# Steel:
# Scaling up verification in $\mathbf{F}^\star$

AYMERIC FROMHERZ, DENIS MERIGOUX

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EVERCRYPT

everparse

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- F*: Classical Hoare logic and select/update reasoning. How to scale?

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What about verification?

- Rust programs aren't proven correct
- Rust programs have unsafe blocks

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3. Fork/join concurrency with locks

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- Core memory model
- Resource separation
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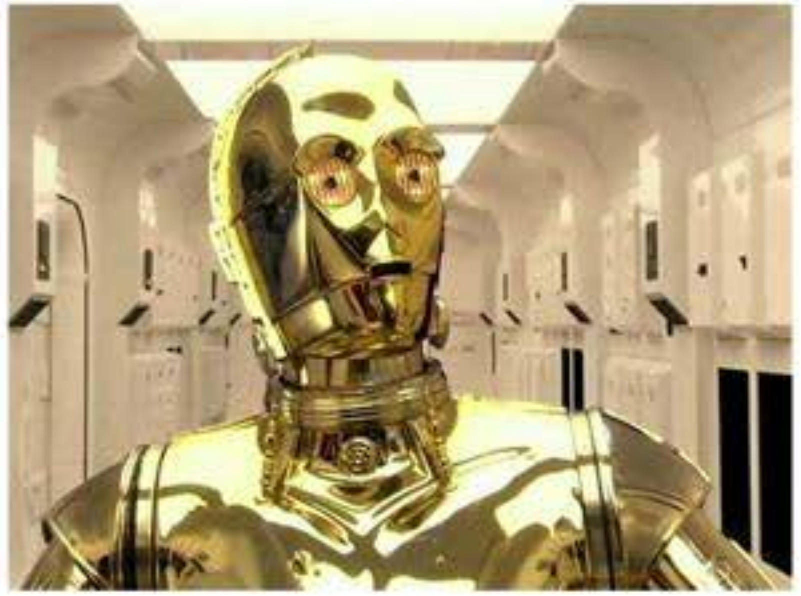

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`RST` $(\alpha$: `Type`)

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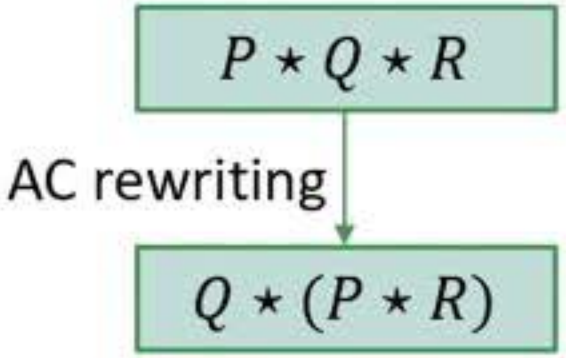


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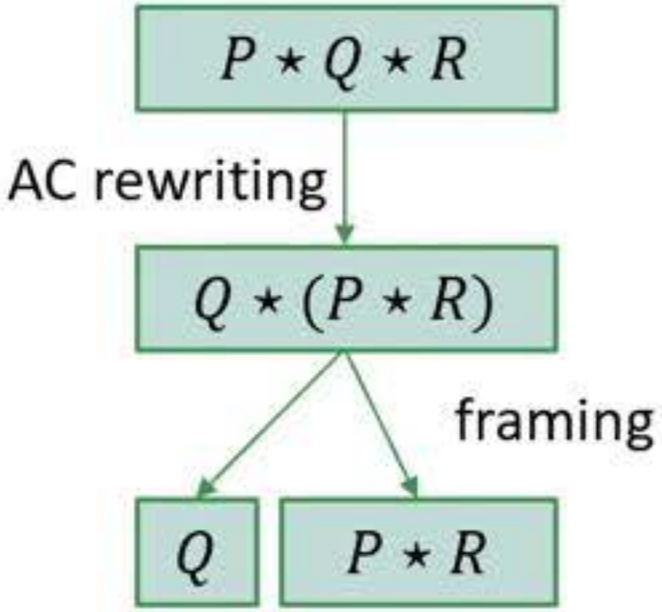


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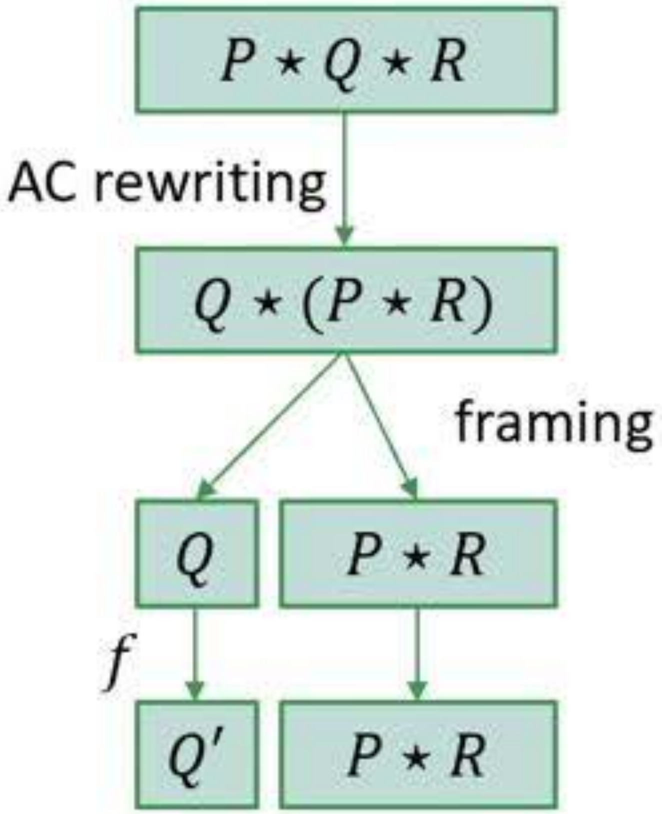


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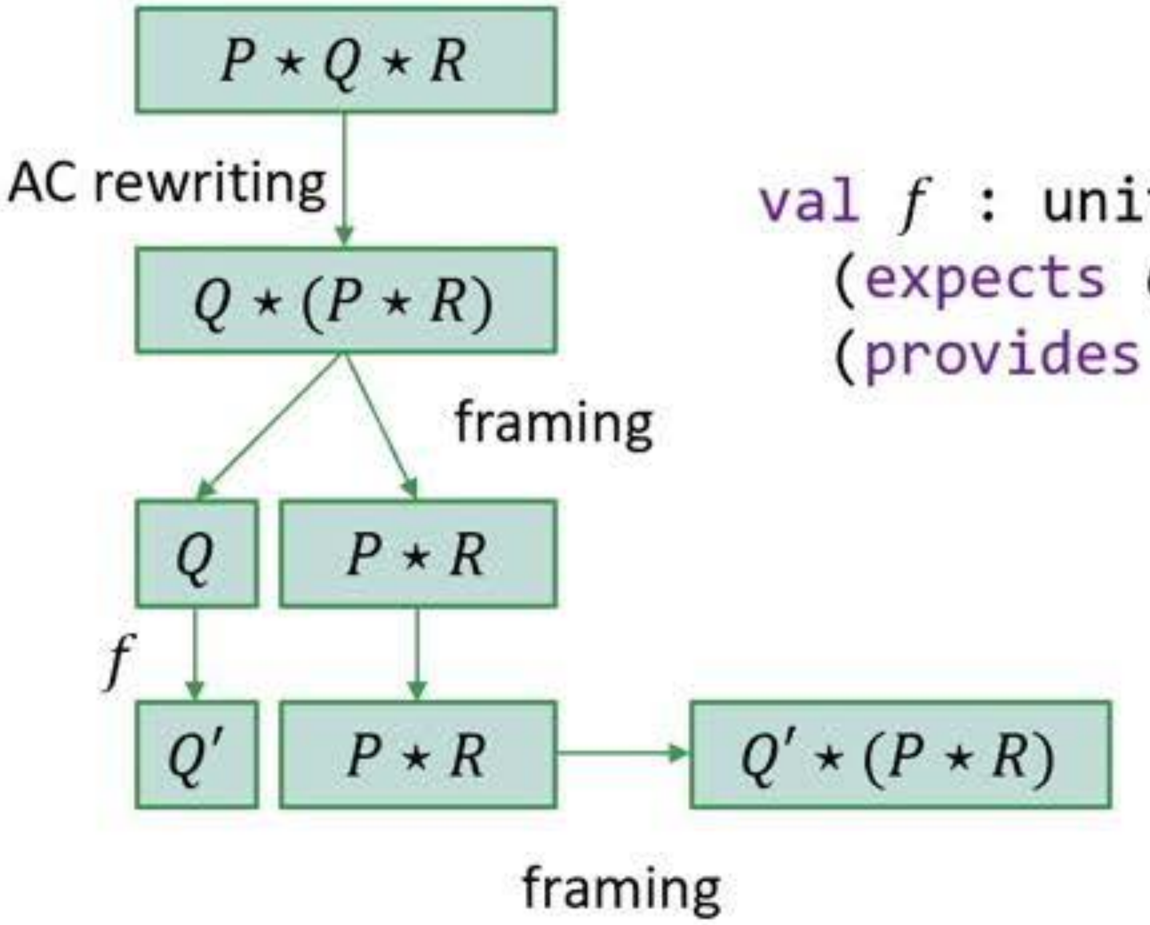


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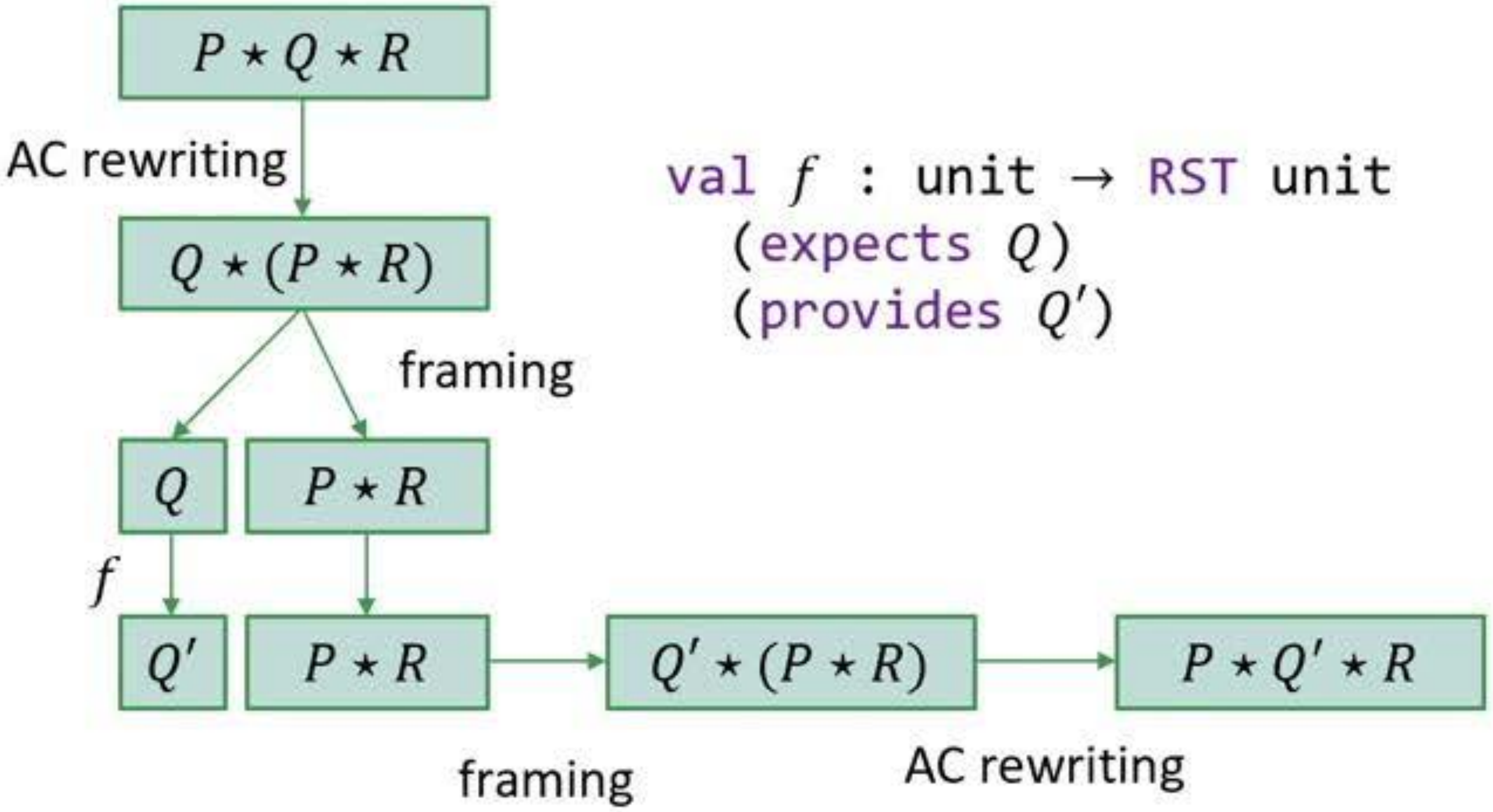


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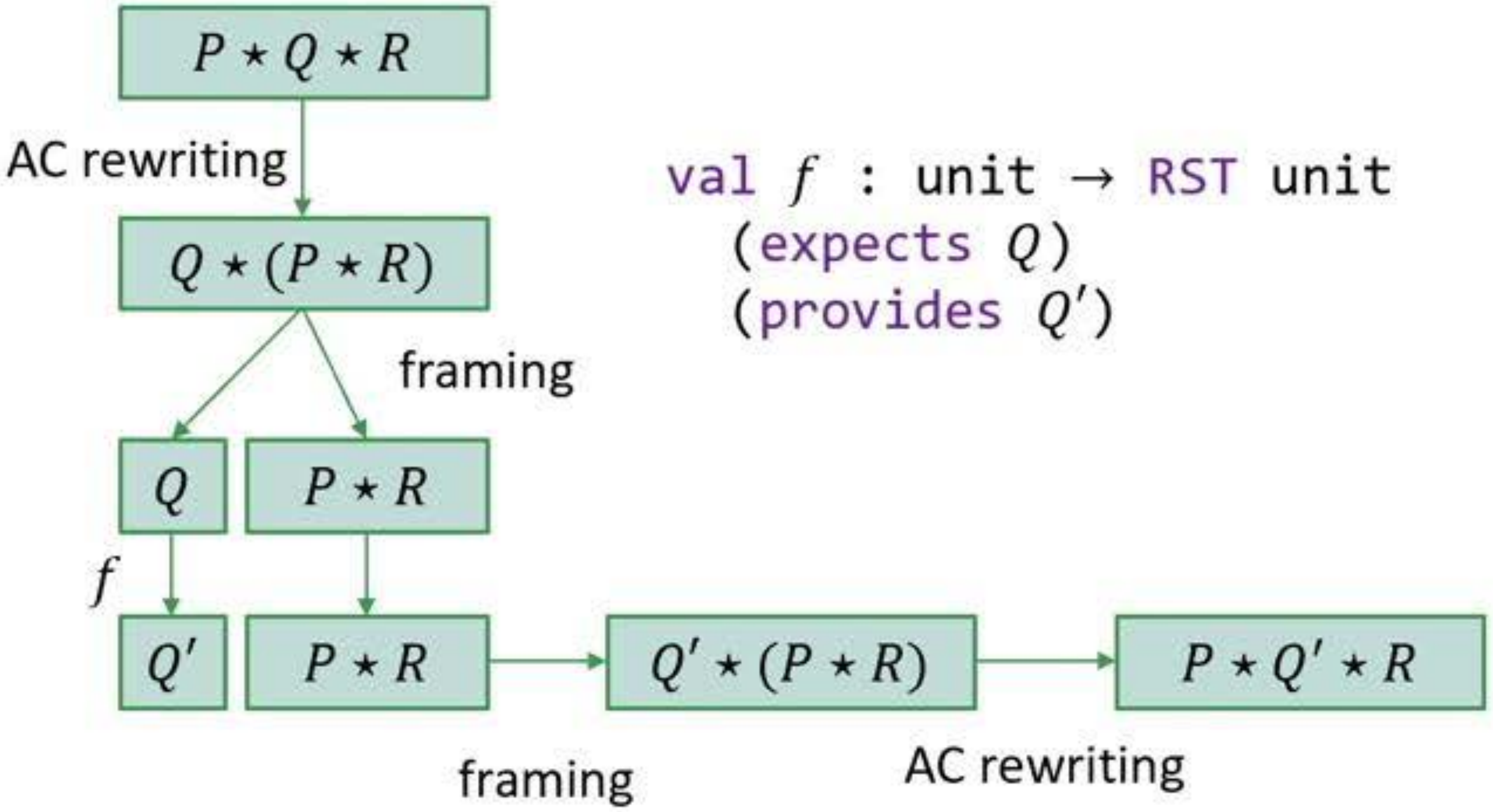


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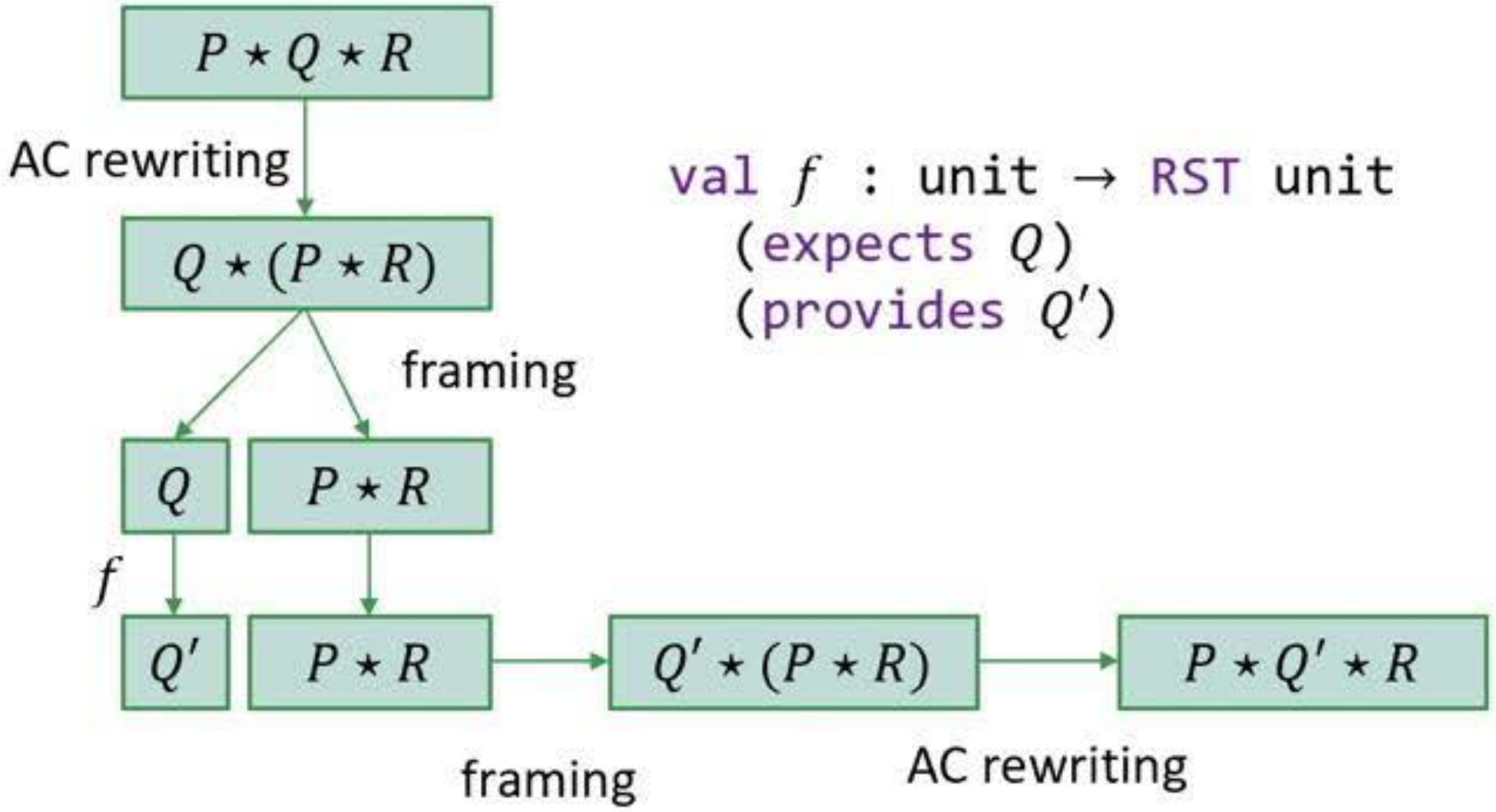


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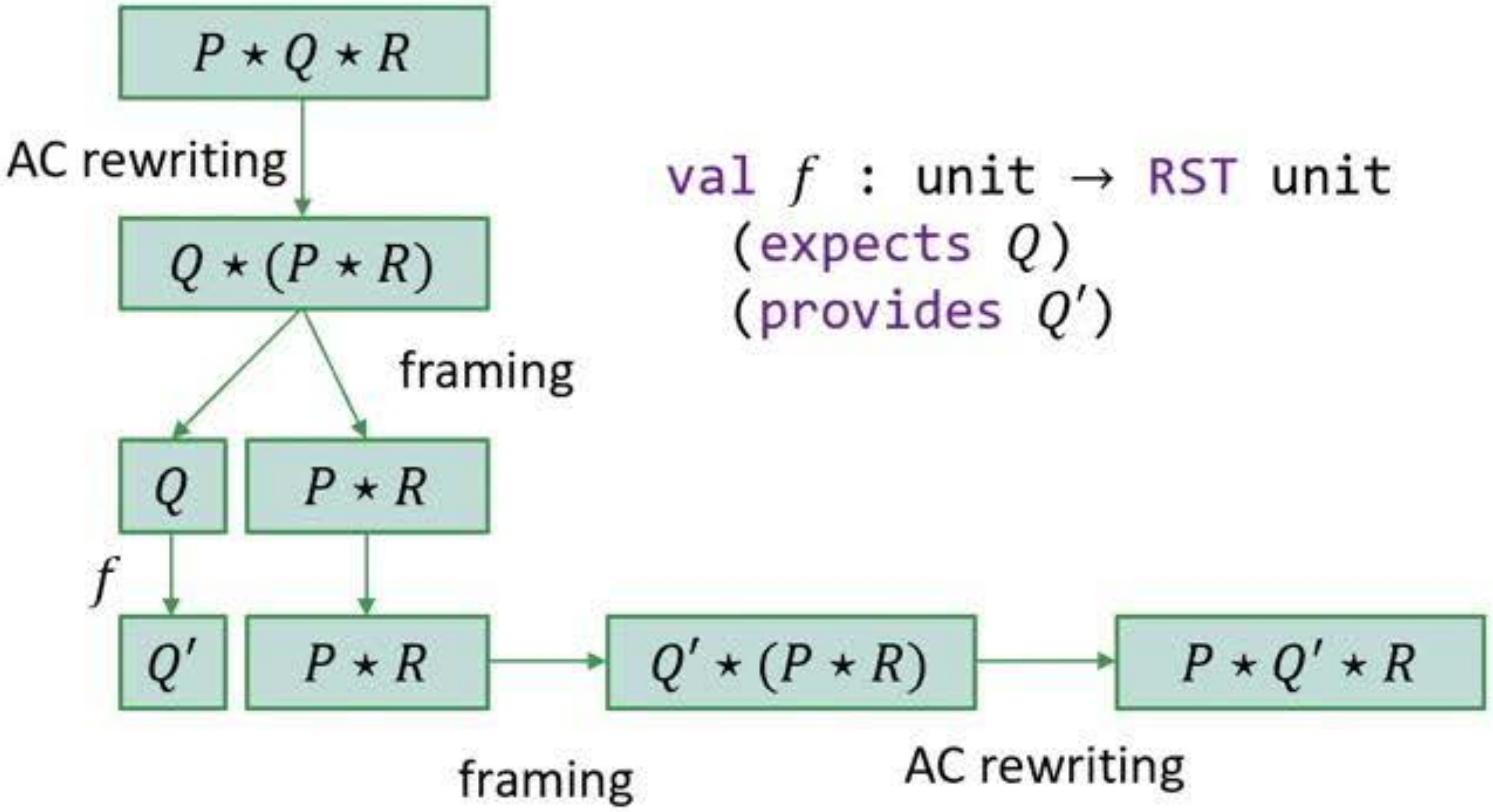


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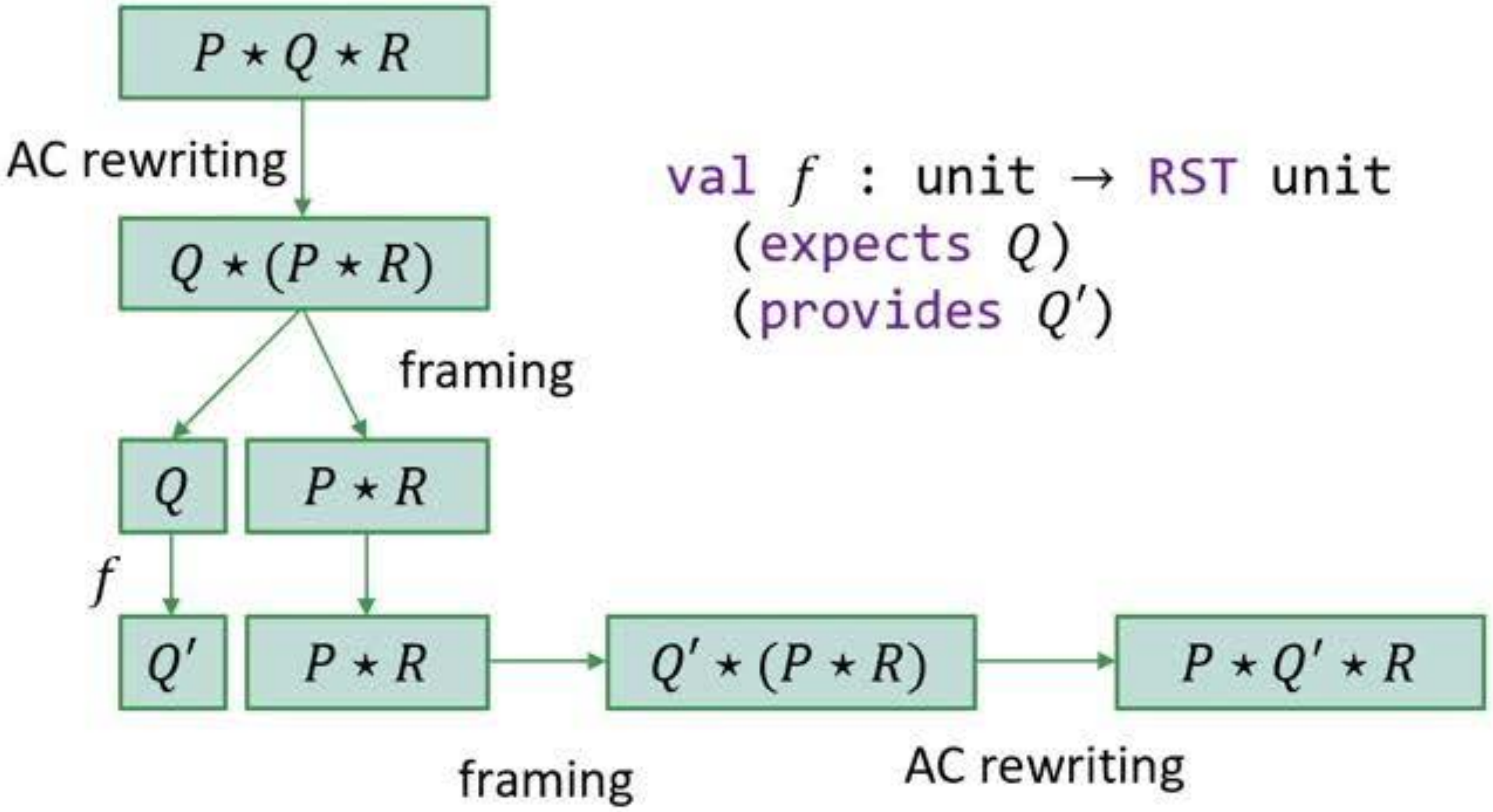


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- `⋆ : resource → resource → resource` is higher-order

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Verification conditions

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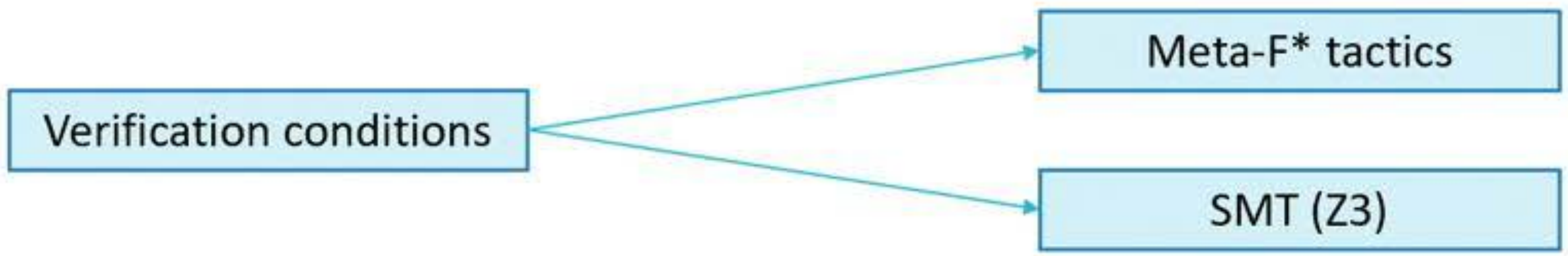


(since 2017)

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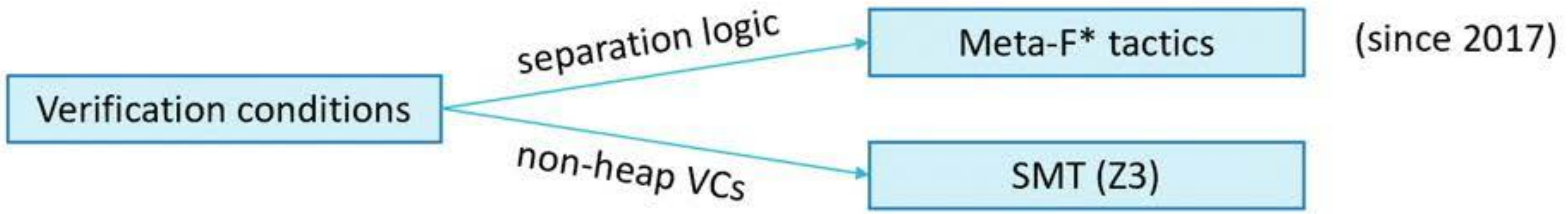

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read_only p:

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Read-only resource:

RO $R$

Read-write resource:

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Immutable sharing:

```
val share : (p: pointer α) →
  RST (pointer α)
```

# Sharing and read-only resources

Read-only resource:

RO $R$

Read-write resource:

RW $R$

Pointer dereference:

```
val (!) : (p: pointer α) →
  RST α
      (expects (RO (ptr p)))
      (provides (λ v → RO (ptr p ↦ v)))
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<u>Immutable sharing:</u>

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val share : (p: pointer α) →
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      (expects (RW (ptr p)))
      (provides (λ p′ → RO (ptr p) ⋆ RO (ptr p′)))
```

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val gather : ($p$: pointer $\alpha$) → ($p'$: pointer $\alpha$) →
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# Main idea 3: Concurrency in Steel

Currently in scope:

- Data-race freedom
- Sequential consistency
- Scoped fork-join model (par combinator)
- Mutable memory shared through locks

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Concurrent separation logic:

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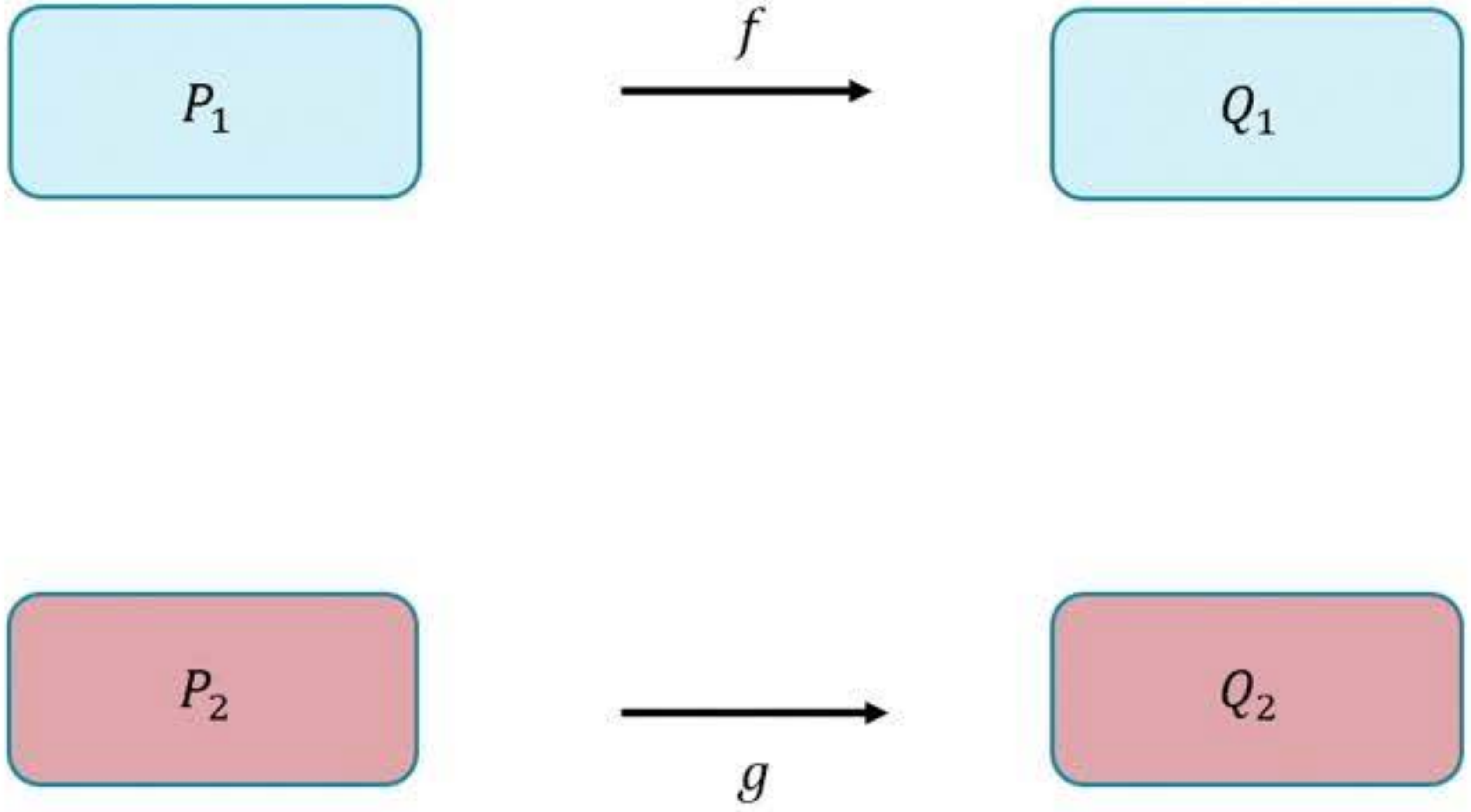

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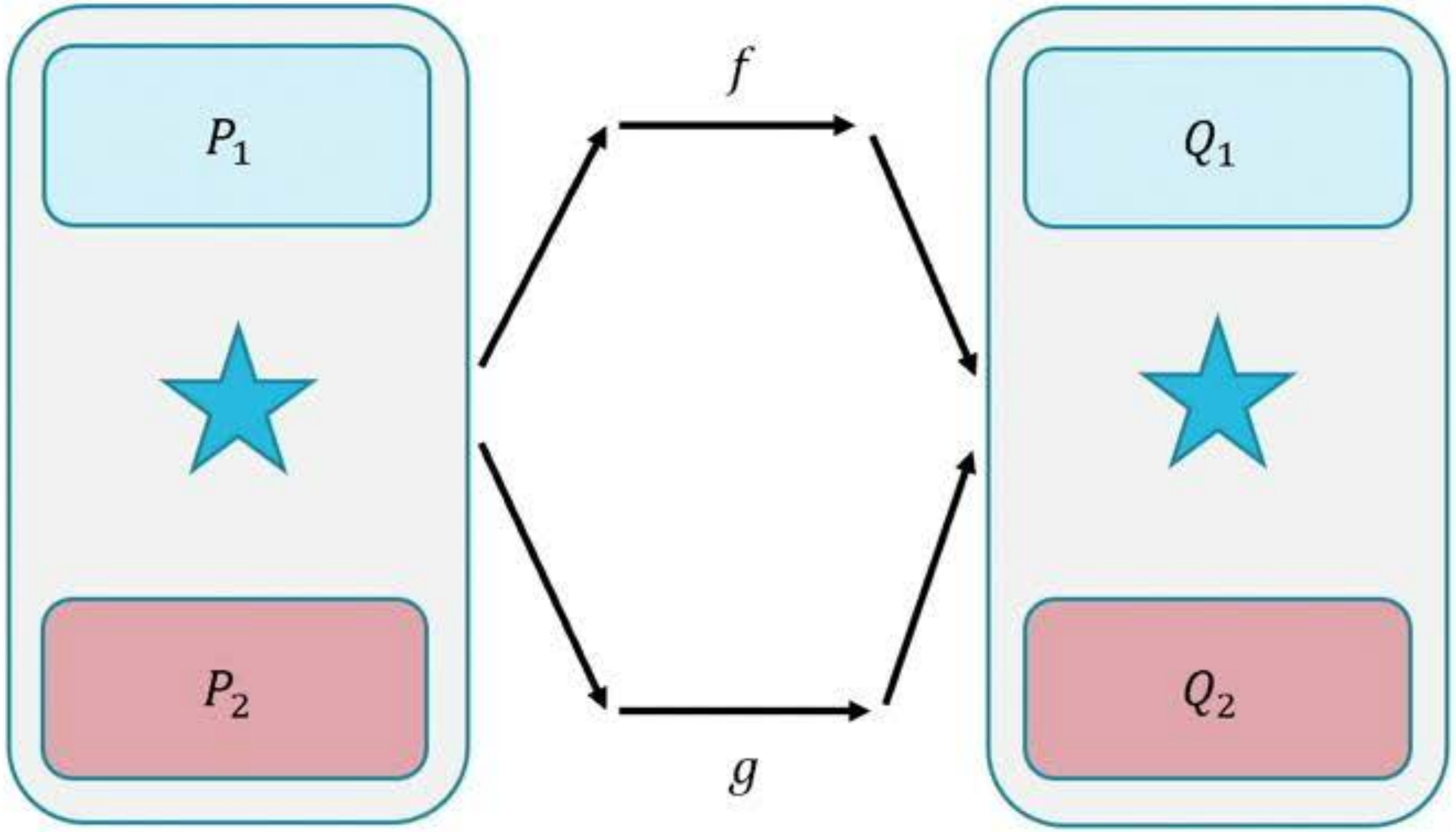
$$\frac{\{\, P_1 \,\}\, f \,\{\, Q_1 \,\} \qquad \{\, P_2 \,\}\, g \,\{\, Q_2 \,\}}{\{\, P_1 \star P_2 \,\}\, f \,||\, g \,\{\, Q_1 \star Q_2 \,\}}$$



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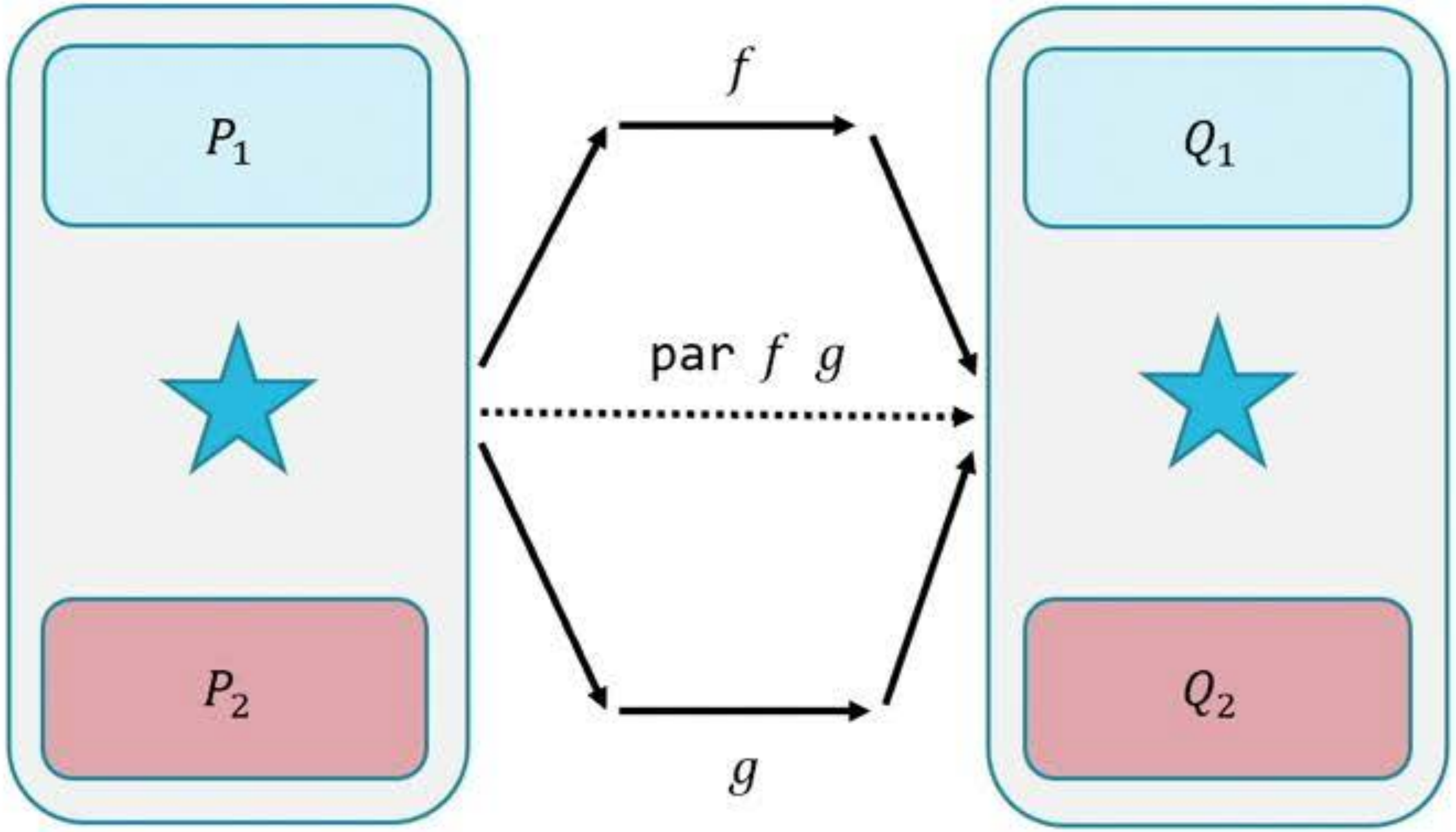
Steel:

```
val par:
  (f: unit → RST α P₁ Q₁) →
  (g: unit → RST β P₂ Q₂) →
  RST (α * β)
     (expects P₁ ⋆ P₂)
     (provides Q₁ ⋆ Q₂)
```



# Shared mutable access using locks

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Concurrent separation logic:

Stable invariant

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val acquire (ℓ:lock R) →
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     (provides R)
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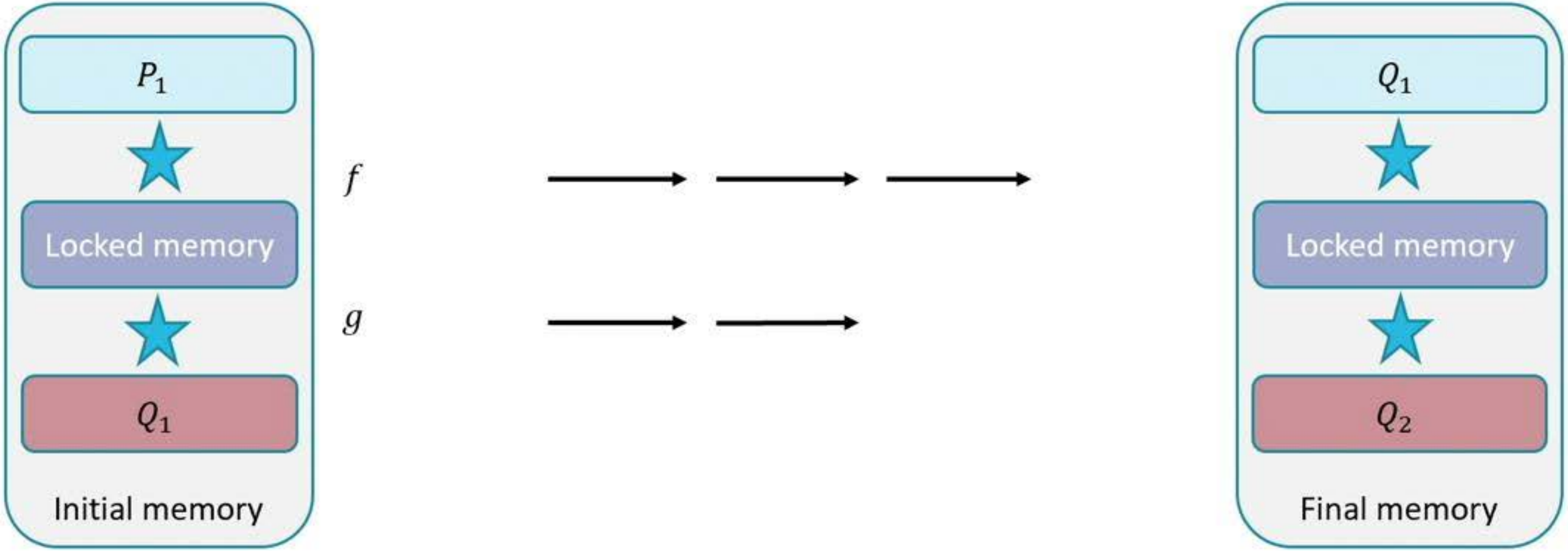
- Lock predicates checked statically
- Lock availability checked at runtime

# Soundness of the concurrency model
## (Work in progress)



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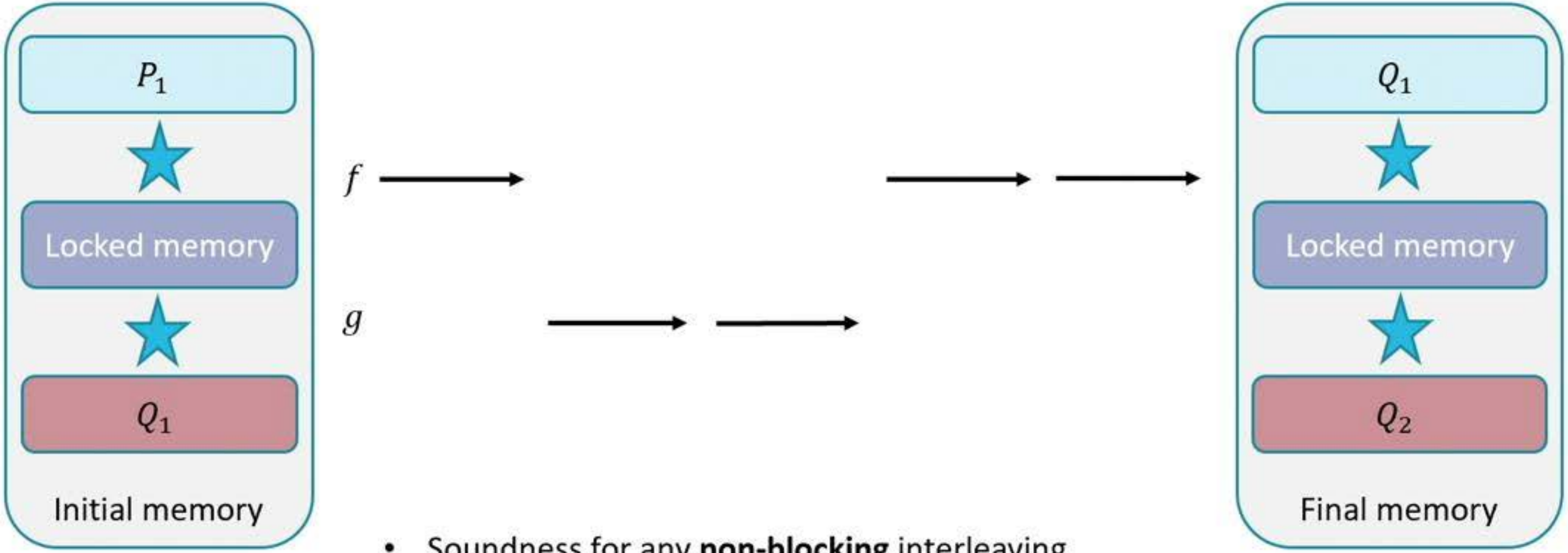


- Soundness for any **non-blocking** interleaving
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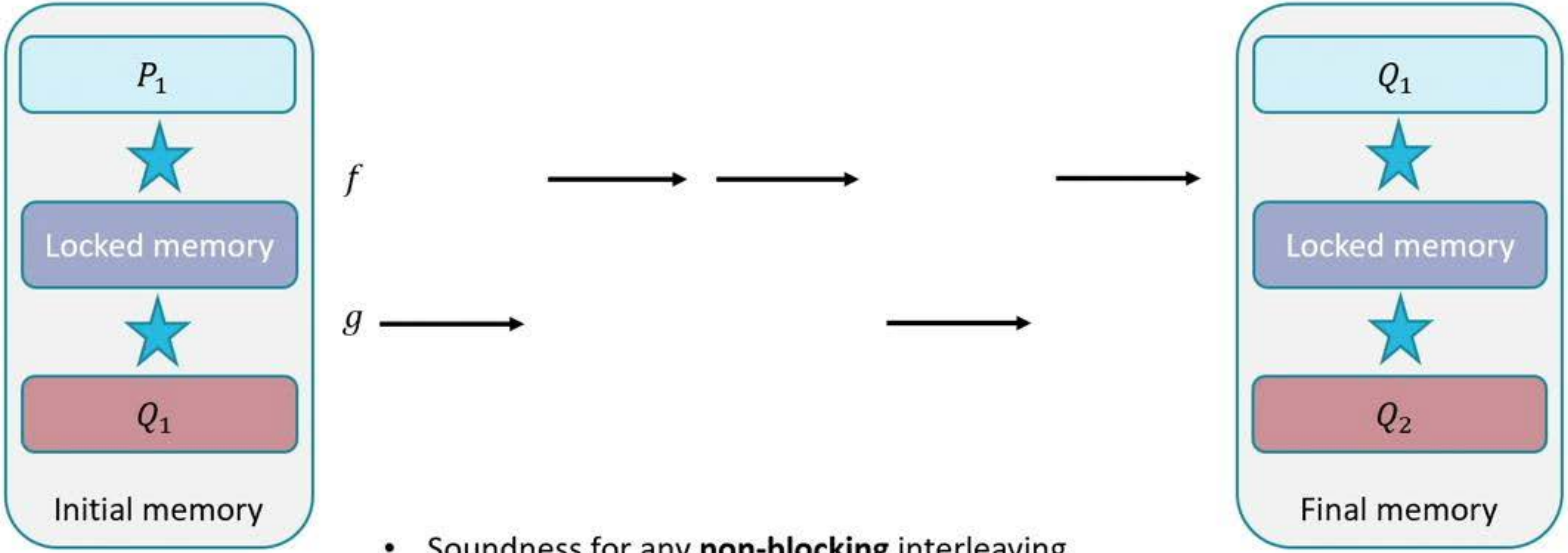


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# Case study: Linked lists specification

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<u>Steel:</u>

```
let rec slist x (ℓ:ghost (list cell)) : resource =
  match ℓ with
  | [] -> emp
  | hd::tl -> (x ↦ hd) ⋆ (slist hd.next tl)
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val map f p ℓ : RST unit
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```

Low*:

```
let well_formed x ℓ = … (10 lines)
let footprint x ℓ = … (8 lines)

val cons p v x ℓ : ST unit
  (requires
     well_formed x ℓ &&
     disjoint (loc p) (footprint x ℓ) &&
     live p &&
     get p == v)
  (ensures
     well_formed p (v :: ℓ) &&
     modifies (footprint p (v :: ℓ)))
```

cons, head, tail, map specification

- Steel: 30 LOC
- Low*: 100 LOC

# Case study: Linked lists implementation

<u>Steel:</u>

```
let rec map f x ℓ =
  …
  frame
    ((x ↦ hd ℓ) ⋆ slist (hd ℓ).next (tl ℓ))
    (λ _ → (x ↦ f (hd ℓ)) ⋆ slist (hd ℓ).next (tl ℓ))
    (update_cell f x);
  frame
    ((x ↦ f (hd ℓ)) ⋆ slist (hd ℓ).next (tl ℓ))
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    (map f (hd ℓ).next (tl ℓ))
```

Ideally:

```
let rec map f x ℓ =
  …
  update_cell f x;
  map f (hd ℓ).next (tl ℓ)
```

Work in progress: Better frame inference

# Case study: Doubly-linked lists

- Doubly-linked lists in Steel: 400 LoCs
- In $\mathrm{Low}^\star$: 4000 LoCs!

# Case study: Doubly-linked lists

- Doubly-linked lists in Steel: 400 LoCs
- In Low*: 4000 LoCs!

- Doubly-linked lists are not expressible in Rust without unsafe blocks due to aliasing restrictions
- Steel is expressive enough to capture complex aliasing patterns

# Future work

- Improve usability of the framework (3 – 6 months)
  - Frontend syntax
  - More fine-tuning of SMT queries
  - Additional libraries
  - Complete interoperation with Low*

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  - Frontend syntax
  - More fine-tuning of SMT queries
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- Concurrency (1 – 2 months)
  - Deadlock prevention
  - Complete proof of soundness

# At last, a $\star$ for $\mathbf{F}^\star$!

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- Separation logic in $F^\star$: Why so long?
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**fromherz@cmu.edu** **denis.merigoux@inria.fr**

# A frame rule for Steel

Classic frame rule:

$$\frac{\{Q\}\ f\ \{R\}}{\{P \star Q\}\ f\ \{P \star R\}}$$

In Steel:

```
val frame :
  (P ⋆ Q: resource) →
  (P ⋆ R: resource) →
  (f: unit → RST α (expects Q) (provides R)) →
  RST α
      (expects (P ⋆ Q))
      (provides (P ⋆ R))
```