On Library Correctness under Weak Memory Consistency

Specifying and Verifying Concurrent Libraries under Declarative Consistency Models

plv.mpi-sws.org/yacovet/

Azalea Raad Marko Doko Lovro Rožić Ori Lahav Viktor Vafeiadis

Max Planck Institute for Software Systems (MPI-SWS)
Tel Aviv University

azalea@mpi-sws.org SoundAndComplete.org @azalearaad

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  - semantic-based: linearisability
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E.g. C11, TSO, ...

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<u>wanted</u>

general

MM-agnostic

declarative

specification & verification

framework

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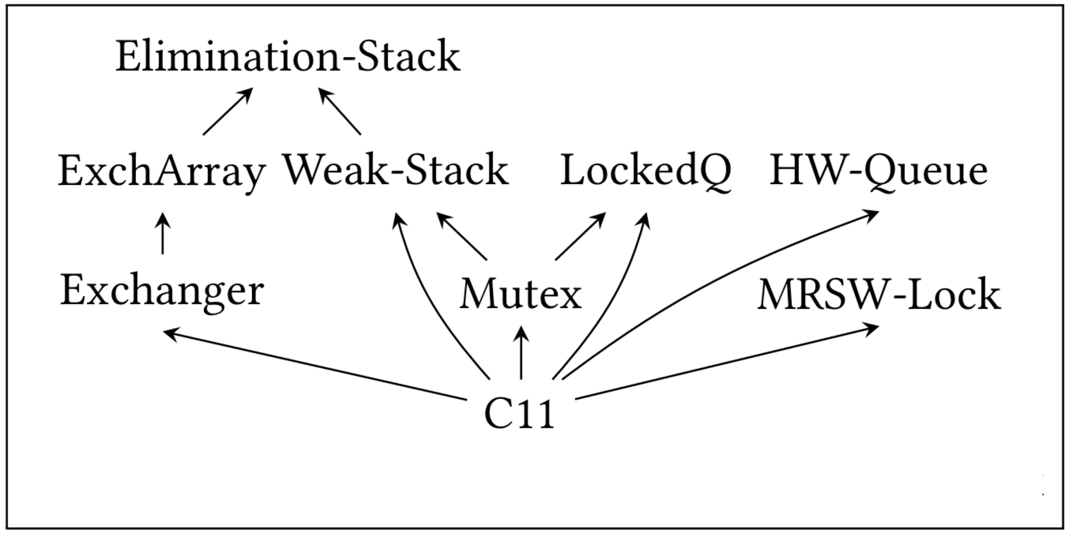

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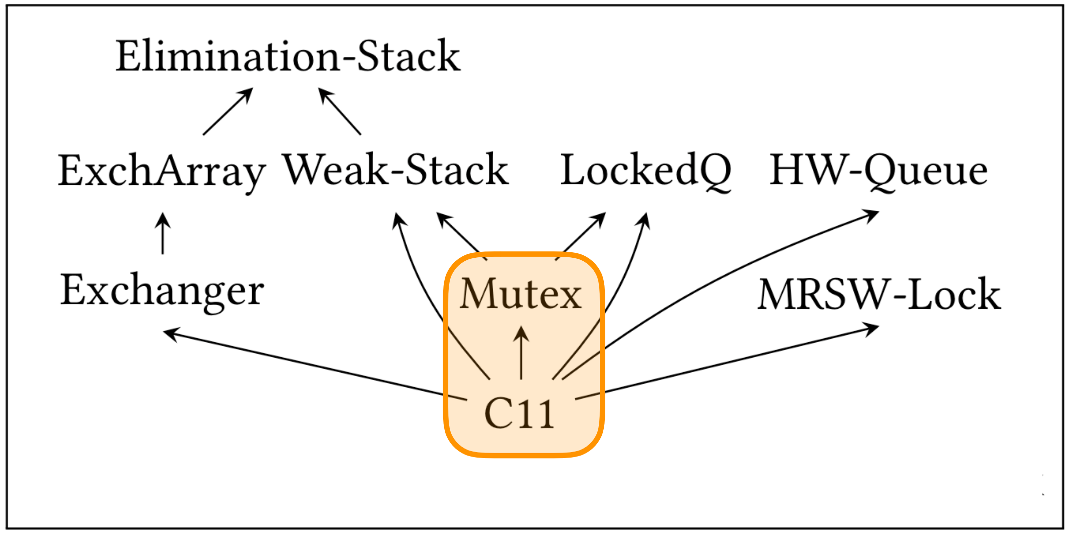

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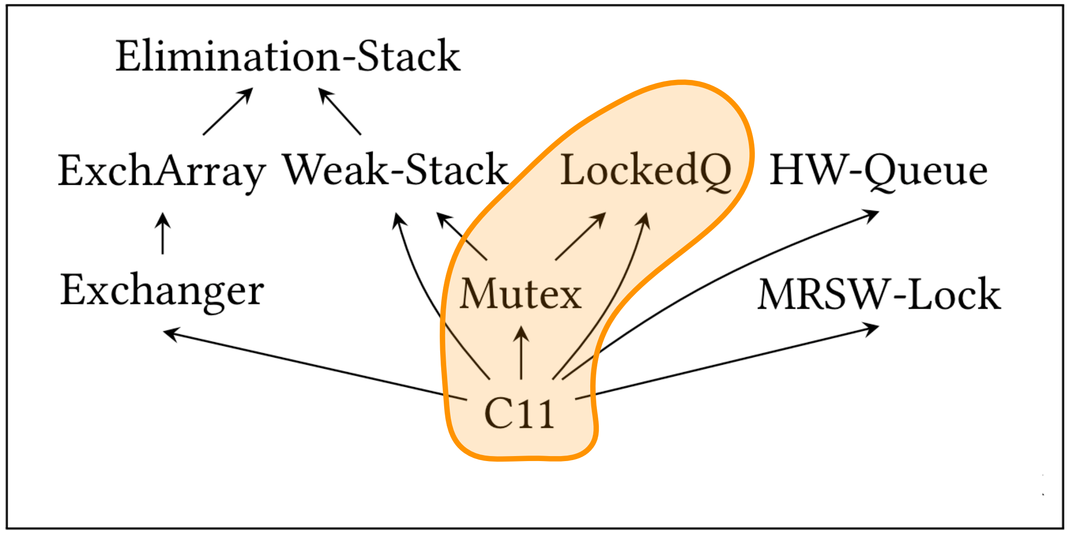
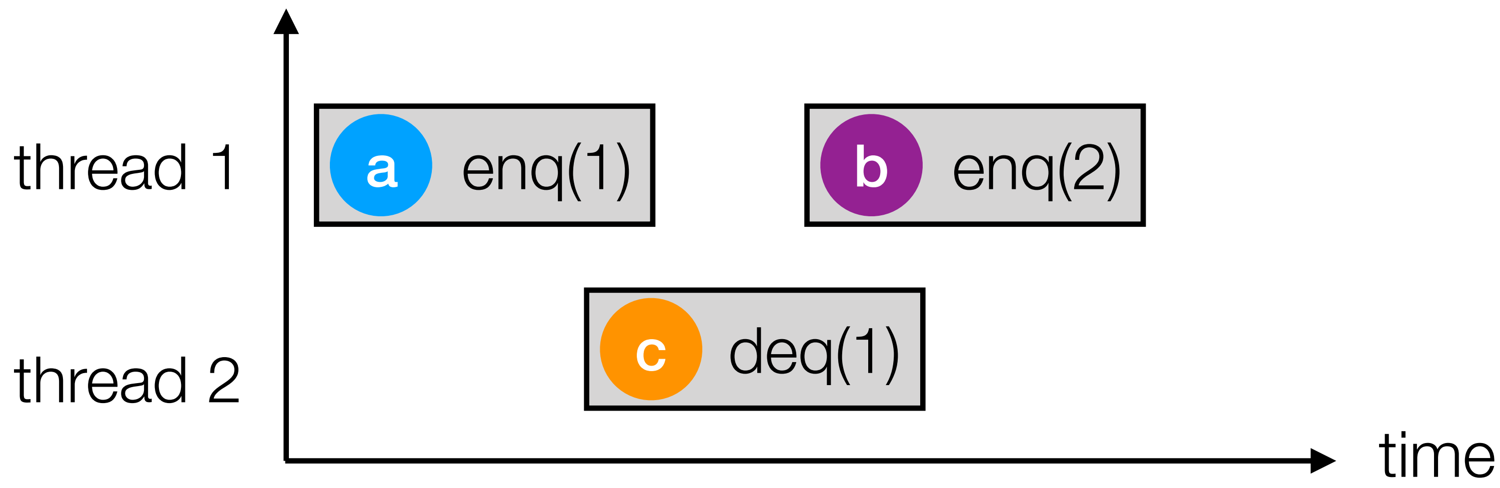


Linearisability



- Define a (partial) happens-before relation *hb* on events
  - $(e_1, e_2) \in hb \iff e_1.\mathrm{end} <_{\mathbf{time}} e_2.\mathrm{begin}$

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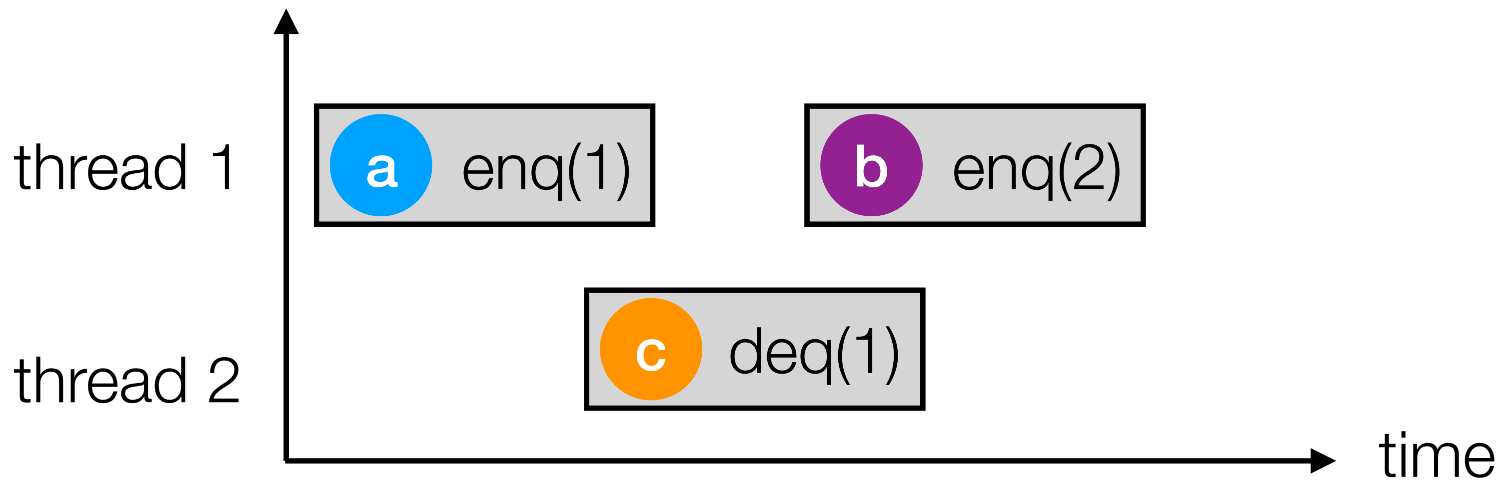

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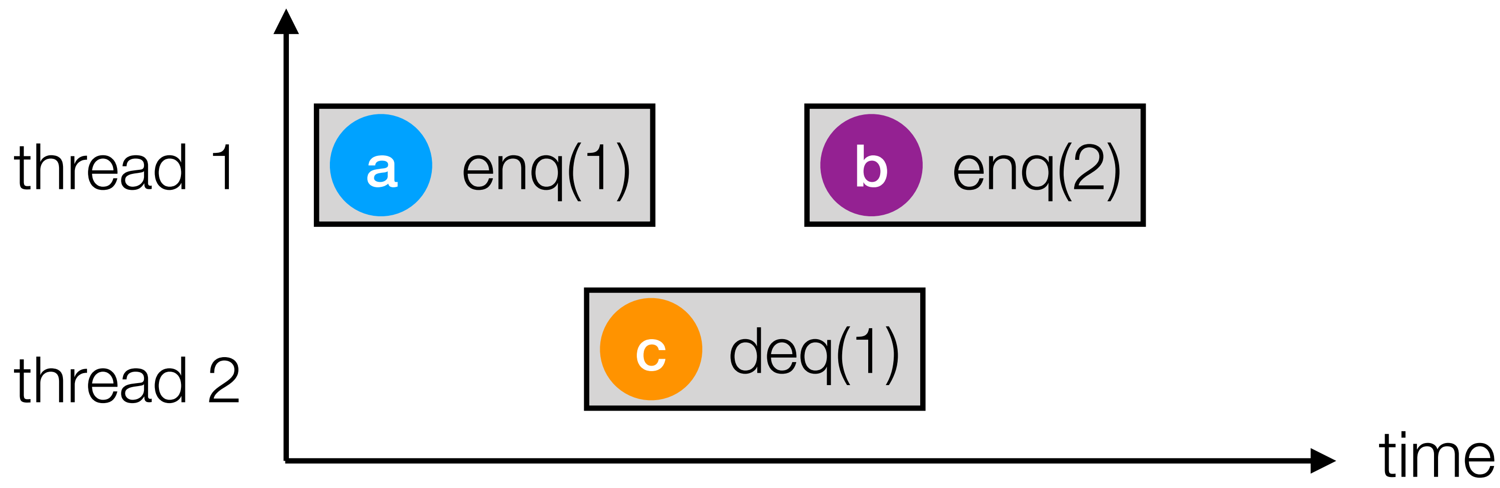

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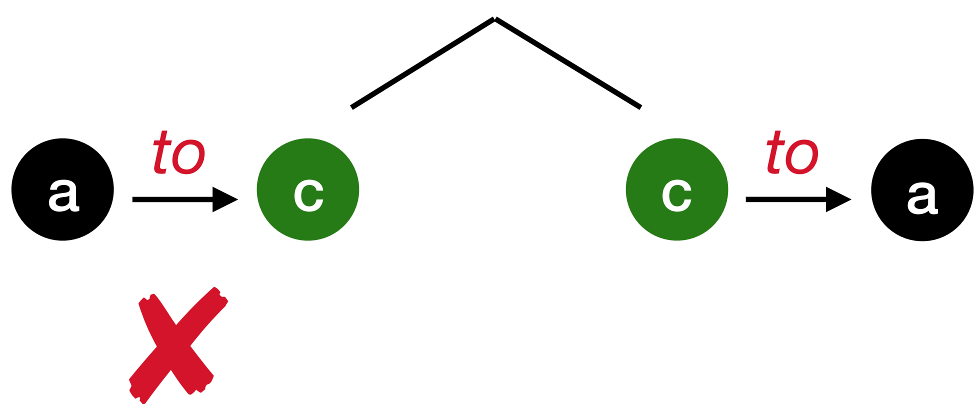

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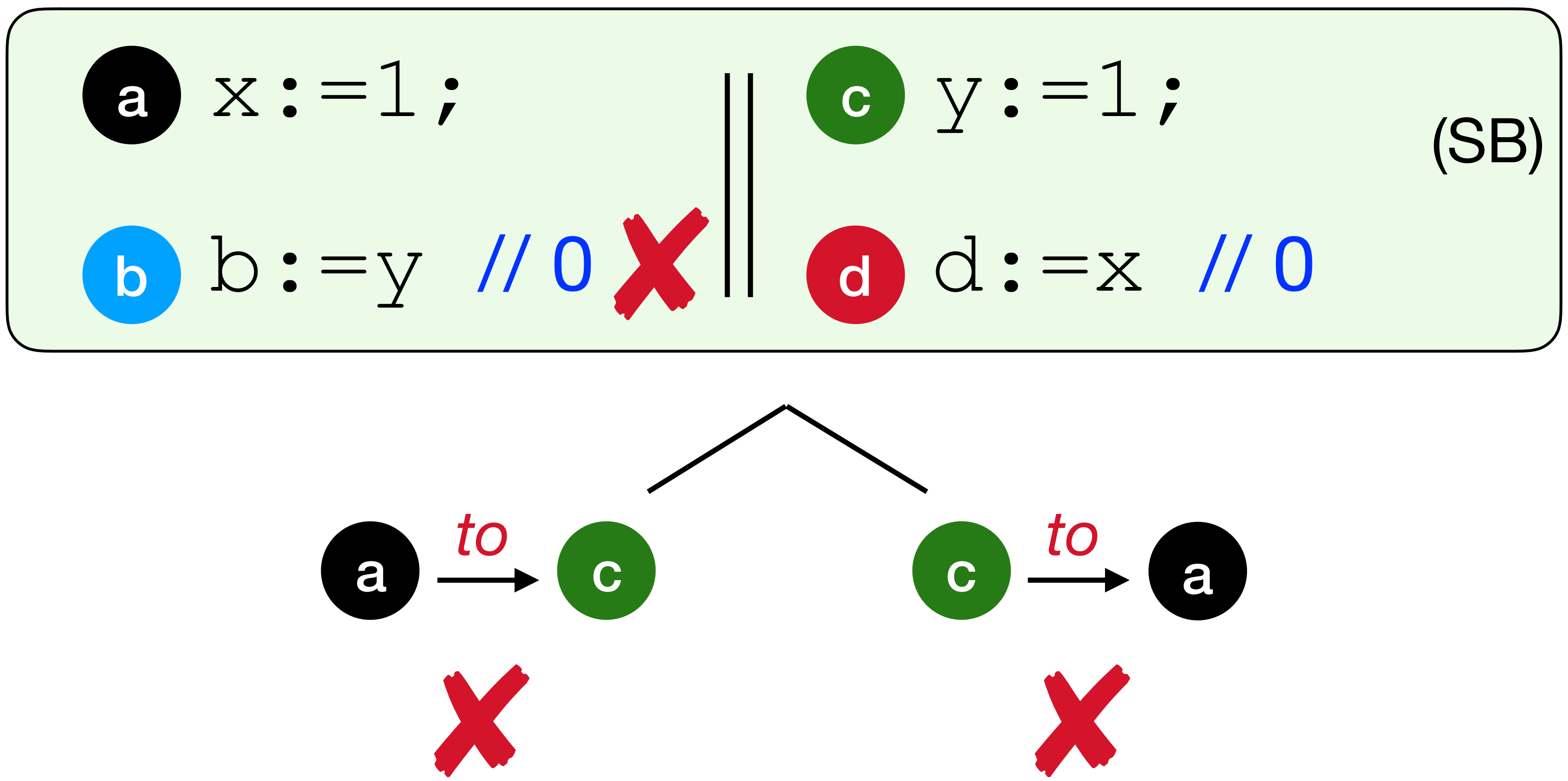

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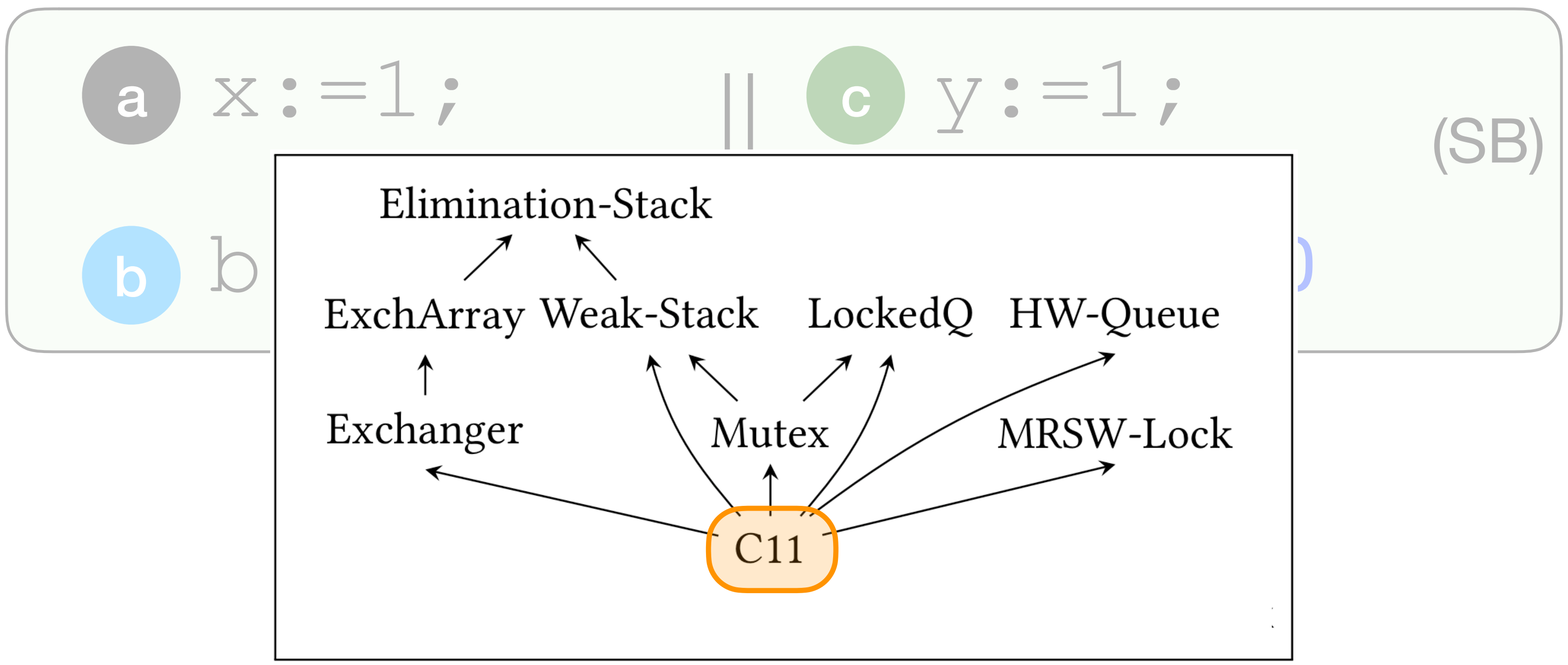

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Our Solution

✔ ***no*** particular ***memory model***

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- ✔ ***per-library*** specification
  - ➡ set of ***library executions***

$$\{G \mid G \text{ satisfies certain } \textbf{\textit{axioms}}\}$$

library execution

Library Executions

Example: ***Queue*** Library

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enq(q,1);    ||  a:=pop(s);
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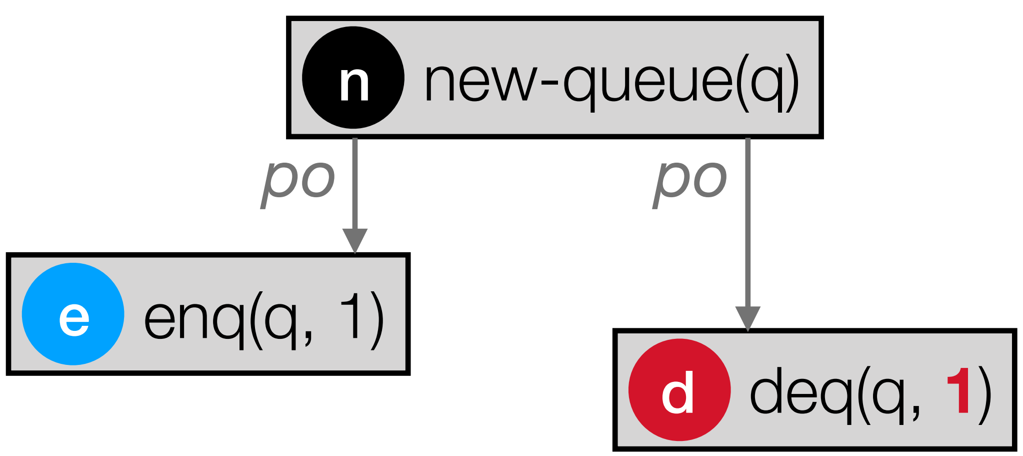

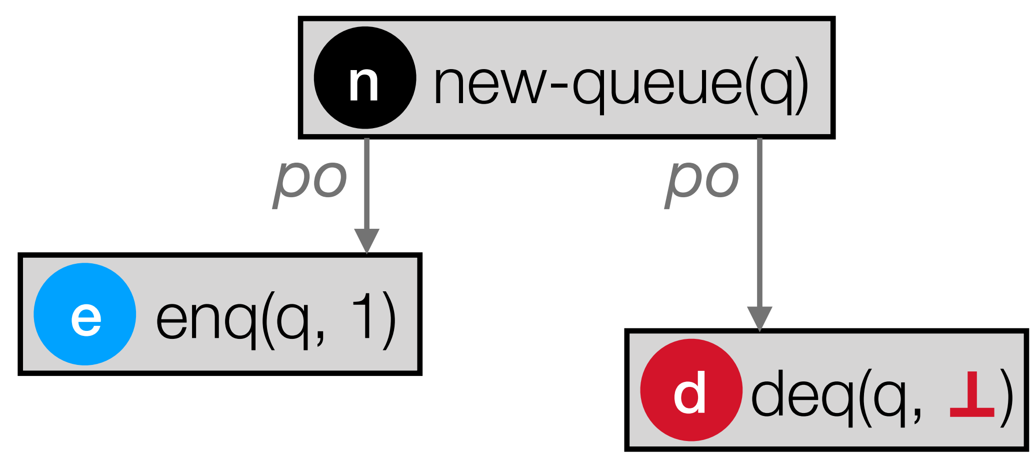

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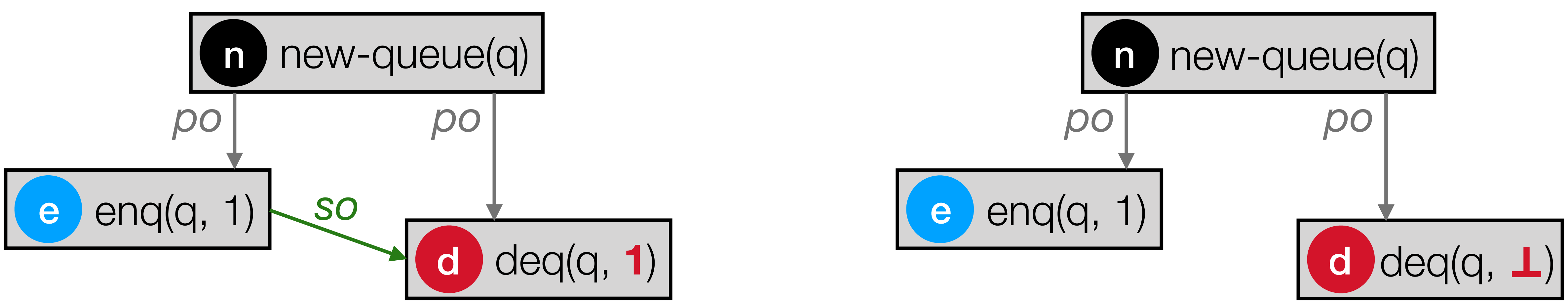

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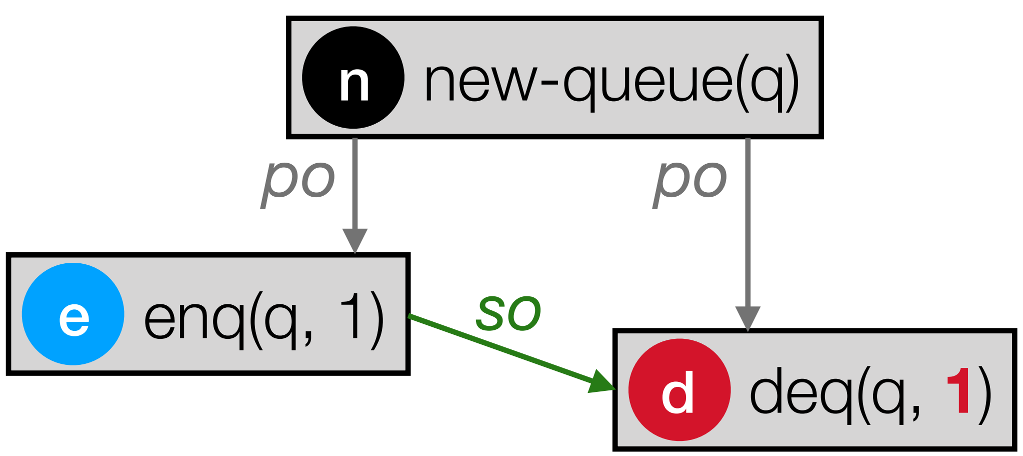

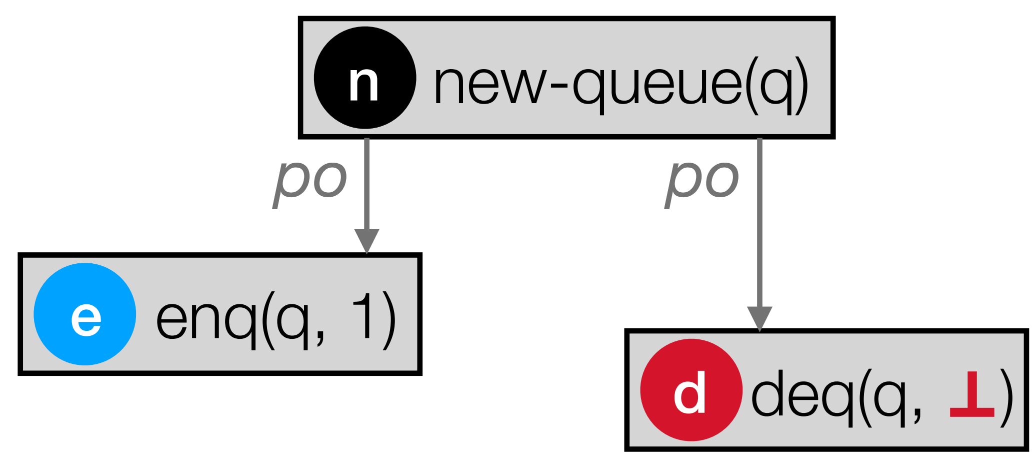

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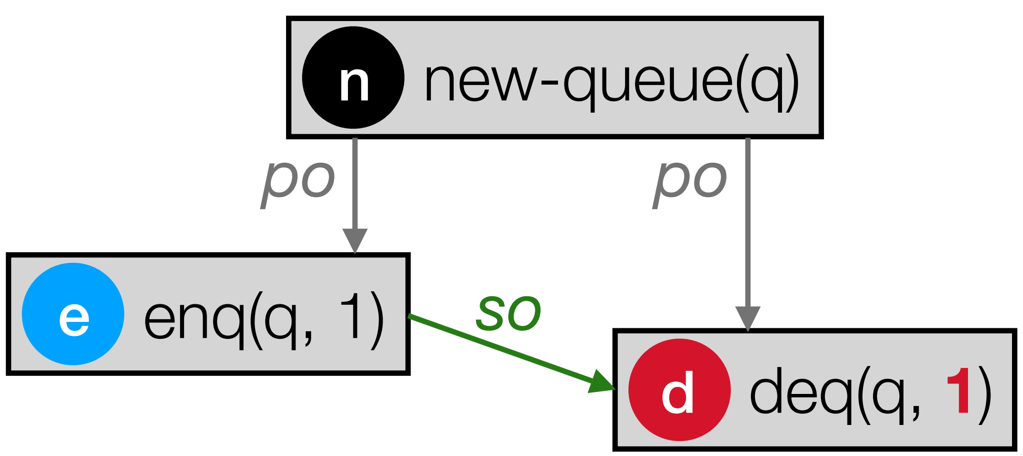

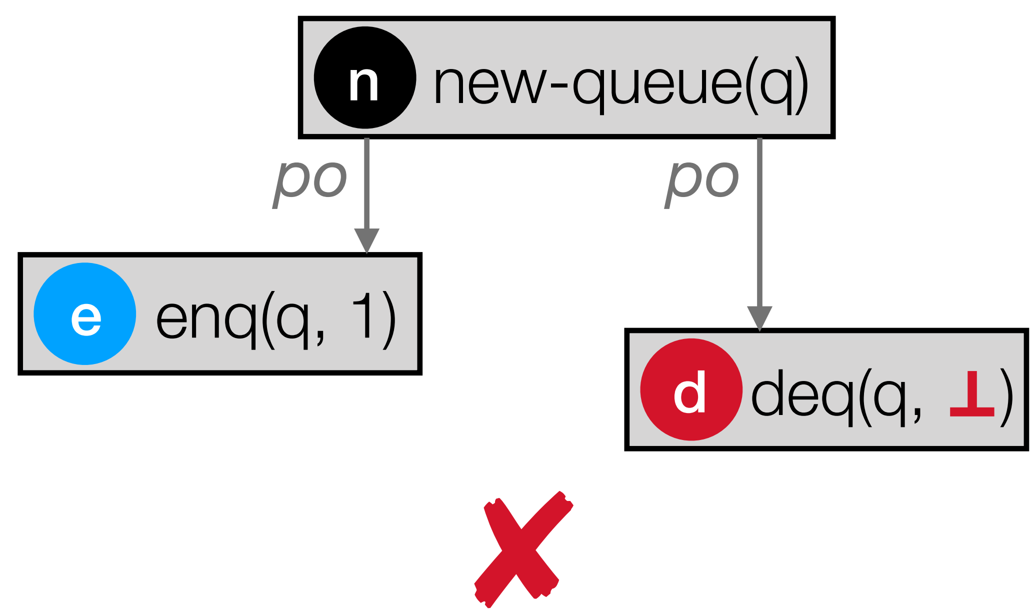

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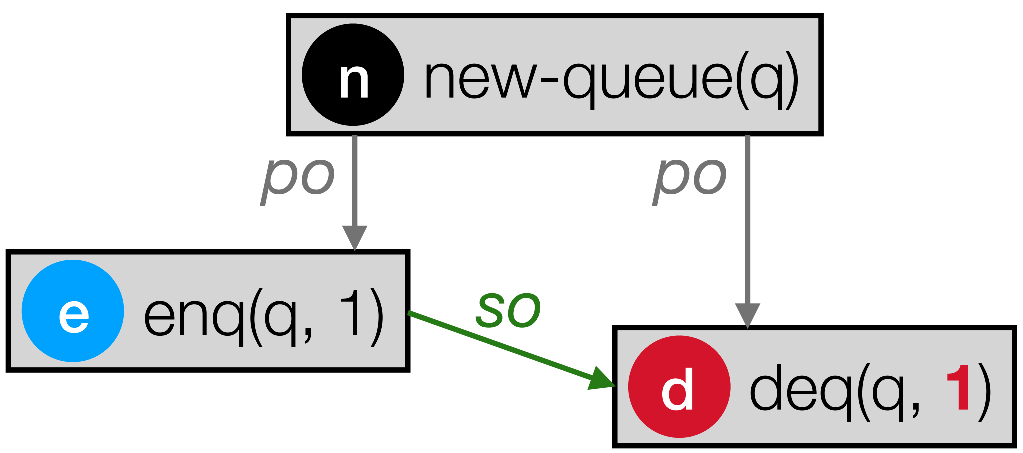

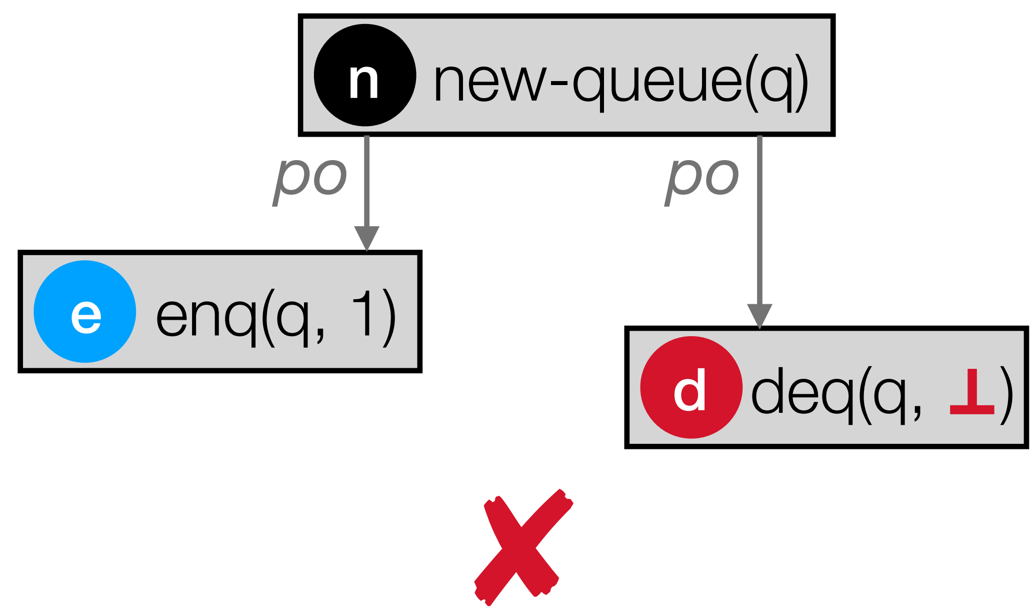

Program Executions

$$[\![P]\!] = \{ G_P = \langle E, po, so \rangle \mid \cdots \}$$

semantics of P

execution of P

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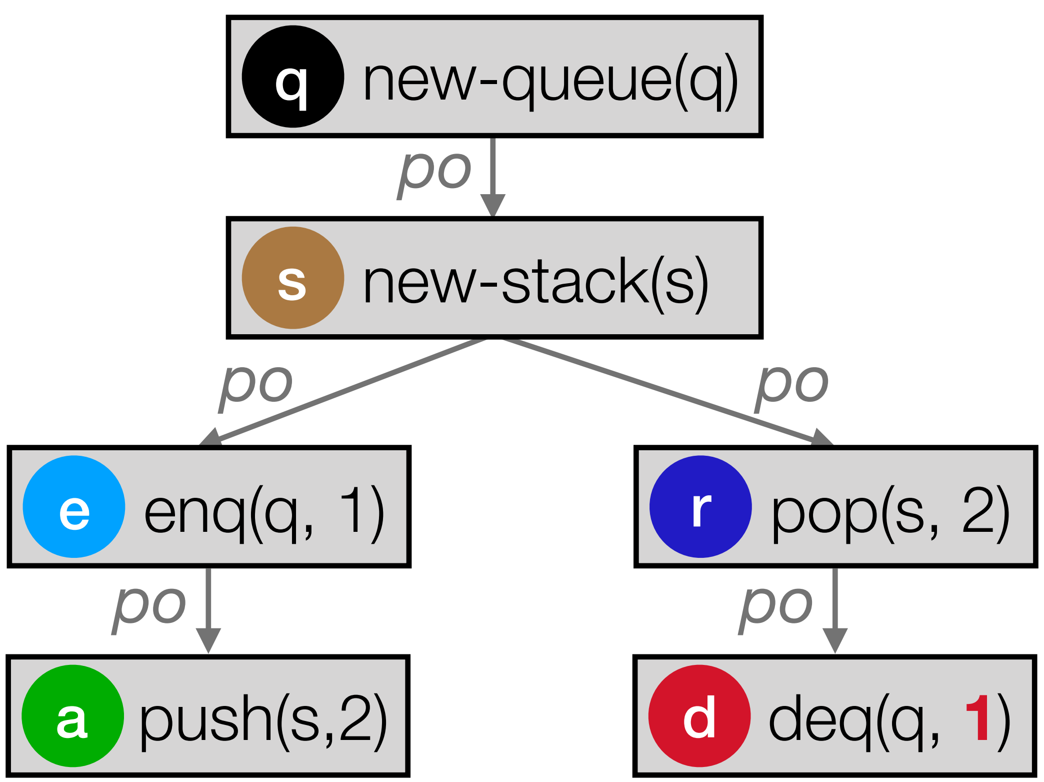

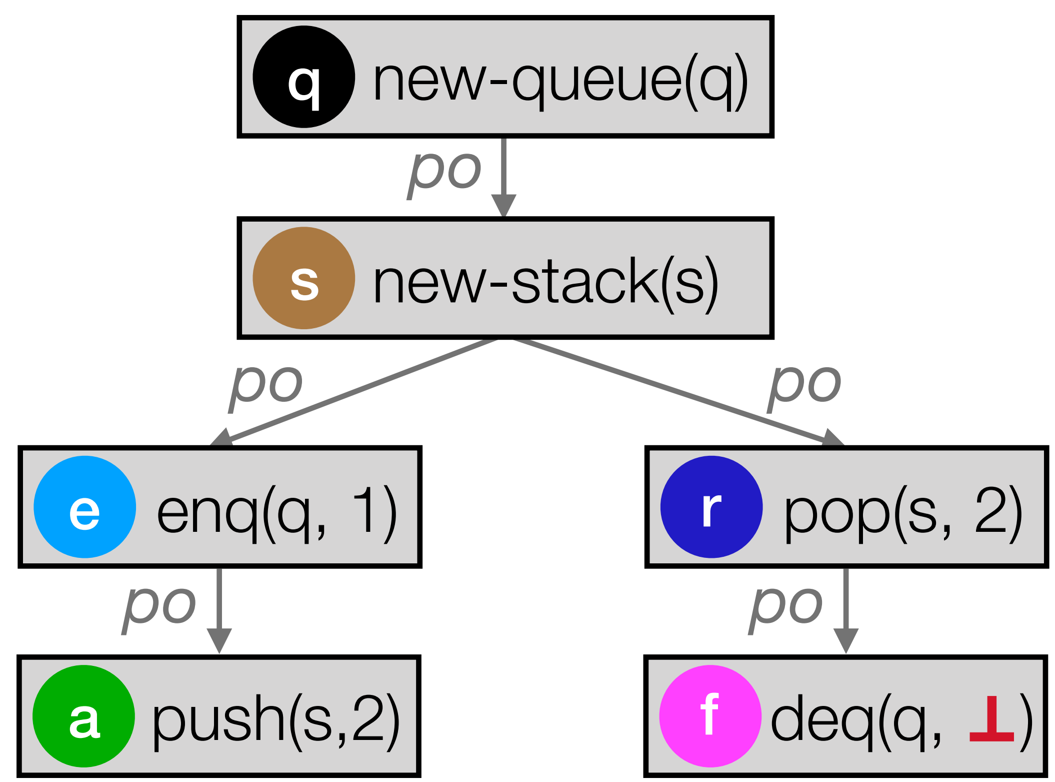

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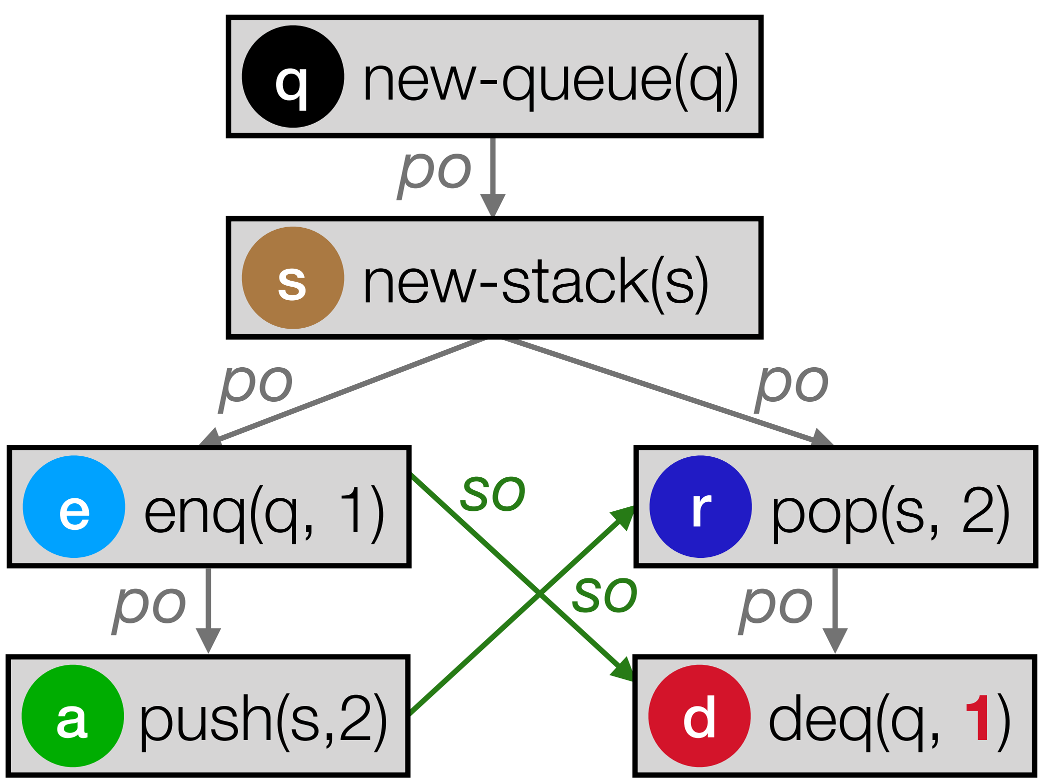

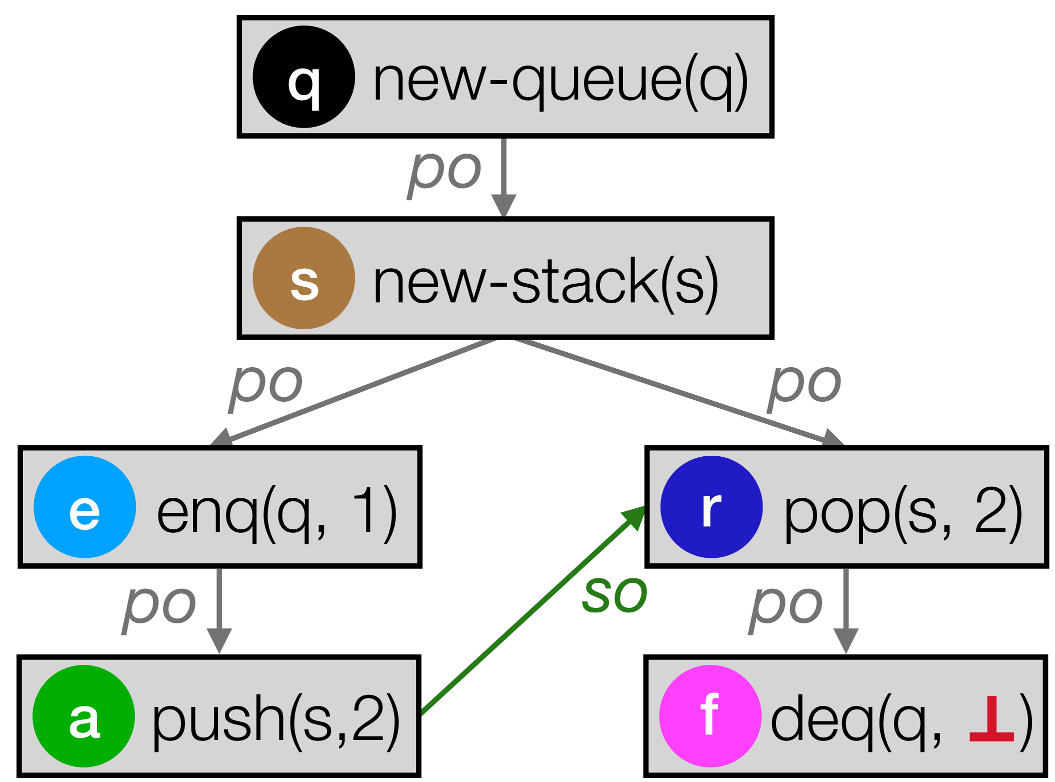

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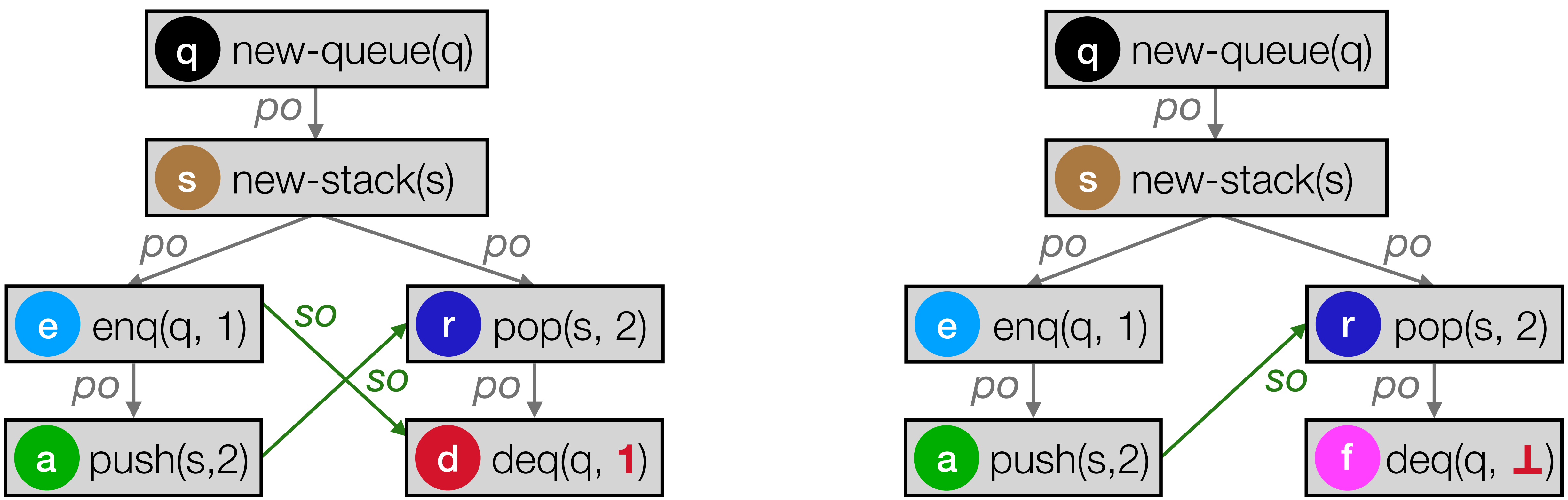

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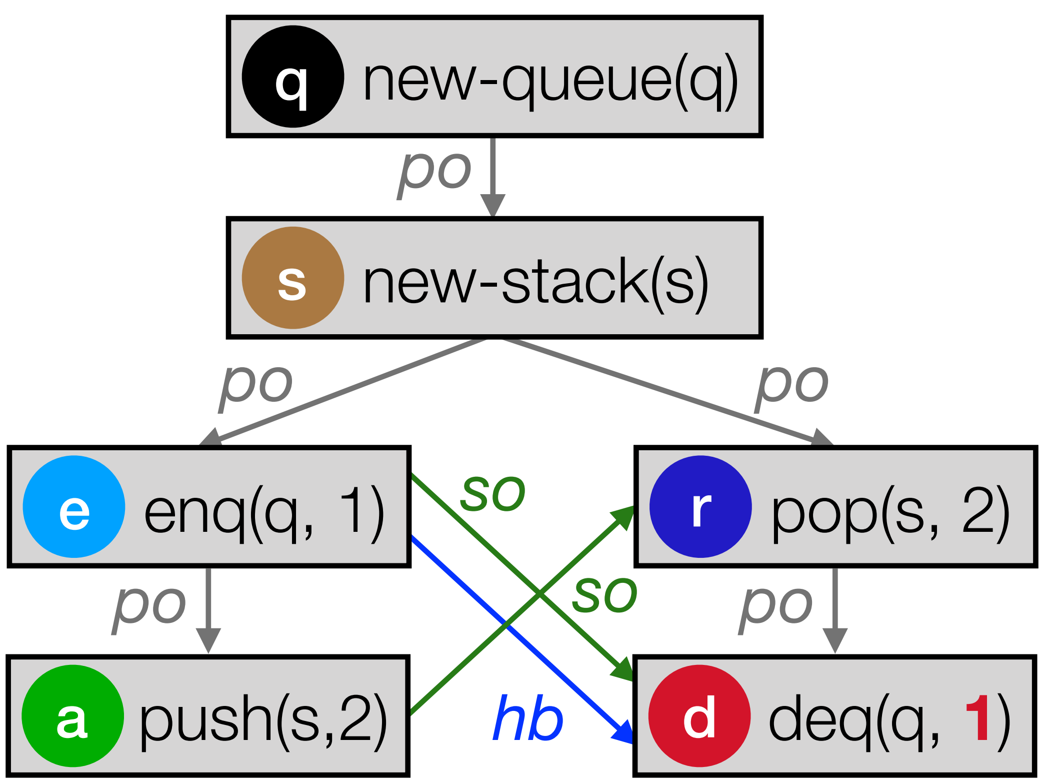

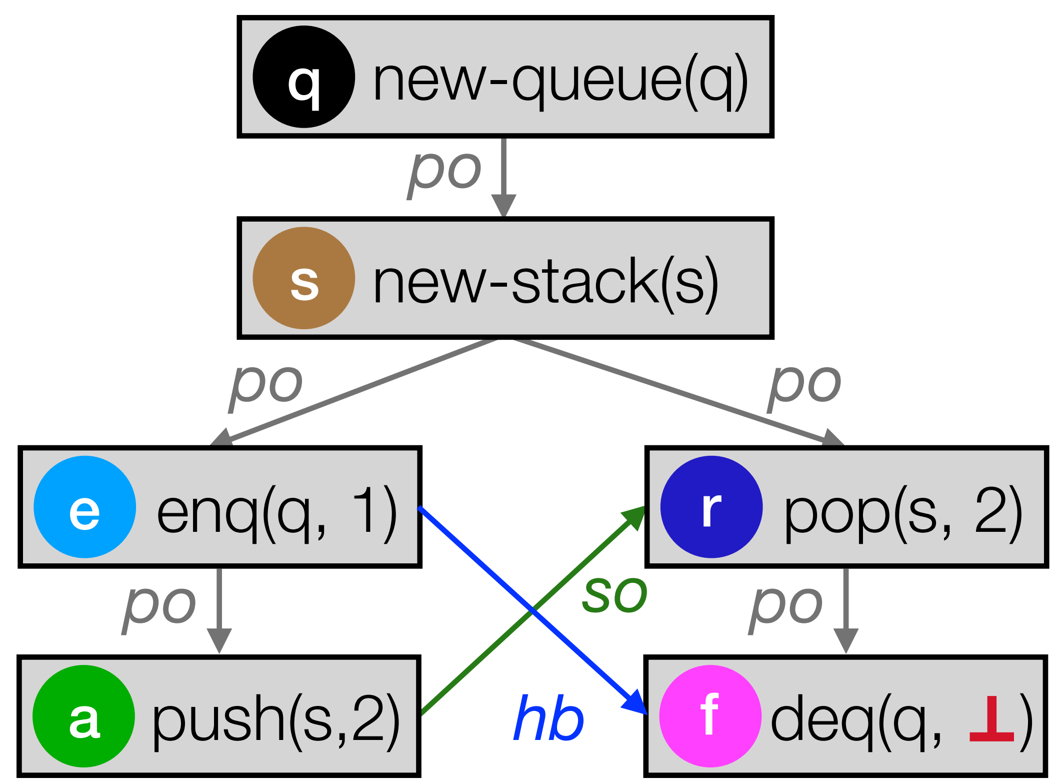

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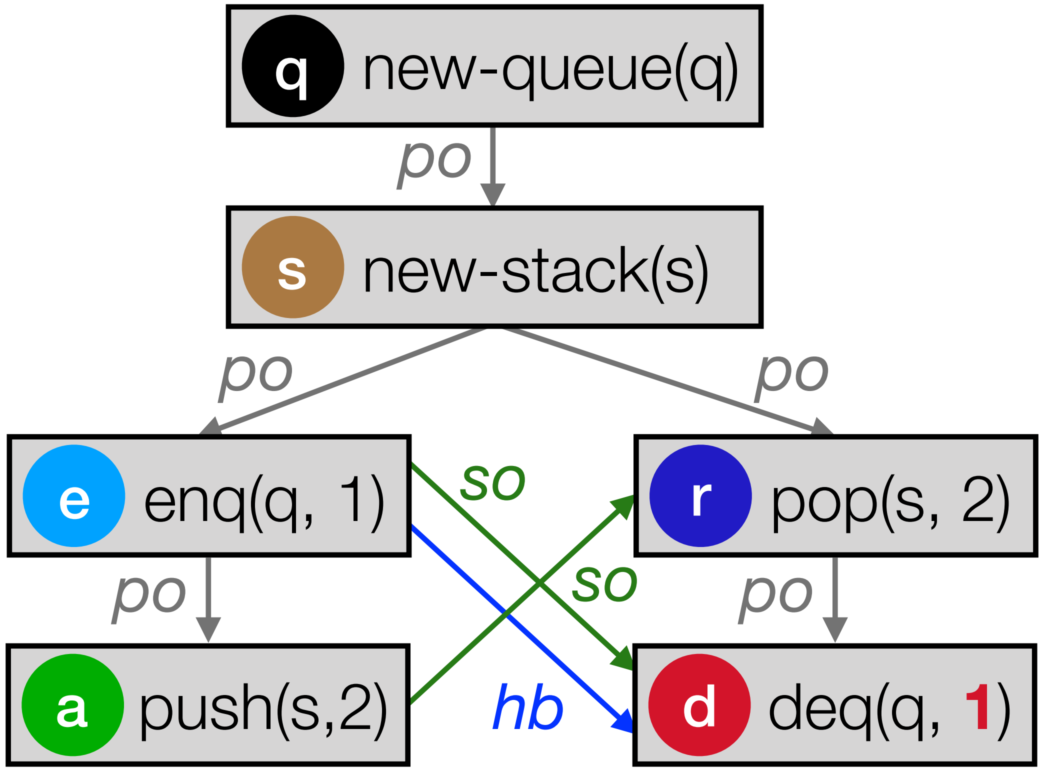

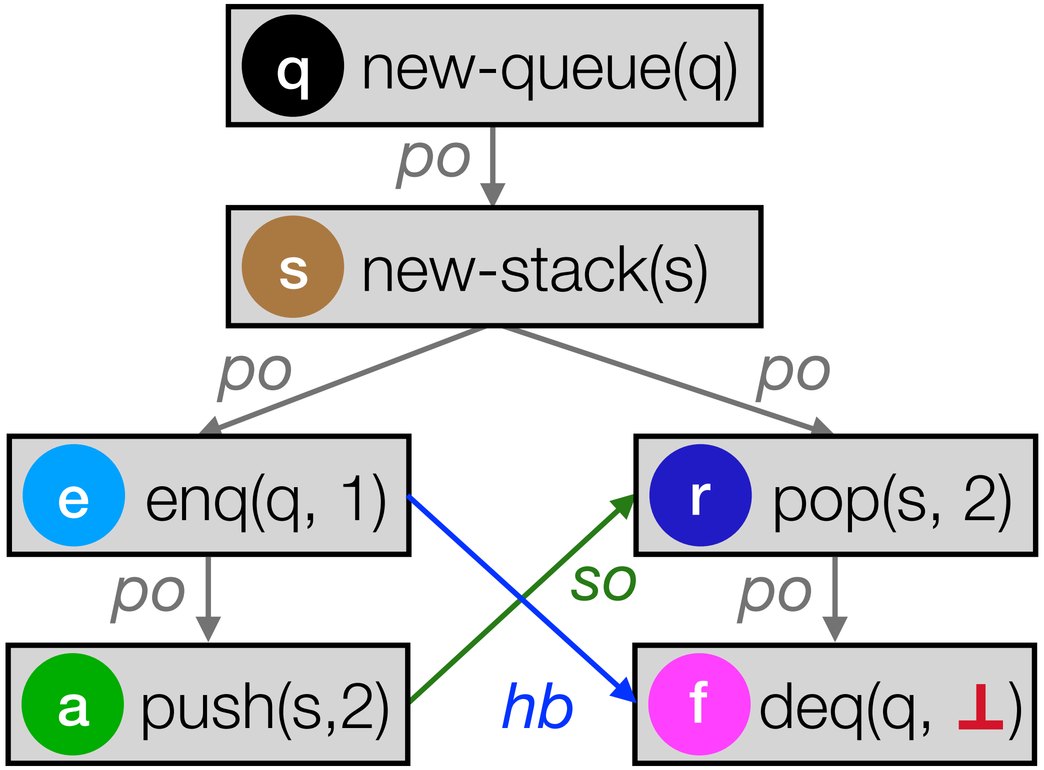

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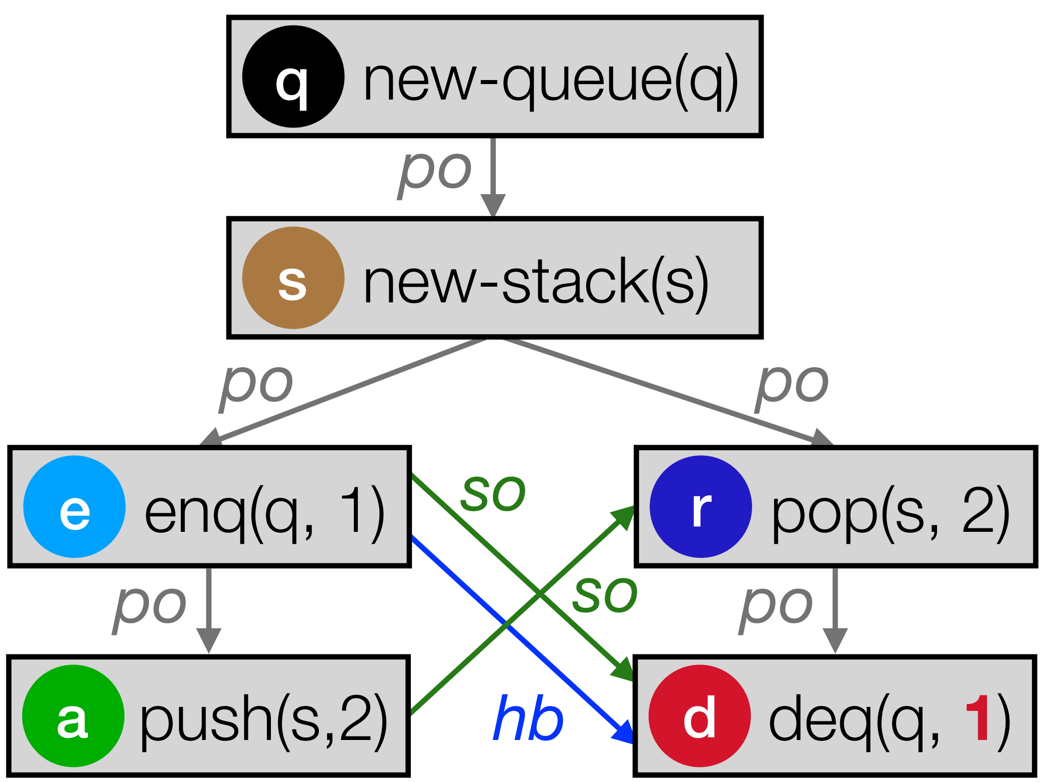
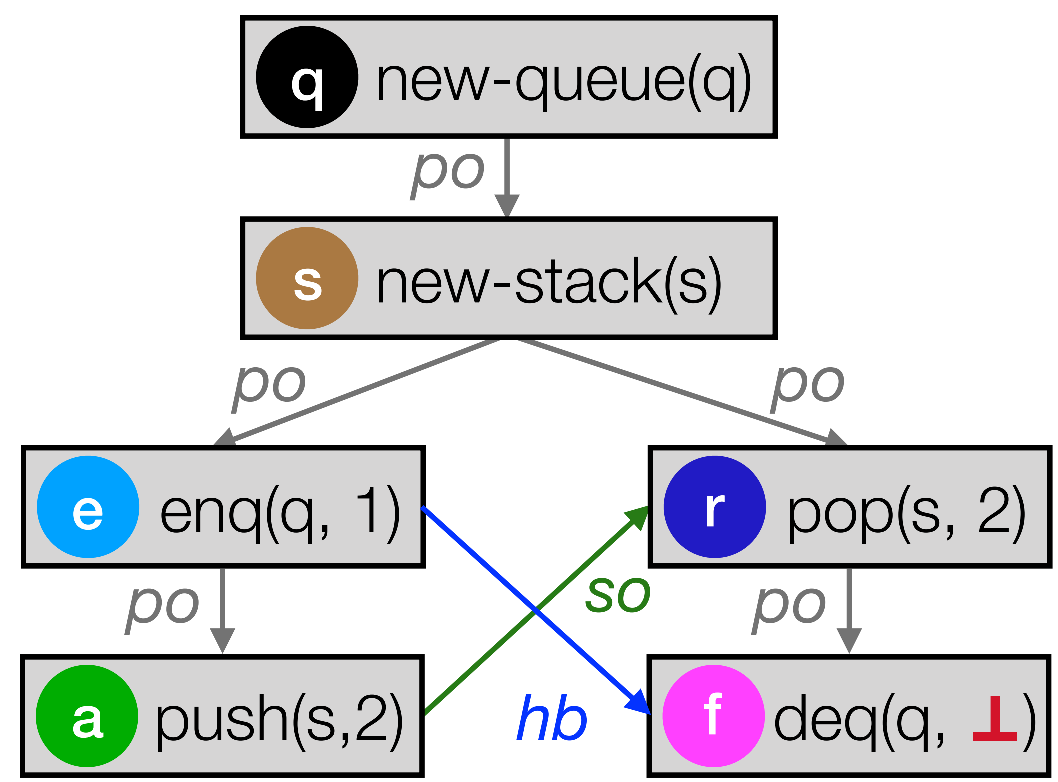
How? *hb* defined on program executions





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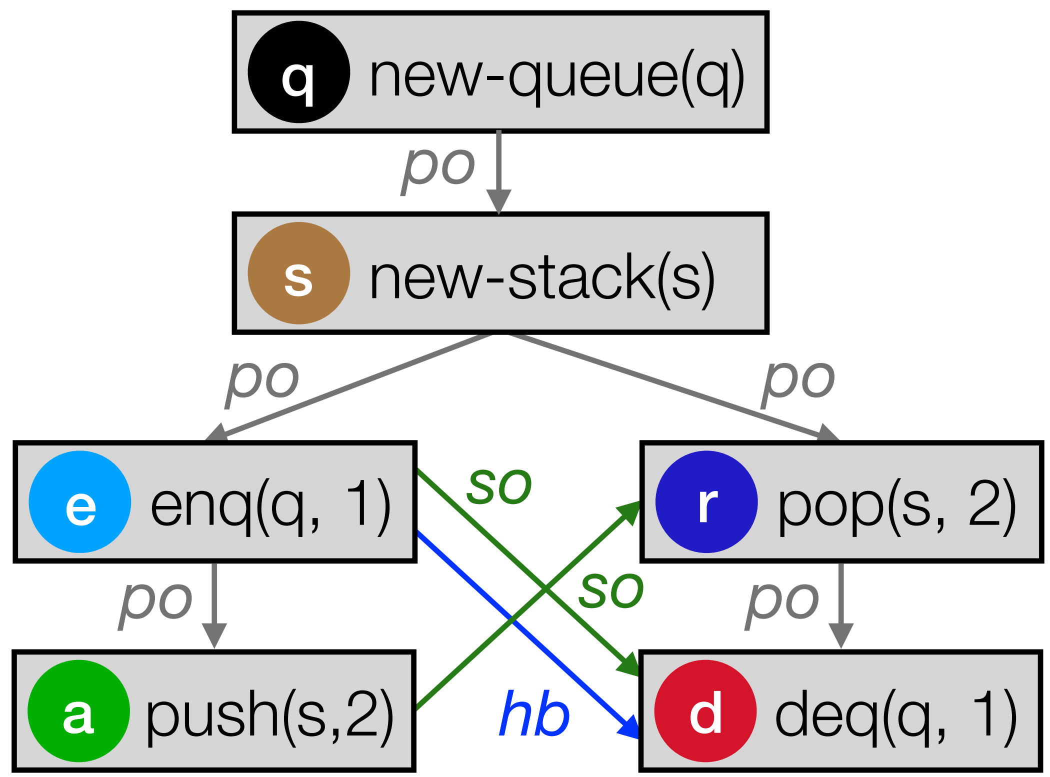

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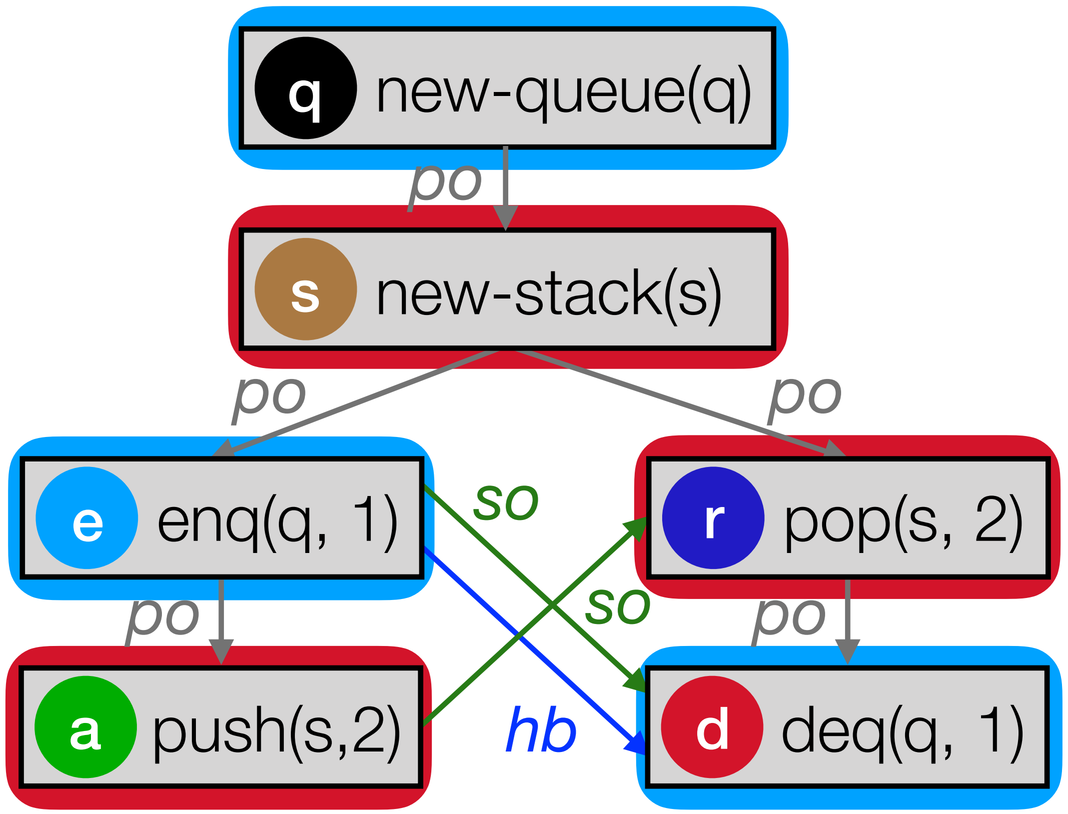

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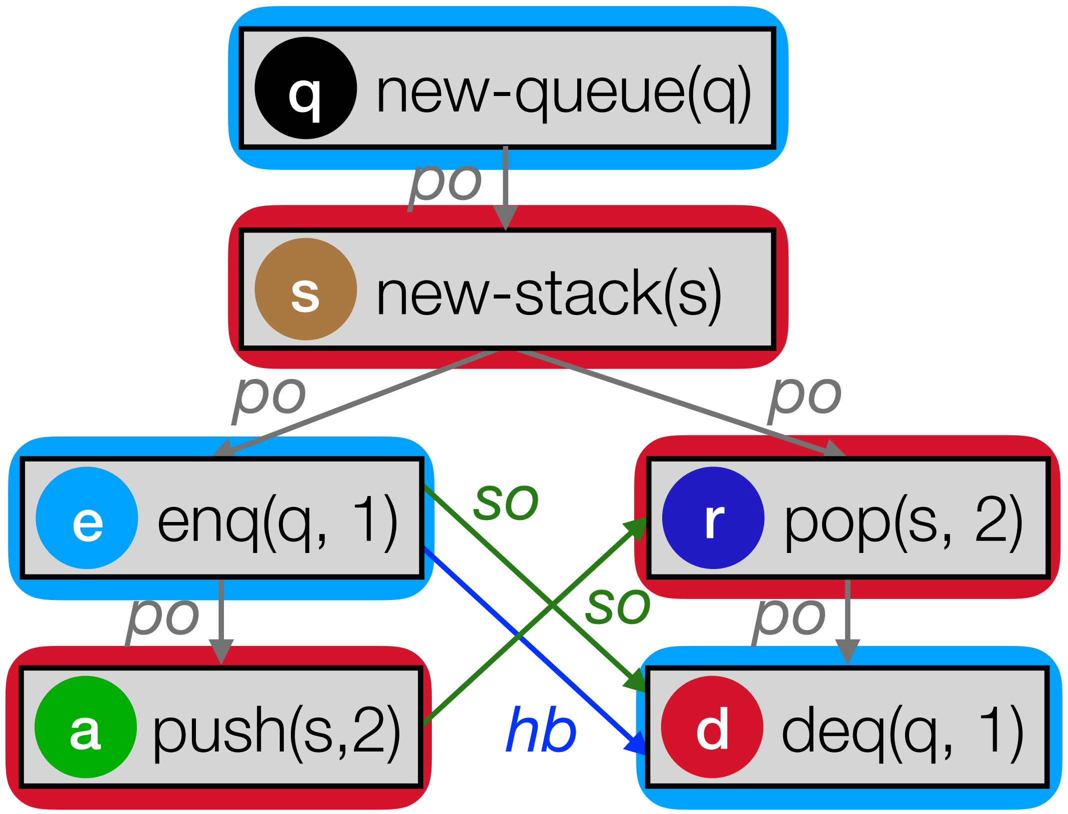
$$hb = (\ po \cup so\ )^+$$



From ***Program*** to ***Library*** Executions

$$G_P = \langle\ E\ ,\ po\ ,\ so\ \rangle$$

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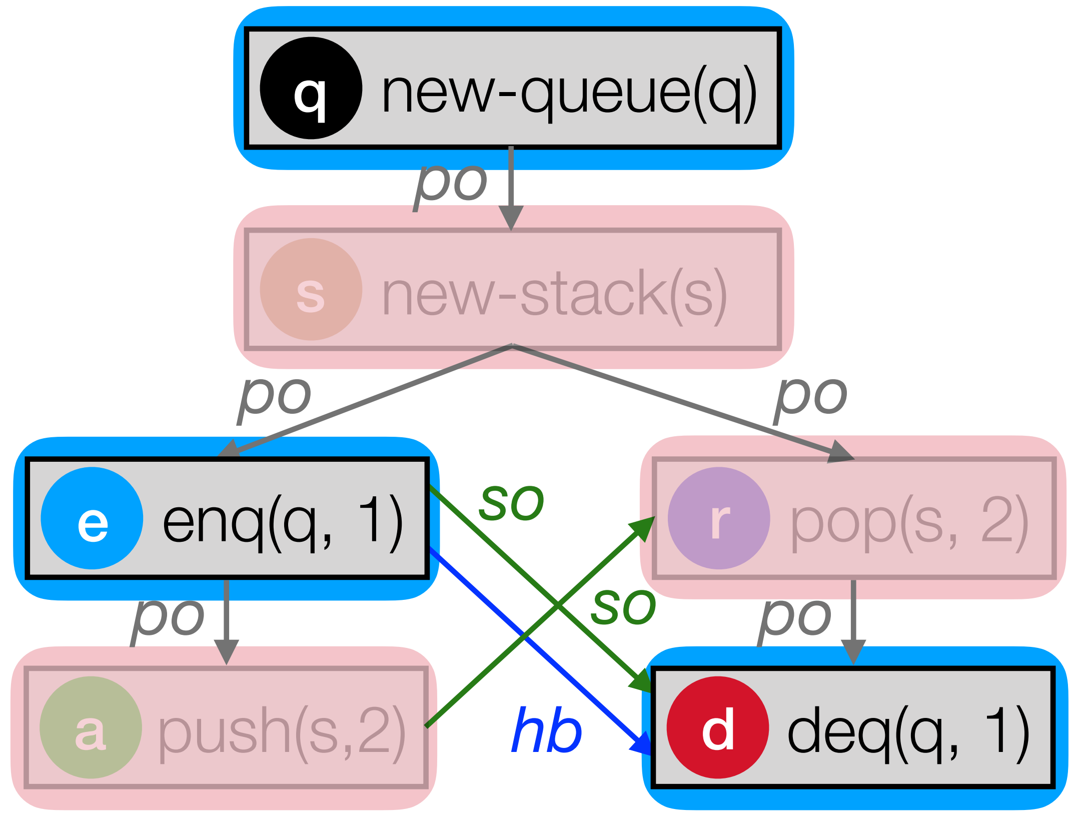

$$G_{queue} = \langle\ E_{queue}\ , \qquad\qquad\qquad\qquad \rangle$$

From ***Program*** to ***Library*** Executions

$$G_P = \langle\ E\ ,\ po\ ,\ so\ \rangle$$

$$G_P = G_{queue} \oplus G_{stack}$$

$$E = E_{queue} \cup E_{stack}$$

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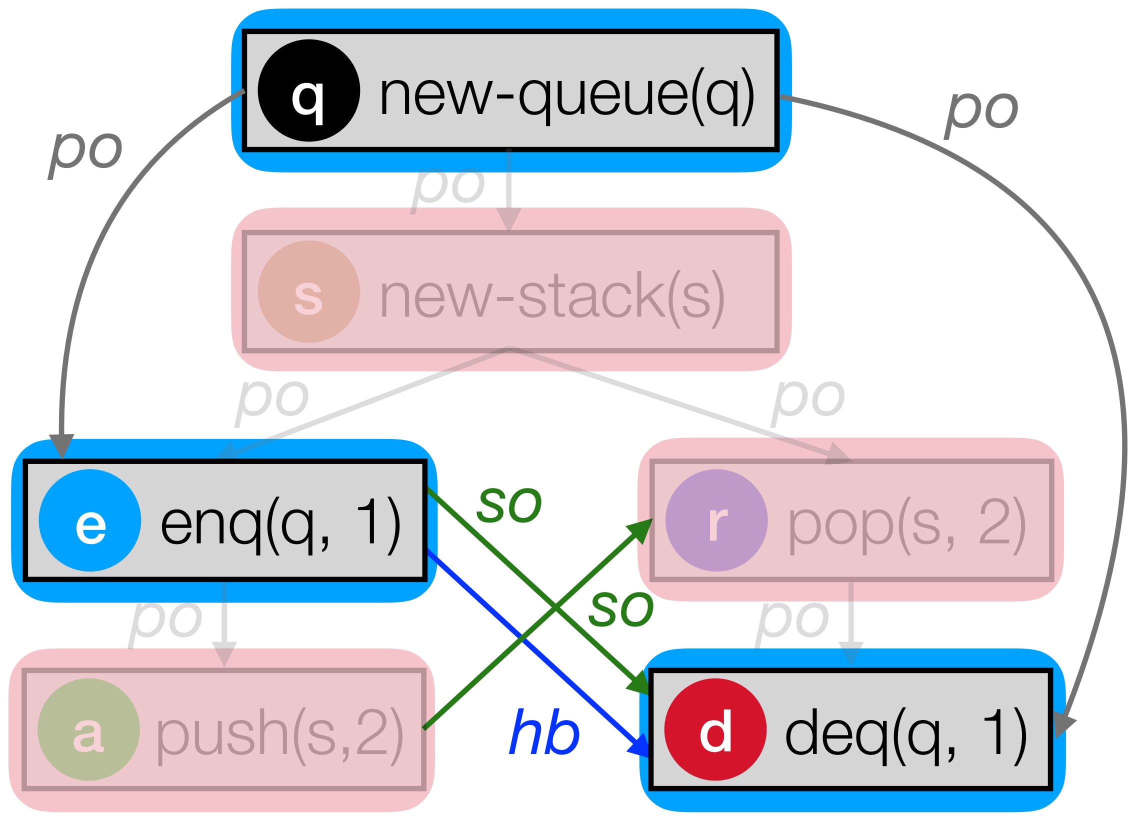

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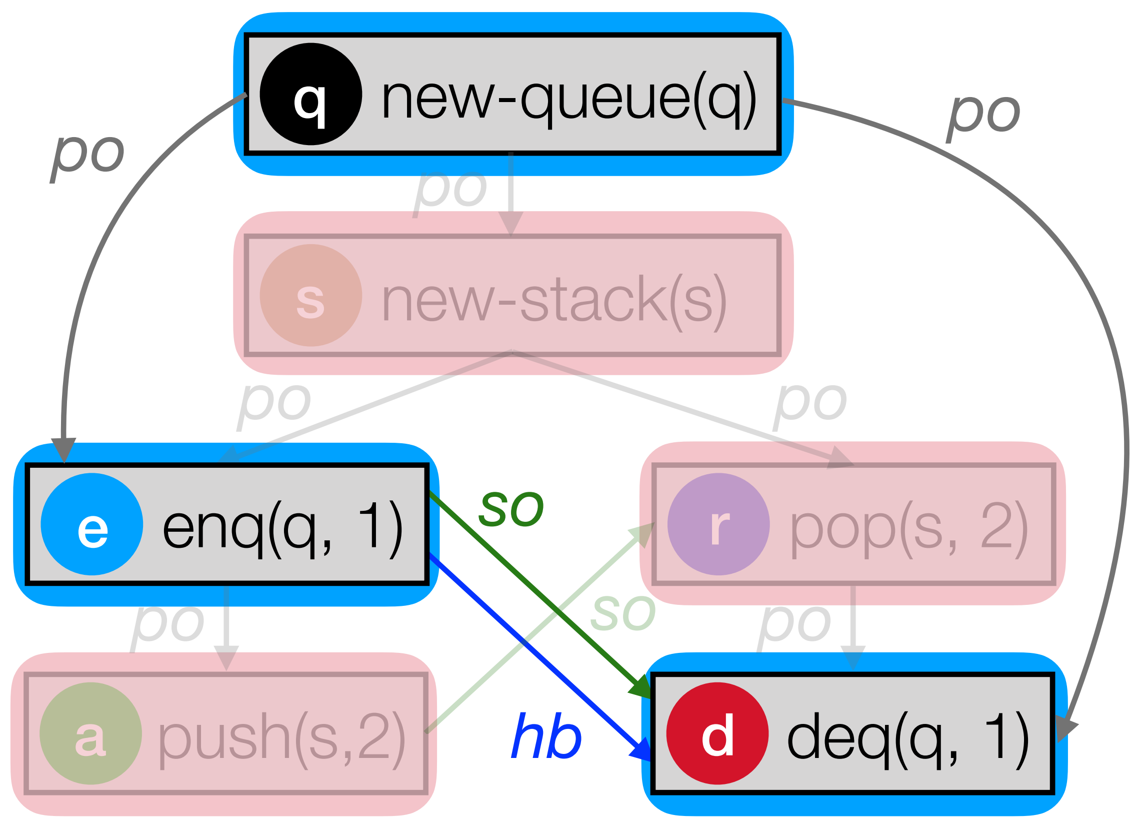

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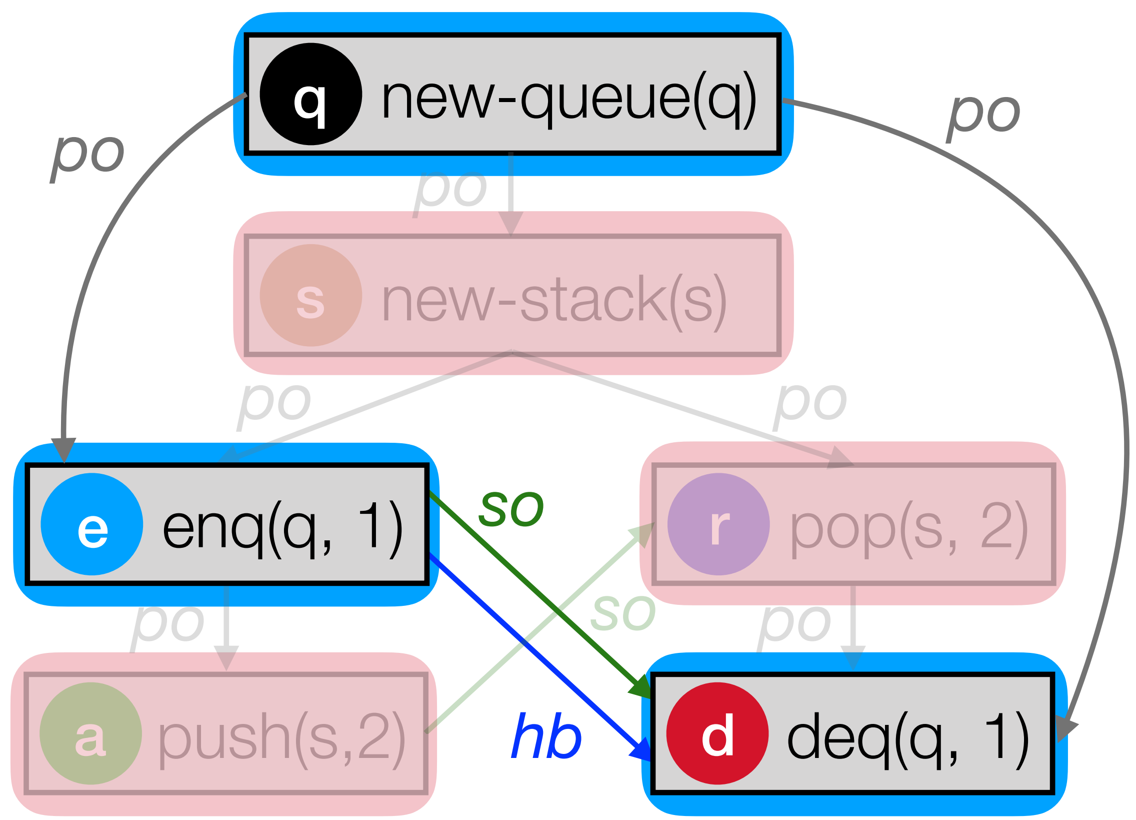

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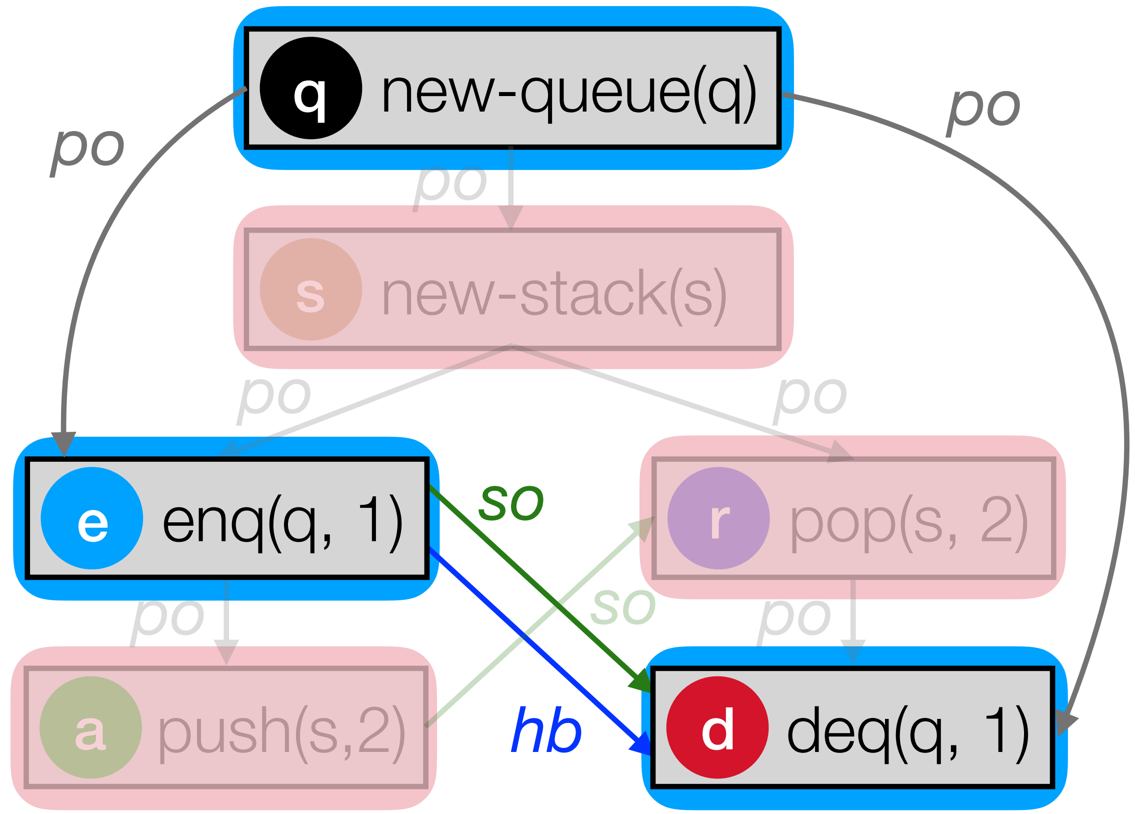

$$G_{queue} = \langle\ E_{queue}, po_{queue}, so_{queue}, hb?\ \rangle$$

$$hb_{queue}$$

Example Revisited

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q:=new-queue();
s:=new-stack();

enq(q,1);     ||  a:=pop(s);
push(s,2)     ||  if(a==2)
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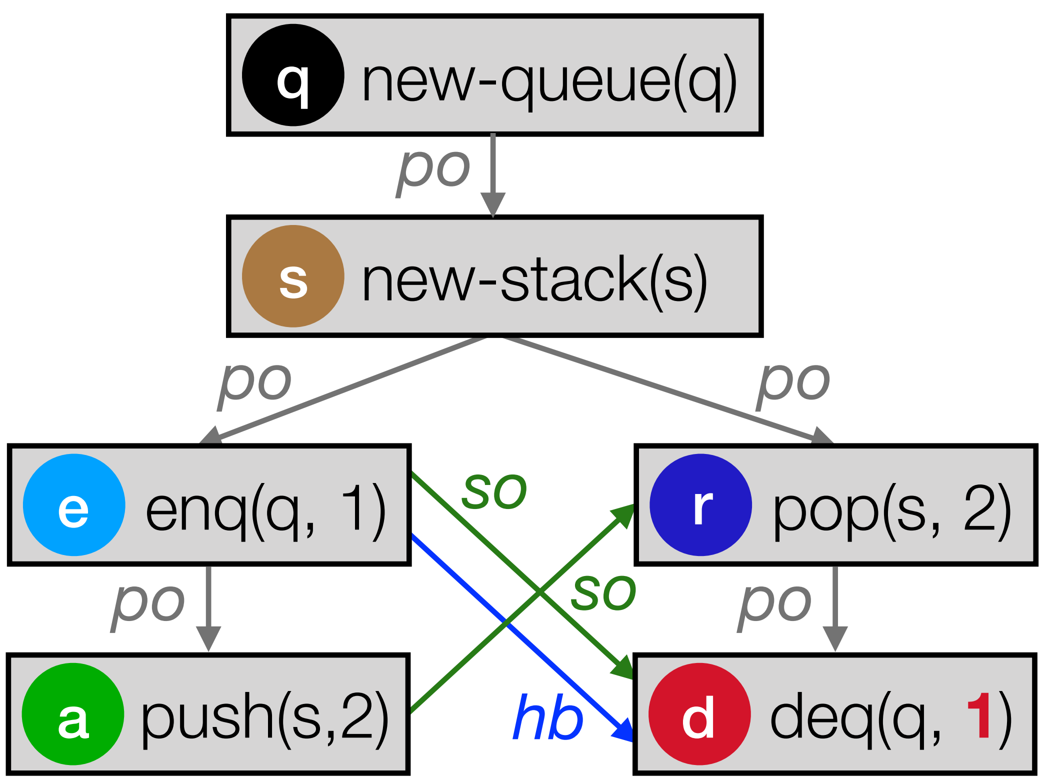

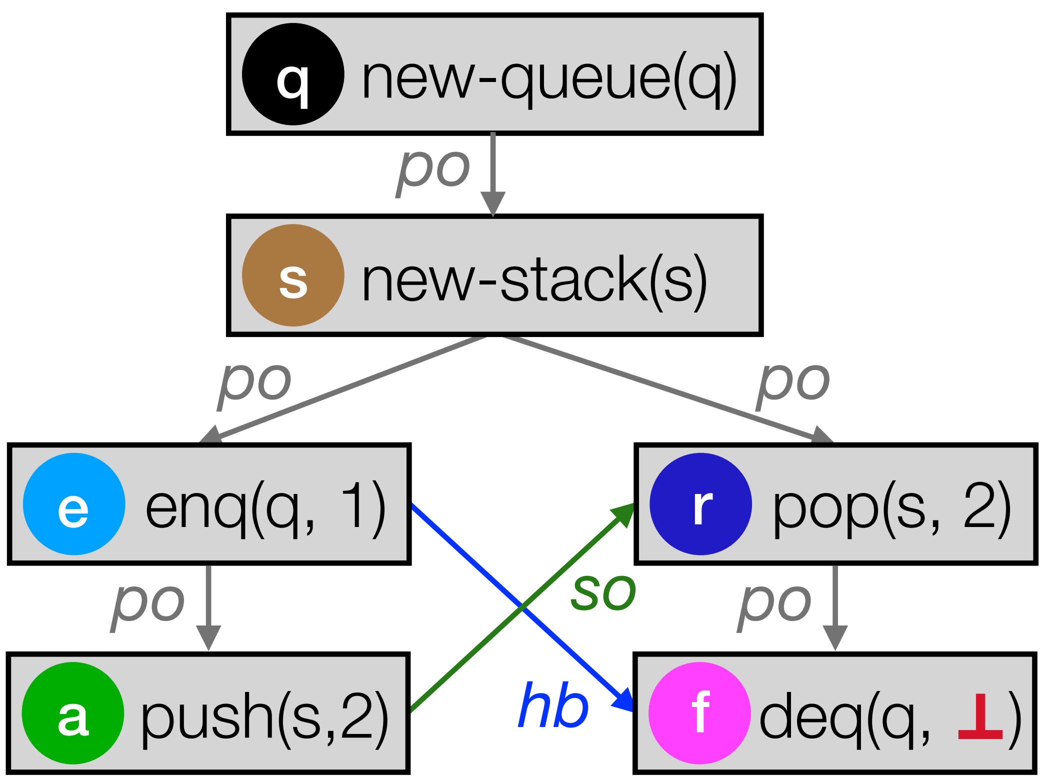

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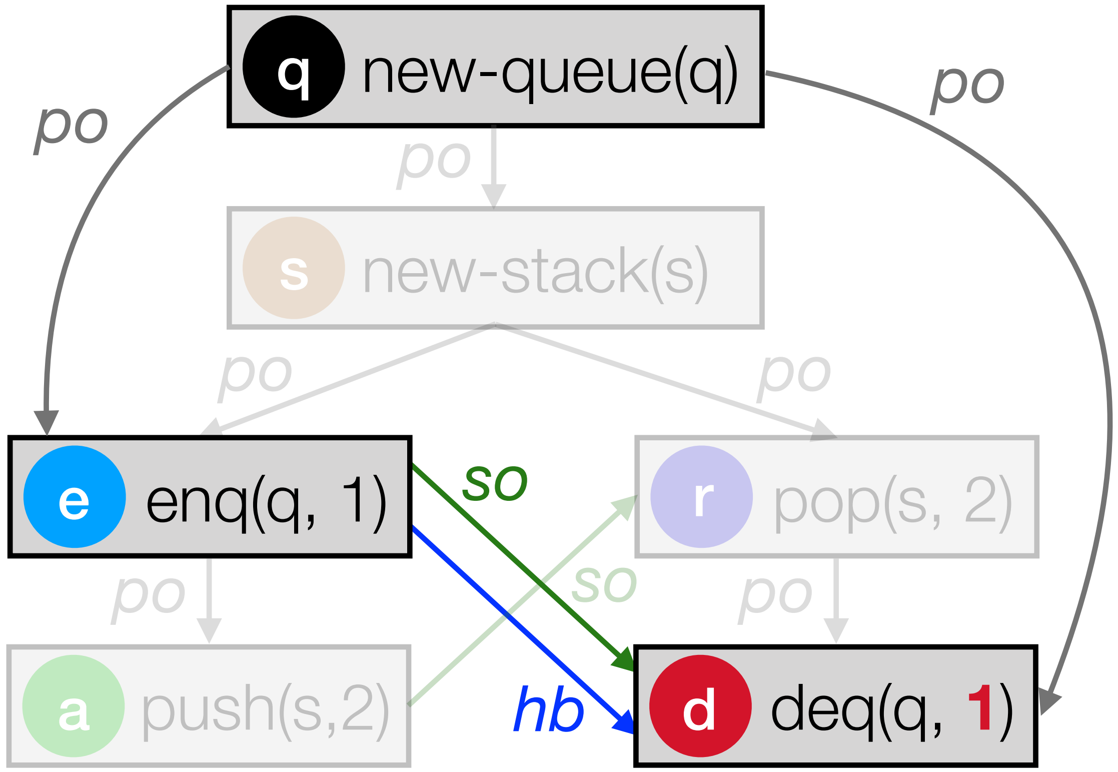

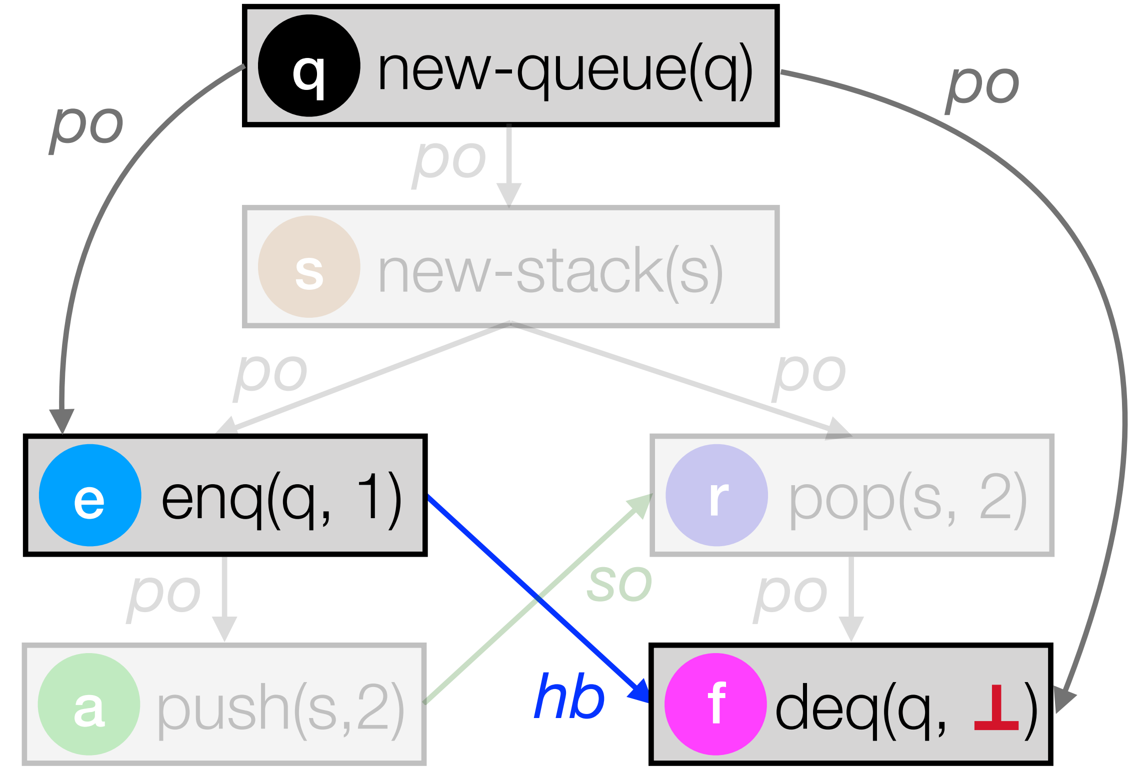

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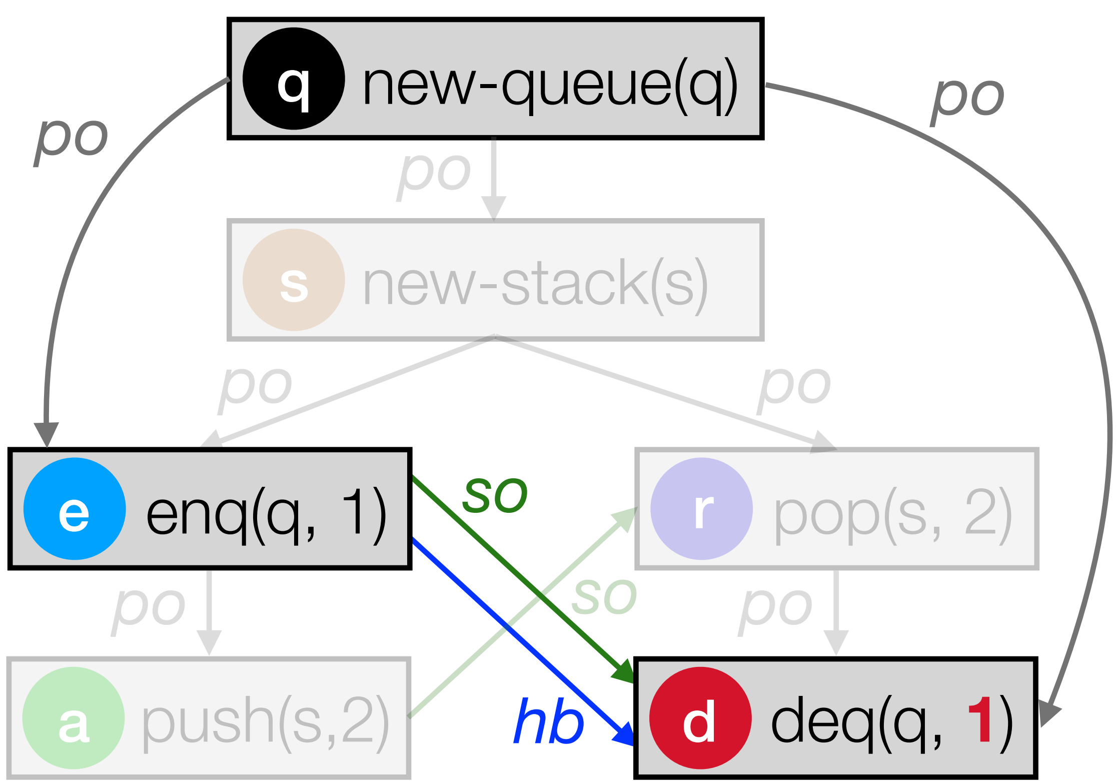
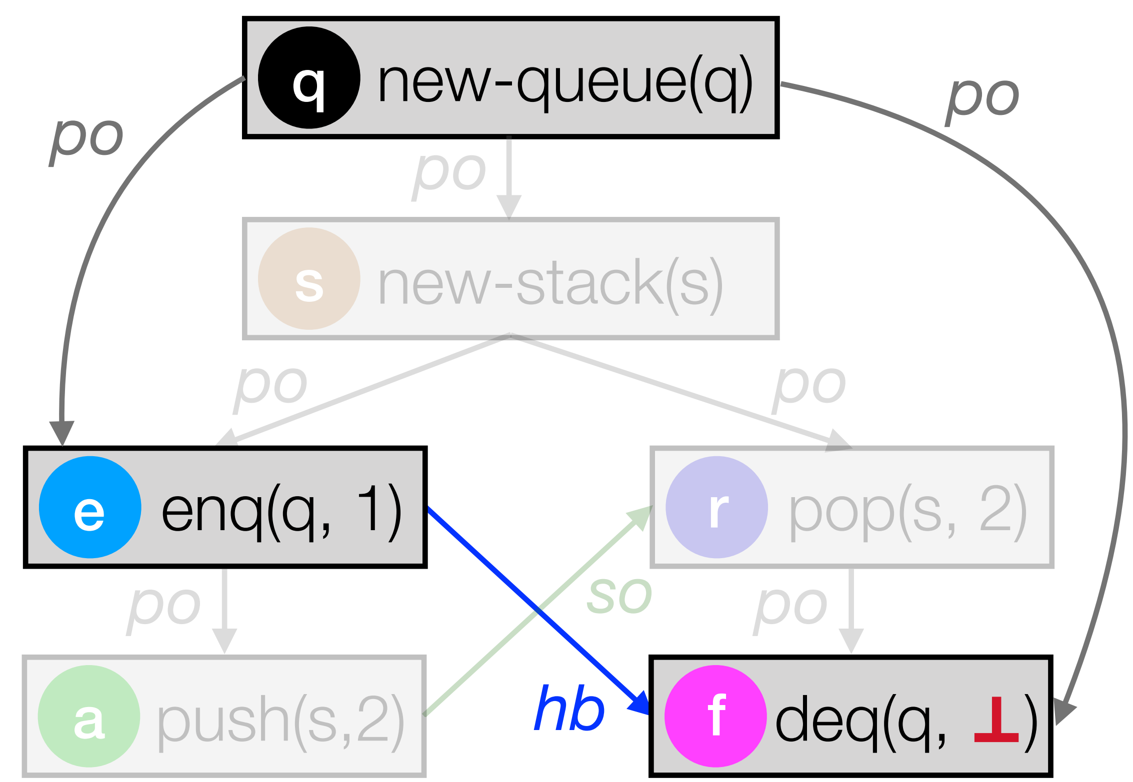
How does *hb* ***exclude*** the ***RHS*** execution?

☛ library ***axioms***!





Queue Axioms

G = < *E* , *po* , *so* , *hb* > is a consistent ***queue*** execution iff*:*

1. *E* contains queue events

q new-queue(q)	e enq(q, v)	d deq(q, w)	f deq(q, ⊥)	v,w ∈ Val

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2. *so* is ***1-to-1***
   so relates ***matching*** `enq`/`deq` events;

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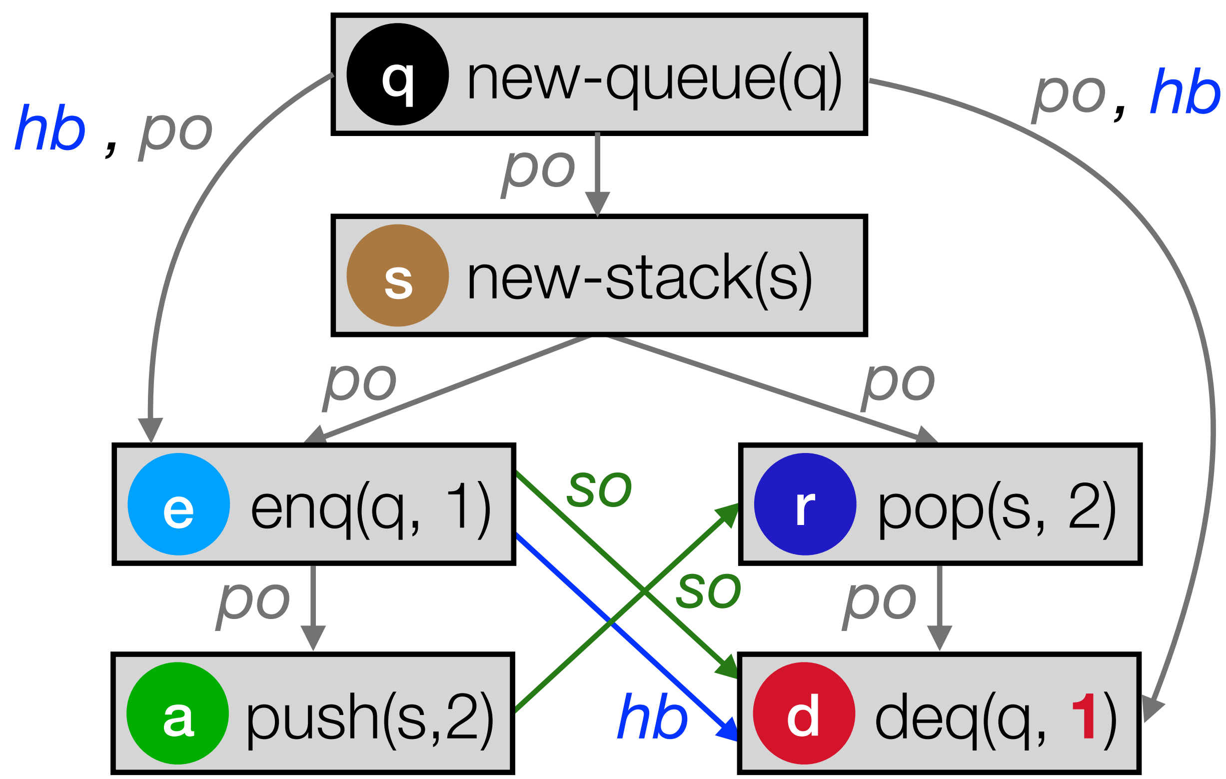

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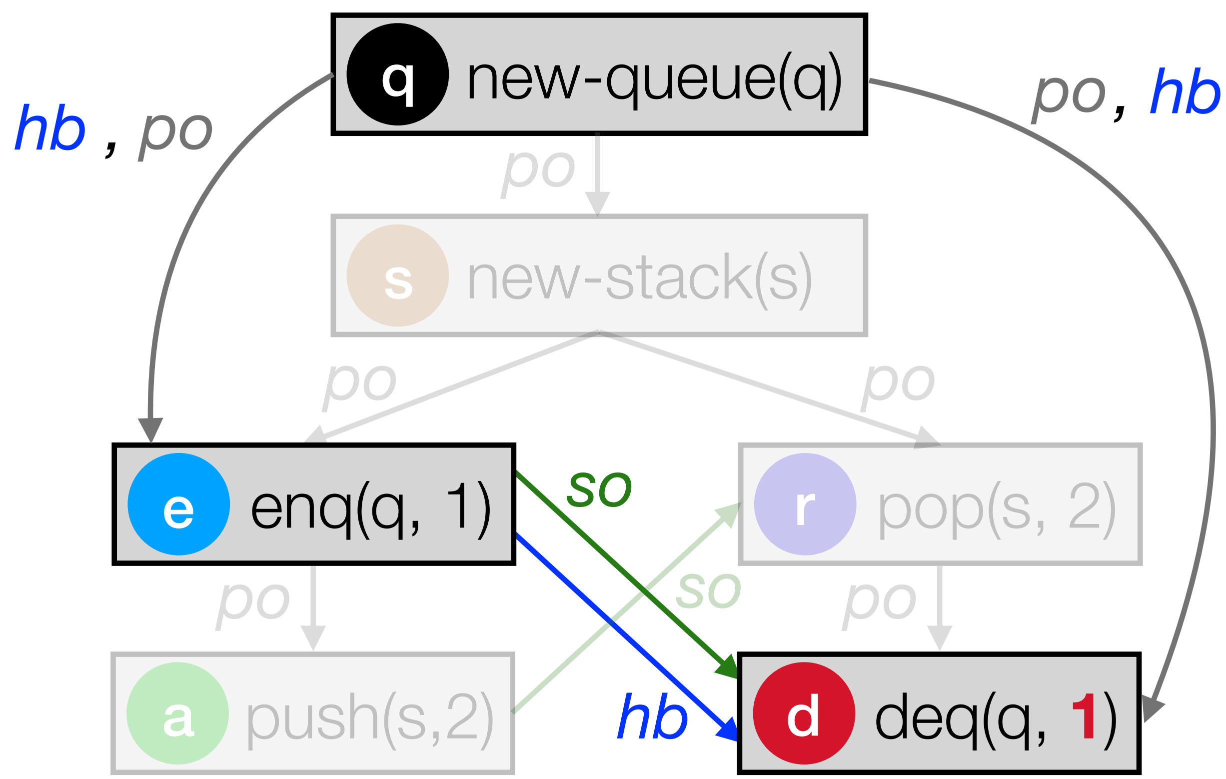

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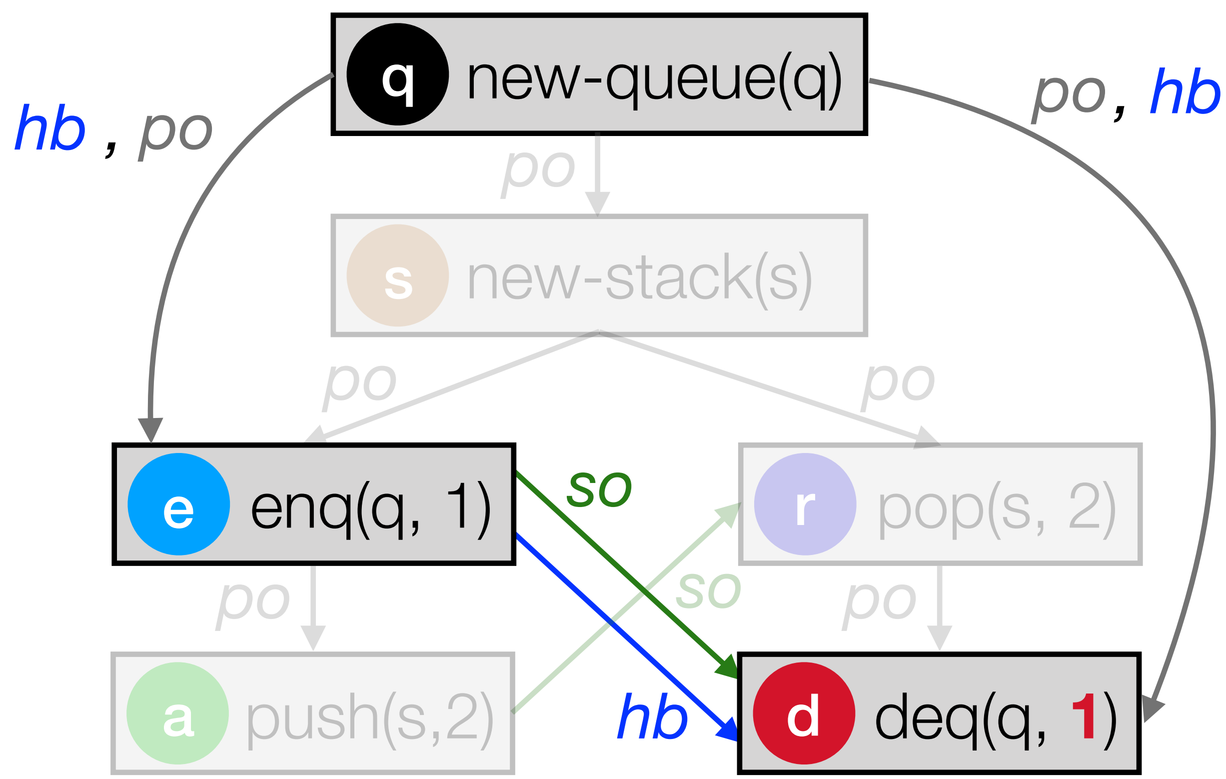

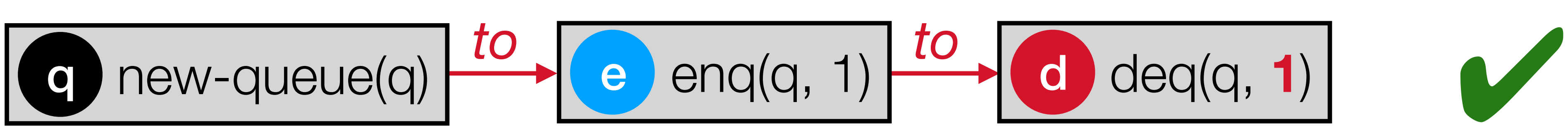

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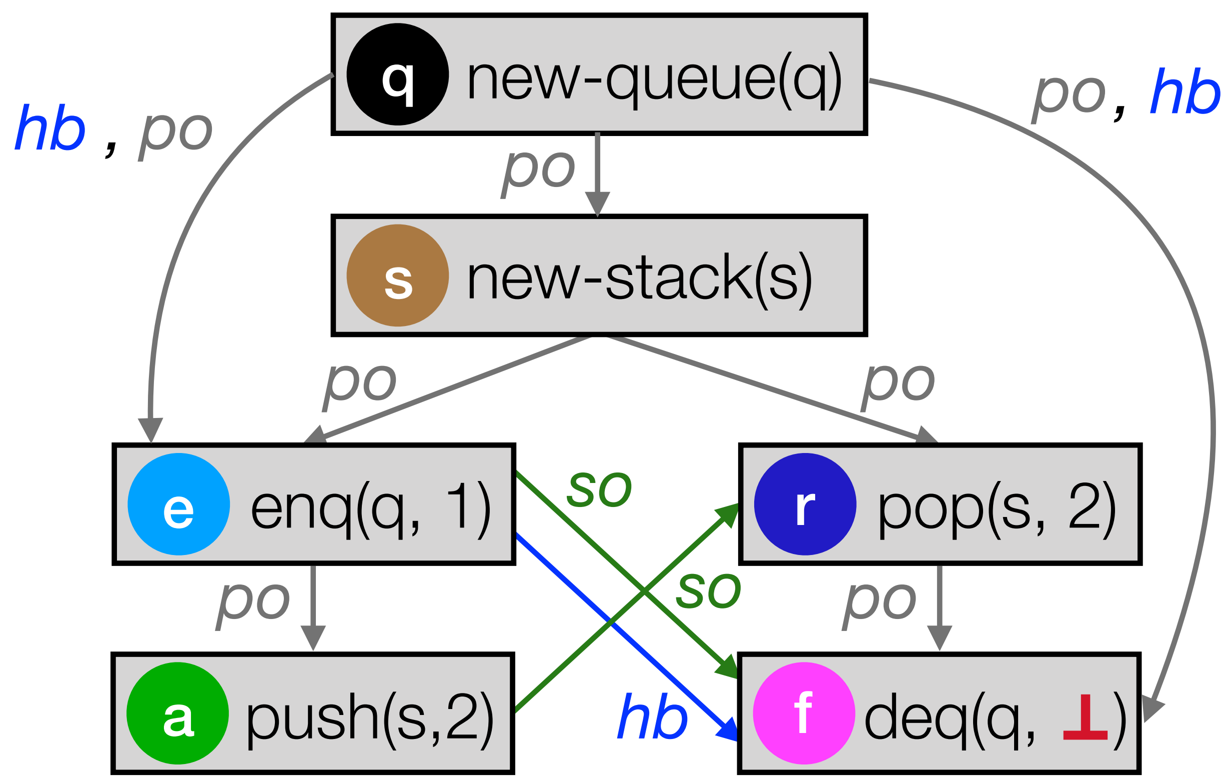

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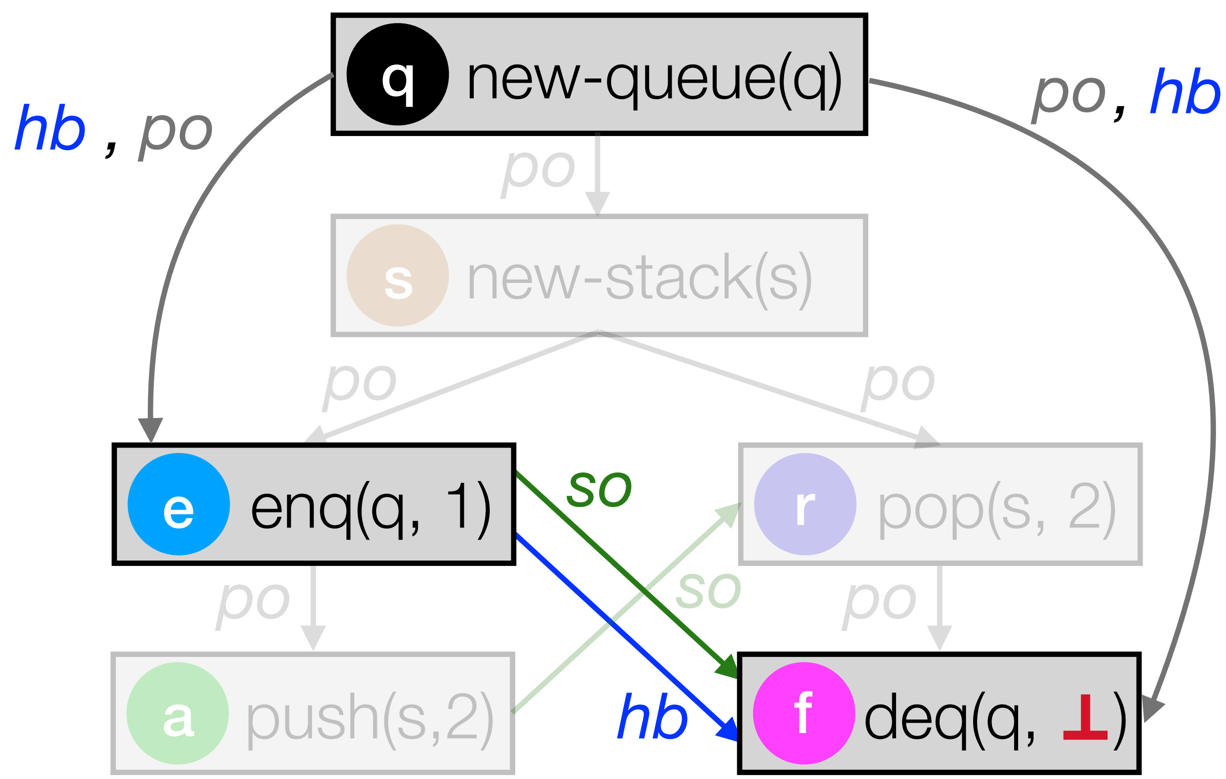

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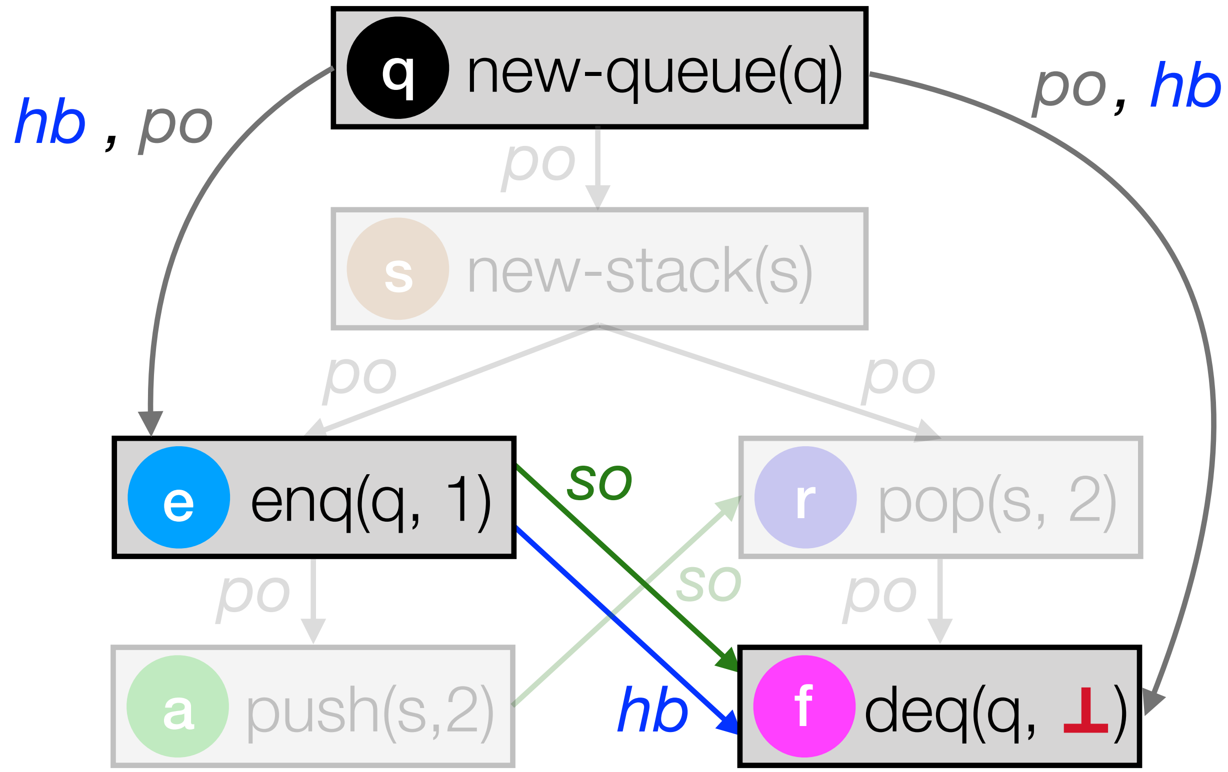

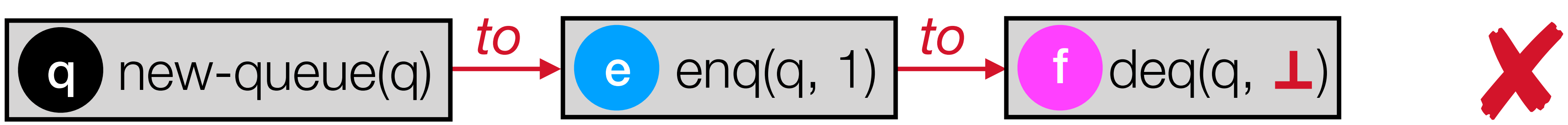

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✘ too strong

✘ difficult to find *to* witness

Why Not Strong Queue Axioms?

C11 Herlihy-Wing Queue Implementation

$new\text{-}queue() \triangleq$
  $\texttt{let}\ q = alloc(+\infty)\ \texttt{in}\ q$

$enq(q, v) \triangleq$
  $\texttt{let}\ i = fetch\text{-}add(q, 1, \texttt{rel})\ \texttt{in}$
  $store(q + i + 1, v, \texttt{rel});$

$deq(q) \triangleq$
  $\texttt{loop}$
    $\texttt{let}\ range = load(q, \texttt{acq})\ \texttt{in}$
    $\texttt{for}\ i = 1\ \texttt{to}\ range\ \texttt{do}$
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✘ does ***not*** satisfy ***strong*** queue axioms

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$$

wanted

Weaker *queue axioms*

Why weak axioms?

strong enough for certain uses: ***single-producer-single-consumer***

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equivalent acyclicity axiom

(see our paper)

Summary

A declarative ***specification*** and ***verification*** framework:

✓ ***Agnostic*** to memory model

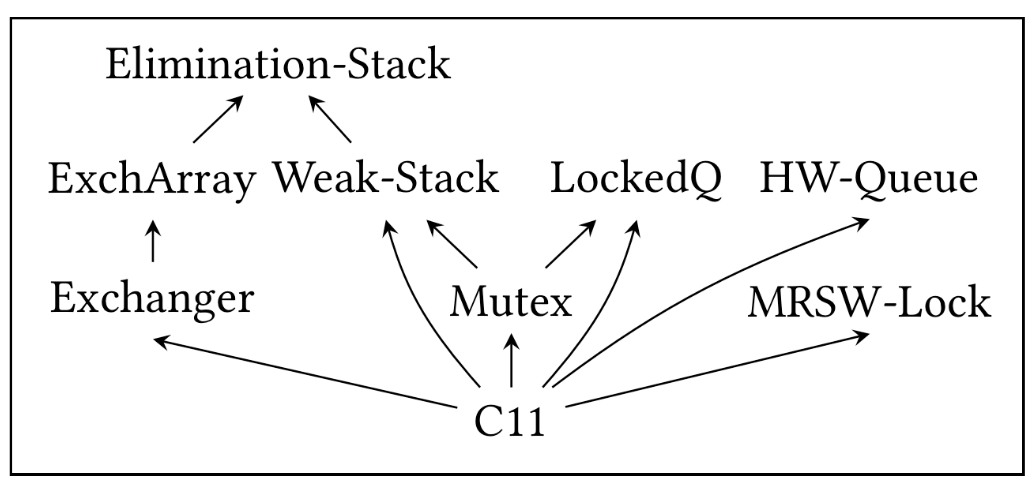
- ➡ support *both SC* and *WMC* specs

✓ ***General***

- ➡ port *existing SC (linearisability) specs*
- ➡ port *existing WMC specs* (e.g. C11, TSO)
- ➡ built from the *ground up*: assume *no pre-existing* libraries or specs

✓ ***Compositional***

- ➡ *vertical* composition to verify *library implementations*
- ➡ *horizontal* composition to verify *client programs*



Thank You for Listening!

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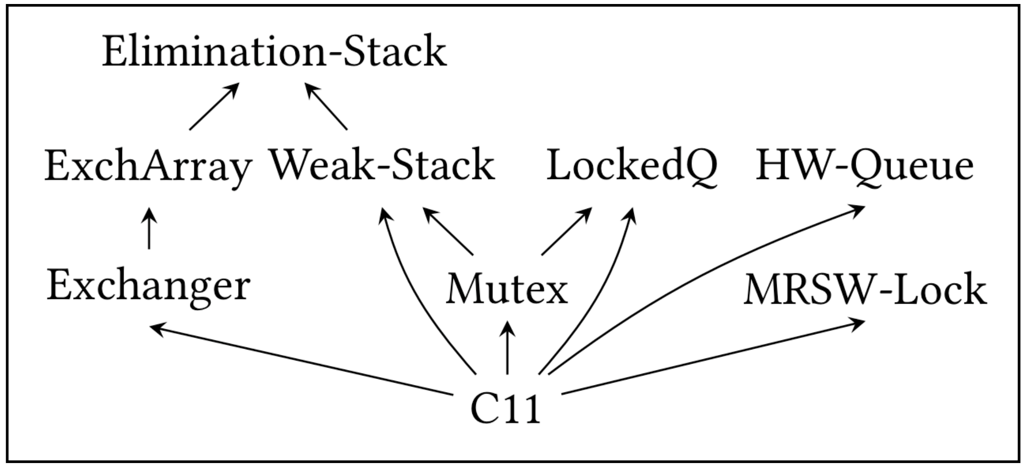

azalea@mpi-sws.org
SoundAndComplete.org
@azalearaad