Custom Stream Operators Made Safe And Simple with Libretto

SCALAR

Scala Conference in Central Europe

Tomas Mikula

Mar 24, 2023

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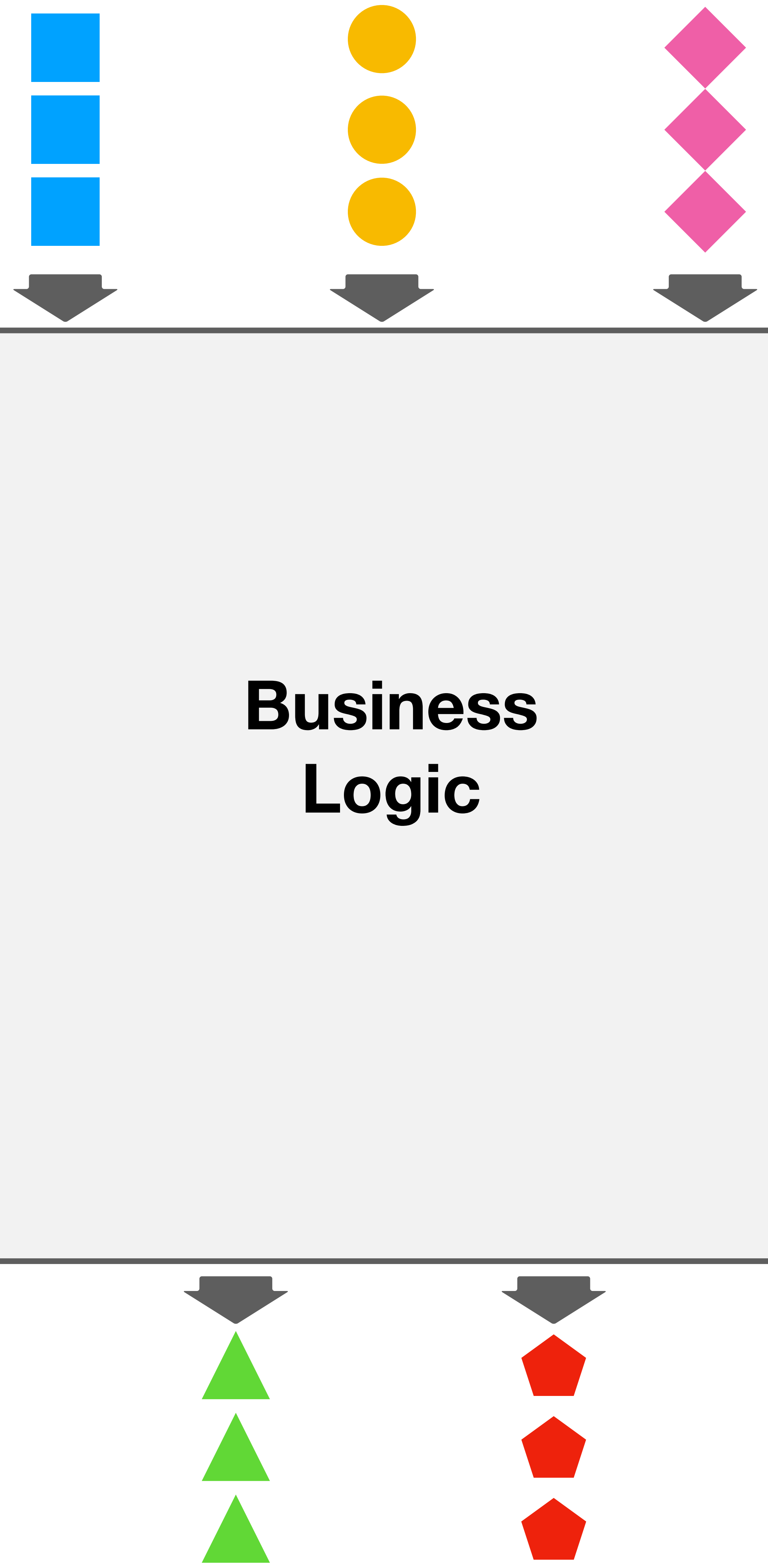

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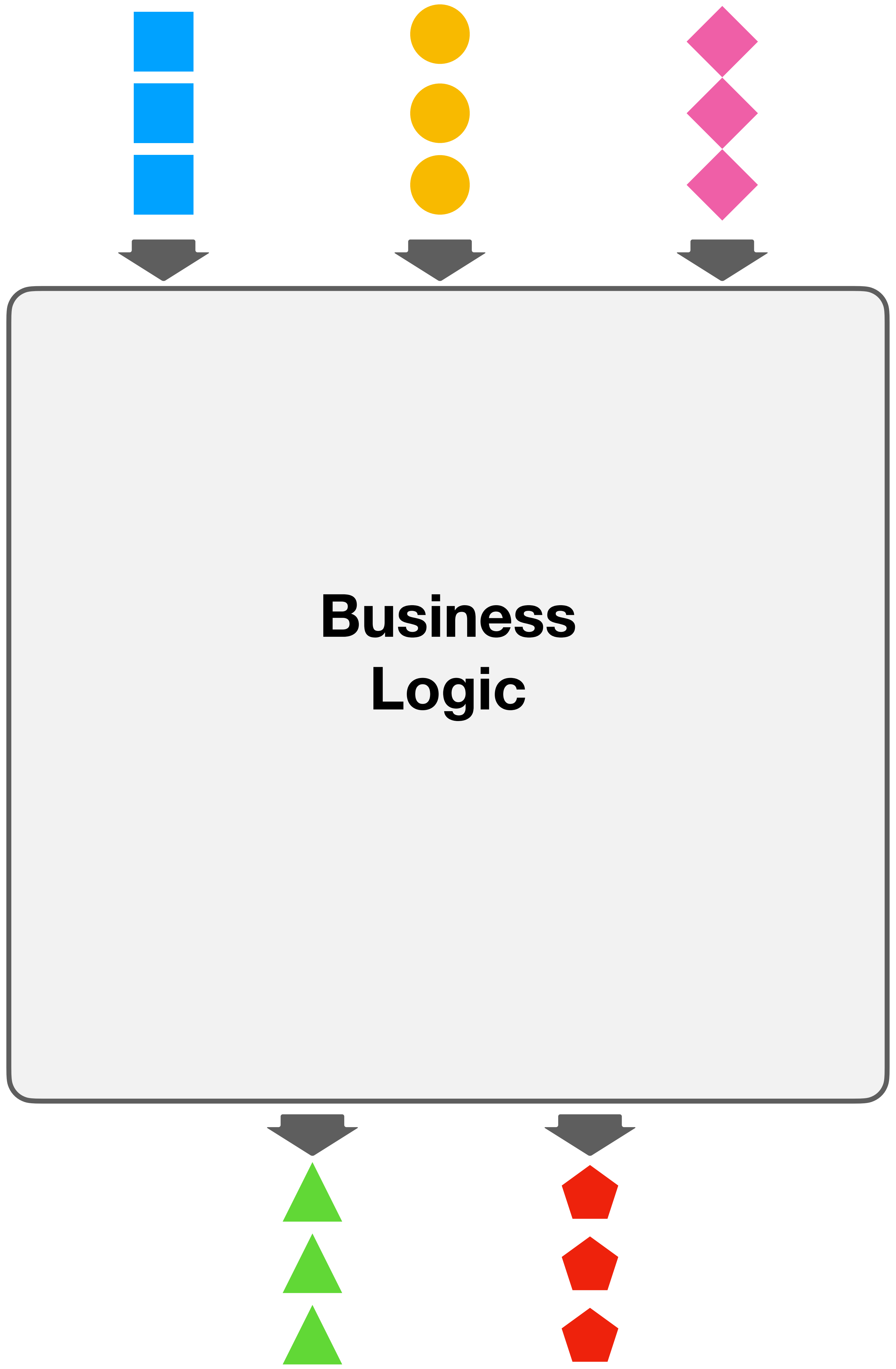

Safe

high rejection rate of wrong programs

(hard to shoot ourselves in the foot)

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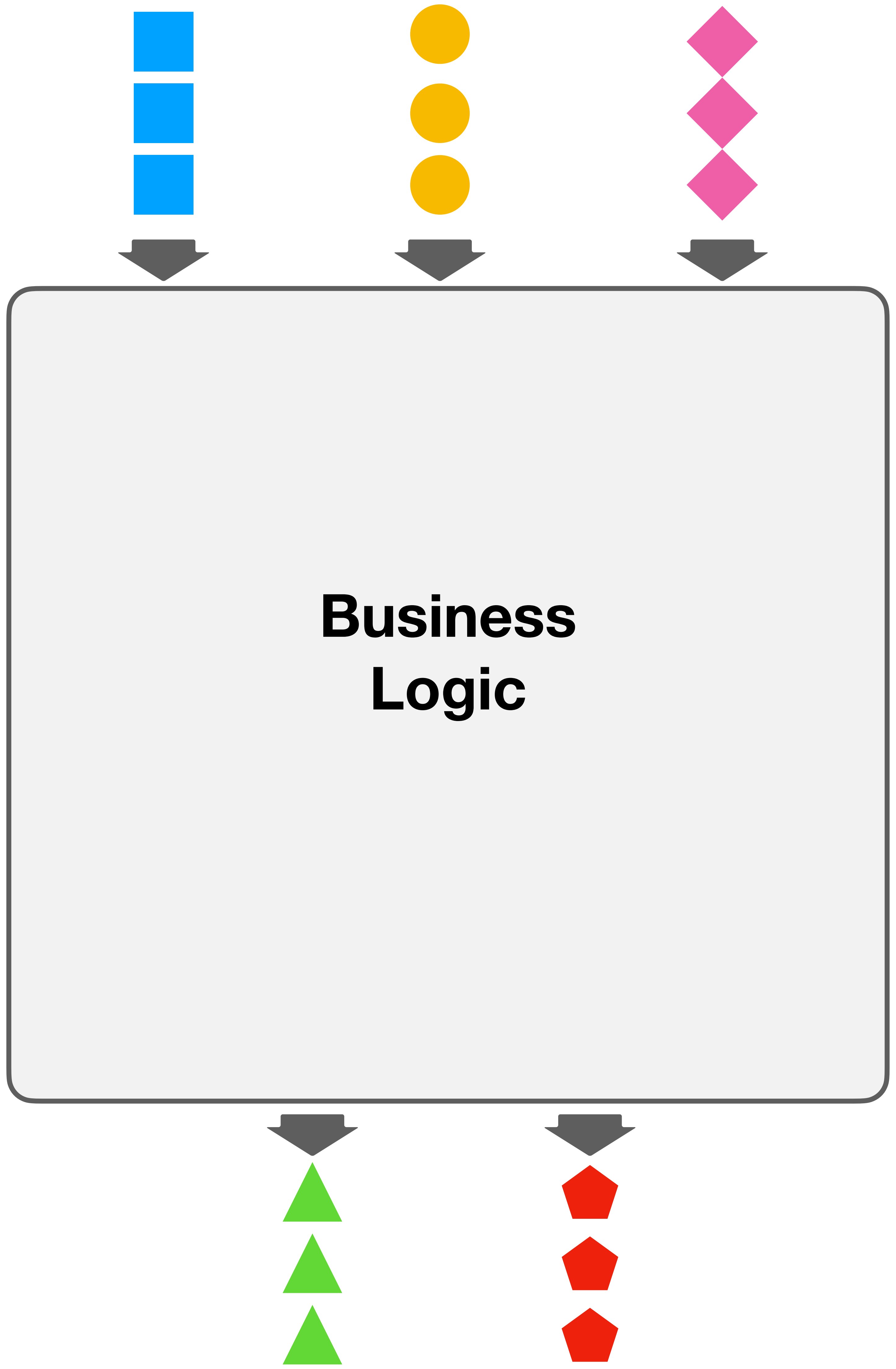

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low accidental complexity

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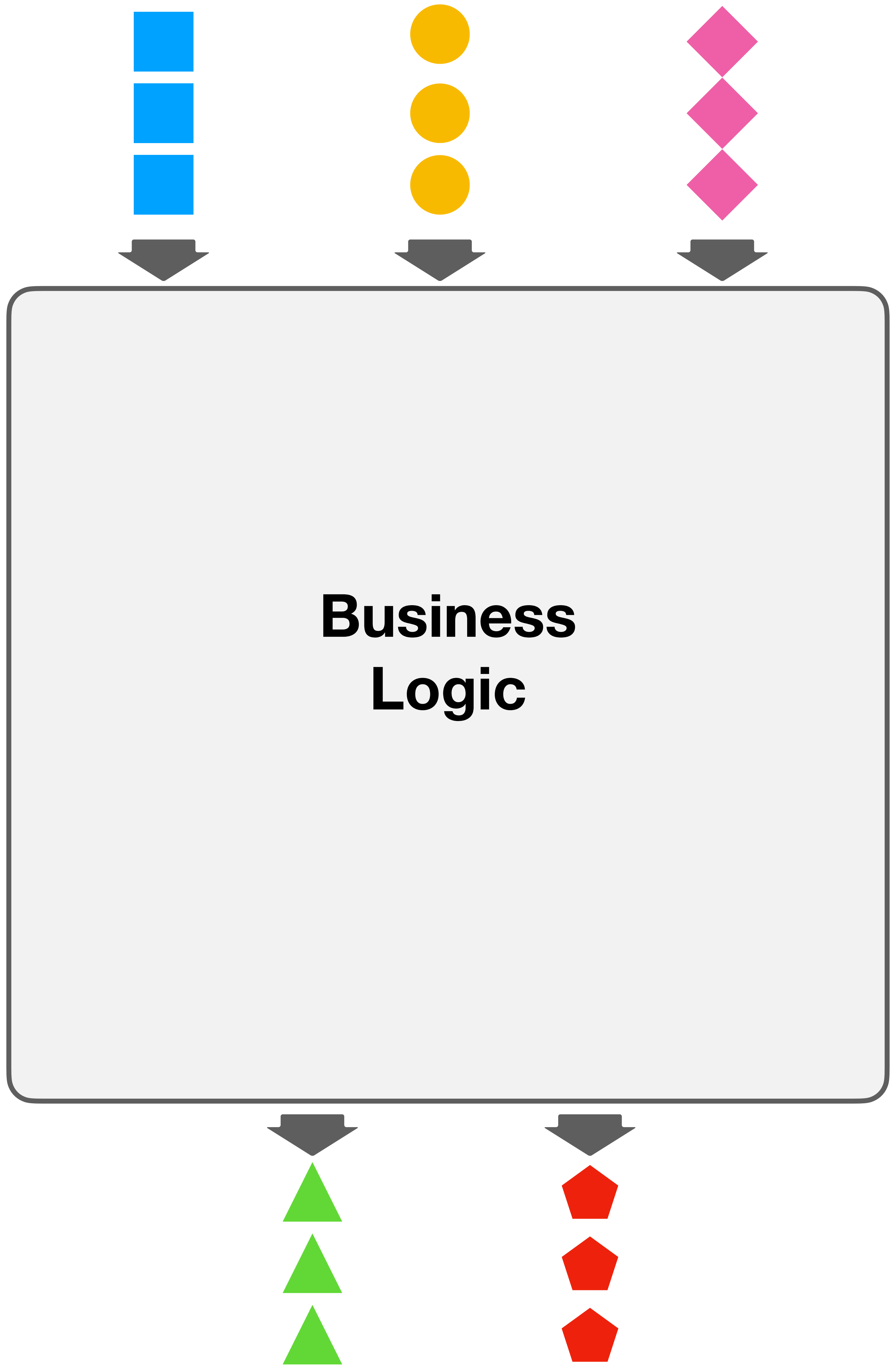

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a sequence of *elements* produced and consumed gradually

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Control Flow	
proactive	reactive (not to be confused with “Reactive Streams”)

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Reactive Streams `Publisher` Akka `Source`	

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Control Flow	
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Reactive Streams `Publisher`
Akka `Source`
	`fs2.Stream`
	`zio.stream.ZStream`
	`libretto.stream.Source`

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		Control Flow	
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Payload Flow	producer	Reactive Streams `Publisher`
		Akka `Source`
			`fs2.Stream`
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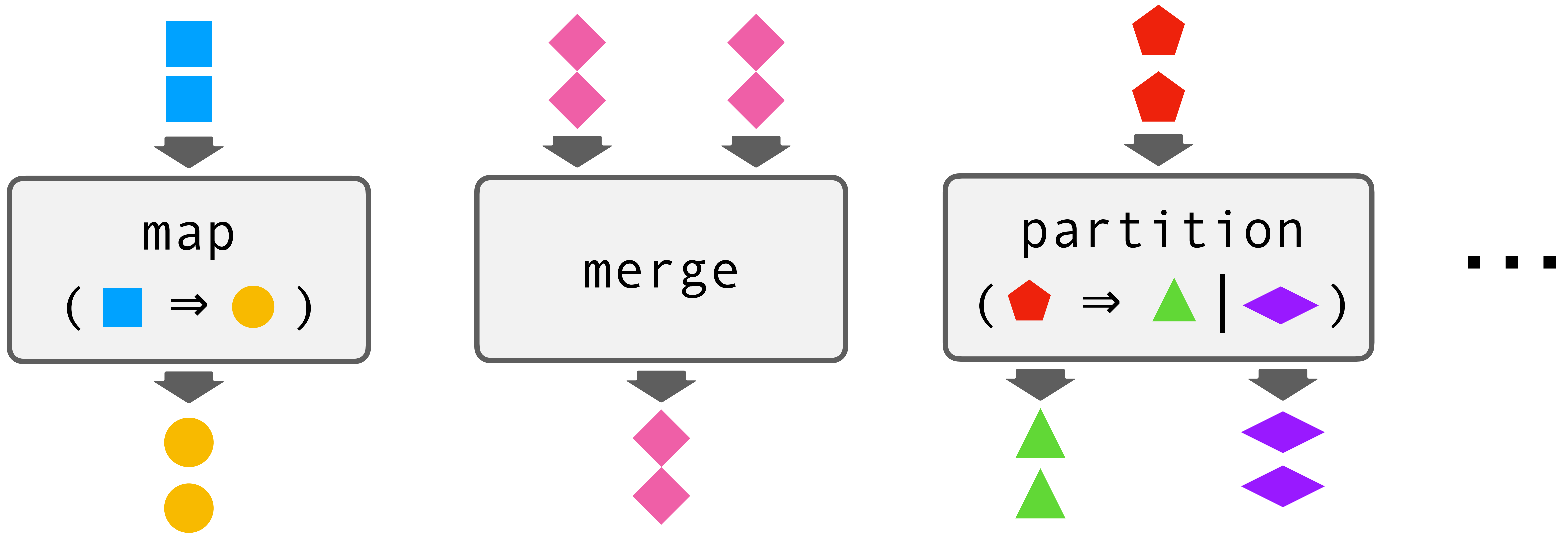
			`libretto.stream.Source`

	consumer		

Libraries come with batteries included



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- *“declarative concurrency”*
- can go a long way
- ideally, never need anything custom

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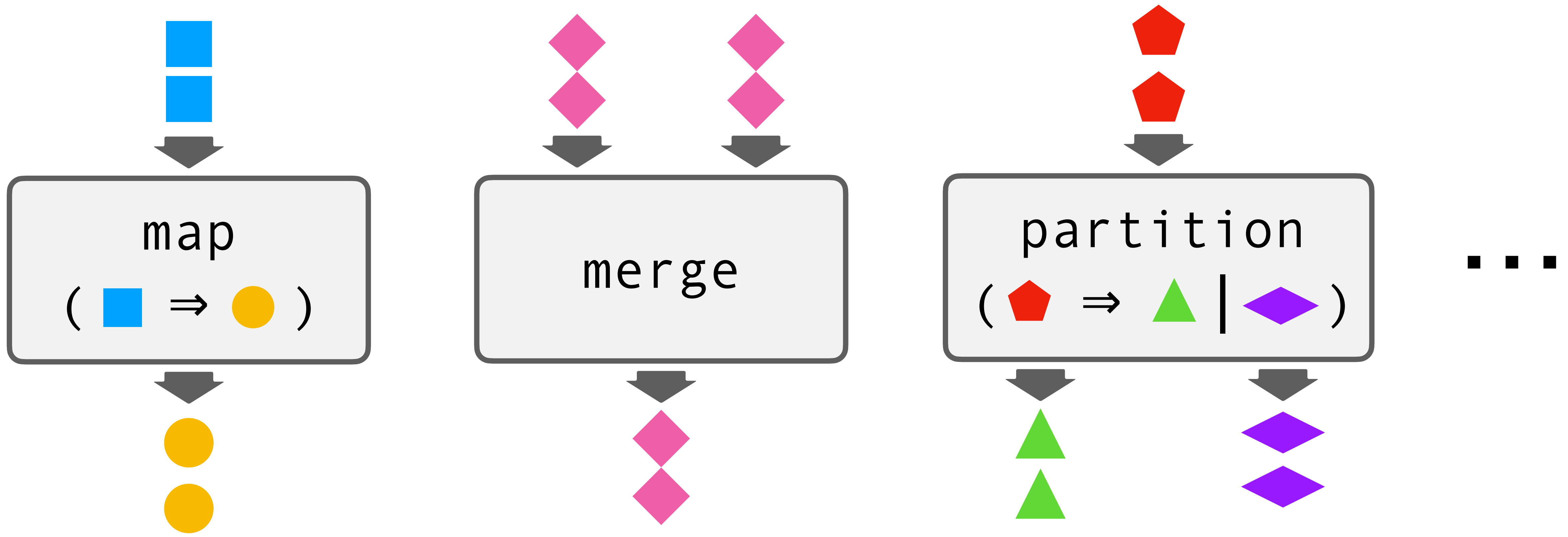

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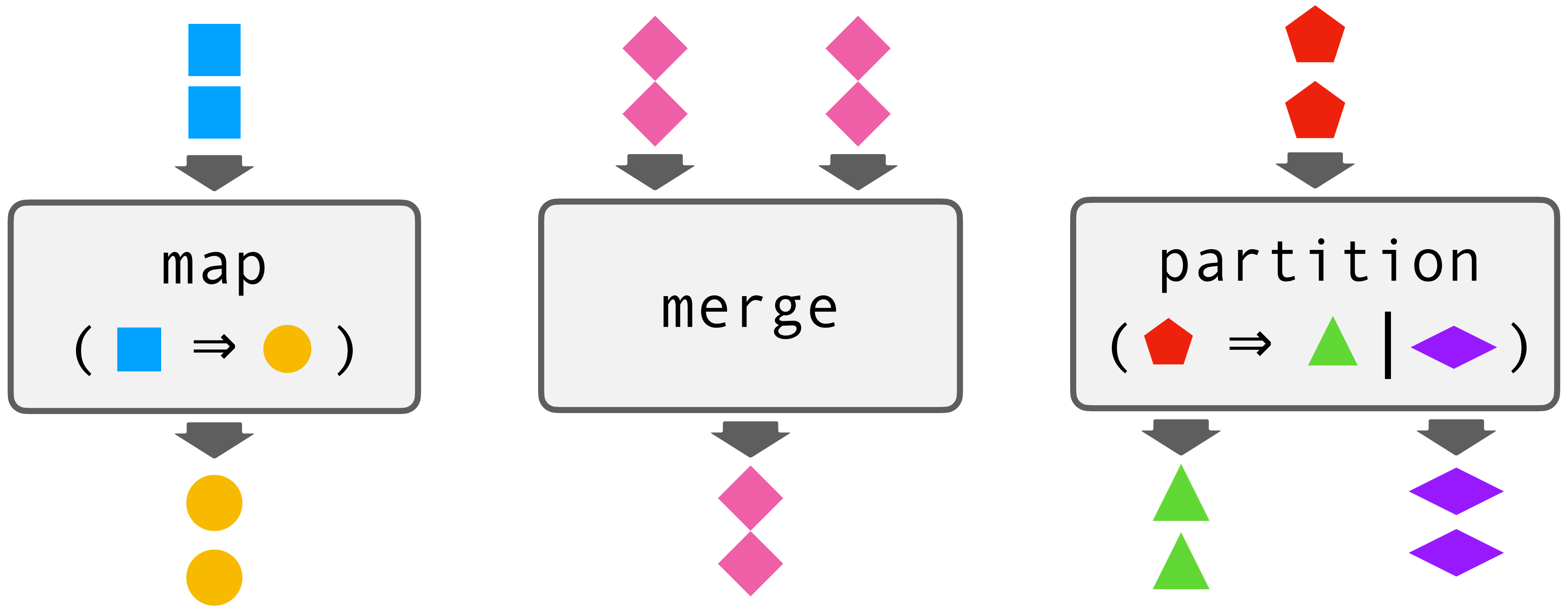

map (■ ⇒ ●)

merge

partition (⬟ ⇒ ▲ | ◆)

...

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promises

queues

mutable variables

interruptions

fibers

illegal state

scopes

locks

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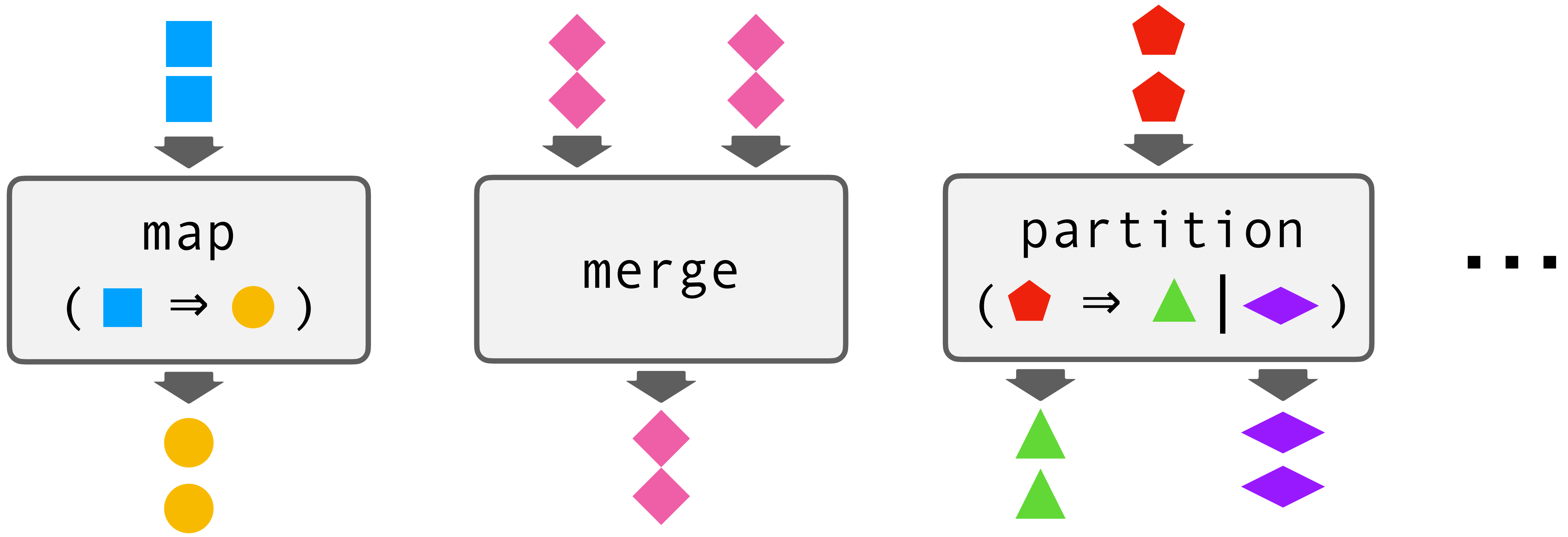

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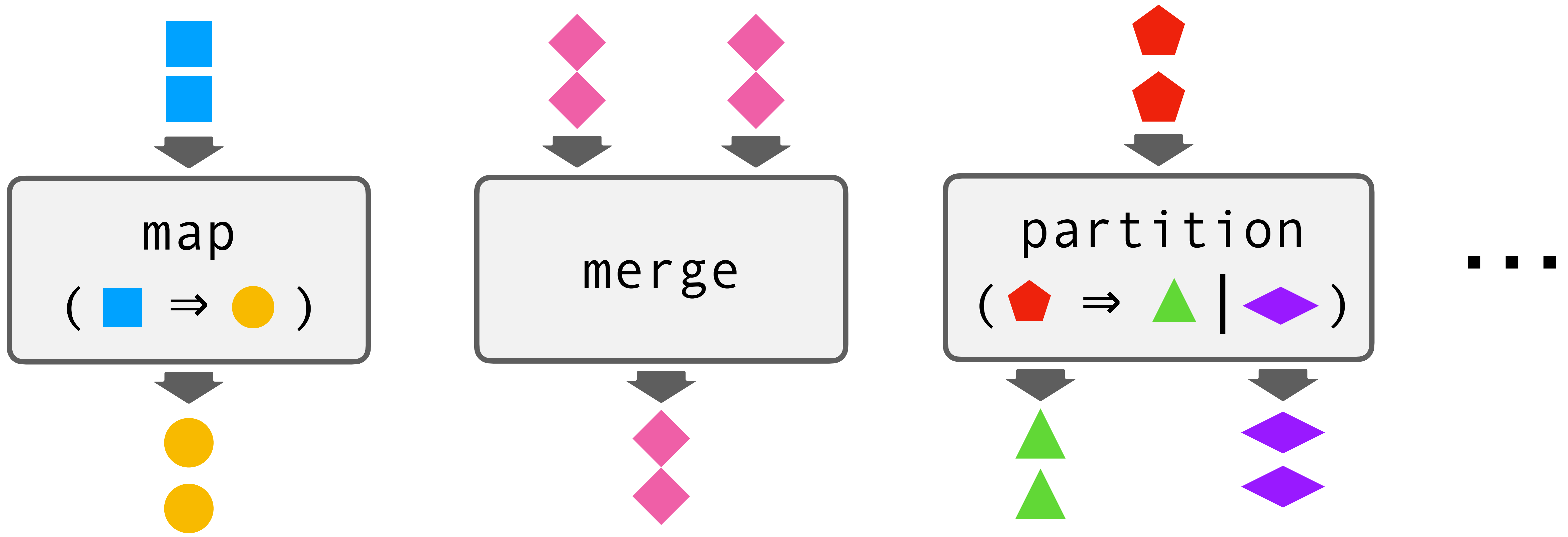

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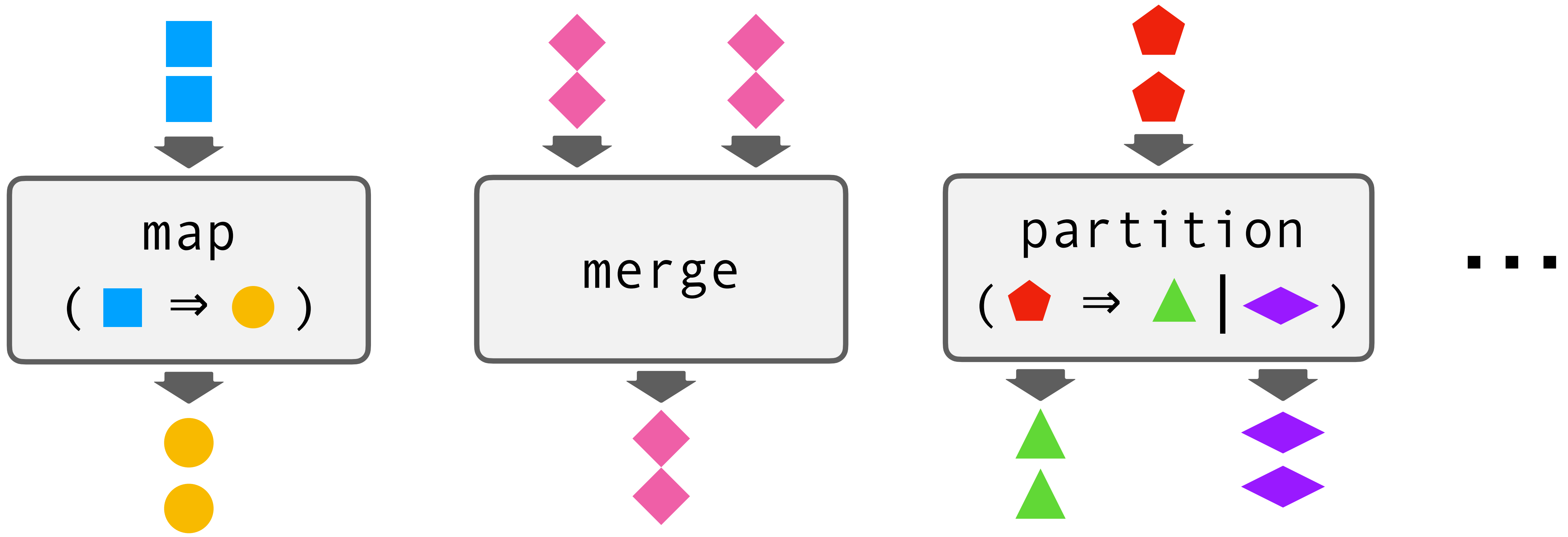

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- All promises completed? Exactly once?
- Are we not losing elements?

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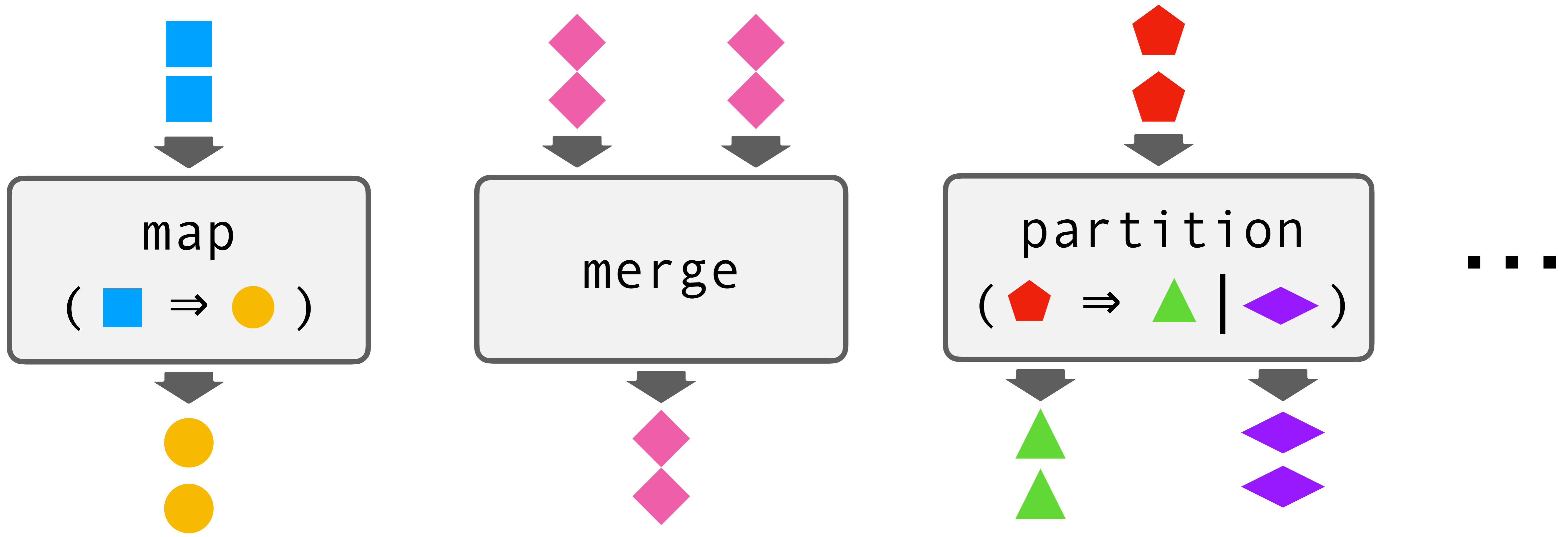

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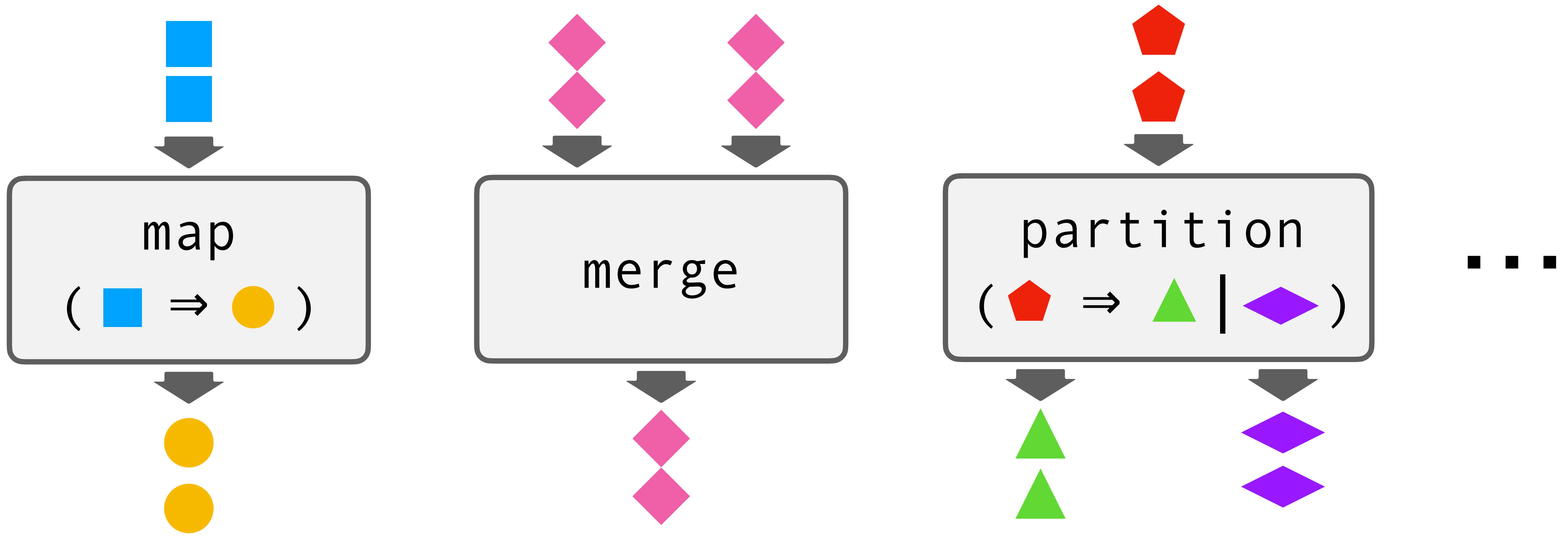

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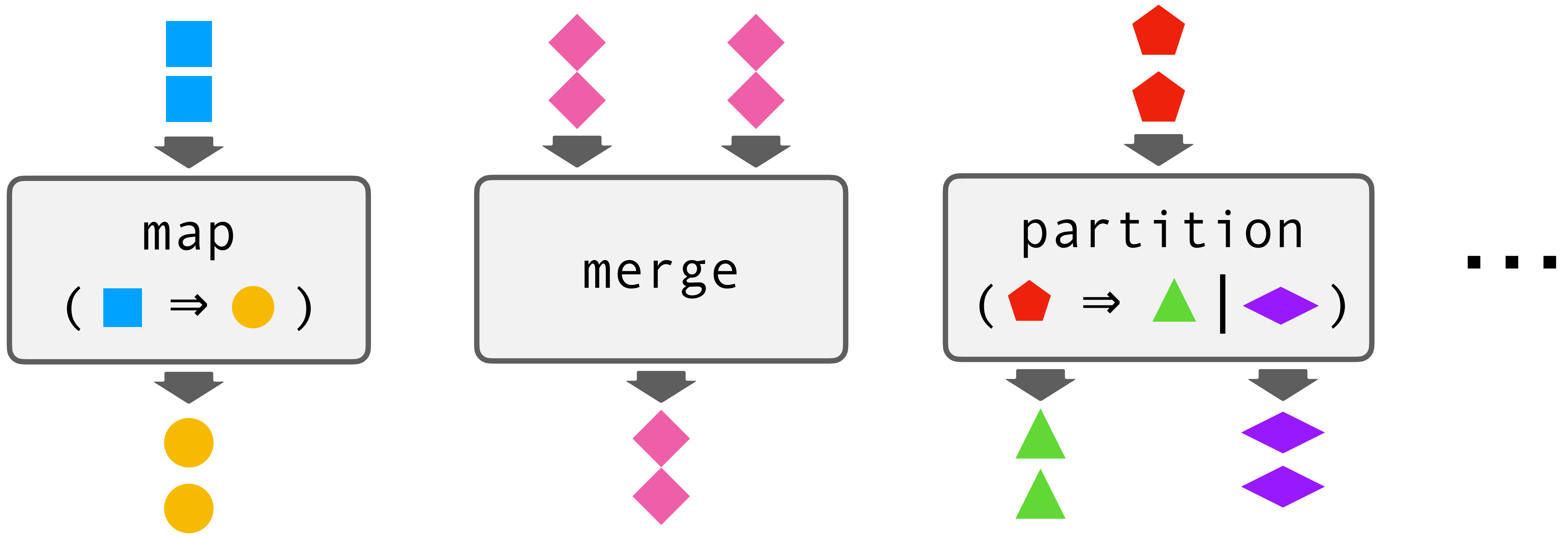

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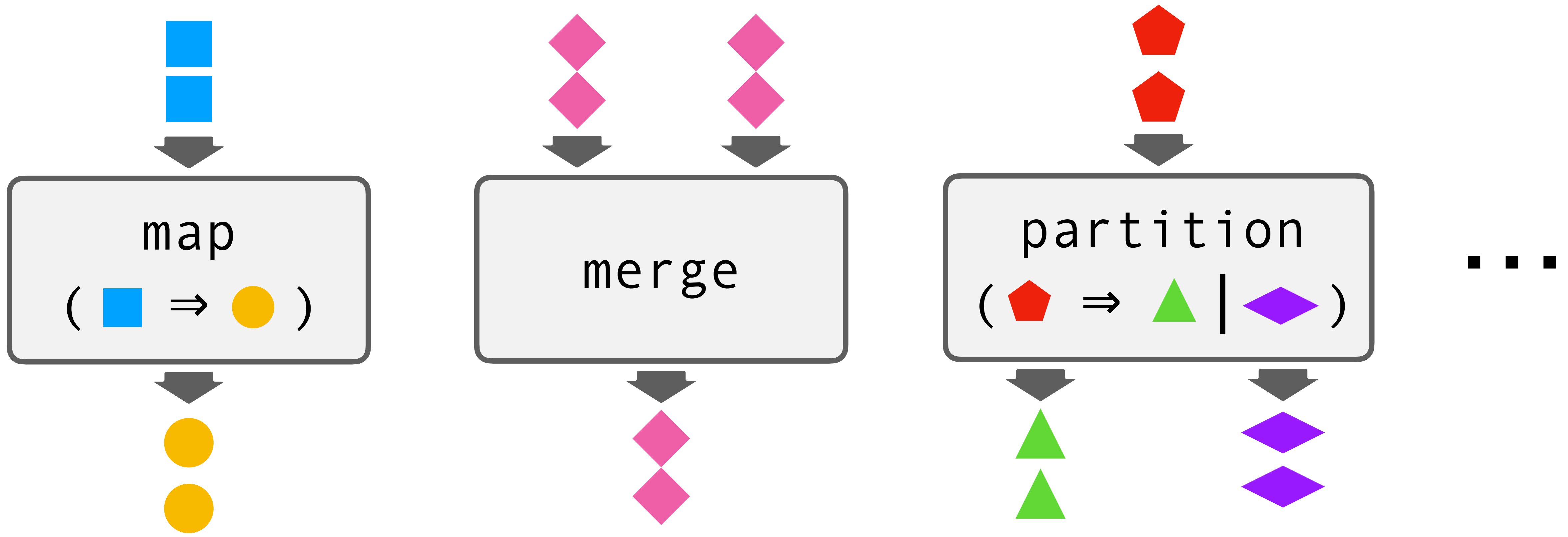

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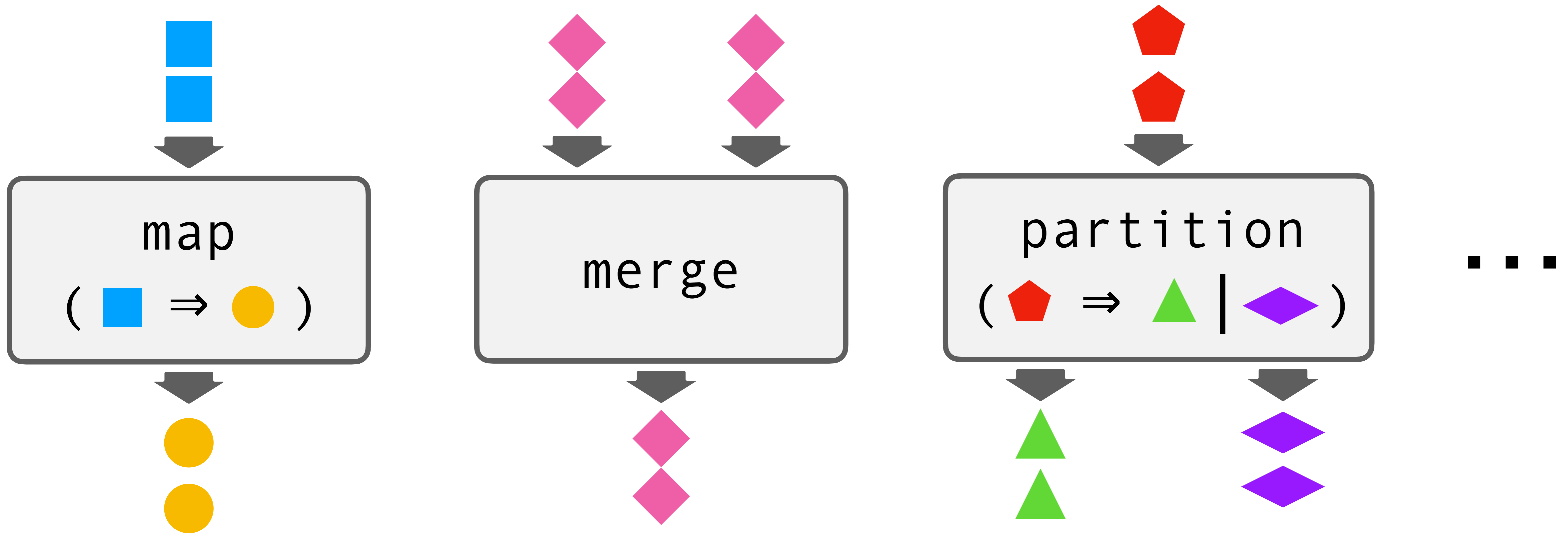

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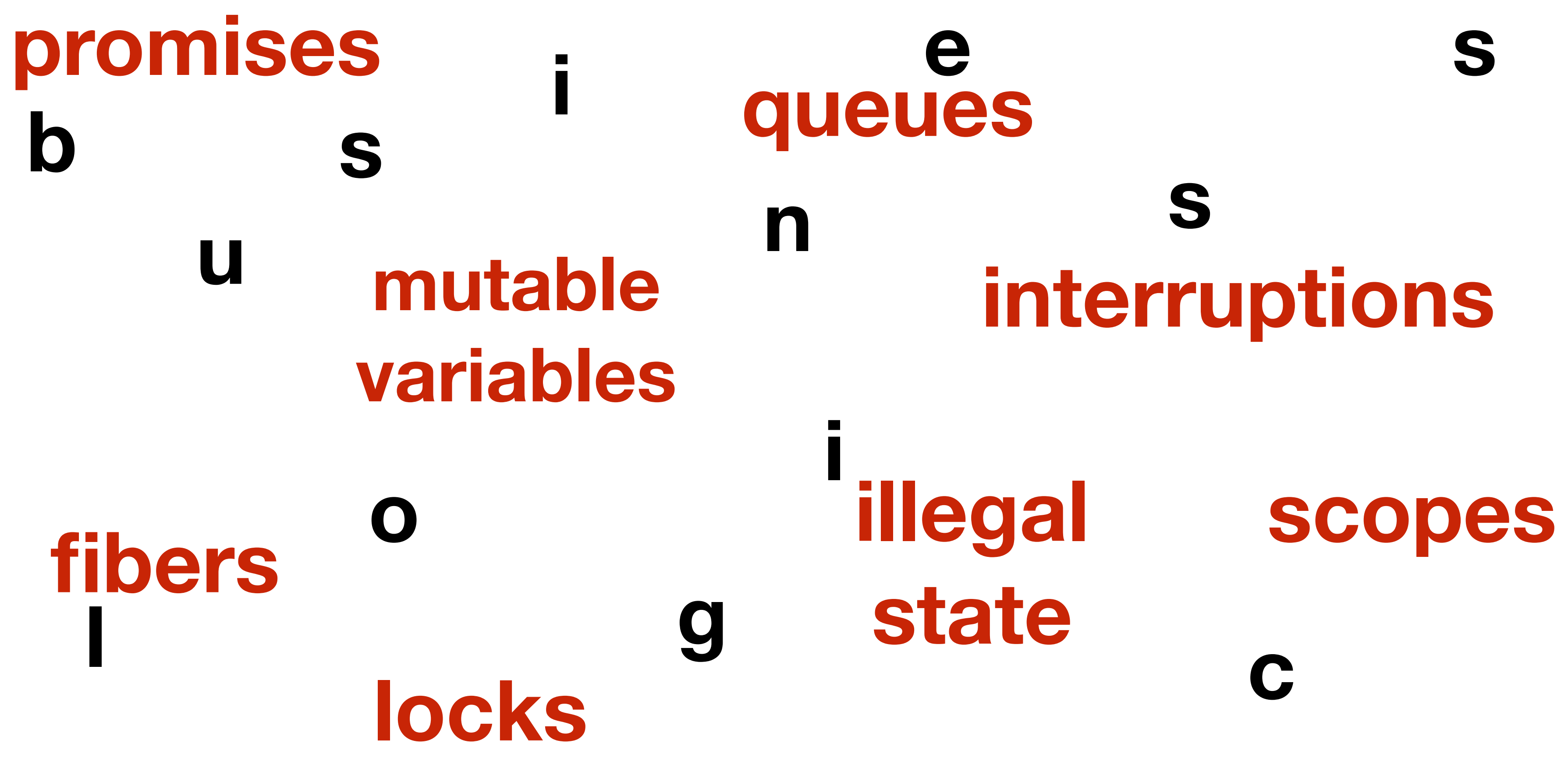

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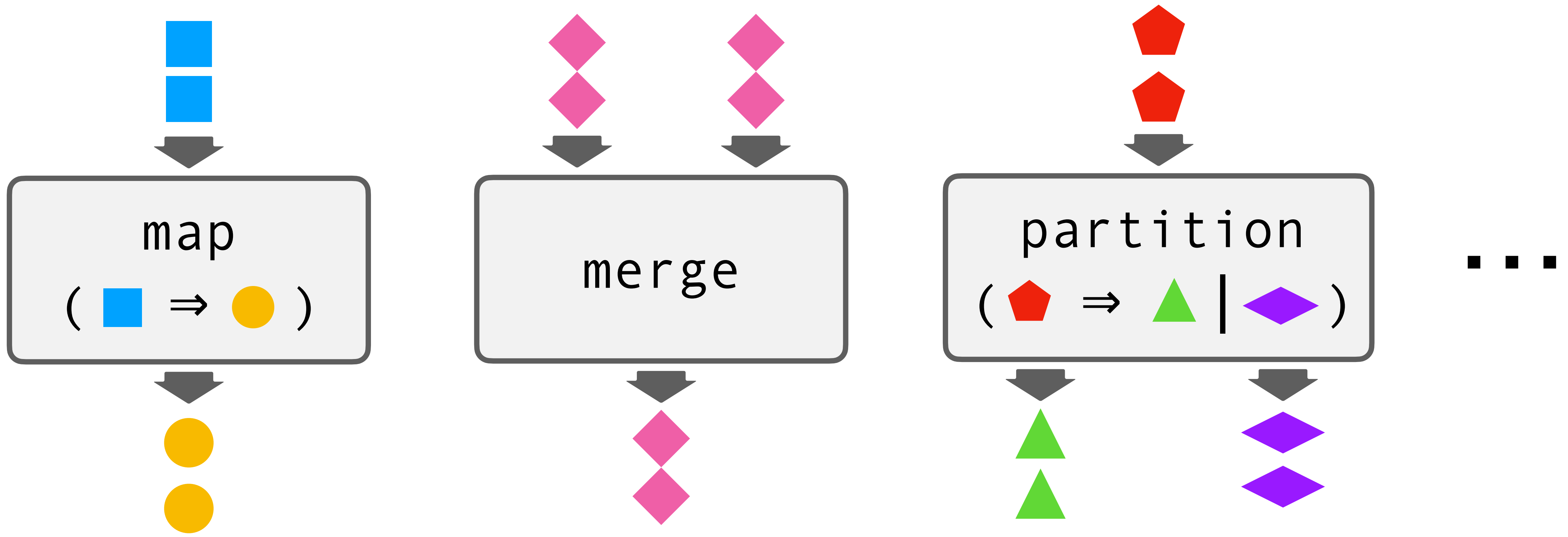

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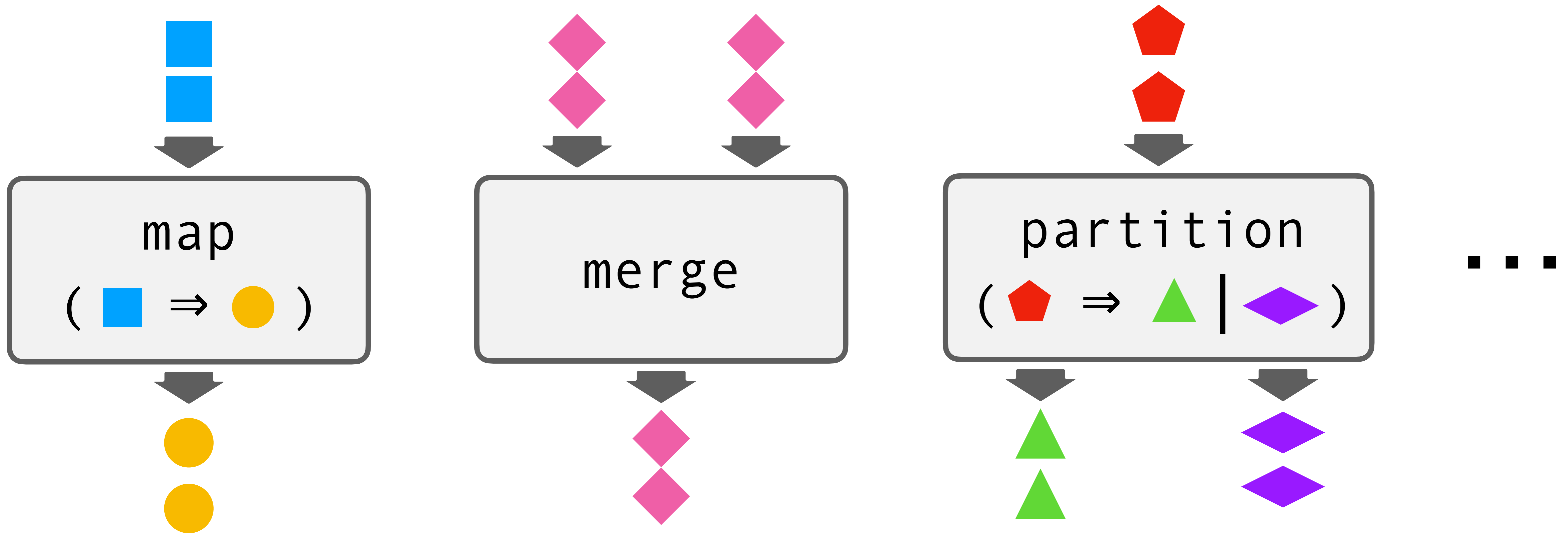

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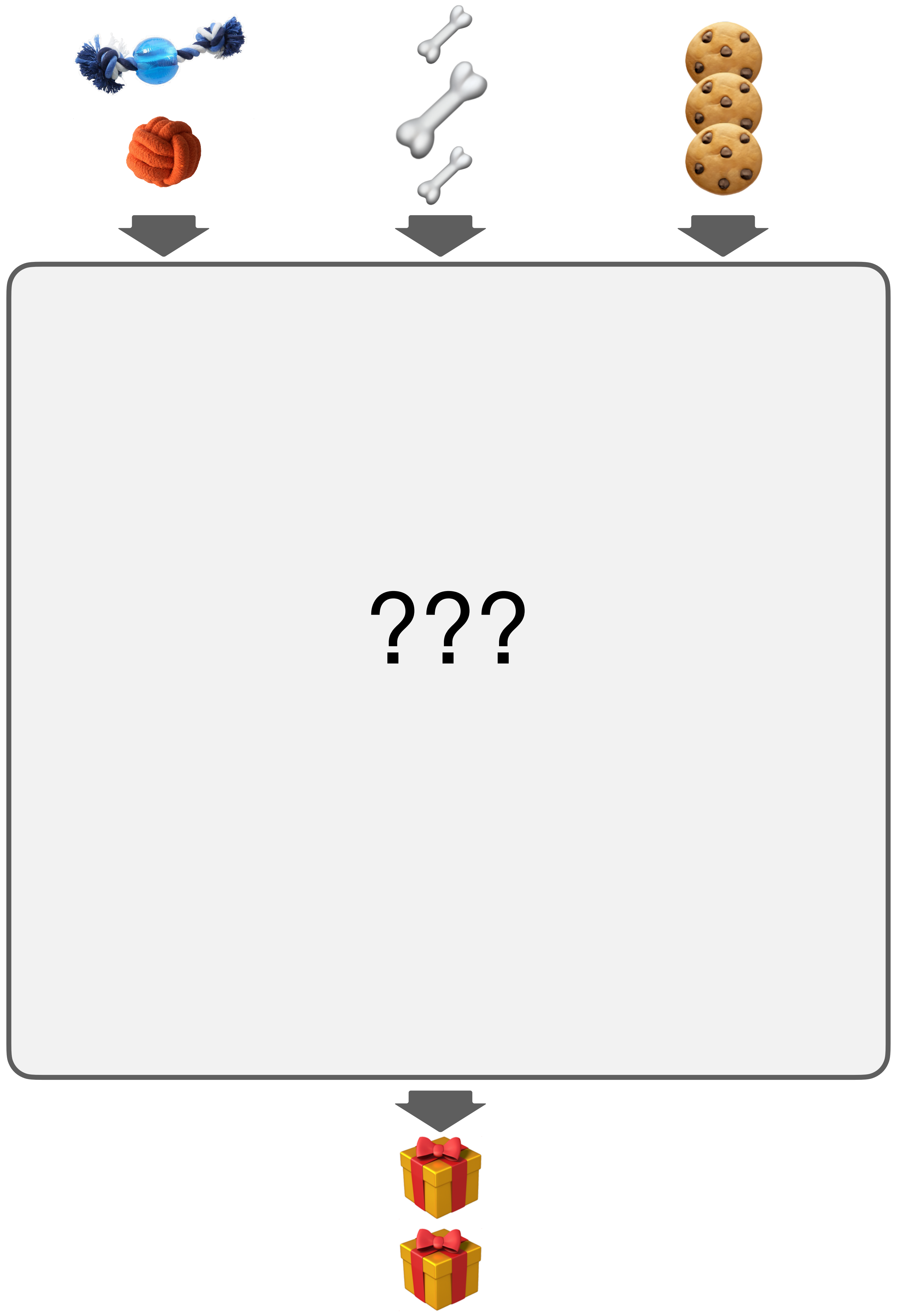
neither **Safe** nor **Simple**

The Libretto Way

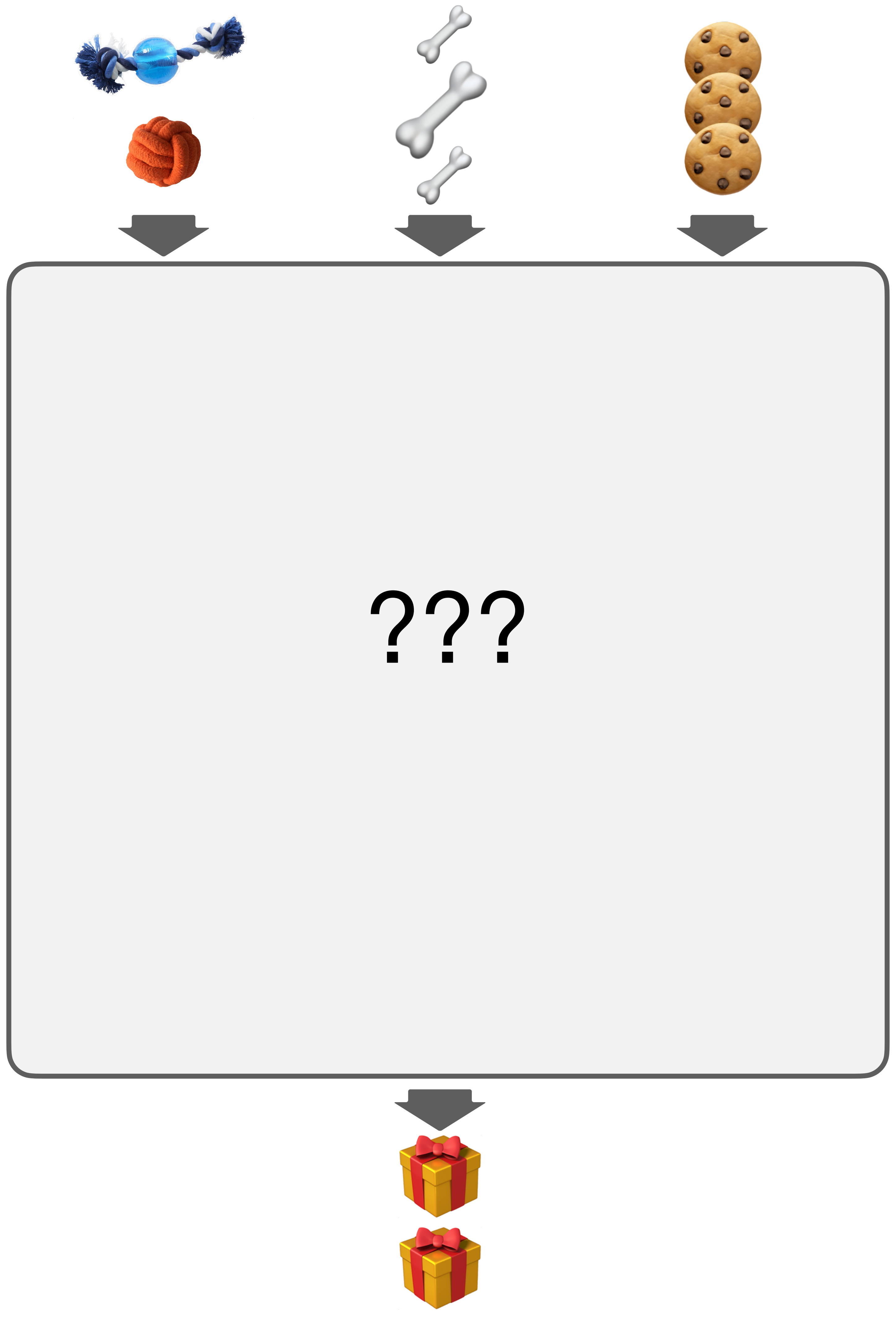
by example

Packaging Dog Presents



- **In:** toys, bones, biscuits
- **Out:** packages of either
  - 1 toy, 1 *large* bone, *3* biscuits
  - 1 toy, 1 *small* bone, *5* biscuits
- Halt when either:
  - no more downstream demand
  - any upstream runs out of items
- Discard at most 1 toy, 1 bone, 5 biscuits

Packaging Dog Presents



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Pulling behavior depends on previously pulled values (size of the pulled bone).

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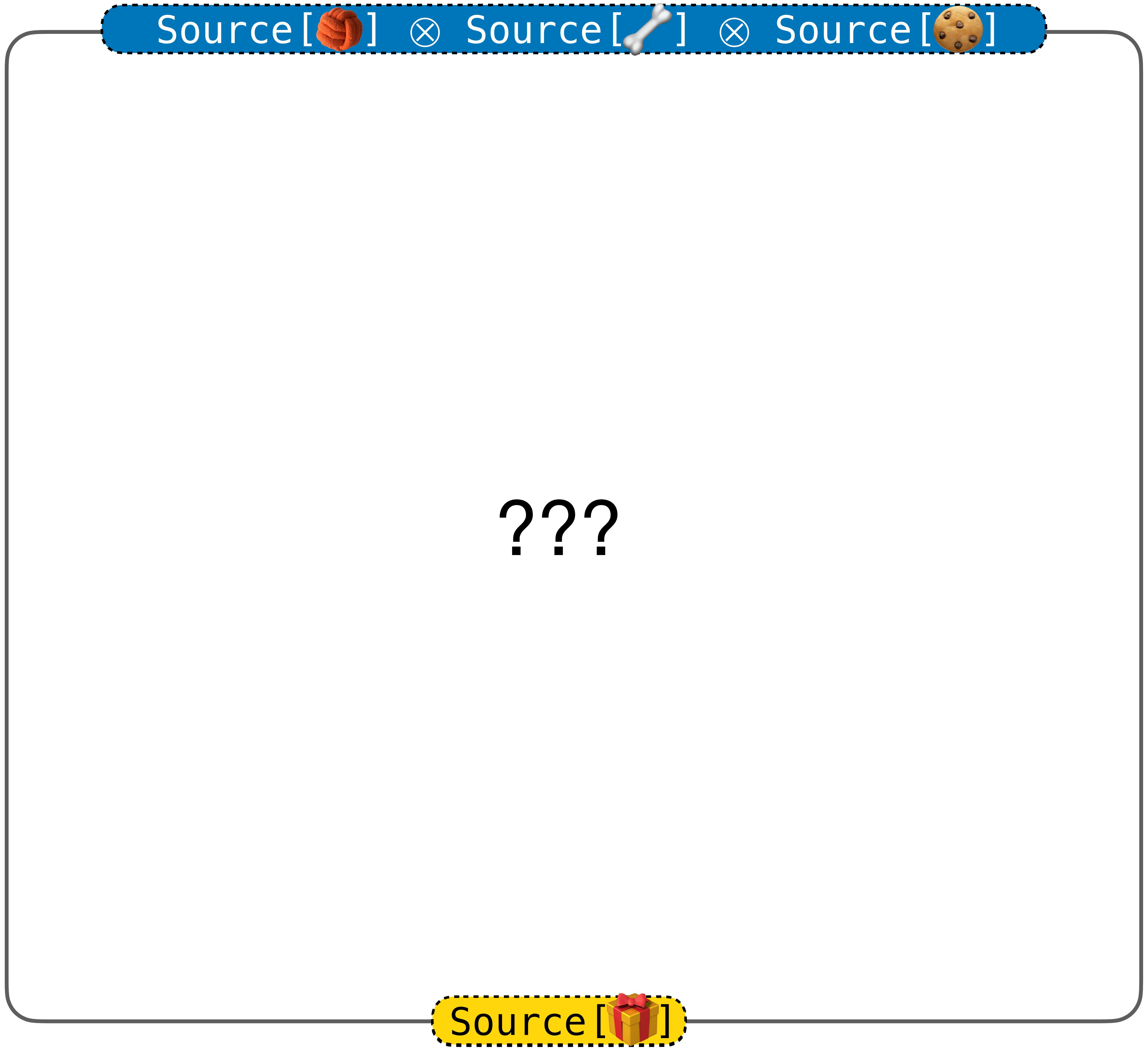


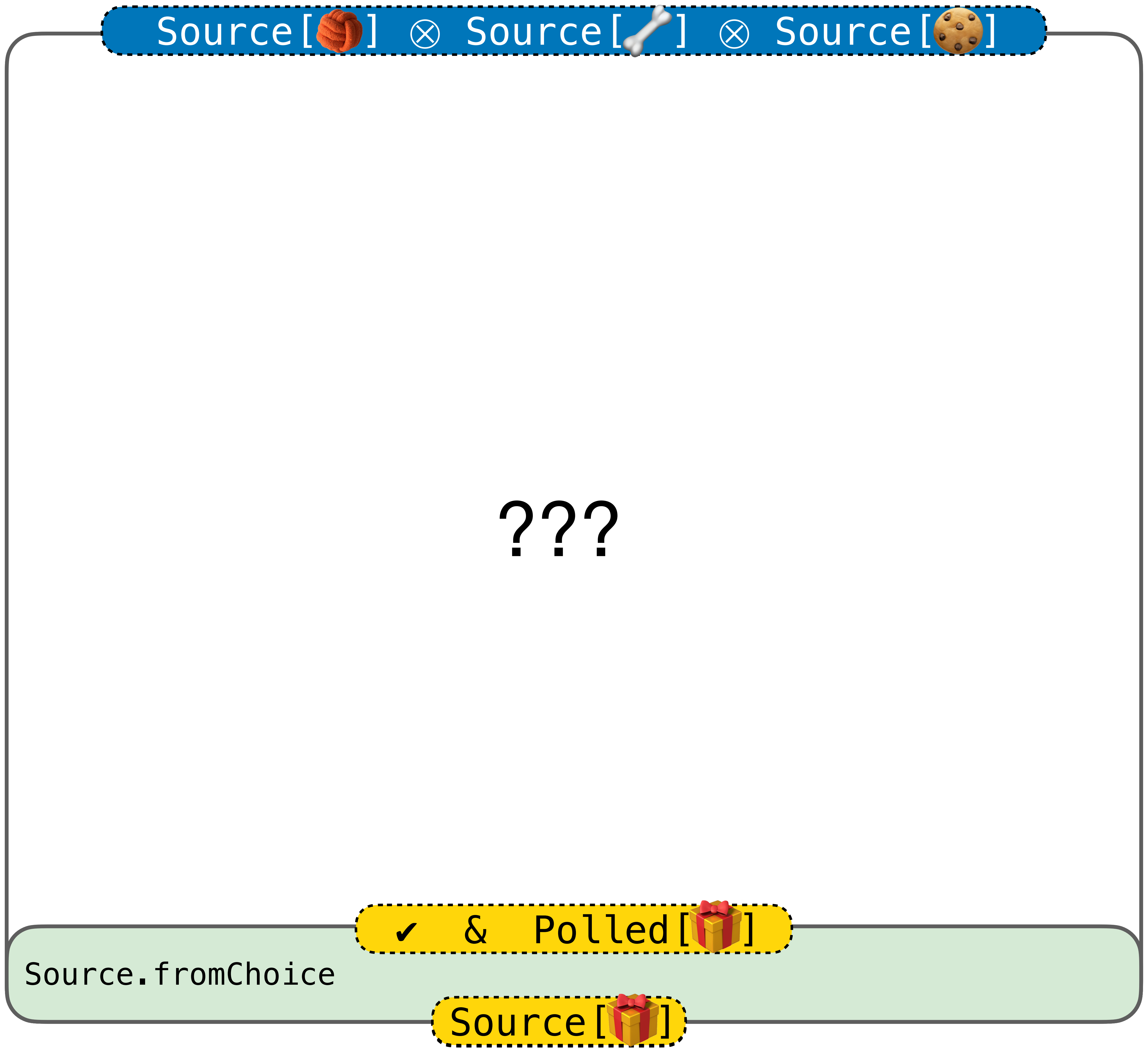
Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

???

Source[🎁]

???	hole to be filled
🟦	to be consumed
🟨	to be produced
⊗	concurrent pair

Packaging Dog Presents



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✔ & Polled[🎁]

Source.fromChoice

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✔	Done signal
`Polled[A]`	requested next elem

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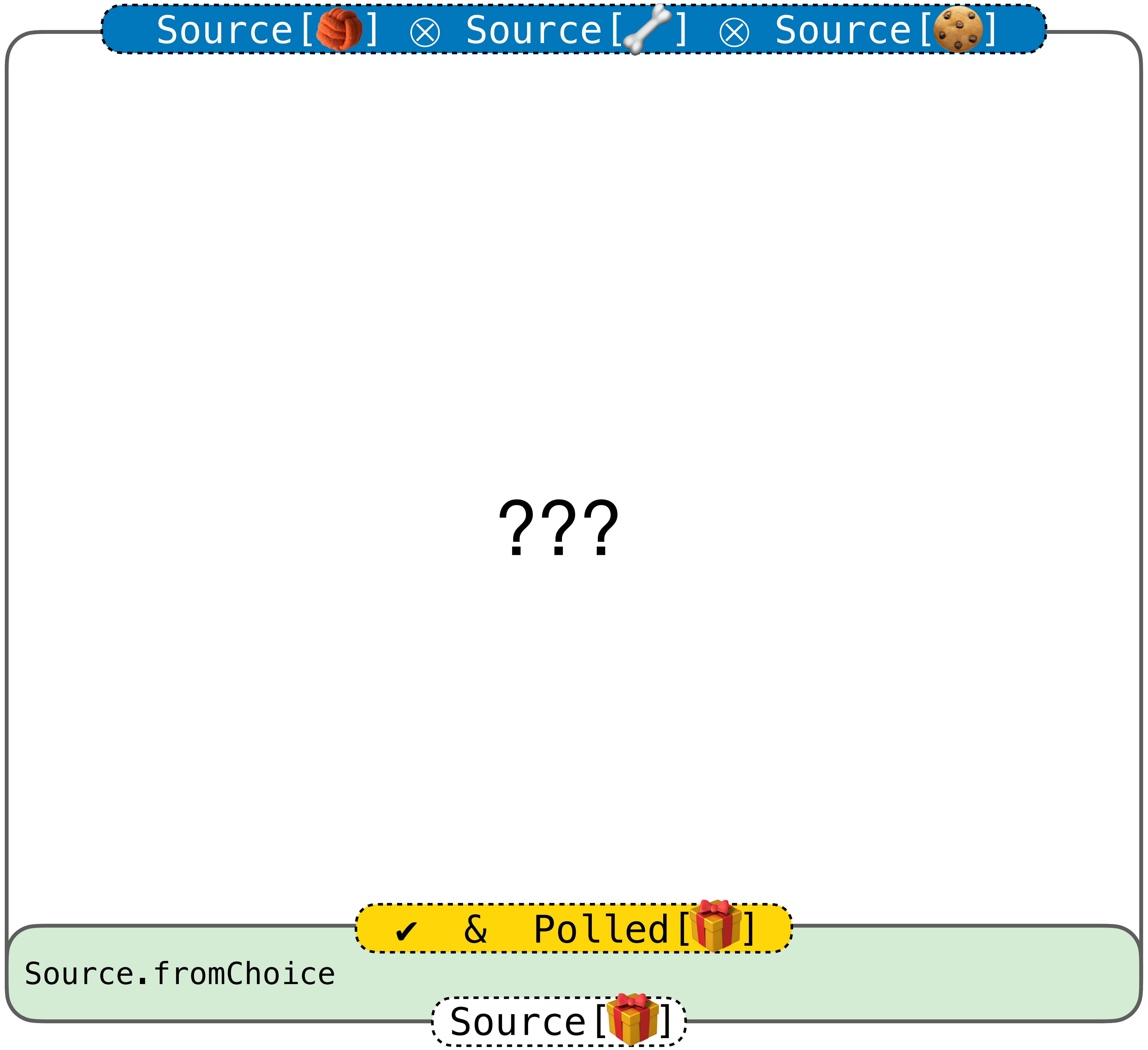

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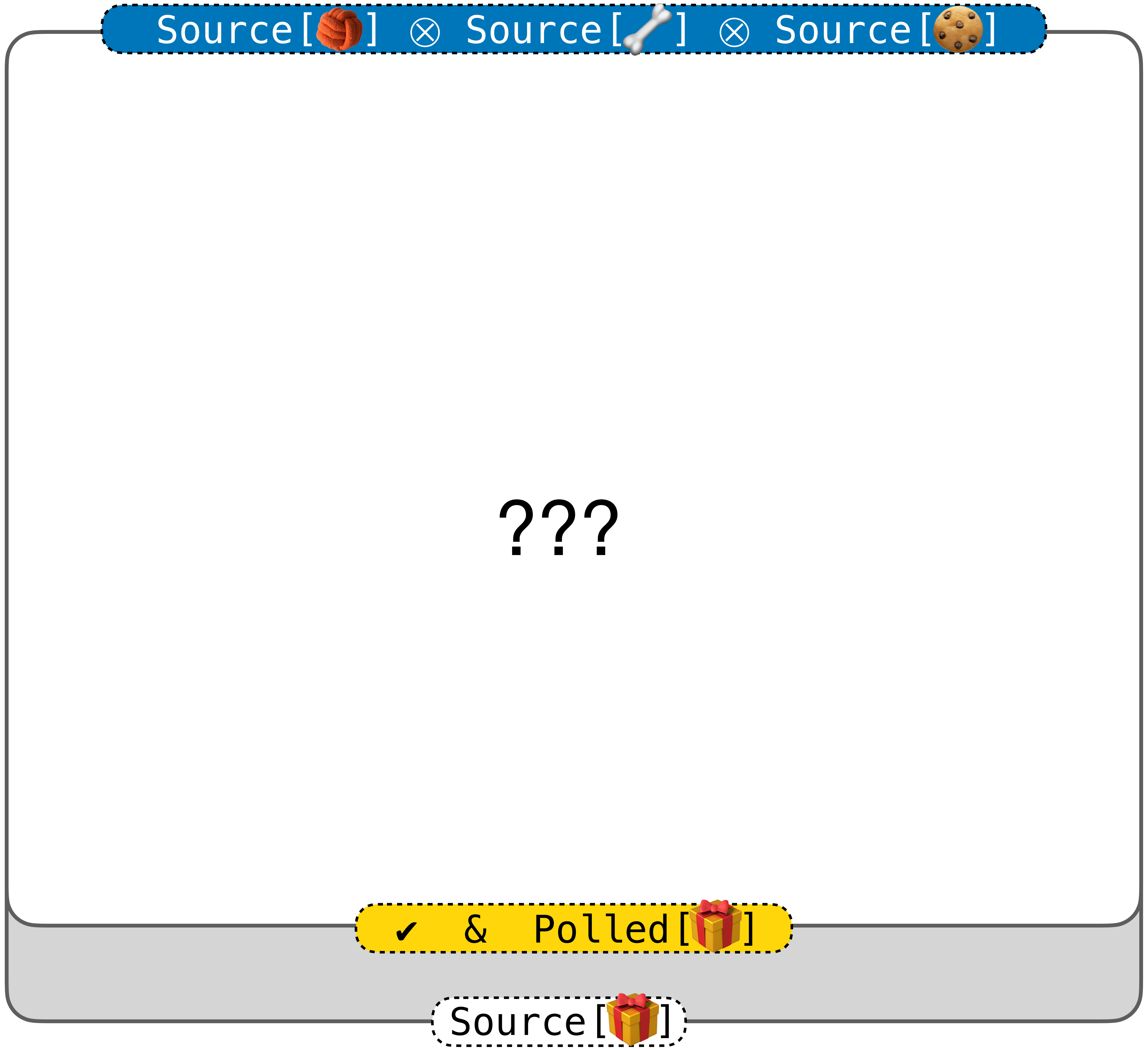

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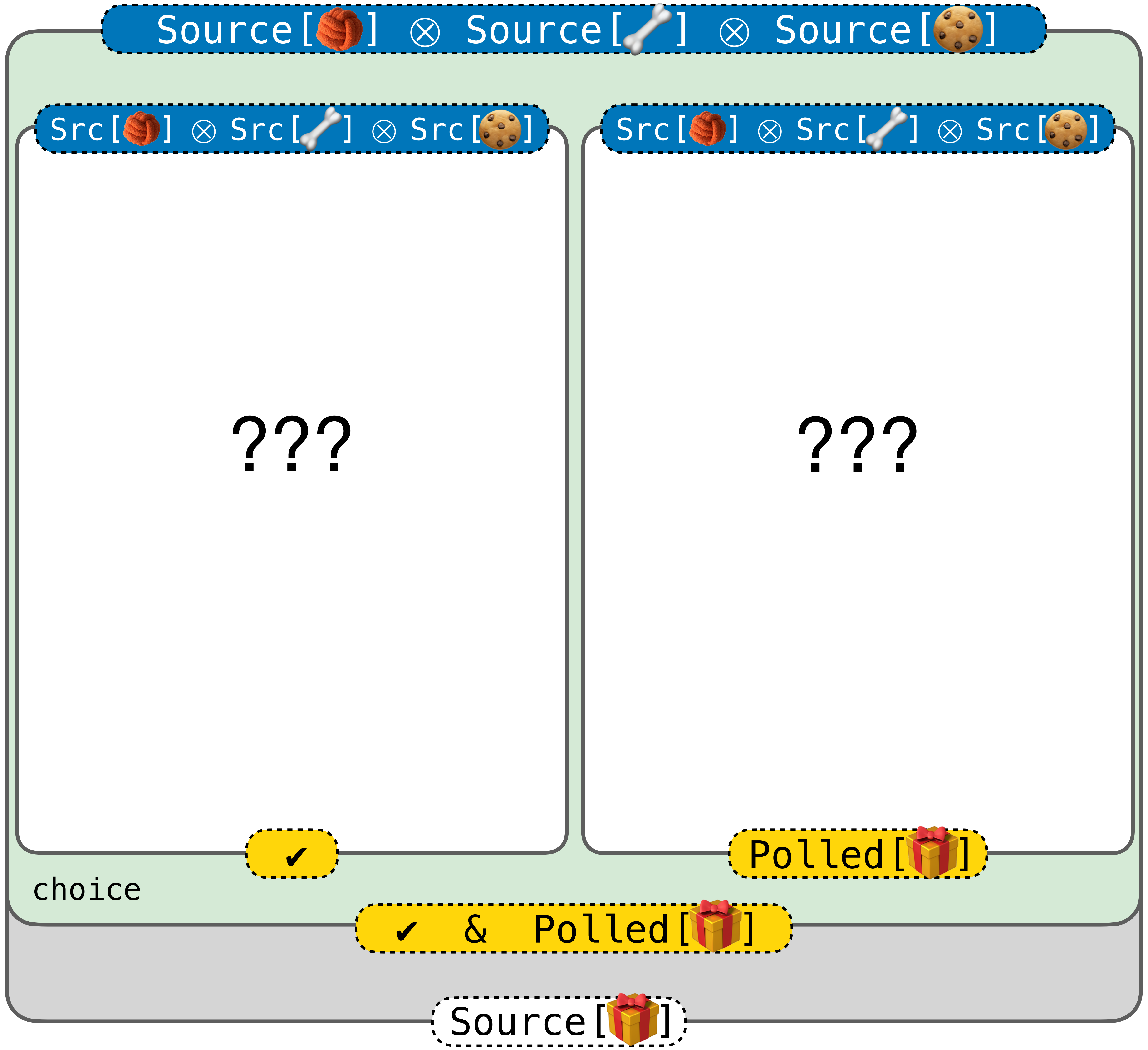

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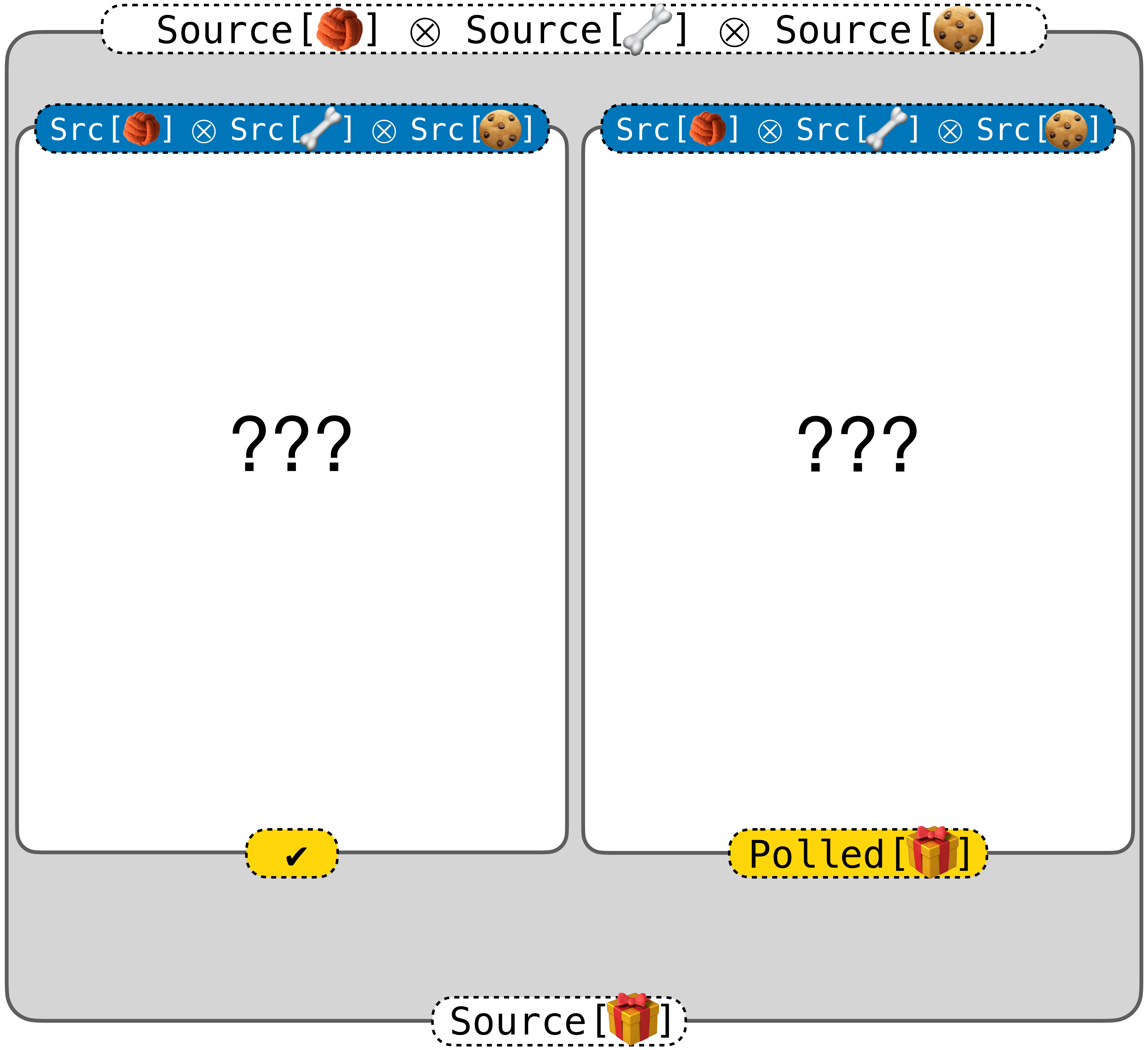

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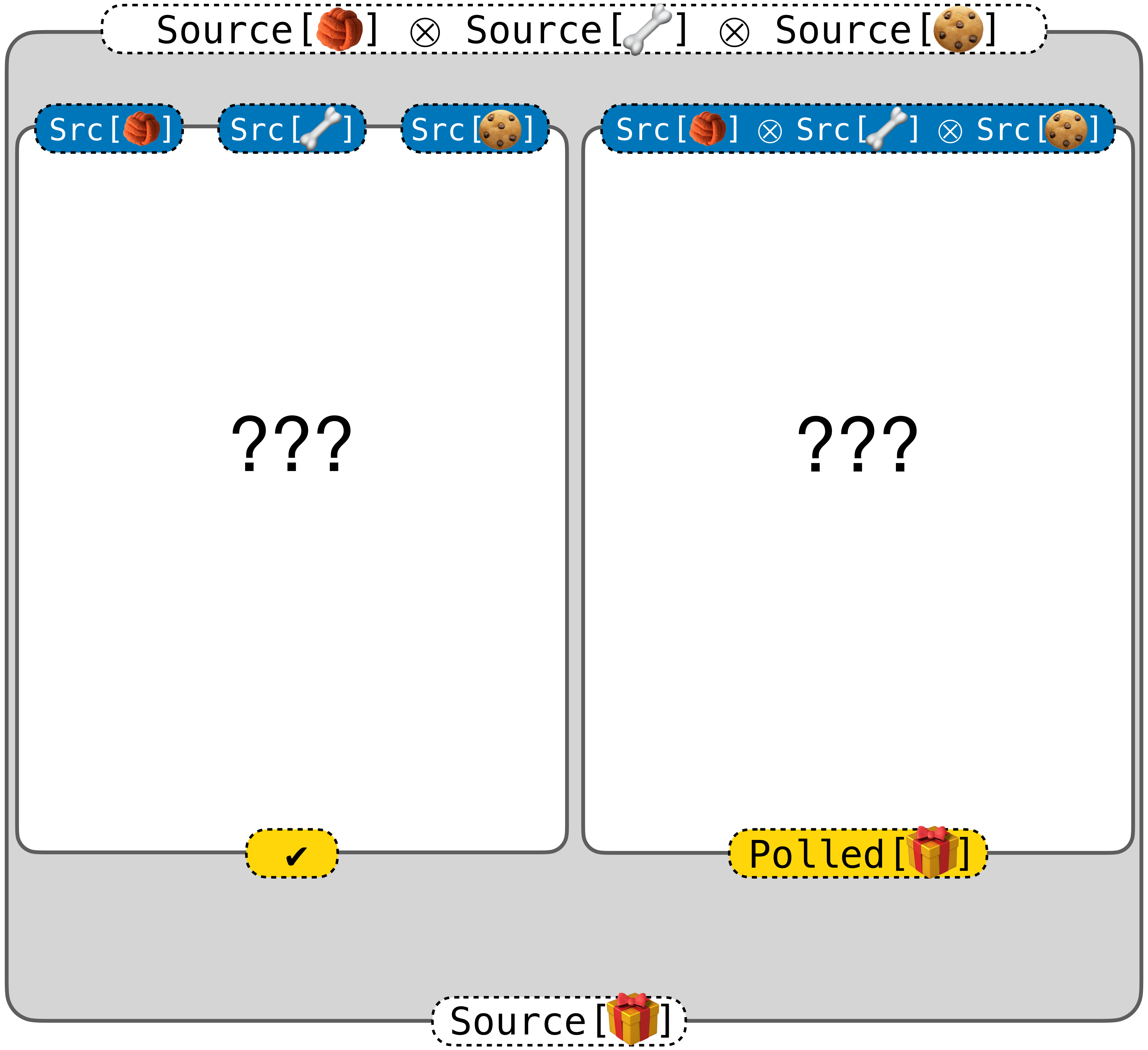

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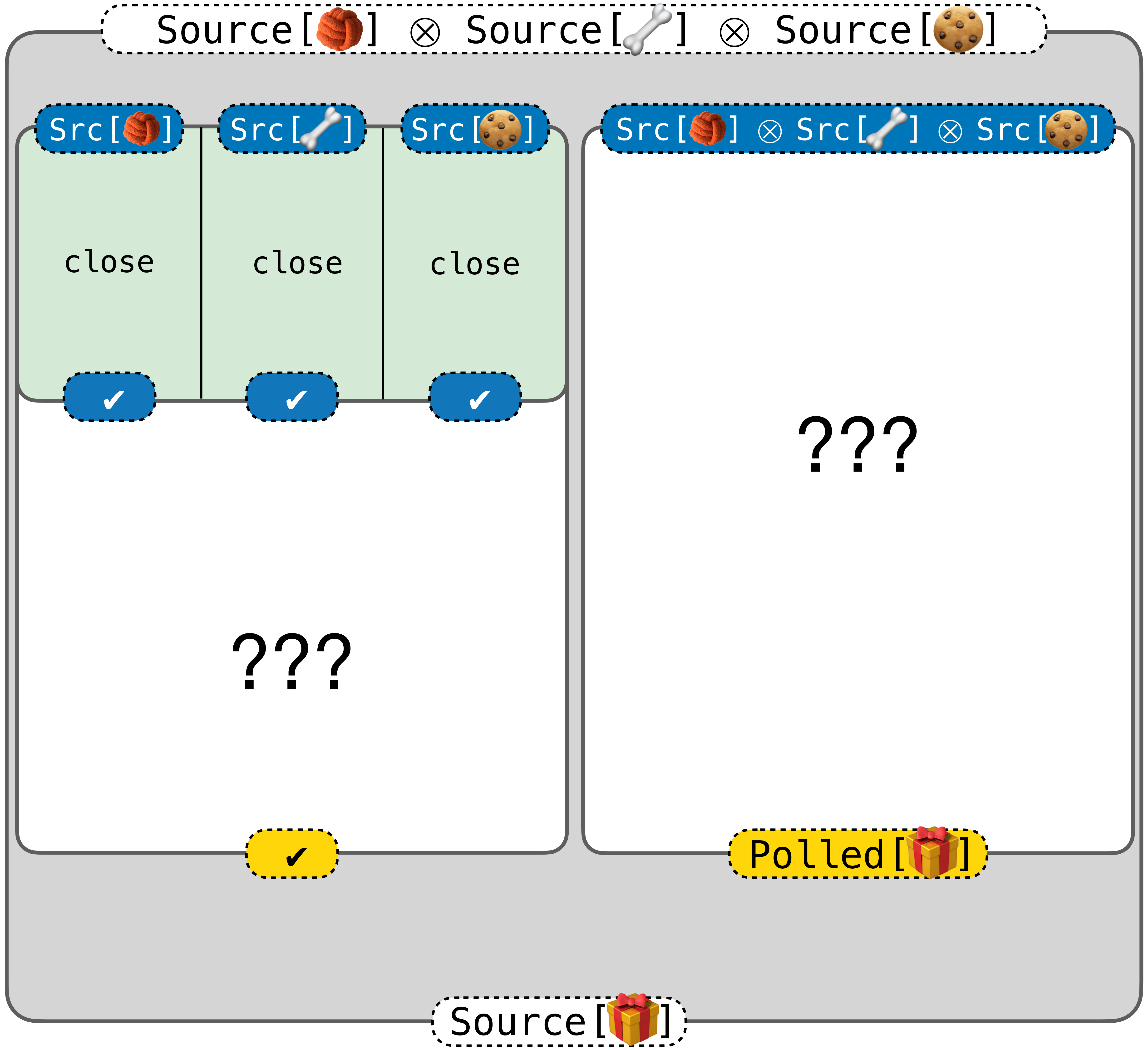

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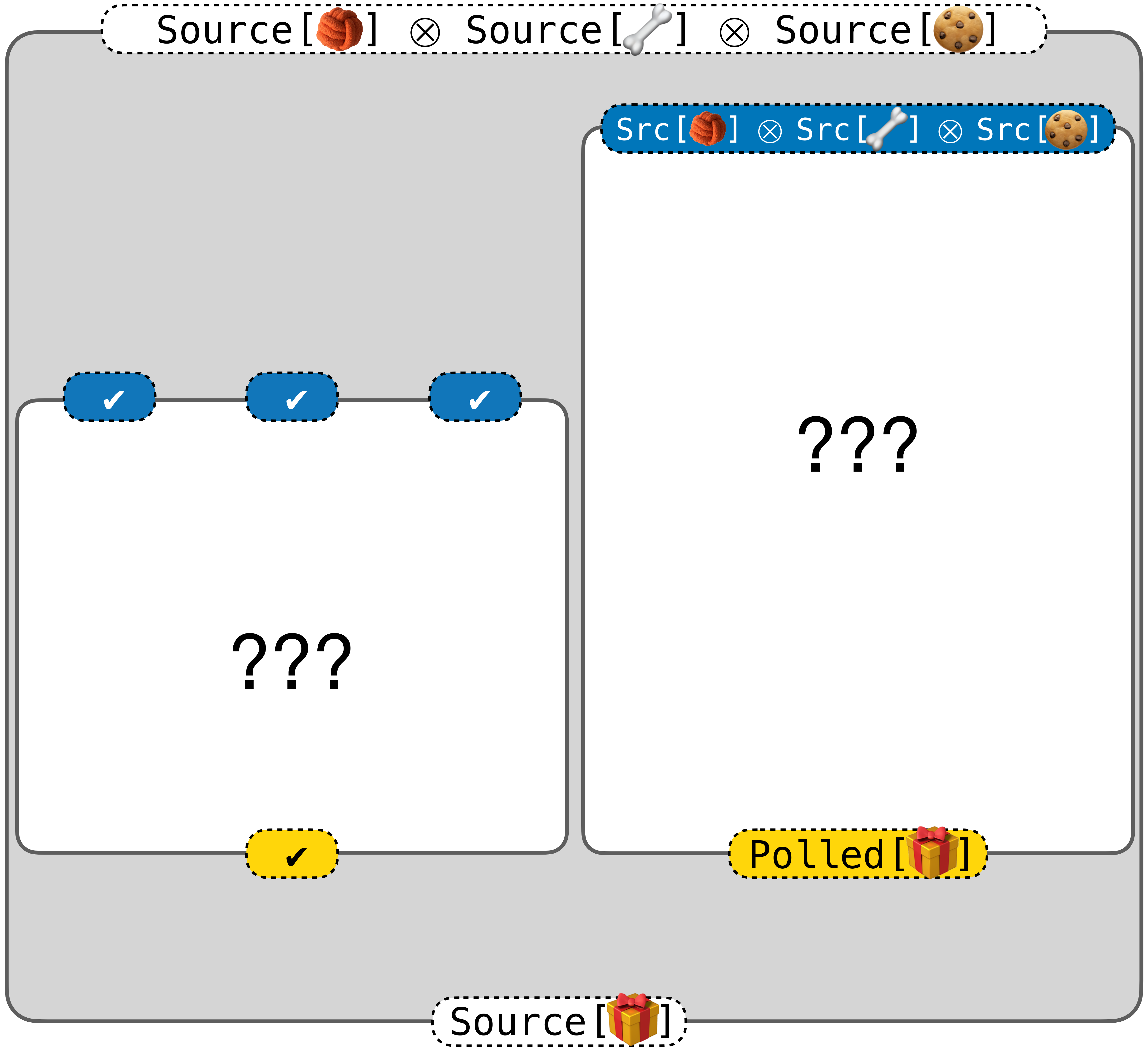

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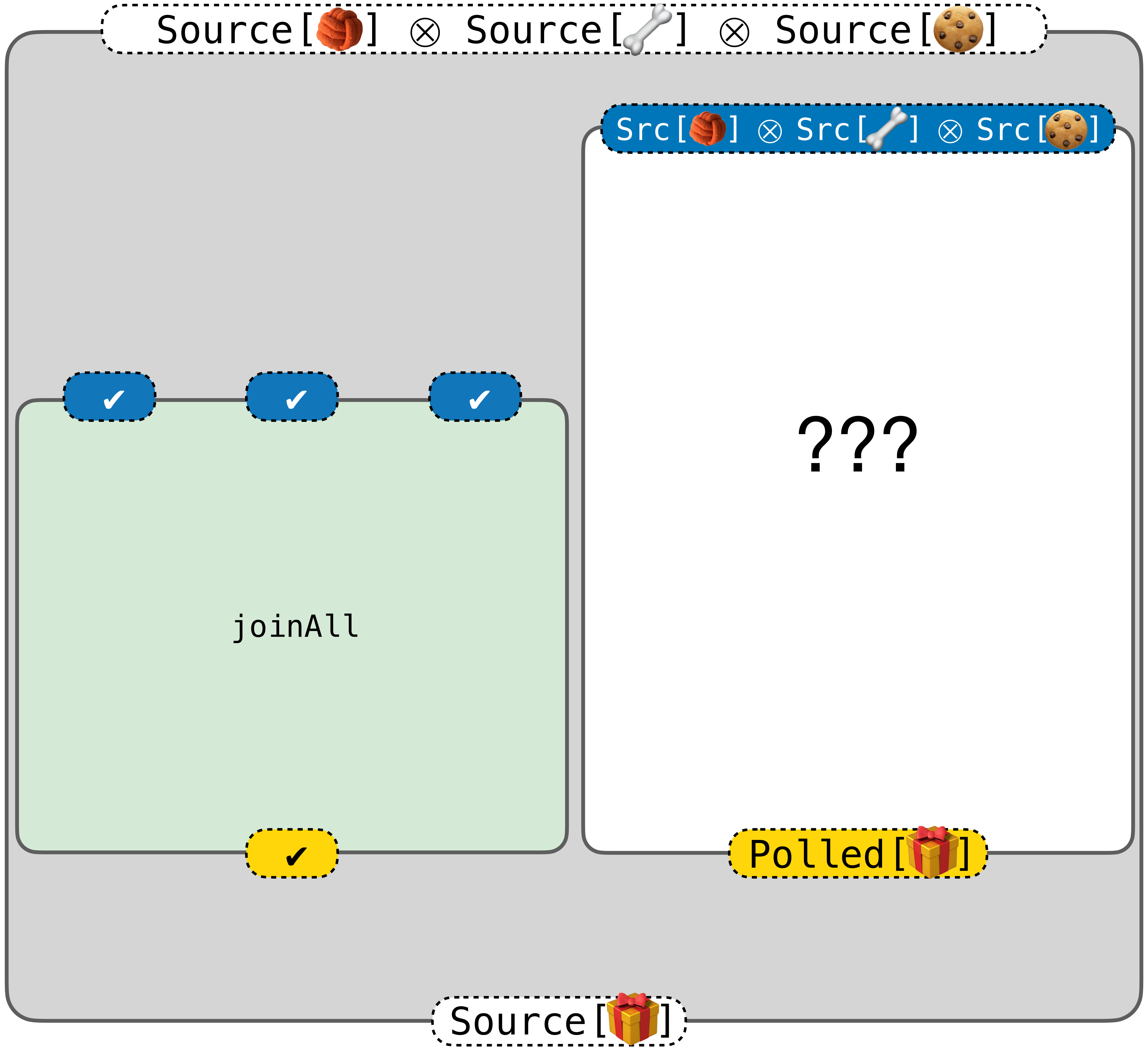

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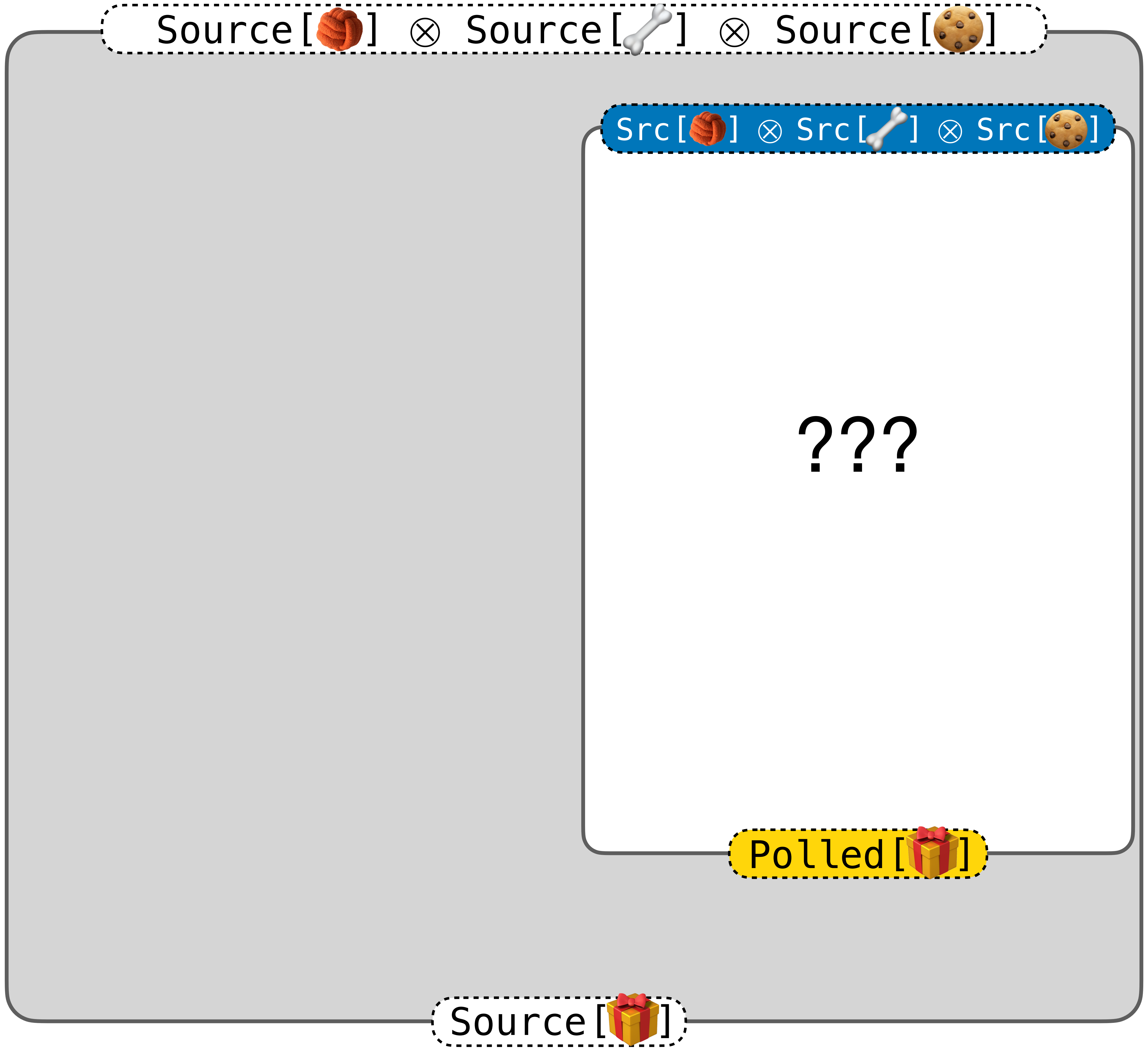

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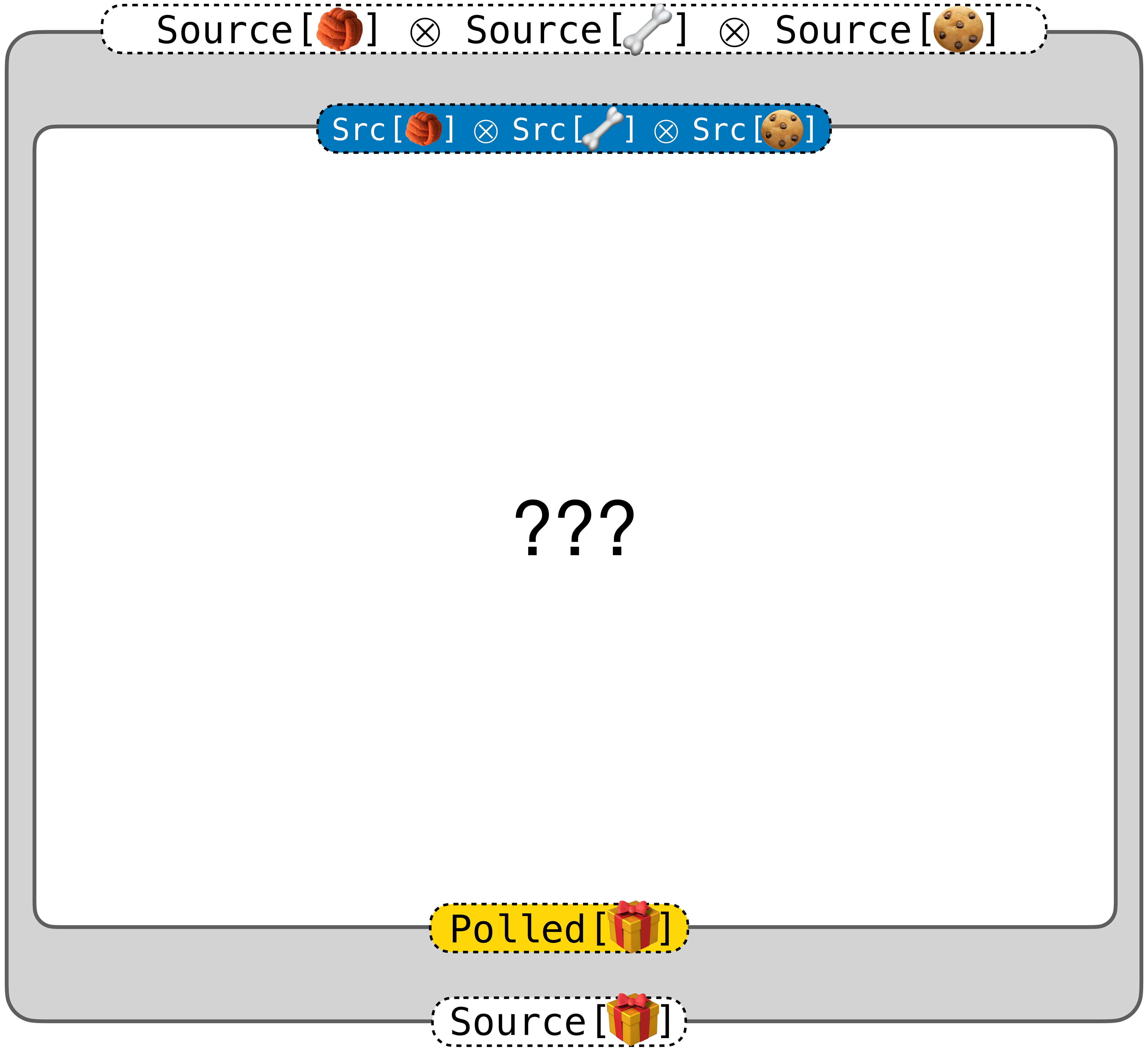

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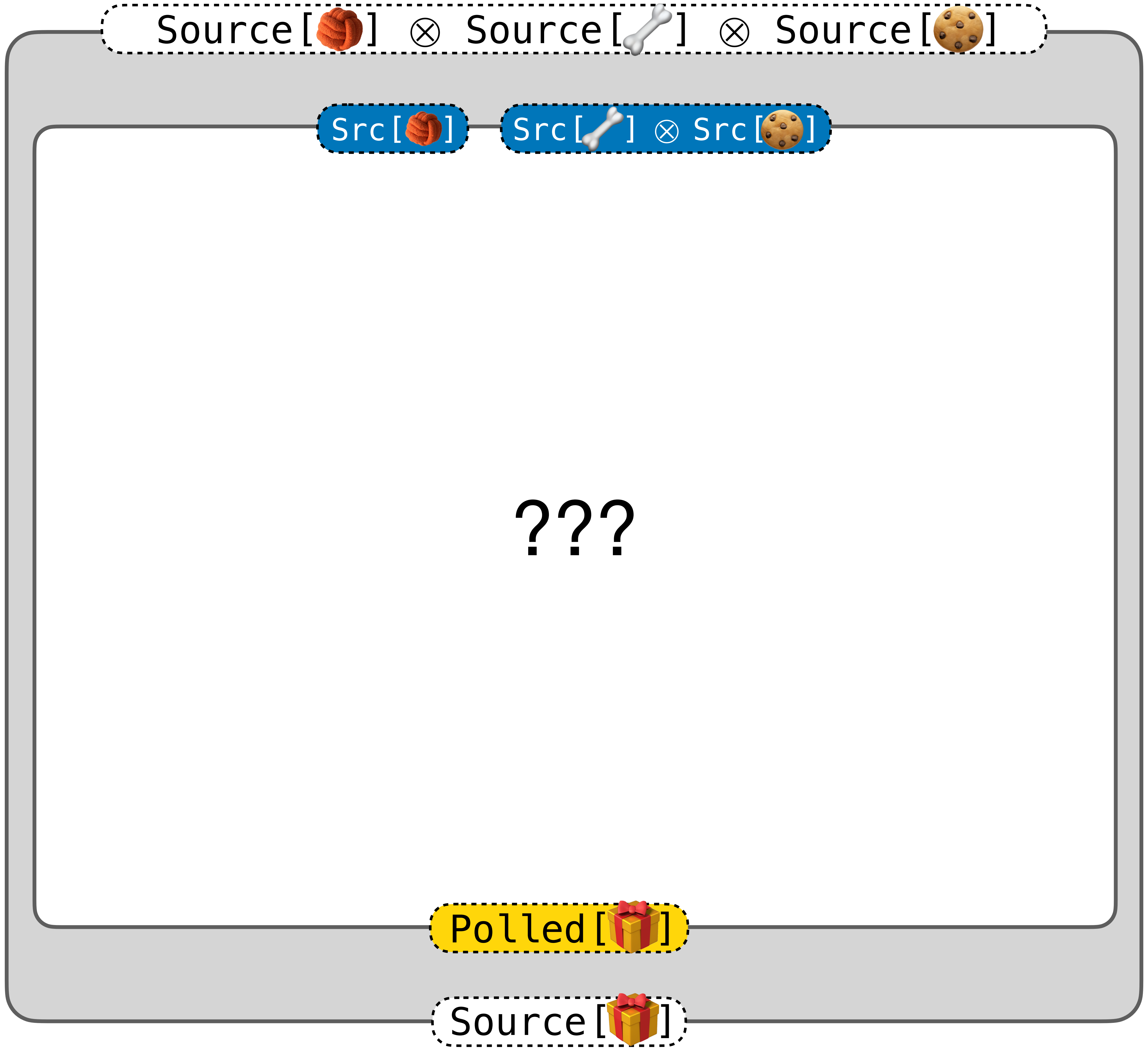

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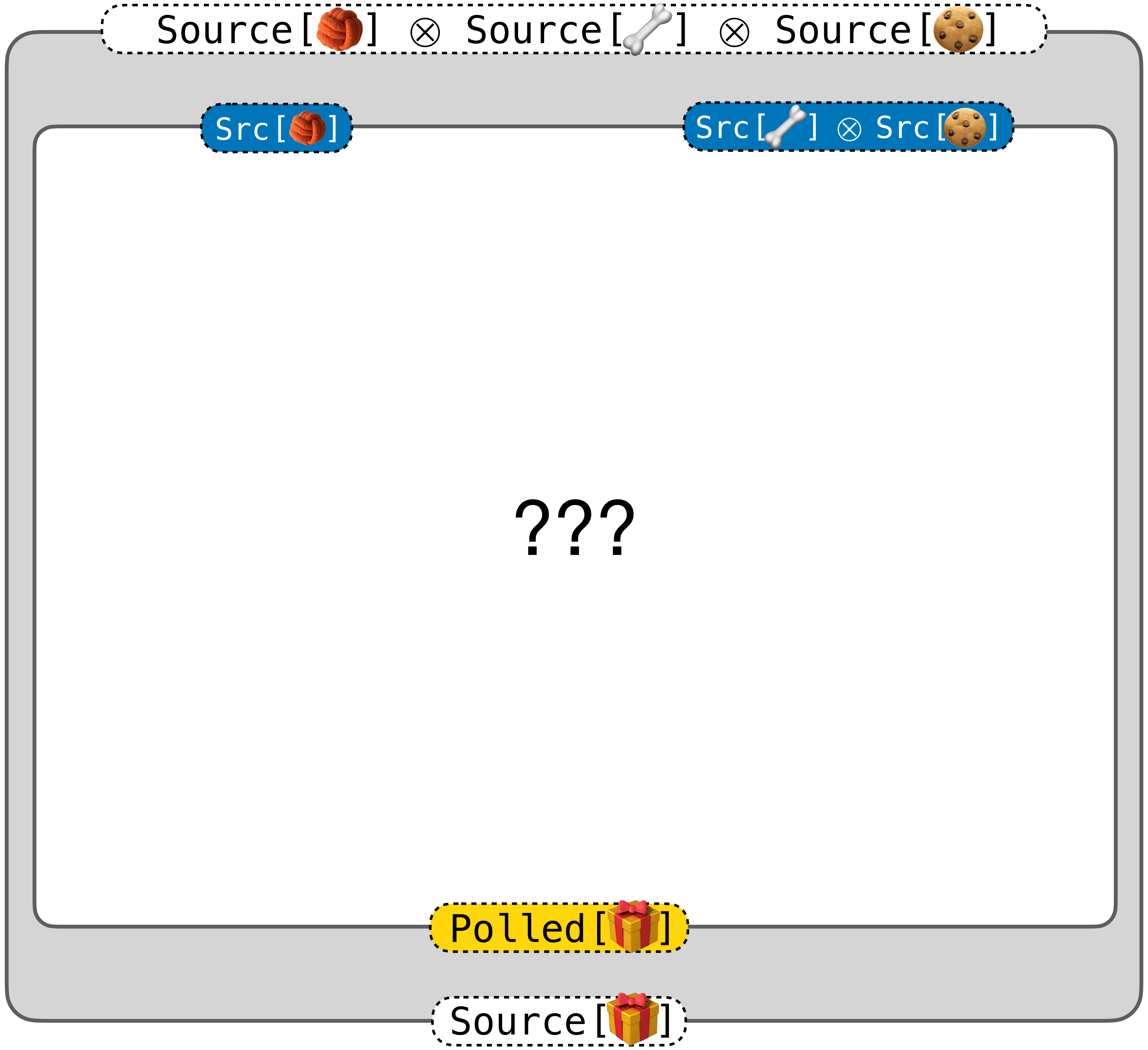

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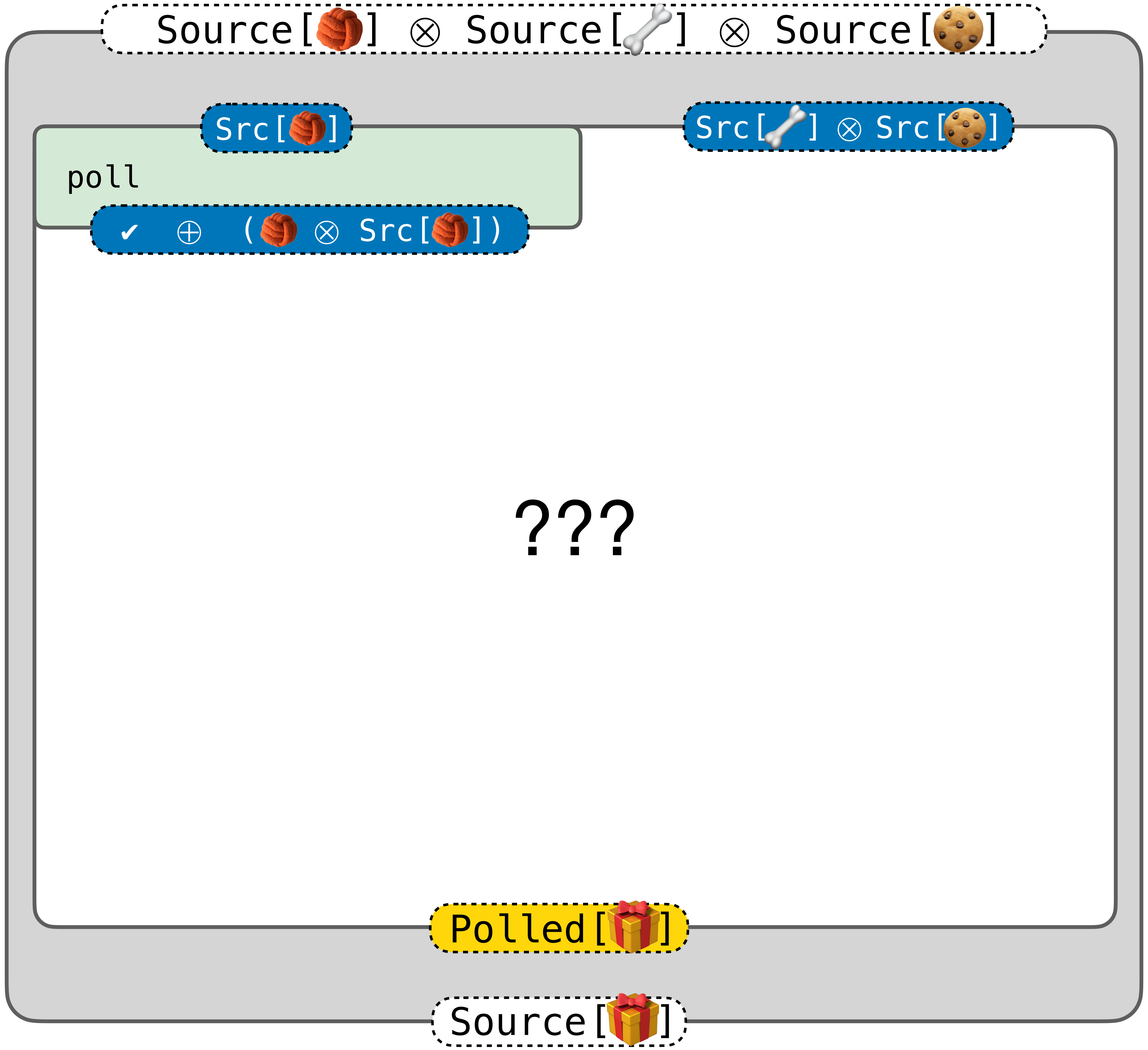

Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

Src[🧶]

Src[🦴] ⊗ Src[🍪]

poll

✔ ⊕ (🧶 ⊗ Src[🧶])

???

Polled[🎁]

Source[🎁]

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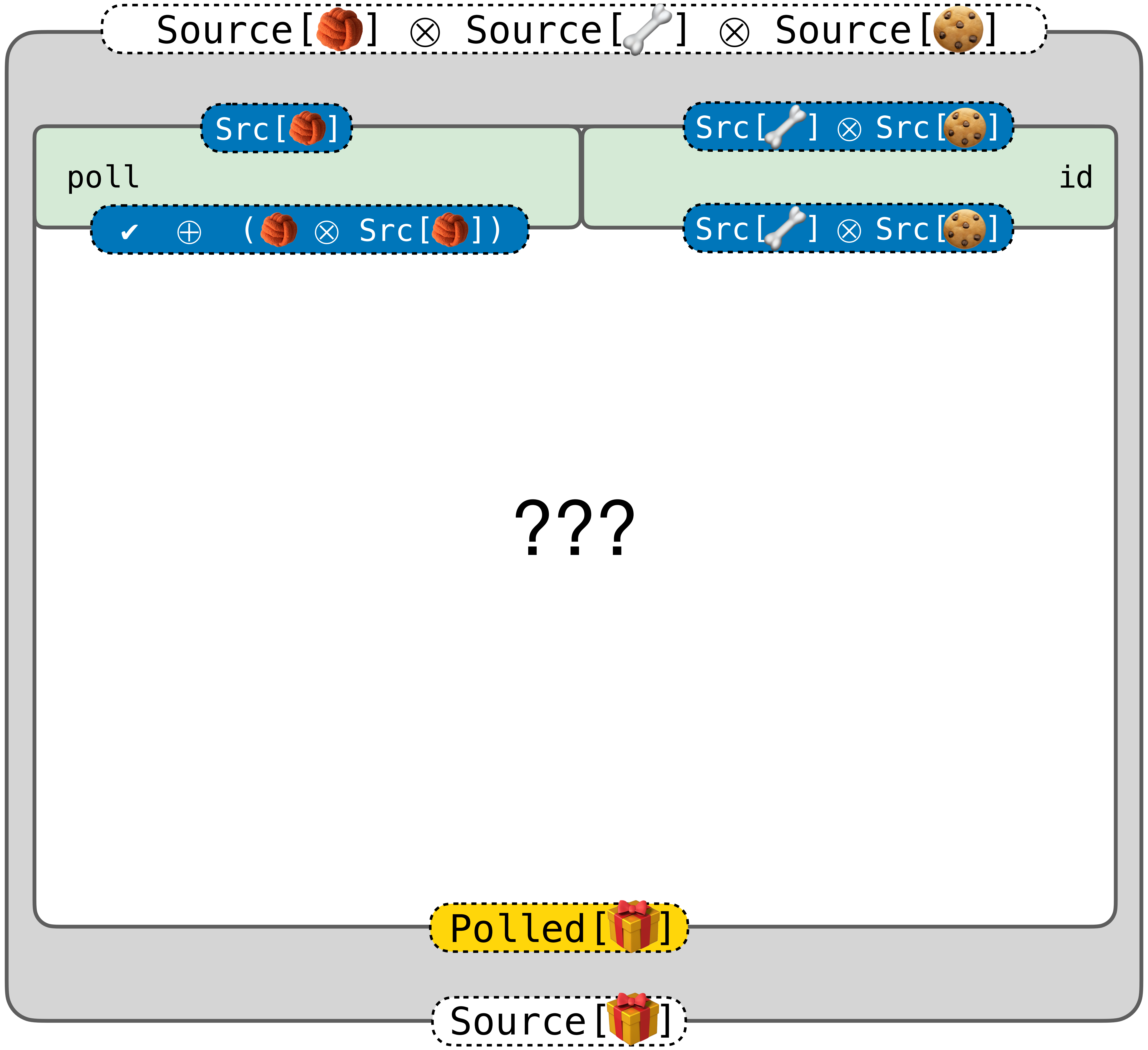

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Src[🧶]

poll

✔ ⊕ (🧶 ⊗ Src[🧶])

Src[🦴] ⊗ Src[🍪]

id

Src[🦴] ⊗ Src[🍪]

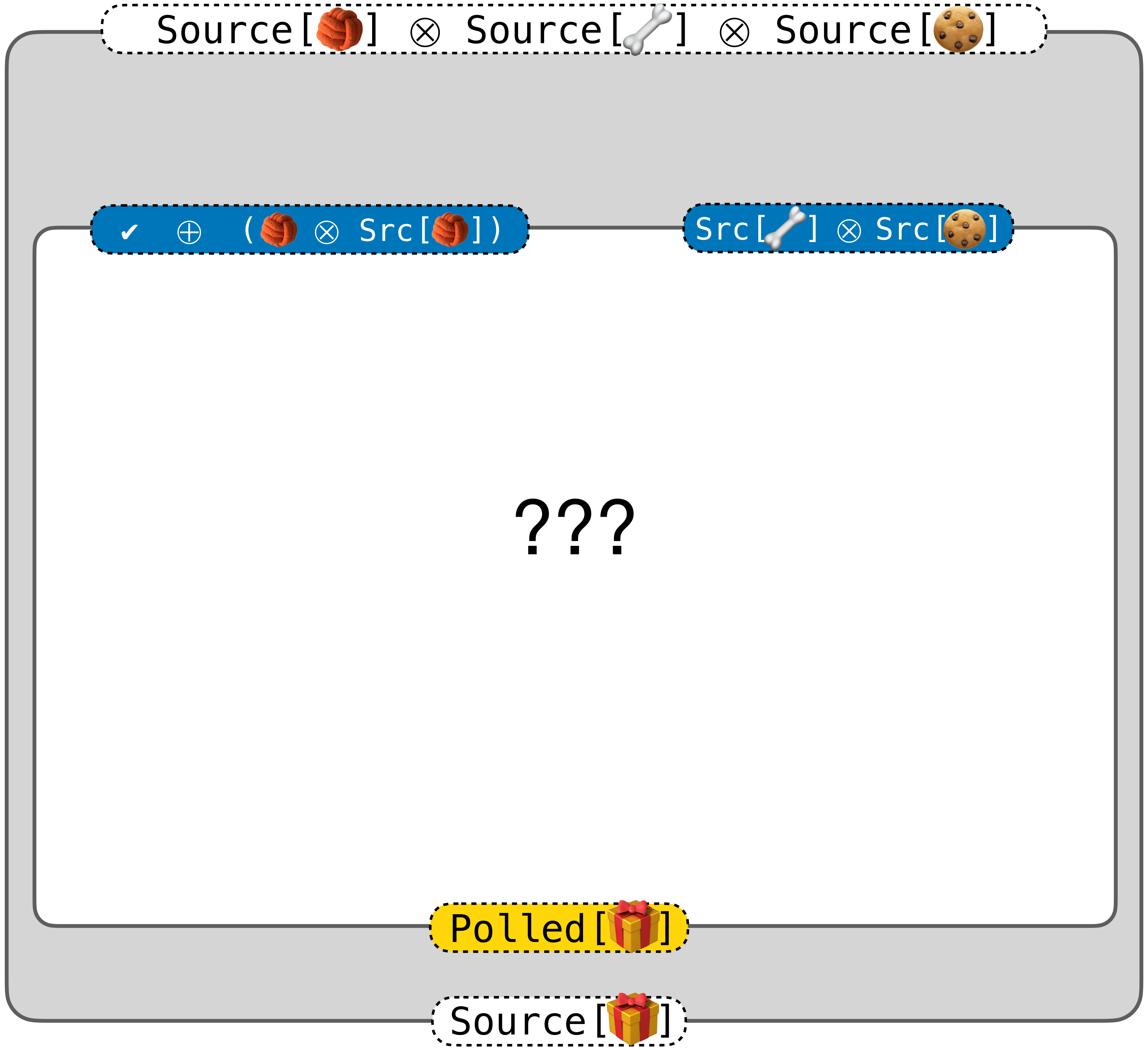
???

Polled[🎁]

Source[🎁]

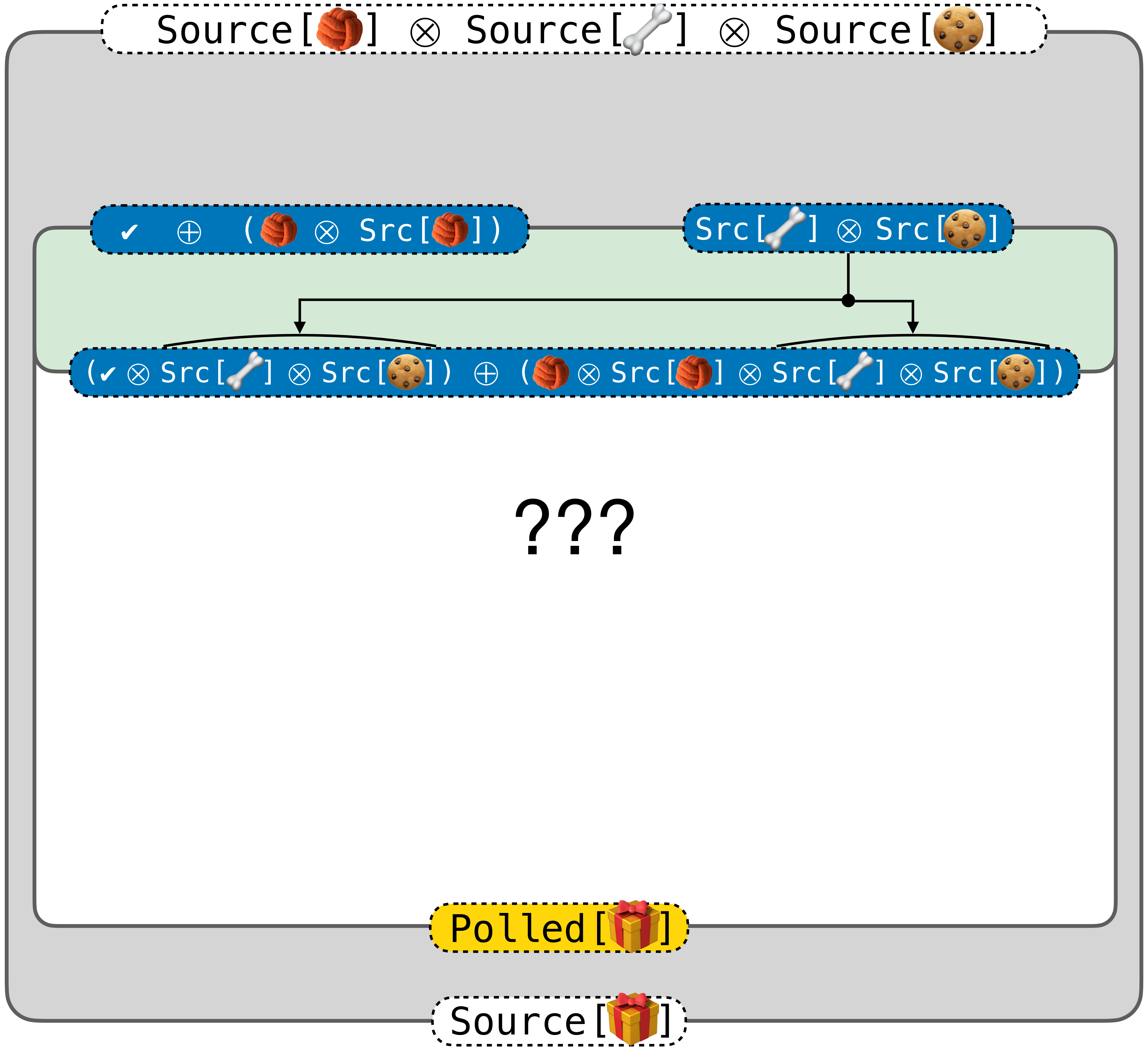
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	✔ ⊕ (A ⊗ Source[A])
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



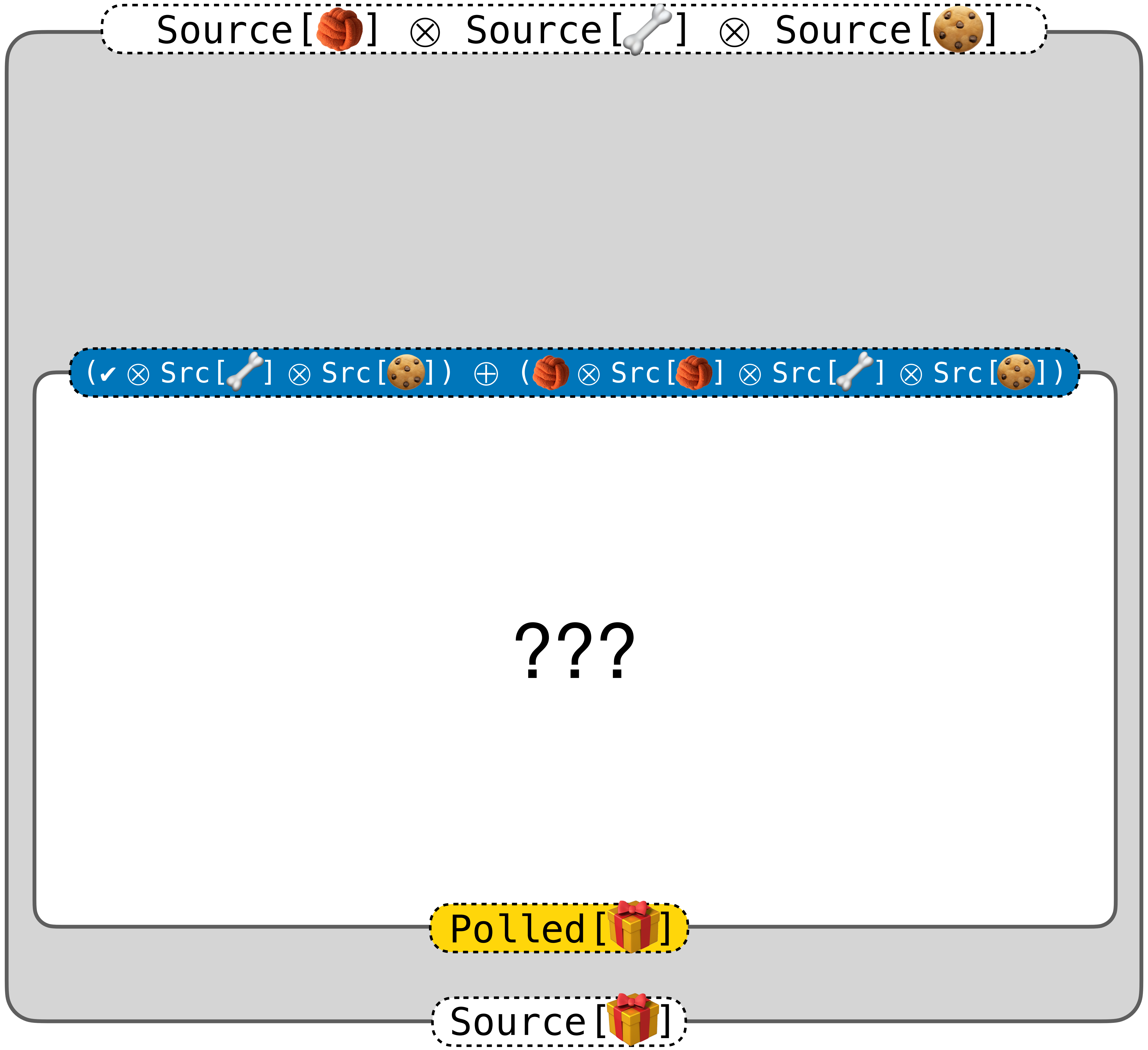
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
✔ ⊕ (🧶 ⊗ Src[🧶])
Src[🦴] ⊗ Src[🍪]
(✔ ⊗ Src[🦴] ⊗ Src[🍪]) ⊕ (🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪])
???
Polled[🎁]
Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



`Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]`

`(✔ ⊗ Src[🦴] ⊗ Src[🍪]) ⊕ (🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪])`

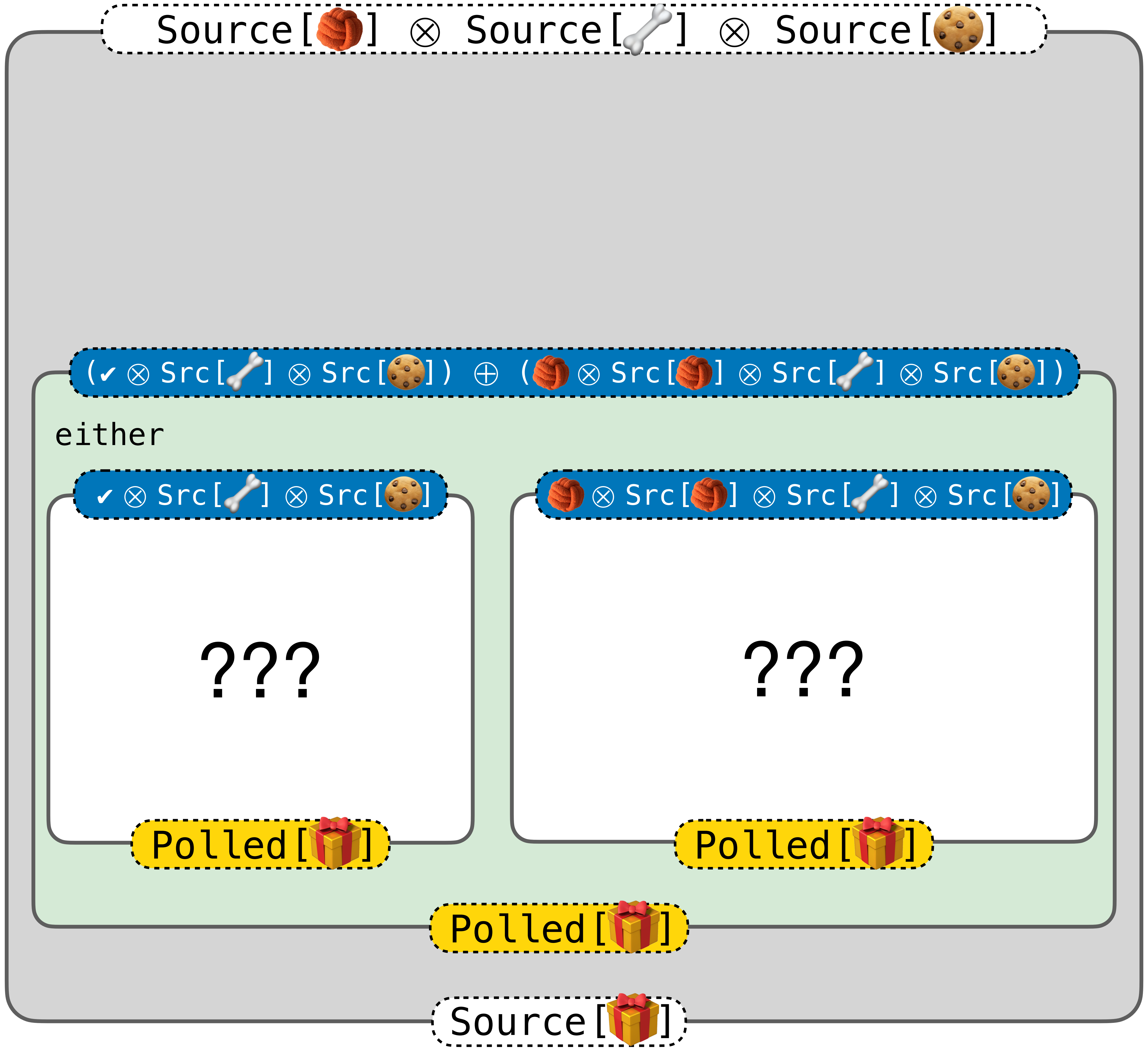
???

`Polled[🎁]`

`Source[🎁]`

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	`Done` signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

(✔ ⊗ Src[🦴] ⊗ Src[🍪]) ⊕ (🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪])

either

✔ ⊗ Src[🦴] ⊗ Src[🍪]

🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

???

???

Polled[🎁]

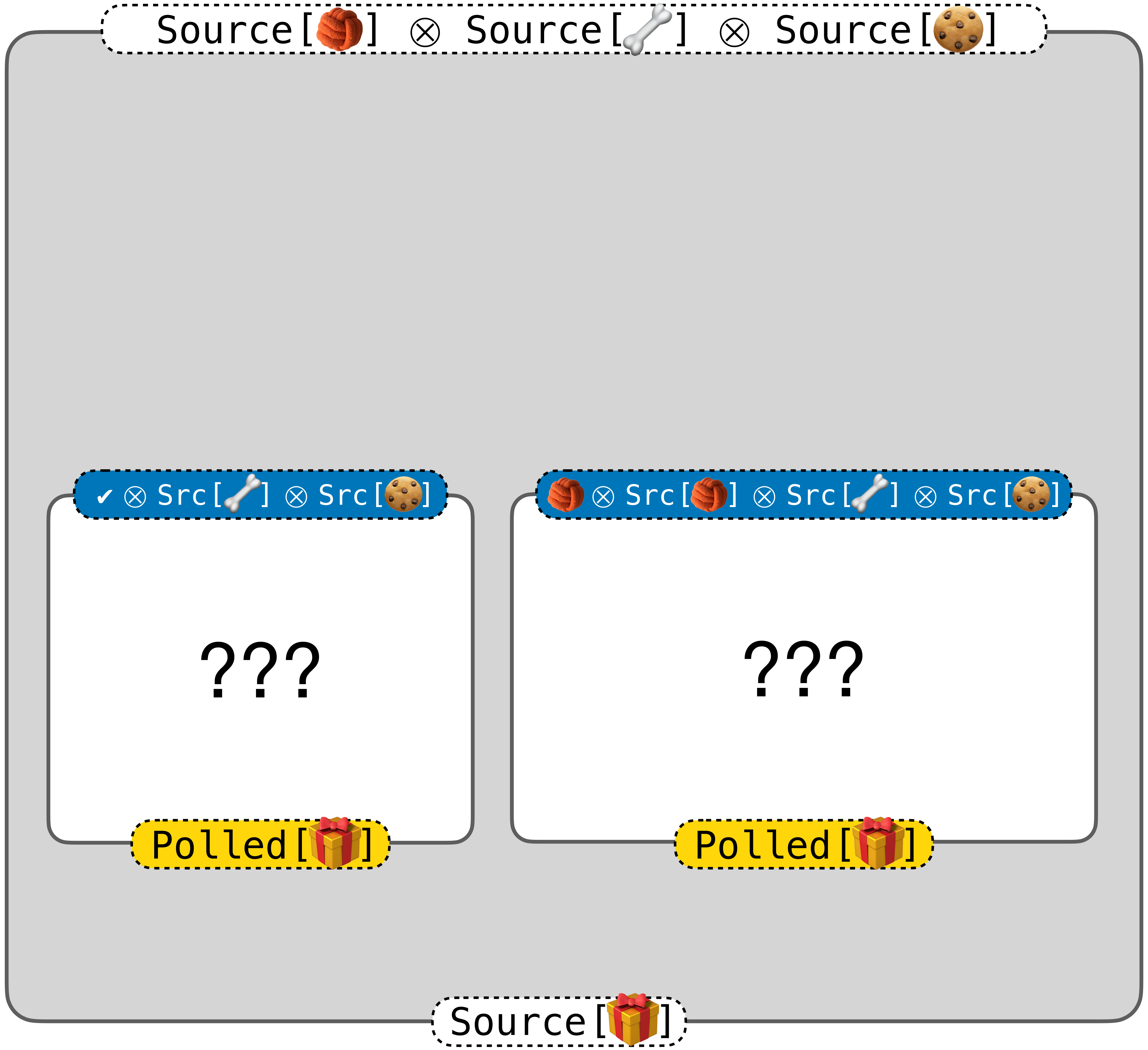
Polled[🎁]

Polled[🎁]

Source[🎁]

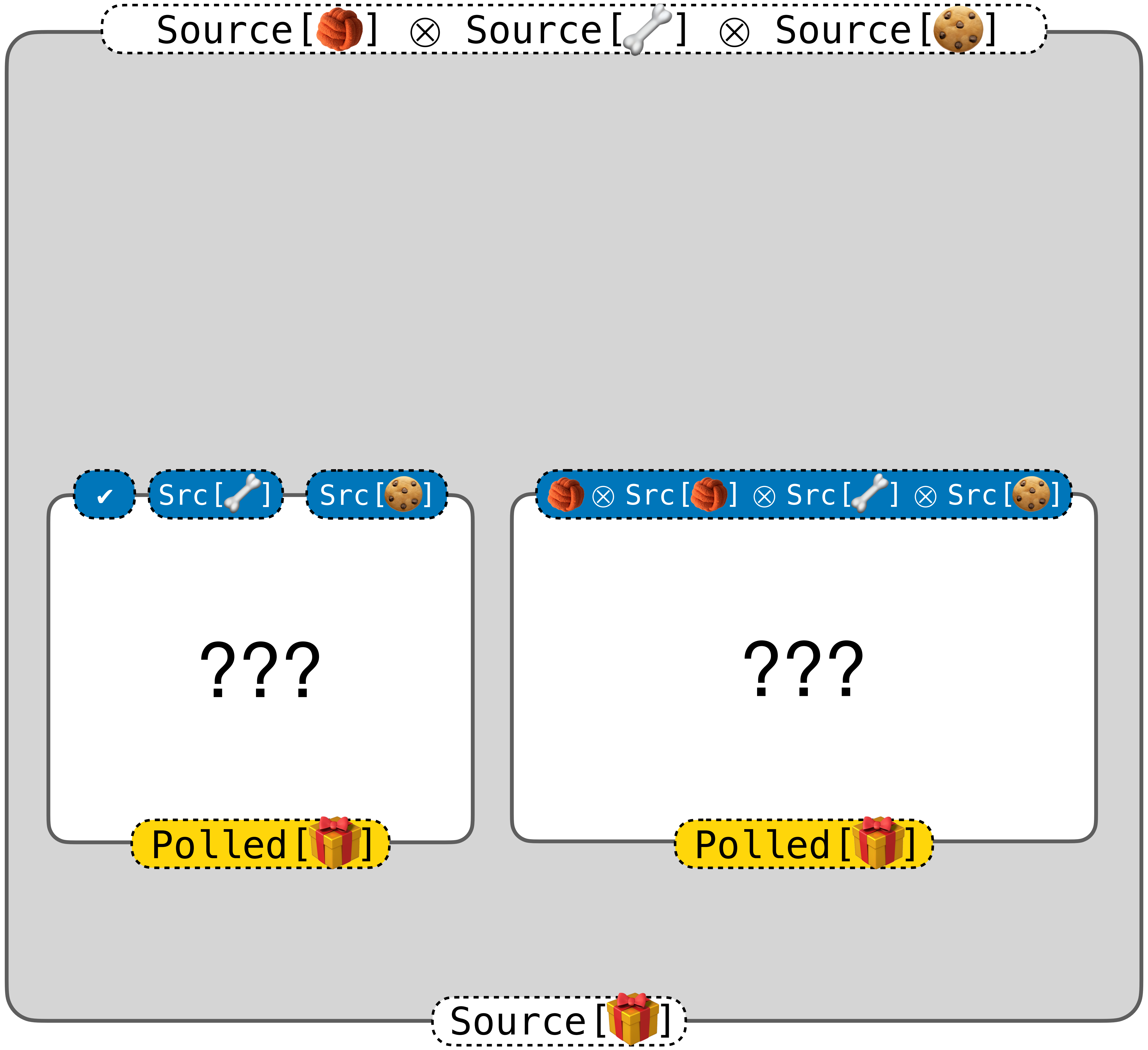
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
✔ ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

✔ Src[🦴] Src[🍪]

???

Polled[🎁]

🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

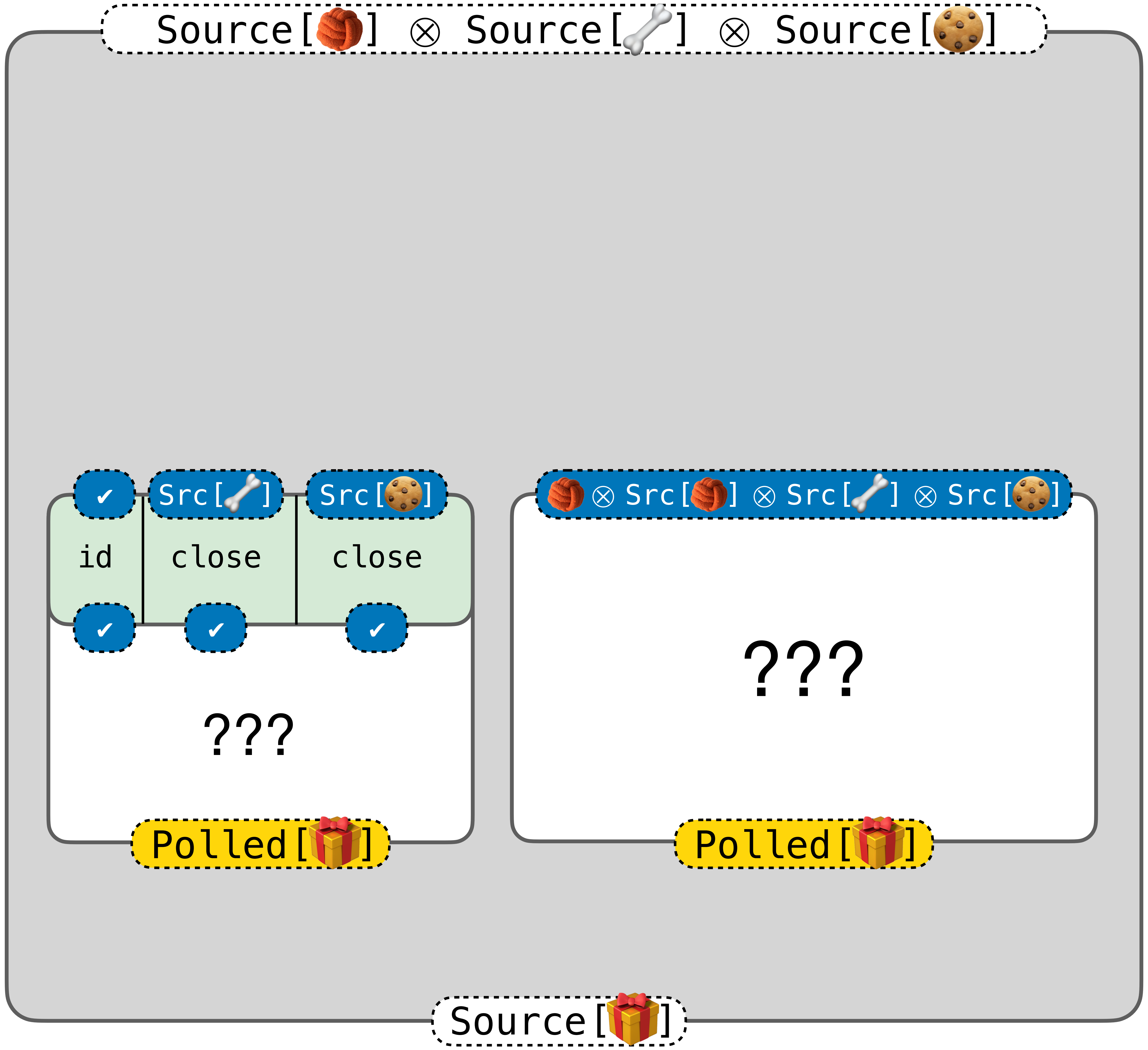
???

Polled[🎁]

Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

✓ Src[🦴] Src[🍪]

id close close

✓ ✓ ✓

???

Polled[🎁]

🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

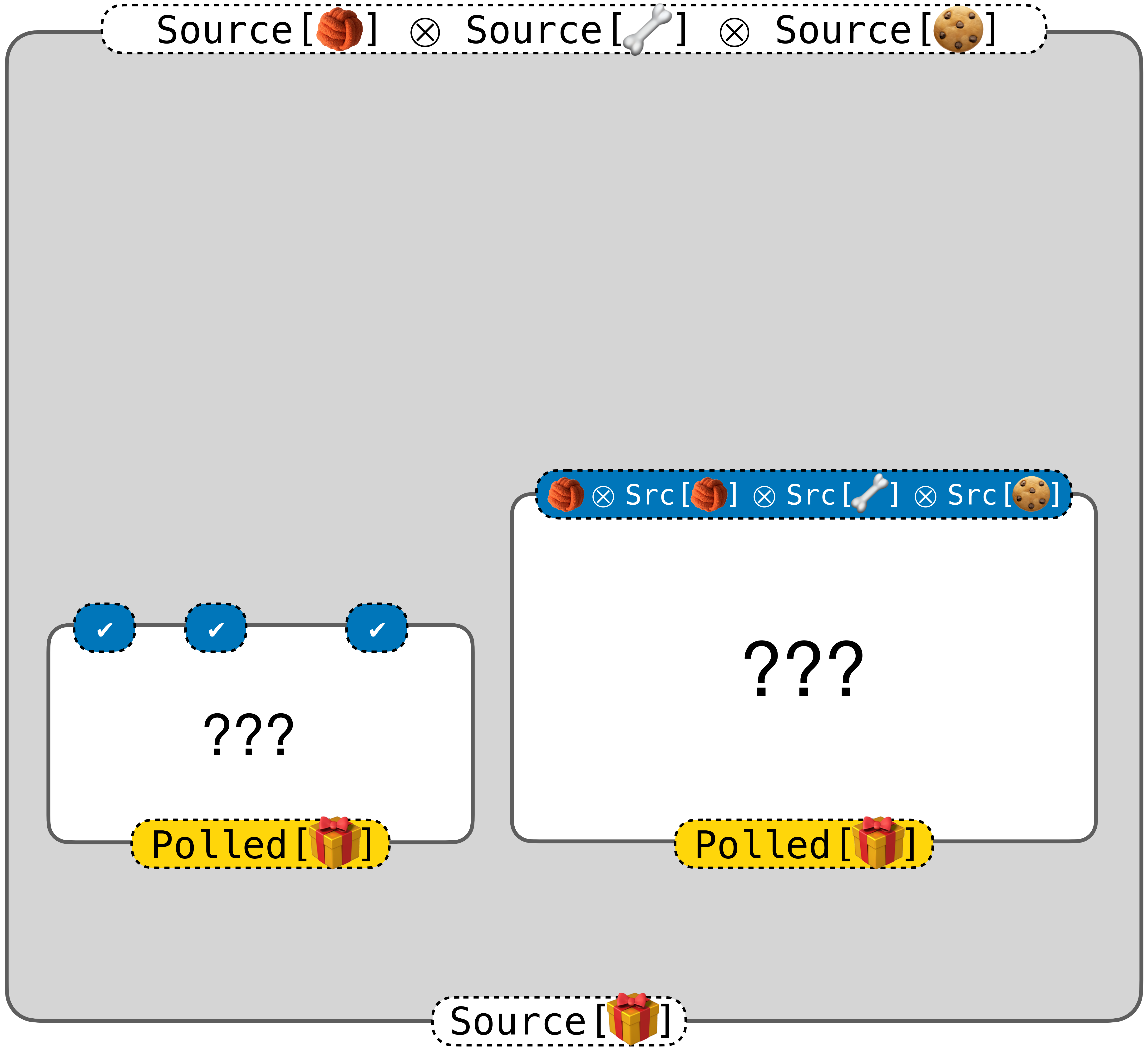
???

Polled[🎁]

Source[🎁]

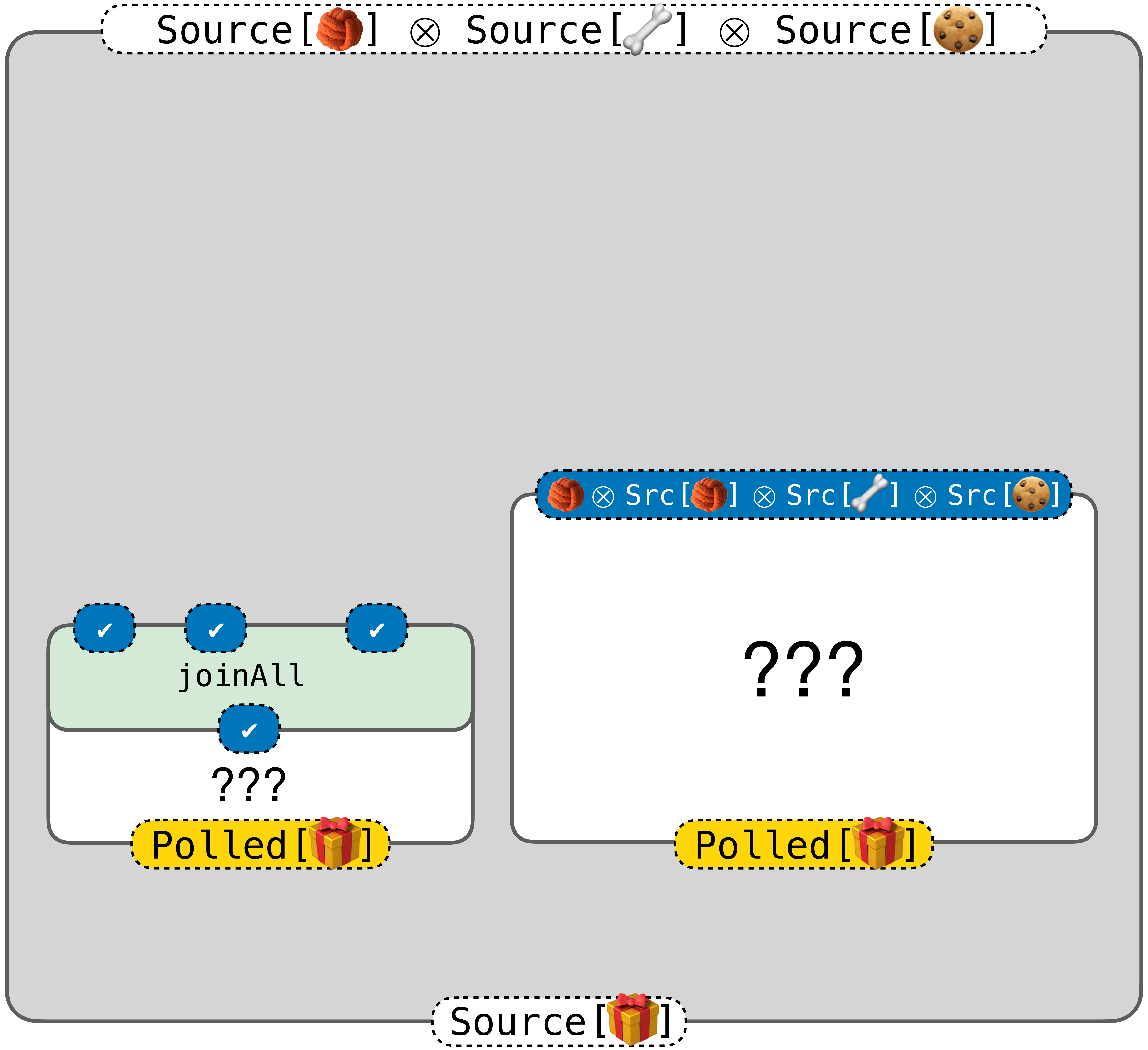
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✓	Done signal	
`Polled[A]`	requested next elem	`✓ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
✓
✓
✓
???
Polled[🎁]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
Source[🎁]

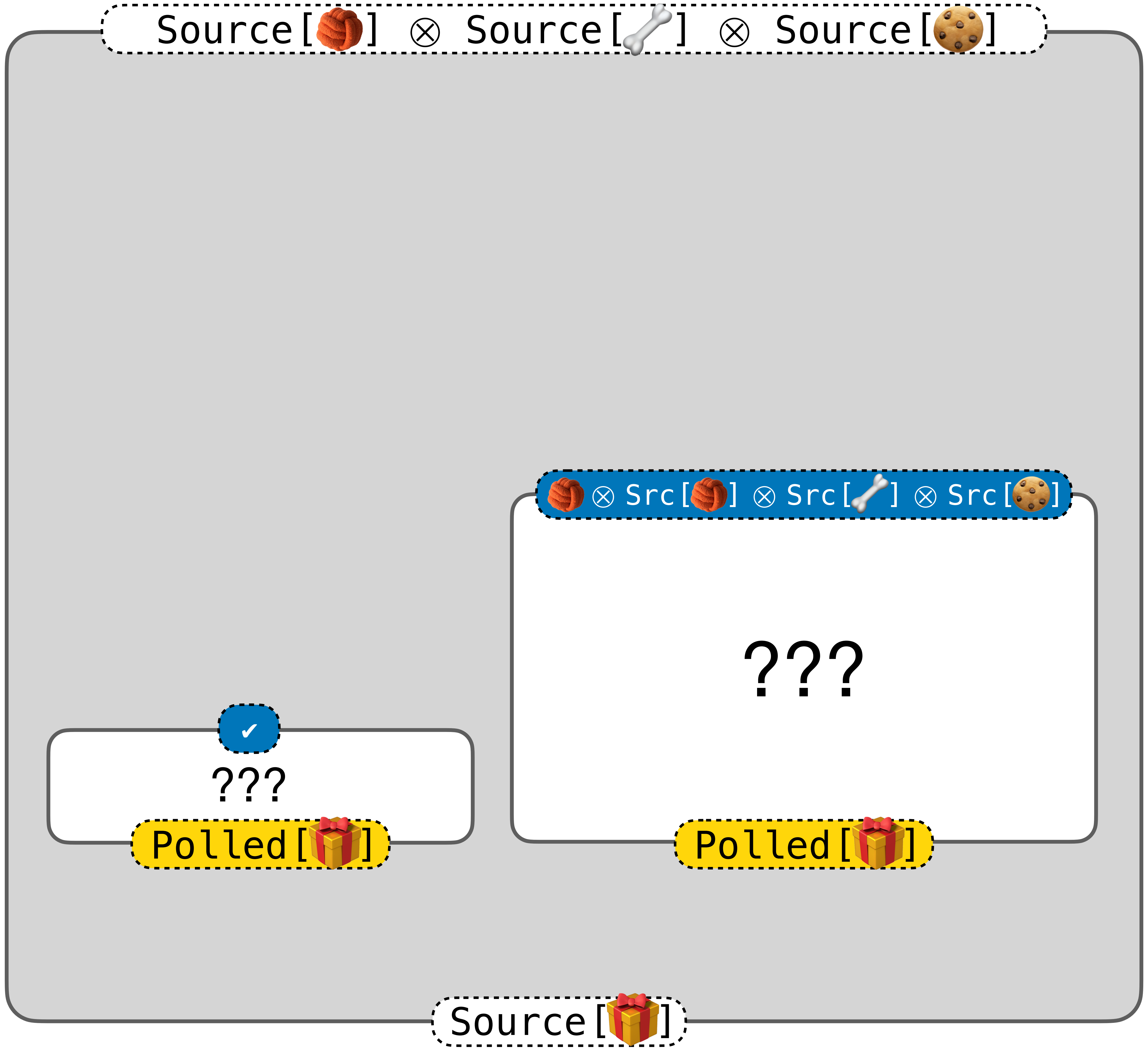
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
✔
✔
✔
joinAll
✔
???
Polled[🎁]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
Source[🎁]

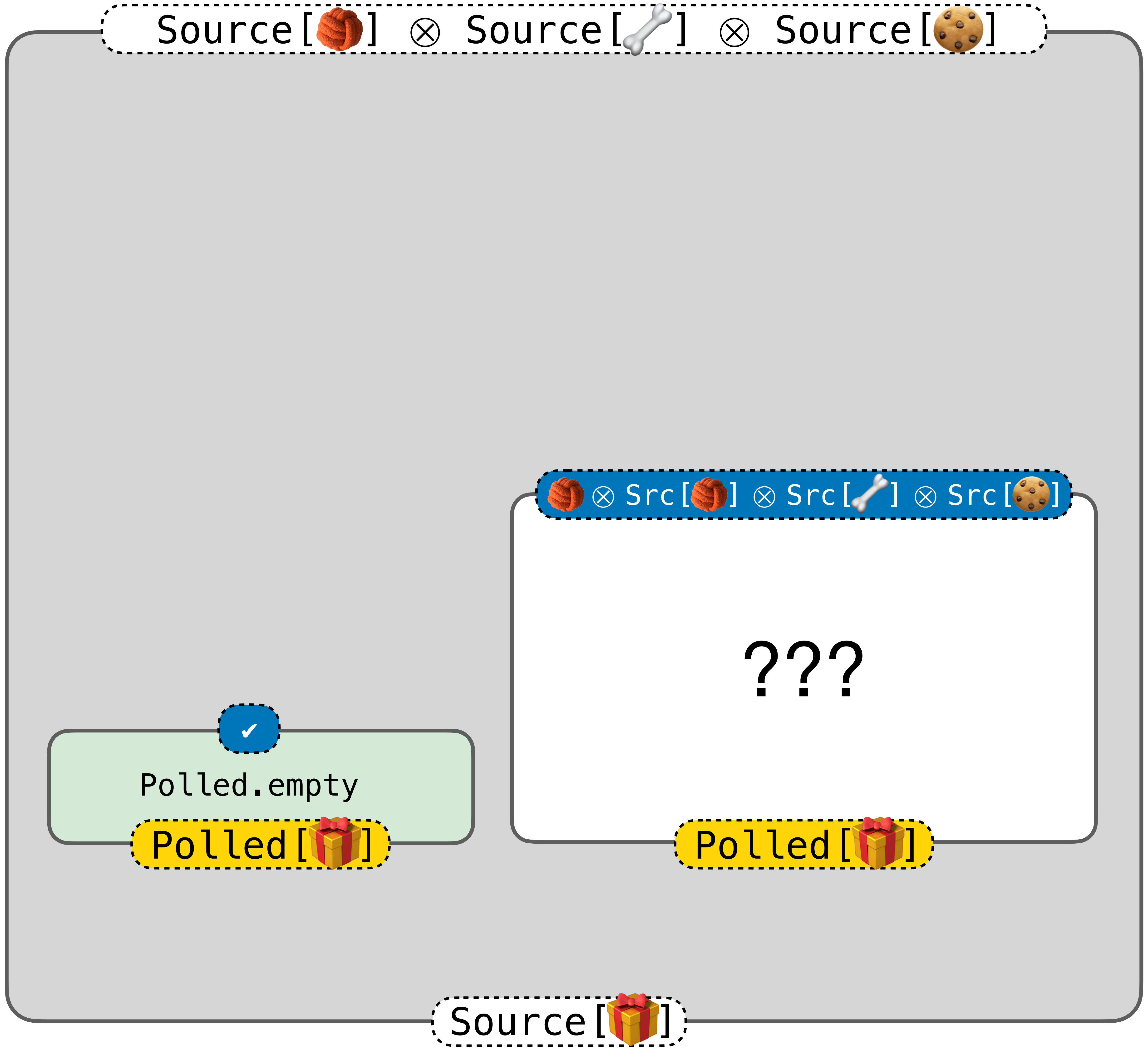
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
✔
???
Polled[🎁]
Polled[🎁]
Source[🎁]

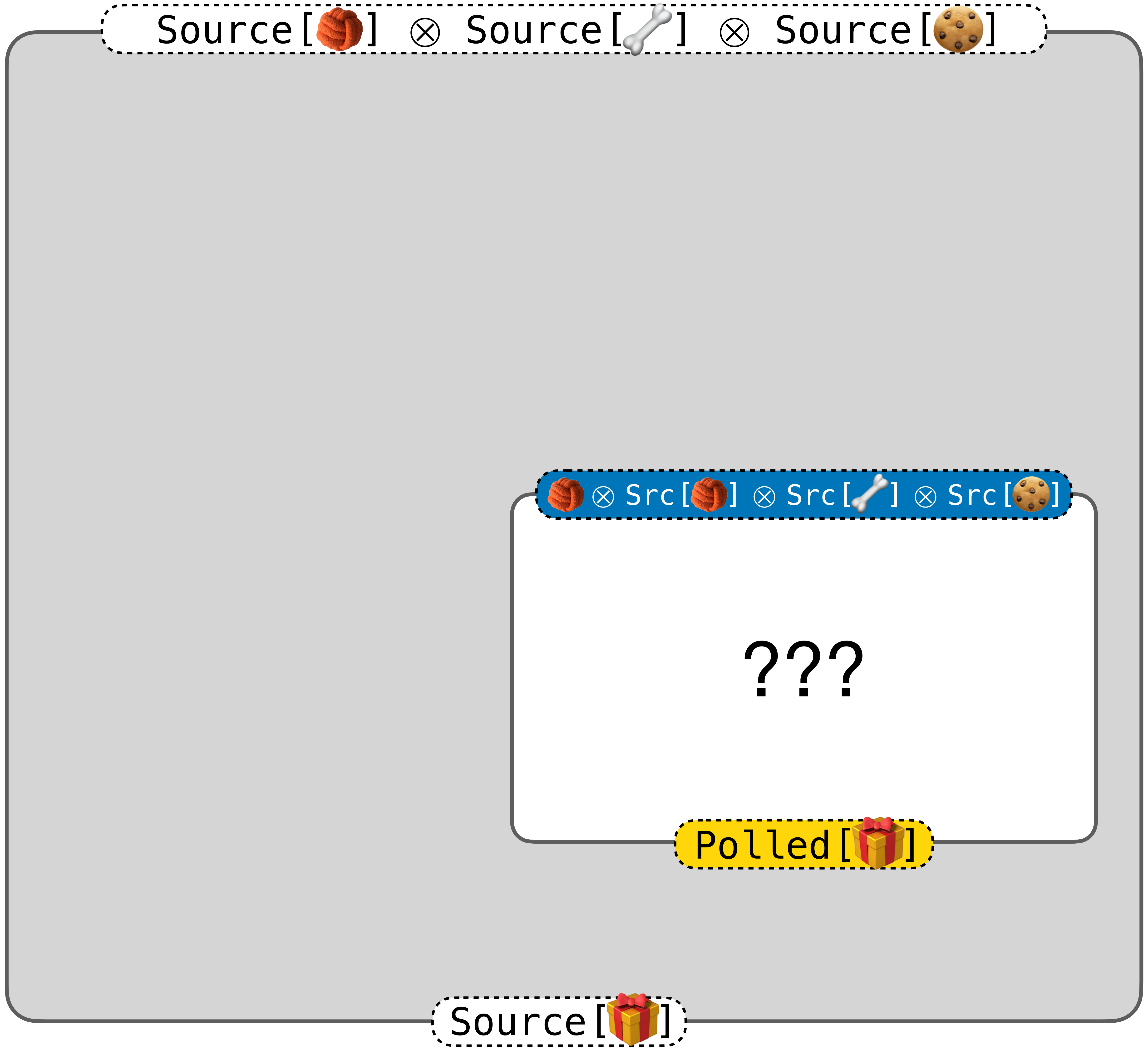
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	

Packaging Dog Presents


Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
✓
Polled.empty
Polled[🎁]
Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	✔ ⊕ (A ⊗ Source[A])
`Src[A]`	abbr. Source[A]	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

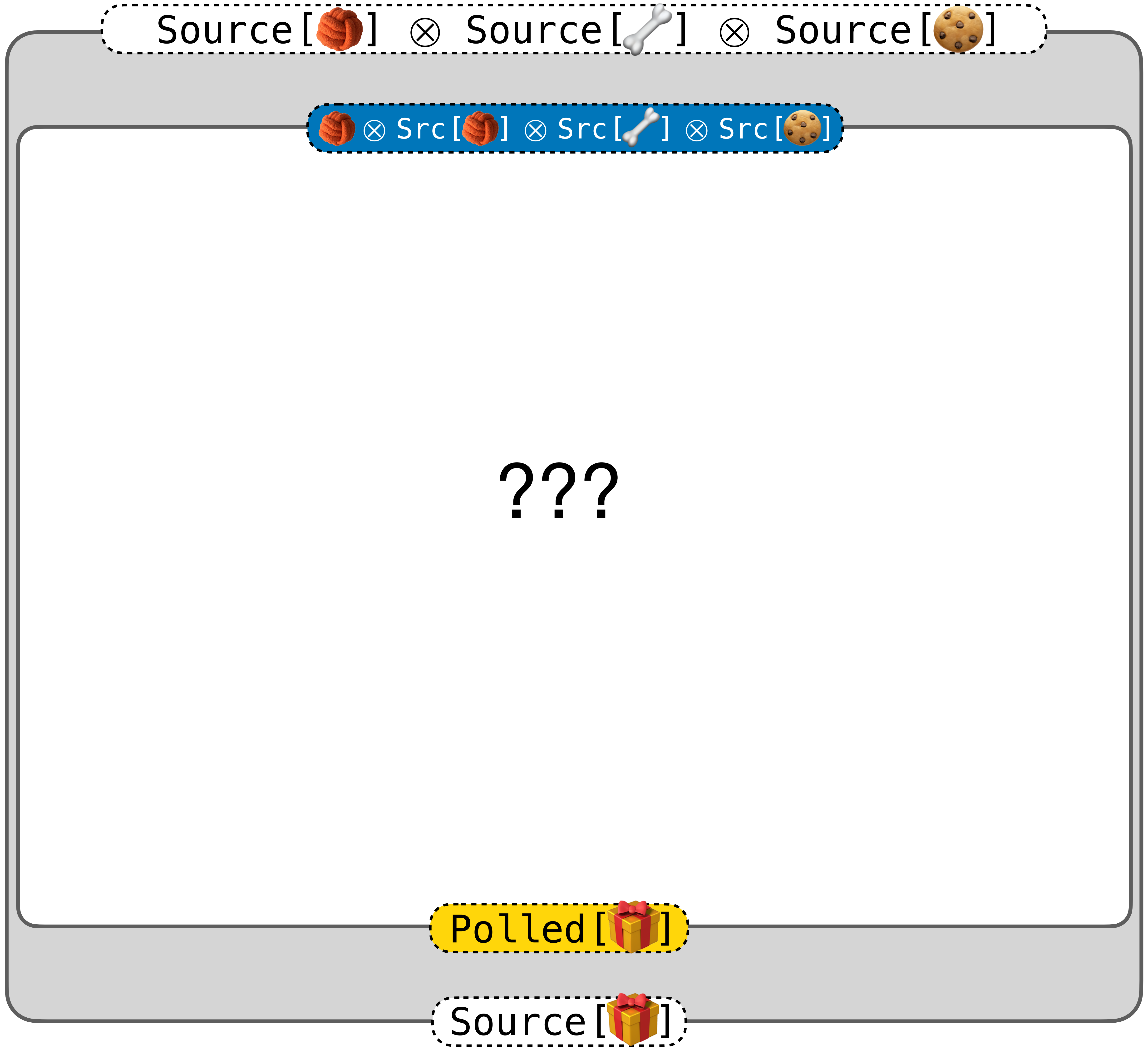
???

Polled[🎁]

Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

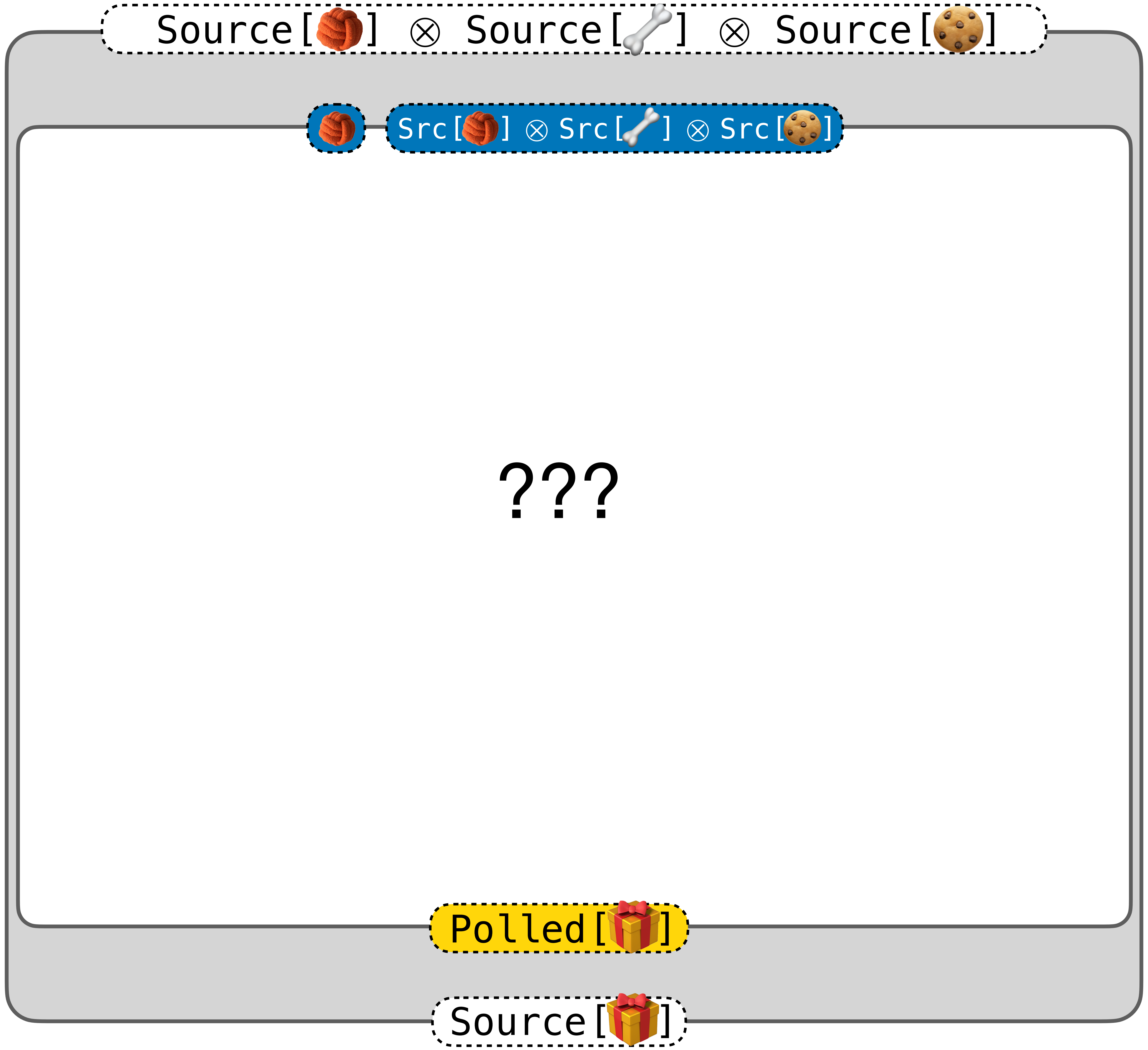
Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]
🧶 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]
???
Polled[🎁]
Source[🎁]

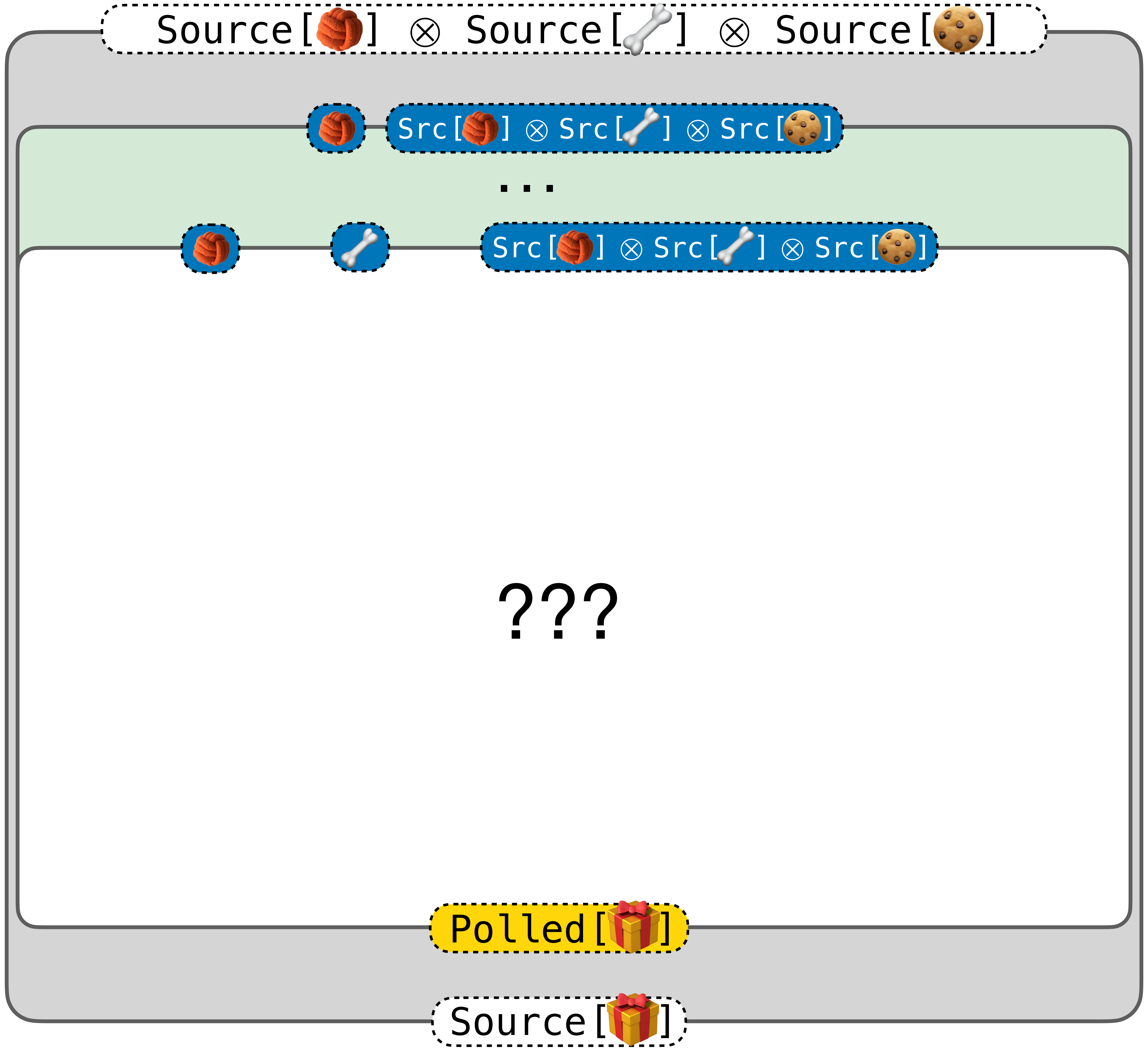
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	✔ ⊕ (A ⊗ Source[A])
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



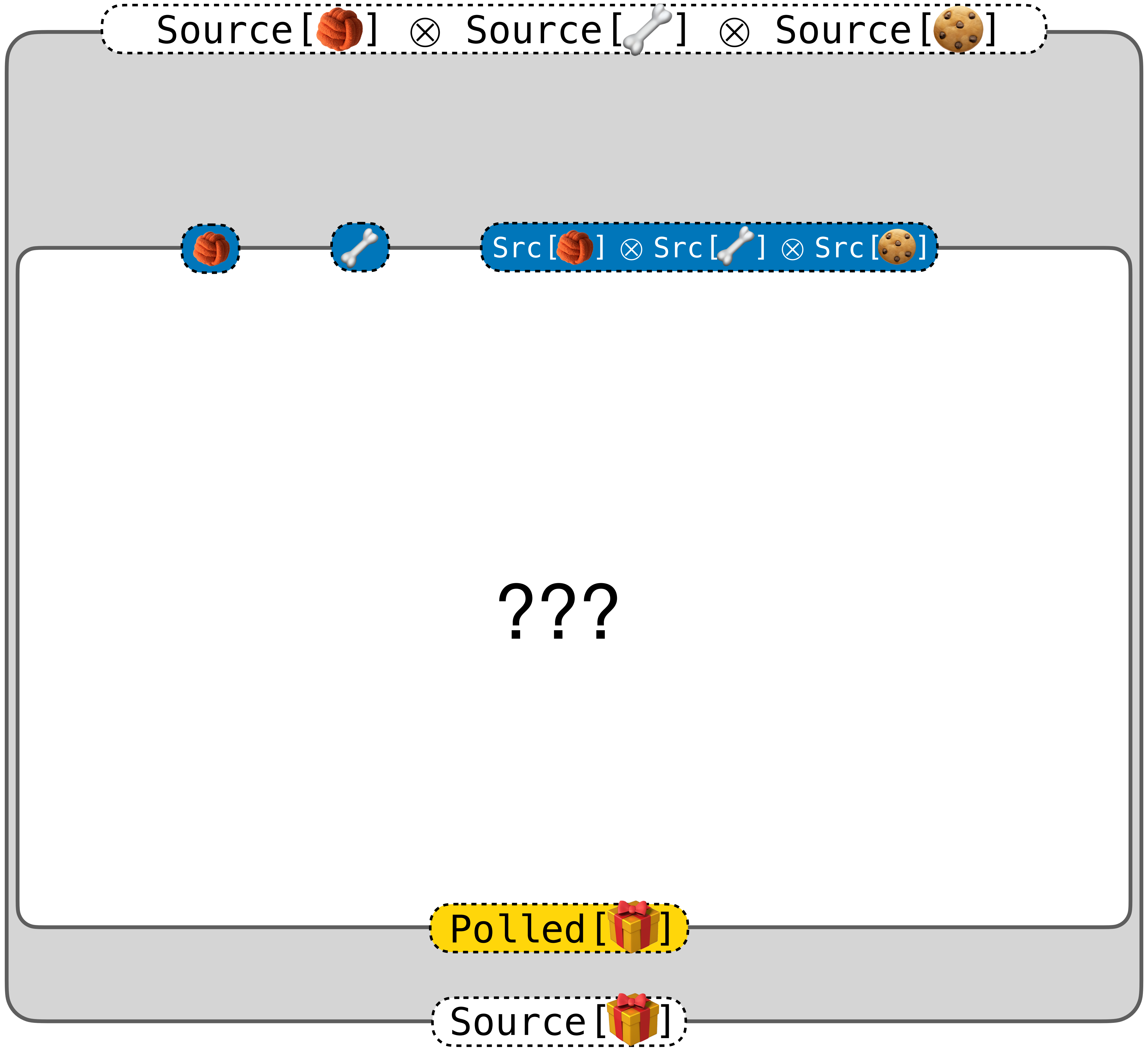
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶

🦴

Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

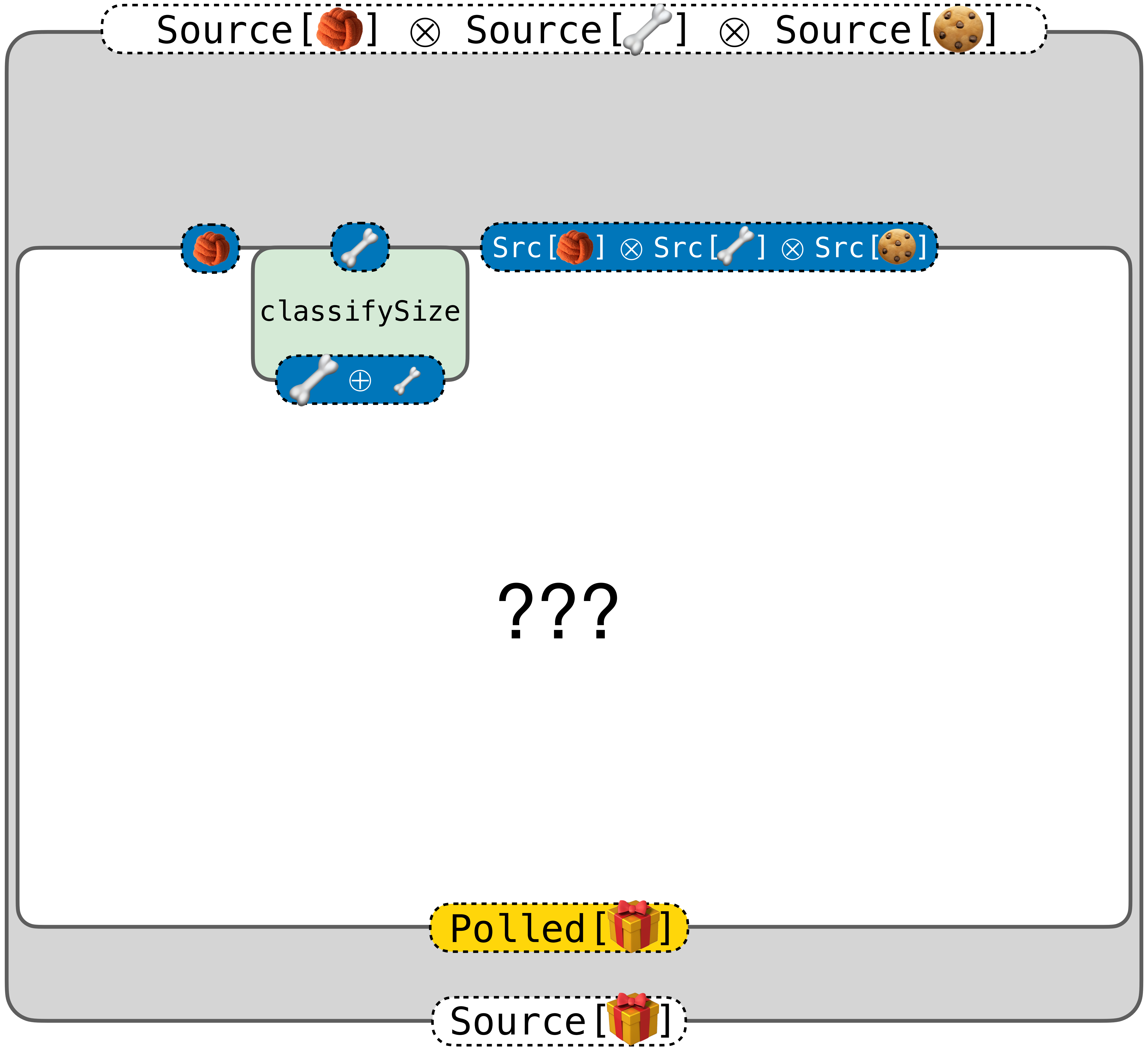
???

Polled[🎁]

Source[🎁]

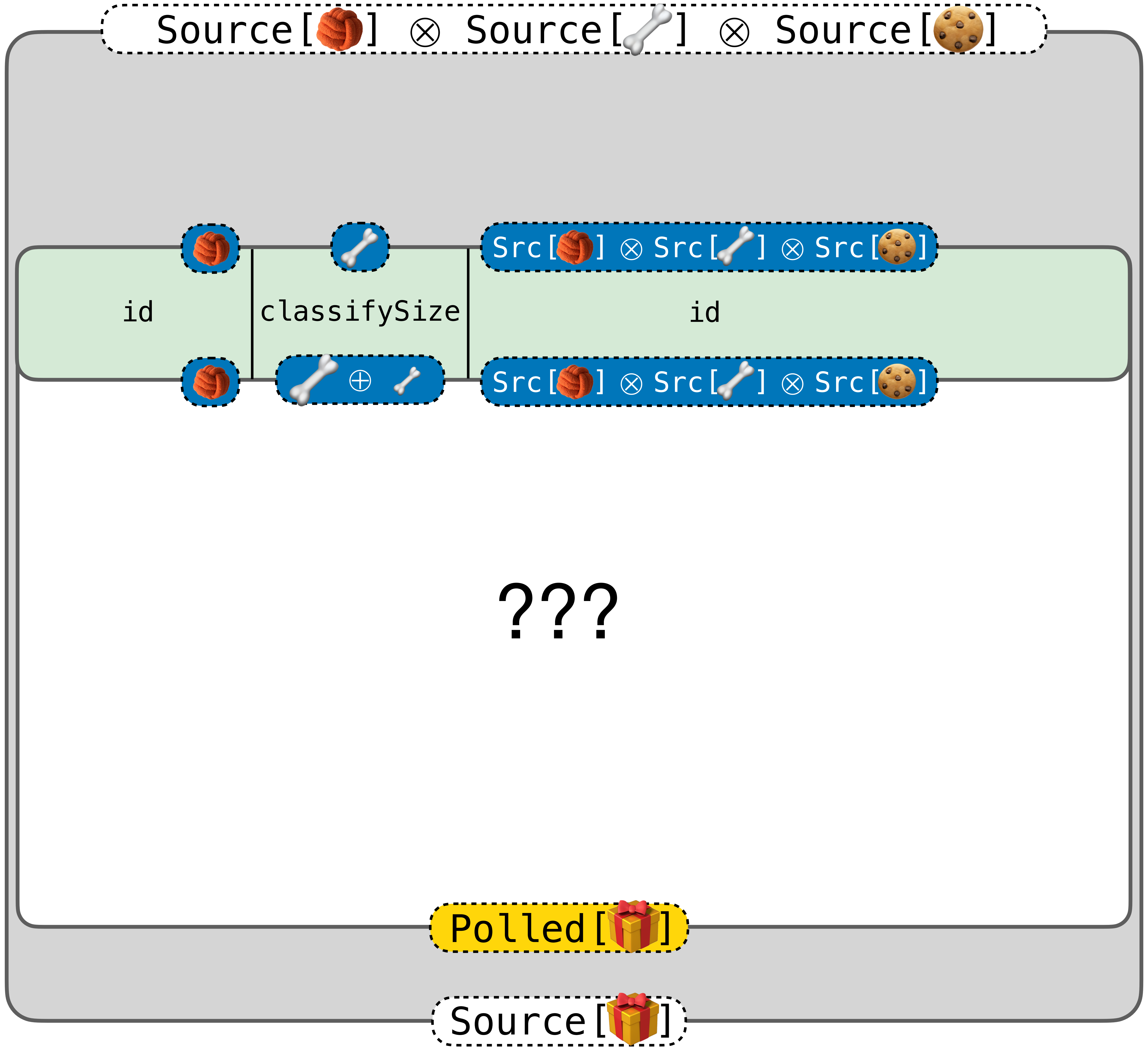
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



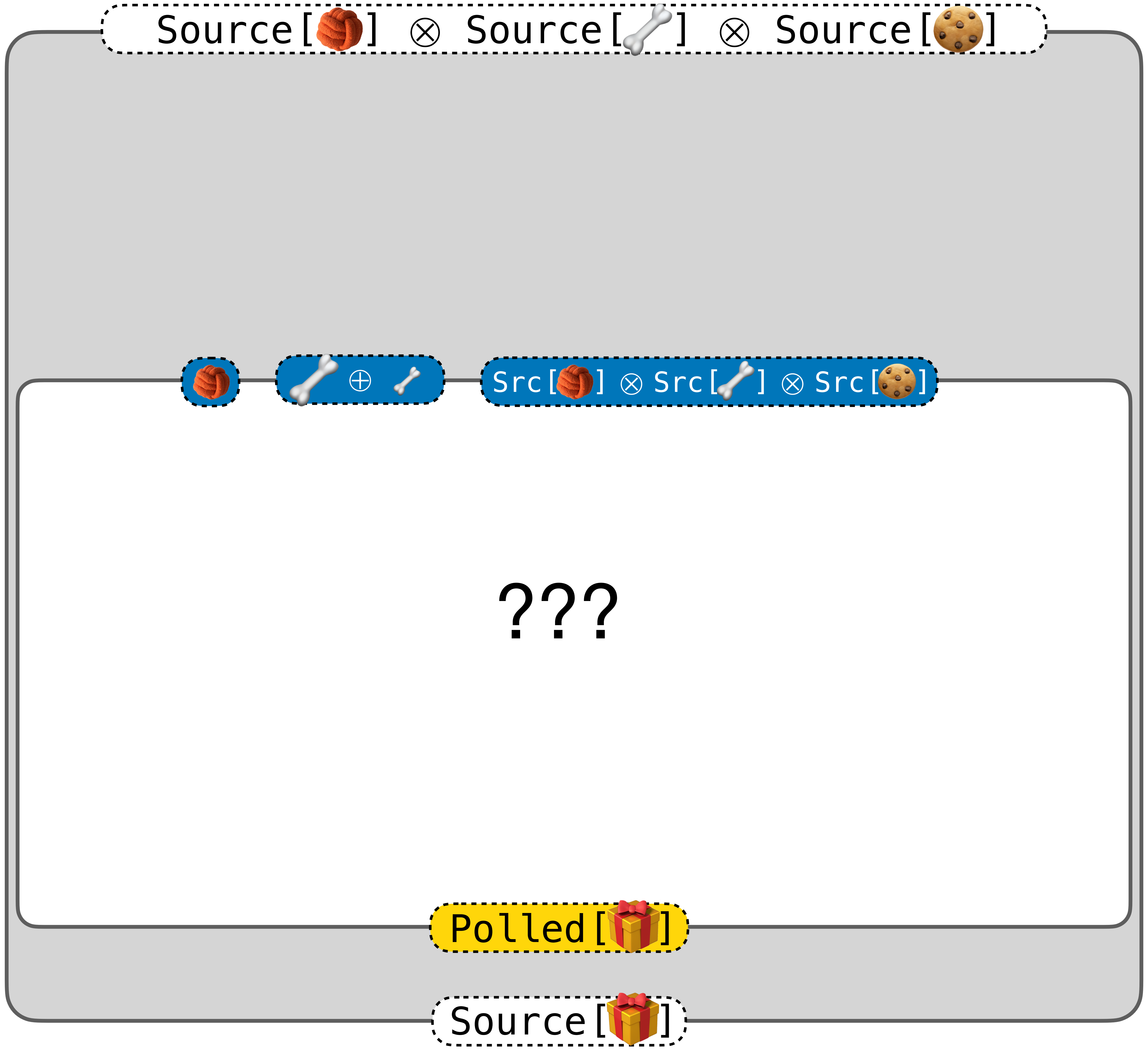
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



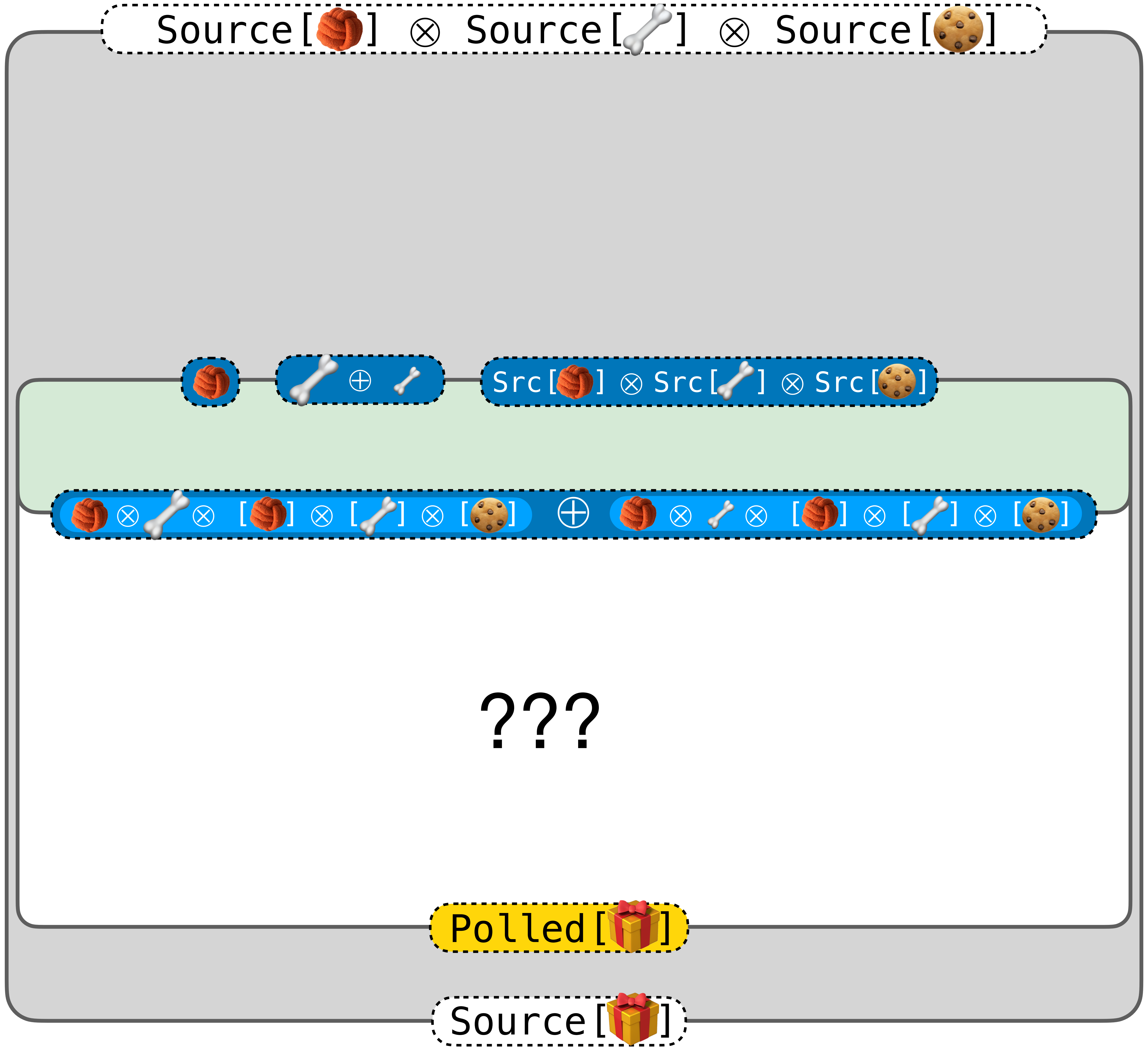
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	

Packaging Dog Presents



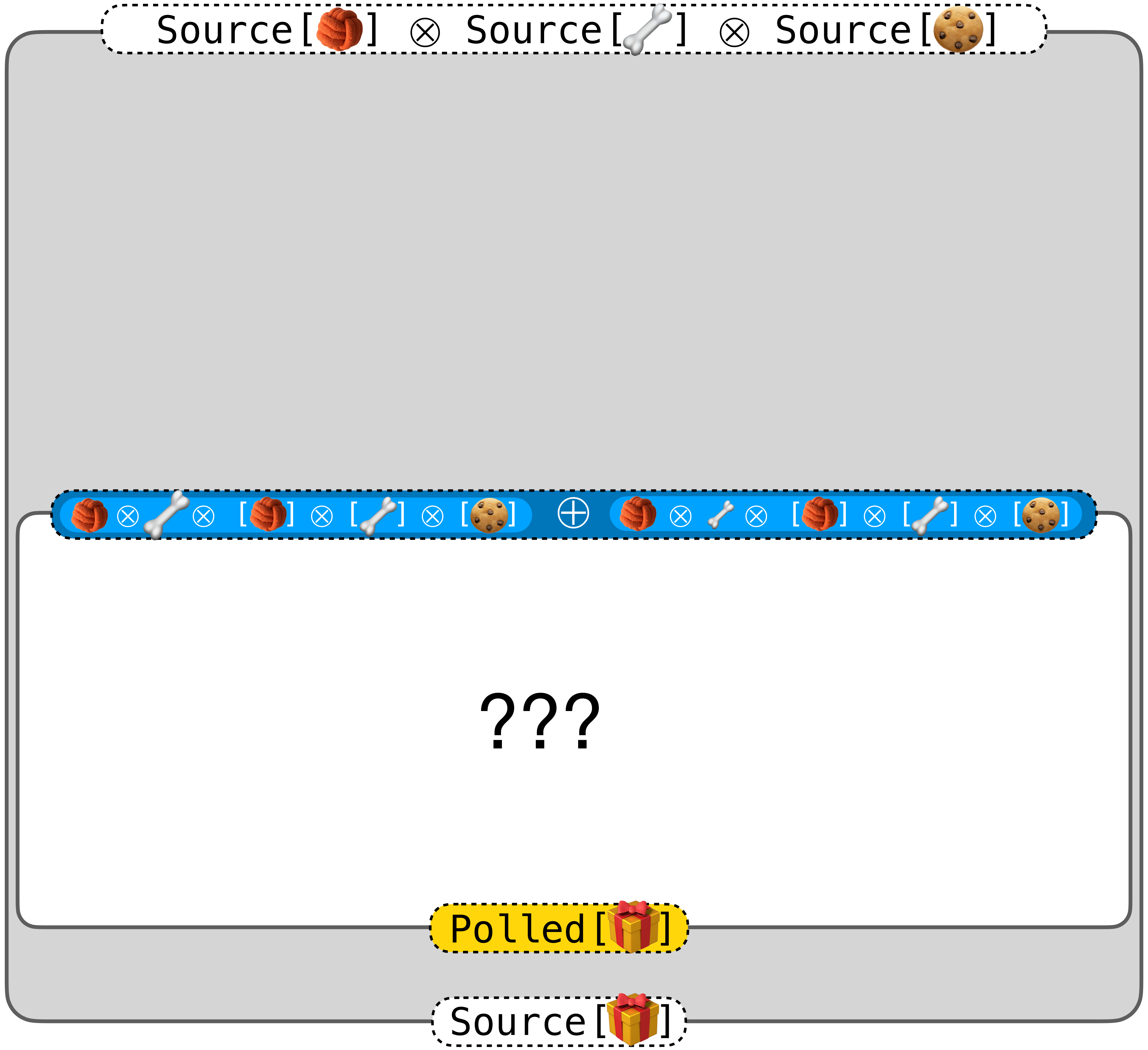
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶 ⊗ 🦴 ⊗ [🧶] ⊗ [🦴] ⊗ [🍪] ⊕ 🧶 ⊗ 🦴 ⊗ [🧶] ⊗ [🦴] ⊗ [🍪]

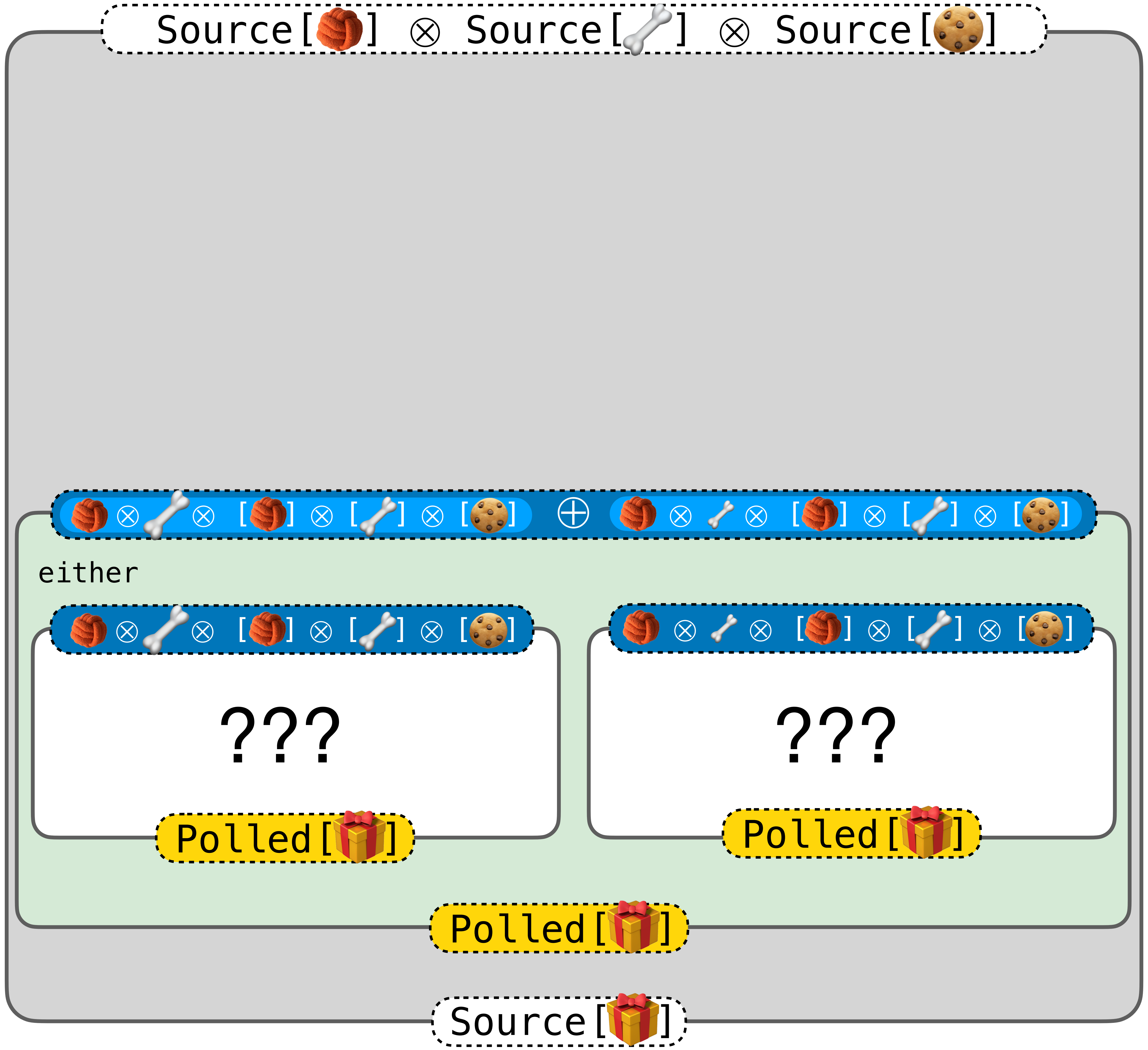
???

Polled[🎁]

Source[🎁]

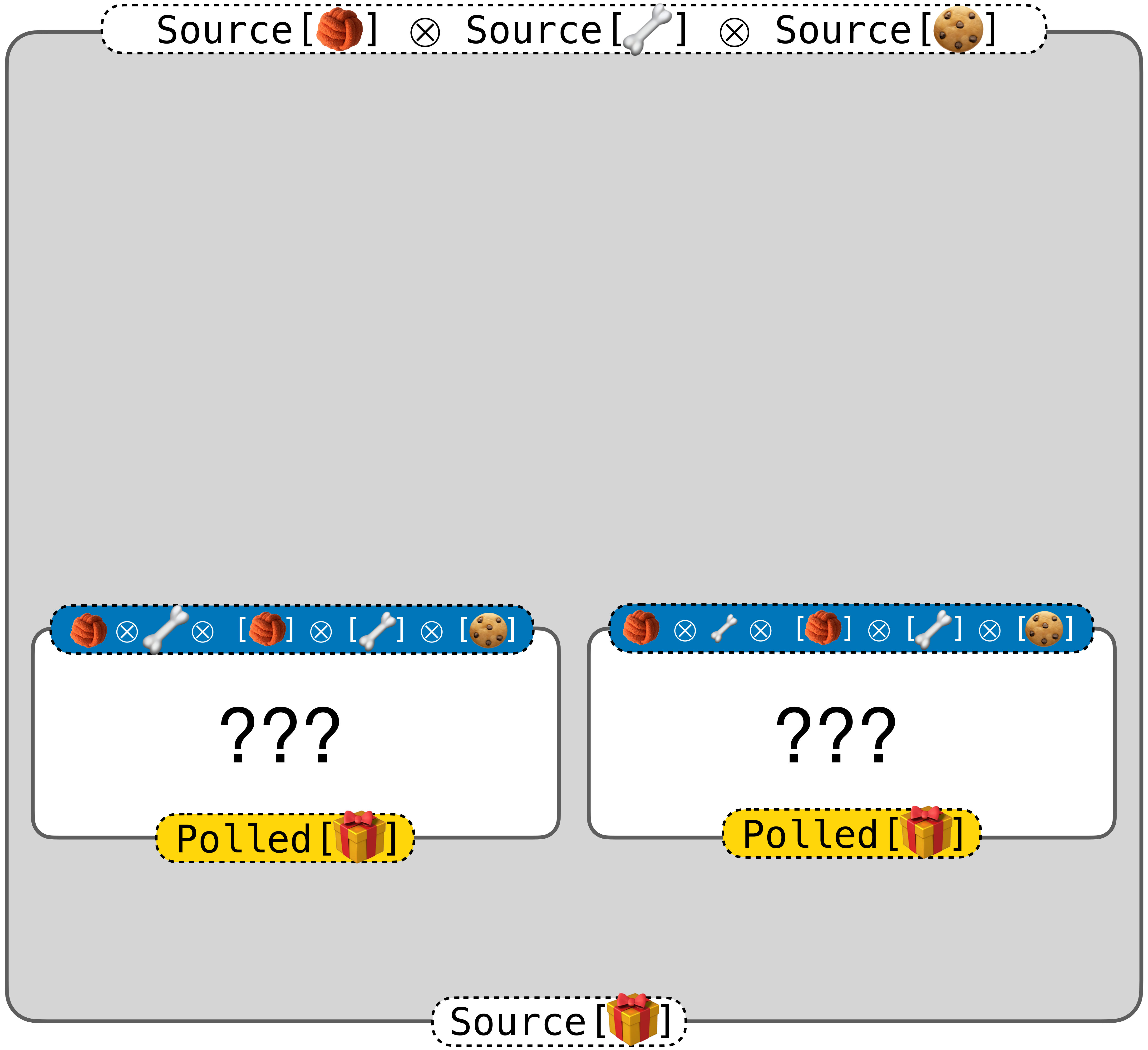
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



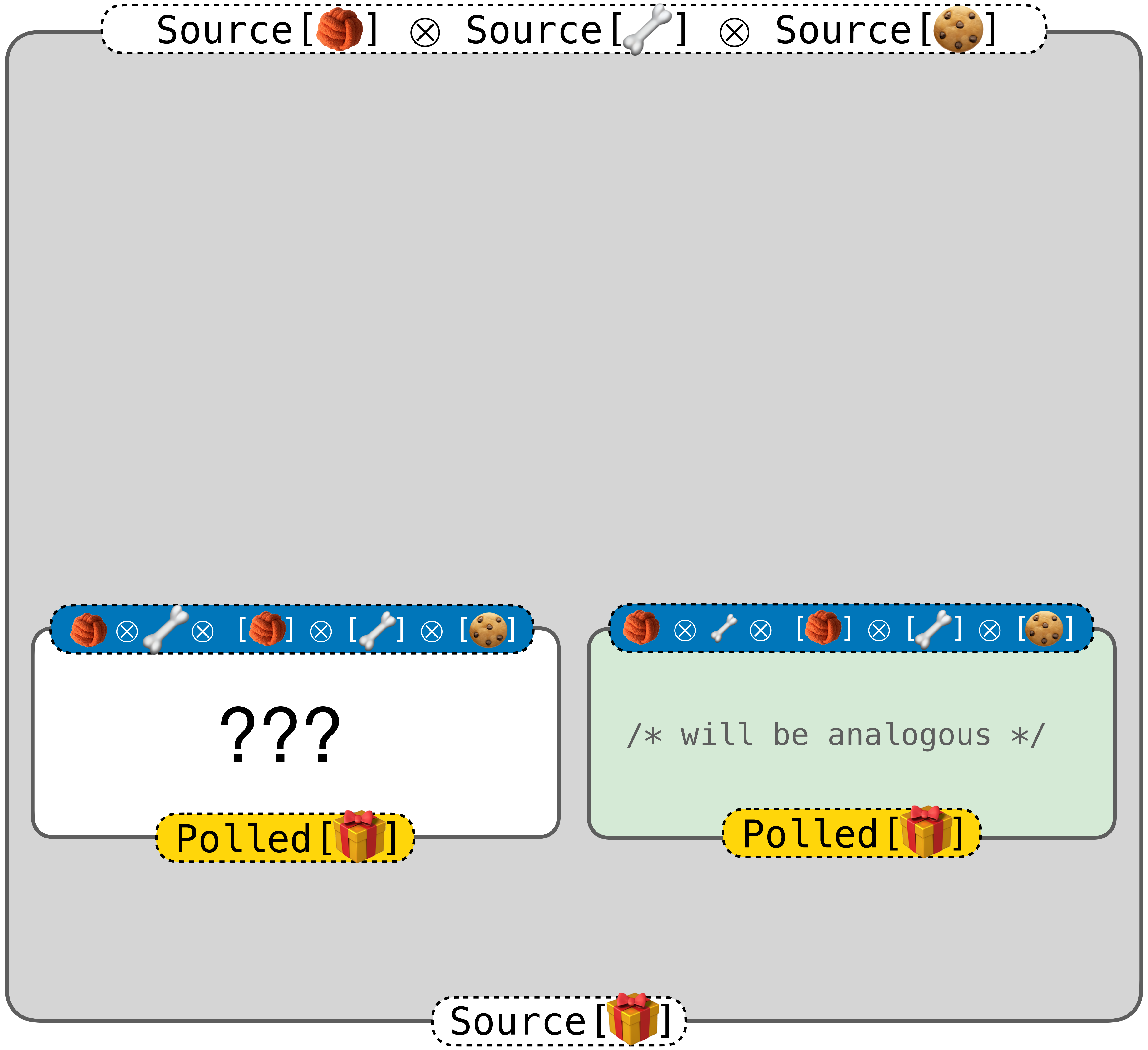
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



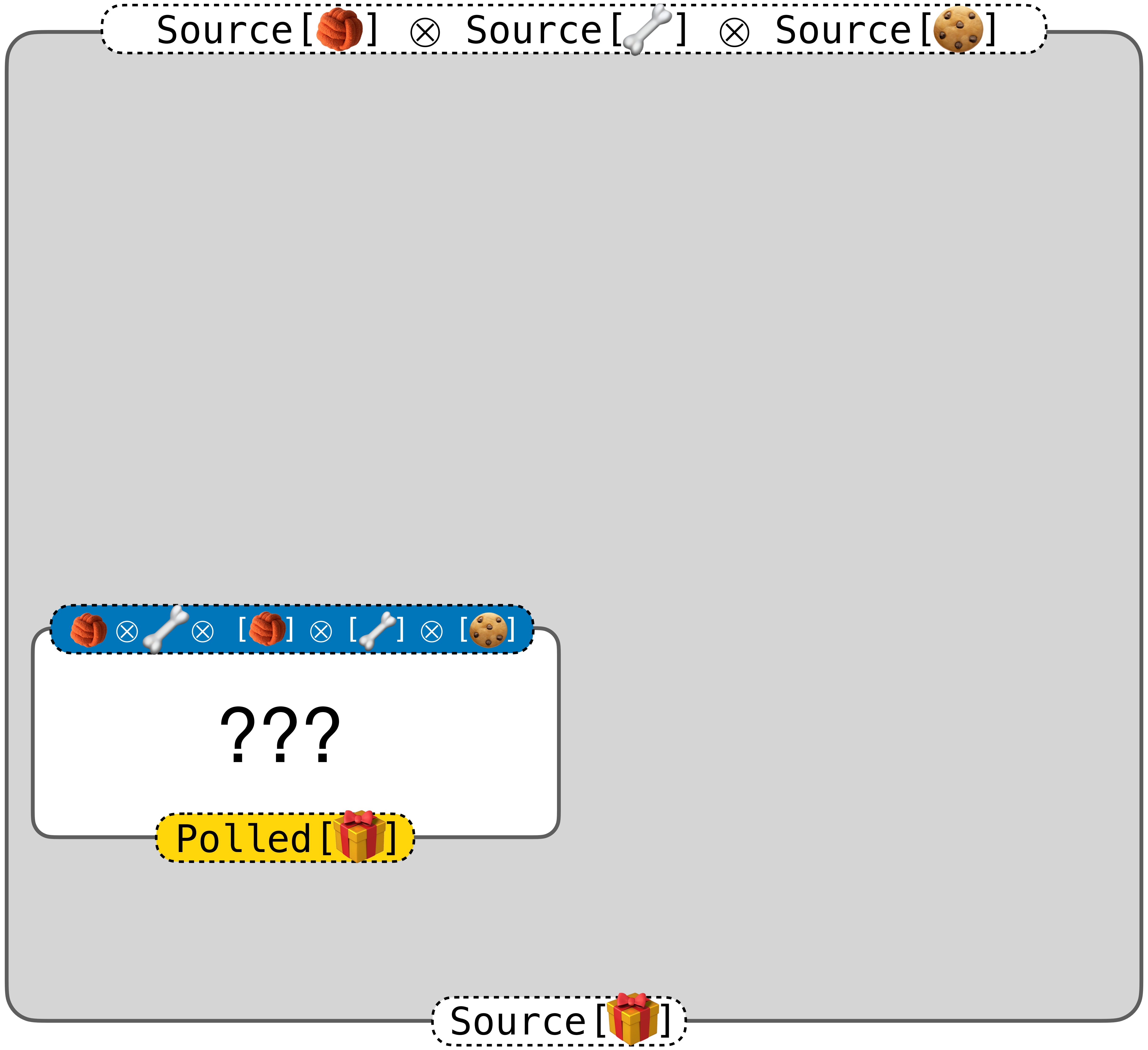
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



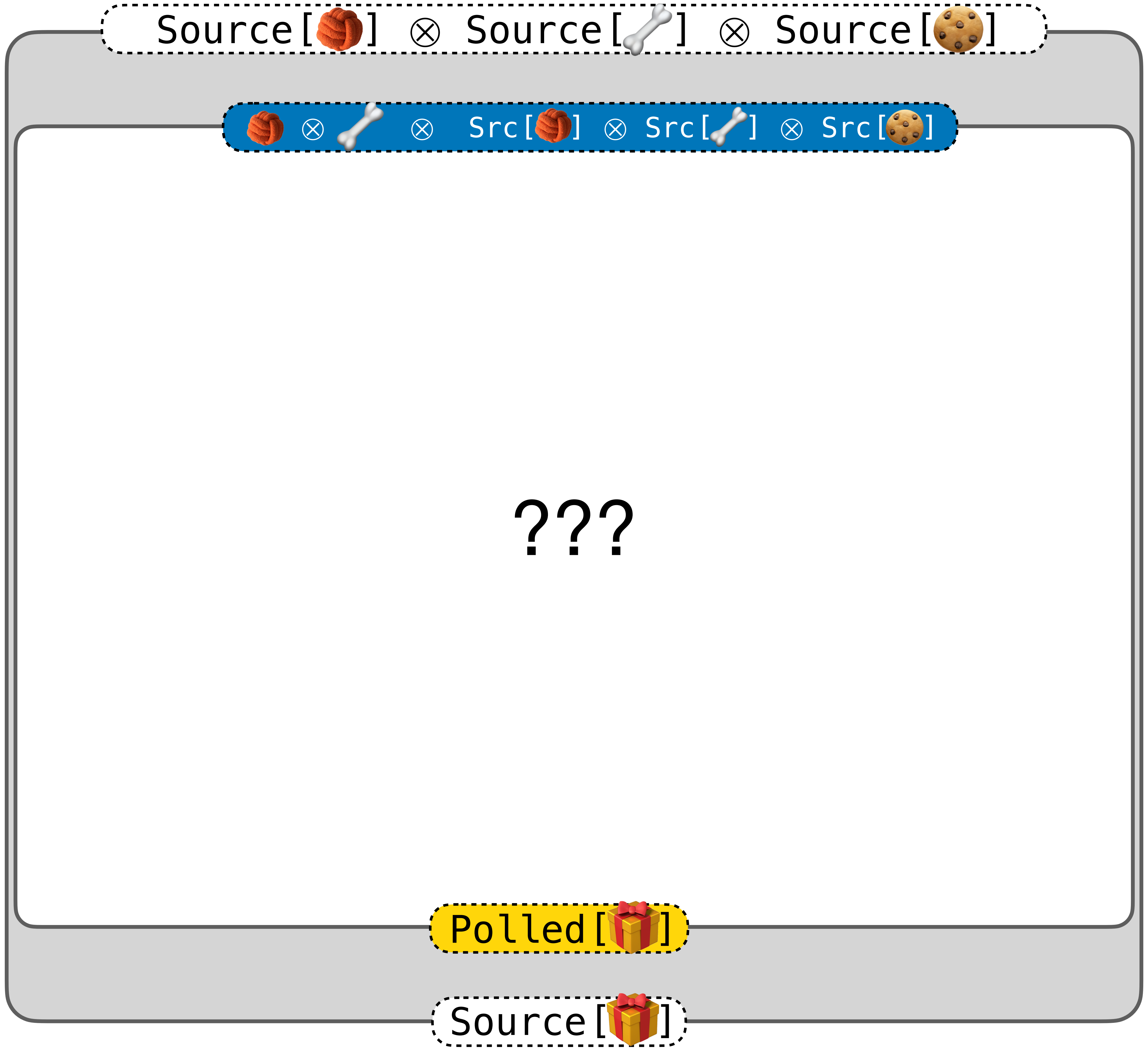
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶 ⊗ 🦴 ⊗ Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

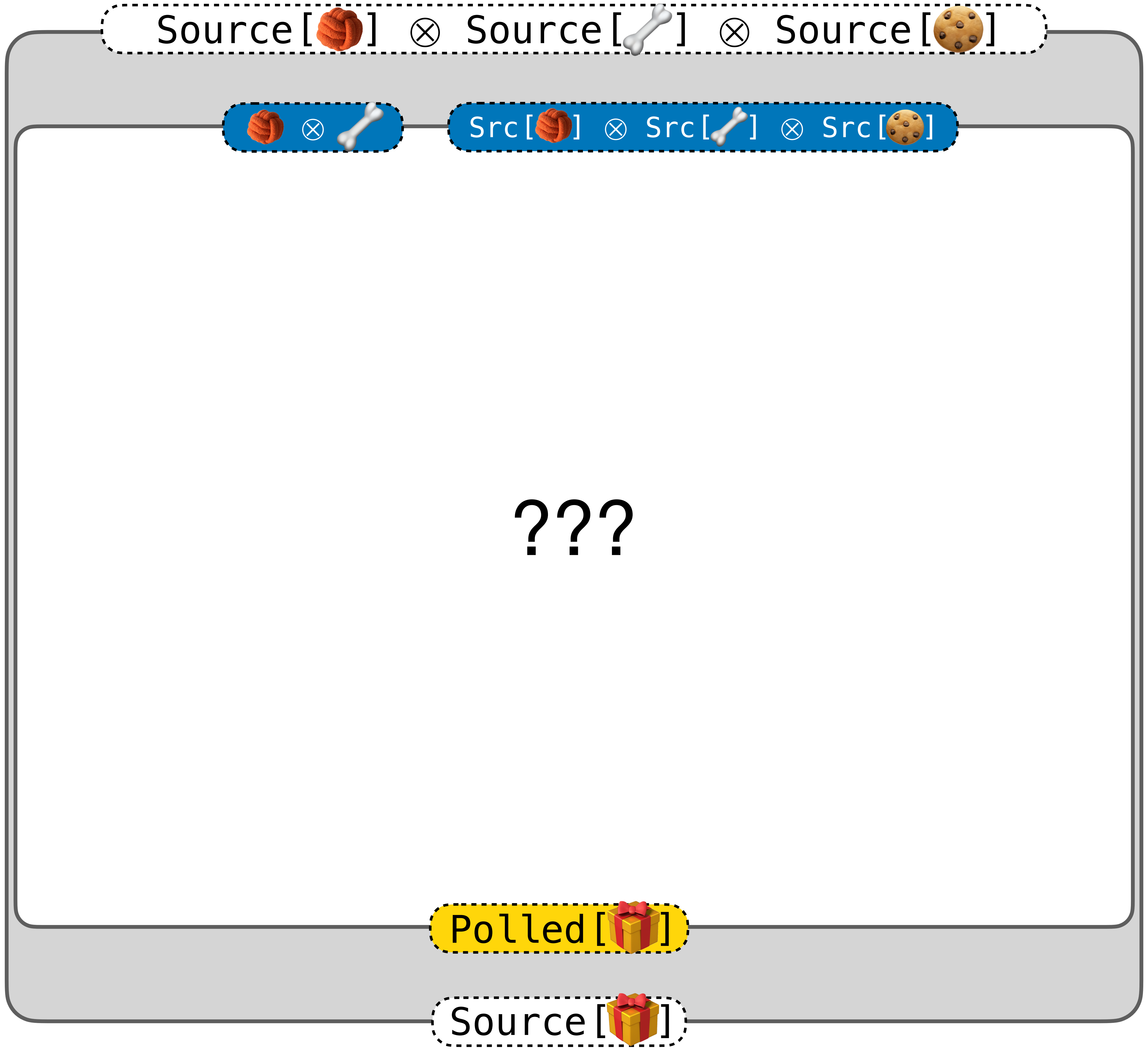
???

Polled[🎁]

Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶 ⊗ 🦴

Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

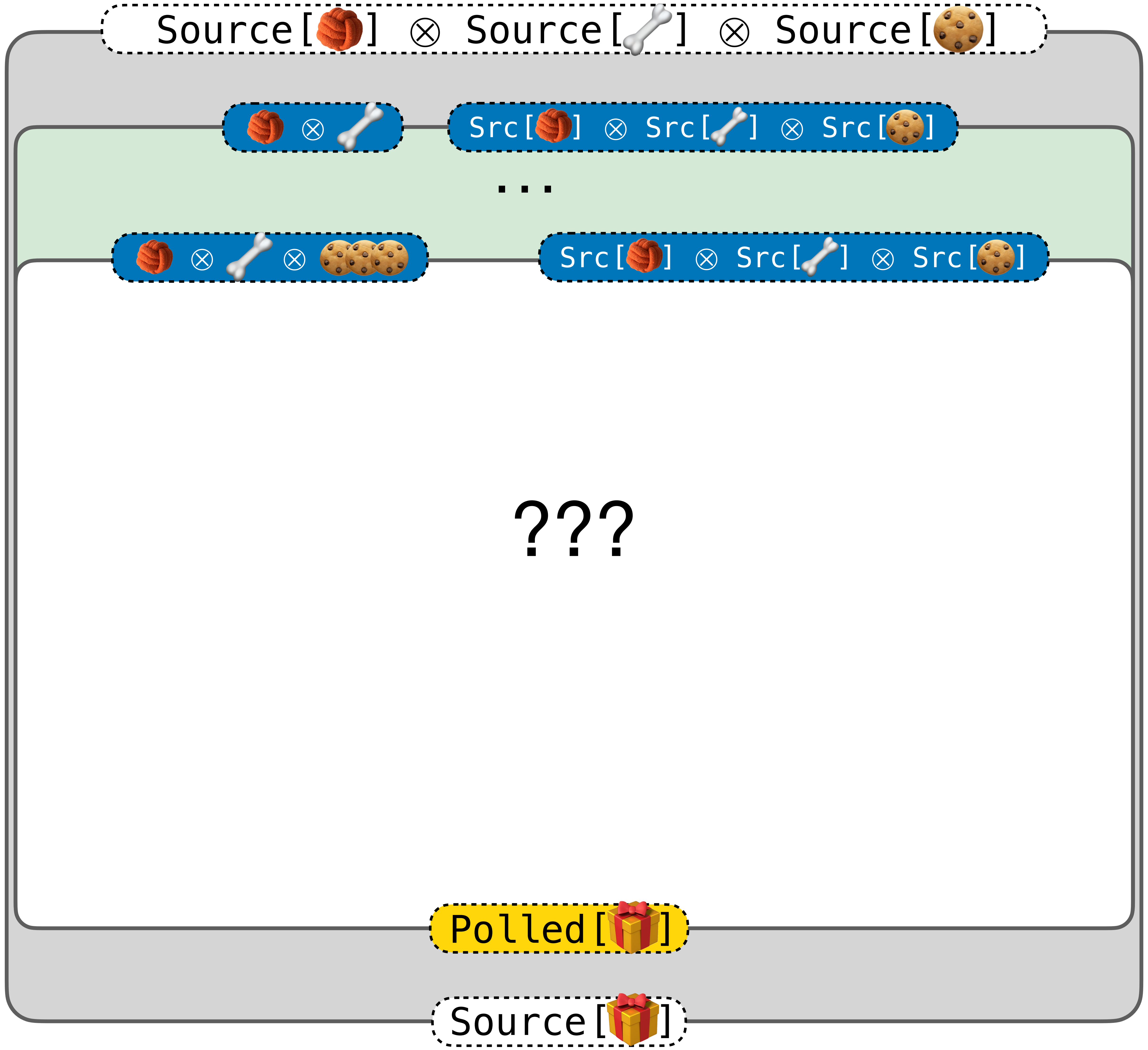
???

Polled[🎁]

Source[🎁]

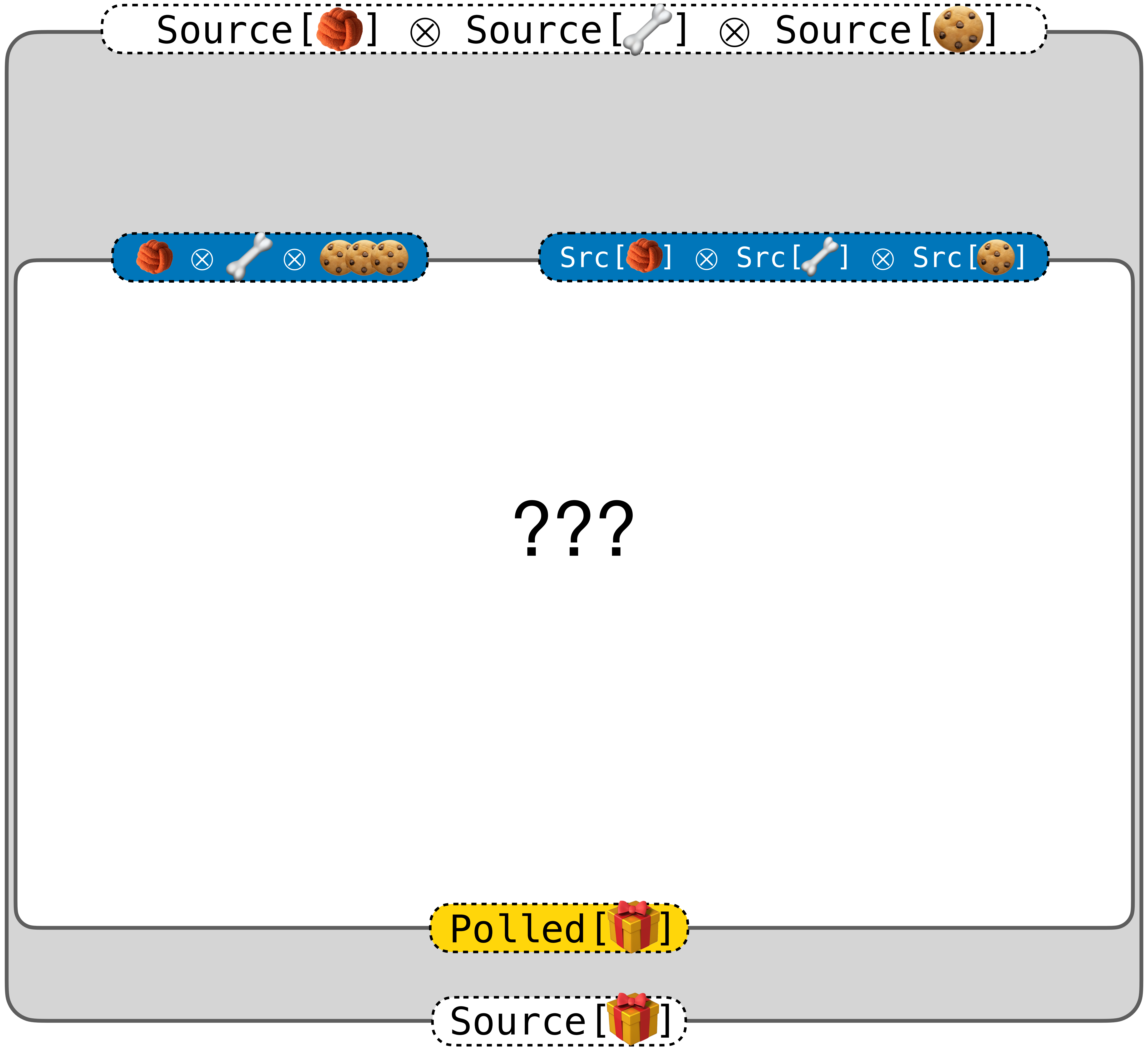
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



Source[🧶] ⊗ Source[🦴] ⊗ Source[🍪]

🧶 ⊗ 🦴 ⊗ 🍪🍪🍪

Src[🧶] ⊗ Src[🦴] ⊗ Src[🍪]

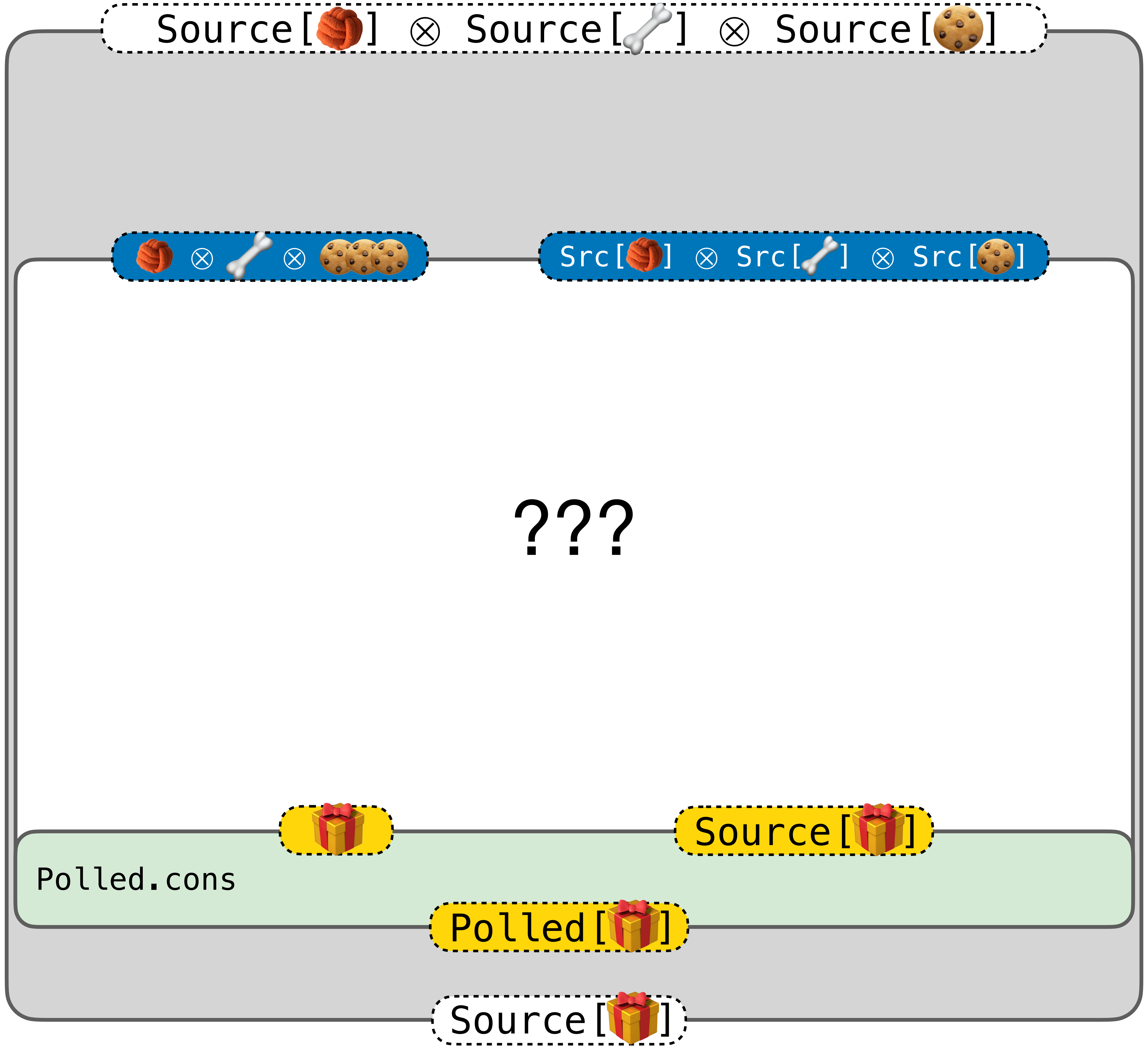
???

Polled[🎁]

Source[🎁]

???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
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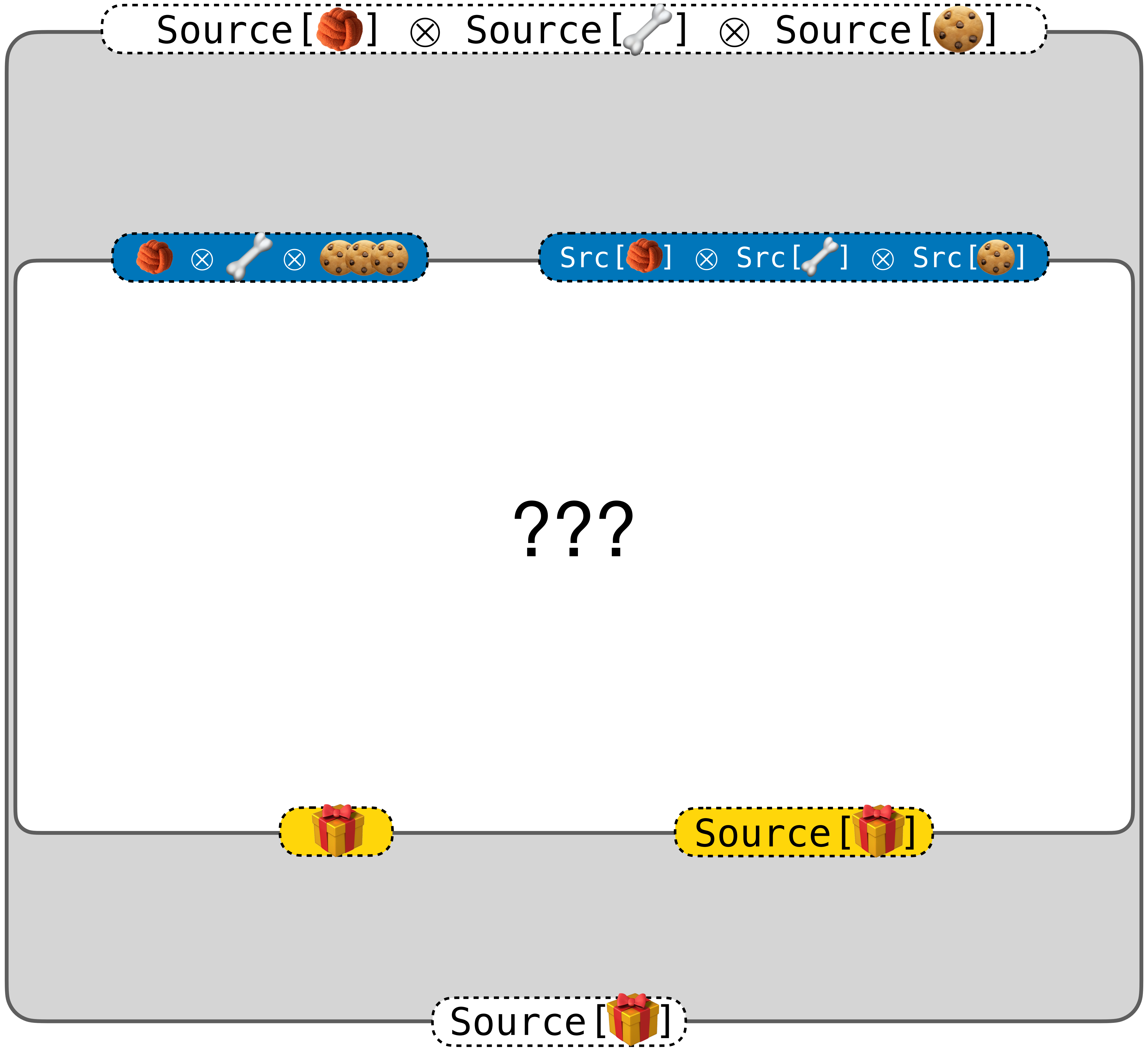
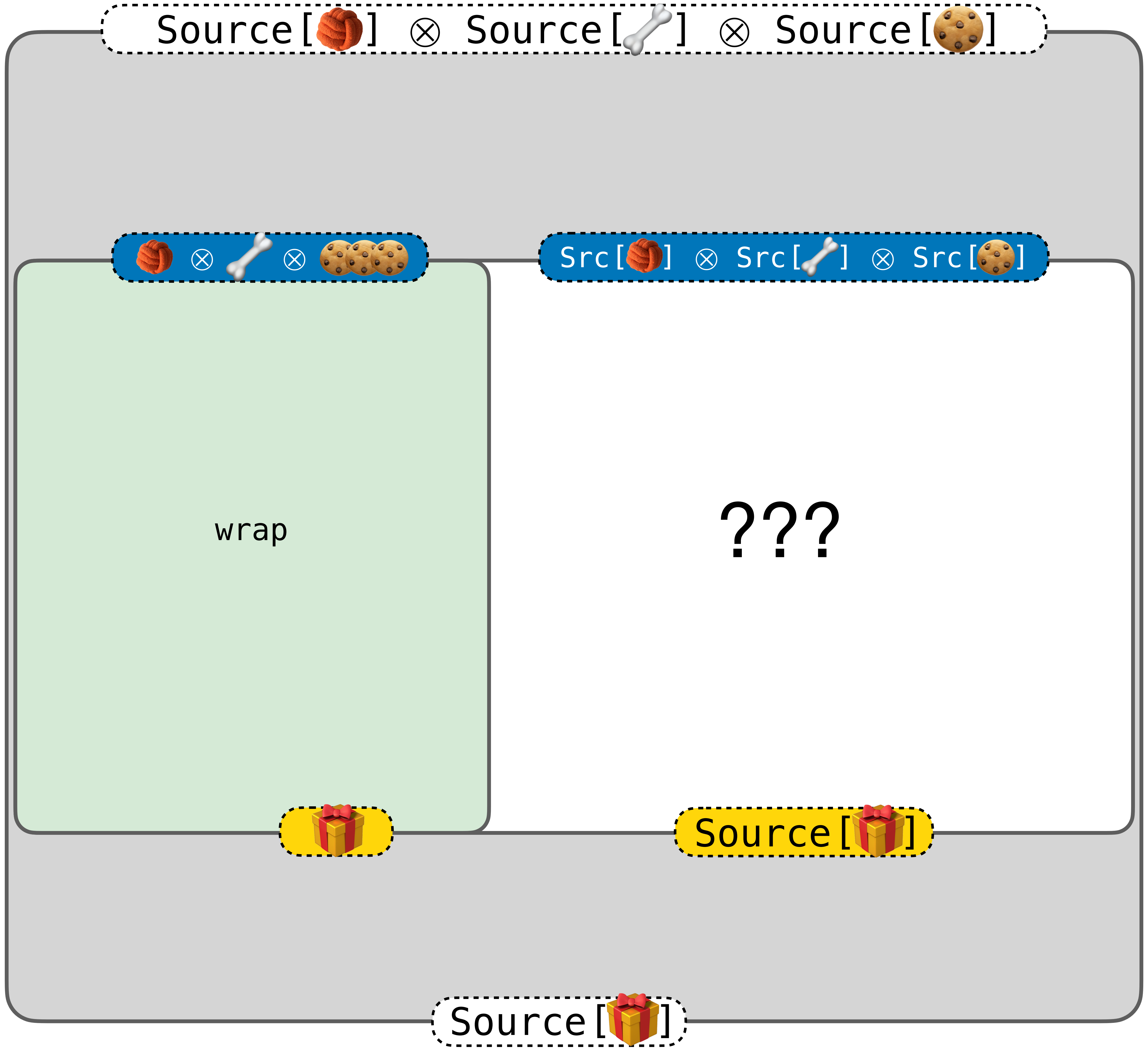
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



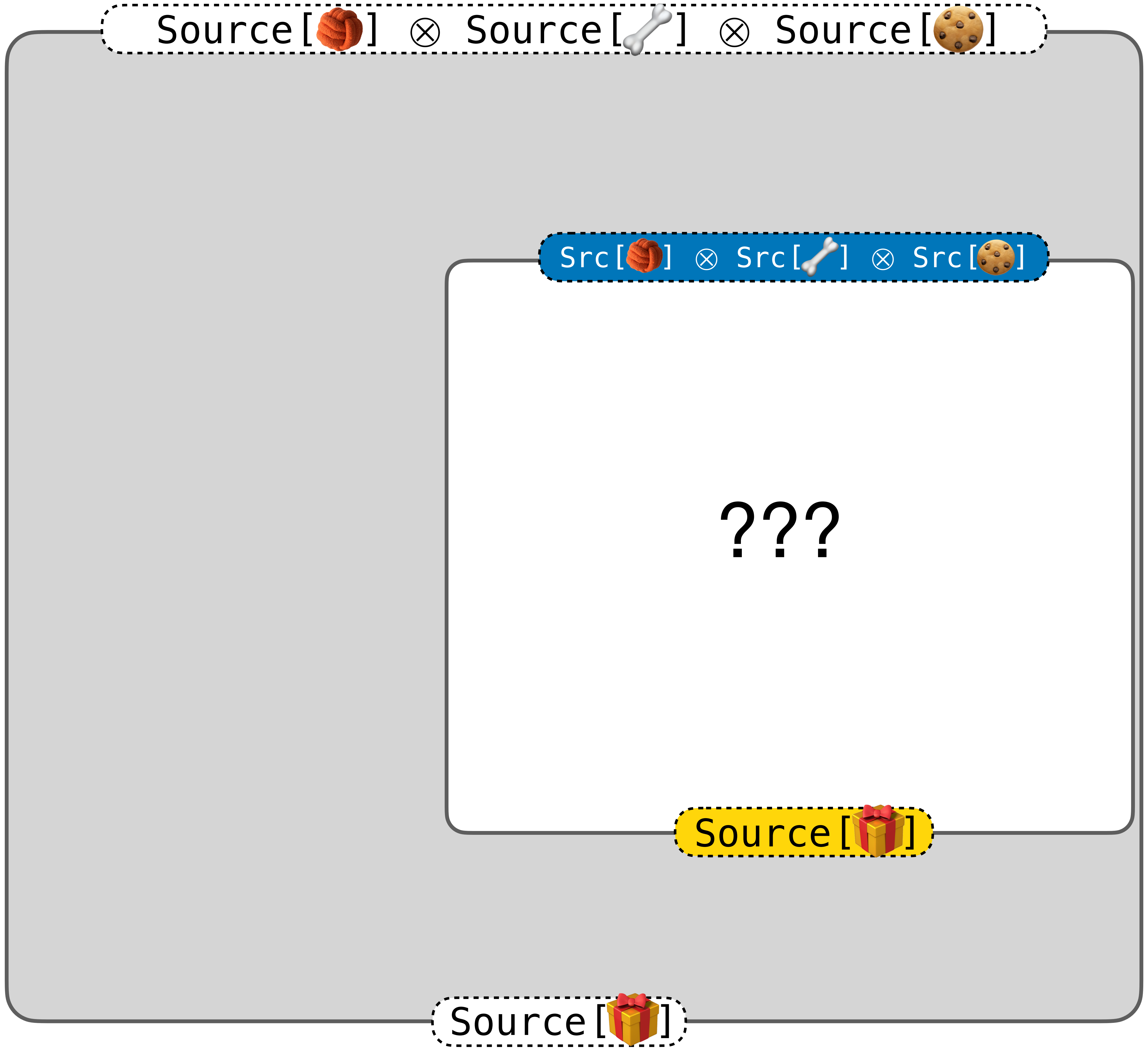
???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	Done signal	
Polled[A]	requested next elem	✔ ⊕ (A ⊗ Source[A])
Src[A]	abbr. Source[A]	
[A]	abbr. Source[A]	

Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
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⊕	producer choice	
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`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
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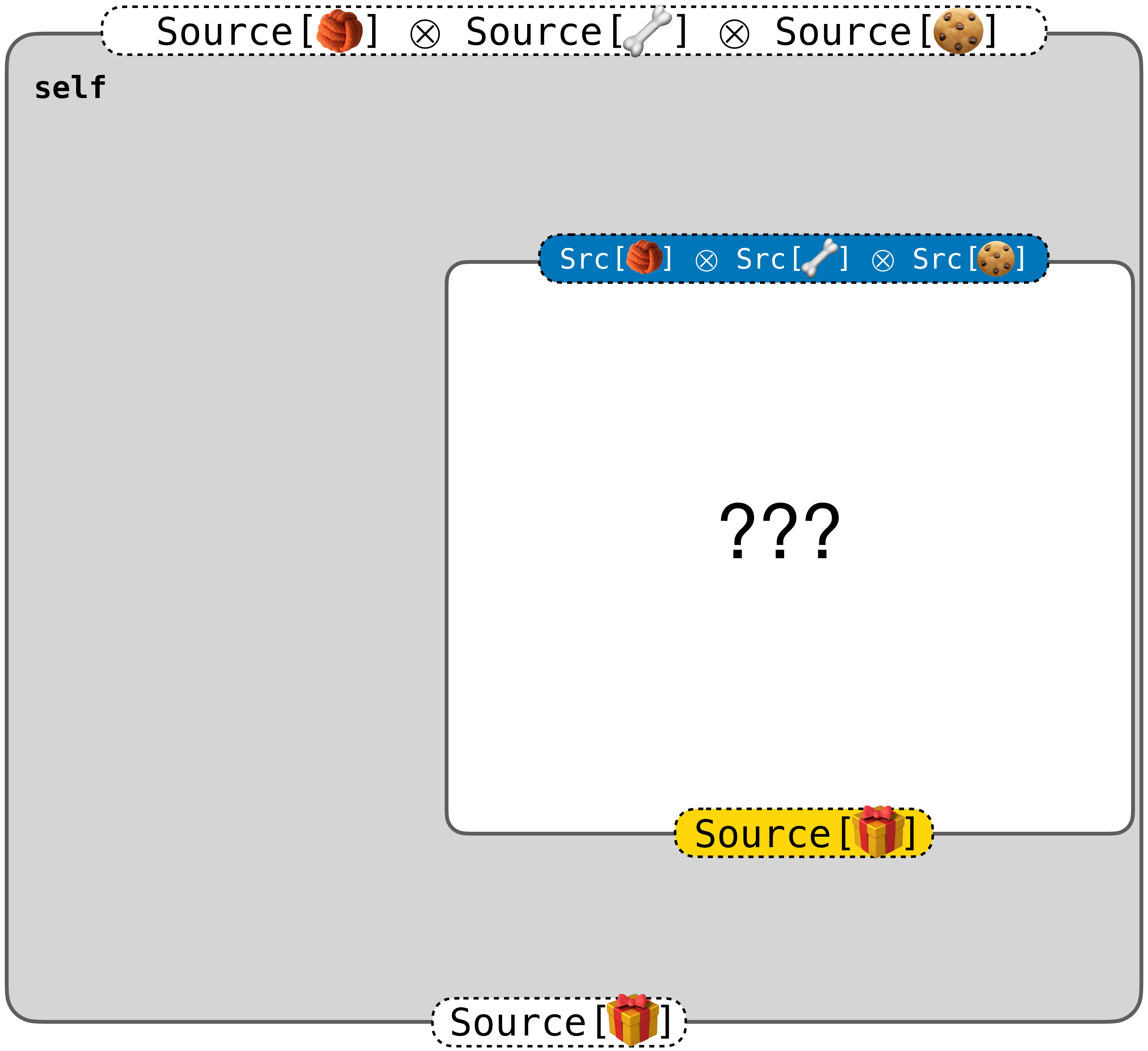
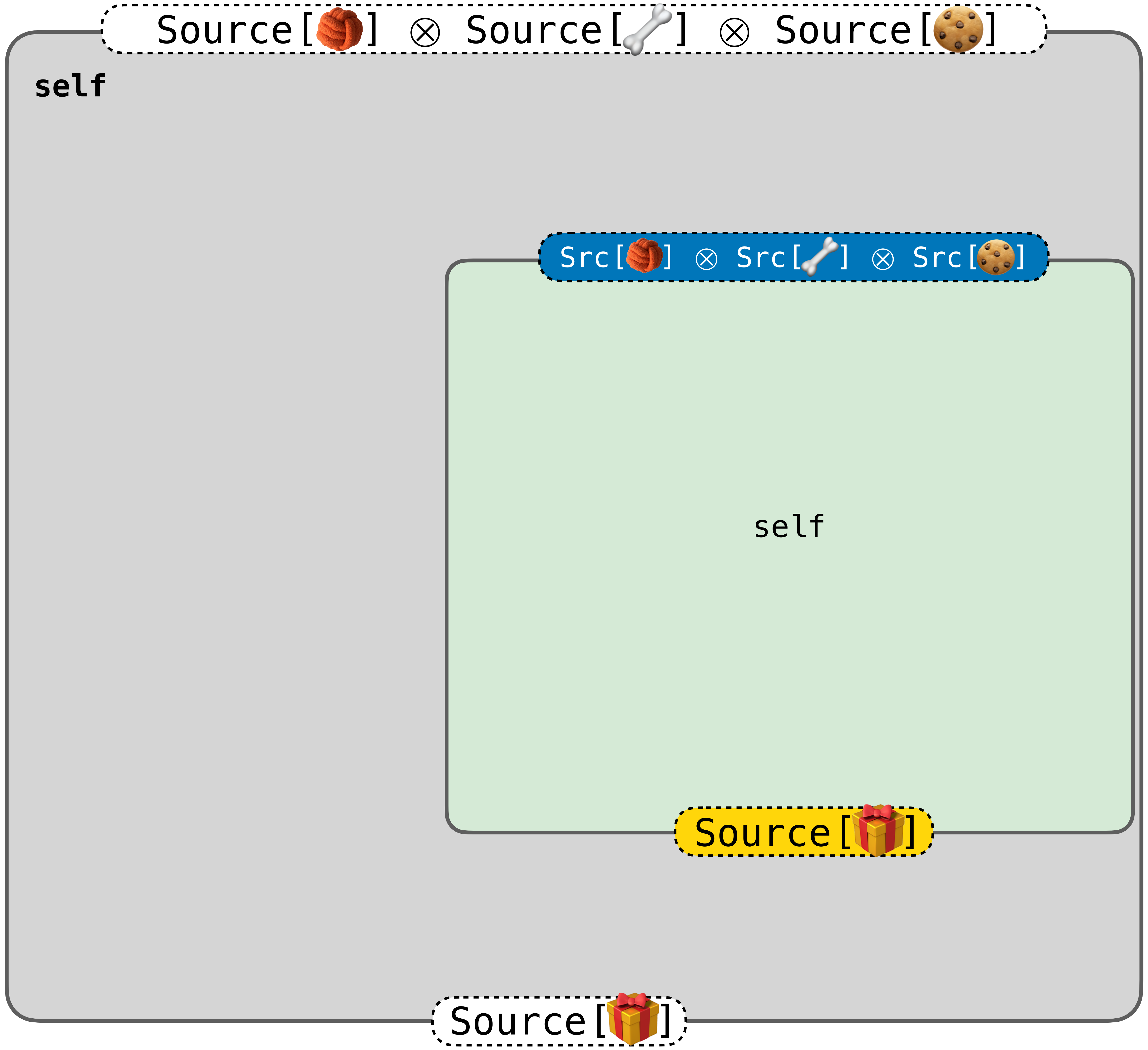
Packaging Dog Presents



???	hole to be filled	
🟦	to be consumed	
🟨	to be produced	
⊗	concurrent pair	
&	consumer choice	
⊕	producer choice	
✔	`Done` signal	
`Polled[A]`	requested next elem	`✔ ⊕ (A ⊗ Source[A])`
`Src[A]`	abbr. `Source[A]`	
`[A]`	abbr. `Source[A]`	

Packaging Dog Presents



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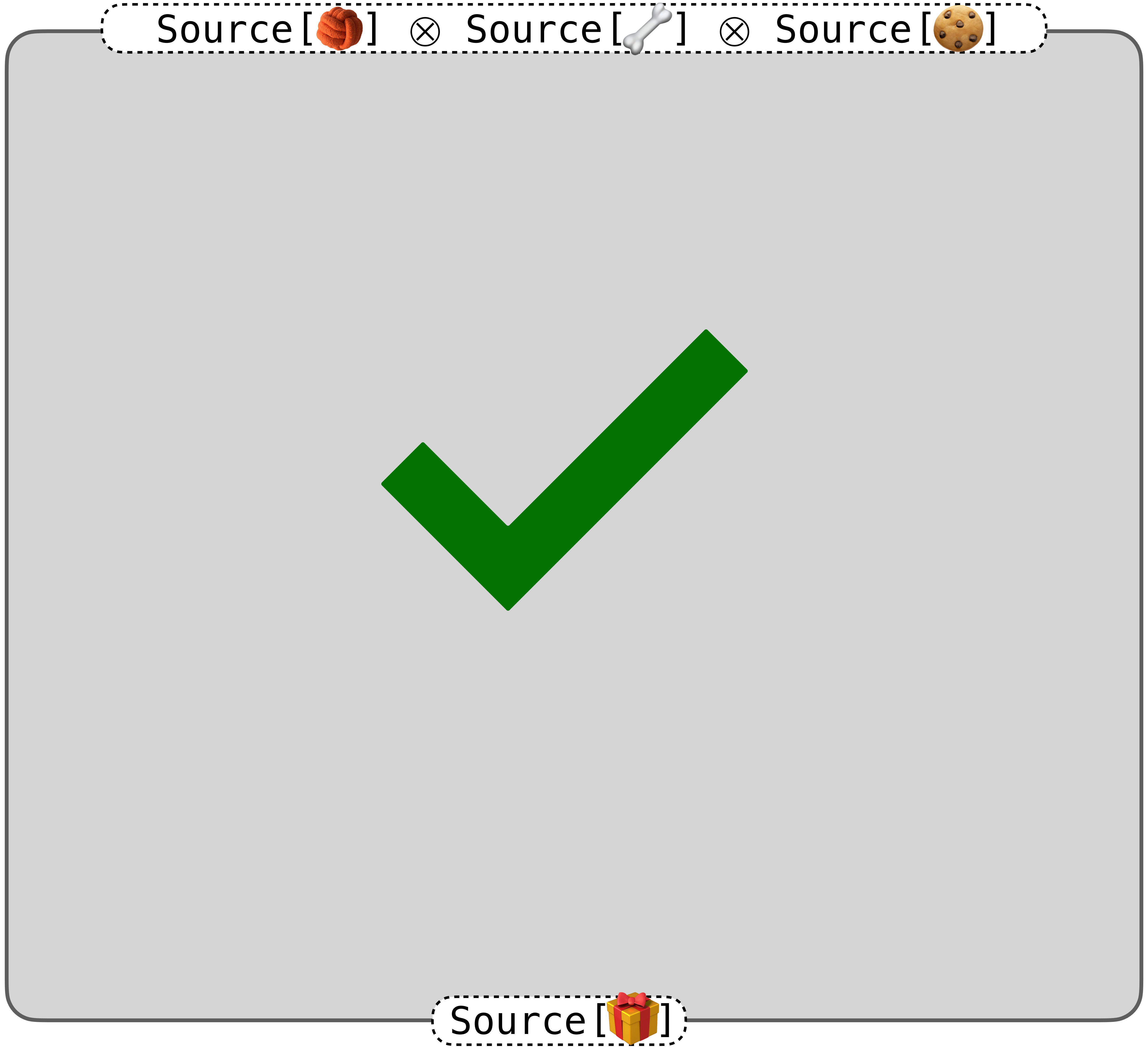
Packaging Dog Presents



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Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -o Source[Present] =
  ???
```

Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -o Source[Present] =
  ???
```

Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -⚬ Source[Present] =
  rec { self =>
    ???
  }
```

Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -o Source[Present] =
  rec { self =>
    Source.from(
      onClose =
        λ { case (toys |*| bones |*| biscuits) =>
          ??? : $[✓]
        },

      onPoll =
        λ { case (toys |*| bones |*| biscuits) =>
          ??? : $[Polled[Present]]
        },
    )
  }
```

Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -o Source[Present] =
  rec { self =>
    Source.from(
      onClose =
        λ { case (toys |*| bones |*| biscuits) =>
          ??? : $[✔]
        },

      onPoll =
        λ { case (toys |*| bones |*| biscuits) =>
          ??? : $[Polled[Present]]
        },
    )
  }
```

Packaging Dog Presents

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -⚬ Source[Present] =
 rec { self =>
  Source.from(
   onClose =
    λ { case (toys |*| bones |*| biscuits) =>
     joinAll(close(toys), close(bones), close(biscuits))
    },

   onPoll =
    λ { case (toys |*| bones |*| biscuits) =>
     ??? : $[Polled[Present]]
    },
  )
 }
```

Packaging Dog Presents

```
λ { case (toys |*| bones |*| biscuits) =>
  ??? : $[Polled[Present]]
}
```

Packaging Dog Presents

```
λ { case (toys |*| bones |*| biscuits) =>
  poll(toys) switch {
    case Left( ✔ ) => // no toys left, still have bones and biscuits
      ??? : $[Polled[Present]]

    case Right(toy |*| toys) => // got a toy, still have bones and biscuits
      ??? : $[Polled[Present]]
  }
}
```

Packaging Dog Presents

```
λ { case (toys |*| bones |*| biscuits) =>
  poll(toys) switch {
    case Left( ✔ ) => // no toys left
      Polled.empty(joinAll( ✔ , close(bones), close(biscuits)))

    case Right(toy |*| toys) => // got a toy, still have bones and biscuits
      ??? : $[Polled[Present]]
  }
}
```

Packaging Dog Presents

```
λ { case (toys |*| bones |*| biscuits) =>
 poll(toys) switch {
  case Left( ✔ ) => // no toys left
   Polled.empty(joinAll( ✔ , close(bones), close(biscuits)))

  case Right(toy |*| toys) => // got a toy, still have biscuits
   poll(bones) switch {
    case Left( ✔ ) => // no bones left
     Polled.empty(joinAll( ✔ , neglect(toy), close(toys), close(biscuits)))
    case Right(bone |*| bones) => // got a bone, still have toy, toys, biscuits
     ??? : $[Polled[Present]]
   }
 }
}
```

Packaging Dog Presents

```
case Right(bone |*| bones) => // got a bone, still have toy, toys, biscuits
  ??? : $[Polled[Present]]
```

Packaging Dog Presents

```
case Right(bone |*| bones) => // got a bone
  Bone.classifySize(bone) switch {
    case Left(largeBone) => // got a large bone
      pullThreeBiscuits(biscuits) switch {
        case Left( ✔ ) => // not enough biscuits
          Polled.empty(joinAll(✔, neglect(toy), neglect(largeBone), close(toys), close(bones)))
        case Right(biscuit3 |*| biscuits) => // got three biscuits
          Polled.cons(
            wrap(toy, largeBone, biscuit3) |*|
            self(toys |*| bones |*| biscuits)
          )
      }
    case Right(smallBone) => // got a small bone
      // analogous
```

Packaging Dog Presents

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✔

Packaging Dog Presents

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Unused variable `largeBone`

Packaging Dog Presents

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            self(toys |*| bones |*| biscuits)
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Unused variable `largeBone`

Overused variable `toys`

Packaging Dog Presents

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        case Left( ✔ ) => // not enough biscuits
          Polled.empty(joinAll(✔, neglect(toy),        close(toys), close(toys), close(bones)))
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          Polled.cons(
            wrap(toy, largeBone, biscuit3) |*|
            self(toys |*| bones |*| biscuits)
          )
      }
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Unused variable `largeBone`

Overused variable `toys`

Not properly wired ⇒ **unrepresentable**

- exception from the surrounding λ
- *assembly-time* error

Packaging Dog Presents

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case Right(bone |*| bones) => // got a bone
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      // analogous
```

Unused variable `largeBone`

Overused variable `toys`

Not properly wired ⇒ **unrepresentable**

- exception from the surrounding λ
- *assembly-time* error

`test("packagingLine") { packagingLine }`

Packaging Dog Presents: Alternatives

Packaging Dog Presents: Alternatives

FS2’s `Stream.pull`

ZIO’s `ZStream.toPull`

Packaging Dog Presents: Alternatives

FS2’s `Stream.pull`

ZIO’s `ZStream.toPull`

- much less safe
- slightly more accidental complexity

Integrating with ZIO Streams

Libretto

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -⚬ Source[Present]
```

Integrating with ZIO Streams

Libretto

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -⚬ Source[Present]
```

ZIO

```
def go(
  toys: UStream[Toy],
  bones: UStream[Bone],
  biscuits: UStream[Biscuit],
): ZIO[Scope, Nothing, UStream[Present]] =
```

Integrating with ZIO Streams

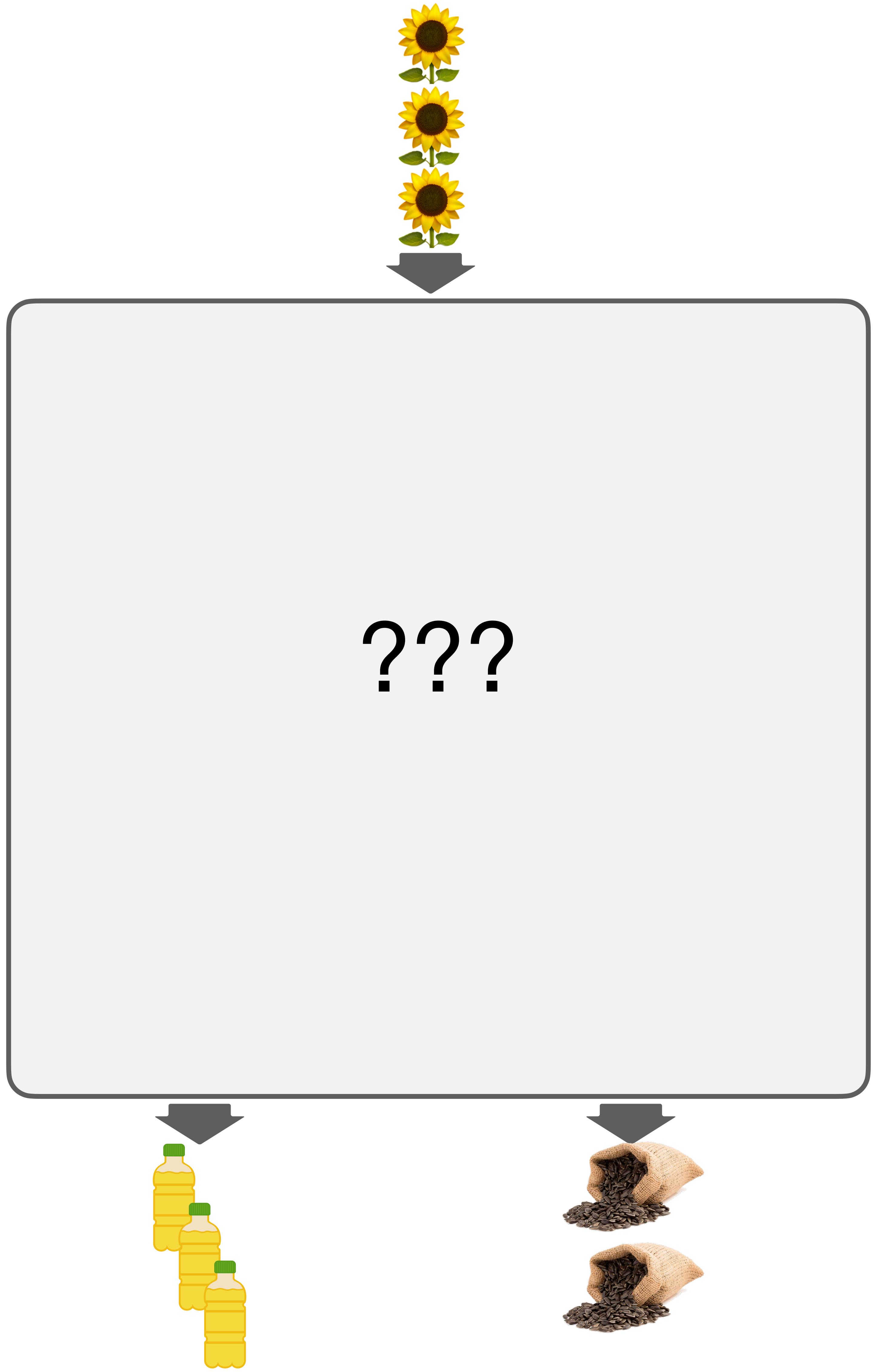
Libretto

```
def packagingLine: (Source[Toy] |*| Source[Bone] |*| Source[Biscuit]) -⚬ Source[Present]
```

ZIO

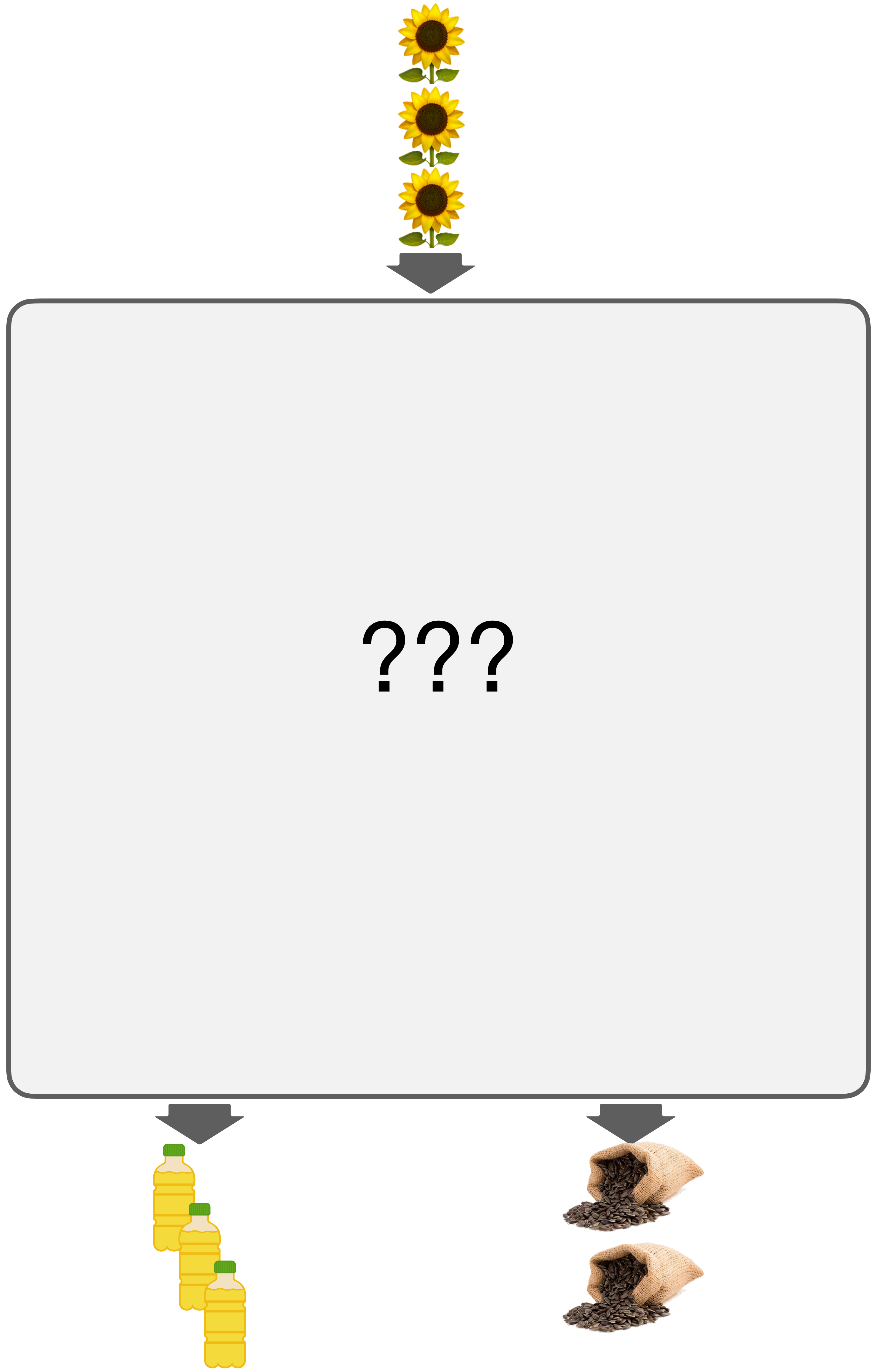
```
def go(
  toys: UStream[Toy],
  bones: UStream[Bone],
  biscuits: UStream[Biscuit],
): ZIO[Scope, Nothing, UStream[Present]] =
  (toys.asSource |*| bones.asSource |*| biscuits.asSource)
    .through_(packagingLine)
    .map(_.zstream)
```

Sunflower Processing Facility



- **In:** sunflowers
- **Out:** oil bottles 🧴, packs of seeds 🫘
- 5 🌻 for 🧴, 3 🌻 for 🫘
- Start on whichever item demanded first
- Halt when either:
  - both downstreams close
  - run out of sunflowers
- Waste at most 4 sunflowers

Sunflower Processing Facility



- **In:** sunflowers
- **Out:** oil bottles 🧴, packs of seeds 🌰
- 5 🌻 for 🧴, 3 🌻 for 🌰
- Start on whichever item demanded first
- Halt when either:
  - both downstreams close
  - run out of sunflowers
- Waste at most 4 sunflowers

Behavior depends on which downstream acts first (racing).

Sunflower Processing Facility: Idea

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- feed the input source into a **queue**

Sunflower Processing Facility: Idea

- feed the input source into a **queue**
- start each consumer in a **fiber** and let them compete in pulling from queue

Sunflower Processing Facility: Idea

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- obtain a **lock** to pull the respective number of sunflowers (3 or 5)

Sunflower Processing Facility: Idea

- feed the input source into a **queue**
- start each consumer in a **fiber** and let them compete in pulling from queue
- obtain a **lock** to pull the respective number of sunflowers (3 or 5)
- notify the upstream when both consumer close using a **CountdownLatch**

Sunflower Processing Facility: Bad Idea

- feed the input source into e
- start each consumer in a **fiber** ompete in pulling from queue
- obtain a **lock** to pull the respec f sunflowers (3 or 5)
- notify the upstream when nsumer ing a **CountdownLatch**

Sunflower Processing Facility

```
def sunflowerProcessor: Source[Sunflower] -⚬ (Source[SeedsPack] |*| Source[OilBottle]) =
  rec { self =>
    λ { sunflowers =>
      producing { case seedsOut |*| oilOut => // give names to the outputs
        ???
      }
    }
  }
```

Sunflower Processing Facility

```
def sunflowerProcessor: Source[Sunflower] -o (Source[SeedsPack] |*| Source[OilBottle]) =
  rec { self =>
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Sunflower Processing Facility

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    ???
   }
  }
 }
```

Sunflower Processing Facility

```
def sunflowerProcessor: Source[Sunflower] -o (Source[SeedsPack] |*| Source[OilBottle]) =
  rec { self =>
    λ { sunflowers =>
      producing { case seedsOut |*| oilOut => // give names to the outputs
        // race the outputs by which one acts (i.e. pulls or closes) first
        (selectBy(notifyAction, notifyAction) >>: (seedsOut |*| oilOut)) switch {
          case Left(seedsOut |*| oilOut) => // seed output acted first
            ???
          case Right(seedsOut |*| oilOut) => // oil output acted first
            ???
        }
      }
    }
  }
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first, still have sunflowers
  ???
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first
  (fromChoice >>: seedsOut) switch {
    case Left( ✔ ) => // seed output closing, still have sunflowers, oilOut
      ???
    case Right(pullingSeeds) => // seed output pulling, still have sunflowers, oilOut
      ???
  }
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first
  (fromChoice >>: seedsOut) switch {
    case Left( ✔ ) => // seed output closing, still have sunflowers, oilOut
      ???
    case Right(pullingSeeds) => // seed output pulling, still have sunflowers, oilOut

        pull3(sunflowers) switch {
          case Right(sunflower3 |*| sunflowers) =>


            ???


          case Left(   ✔  ) => // no more sunflowers
            ???
        }
  }
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first
  (fromChoice >>: seedsOut) switch {
    case Left( ✔ ) => // seed output closing, still have sunflowers, oilOut
      ???
    case Right(pullingSeeds) => // seed output pulling, still have sunflowers, oilOut

        pull3(sunflowers) switch {
          case Right(sunflower3 |*| sunflowers) =>
            val seedsPack = roastSeedsAndPack(sunflower3)
            val seedsPacks |*| oilBottles = self(sunflowers)
            ???
          case Left(  ✔  ) => // no more sunflowers
            ???
        }
  }
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first
  (fromChoice >>: seedsOut) switch {
    case Left( ✔ ) => // seed output closing, still have sunflowers, oilOut
      ???
    case Right(pullingSeeds) => // seed output pulling, still have sunflowers, oilOut
      (pullingSeeds |*| oilOut) :=
        pull3(sunflowers) switch {
          case Right(sunflower3 |*| sunflowers) =>
            val seedsPack = roastSeedsAndPack(sunflower3)
            val seedsPacks |*| oilBottles = self(sunflowers)
            Polled.cons(seedsPack |*| seedsPacks) |*| oilBottles
          case Left(+( ✔ )) => // no more sunflowers
            Polled.empty( ✔ ) |*| Source.empty( ✔ )
        }
  }
```

Sunflower Processing Facility

```
case Left(seedsOut |*| oilOut) => // seed output acted first
  (fromChoice >>: seedsOut) switch {
    case Left( ✔ ) => // seed output closing, still have sunflowers, oilOut
      ???
    case Right(pullingSeeds) => // seed output pulling, still have sunflowers, oilOut
      (pullingSeeds |*| oilOut) :=
        pull3(sunflowers) switch {
          case Right(sunflower3 |*| sunflowers) =>
            val seedsPack = roastSeedsAndPack(sunflower3)
            val seedsPacks |*| oilBottles = self(sunflowers)
            Polled.cons(seedsPack |*| seedsPacks) |*| oilBottles
          case Left(+( ✔ )) => // no more sunflowers
            Polled.empty( ✔ ) |*| Source.empty( ✔ )
        }
  }
```

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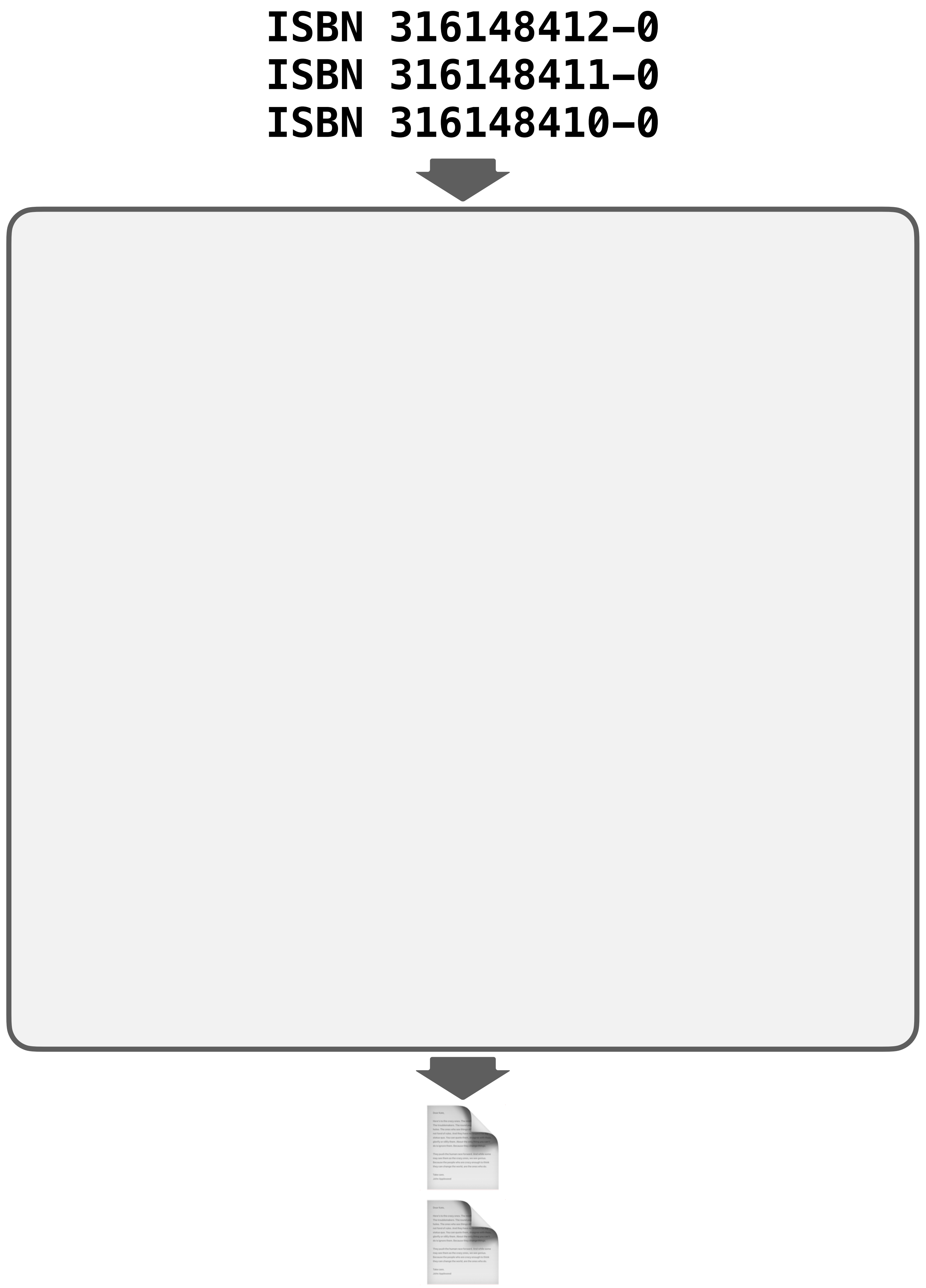
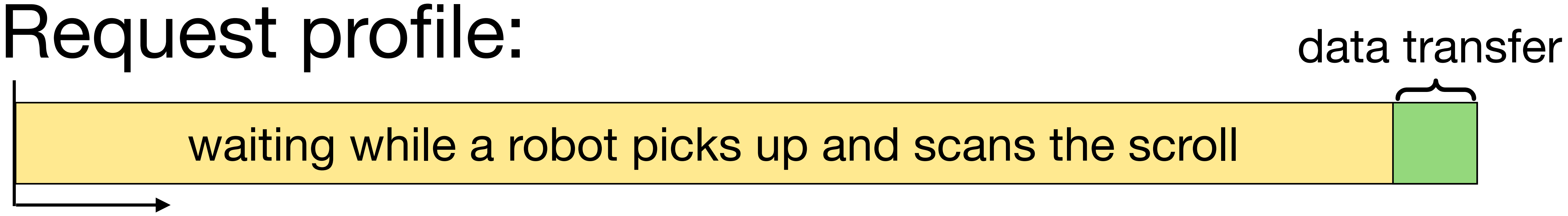


```
ISBN 316148412-0
ISBN 316148411-0
ISBN 316148410-0
```

- **In:** scroll IDs (ISBNs)
- **Out:** pages of all given scrolls, in order
- Use provided API to request a scroll by its ID
  - returns a stream of scanned pages
- Fair use policy: max *k* concurrent connections
- Request profile:



data transfer

waiting while a robot picks up and scans the scroll

- Use all *k* connections to prepare documents, transfer data sequentially

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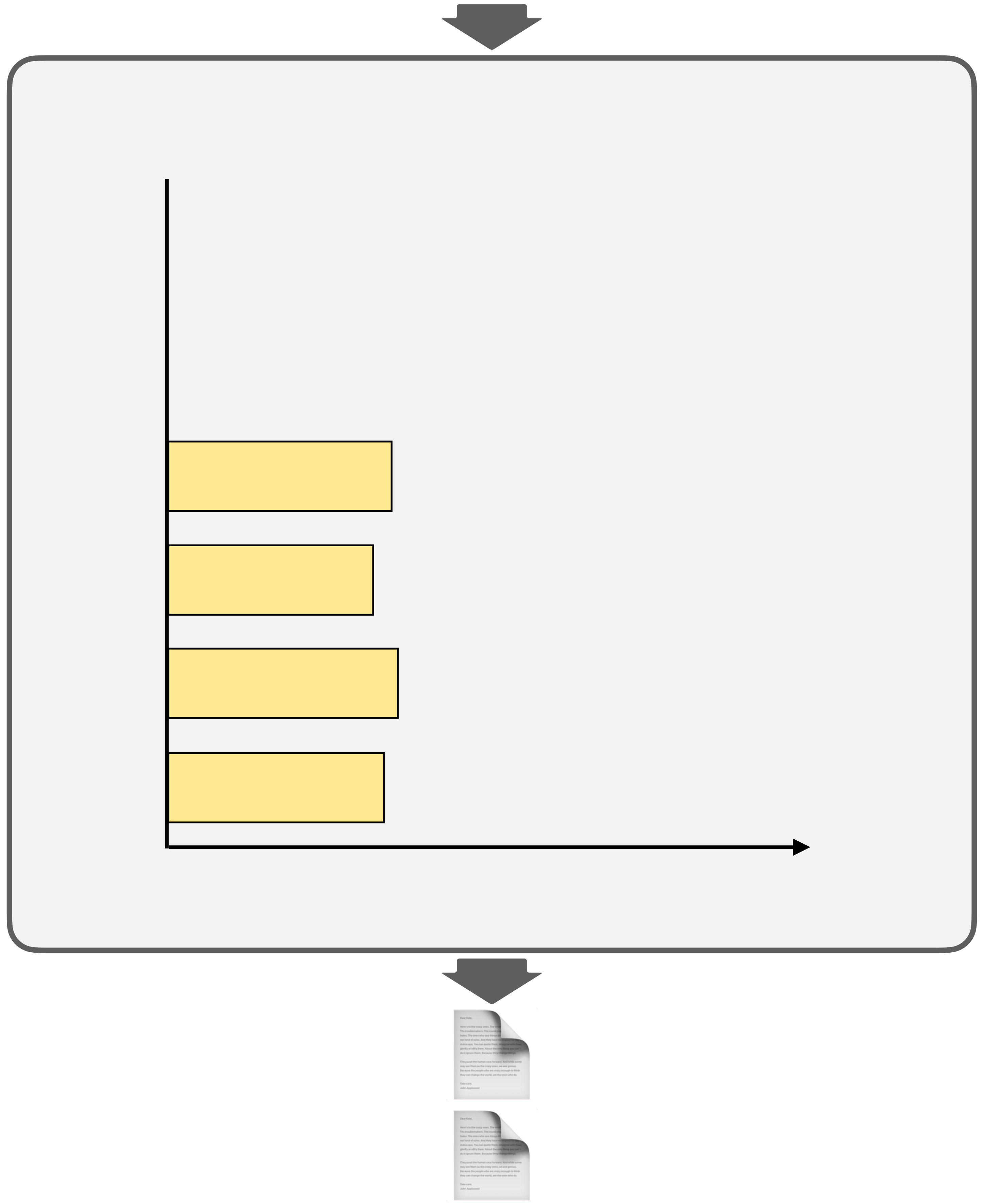
```
ISBN 316148412-0
ISBN 316148411-0
ISBN 316148410-0
```



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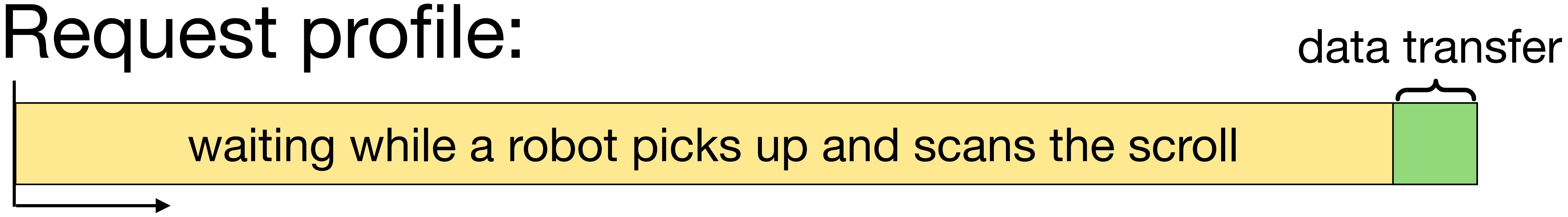

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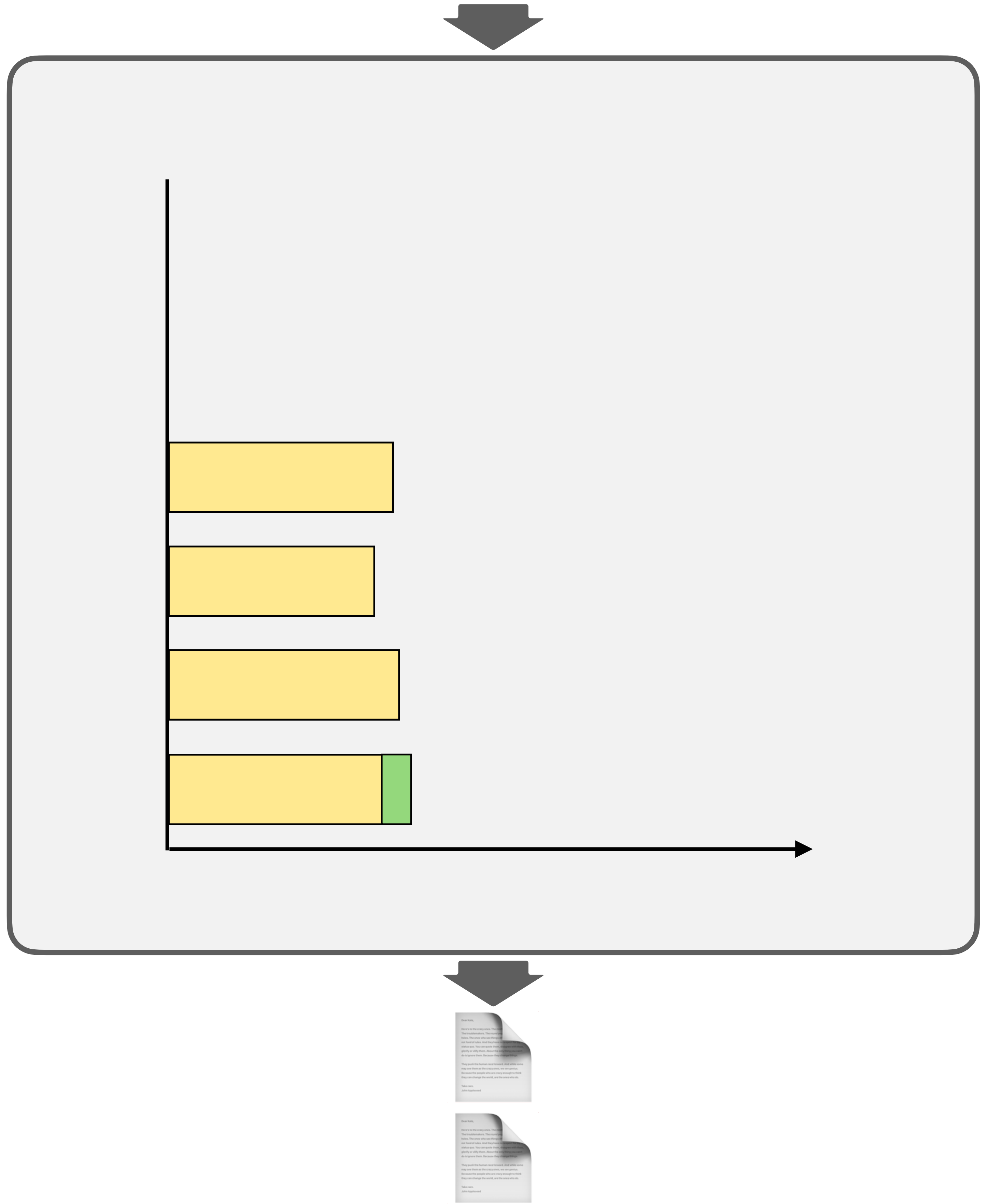
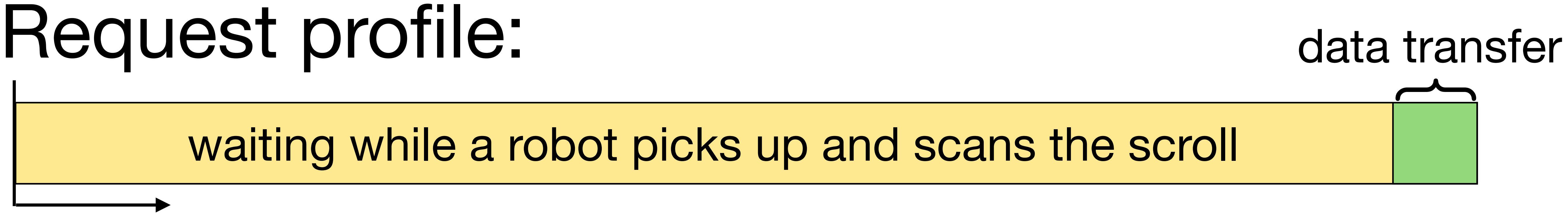
ISBN 316148412-0
ISBN 316148411-0
ISBN 316148410-0



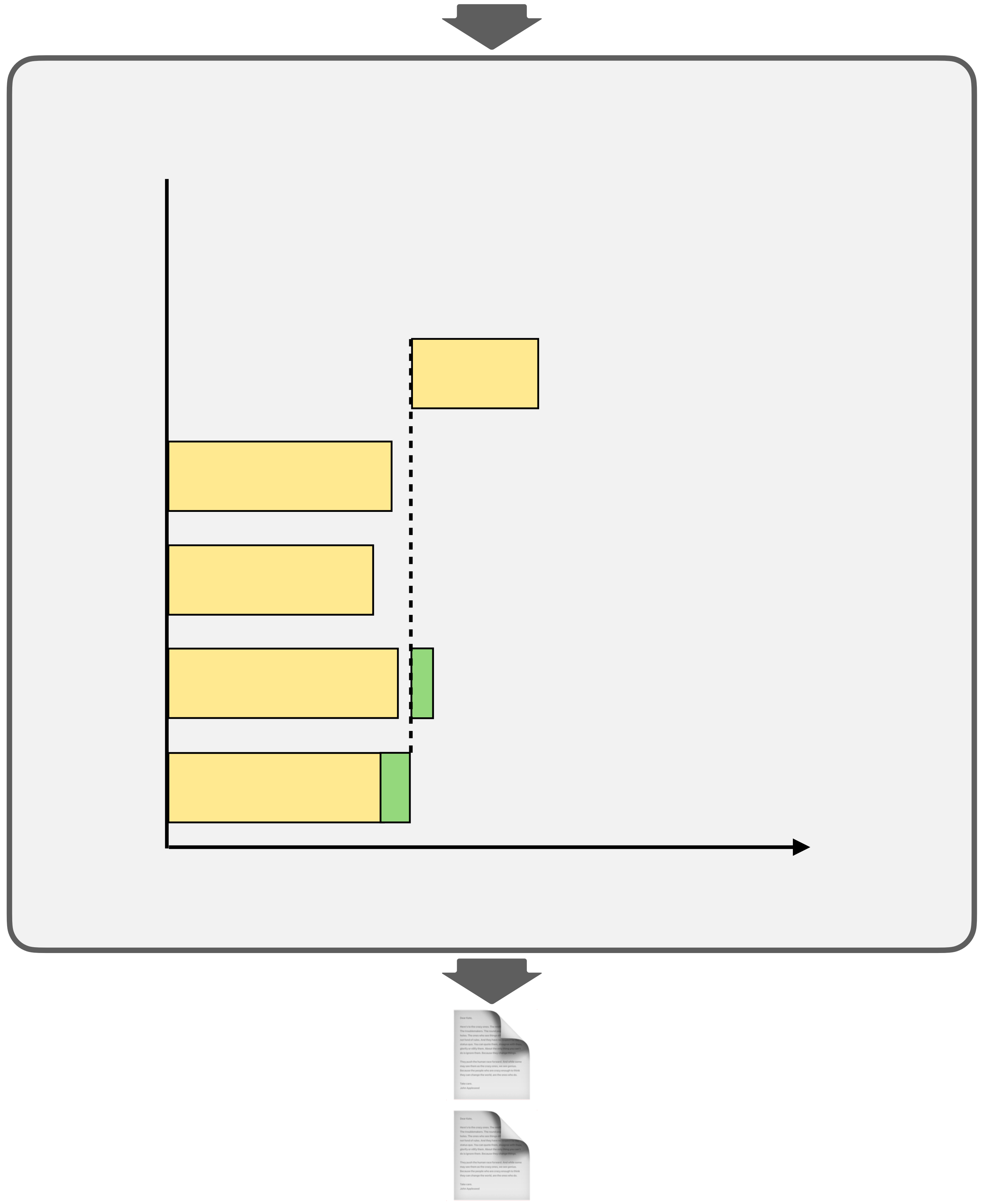
- **In:** scroll IDs (ISBNs)
- **Out:** pages of all given scrolls, in order
- Use provided API to request a scroll by its ID
  - returns a stream of scanned pages
- Fair use policy: max *k* concurrent connections
- Request profile:



- Use all *k* connections to prepare documents, transfer data sequentially

Digital Library of Alexandria

```
ISBN 316148412-0
ISBN 316148411-0
ISBN 316148410-0
```



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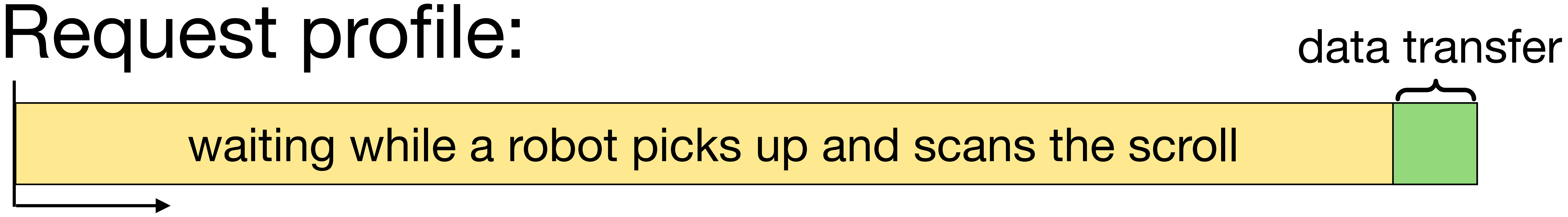

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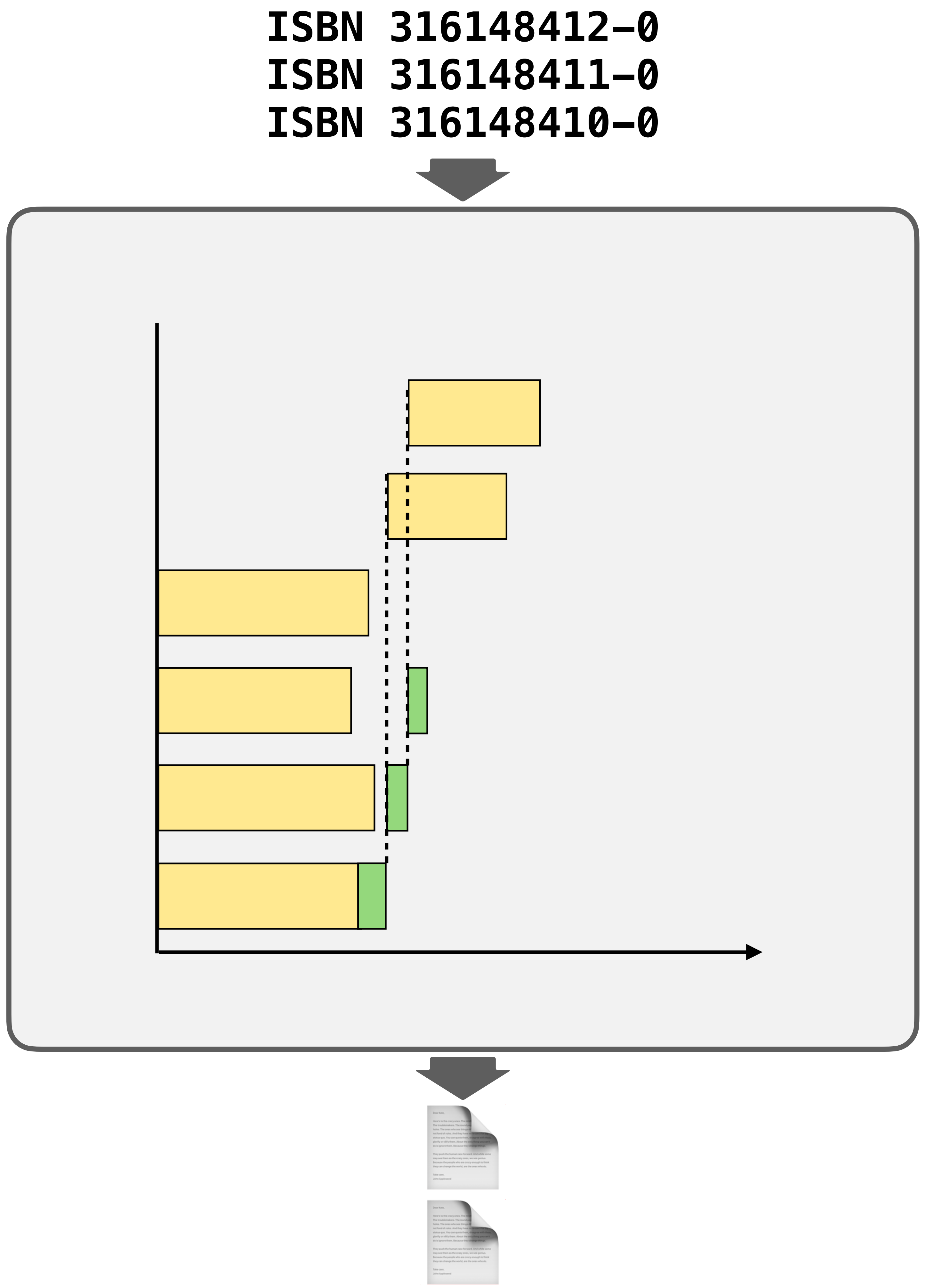

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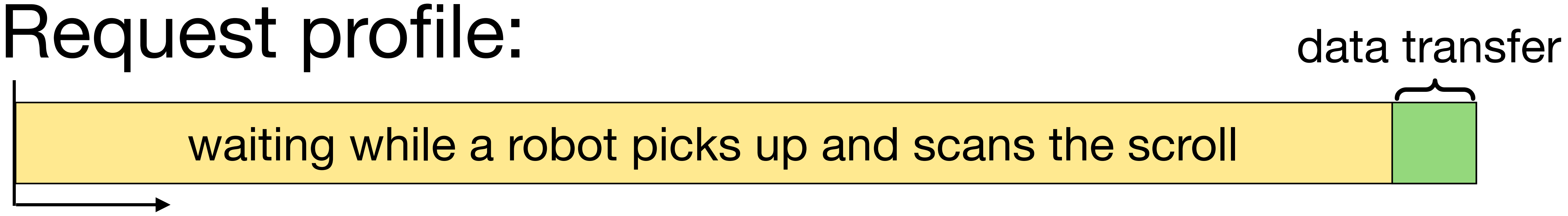

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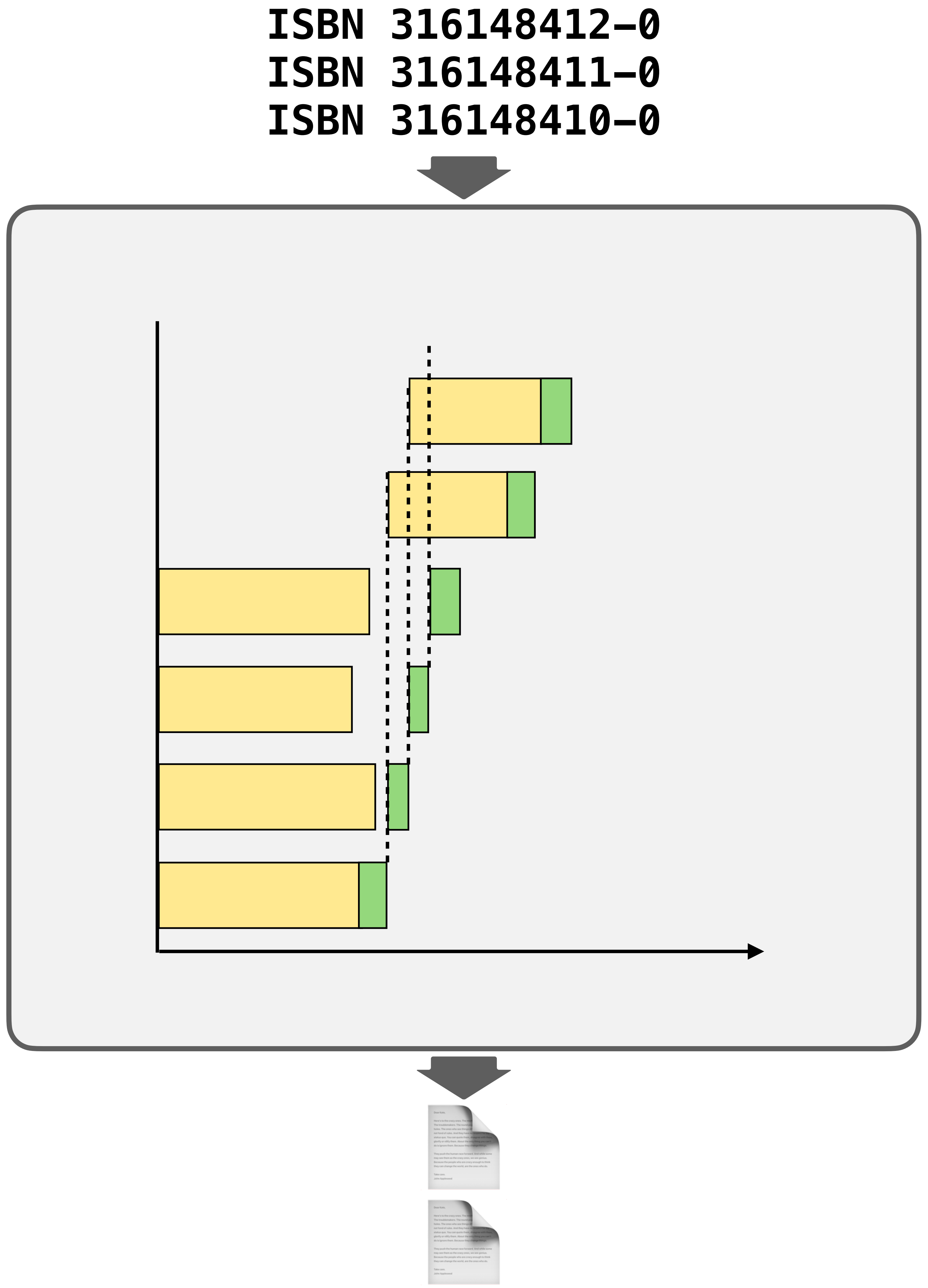

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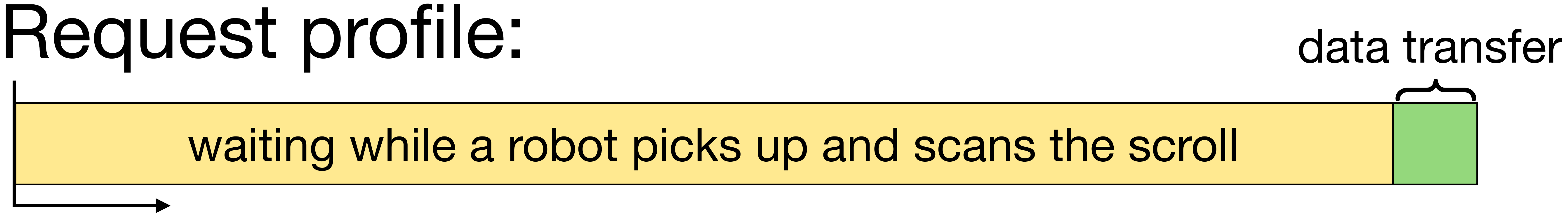

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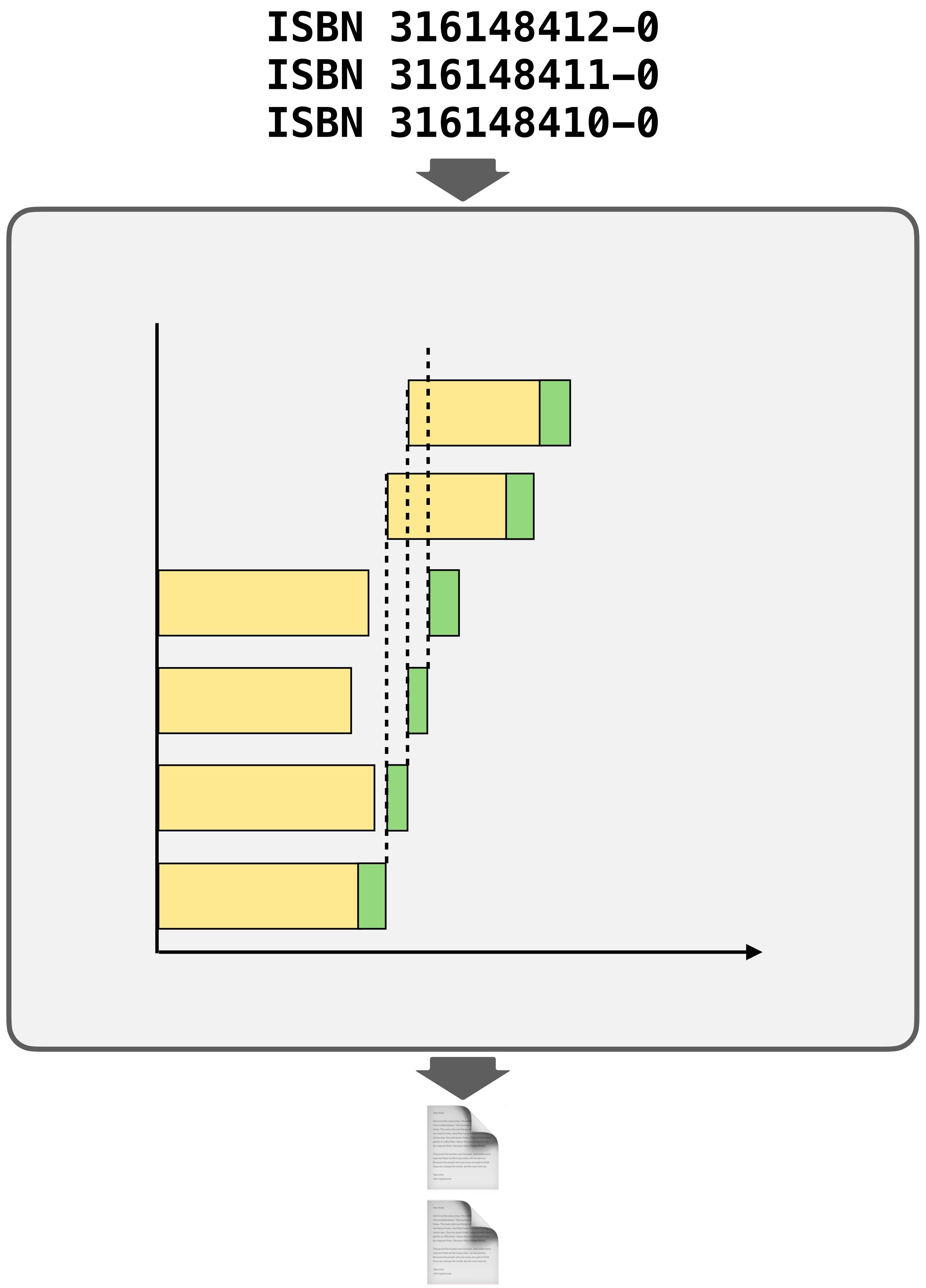

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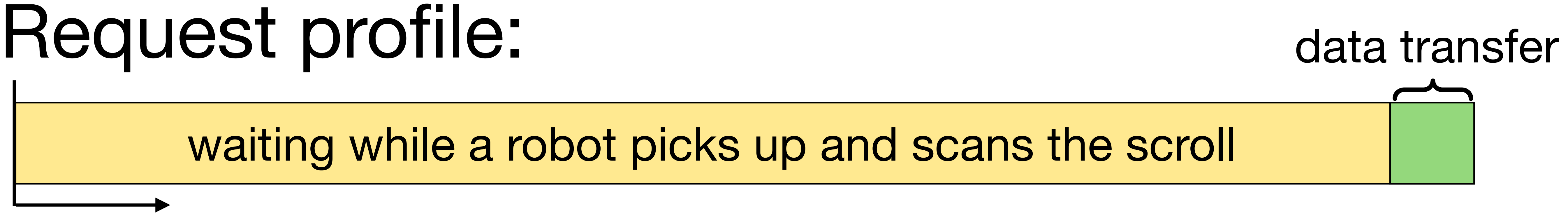

- Use all *k* connections to prepare documents, transfer data sequentially

Non-trivial resource lifetimes
(overlapping, but not nested)

Digital Library of Alexandria

Digital Library of Alexandria

```
// Provided.
// Opens a connection that is closed when the resulting Source is closed.
def fetchScroll: (Connector |*| ISBN) -o Source[📄]
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Digital Library of Alexandria

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Correct
Resource Safe

Digital Library of Alexandria

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Does not work in libs where `Source` / `Stream` is a “blueprint”

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Stream[Stream[📄]] .prefetch(n) .flatten
```

- prefetches blueprints, does not start doc preparation

Digital Library of Alexandria

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Digital Library of Alexandria

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Stream[Stream[📄]] .flatten .prefetch(n)
```

- prefetches n pages of concatenation, instead of preparing n documents

```
Stream[ISBN] .mapAsync(n)(ISBN => IO[Stream[📄]])
```

- if `IO` action starts doc prep in background, who closes connection if `Stream` never consumed?

Digital Library of Alexandria

```
def fetchScroll: (Connector |*| ISBN) -⚬ Source[📄]

def downloadAll(k: Int): (Connector |*| Source[ISBN]) -⚬ Source[📄] =
  mapWith(fetchScroll) > prefetch(k - 1)(discardPrefetched = Source.close) > flatten
```

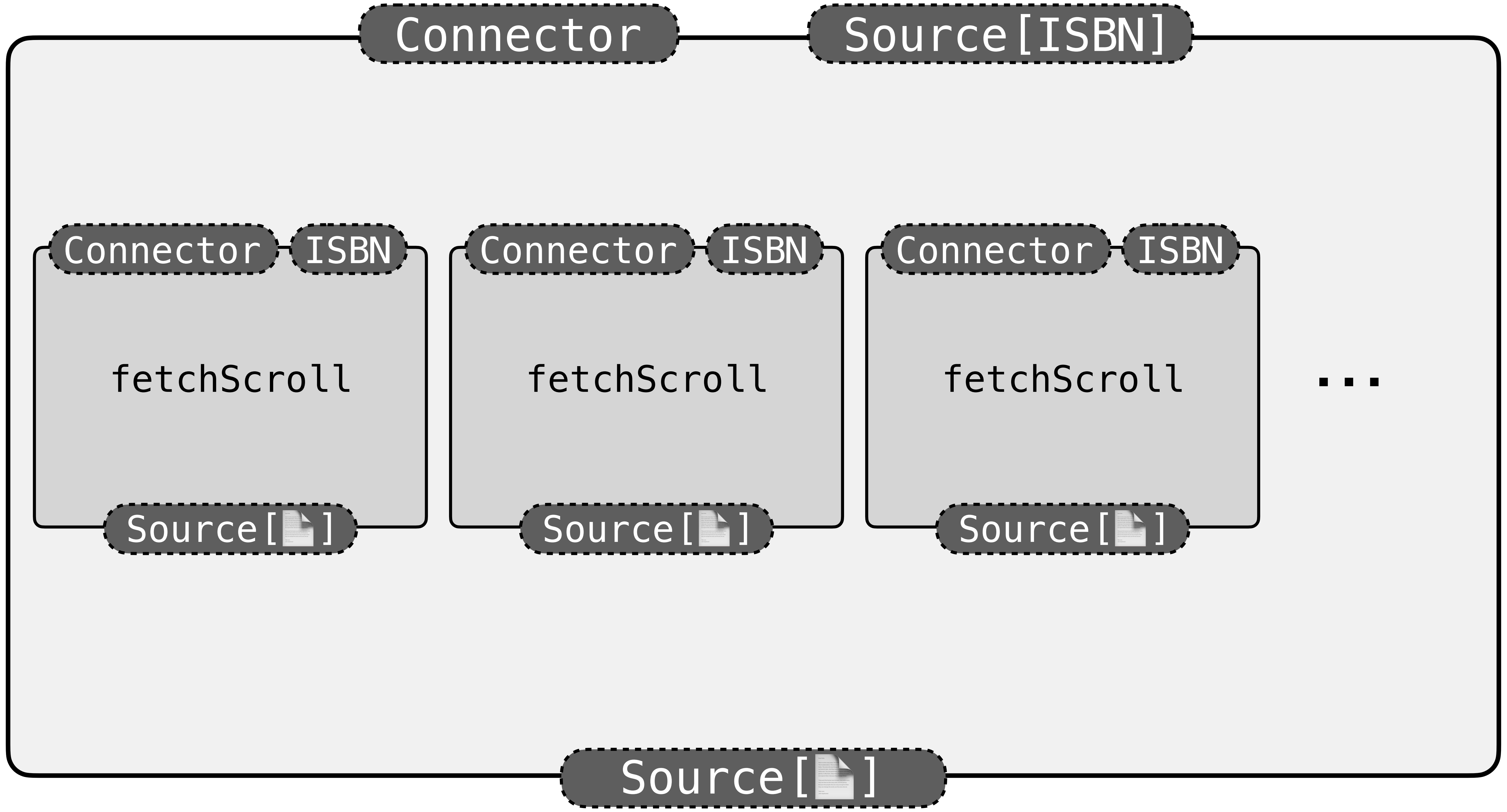
Why does it work in Libretto?

`Source[📄]`

- not a blueprint
- phantom type
- *interface* of interaction (`poll`, `close`)
- *running* process on each sides
- `A -⚬ Source[📄]` is the blueprint

Resources

- not tied to inflexible (nested) scopes
- release guaranteed by **linearity**



Summary

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Stream operators in Libretto are

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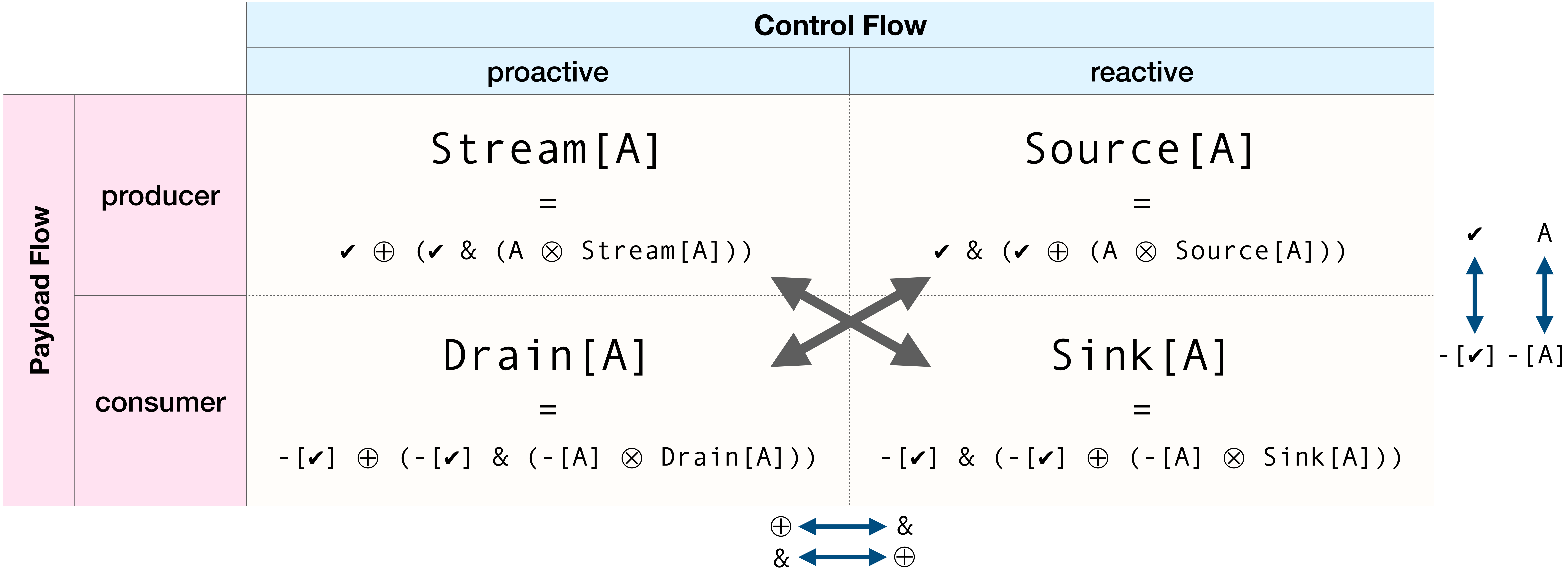
Stream operators in Libretto are
safer and **simpler** than the alternatives.

(I might be biased, feel free to challenge.)

Streams in Libretto



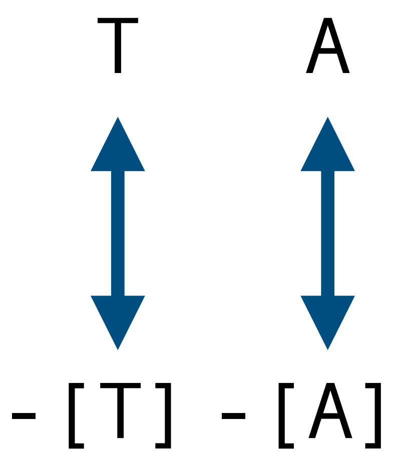
		Control Flow	
		proactive	reactive
Payload Flow	producer	Stream[A] = ✔ ⊕ (✔ & (A ⊗ Stream[A]))	Source[A] = ✔ & (✔ ⊕ (A ⊗ Source[A]))
	consumer	Drain[A] = -[✔] ⊕ (-[✔] & (-[A] ⊗ Drain[A]))	Sink[A] = -[✔] & (-[✔] ⊕ (-[A] ⊗ Sink[A]))

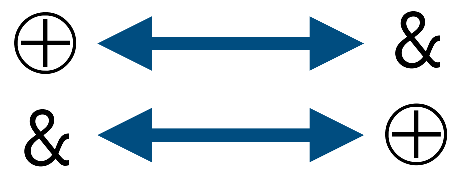
-[Stream[A]] ~ Sink[A]

-[Source[A]] ~ Drain[A]

Bonus: Streams with Custom Terminator

		Control Flow	
		proactive	**reactive**
Payload Flow	**producer**	StreamT[T,A] = T ⊕ (T & (A ⊗ StreamT[T,A]))	SourceT[T,A] = T & (T ⊕ (A ⊗ SourceT[T,A]))
	consumer	DrainT[T,A] = -[T] ⊕ (-[T] & (-[A] ⊗ DrainT[T,A]))	SinkT[A] = -[T] & (-[T] ⊕ (-[A] ⊗ SinkT[T,A]))





Example: API of a TV streaming service

```
Tv = ✔ & (ChannelName =o SourceT[Tv,VideoFrame])
```

- ensures consuming at most 1 channel at a time

Gateway drug to session types

Thank you!

github.com/TomasMikula/libretto/

(includes runnable version of each shown example)