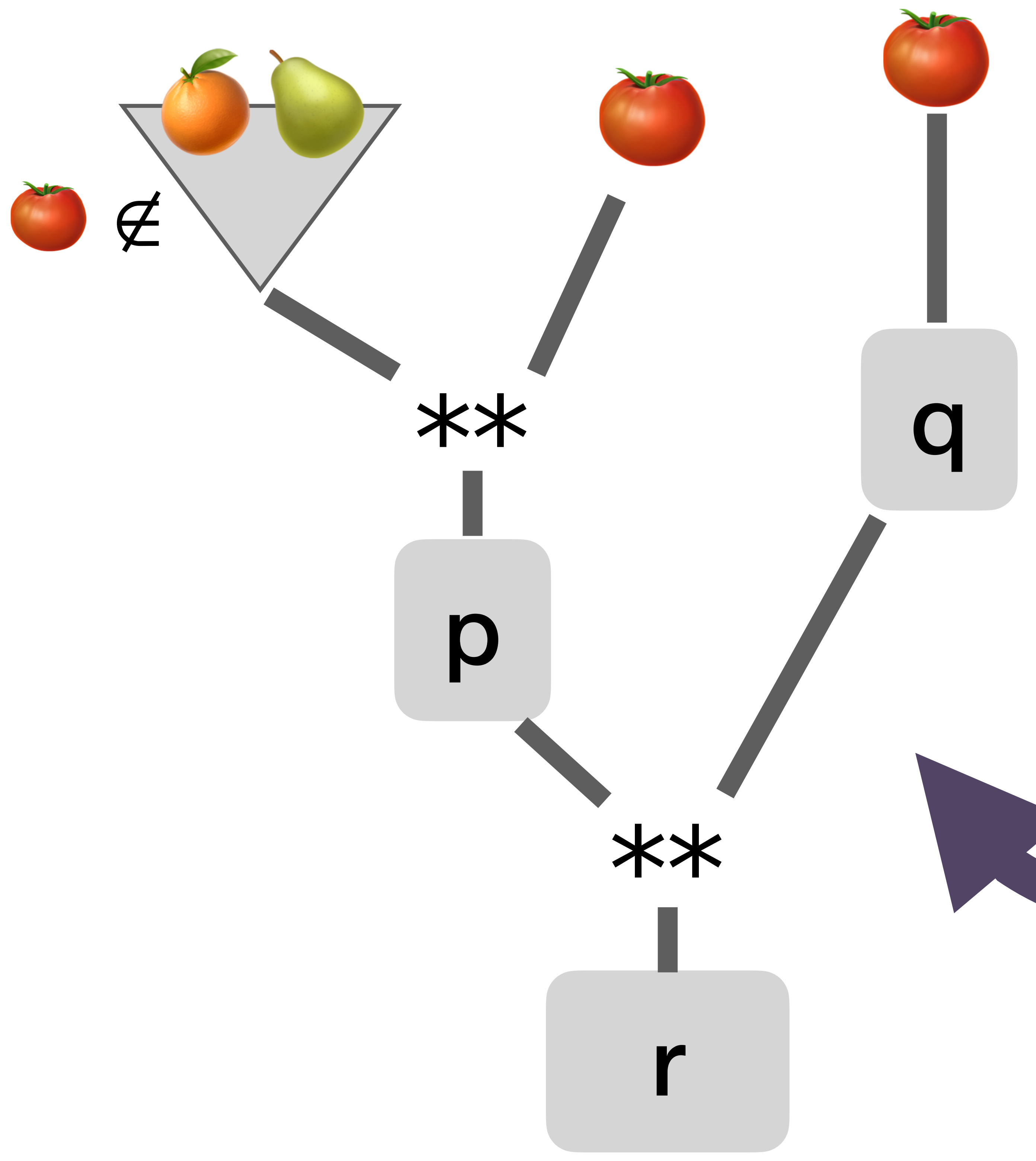
Peek into `libretto-lambda`

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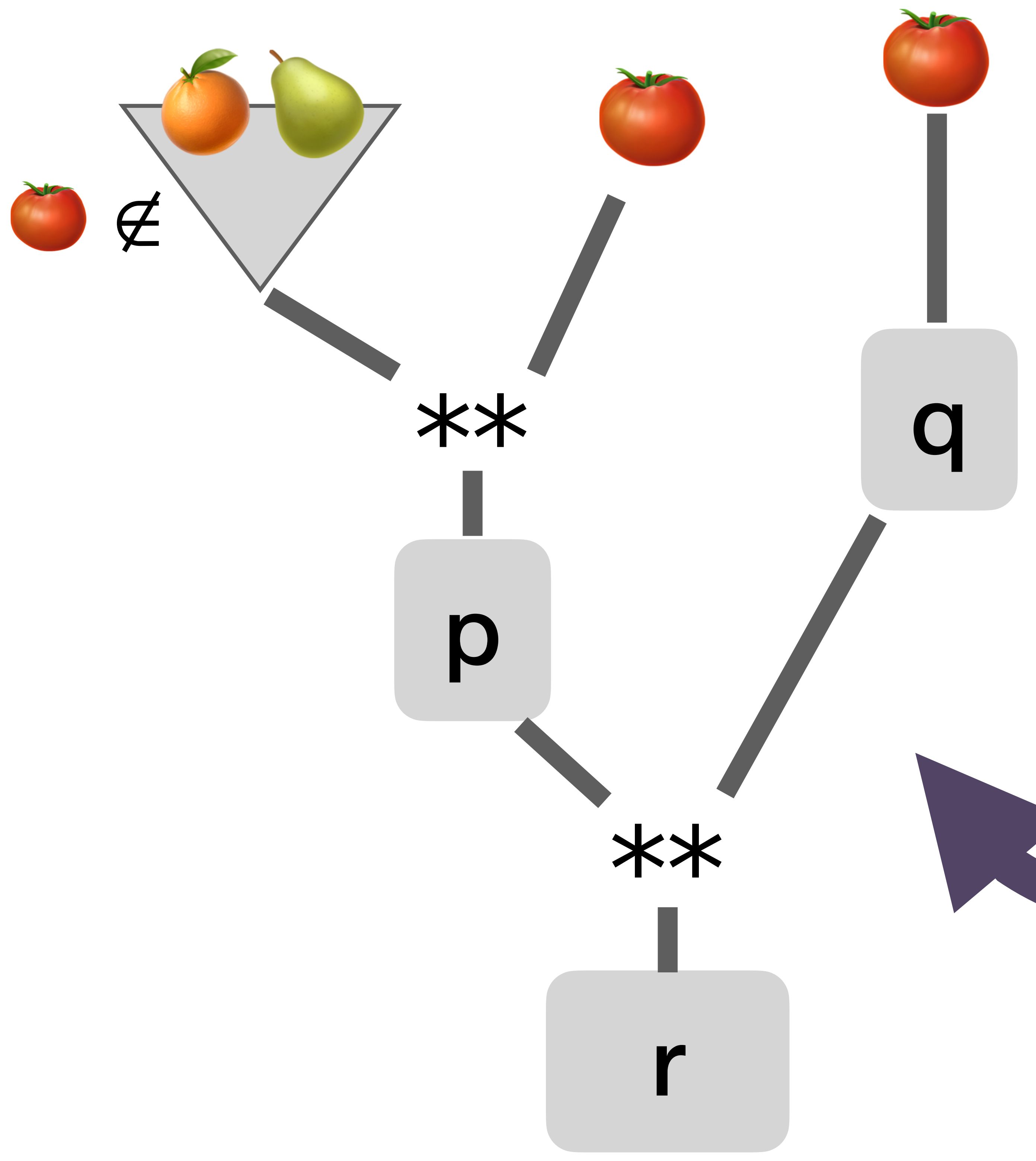


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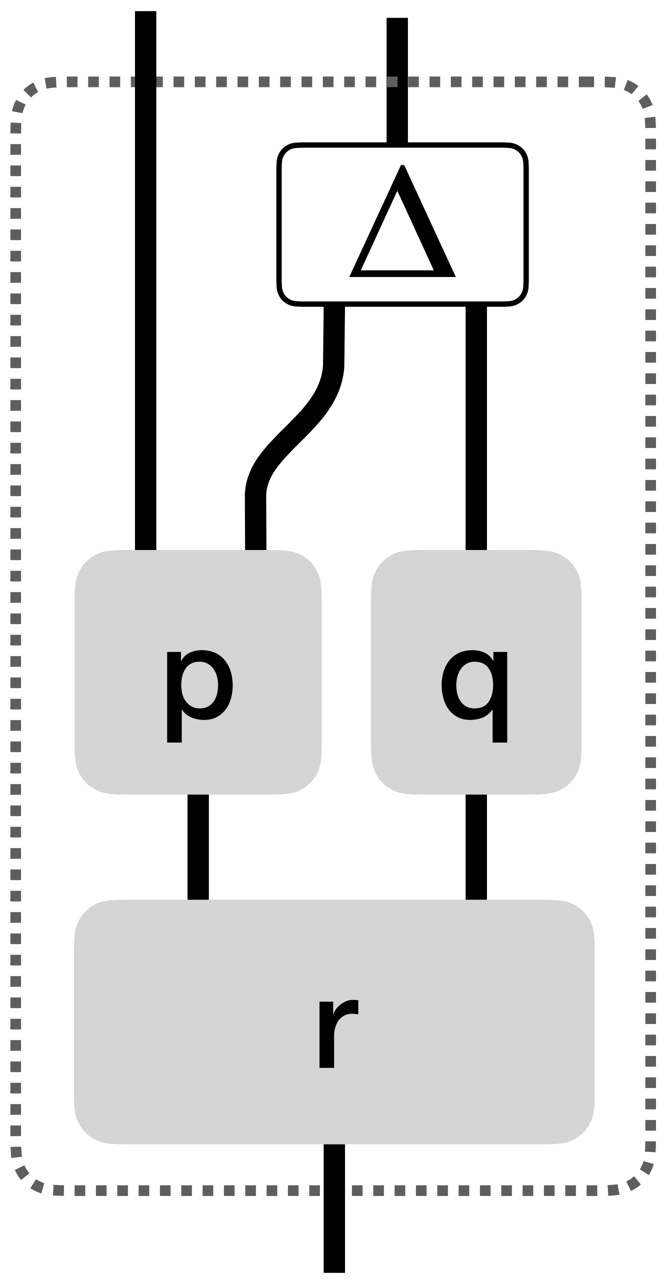

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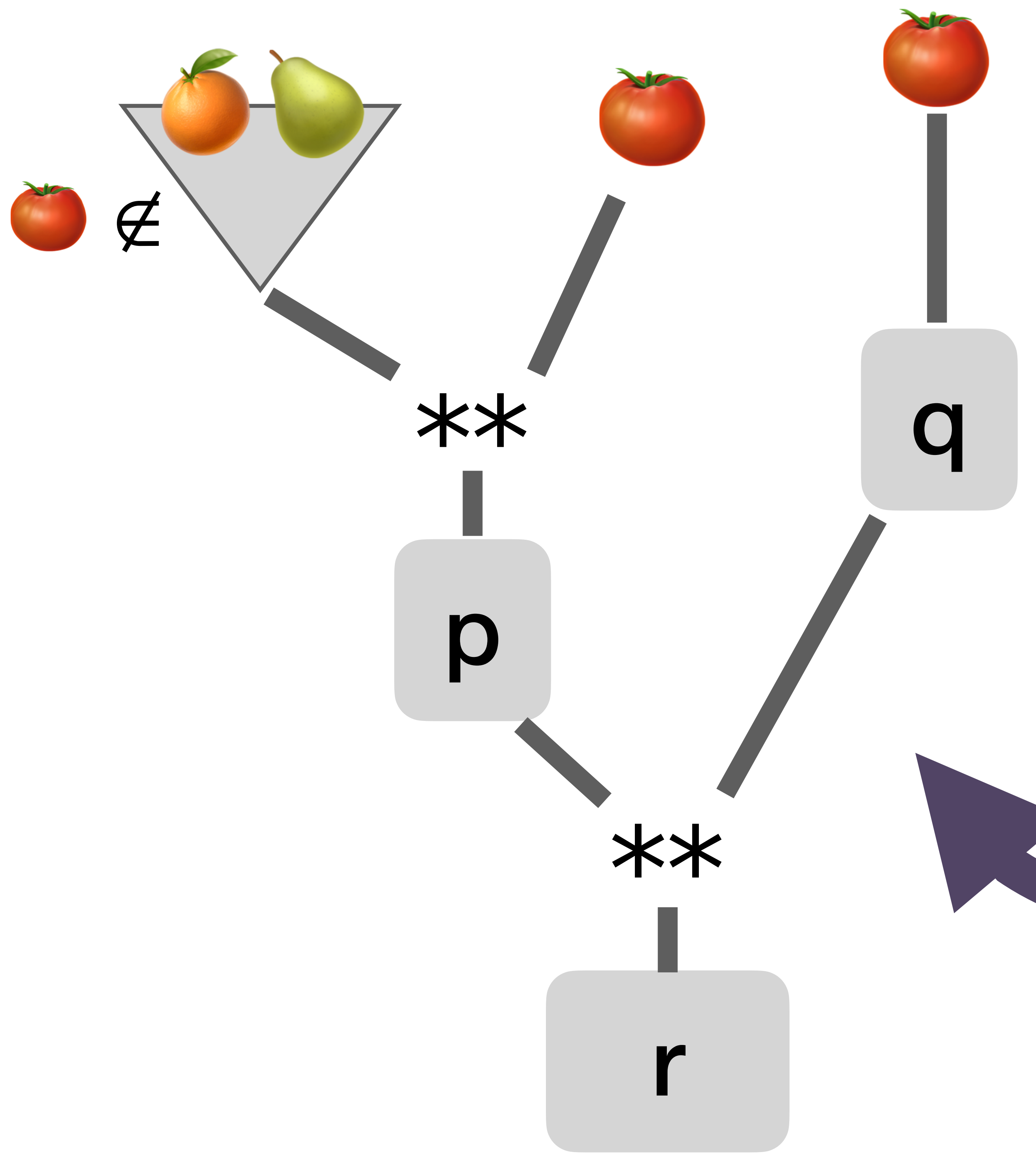


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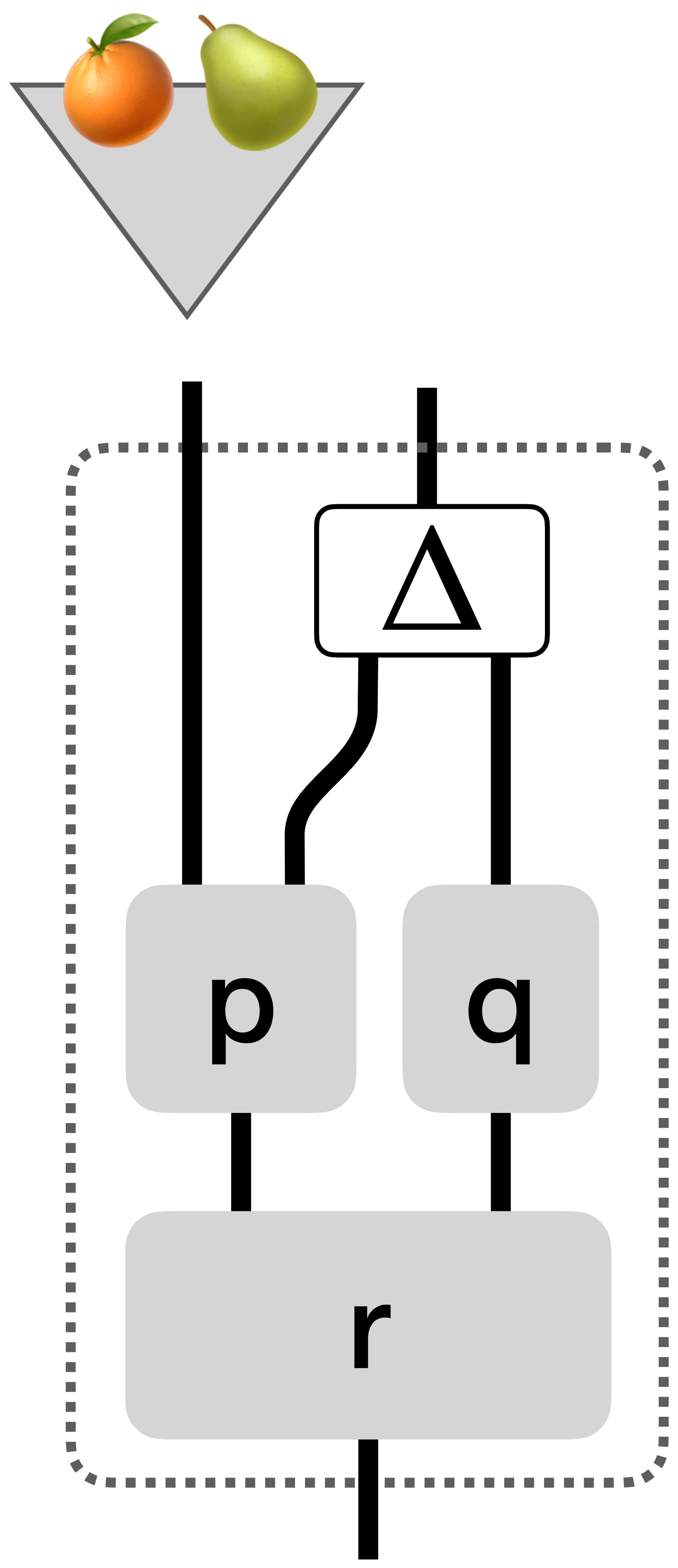

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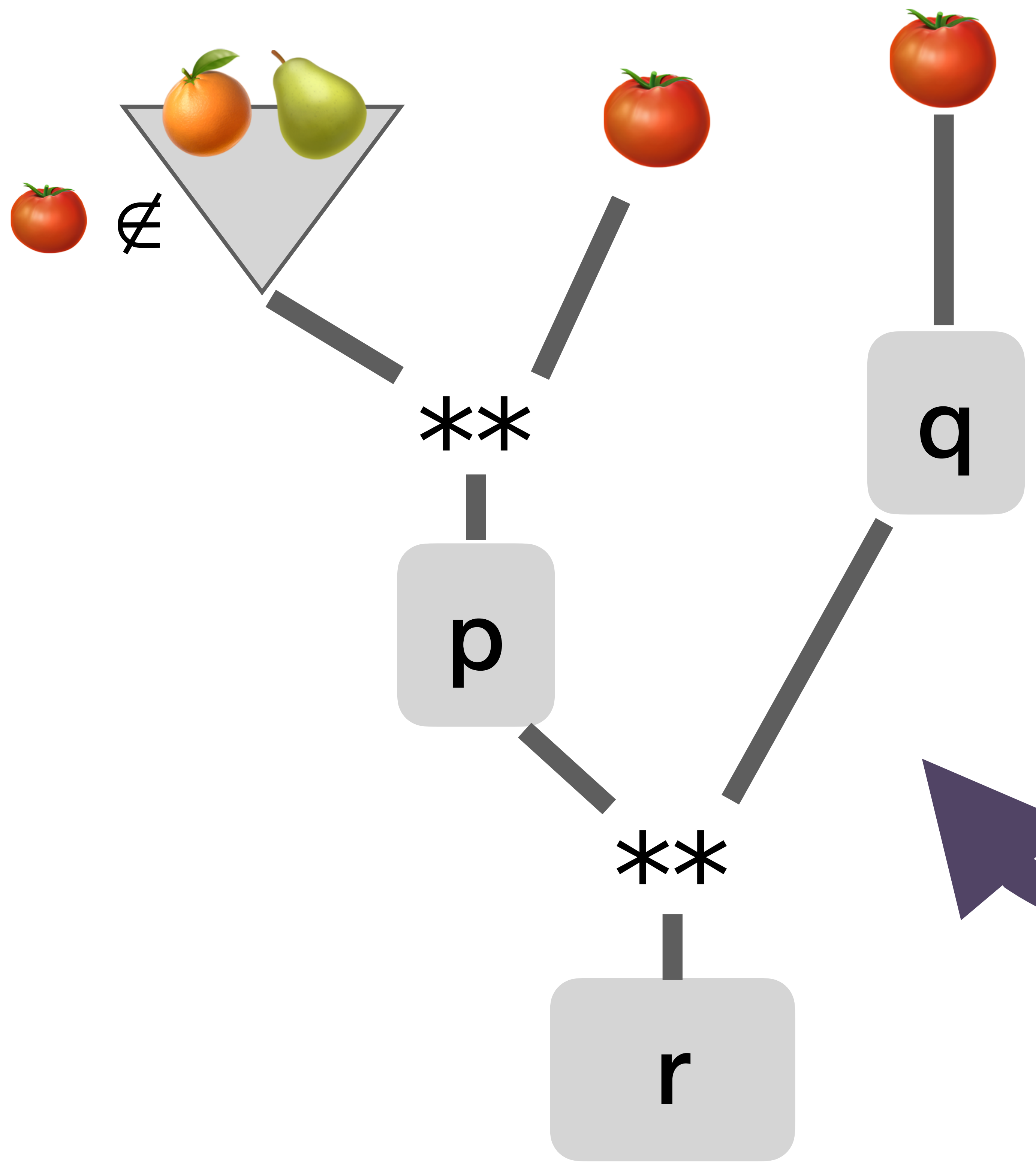


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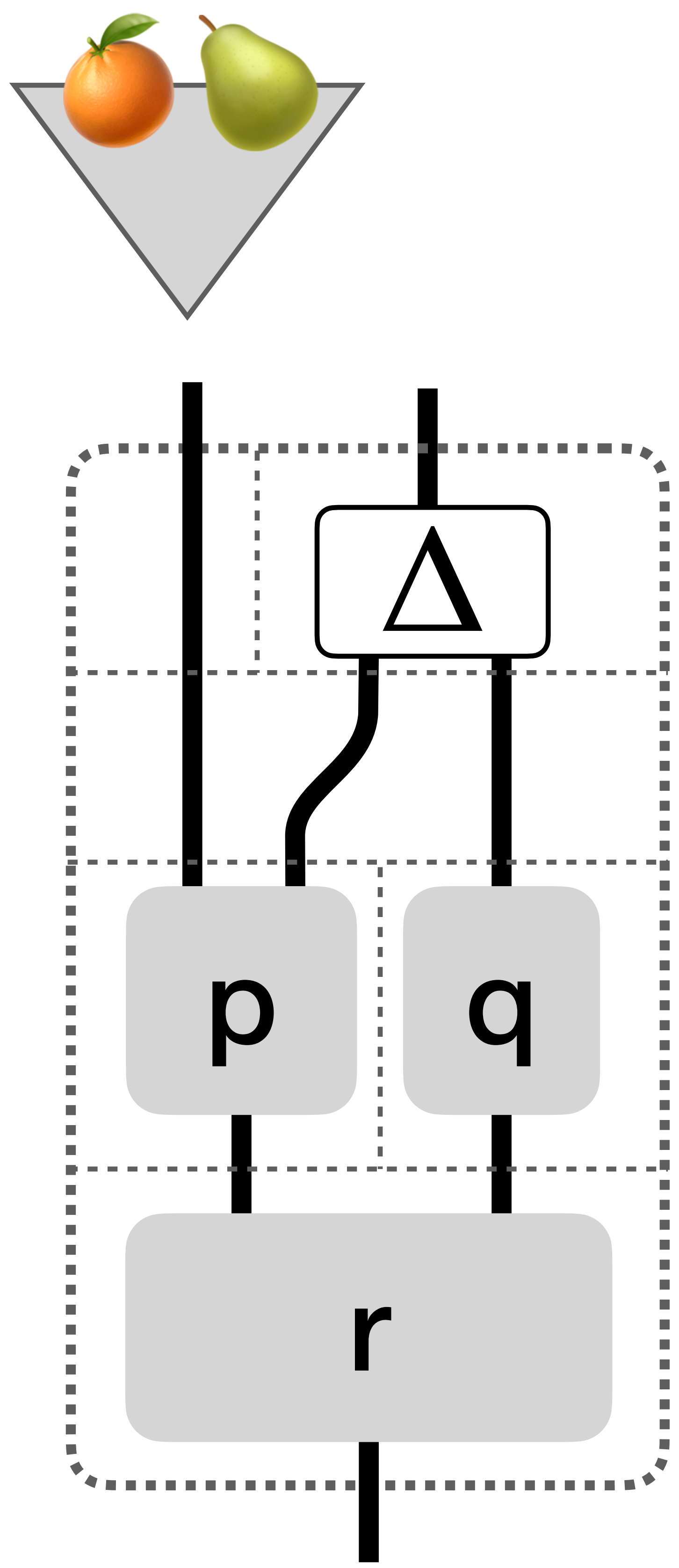

Breaking It Down

```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
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1. What does **`Flow`** do?
2. What does **`switch`** do?
3. What do the **extractors** do?
   (`ForOffice`, `Monitor`, …)

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Enum Extractors

```
type Request = Enum
  [ "ForOffice"    :: (Equipment ** DeskLocation)
  || "WorkFromHome" :: (Equipment ** DeliveryAddress)
  ]
```

Enum Extractors

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Enum Extractors

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object Request:

  val ForOffice     : Extractor[Request, Equipment ** DeskLocation]
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Enum Extractors

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```

Knows the partitioning of a type (`Request`) into disjoint cases.
Represents one partition (`"ForOffice"`).

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```
import libretto.lambda.EnumModule

val Enum = EnumModule[Flow, **, Enum, ||, ::](using ...)
```

Extractors: What Do They *Do?*

🧑‍💻

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Extractors: What Do They *Do?*

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```
extension [A, B](ext: Extractor[A, B])
  def unapply(a: Expr¹[A]): Some[Expr¹[B]] =
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```
extension [A, B](ext: Extractor[A, B])
  def unapply(a: Expr¹[A]): Some[Expr¹[B]] =
    val b = Expr¹.Map(a, ext.toFlow¹)
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```scala
type Flow¹[A, B] = ...
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  def unapply(a: Expr¹[A]): Some[Expr¹[B]] =
    val b = Expr¹.Map(a, ext.toFlow¹)
    Some(b)
```

```
type Flow¹[A, B] = ...
val lambdas¹: Lambdas[Flow¹, **, …]
type Expr¹[A] = lambdas¹.Expr[A]
```

- (at Scala level) always matches
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Breaking It Down

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2. What does **`switch`** do? 👈
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switch

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  case WorkFromHome(item ** address)    => orderFromSupplier(item ** address)
}
```

switch

👨‍💻

```
req switch {
  case ForOffice(Monitor(_) ** deskLoc) => requestMonitorFromIT(deskLoc)
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```

macro-expand(*) to

```
req switch (
  is { case ForOffice(Monitor(_) ** deskLoc) => requestMonitorFromIT(deskLoc)       },
  is { case ForOffice(Chair(_) ** deskLoc)   => requestChairFromOfficeMgmt(deskLoc) },
  is { case WorkFromHome(item ** address)    => orderFromSupplier(item ** address)  }
)
```

switch

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}
```

macro-expand(*) to

taking each case as it’s own function

```
req switch (
  is { case ForOffice(Monitor(_) ** deskLoc) => requestMonitorFromIT(deskLoc)       },
  is { case ForOffice(Chair(_) ** deskLoc)   => requestChairFromOfficeMgmt(deskLoc) },
  is { case WorkFromHome(item ** address)    => orderFromSupplier(item ** address)  }
)
```

switch

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```

records source position (for error reporting)

switch

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records source position (for error reporting)

(*) not implemented for this demo

`switch`: What Does It *Do*?

👨‍💻

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```
extension [A](a: Expr[A])
  def switch[R](cases: (Expr[A] => Expr[R])*): Expr[R] =
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`switch`: What Does It *Do*?

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```

Calls the library 😎

```
extension [A](a: Expr[A])
  def switch[R](cases: (Expr[A] => Expr[R])*): Expr[R] =
    patmat.delambdifyAndCompile(a, cases)
```

switch: What Does It *Do*?

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Calls the library 😎

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  def switch[R](cases: (Expr[A] => Expr[R])*): Expr[R] =
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```

```
import libretto.lambda.PatternMatching
val patmat = PatternMatching[Flow, **].forLambdas(lambdas¹)(...)
```

`switch`: What Does It *Do*?

👨‍💻

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1. Delambdify each case

switch: What Does It *Do*?

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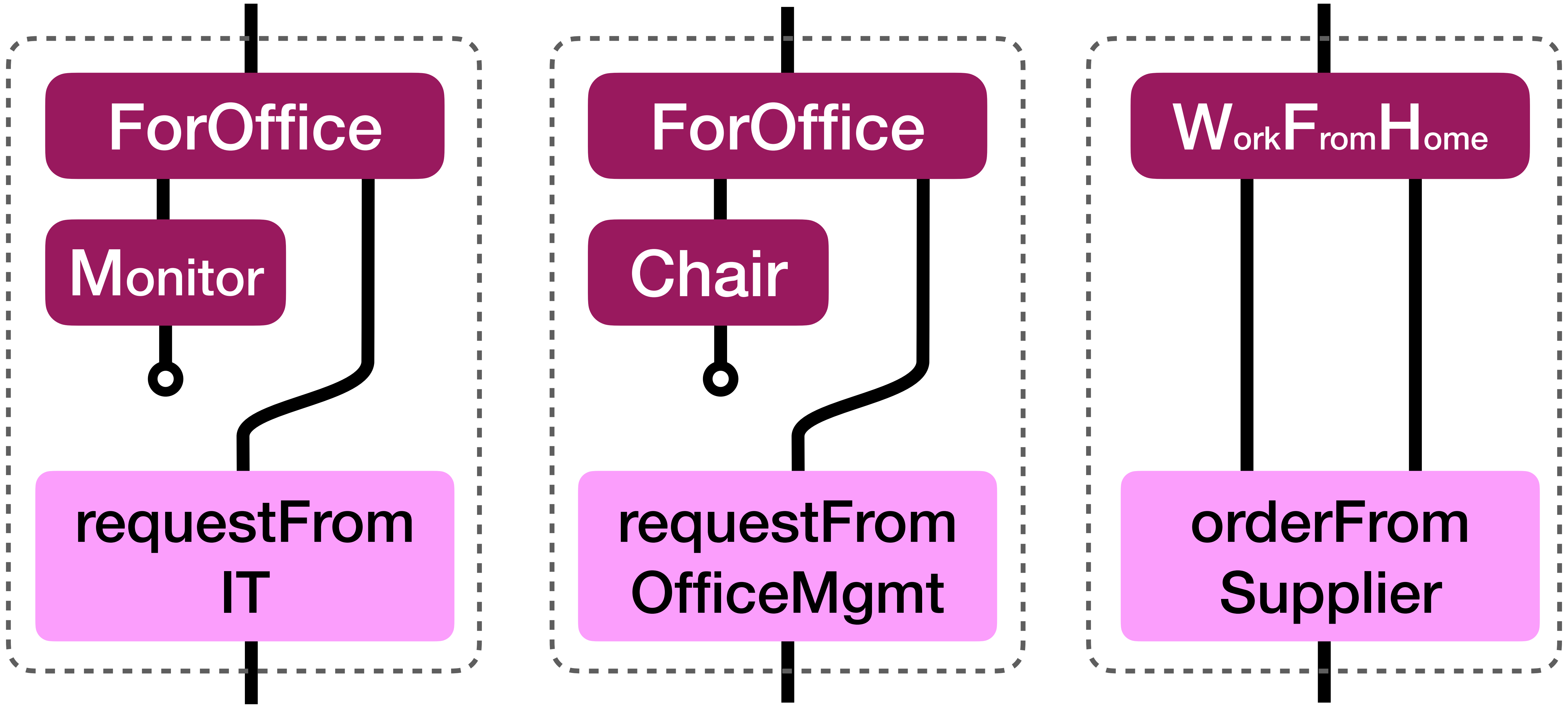
1. Delambdify each case



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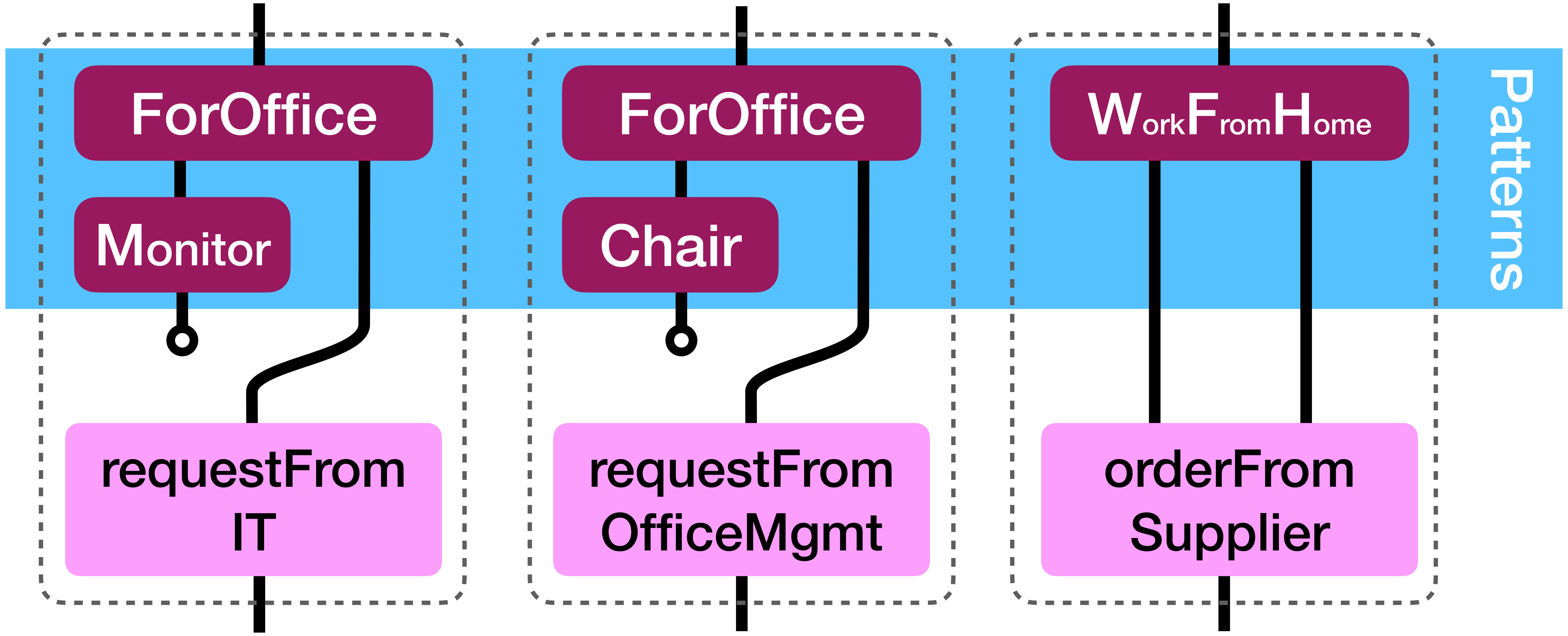

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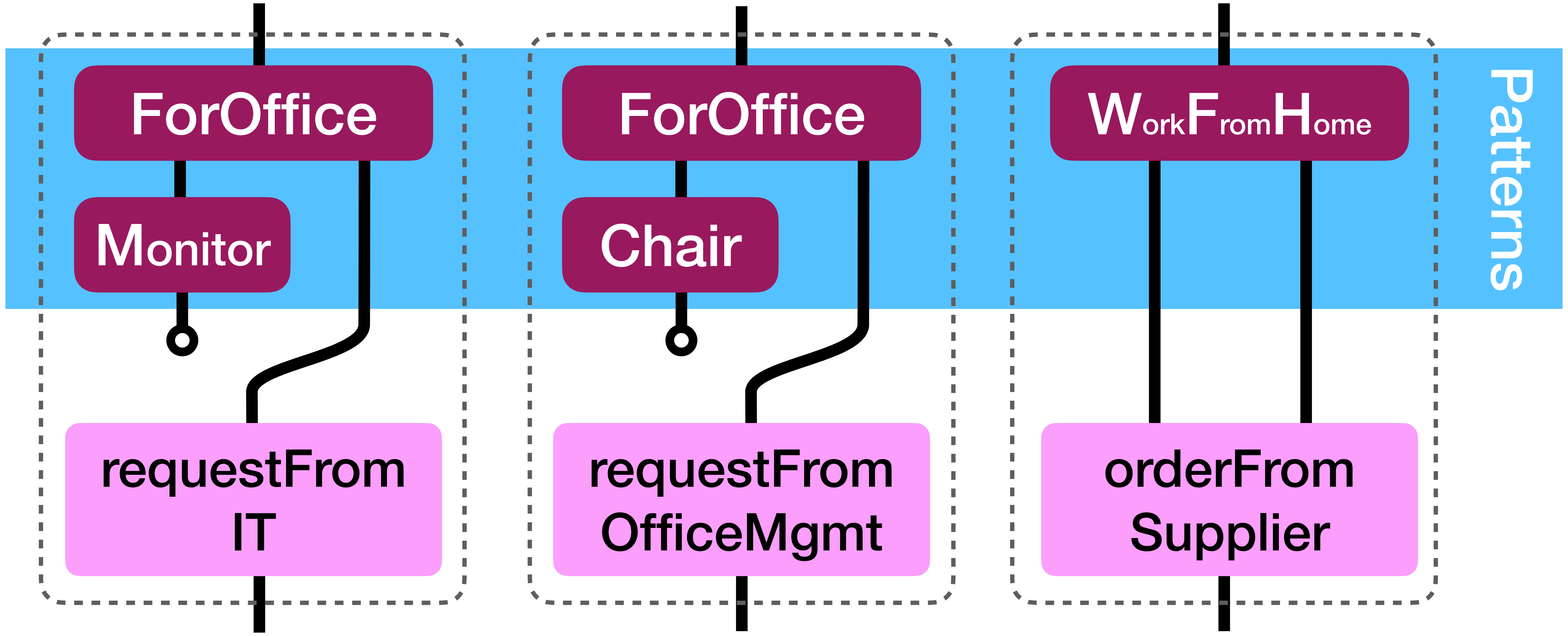
```

1. Delambdify each case

Idea: Recombine to

- eliminate (non-total) Extractors
- form (total) Handlers.

Fail if not possible.



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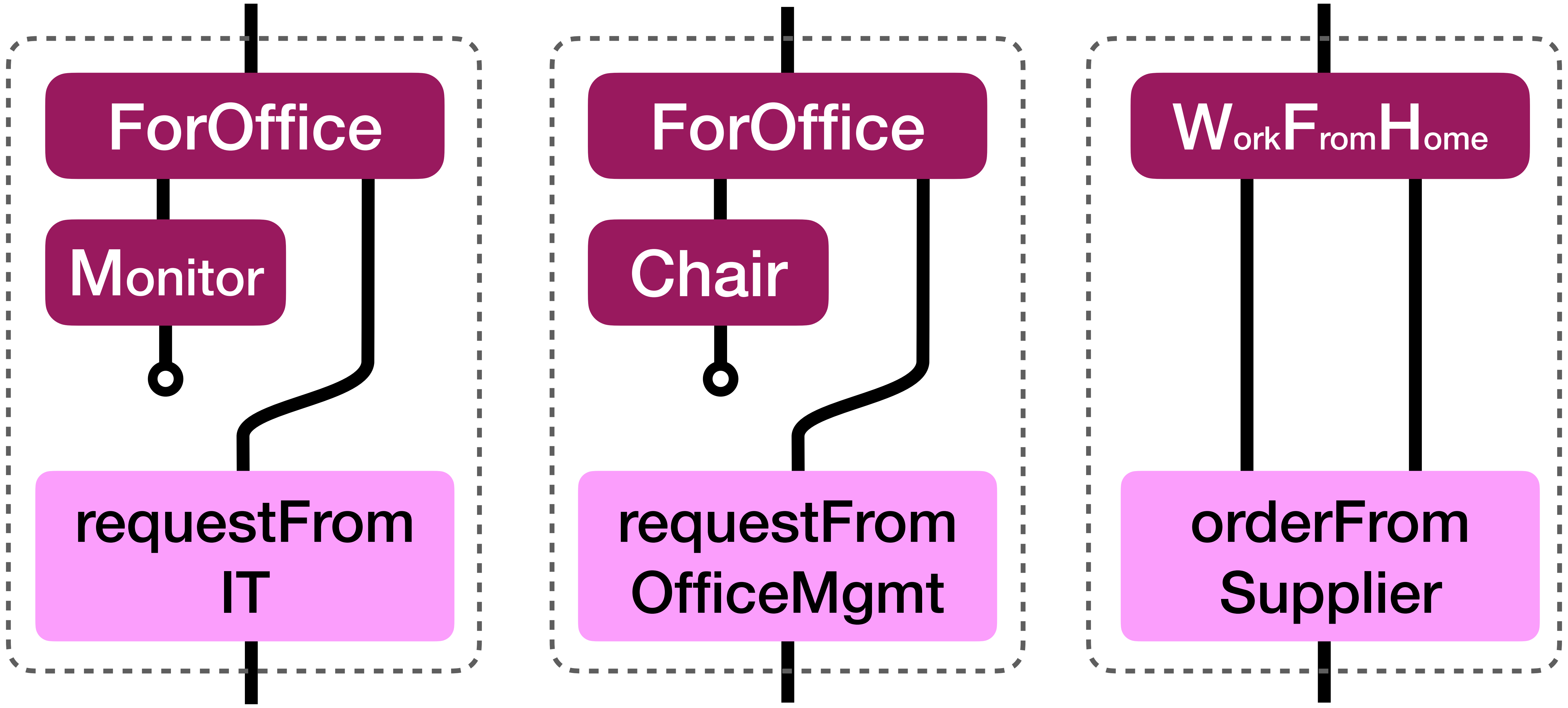

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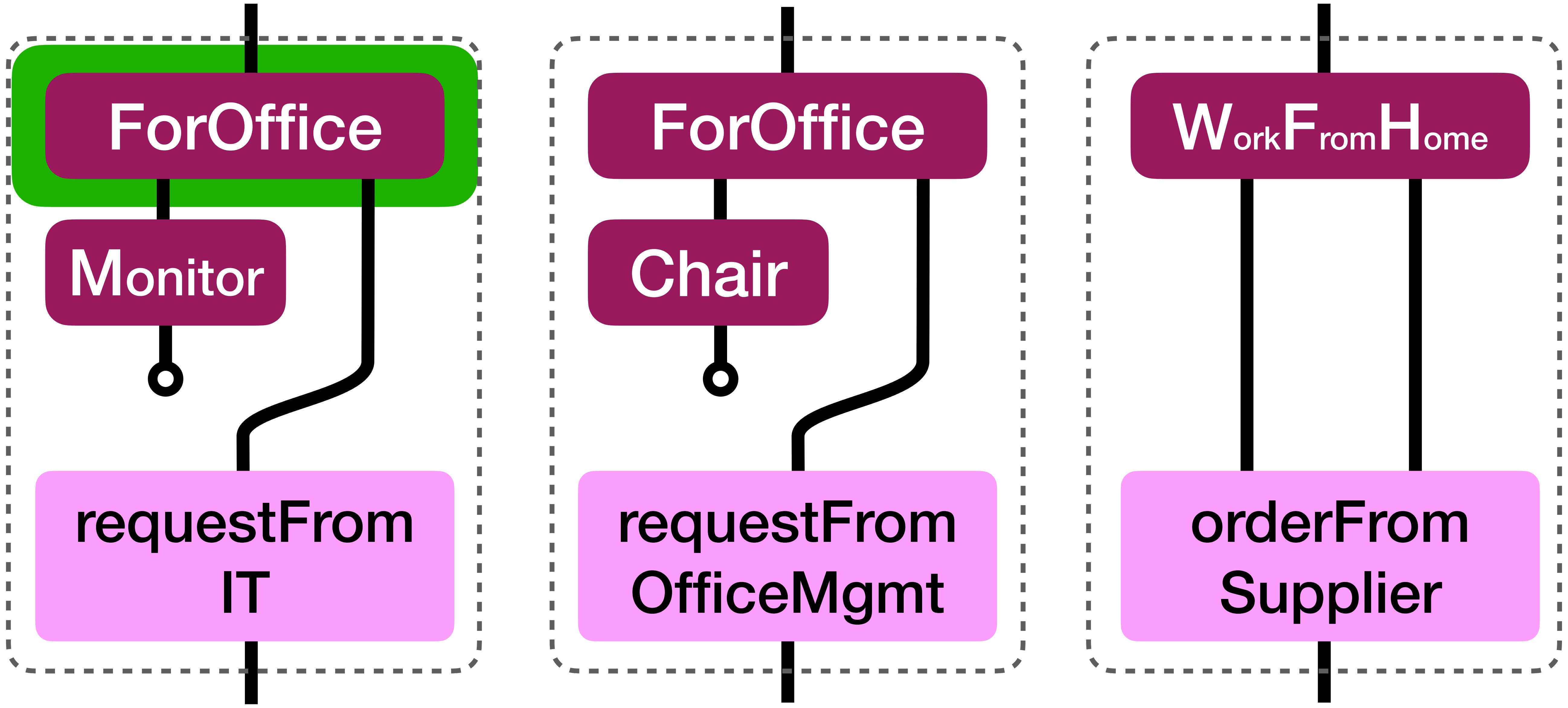
1. Delambdify each case
2. Pick the first Extractor, obtain the whole partitioning



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1. Delambdify each case
2. Pick the first Extractor,
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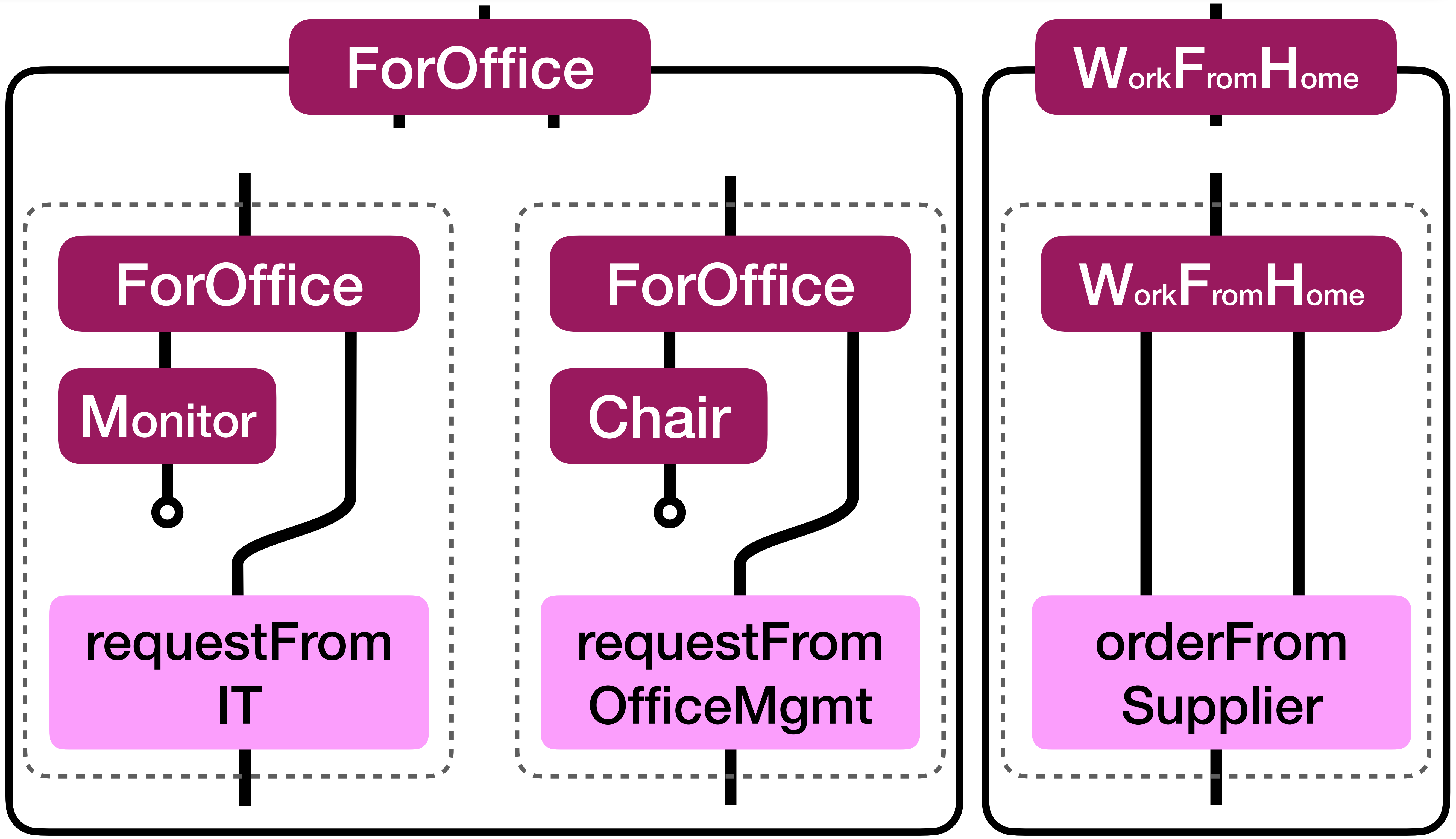
3. Group by partition
   empty group = non-exhaustivity



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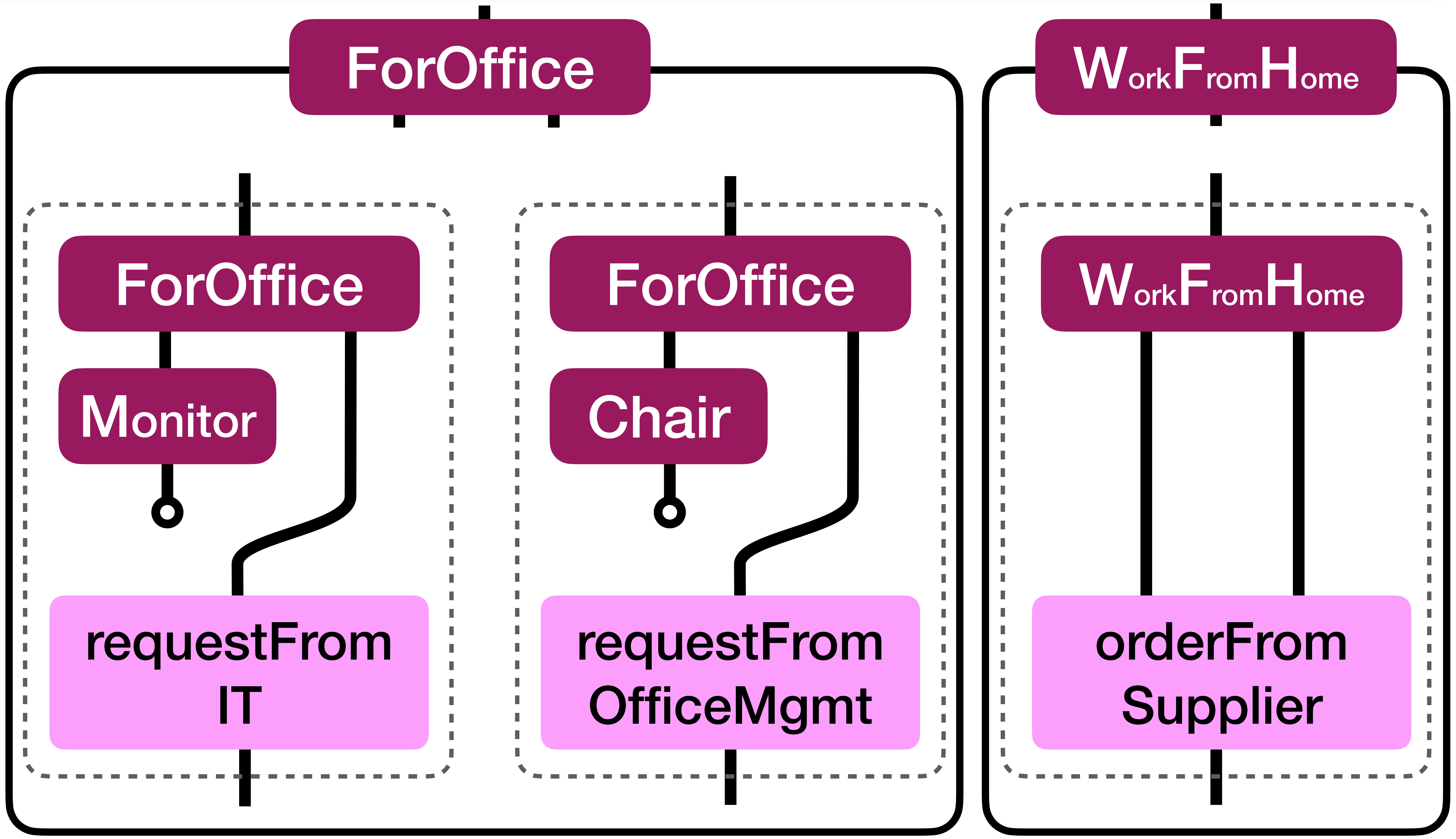
4. Remove the matched extractor



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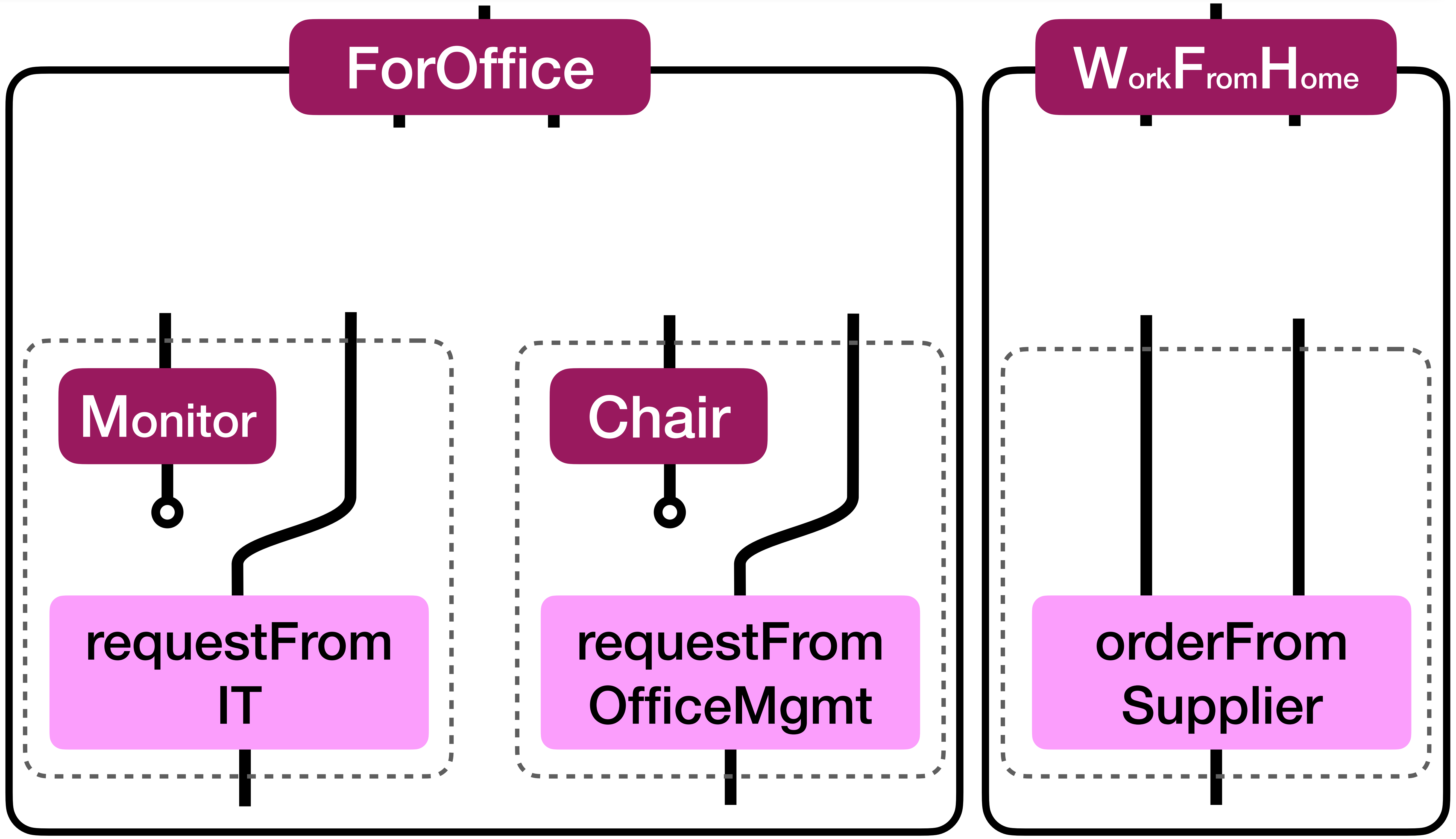

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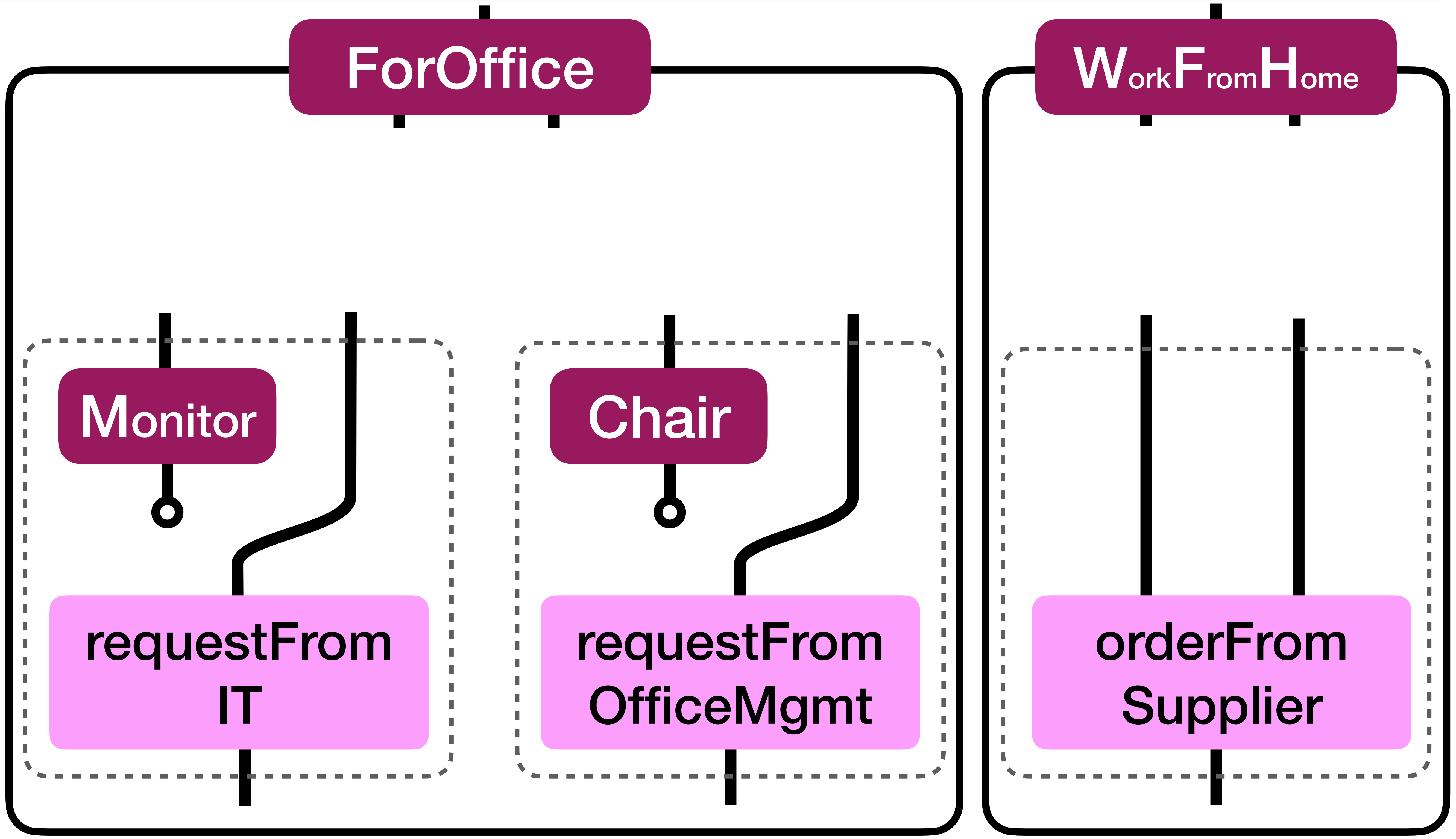

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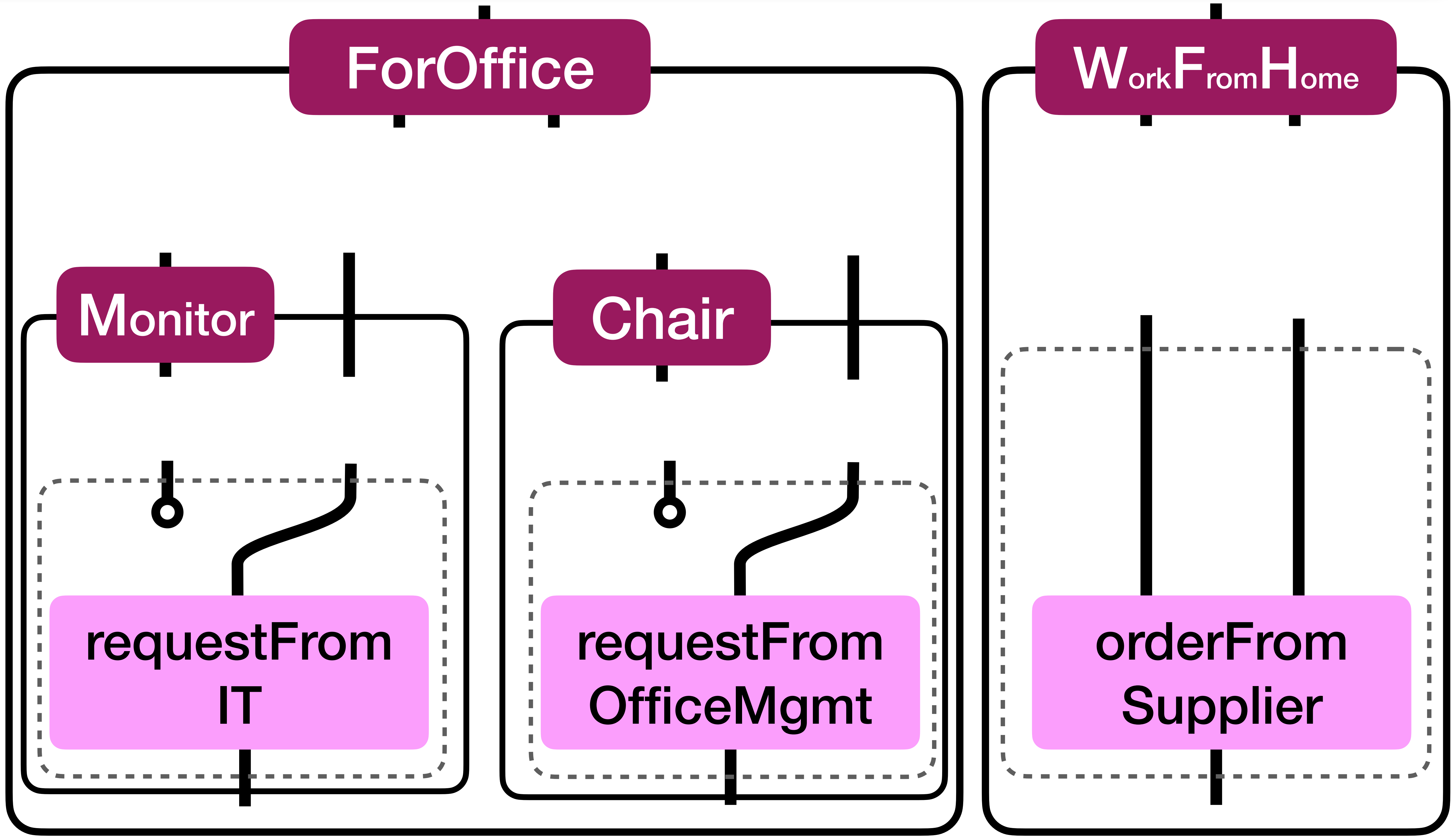

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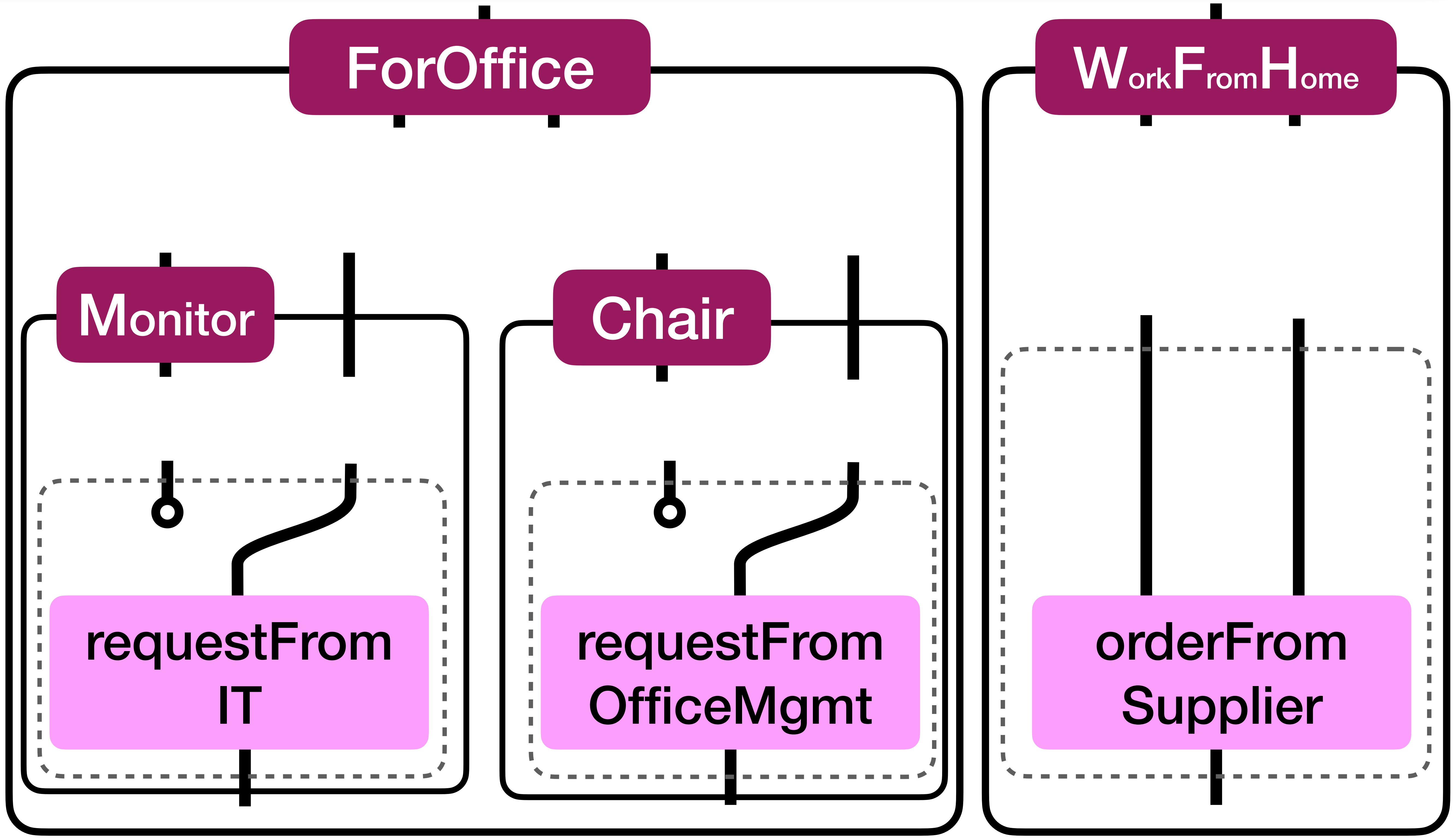

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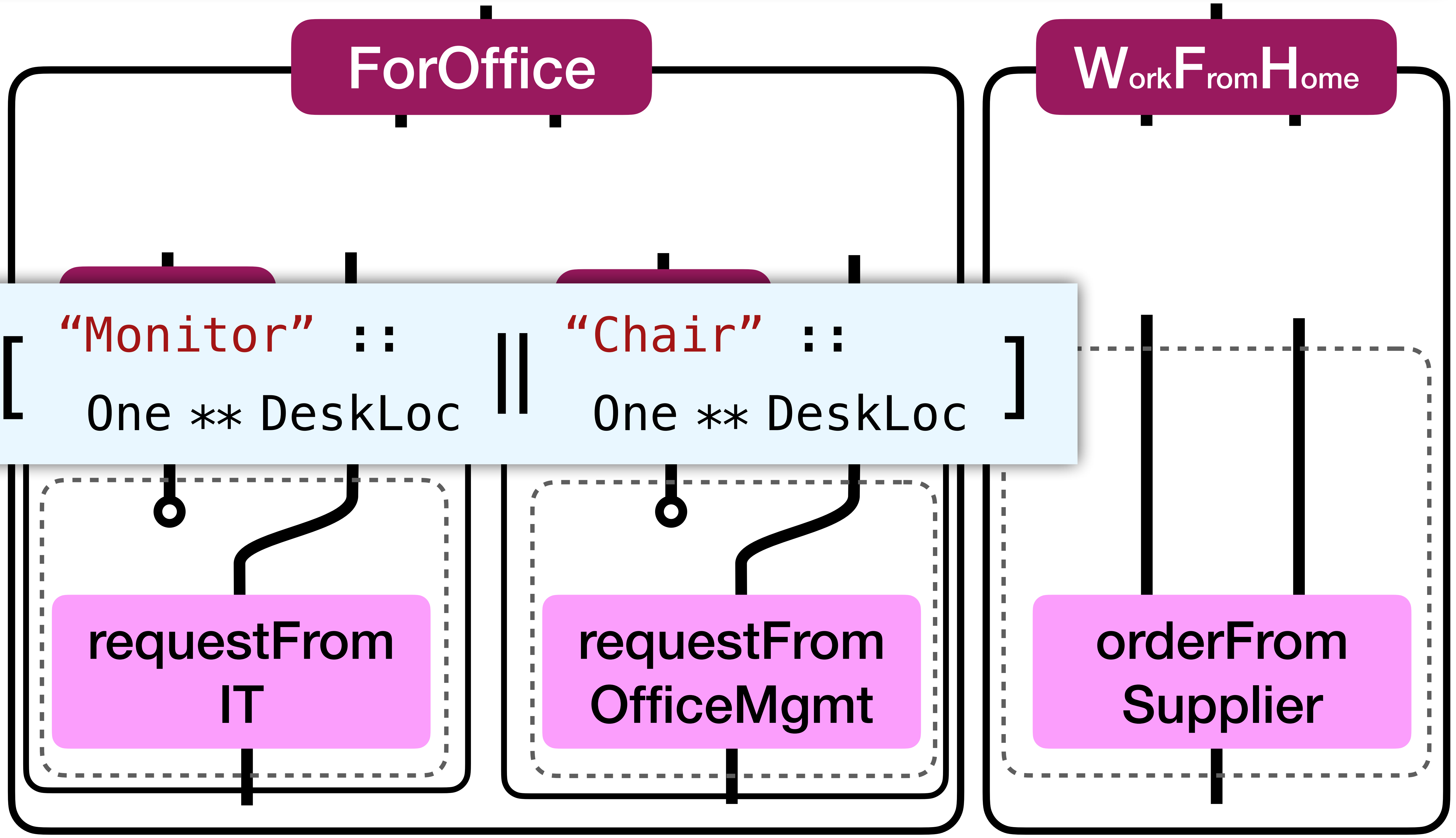
```
Enum [ "Monitor" :: One ** DeskLoc || "Chair" :: One ** DeskLoc ]
```



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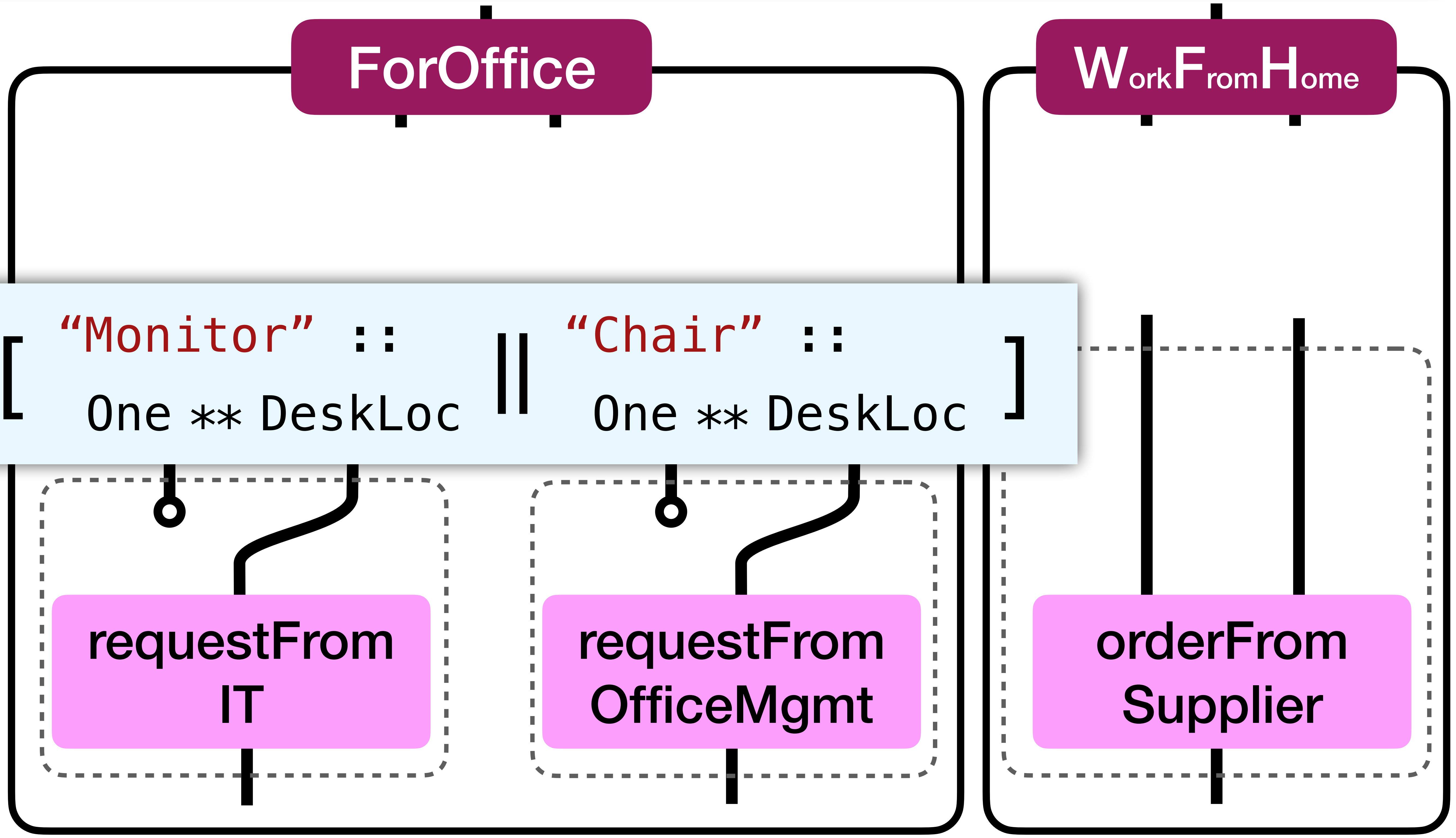

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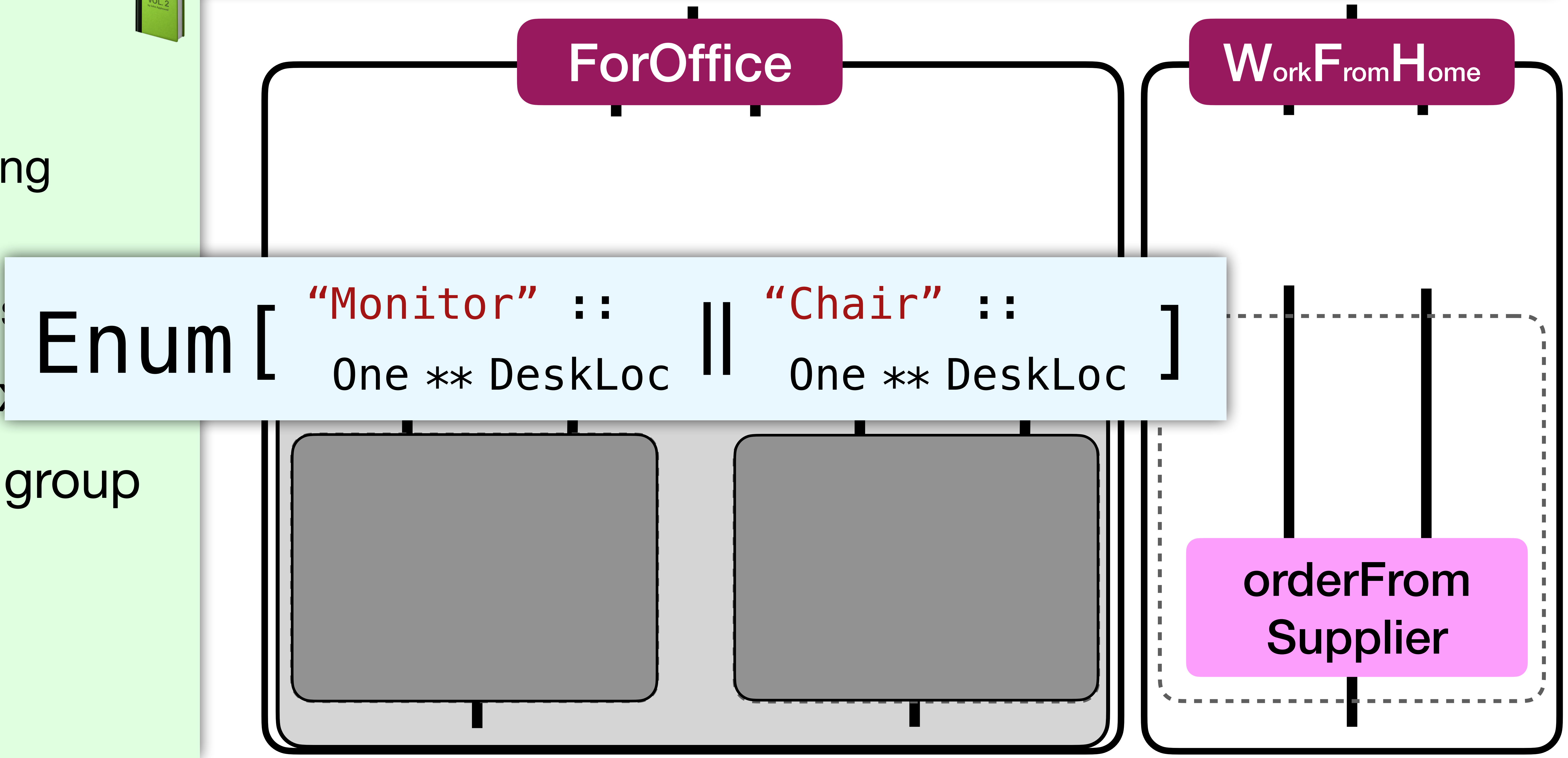

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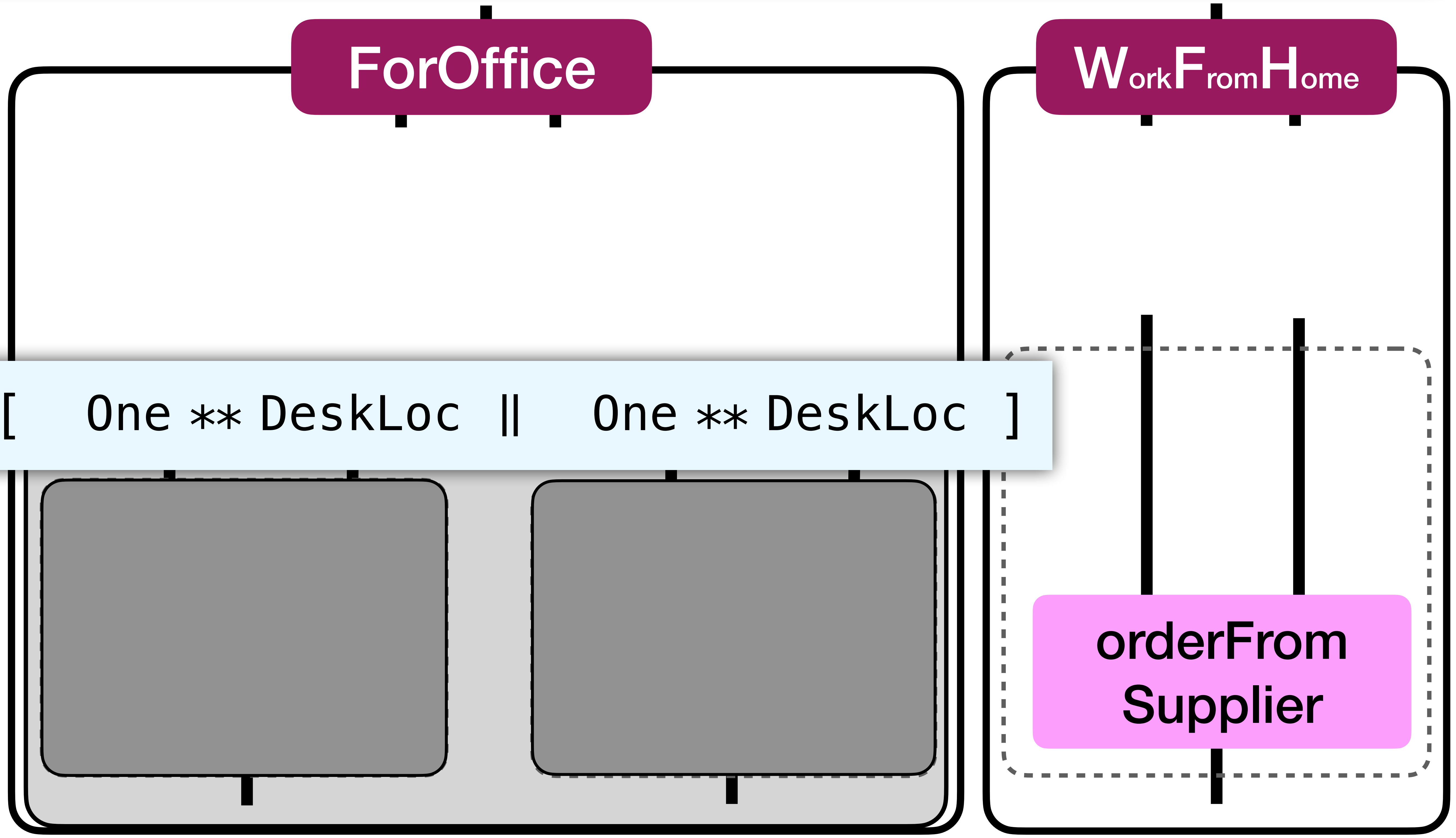

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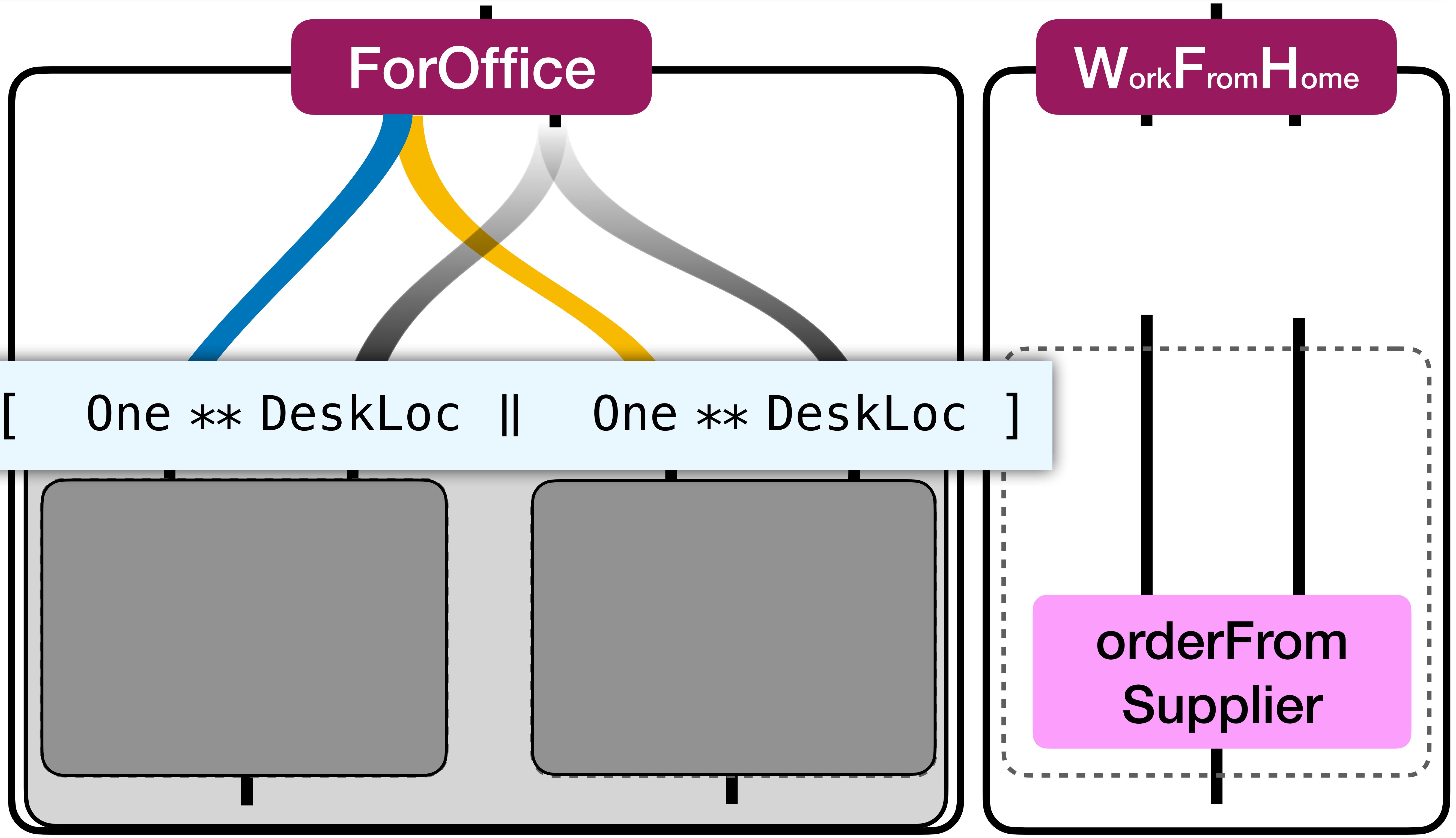

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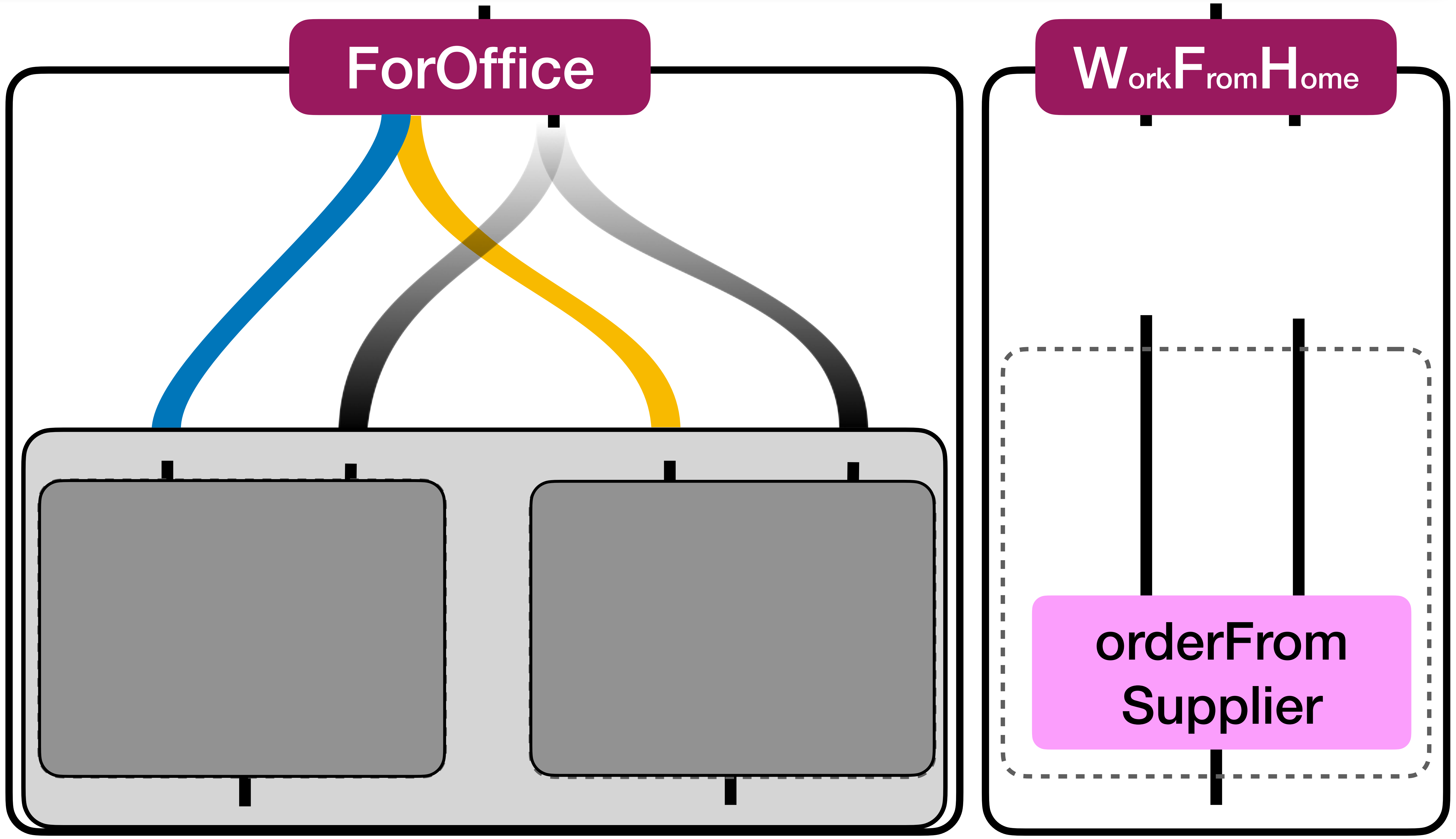

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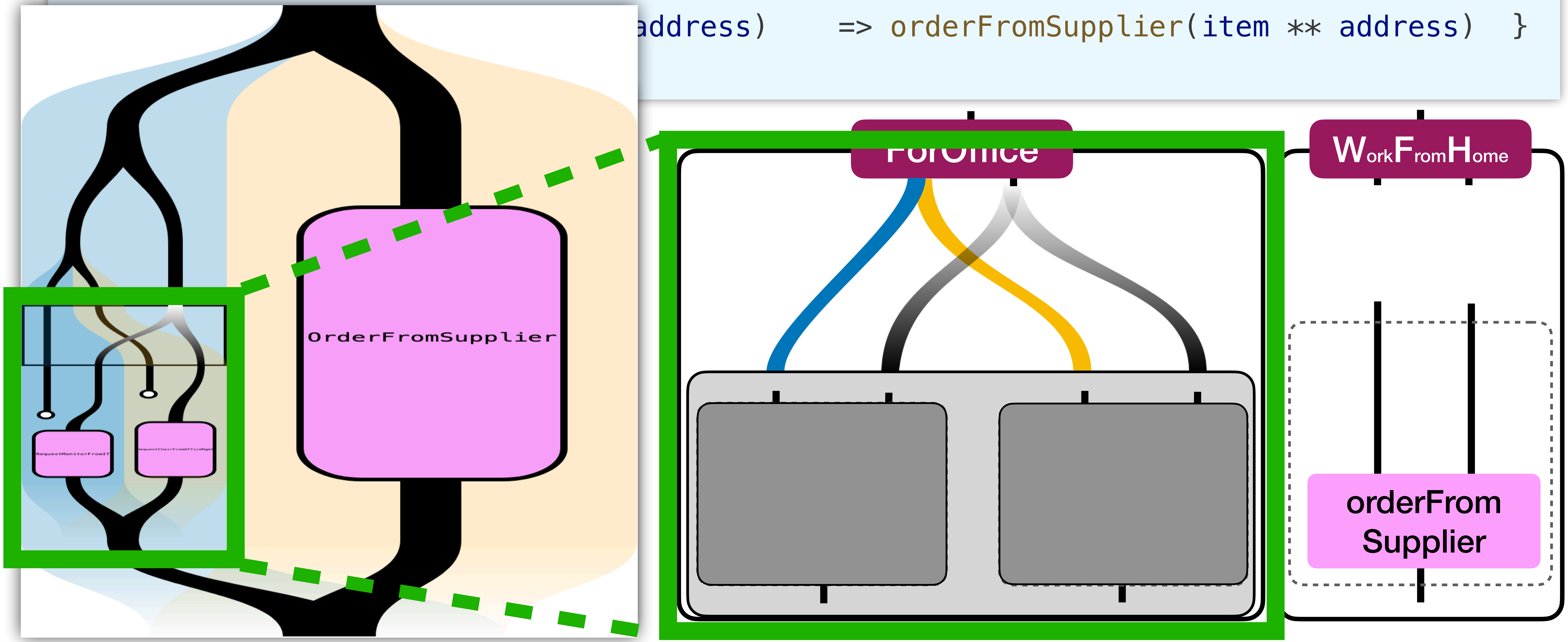

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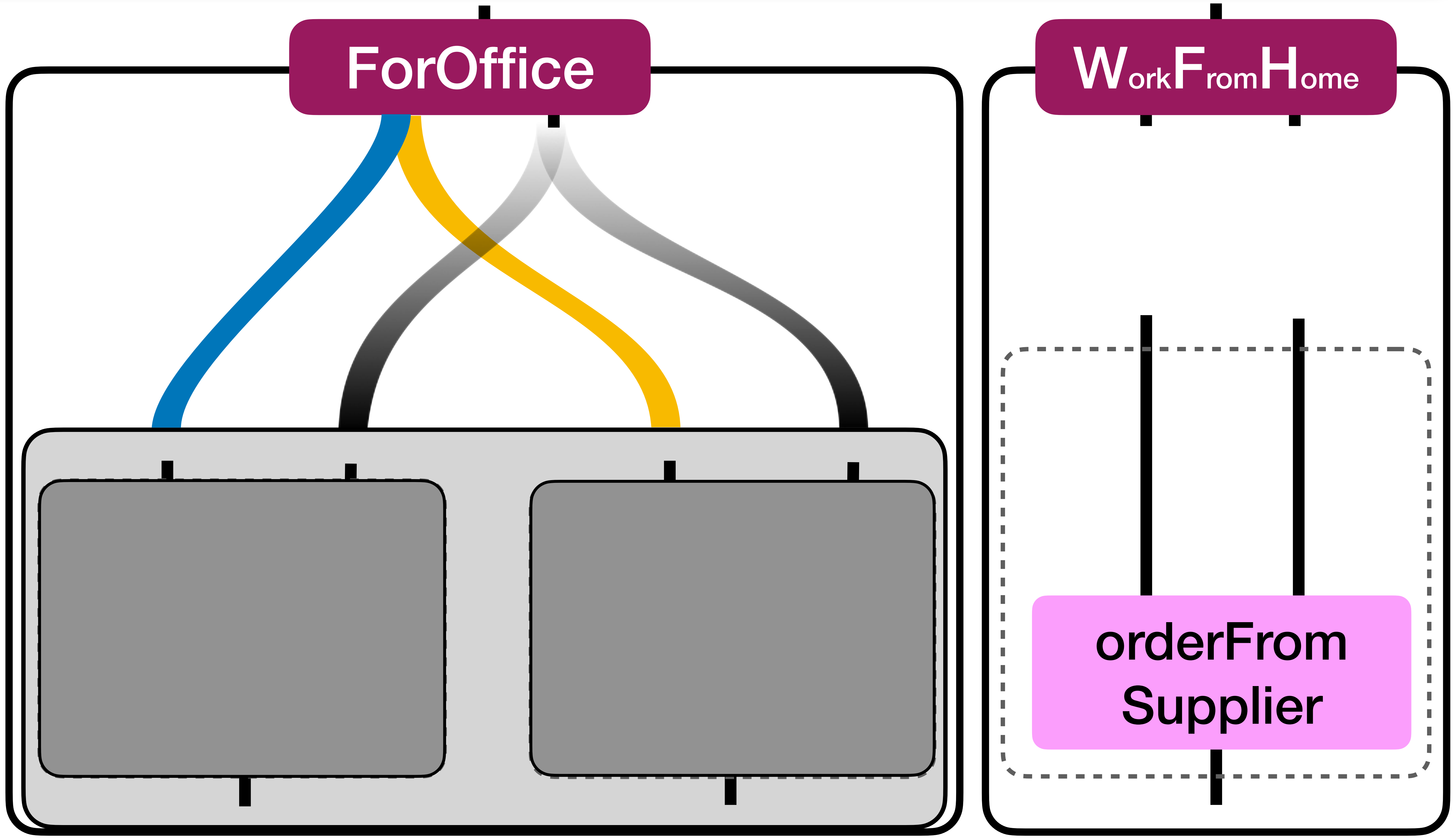

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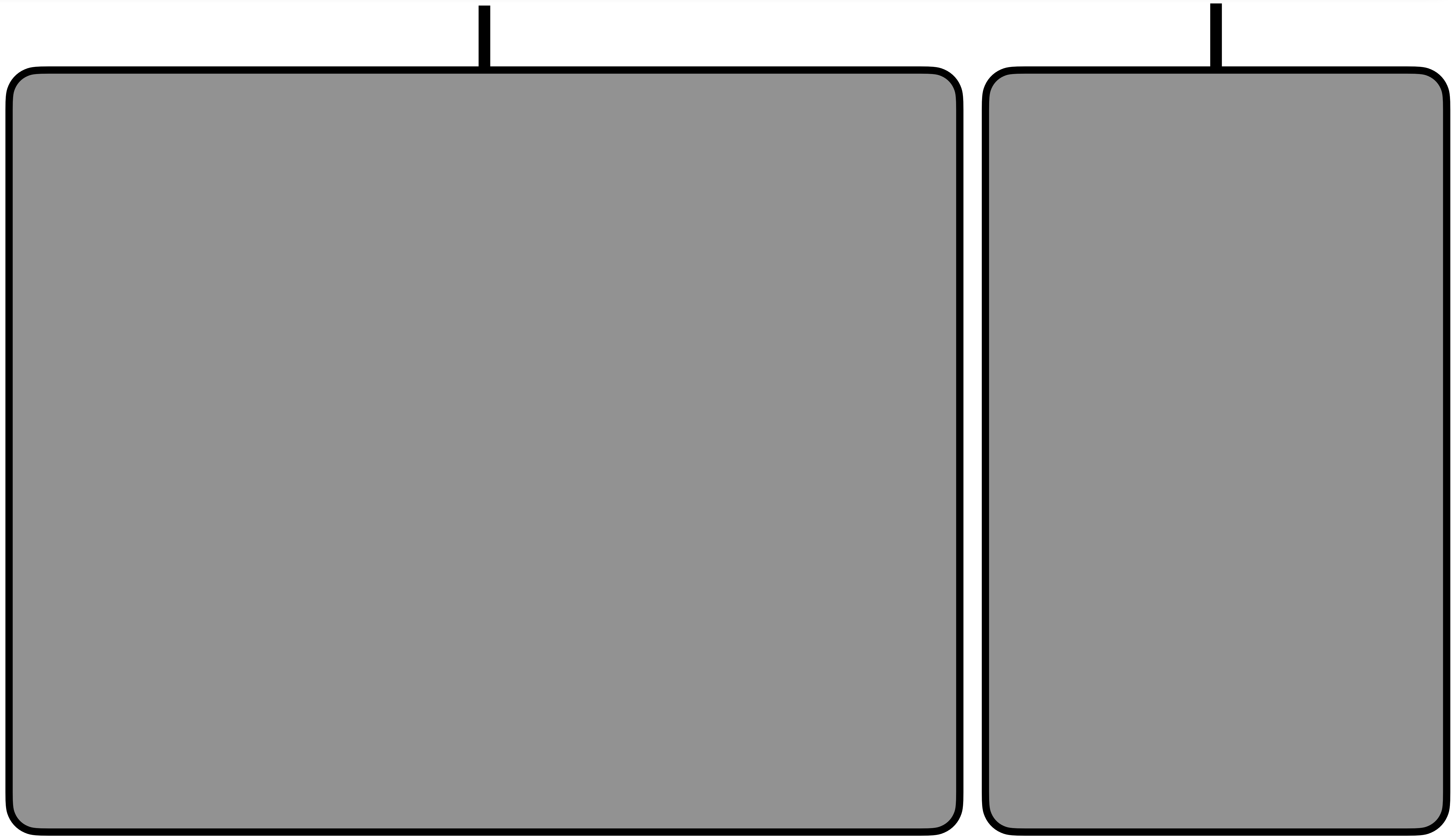

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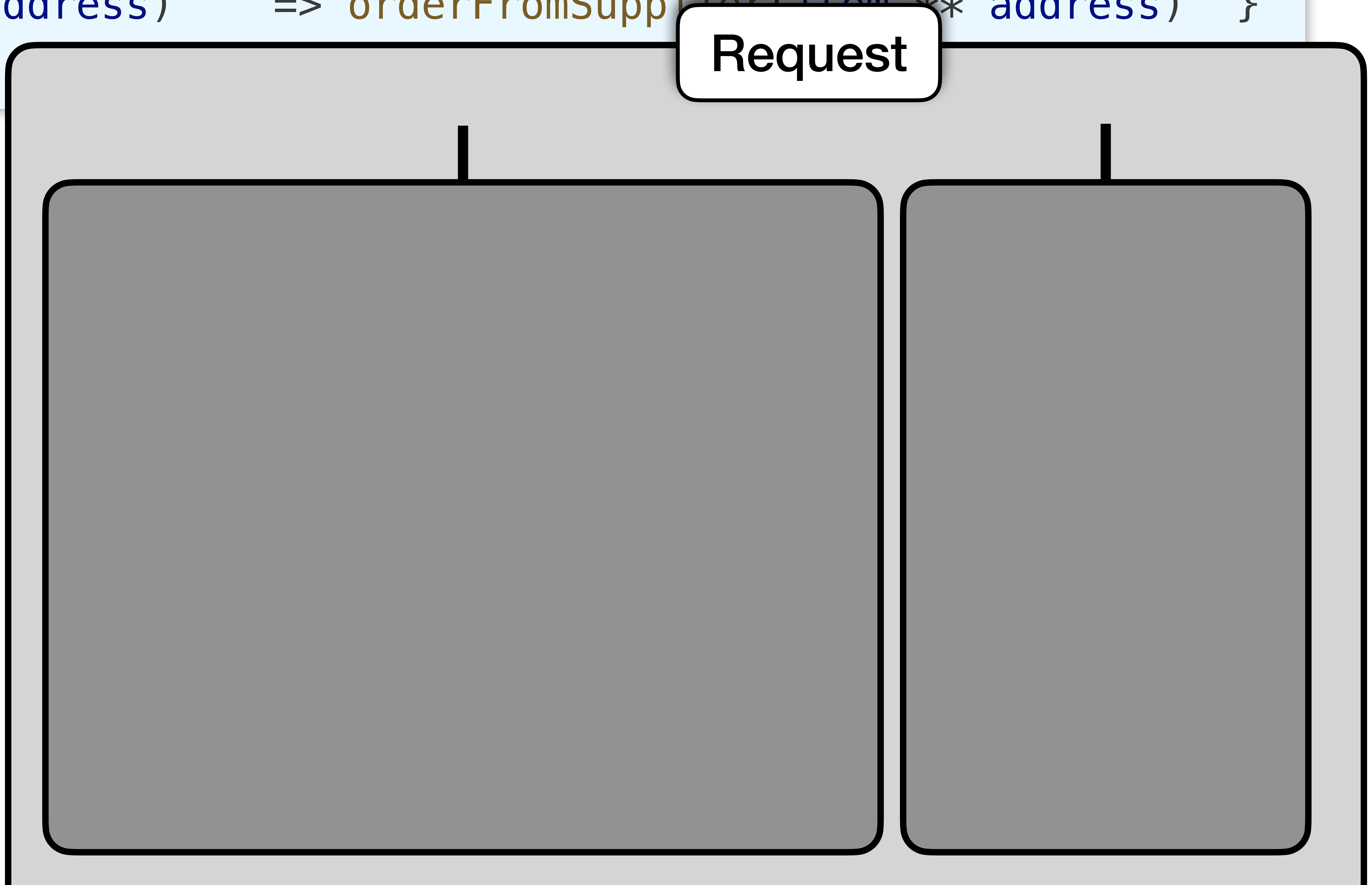

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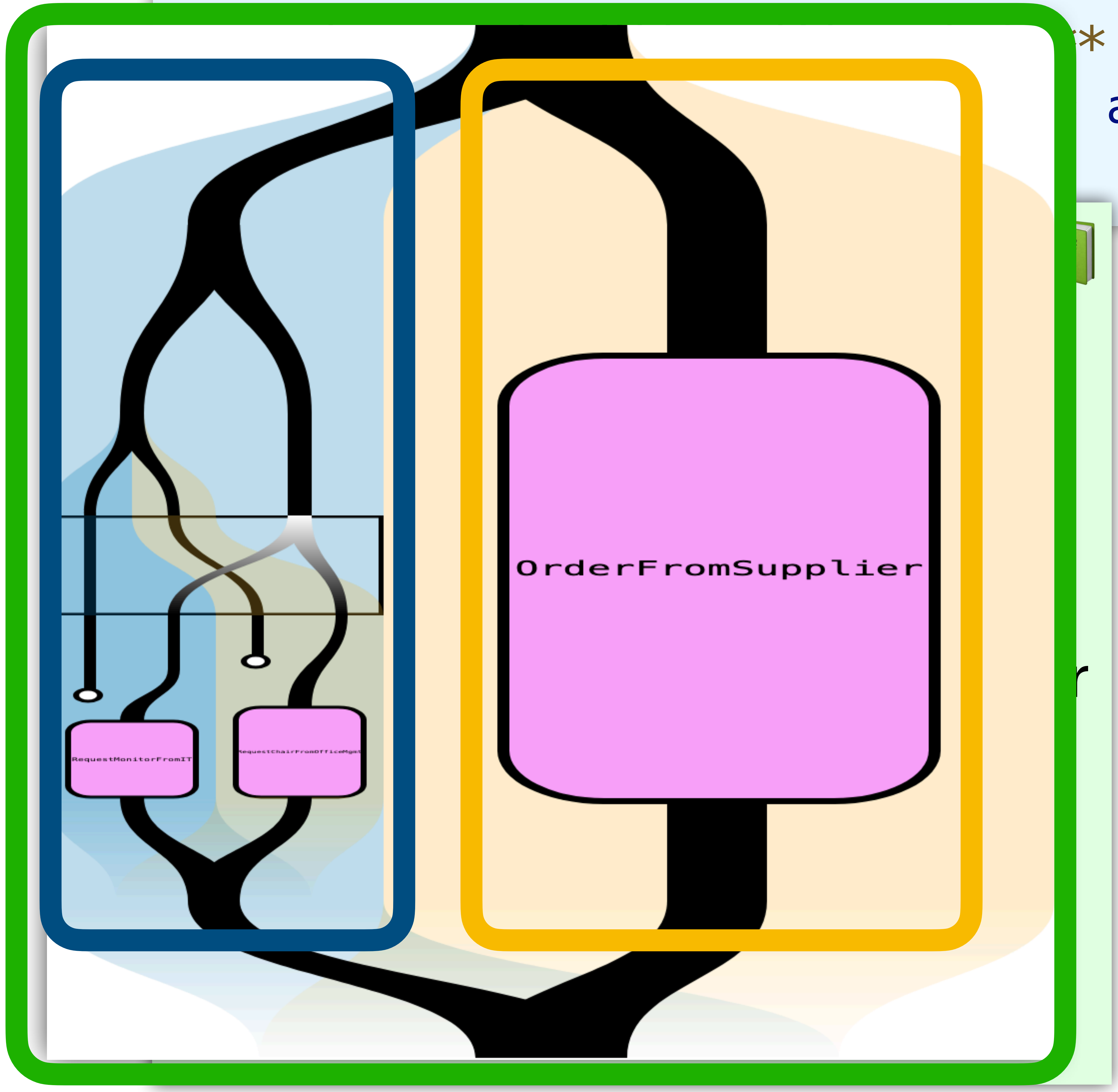

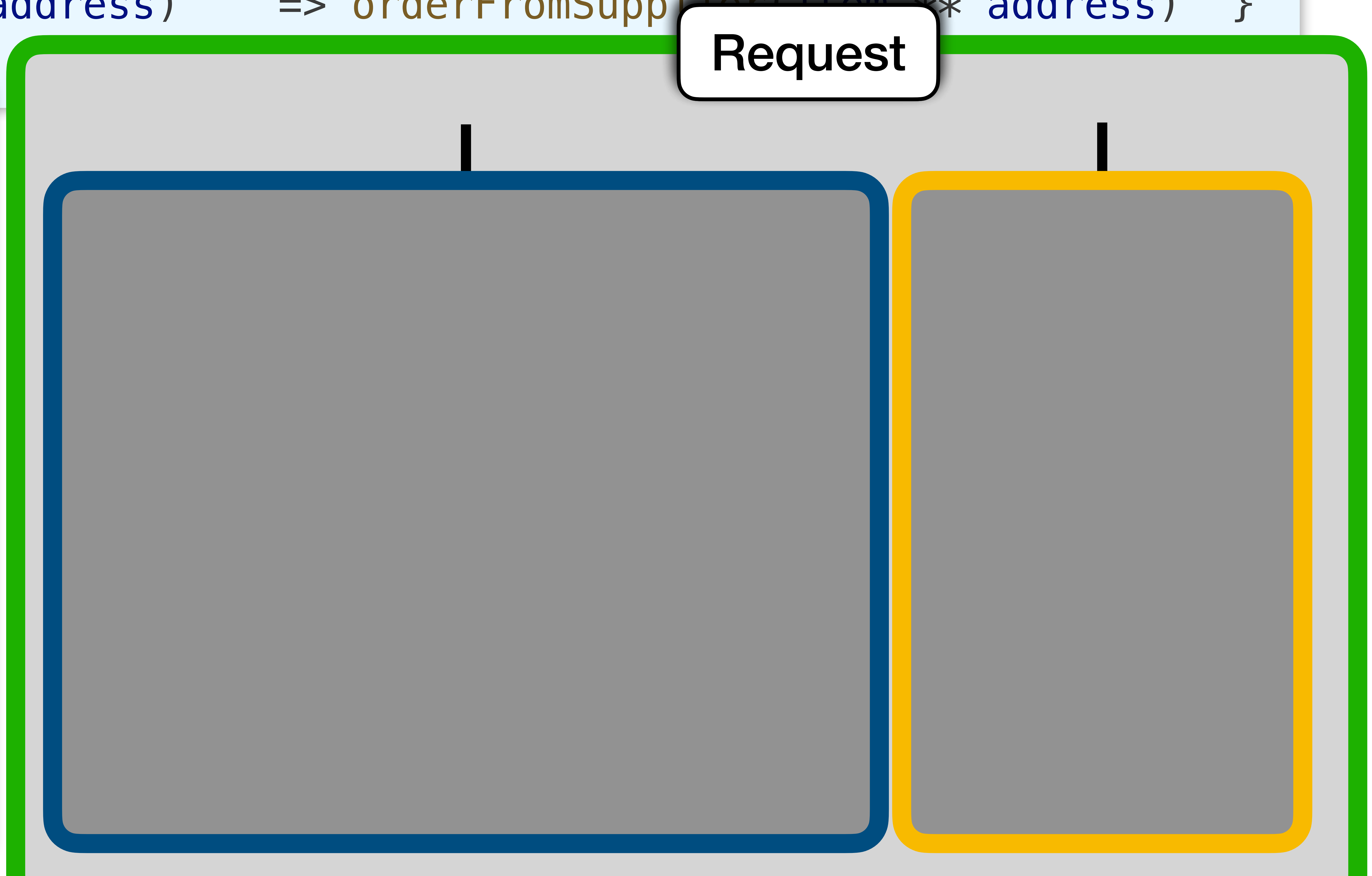

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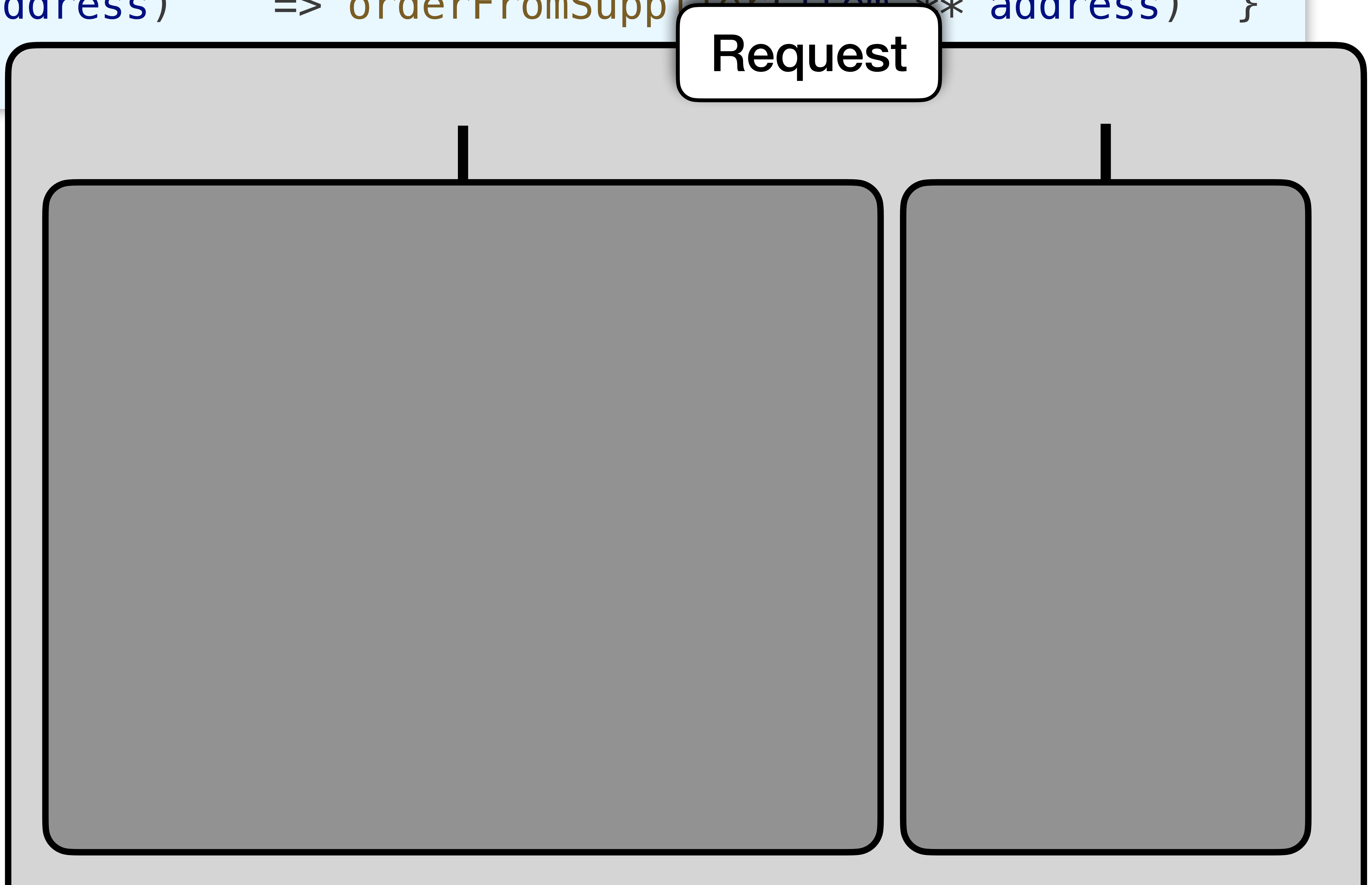

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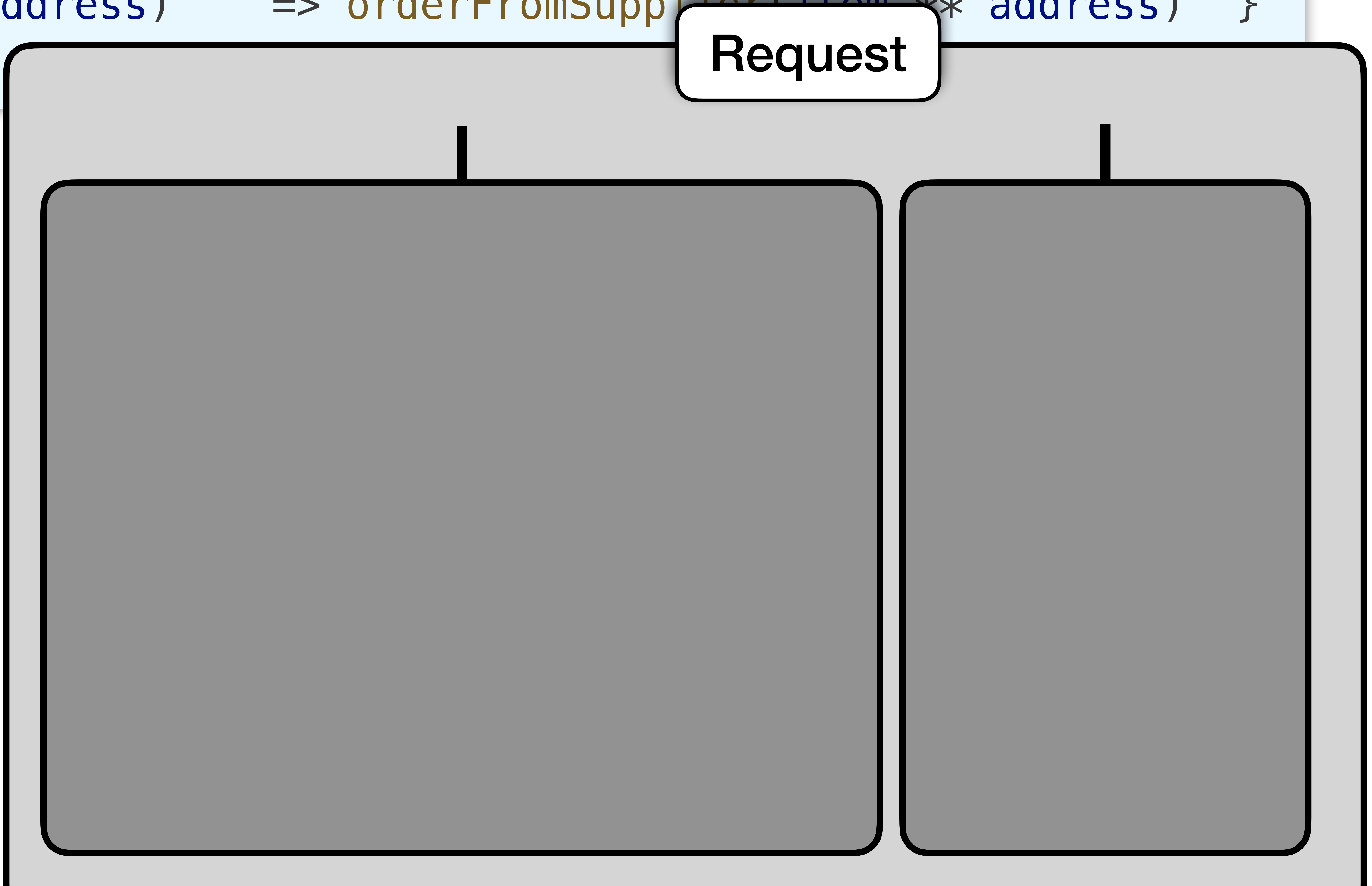
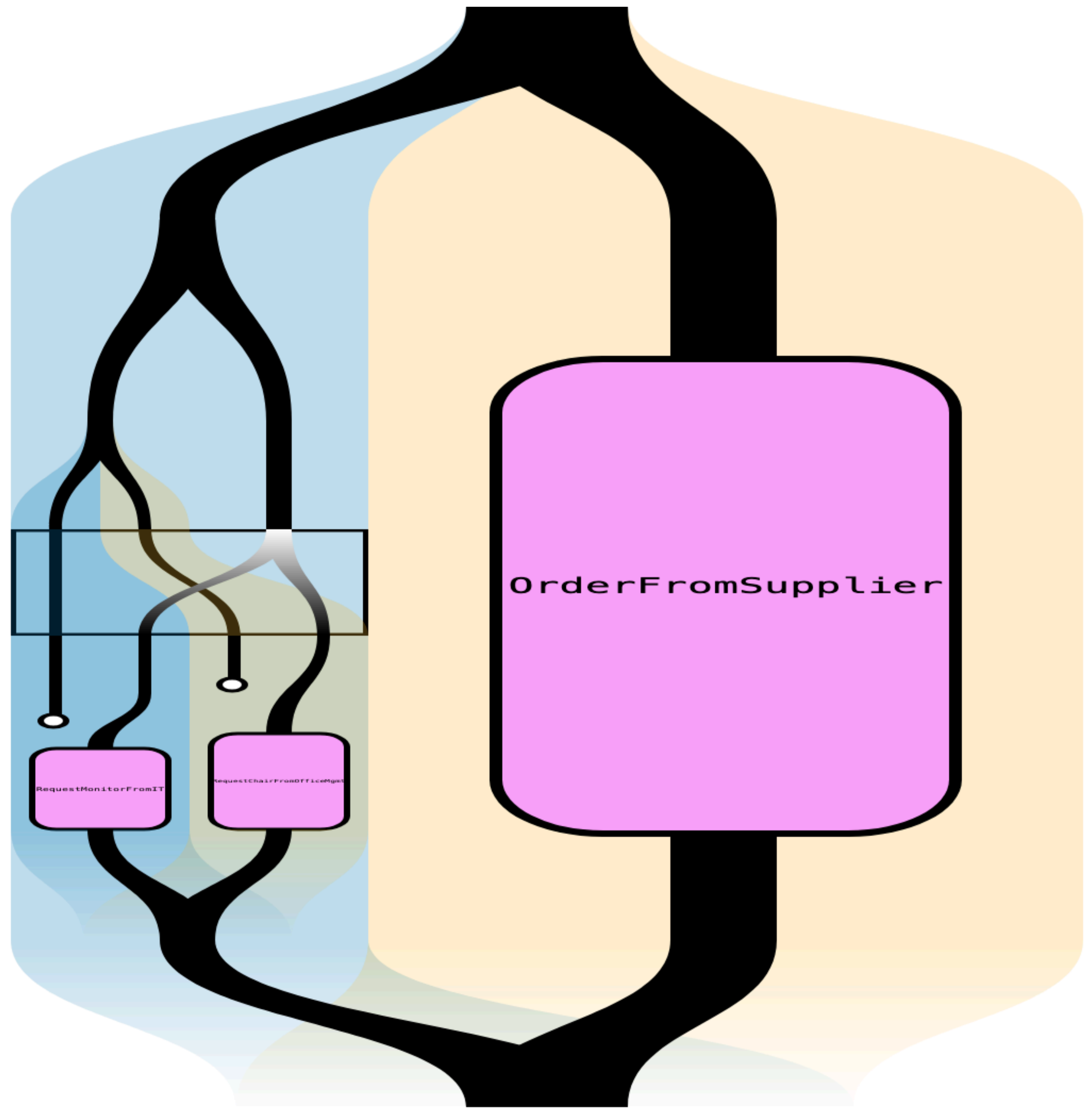
   distribute as needed
7. Lower from Flow^1 to Flow



`switch:` What Does It *Do*?

```
req switch (
  is { case ForOffice(Monitor(_) ** deskLoc) => requestMonitorFromIT(deskLoc)        },
  is { case ForOffice(Chair(_) ** deskLoc)   => requestChairFromOfficeMgmt(deskLoc) },
  is { case WorkFromHome(item ** address)    => orderFromSupplier(item ** address)  }
)
```

1. Delambdify each case
2. Pick the first Extractor,
   obtain the whole partitioning
3. Group by partition
   empty group = non-exhaustivity
4. Remove the matched extractor
5. Apply 2.-6. inside each group
6. Construct Handlers,
   distribute as needed
7. Lower from Flow[1] to Flow



```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
    case ForOffice(Chair(_) ** deskLoc) =>
      requestChairFromOfficeMgmt(deskLoc)
    case WorkFromHome(item ** address) =>
      orderFromSupplier(item ** address)
  }
}
```

1. What does **`Flow`** do? ✔
2. What does **`switch`** do?
3. What do the **extractors** do? ✔
   (`ForOffice`, `Monitor`, ...)

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1. What does **`Flow`** do? ✔
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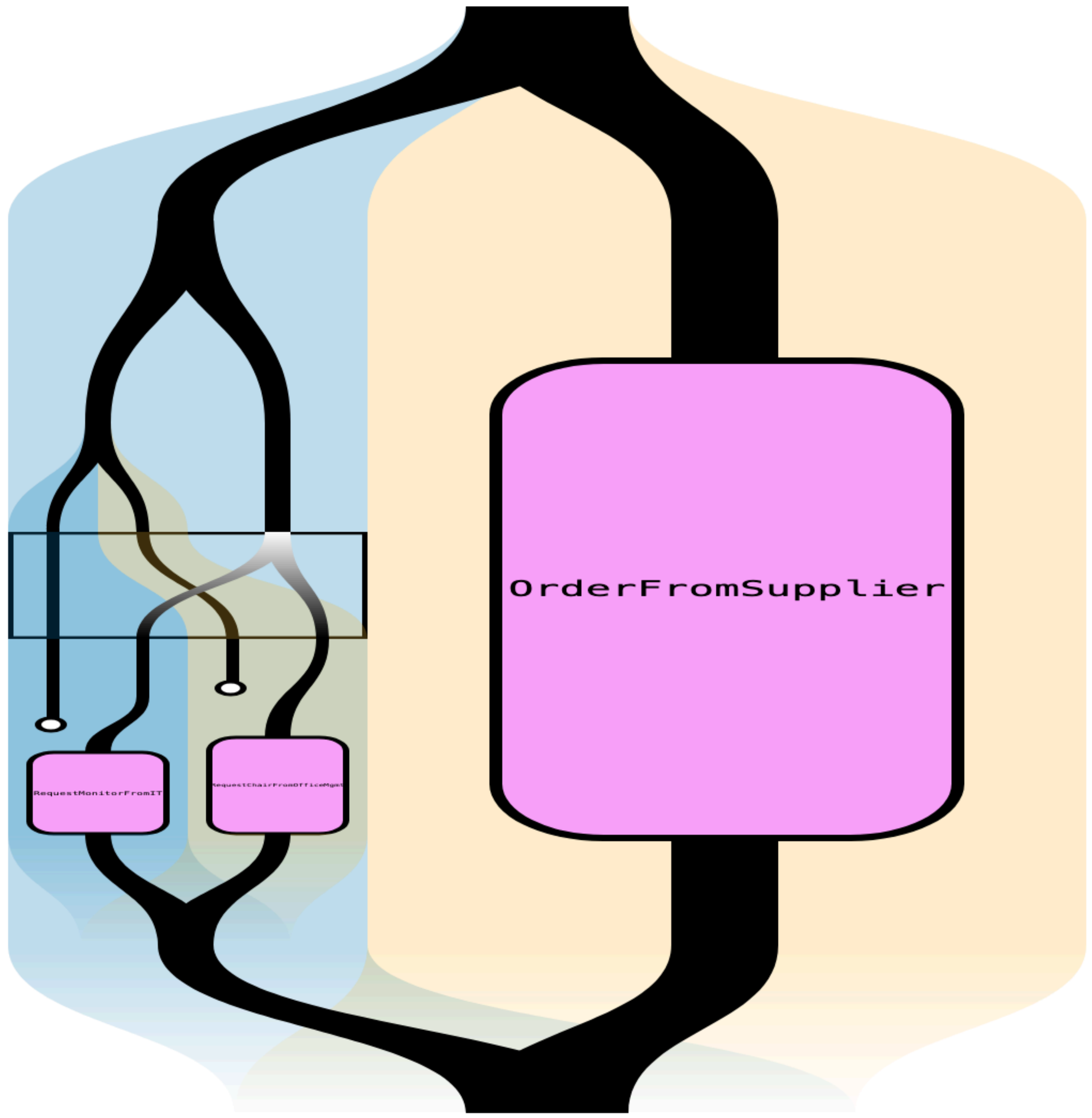

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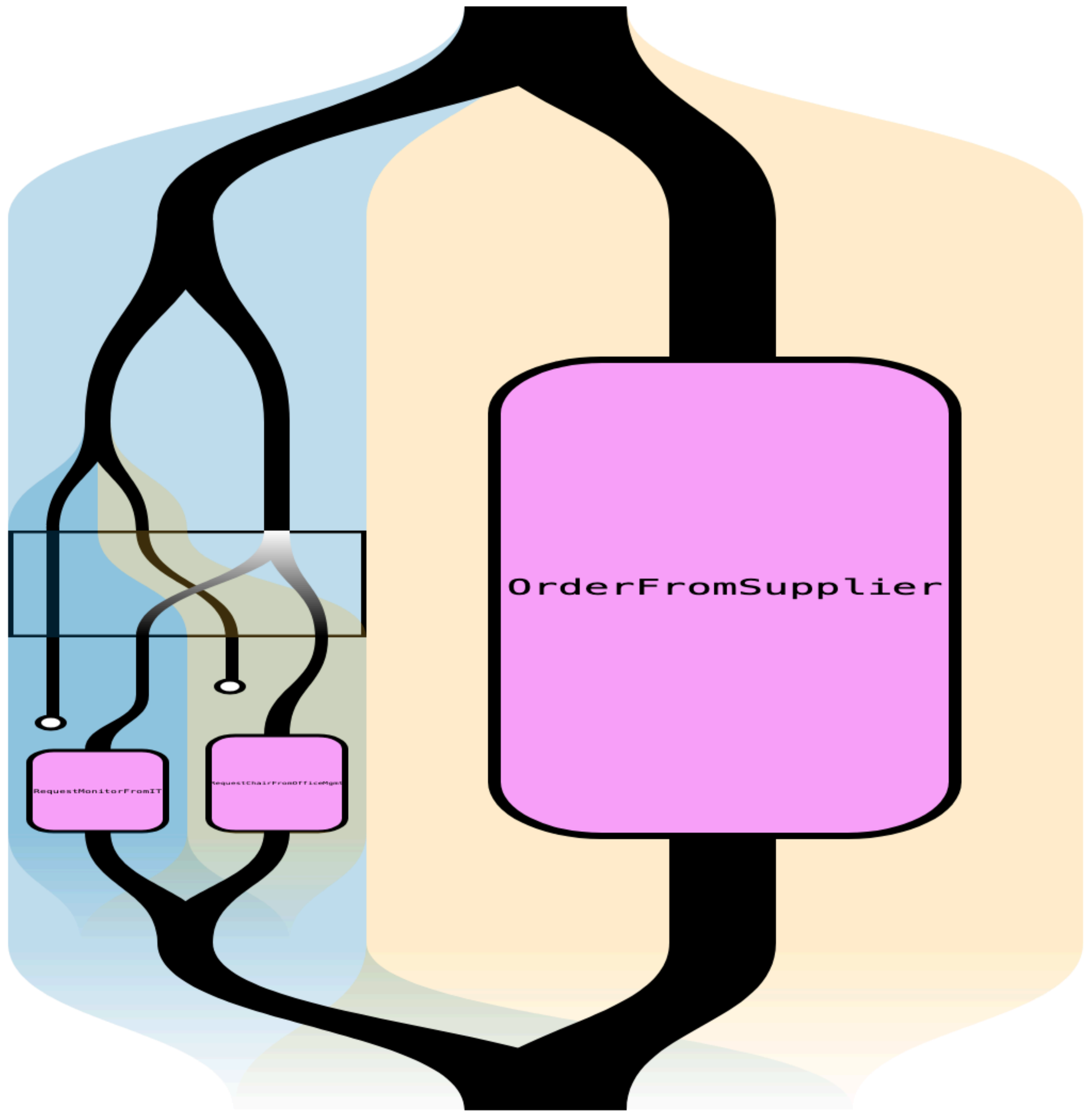

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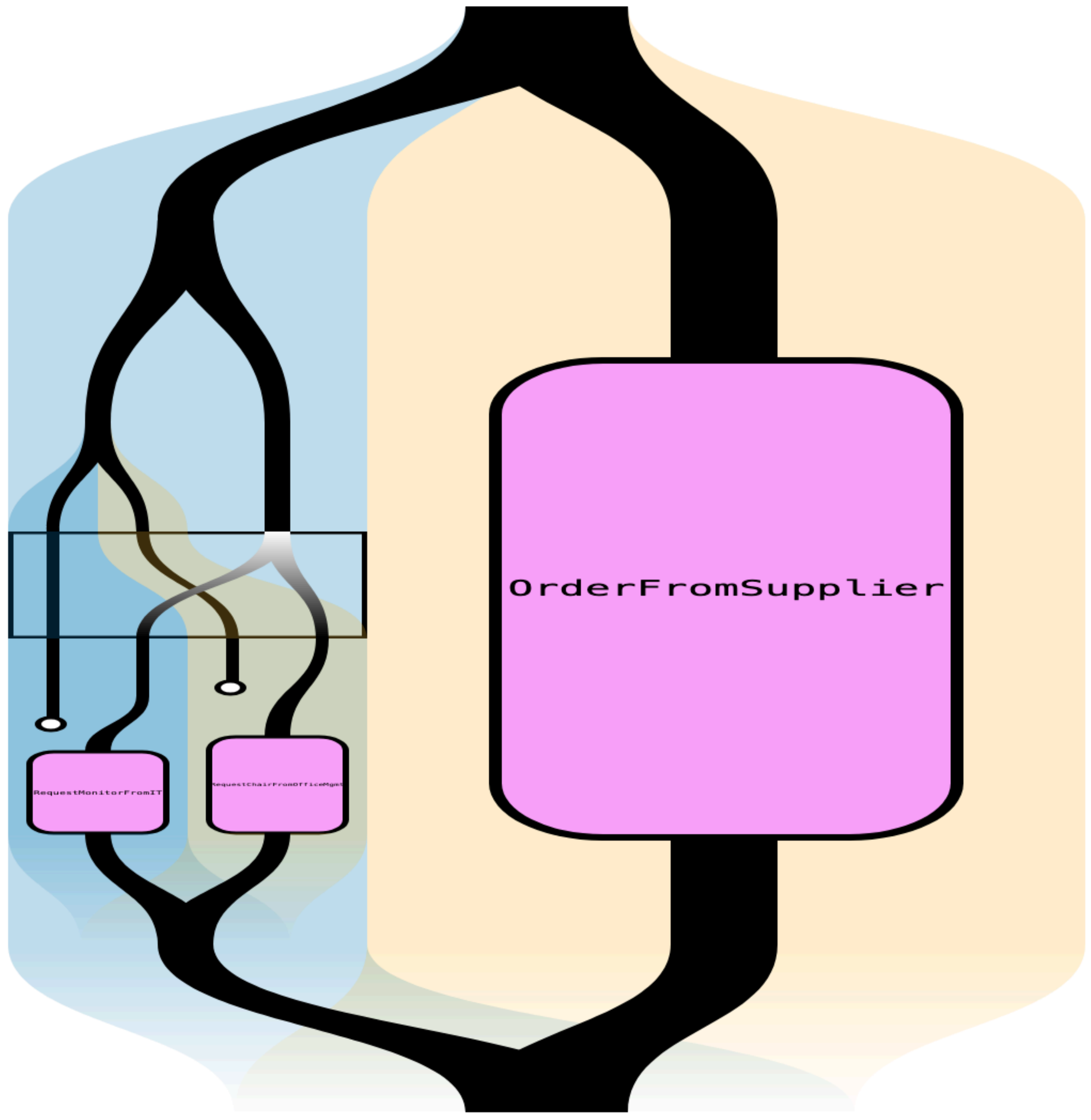

✔ Compiled Scala-like pattern matching

```scala
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
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}
```

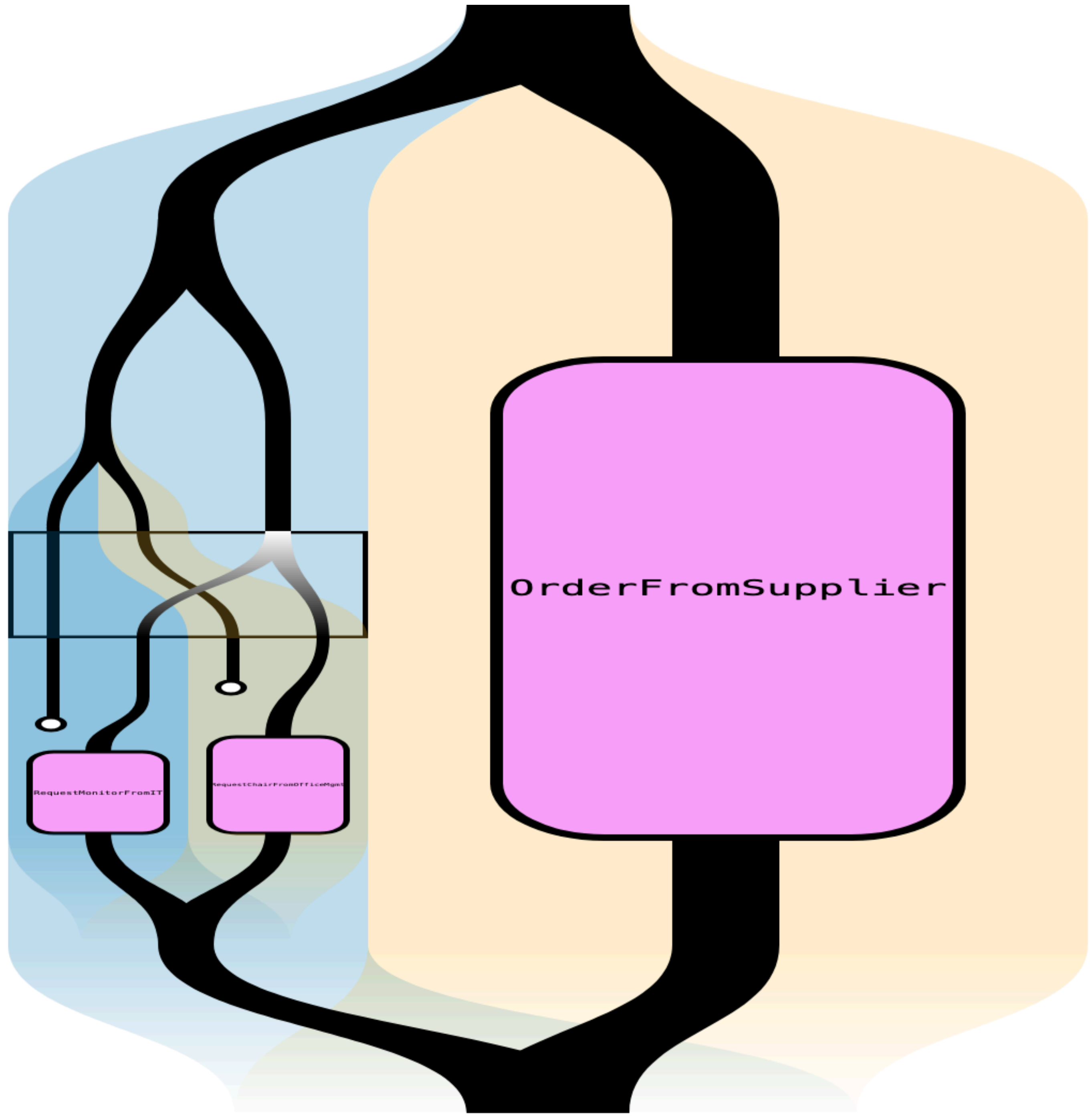

✔ Compiled Scala-like pattern matching

✔ Representation **exhaustive by construction**

```
Flow { req =>
  req switch {
    case ForOffice(Monitor(_) ** deskLoc) =>
      requestMonitorFromIT(deskLoc)
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  }
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```
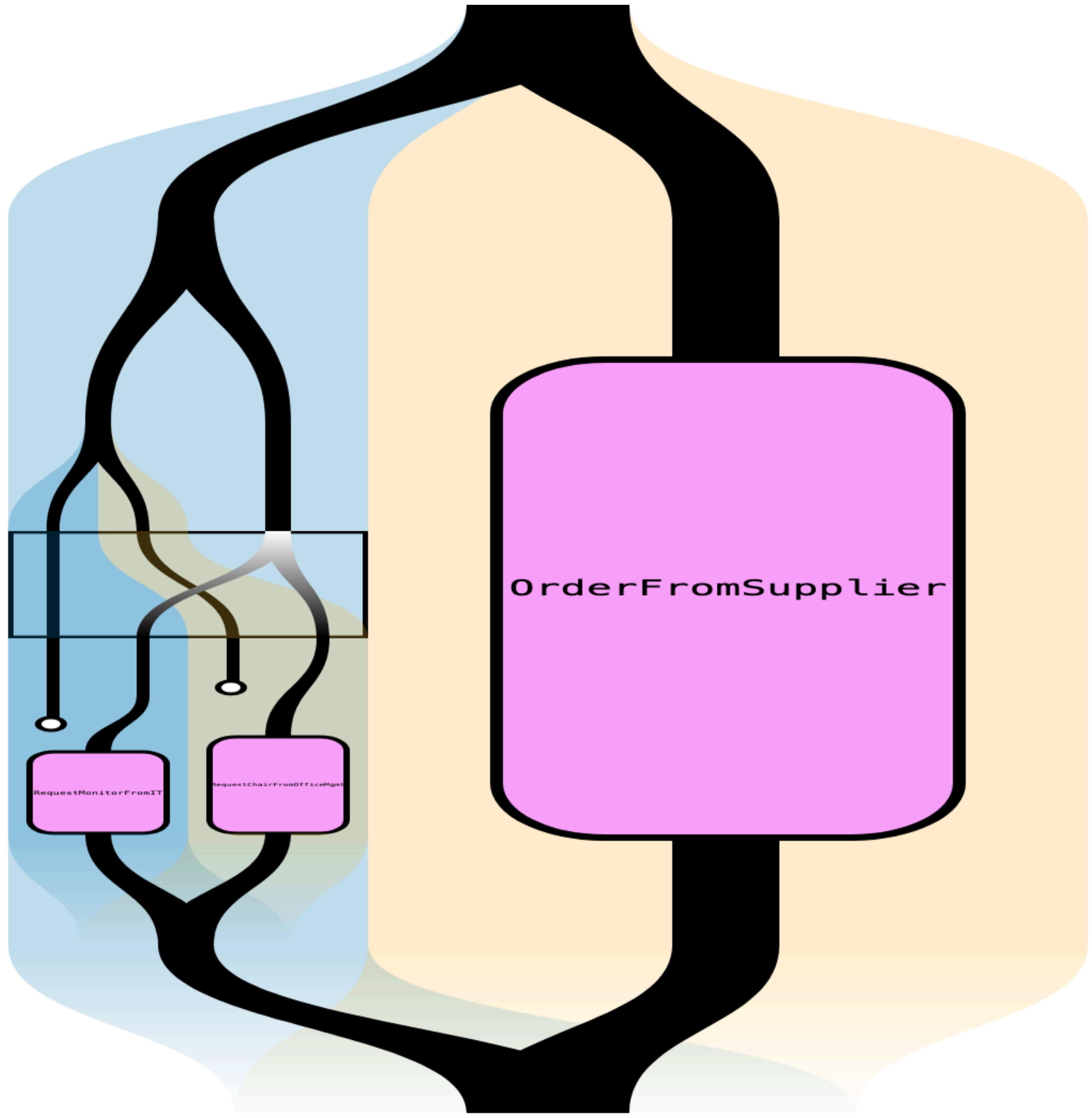
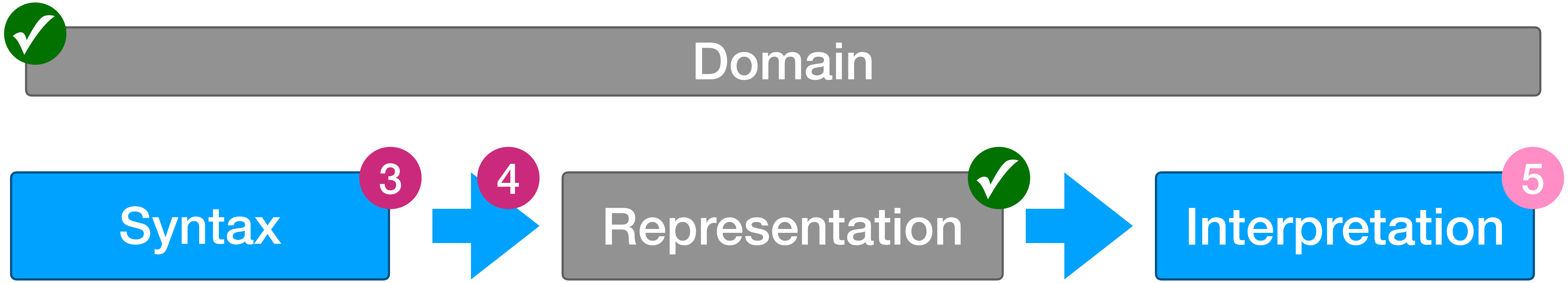
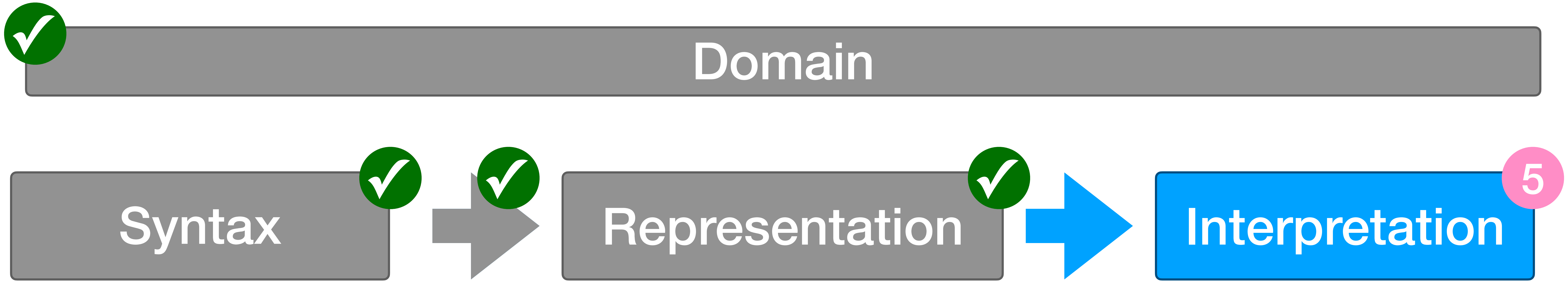



- ✔ Compiled Scala-like pattern matching
- ✔ Representation **exhaustive by construction**
- ✔ Non-exhaustivity reported in **embedded compile-time**

Agenda



Agenda



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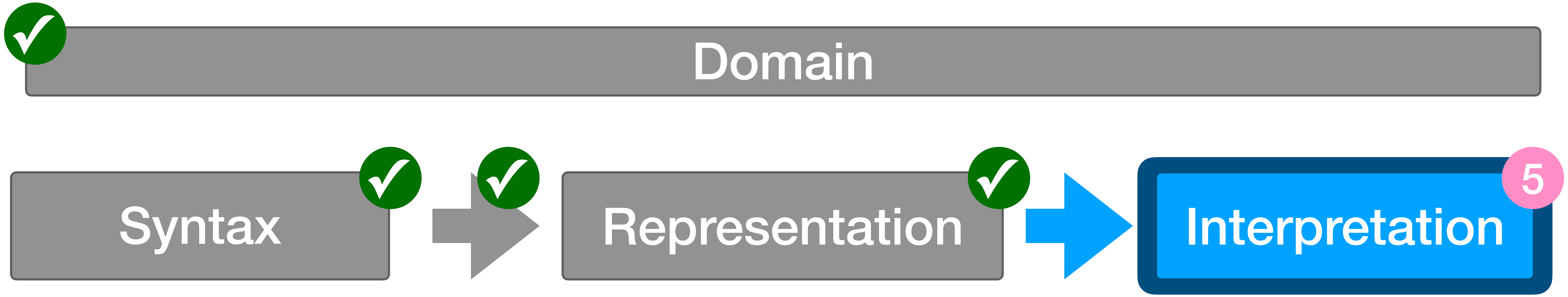
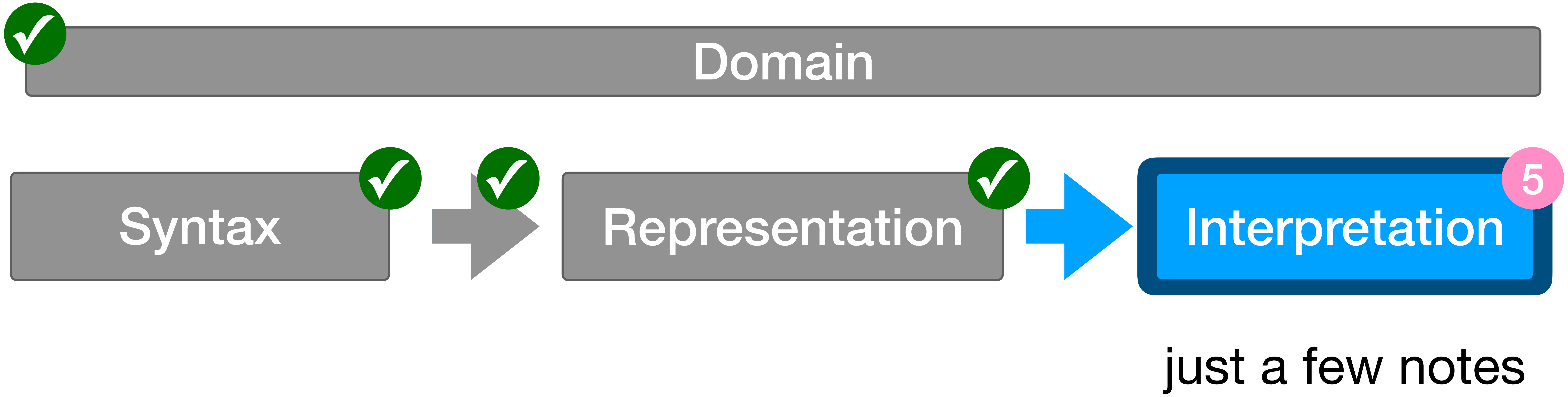


Agenda


Domain
Syntax
Representation
Interpretation
5
just a few notes

Interpretation: What’s Possible

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- Durable execution

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- Workflow Templates
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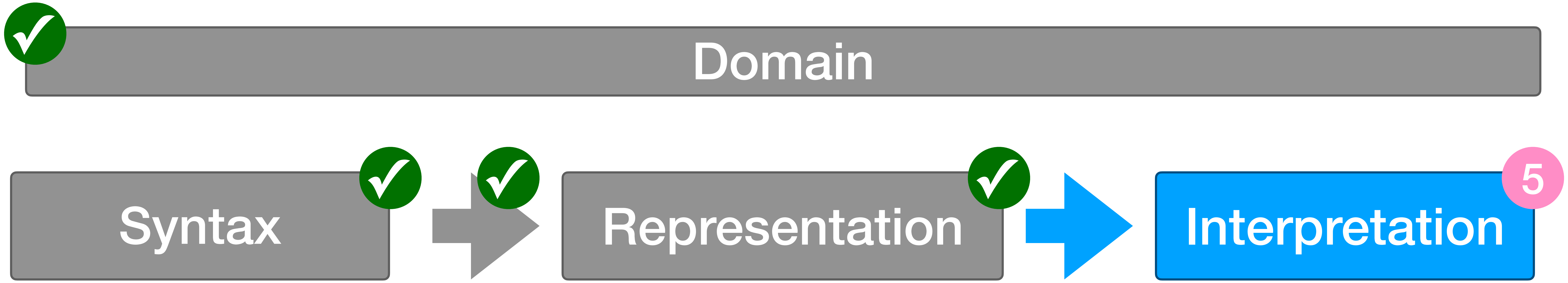
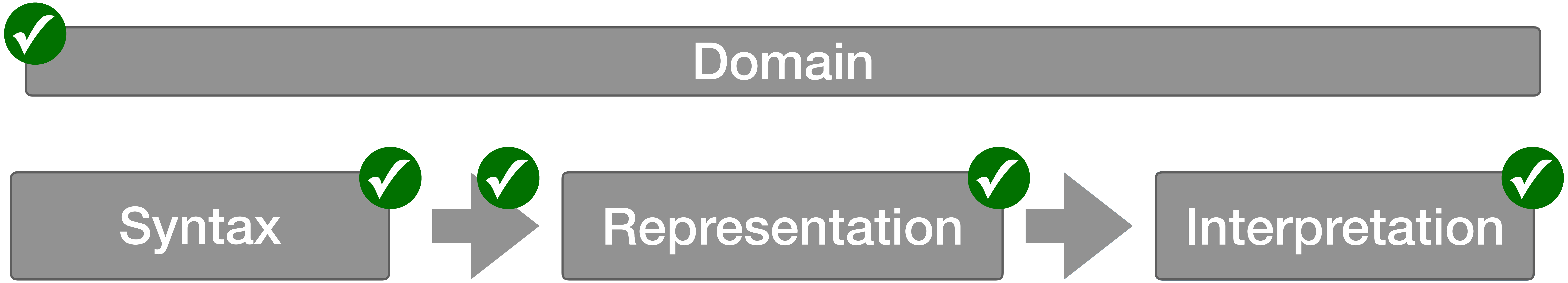
- Graphical Designer / IDE
  - as an alternative to the Scala embedding

Agenda



Agenda



Take Aways

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Regain **control** by going **deep.**

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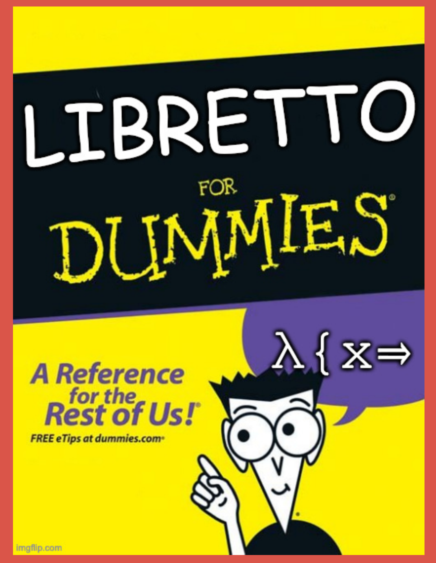

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