Programming Languages and Techniques (CIS120)

Lecture 18

February 24th, 2016

"Objects"

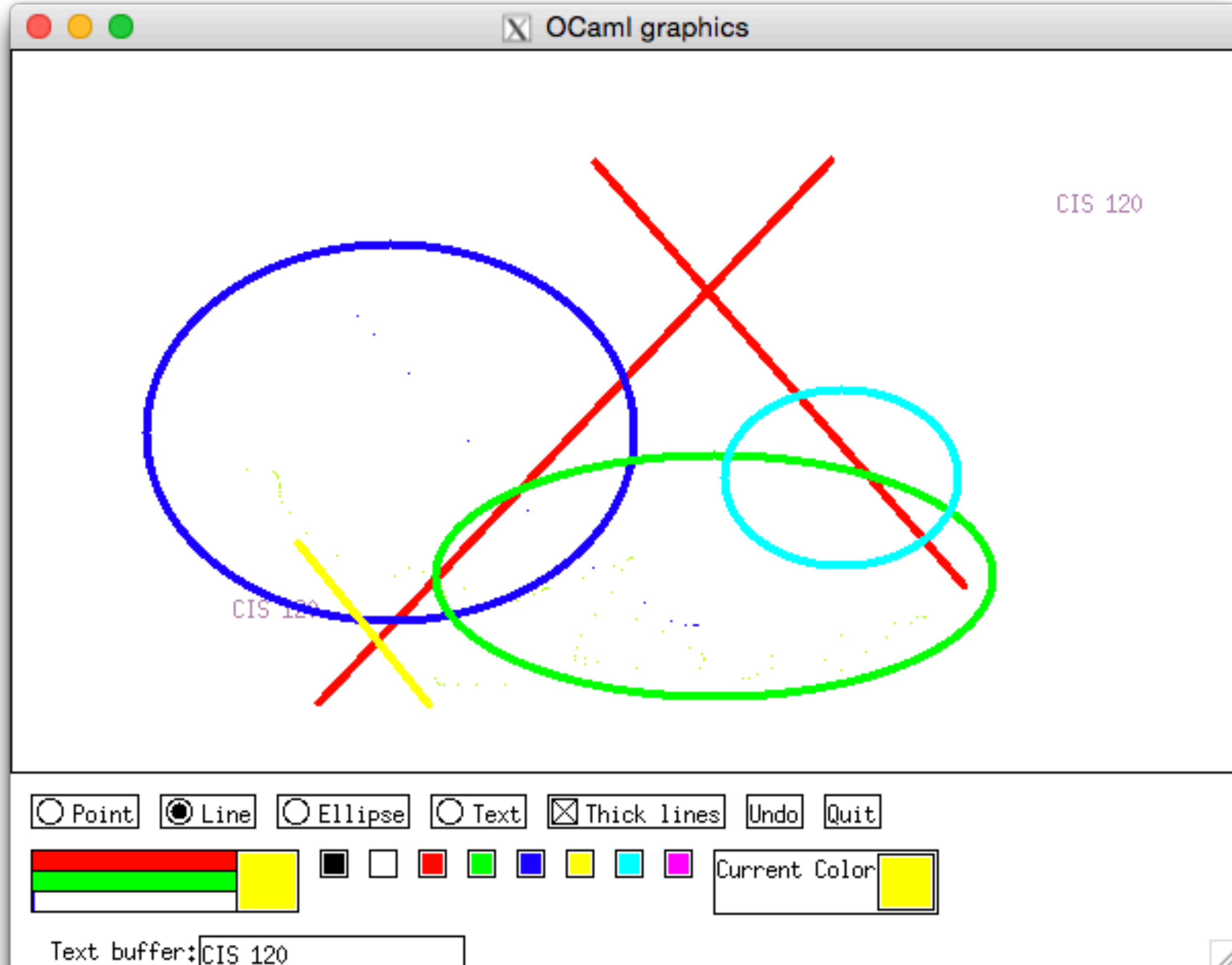
GUI project overview

Announcements

- Midterm exam
  - Solutions available on course website
  - View exams with Ms. Caliman (Levine 309)
  - If you would like a copy of your exam, send her an email (jackie@seas.upenn.edu) by Thursday at 9AM. She will have the copy available for you on Friday.

- HW5: GUI & Paint
  - Available on the web site
  - Due Thursday, March 3rd at midnight

Building a GUI and GUI Applications



Where we're going…

- HW 5: Build a GUI library and client application *from scratch* in OCaml

- Goals:
  - Apply everything we've seen so far to do some pretty serious programming
  - Practice with *first-class functions* and *hidden state*
  - Bridge to object-oriented programming
  - Illustrate the *event-driven* programming model
  - Give you a feel for how GUI libraries (like Java's Swing) work

“Objects” and Hidden State

Encapsulating State

What number is printed by this program?

```
type state = { mutable count : int }
let f =
  let p = { count = 2 } in
  fun (y : int) -> p.count + y
let p = { count = 3 }
;; print_int (f 1)
```

1. 1
2. 2
3. 3
4. 4
5. 5
6. other

How did you answer this question?

1. Substitution model
2. Abstract Stack Machine
3. I just knew the answer
4. I didn't know, so I guessed

Answer: 3

An “incr” function

- Functions with internal state

```
type counter_state = { mutable count:int }

let ctr = { count = 0 }

(* each call to incr will produce the next integer *)
let incr () : int =
  ctr.count <- ctr.count + 1;
  ctr.count
```

- Drawbacks:
  – *No abstraction:* There is only one counter in the world. If we want another, we need another counter_state value and another *incr* function.
  – *No encapsulation*: Any other code can modify count, too.

Using Hidden State

- Make a function that creates a counter state and an incr function each time a counter is needed.

```
(* More useful: a counter generator: *)
let mk_incr () : unit -> int =
  (* this ctr is private to the returned function *)
  let ctr = { count = 0 } in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count

(* make one counter *)
let incr1 : unit -> int = mk_incr ()

(* make another counter *)
let incr2 : unit -> int = mk_incr ()
```

What number is printed by this program?

```
let mk_incr () : unit -> int =
  let ctr = { count = 0 } in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count

let incr1 = mk_incr () (* make one counter *)
let incr2 = mk_incr () (* and another *)

let _ = incr1 () in print_int (incr2 ())
```

1. 1
2. 2
3. 3
4. other

Answer: 1

Running mk_incr

Workspace

```
let mk_incr () : unit -> int =
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count


let incr1 : unit -> int =
mk_incr ()
```

Stack

Heap

Running mk_incr

Workspace

```
let mk_incr : unit -> unit ->
int = fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count


let incr1 : unit -> int =
mk_incr ()
```

Stack

Heap

Running mk_incr

Workspace

```
let mk_incr : unit -> unit ->
int = fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count


let incr1 : unit -> int =
mk_incr ()
```

Stack

Heap

Running mk_incr

Workspace

```
let mk_incr : unit -> unit ->
int = 

let incr1 : unit -> int =
mk_incr ()
```

Stack

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let mk_incr : unit -> unit ->
int =   .

let incr1 : unit -> int =
mk_incr ()
```

Stack

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let incr1 : unit -> int =
mk_incr ()
```

Stack

mk_incr

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let incr1 : unit -> int =
mk_incr ()
```

Stack

mk_incr

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let incr1 : unit -> int =
(   ())
```

Stack

mk_incr	

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let incr1 : unit -> int =
(__ ())
```

Stack

mk_incr	

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Stack

mk_incr	

```
let incr1 : unit -> int =
(___)
```

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Stack

mk_incr	

```
let incr1 : unit -> int =
(___)
```

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Running mk_incr

Workspace

```
let ctr = ● in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

Stack

mk_incr	●

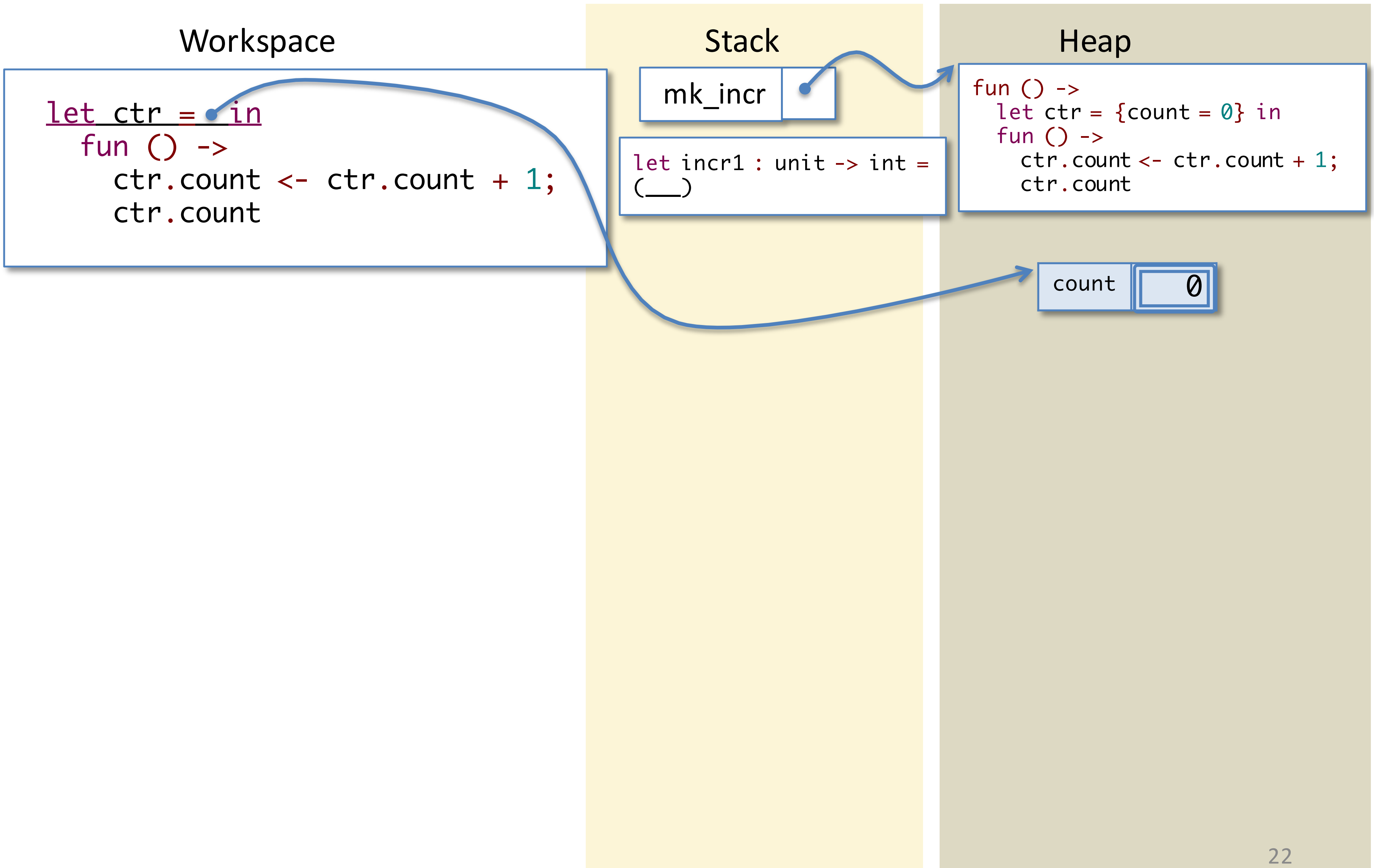
```
let incr1 : unit -> int =
(___)
```

Heap

```
fun () ->
  let ctr = {count = 0} in
  fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```

count	0

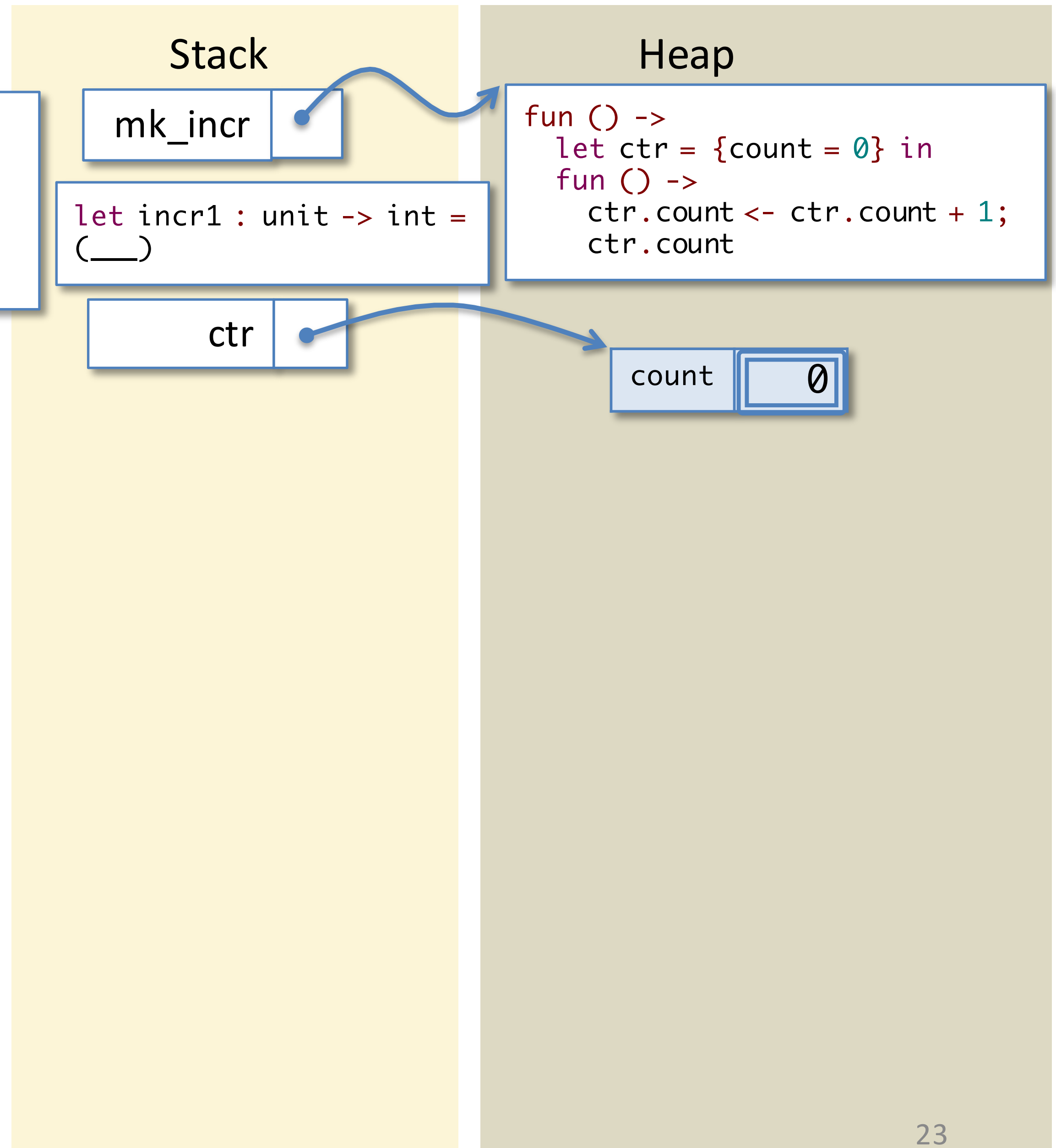
Running mk_incr



Running mk_incr

Workspace

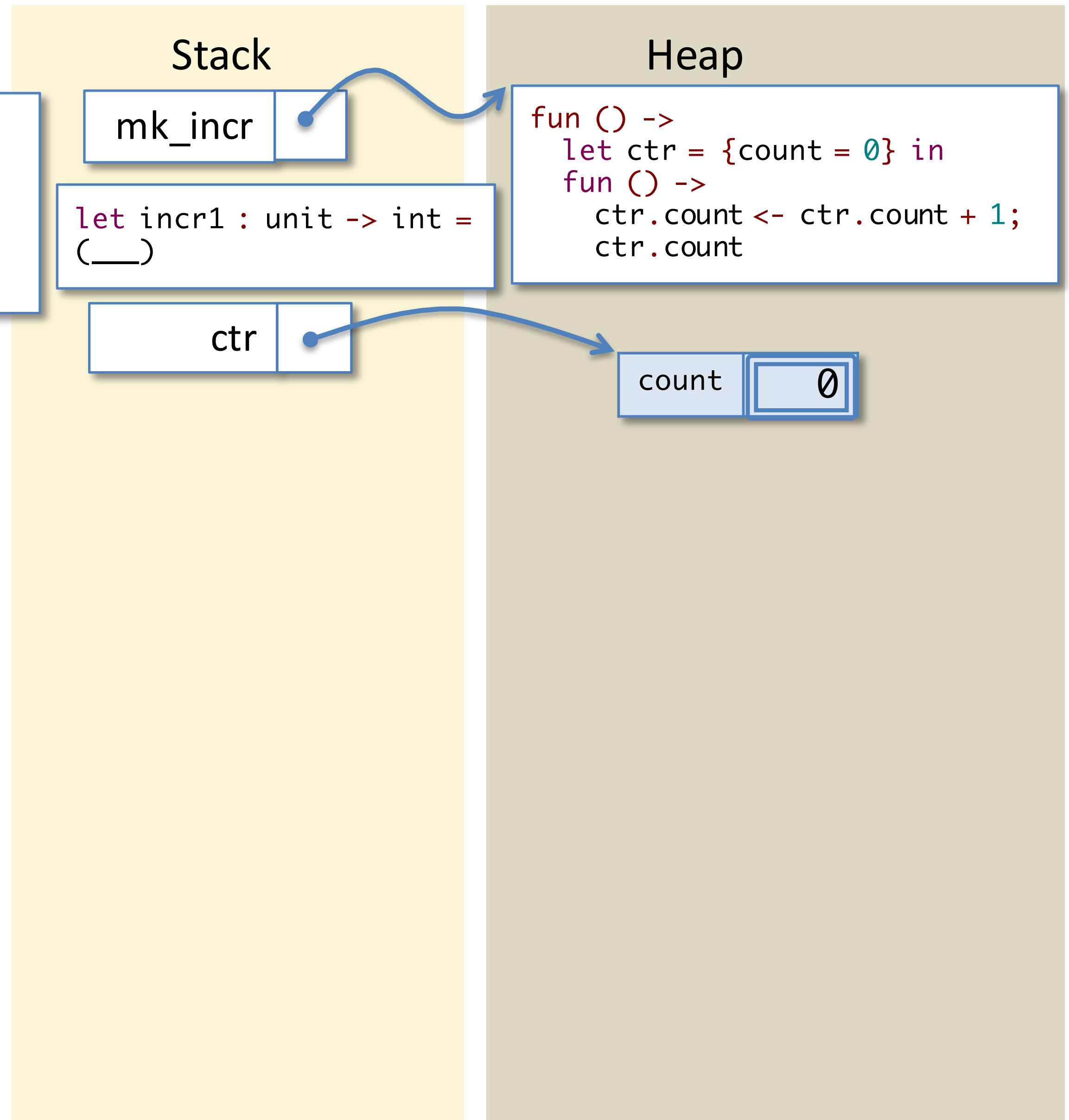
```
fun () ->
  ctr.count <- ctr.count + 1;
  ctr.count
```



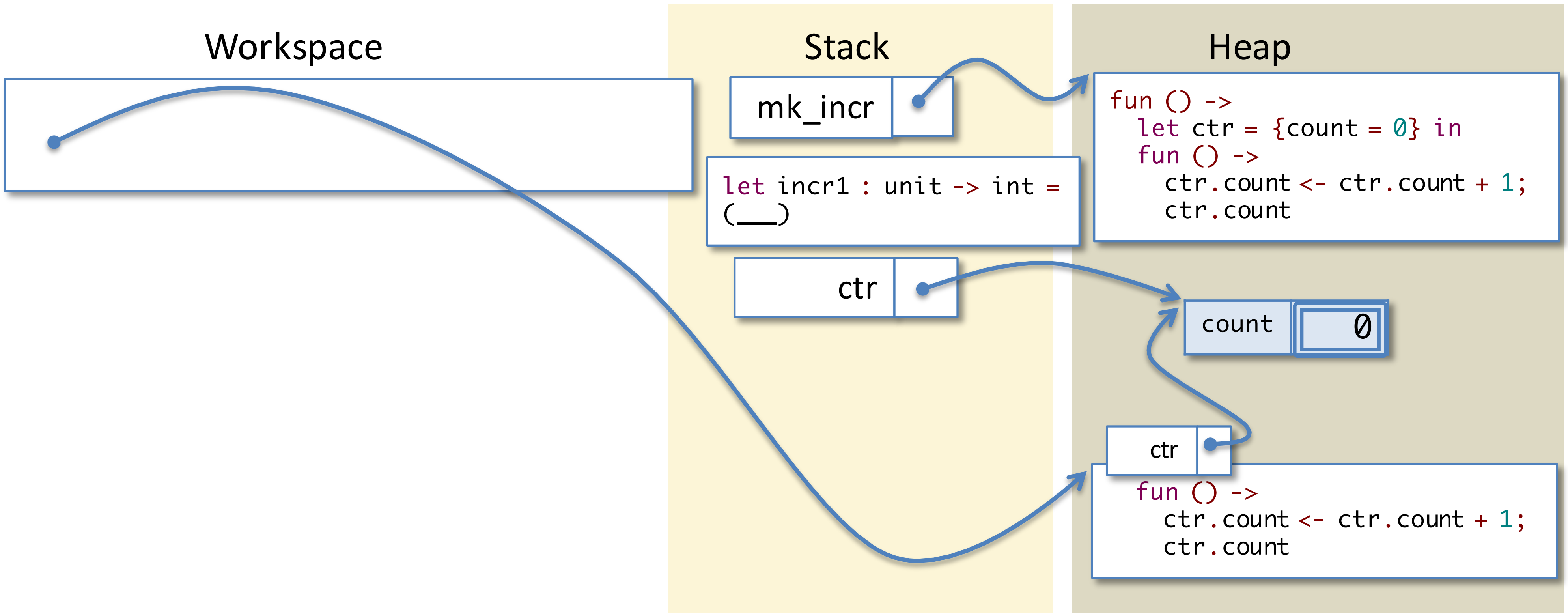
Running mk_incr

Workspace

```
fun () ->
    ctr.count <- ctr.count + 1;
    ctr.count
```



Local Functions

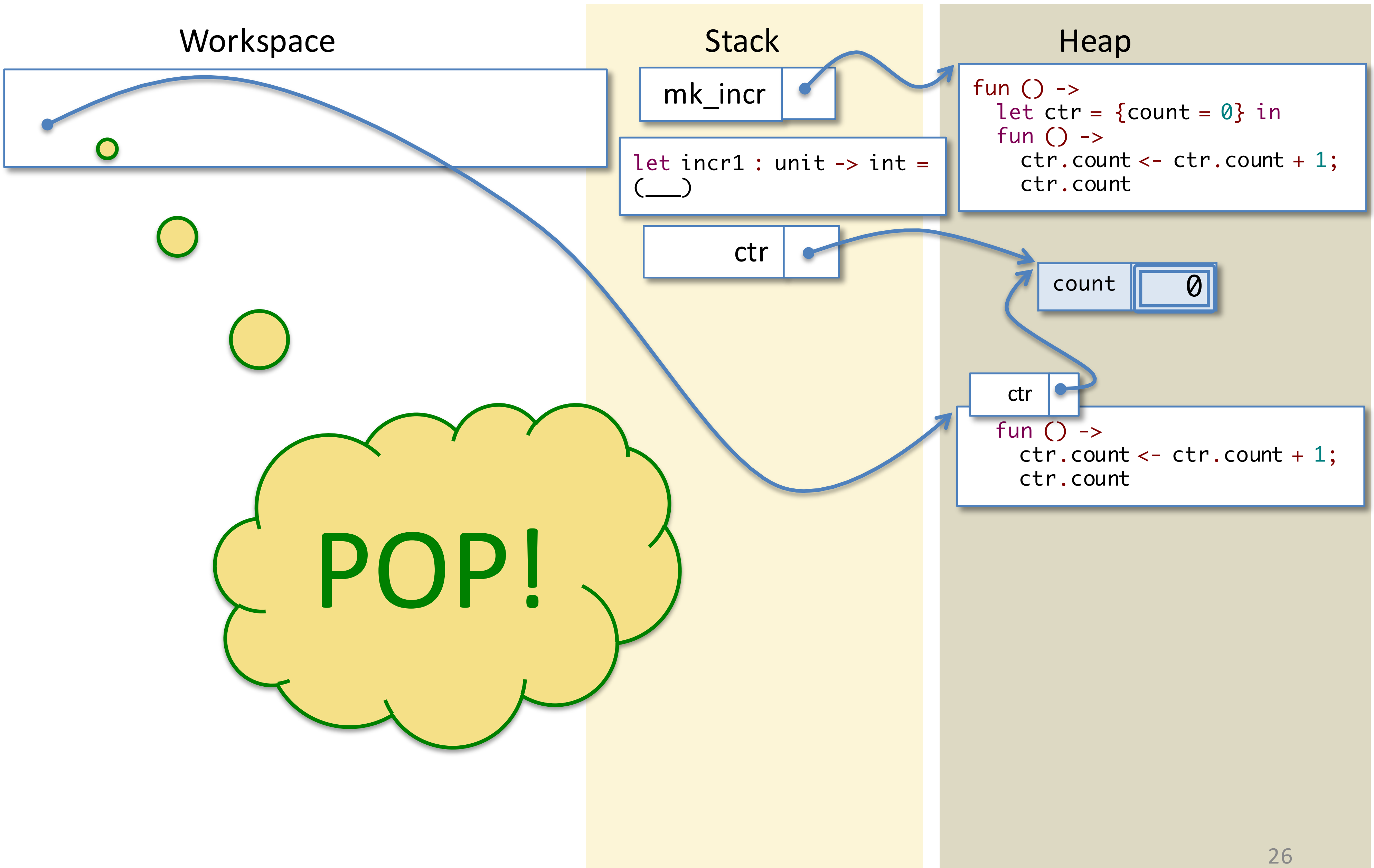


NOTE: We need one refinement of the ASM model to handle local functions. Why?

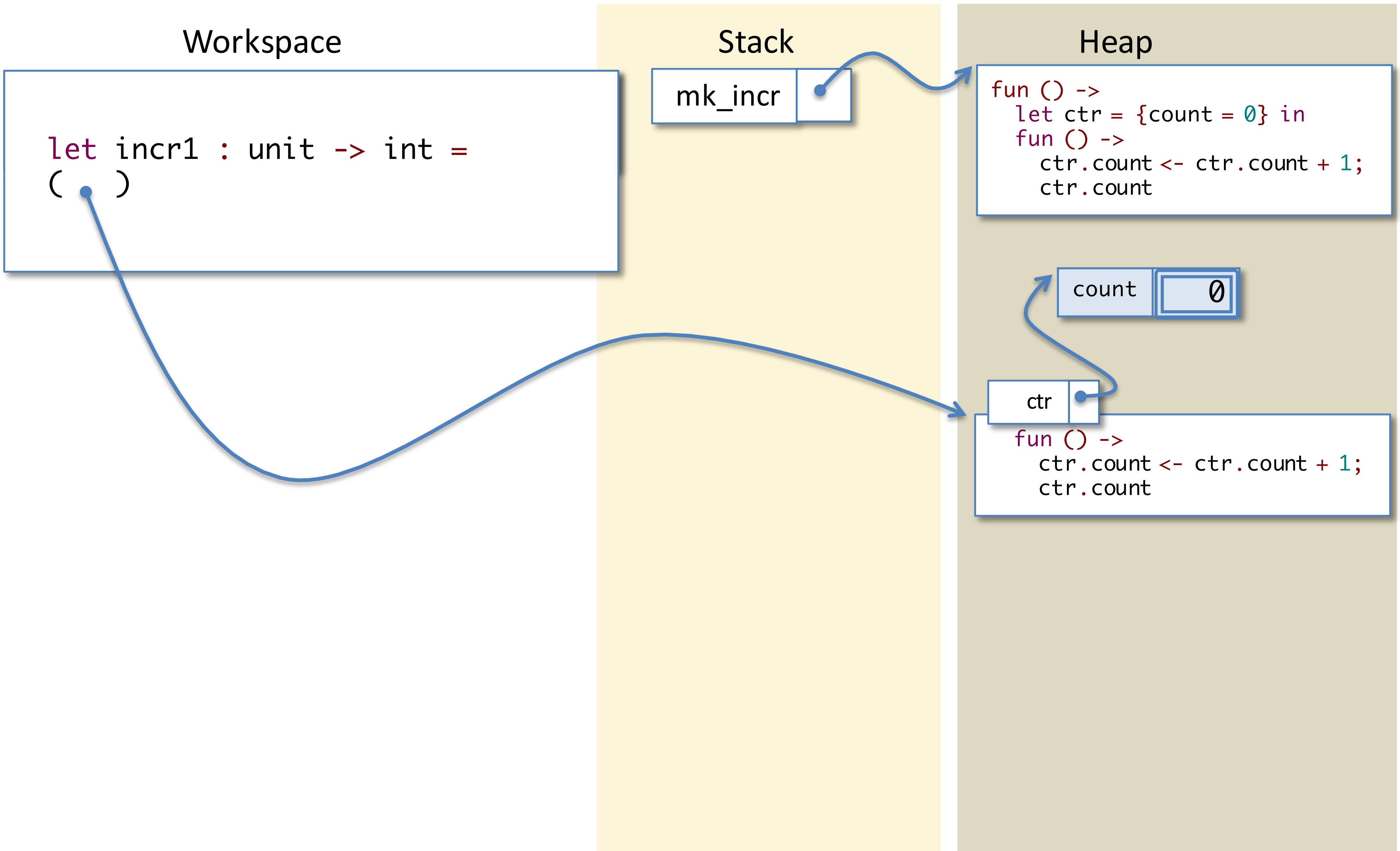
The function mentions "ctr", which is on the stack (but about to be popped off)…

…so we save a copy of the needed stack bindings with the function itself. (This is sometimes called a *closure*…)

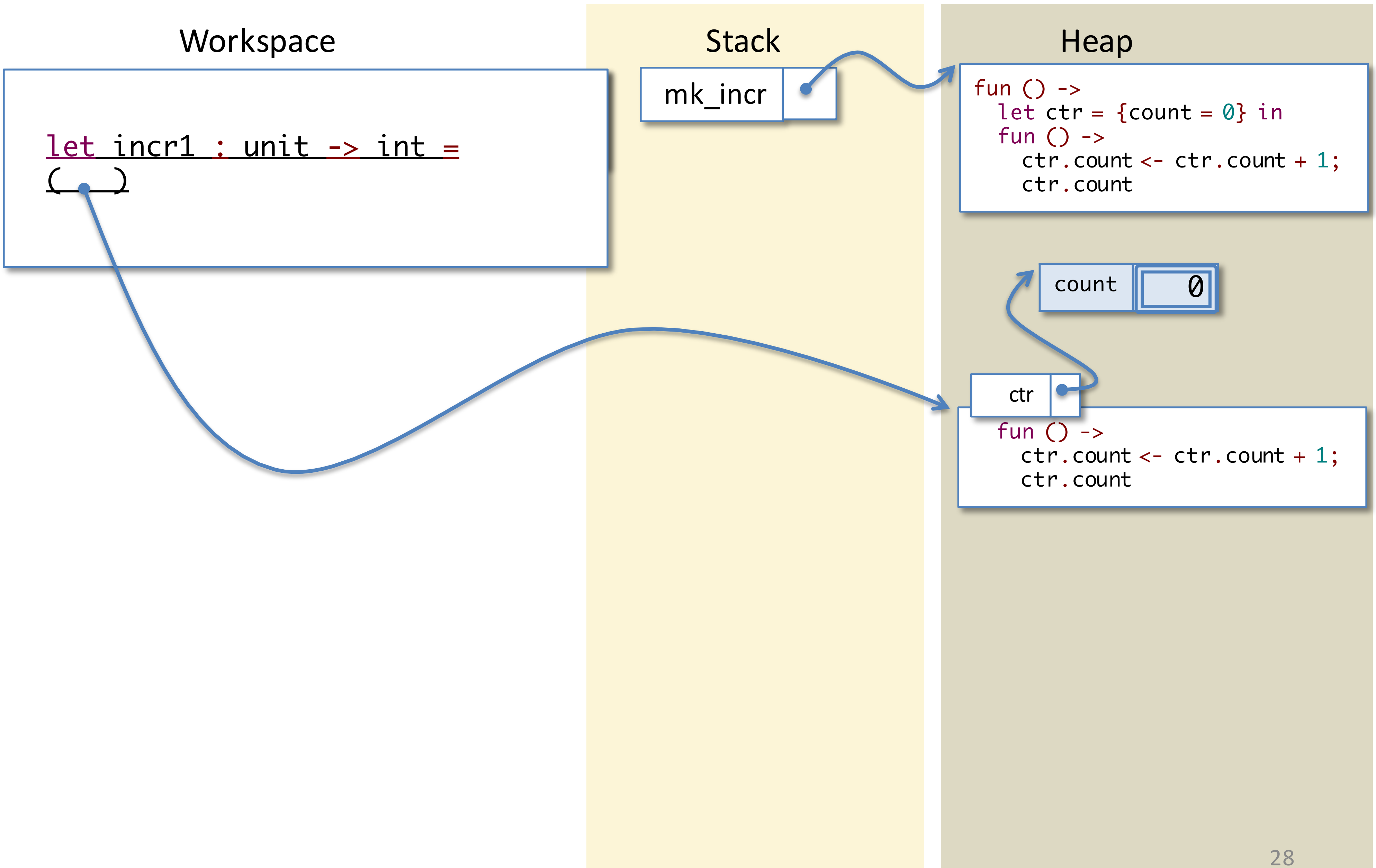
Local Functions



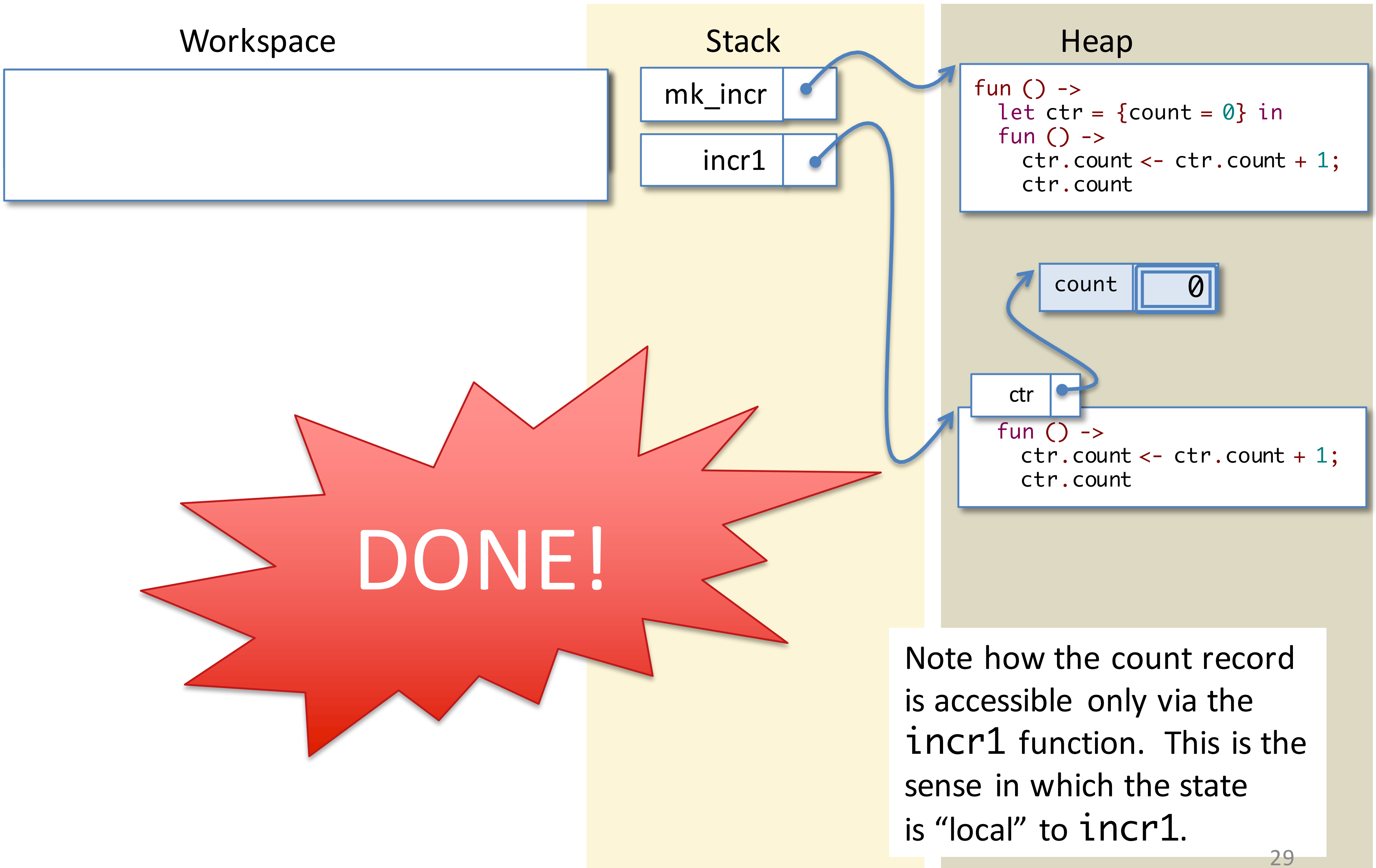
Local Functions



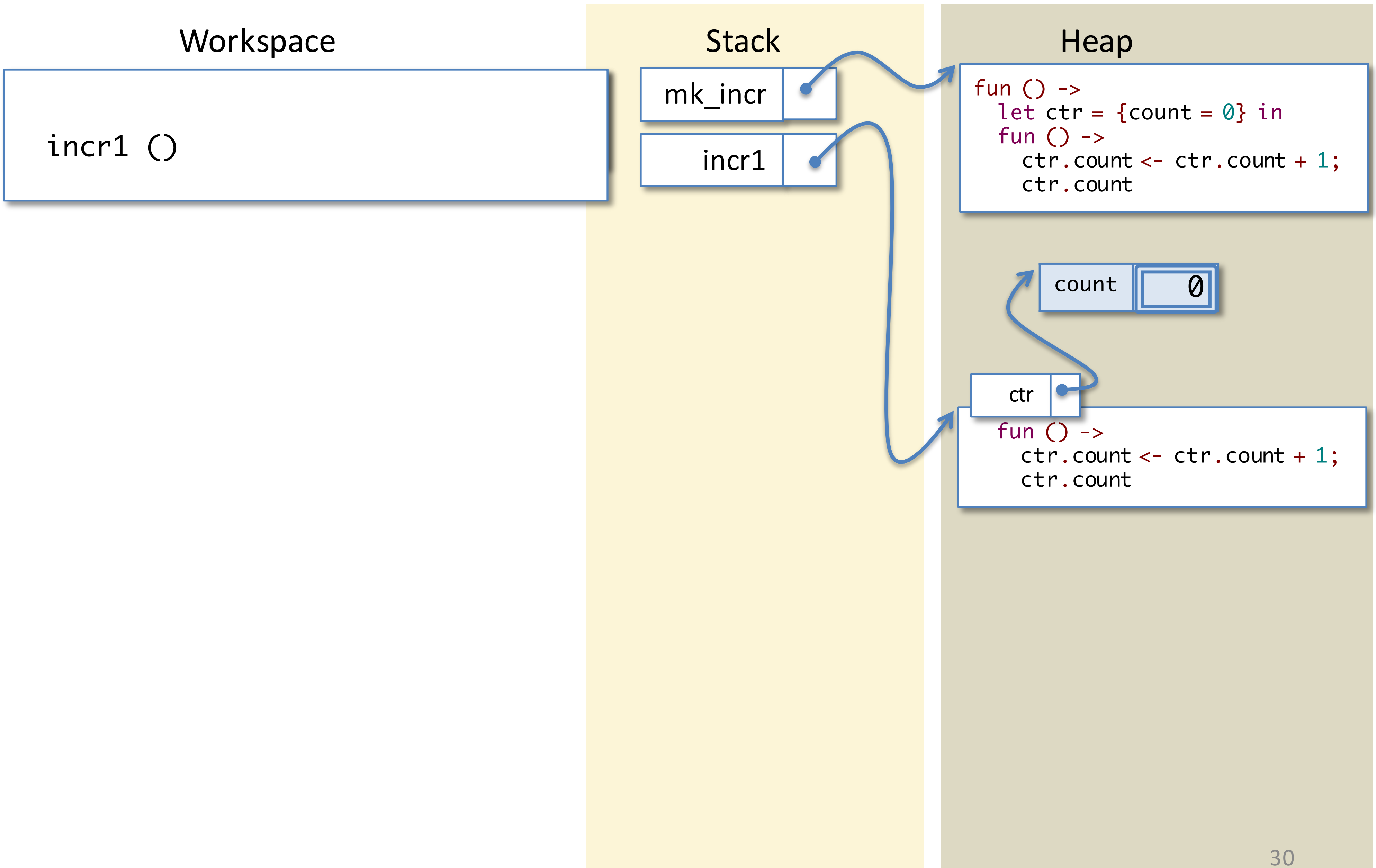
Local Functions



Local Functions



Now let's run "incr1 ()"



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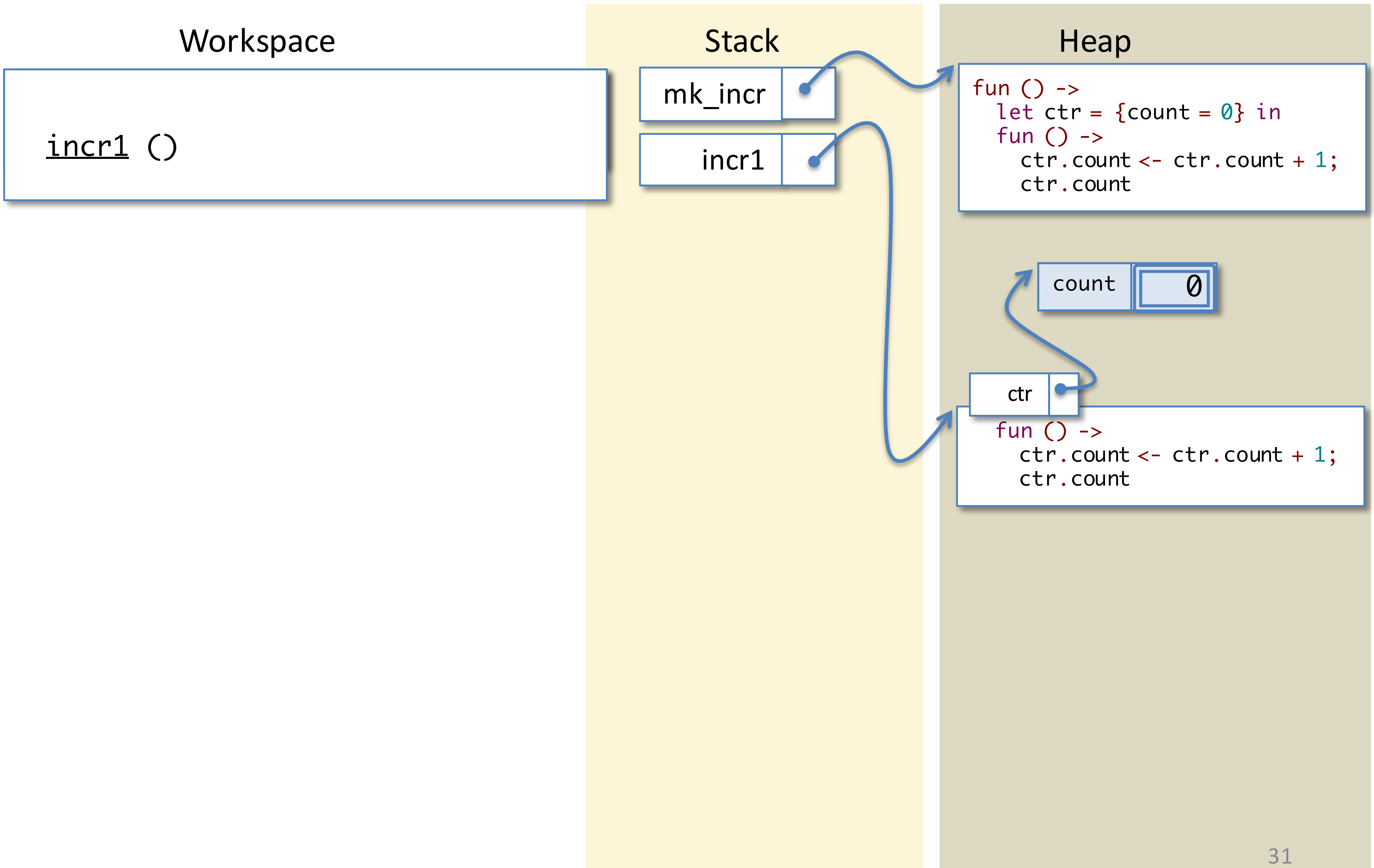

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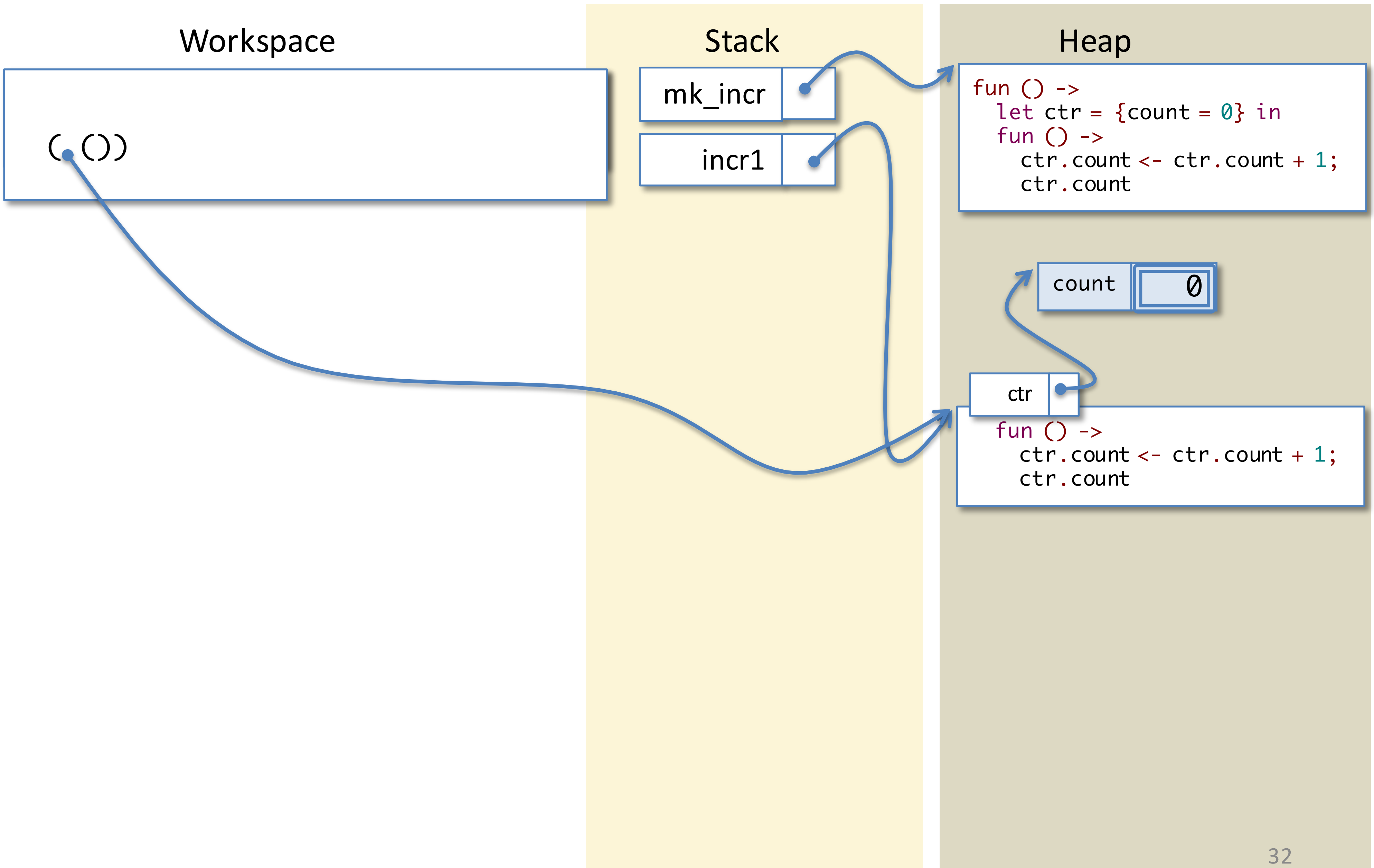

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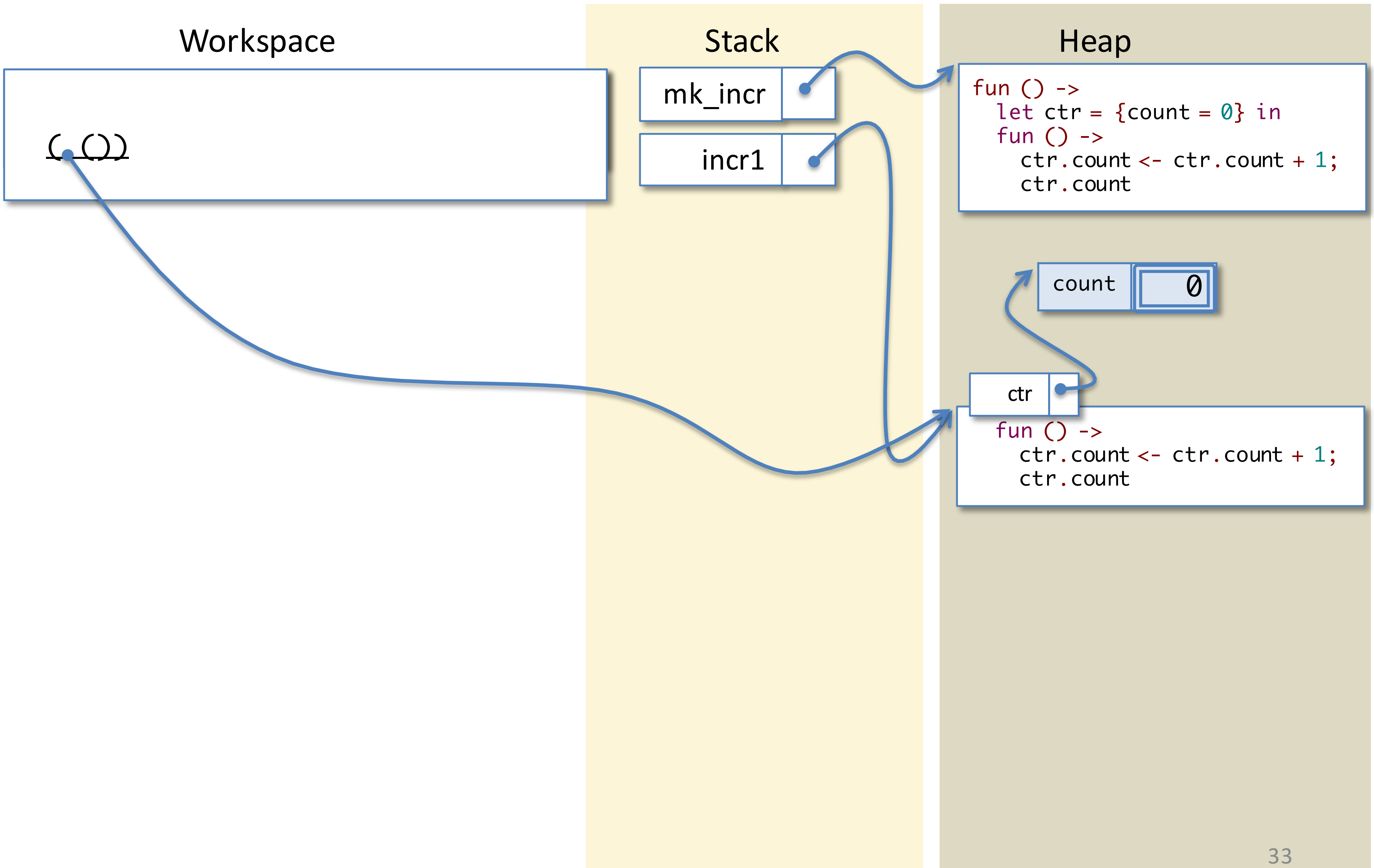
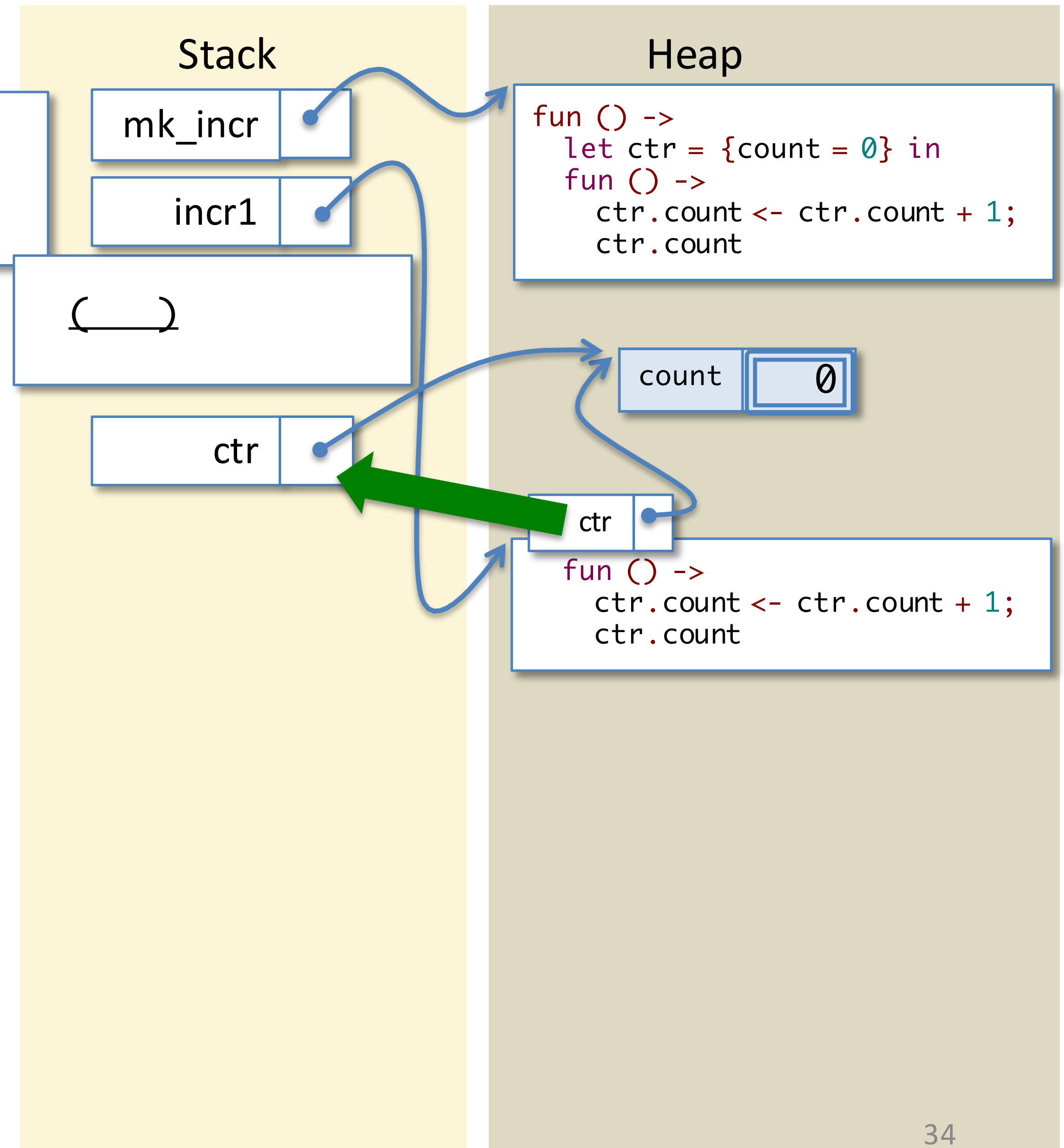


Now let's run "`incr1 ()`"

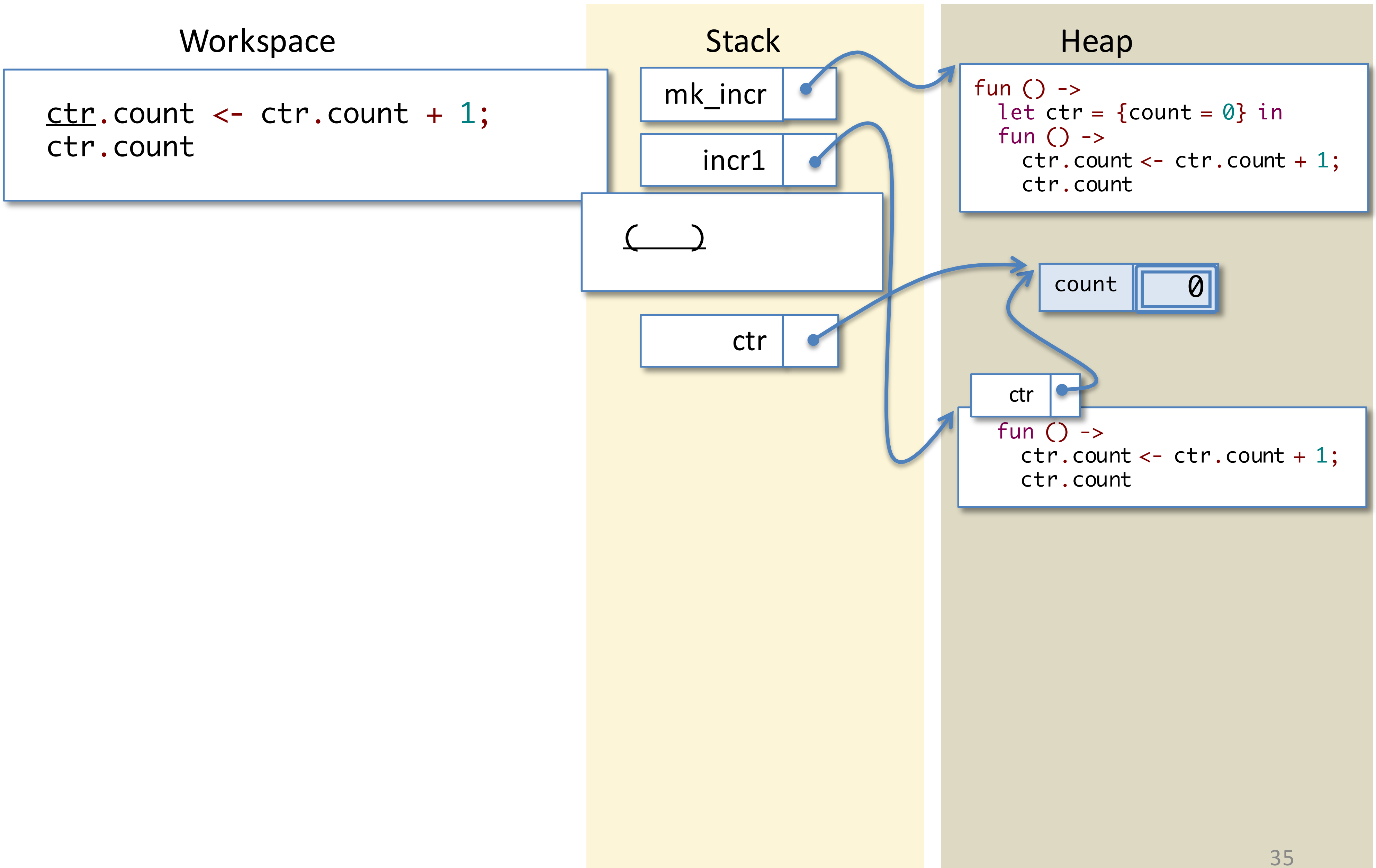
Workspace

```
ctr.count <- ctr.count + 1;
ctr.count
```



NOTE: Since the function had some saved stack bindings, we add them to the stack at the same time that we put the code in the workspace.

Now let's run "`incr1 ()`"



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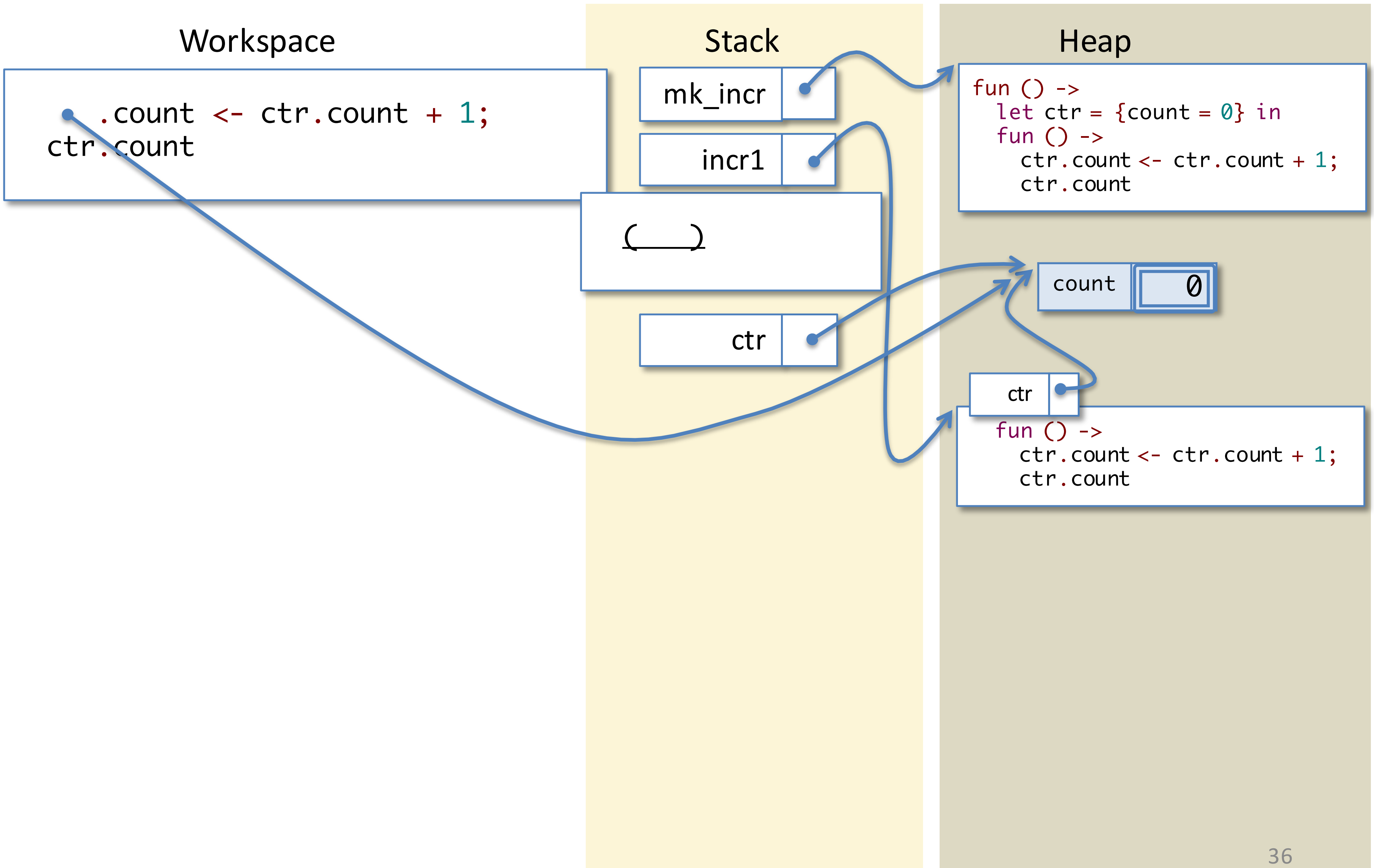

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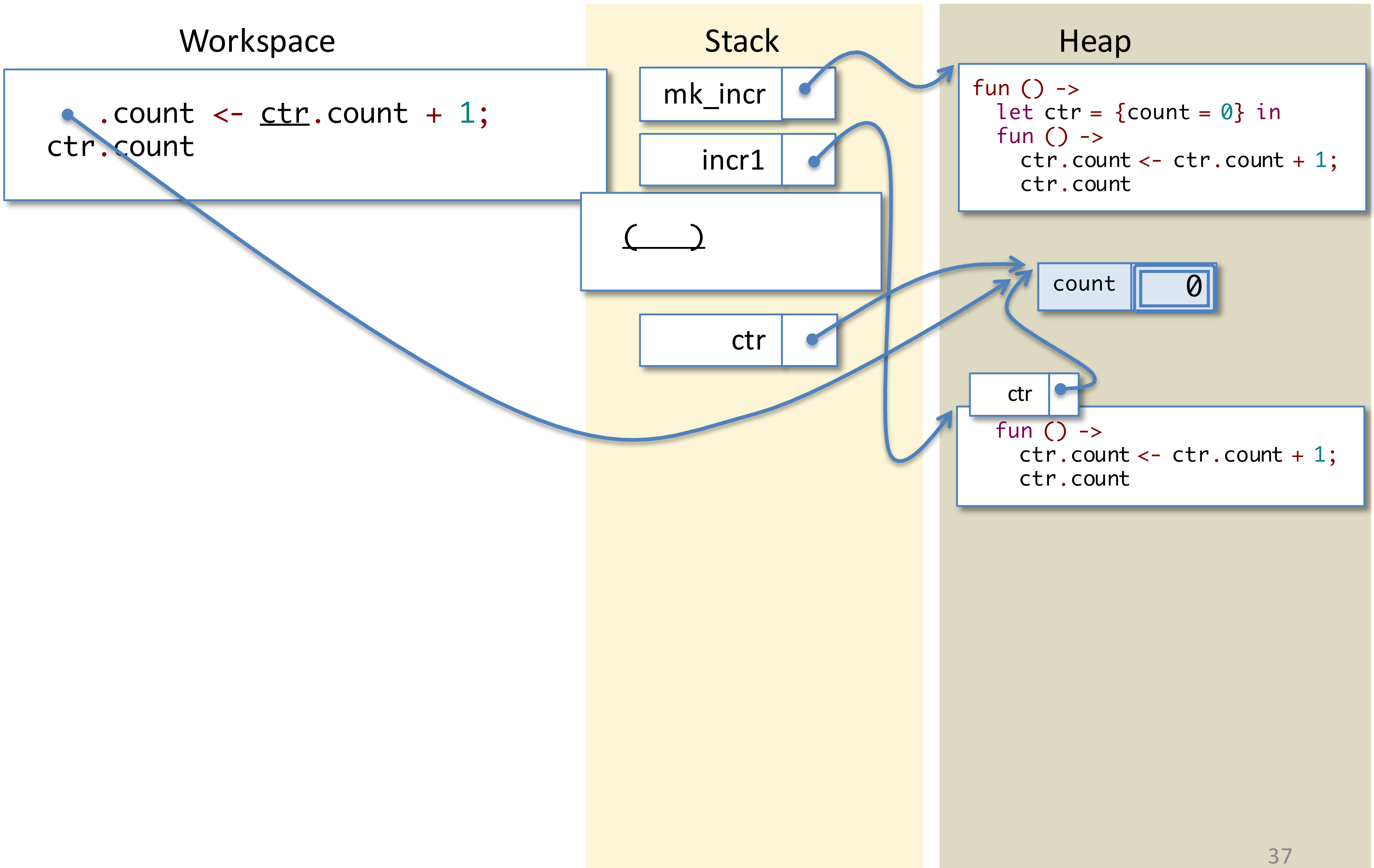

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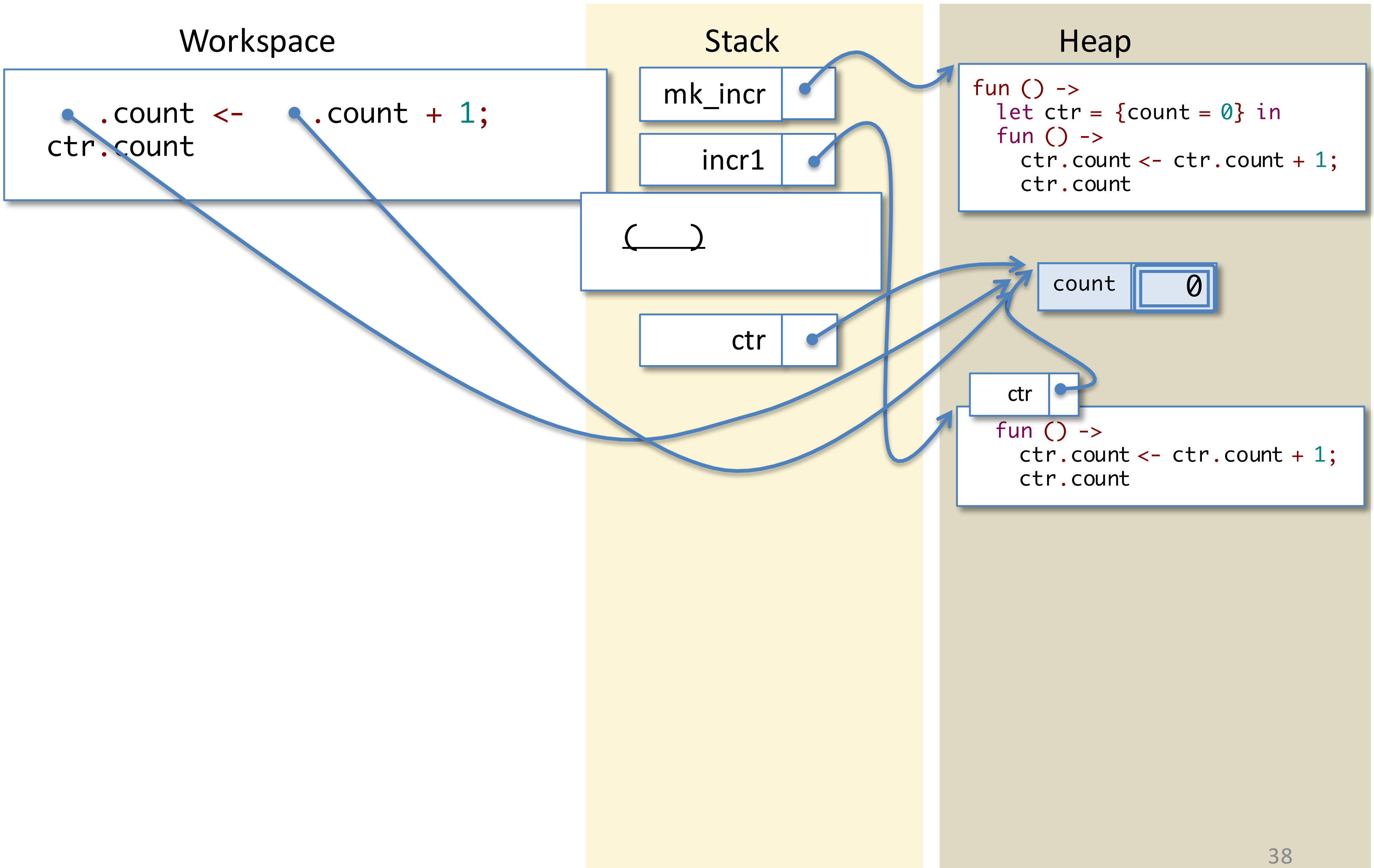

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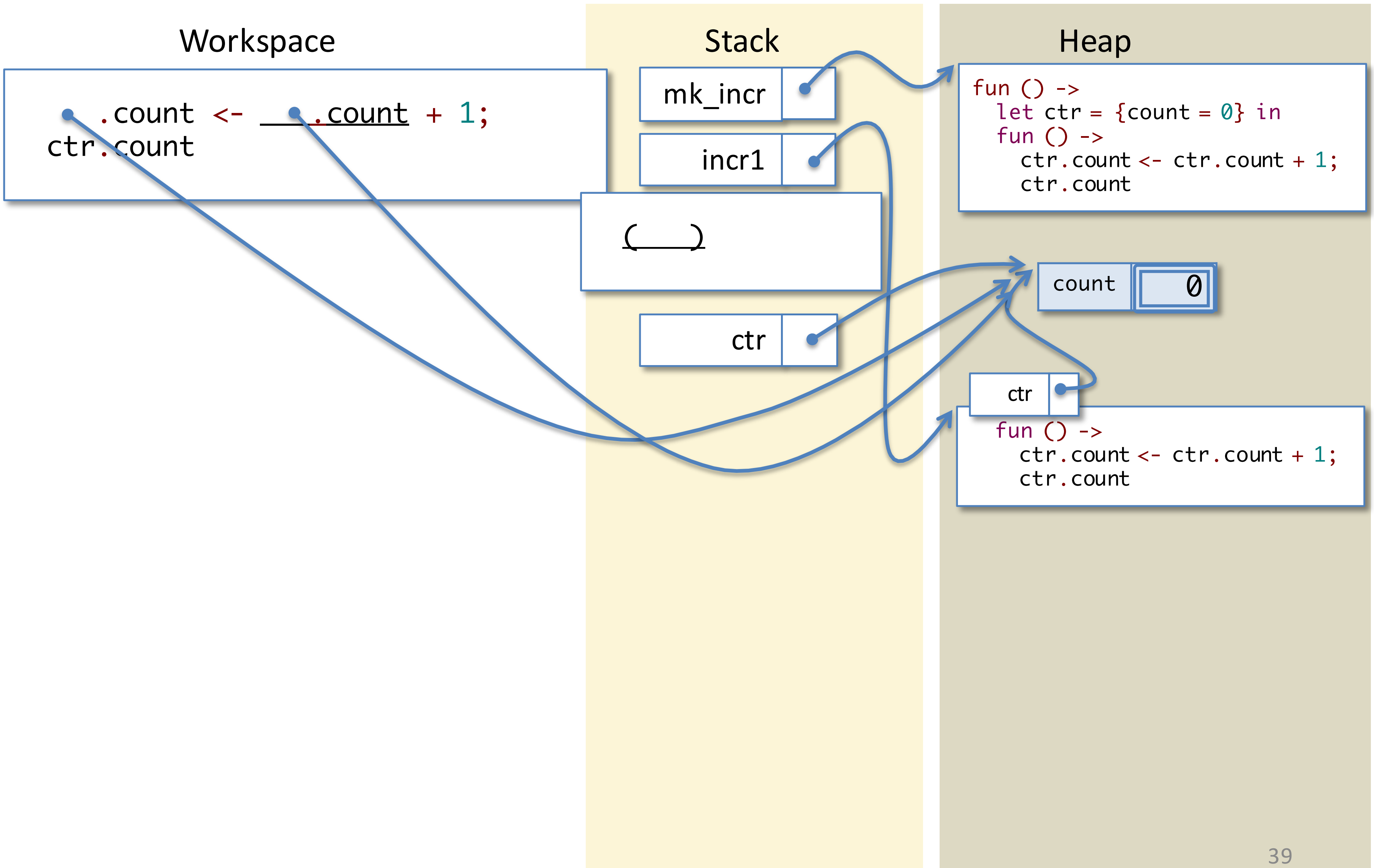

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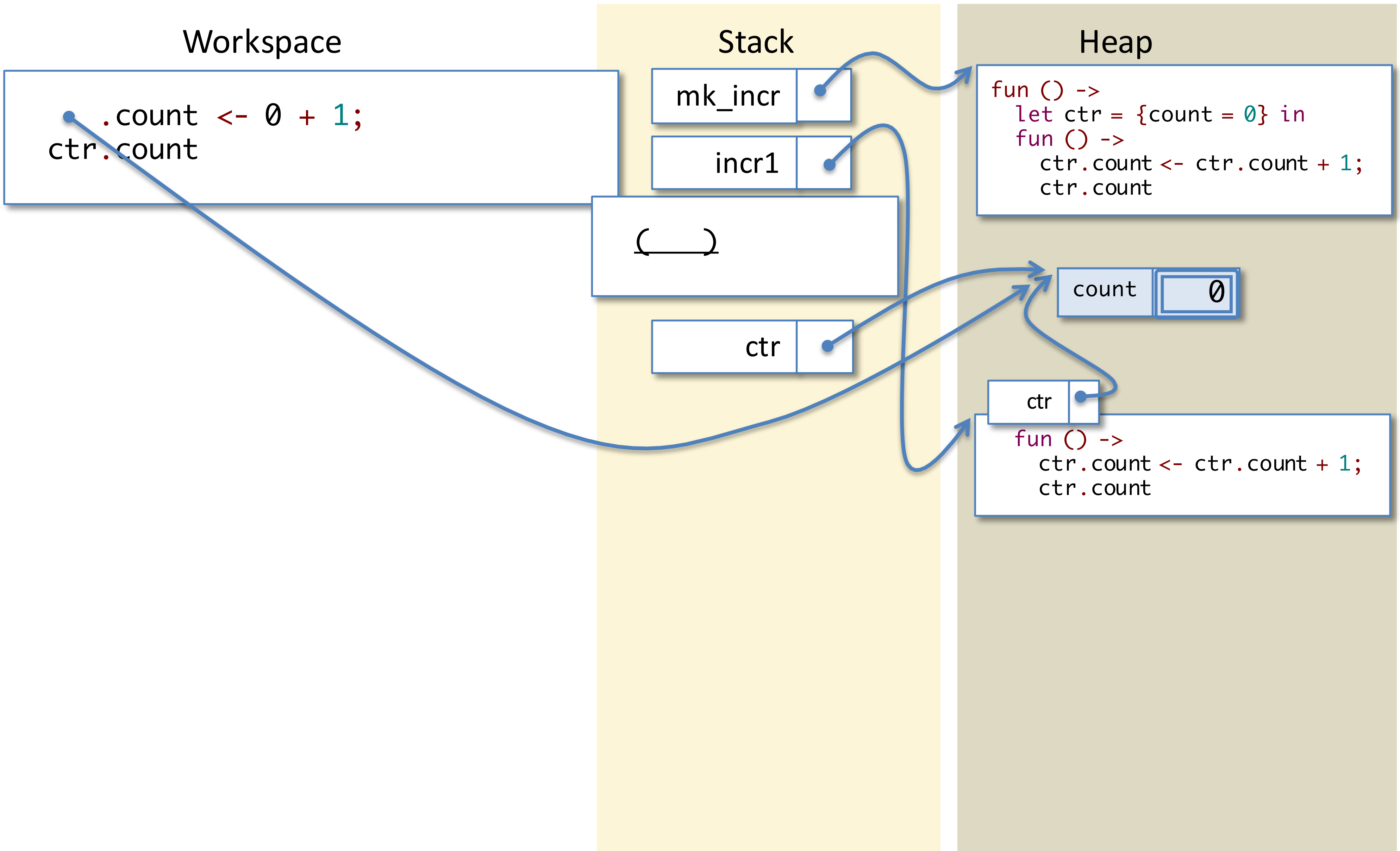

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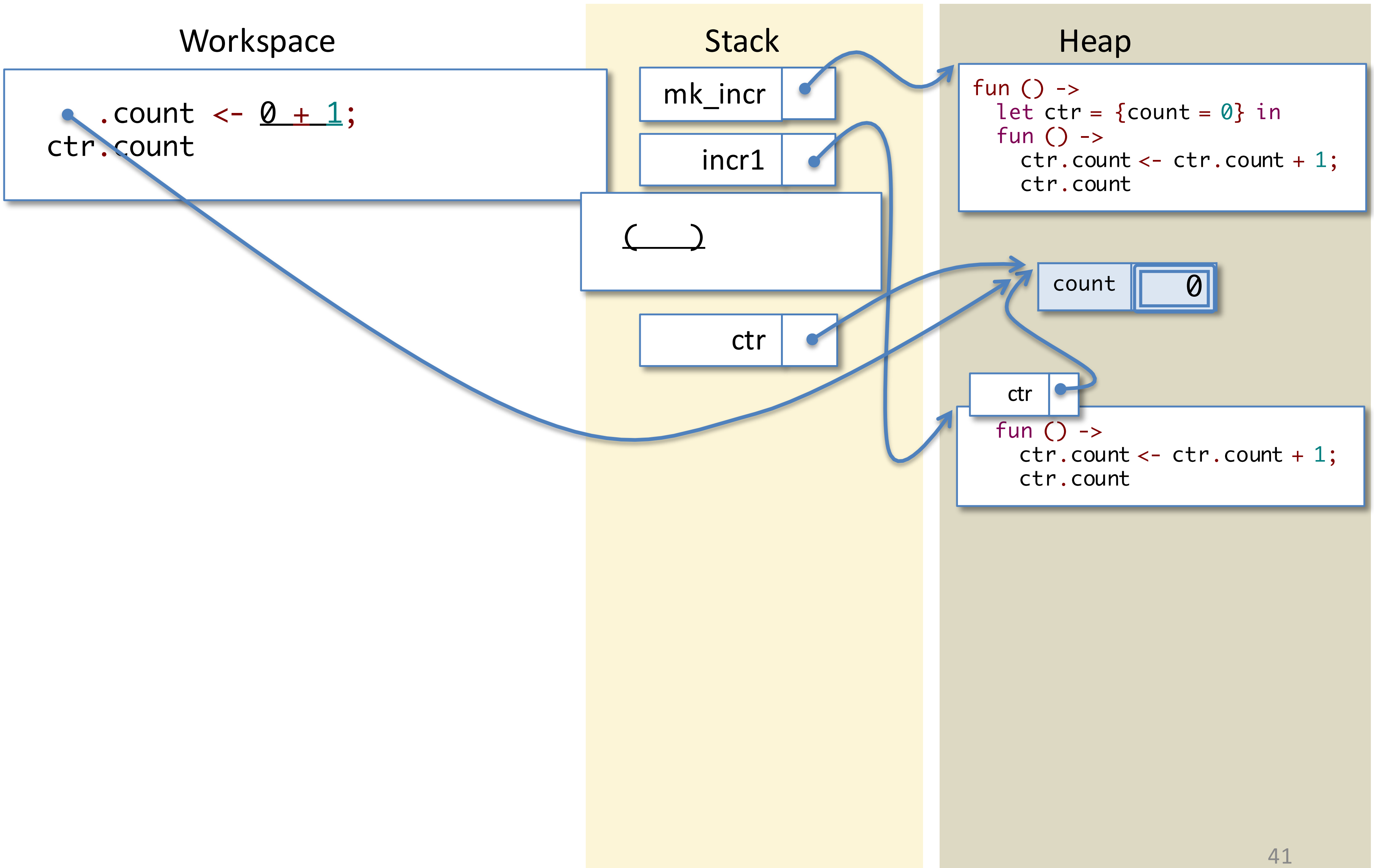
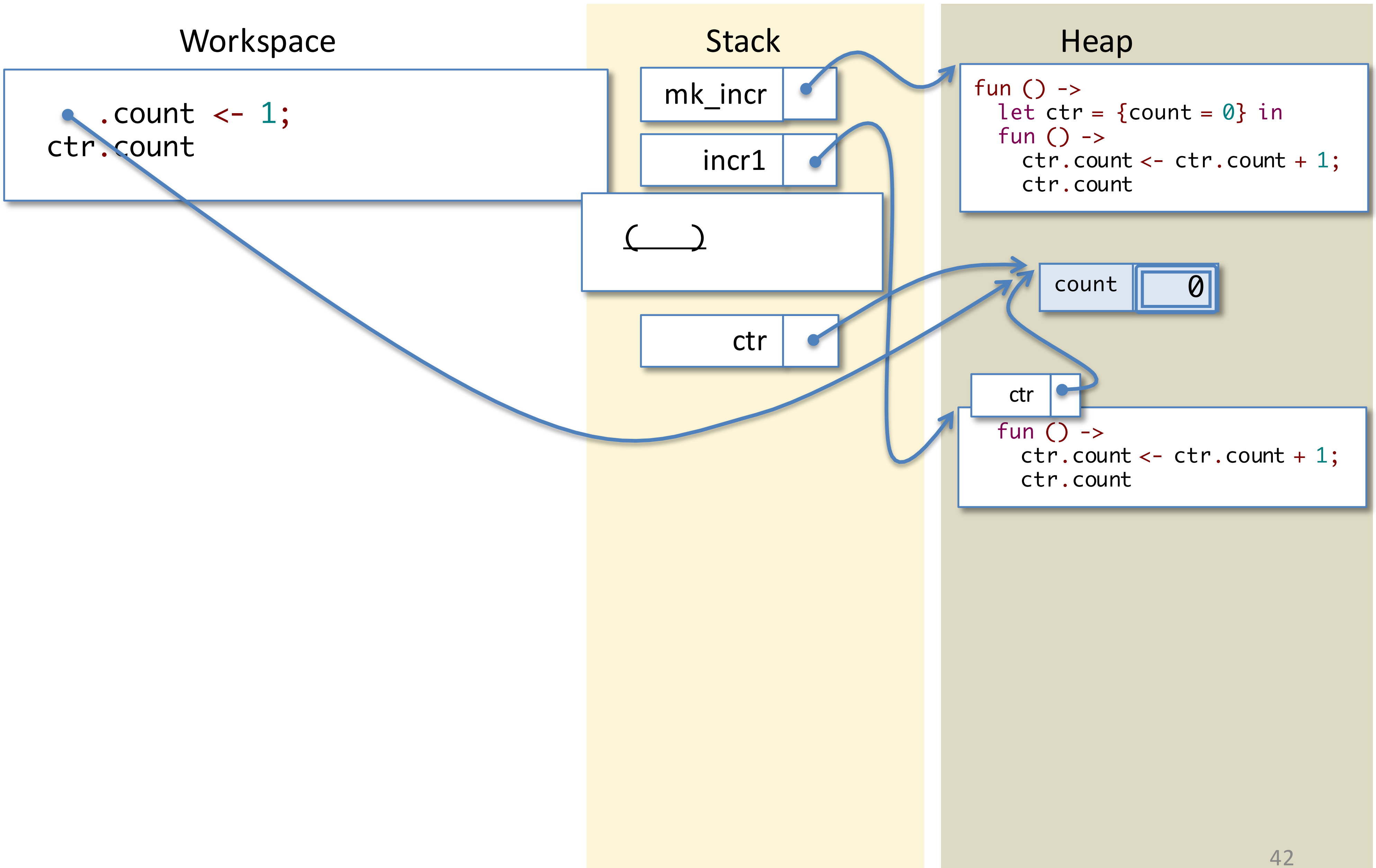


Now let’s run “`incr1 ()`”



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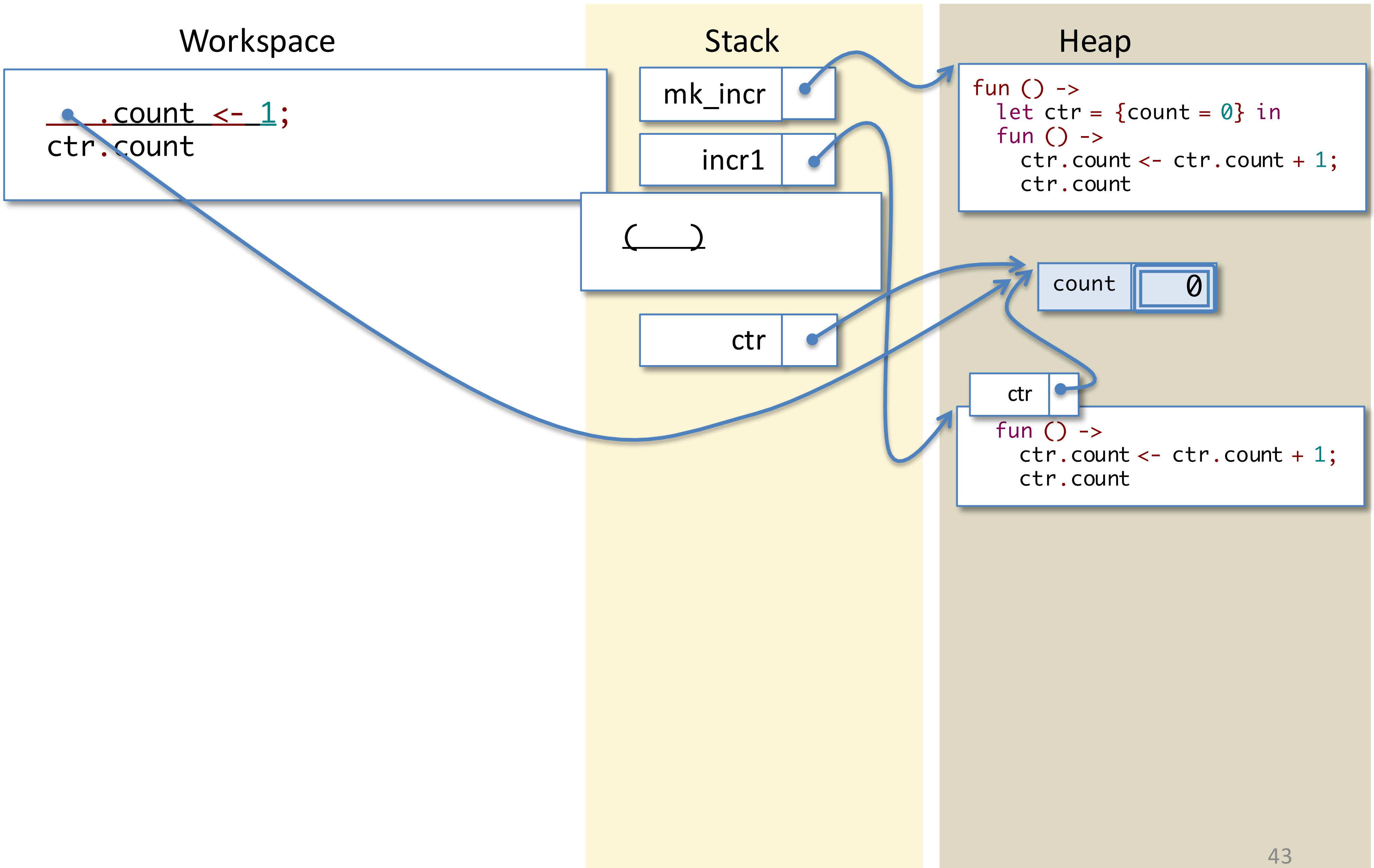

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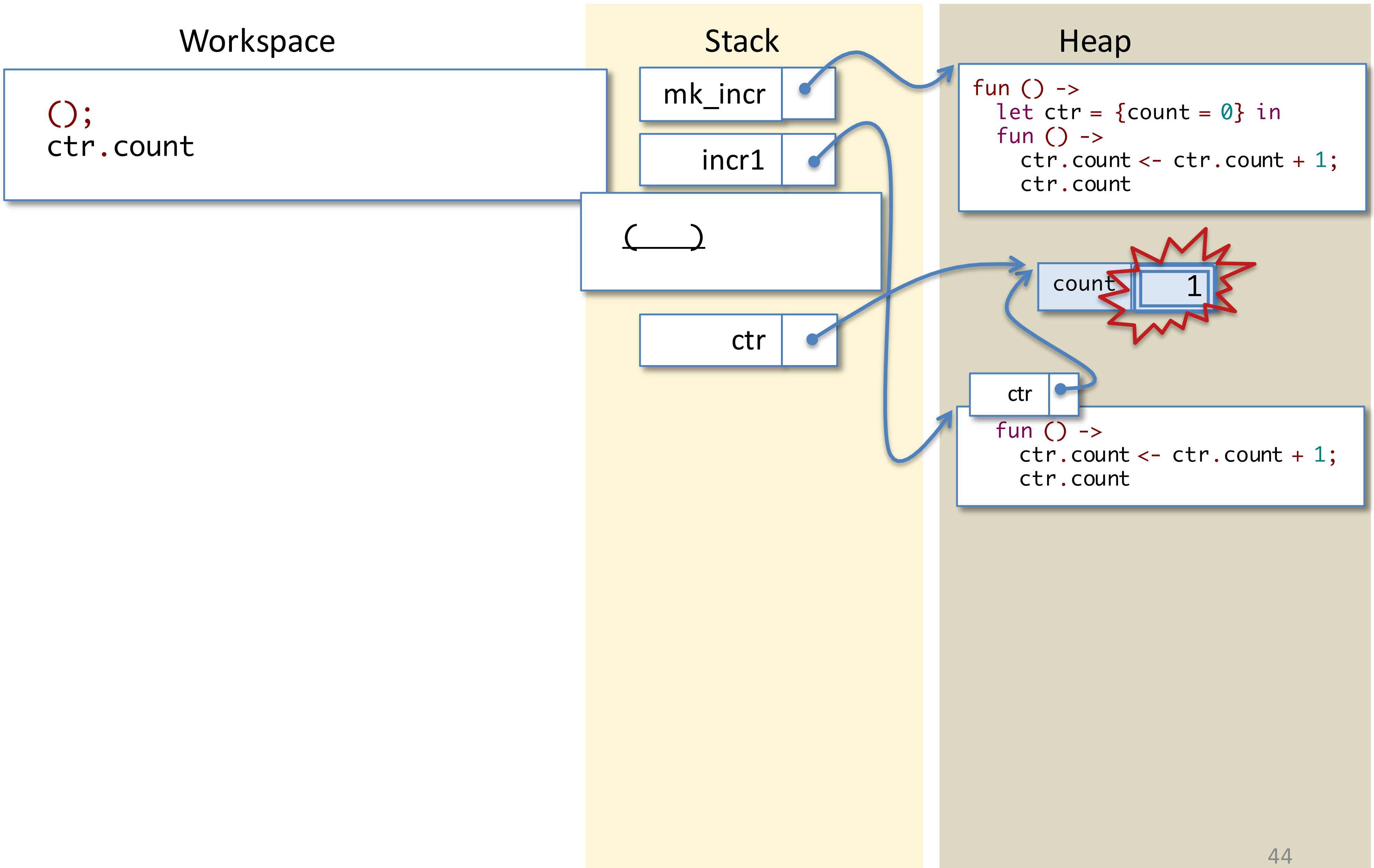

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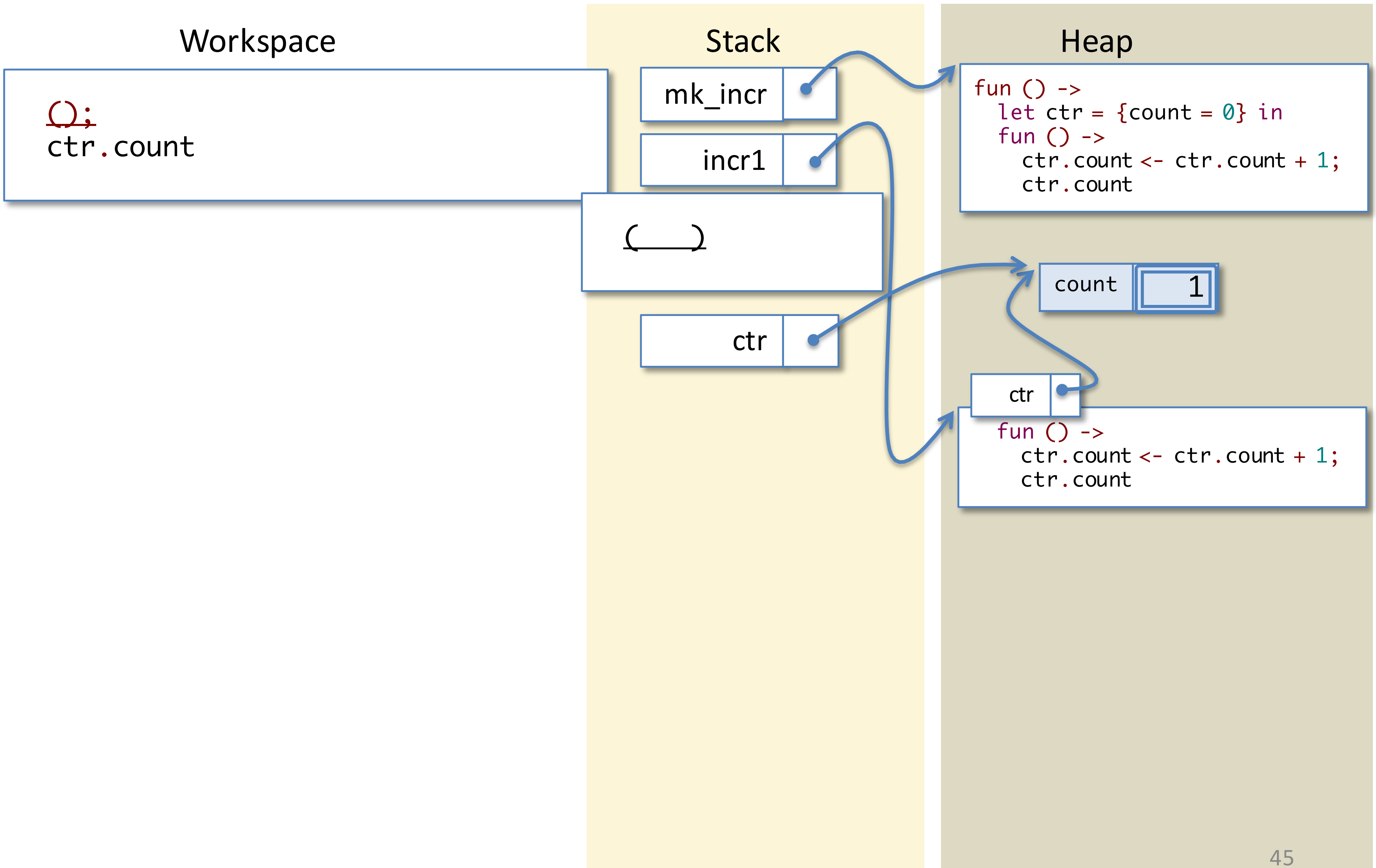

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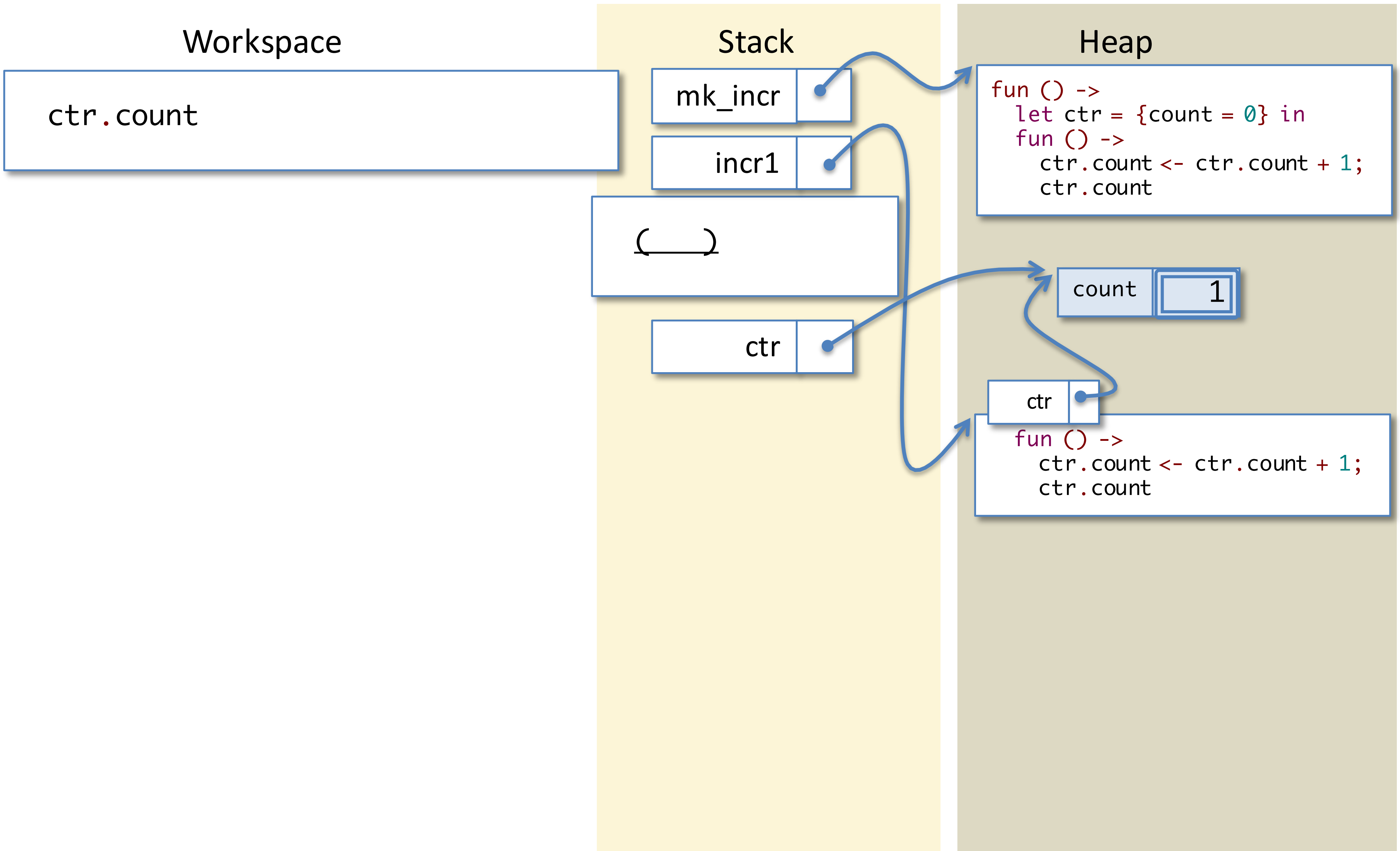

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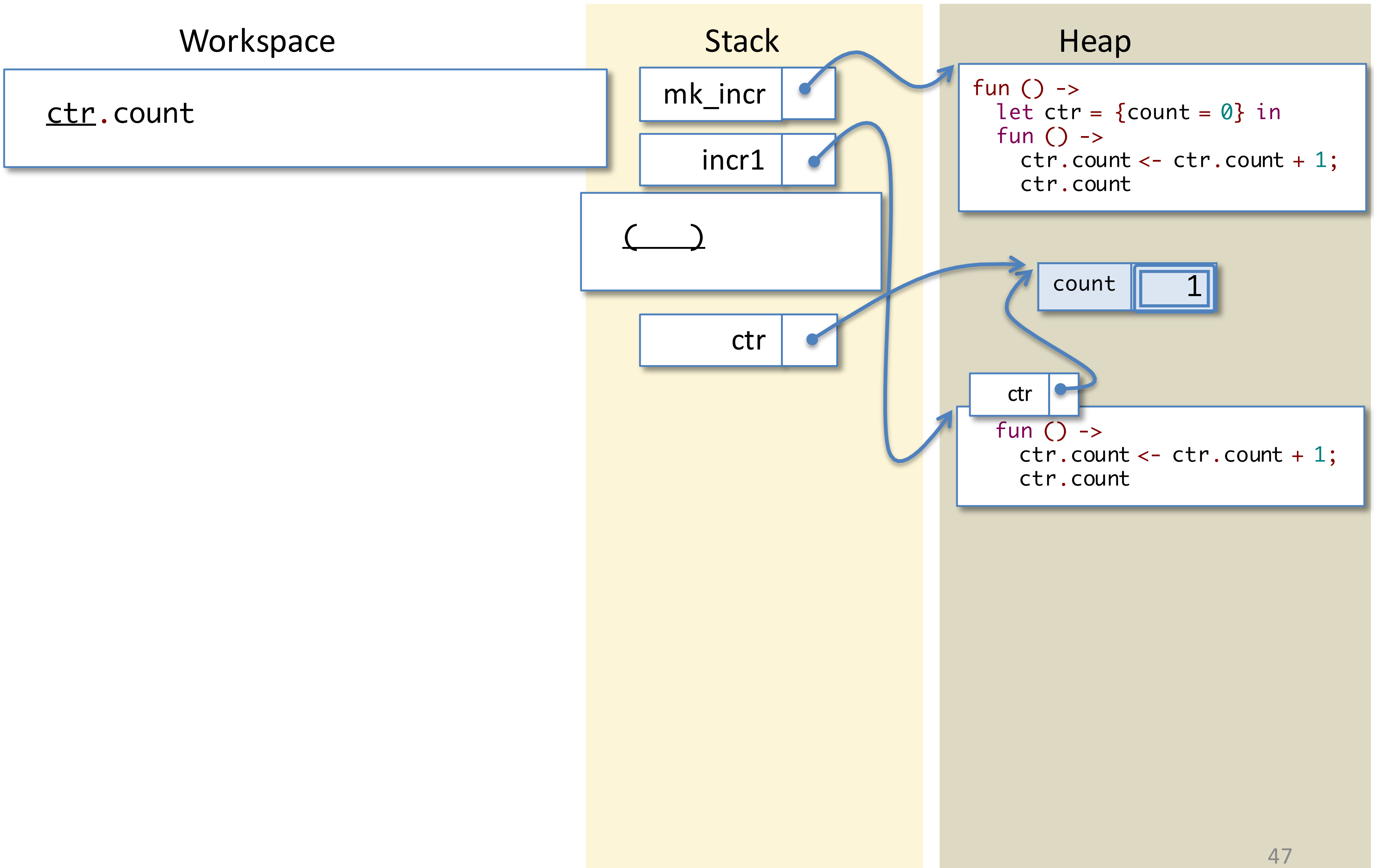

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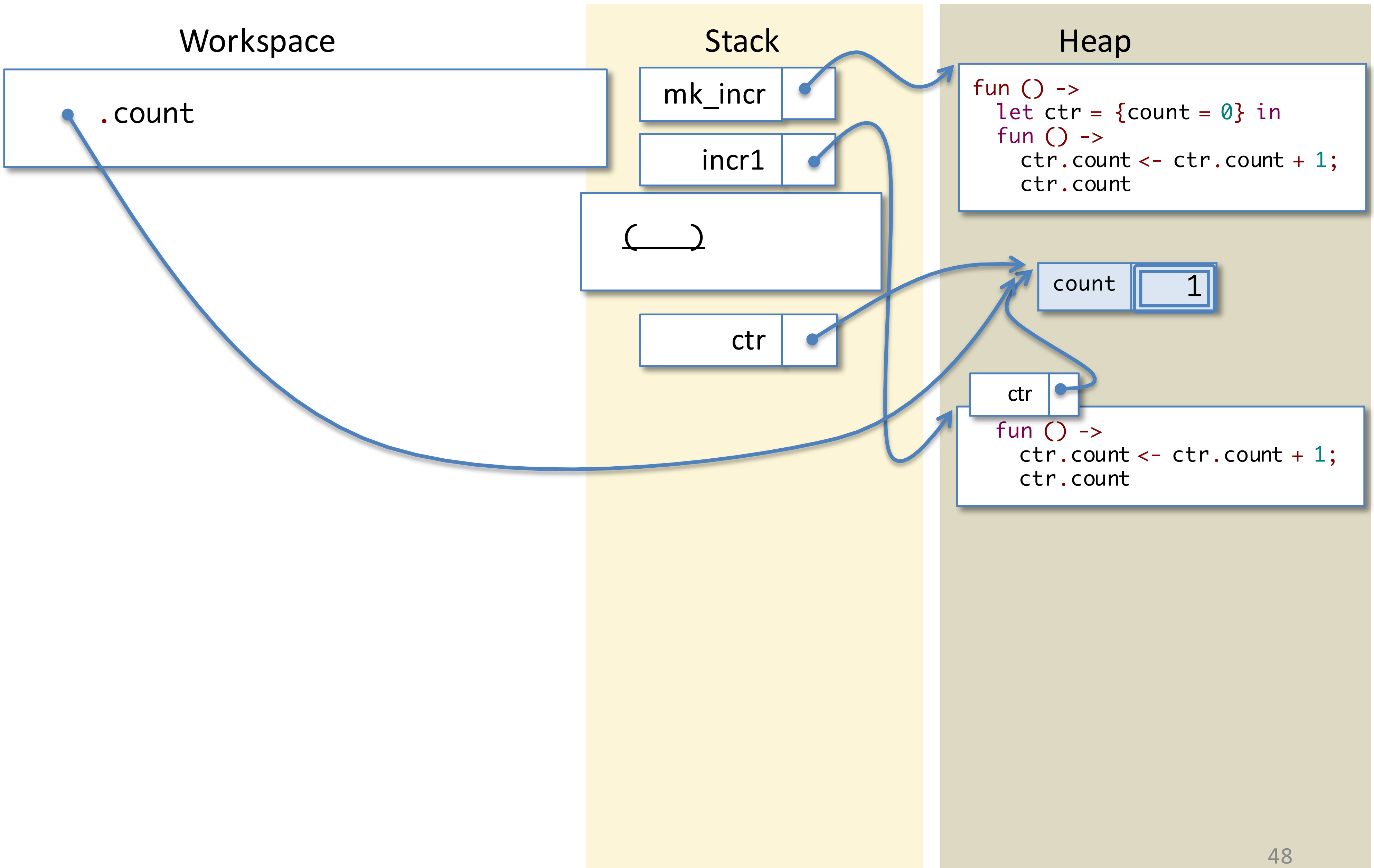
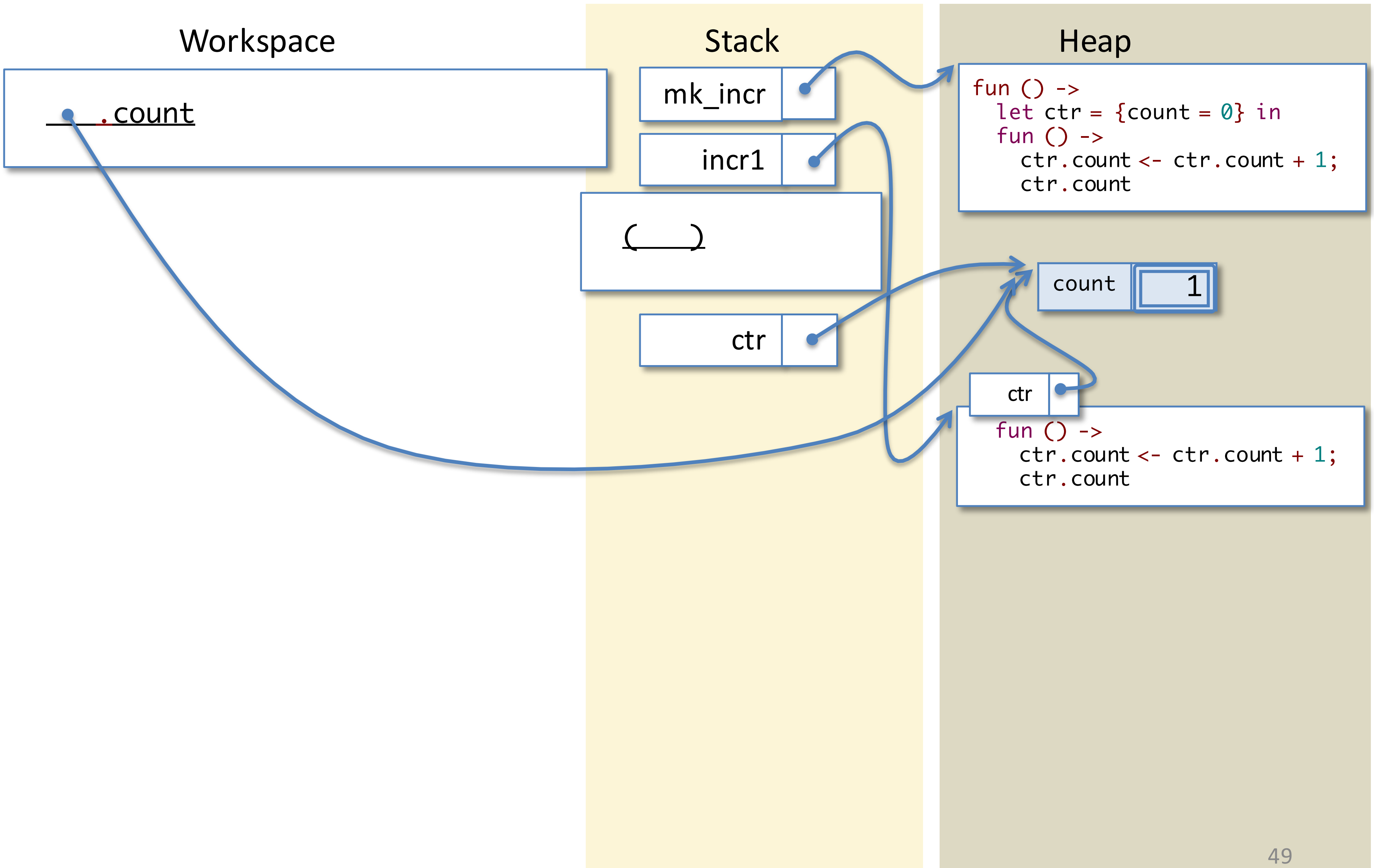
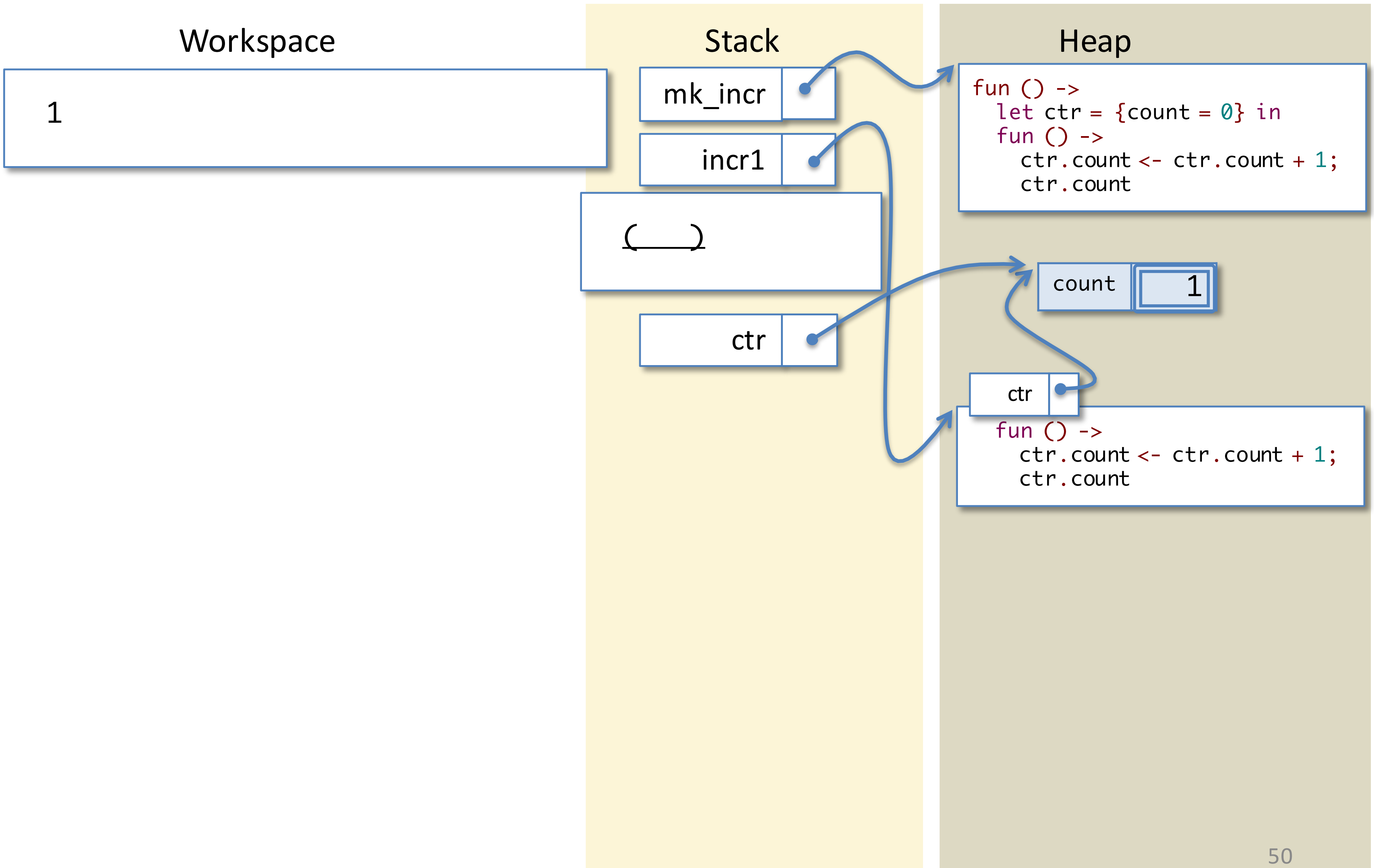


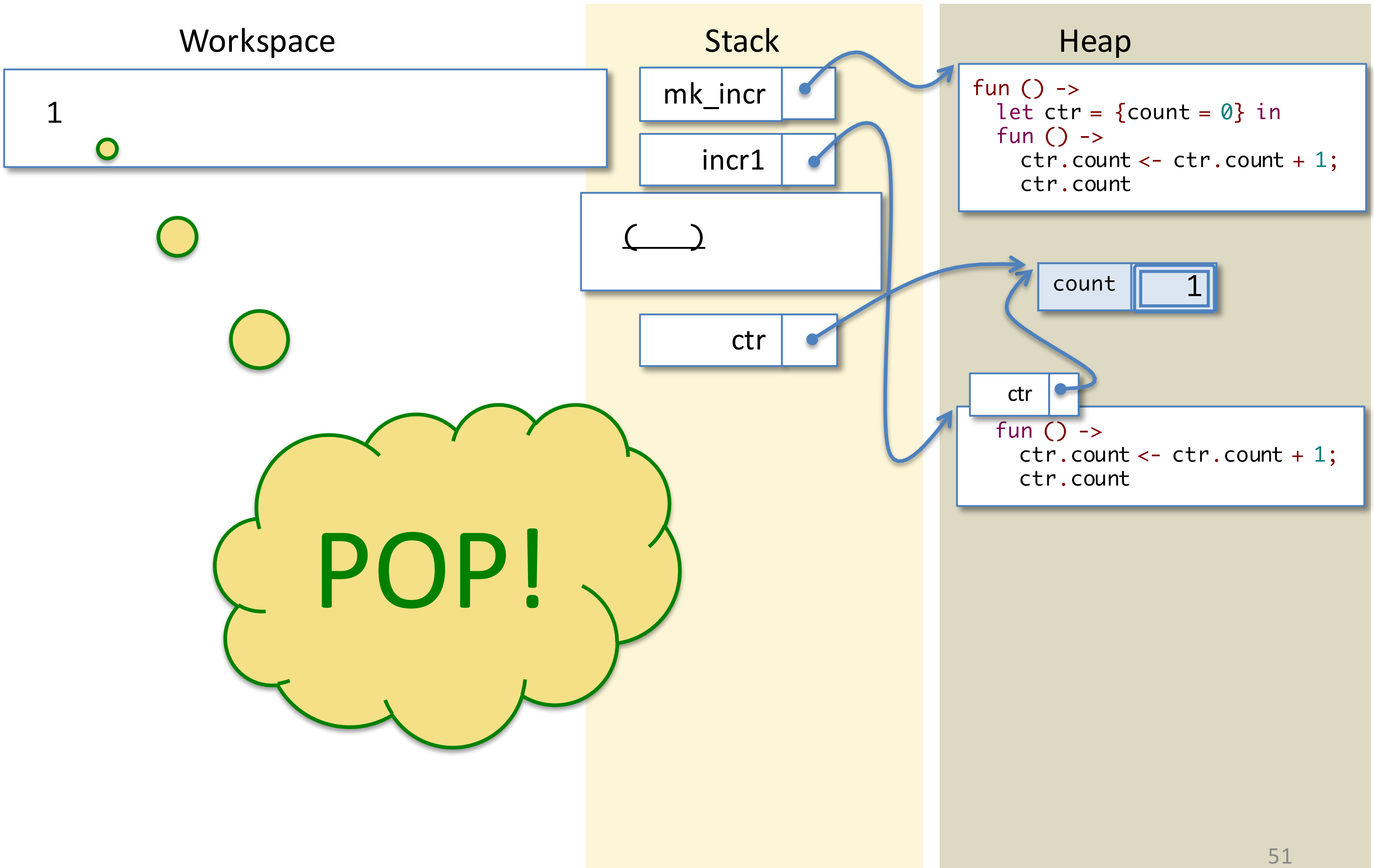
Now let's run "`incr1 ()`"



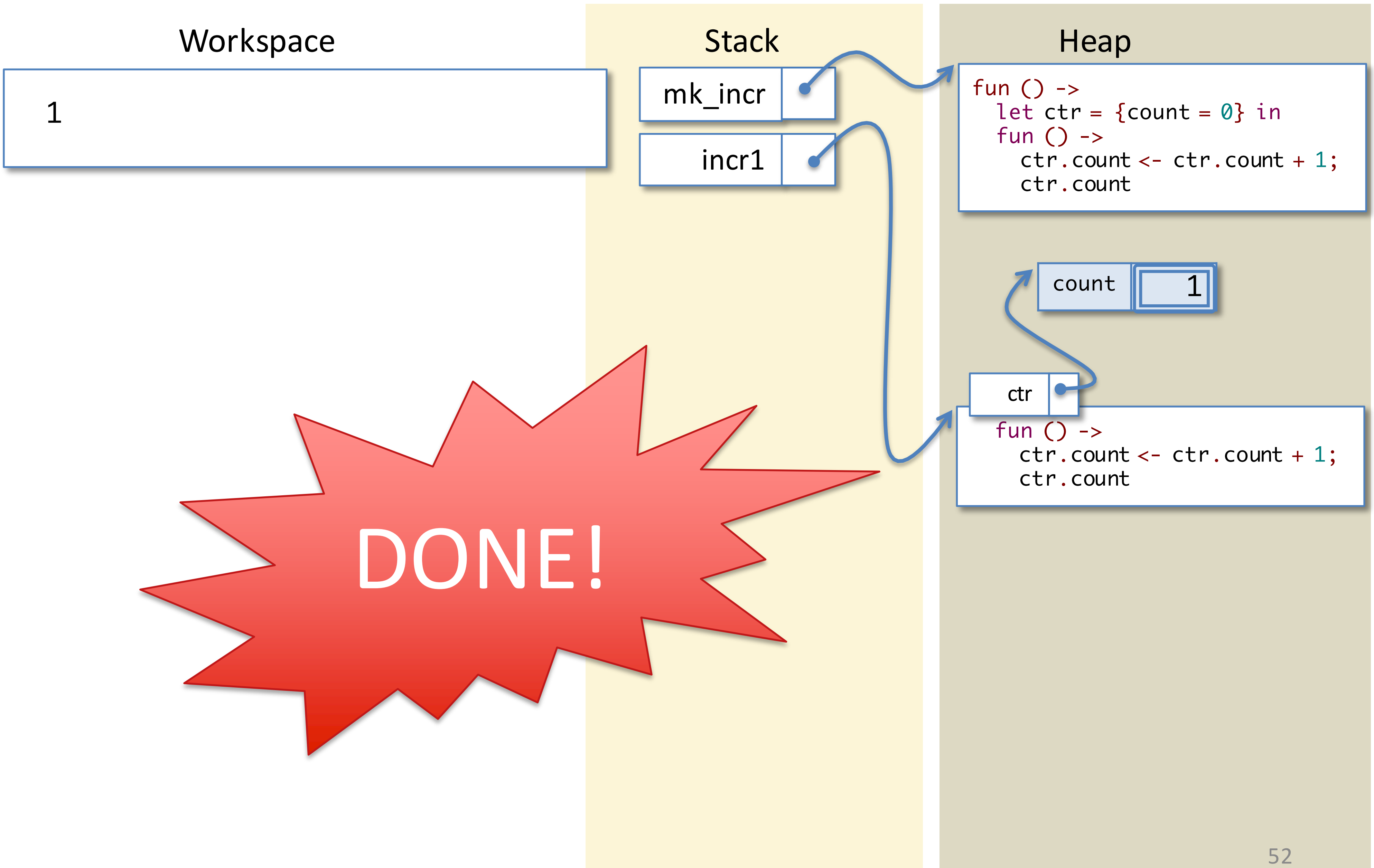
Now let's run "`incr1 ()`"



Now let's run "`incr1 ()`"



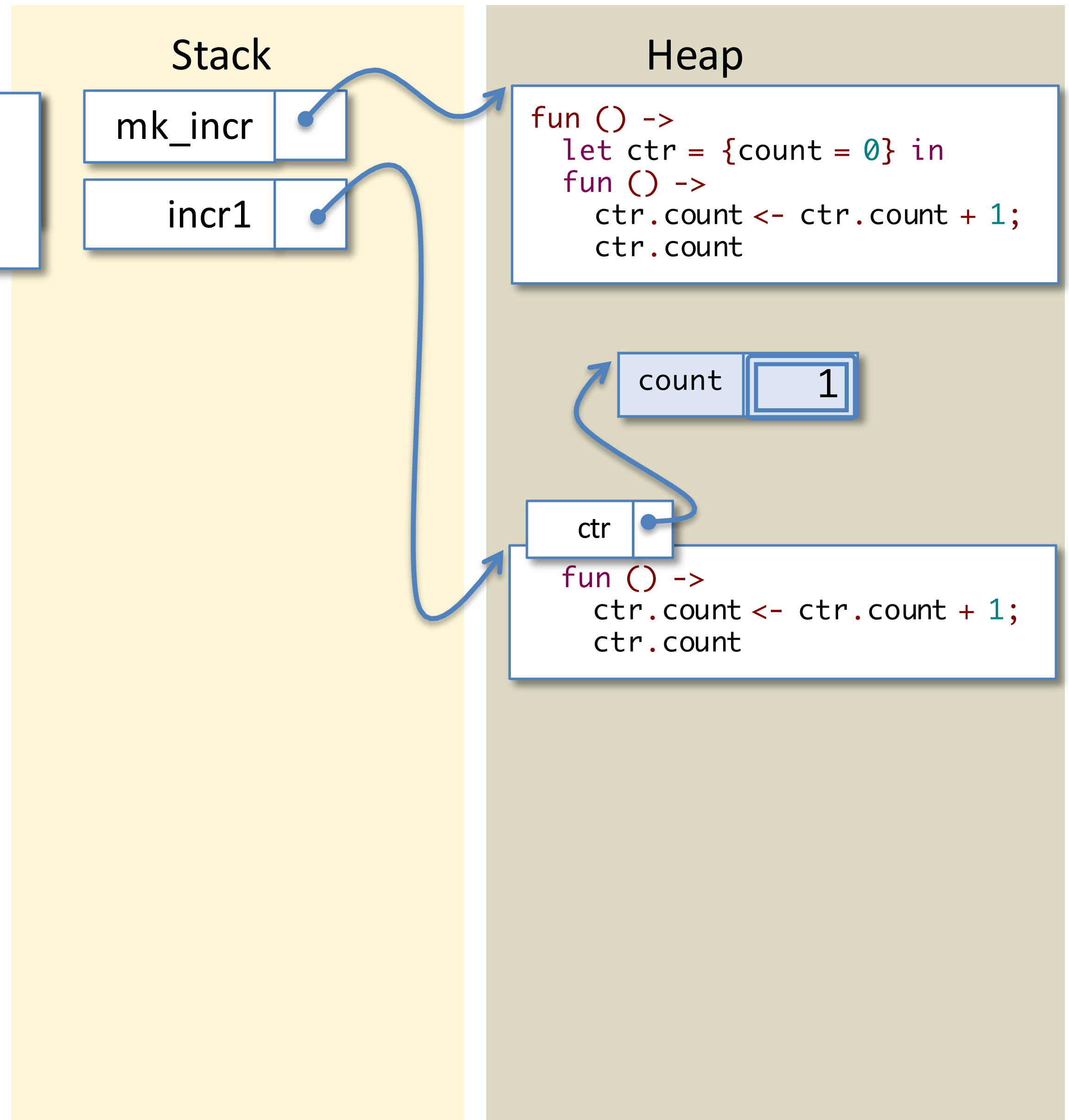
Now let's run "incr1 ()"



Now Let’s run `mk_incr` again

Workspace

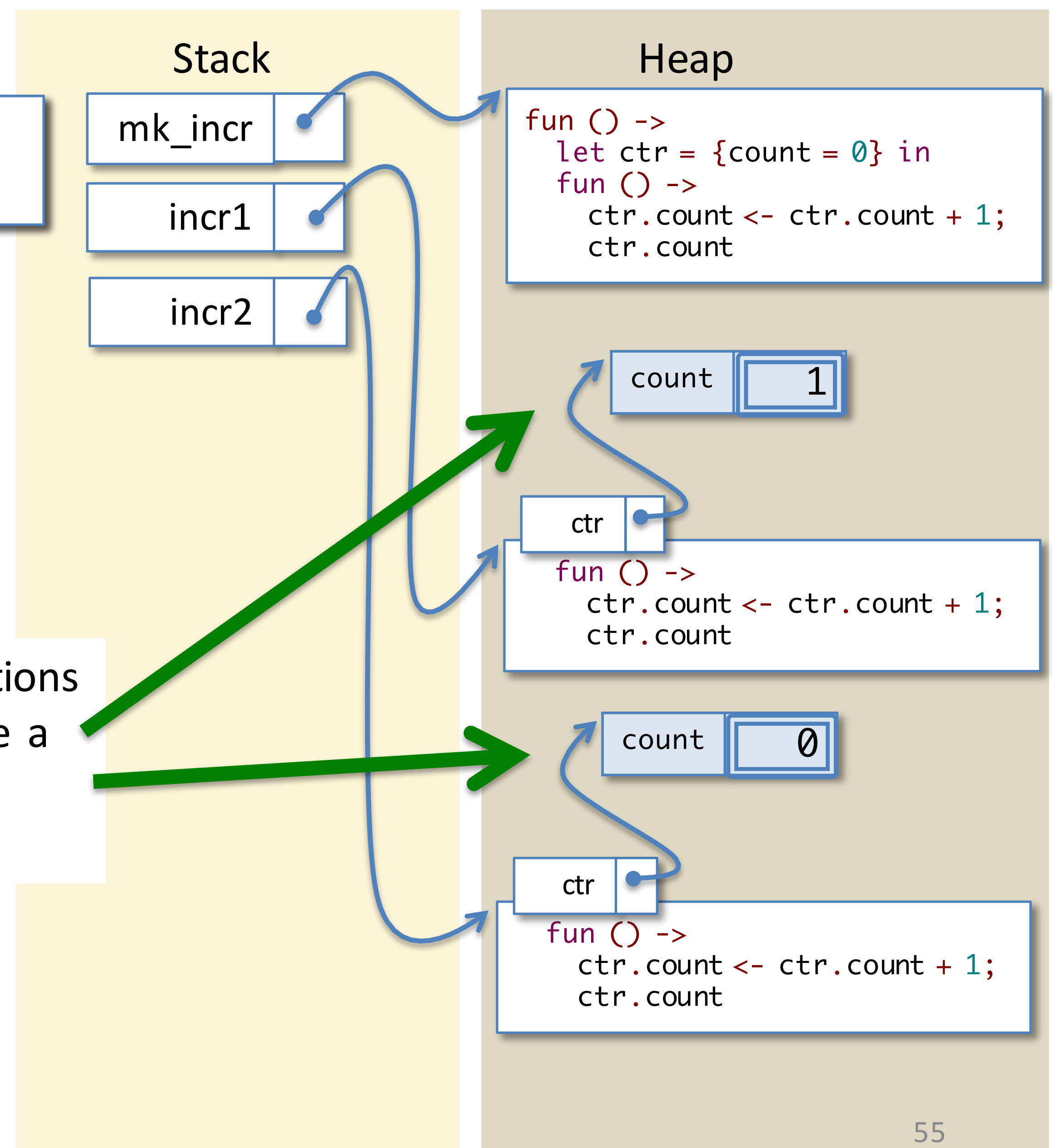
```
let incr2 : unit -> int =
mk_incr ()
```



…time passes…

After creating incr2

Workspace



NOTE: the two different incr functions have *separate* local states because a new count record was created in each call to mk_incr.

One step further

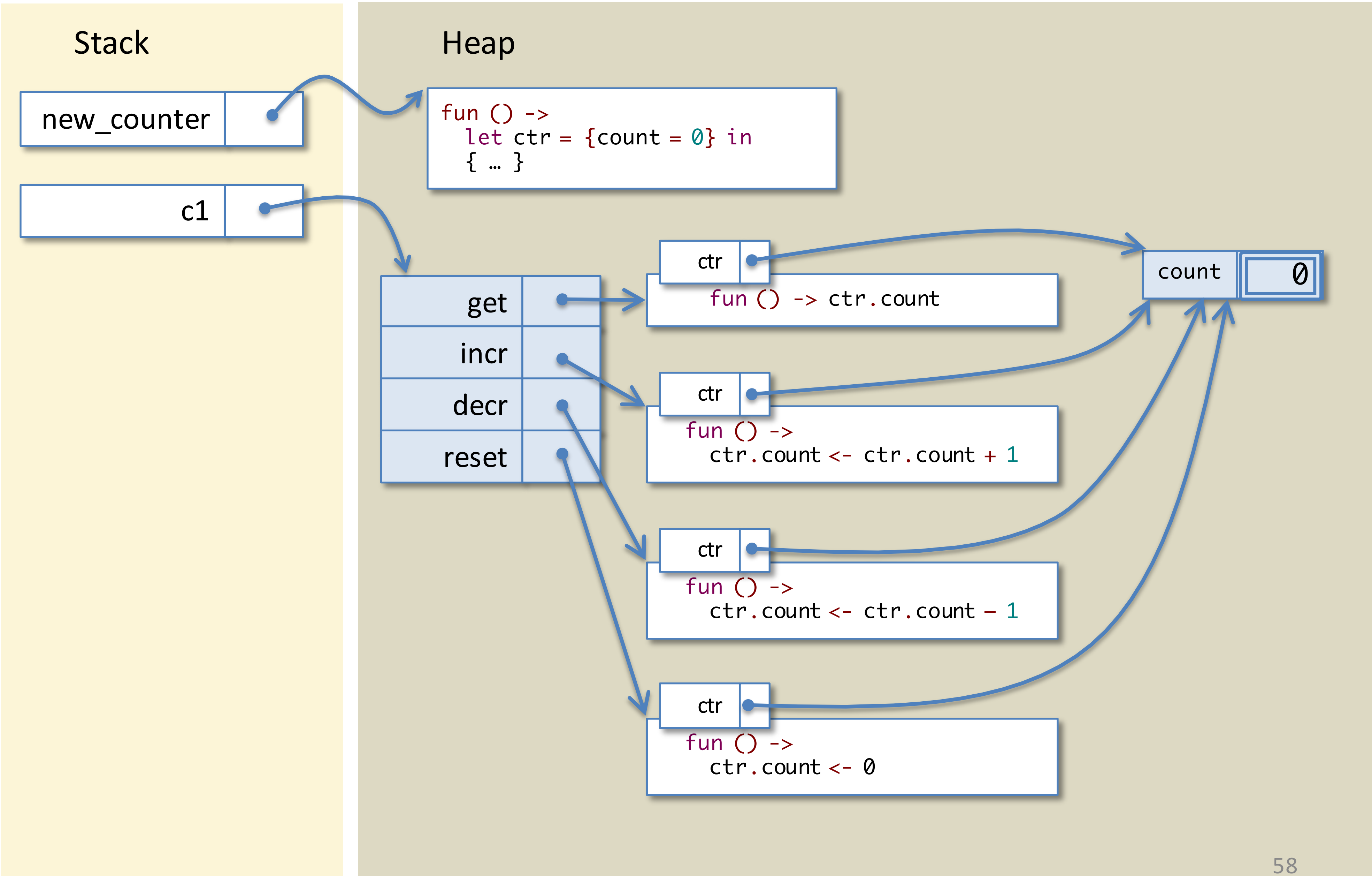
- mk_incr shows us how to create different instance of local state so that we can have several different counters.
- What if we want to bundle together *several* operations that share the same local state?
  - e.g. incr and decr operations that work on the same counter

A Counter *Object*

```
(* The type of counter objects *)
type counter = {
    get   : unit -> int;
    incr  : unit -> unit;
    decr  : unit -> unit;
    reset : unit -> unit;
}

(* Create a fresh counter object with hidden state: *)
let new_counter () : counter =
  let ctr = {count = 0} in
  {
   get   = (fun () -> ctr.count) ;
   incr  = (fun () -> ctr.count <- ctr.count + 1) ;
   decr  = (fun () -> ctr.count <- ctr.count - 1) ;
   reset = (fun () -> ctr.count <- 0) ;
  }
```

```
let c1 = new_counter ()
```



Using Counter Objects

```
(* a helper function to create a nice string for
   printing *)
let ctr_string (s:string) (i:int) =
    s ^ ".ctr = " ^ (string_of_int i) ^ "\n"

let c1 = new_counter ()
let c2 = new_counter ()

;; print_string (ctr_string "c1" (c1.get ()))
;; c1.incr ()
;; c1.incr ()
;; print_string (ctr_string "c1" (c1.get ()))
;; c1.decr ()
;; print_string (ctr_string "c1" (c1.get ()))
;; c2.incr ()
;; print_string (ctr_string "c2" (c2.get ()))
;; c2.decr ()
;; print_string (ctr_string "c2" (c2.get ()))
```

GUI Design

putting objects to work

Have you ever used a GUI library (such as Java's Swing) to construct a user interface?

1. Yes
2. No

Step #1: Understand the Problem

- We don’t want to build just one graphical application: we want to make sure that our code is *reusable.*
- What are the concepts involved in GUI libraries and how do they relate to each other?
- How can we separate the various concerns on the project?

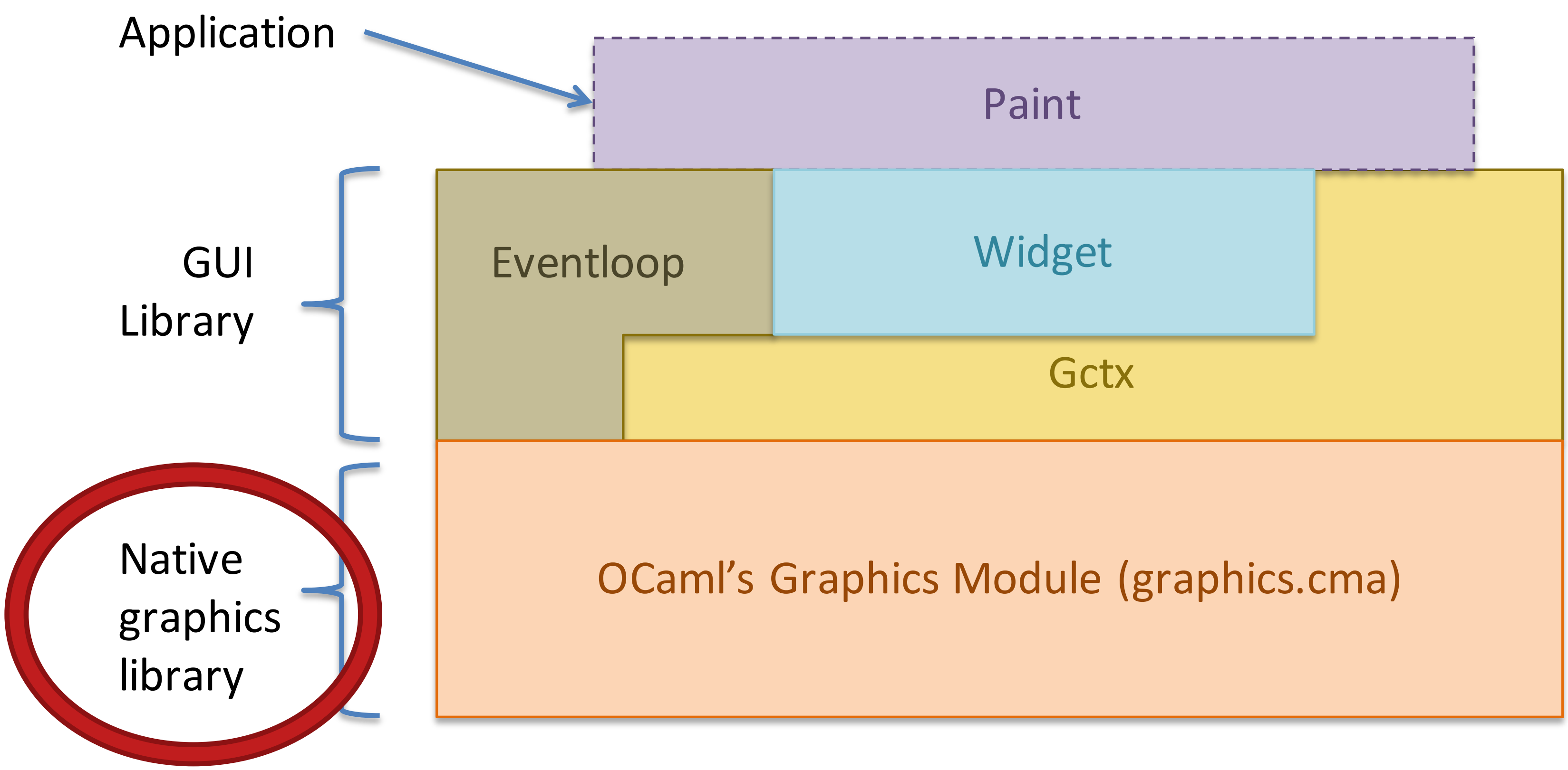
Designing a GUI library – Starting point

- OCaml's Graphics library provides very *simple* primitives for:
  - Creating a window
  - Drawing various shapes: points, lines, text, rectangles, circles, etc.
  - Getting the mouse position, whether the mouse button is pressed, what key is pressed, etc.
  - See: http://caml.inria.fr/pub/docs/manual-ocaml/libref/Graphics.html

- How do we go from that to a functioning, reusable GUI library?

Step 2, Interfaces: Project Architecture*

*Note: Subsequent program snippets are color-coded according to this diagram.



Goal of the GUI library: provide a consistent layer of abstraction *between* the application (Paint) and the Graphics module.

Step 2, Interfaces: Project Architecture*

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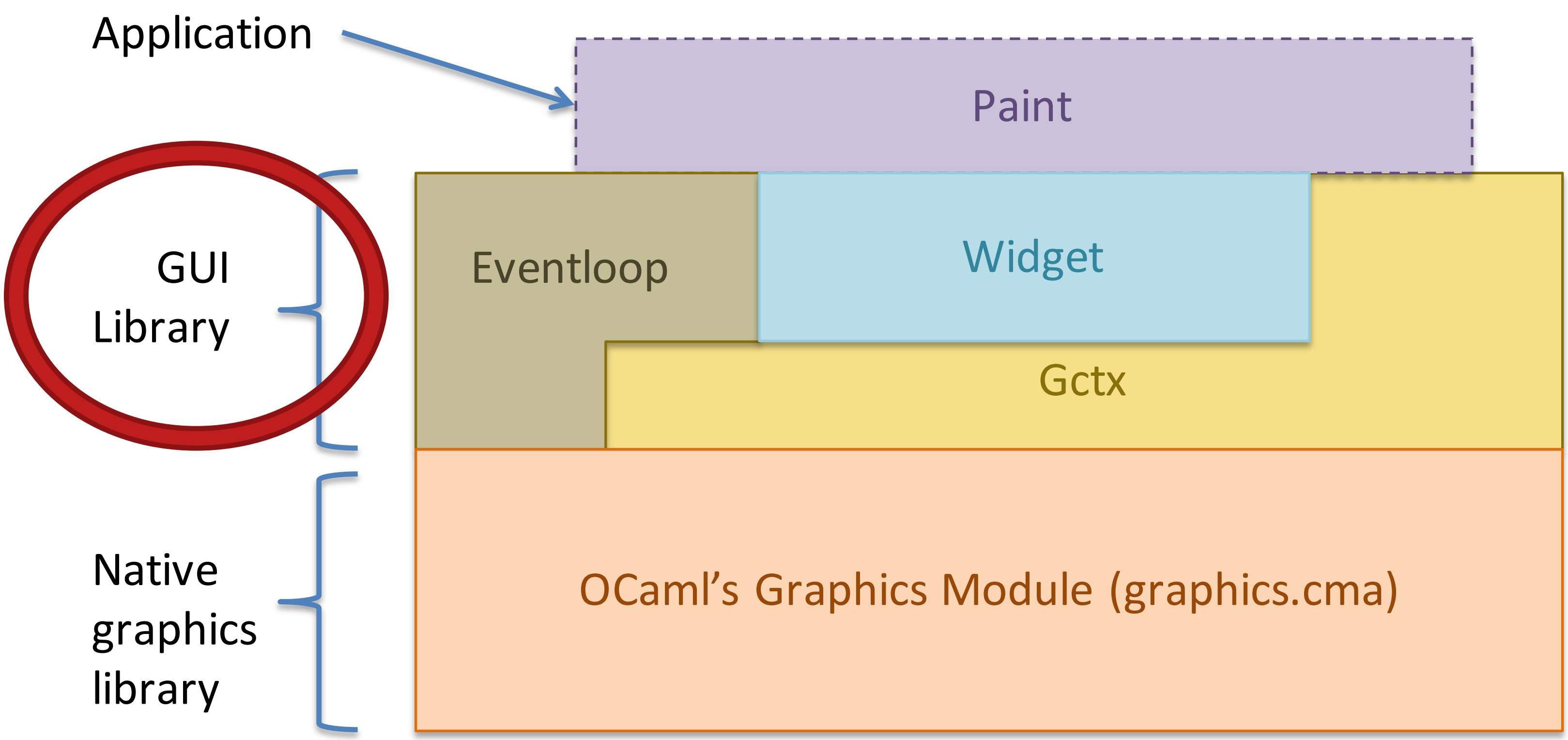

Goal of the GUI library: provide a consistent layer of abstraction *between* the application (Paint) and the Graphics module.

GUI terminology – Widget*

- Basic element of GUIs : buttons, checkboxes, windows, textboxes, canvases, scrollbars, labels
- All have a position on the screen and know how to display themselves
- May be composed of other widgets (for layout)

- Widgets are often modeled by *objects*
  - They often have hidden state (string on the button, whether the checkbox is checked)
  - They need functions that can modify that state

*Each GUI library uses its own naming convention for what we call “Widget”. Java’s Swing calls them “Components”; iOS UIKit calls them “UIViews”; WINAPI, GTK+, X11’s widgets, etc.…

GUI terminology - Eventloop

- Main loop of any GUI application

```
let run (w:widget) : unit =
  Graphics.open_graph "";                  (* open a new window *)
  Graphics.auto_synchronize false;

  let rec loop () : unit =
    Graphics.clear_graph ();

    repaint w;

    Graphics.synchronize ();               (* force window update *)

    wait for user input (mouse movement, key press)
    inform w about the input so widgets can react to it;

    loop ()                                (* tail recursion! *)
  in
    loop ()
```

- Takes "top-level" widget w as argument. That widget *contains* all others in the application.