Scope

Deian Stefan

(adopted from my & Edward Yang's CSE242 slides)

Substitution model

- Way of giving semantics to the λ-calculus
  - E.g., $(\lambda x.f\ x\ x)\ (\lambda y.z) \rightarrow_\beta f\ (\lambda y.z)\ (\lambda y.z)$
- Translate this knowledge to JavaScript functions
  - `(x => f(x)(x)) (y => z)` $\rightarrow_\beta$ `f(y => z)(y => z)`

Substitution model

- Why would you, in practice, not really want to do function application in this way for a language like JavaScript?
  - It’s super slow! Why?
  - It’s actually nonsensical sometimes! When?

Substitution gone wrong

- Consider variable mutation in JavaScript:

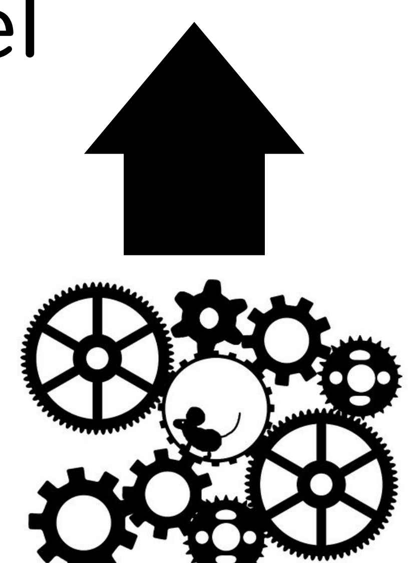
```
let y = 1;
let z = 0;                              ...
z++;                          →β.    0++;
console.log(z);                         ...
```

- There is nothing wrong with substitution per say
  - ➤ It's symbolic evaluation/computation
  - ➤ Problem is JavaScript has mutation and not amendable to symbolic evaluation

What can we do?

λ-calculus

environment model



machine model

tomfishburne.com

The environment model (by example)

- Anatomy of a scope
- First-order functions
- Free variables
- High-order functions (bonus)

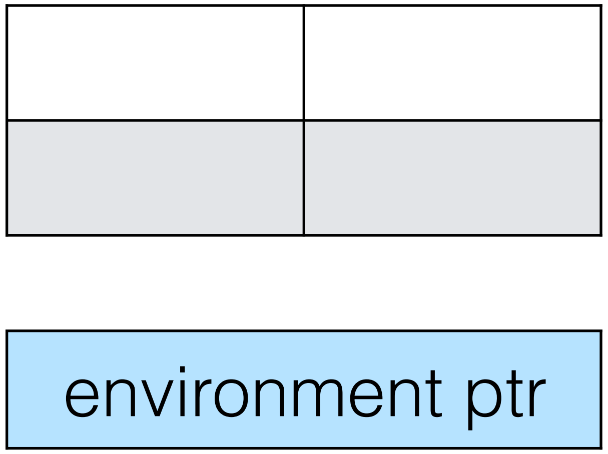
Anatomy of a scope

- What’s the point of a scope (e.g., block scope)?

Anatomy of a scope

- Recall our previous example:

```
let y = 1;
let z = 0;
z++;
console.log(z);
```

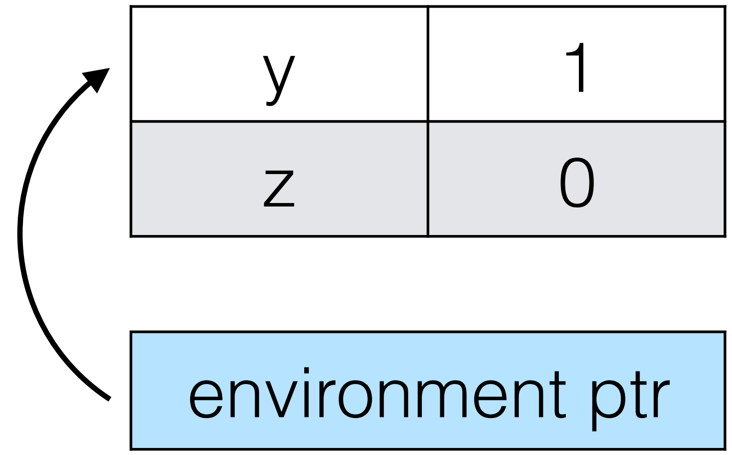


- In this model, we associate an environment (activation record) with the code we're executing
  - ➤ Environment contains entries of all variables in scope
  - ➤ Environment/stack ptr: points to cur activation record

Anatomy of a scope

- Recall our previous example:

```
let y = 1;
let z = 0;
z++;
console.log(z);
```



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  - ➤ Environment contains entries of all variables in scope
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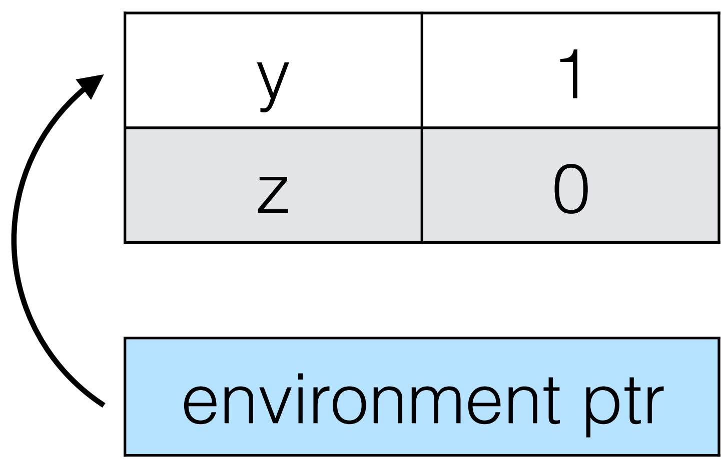
Anatomy of a scope

- In the environment model, we can distinguish between values and locations
  - r-values: plain old values; we can reason about them using substitution semantics
  - l-values: refer to locations where r-values are stored; they persist beyond single expressions.
- Why is this important?
  - It tells us the kind of values operators like ++ must take. A: r-values. **B: l-values**

Anatomy of a scope

- What's the process for executing `z++`:

```
let y = 1;
let z = 0;
z++;
console.log(z);
```



- Algorithm:
  - Find the current environment
  - Check to see if variable being reference is in env: if so, mutate!

Anatomy of a scope

- What's the process for executing `console.log(z)`

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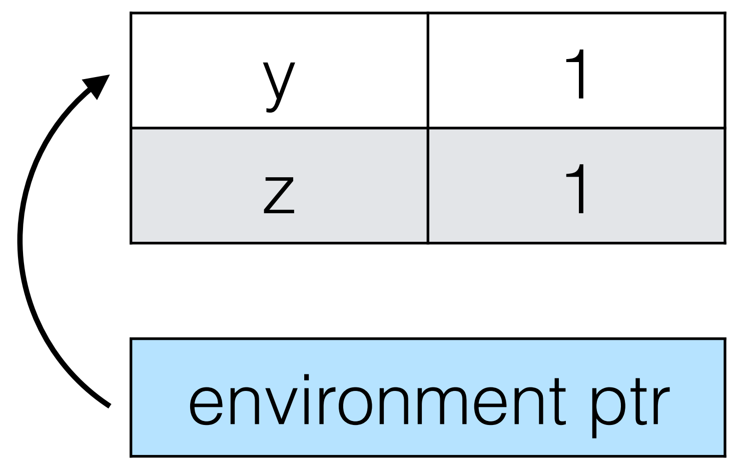
let y = 1;
let z = 0;
z++;
console.log(z);
```



- Algorithm:
  - Find the current environment
  - Check to see if variable being reference is in env: if so, read it!

Anatomy of a scope

- This sounds slow!
  - It is!
  - But remember: this is not the machine model, this is still an abstract model!
- Not too far off from machine model
  - In x86, you dereference %esp to figure out where stack is and use offset to that location
  - In JavaScript, you often do table lookup to find location of variables

The environment model (by example)

- Anatomy of a scope ✓
- First-order functions
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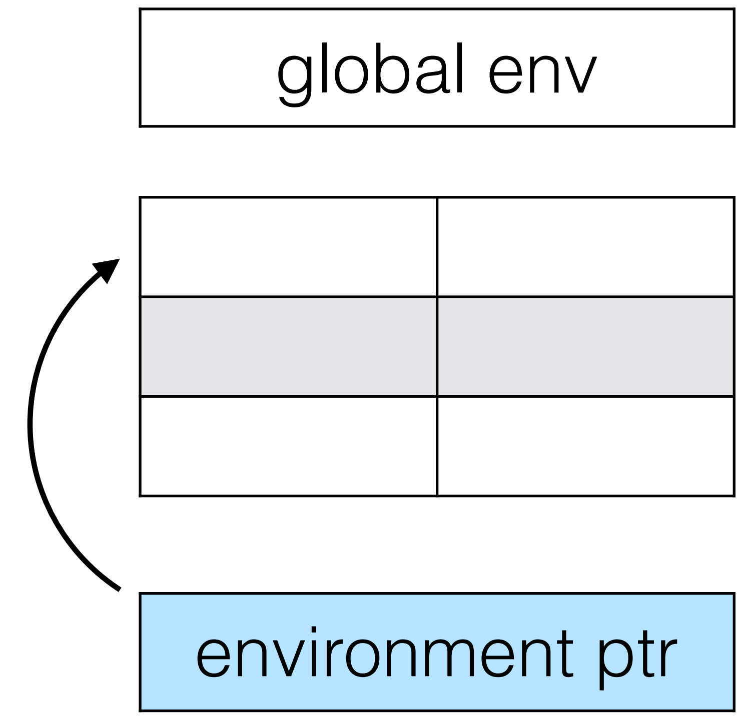
- High-order functions (bonus)

First-order functions

- Consider activation record when calling function:

```
function fact(n) {
  if (n <= 1) {
     return 1;
  } else {
     return n * fact(n-1);
  }
}
fact(3);
```



- What else do we need to keep track of?

First-order functions

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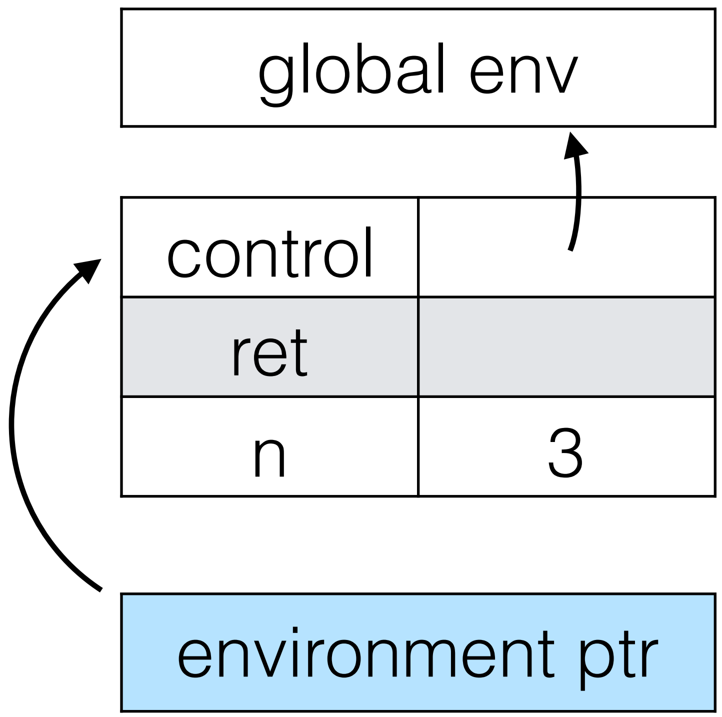

- What else do we need to keep track of?

More bookkeeping

- The parts of an activation record when calling function
  - <u>control link:</u> records where to switch the environment pointer to when we finish evaluating in this scope.
    - Do we need this for block scopes too? A: yes, B:no
  - <u>return value:</u> l-value where the return value of function should be stored
  - <u>parameters:</u> l-value for each formal parameter
  - <u>local variables:</u> l-values for each let+const declaration

More bookkeeping

- Anything else?
  - Yes! Typically activation records will store the return address where to resume ode execution — we'll talk about this in the control flow lecture

Let’s look at how evaluation works

- Consider activation records when calling function:

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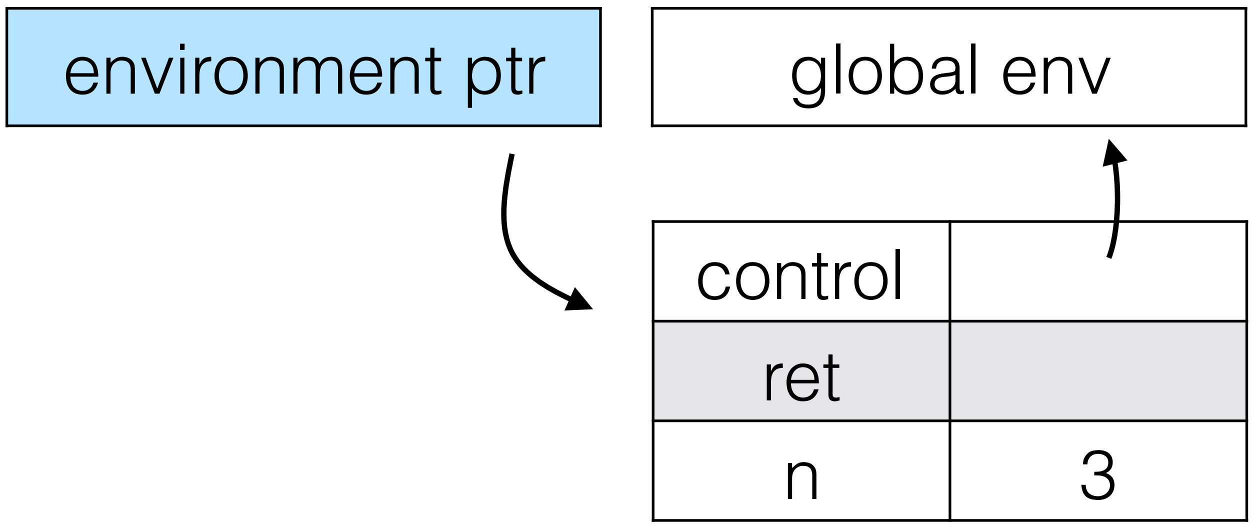

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  A: yes, B: no

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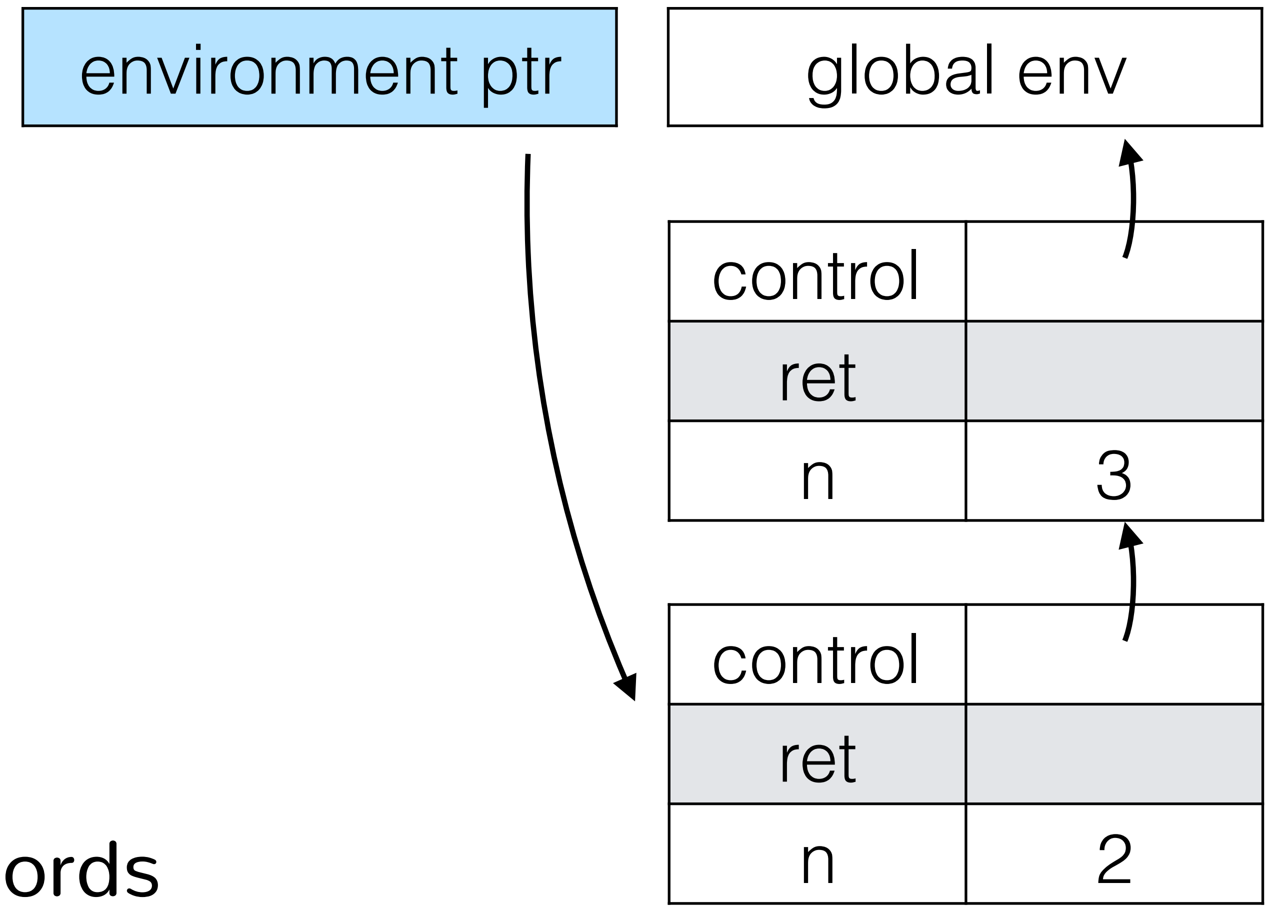

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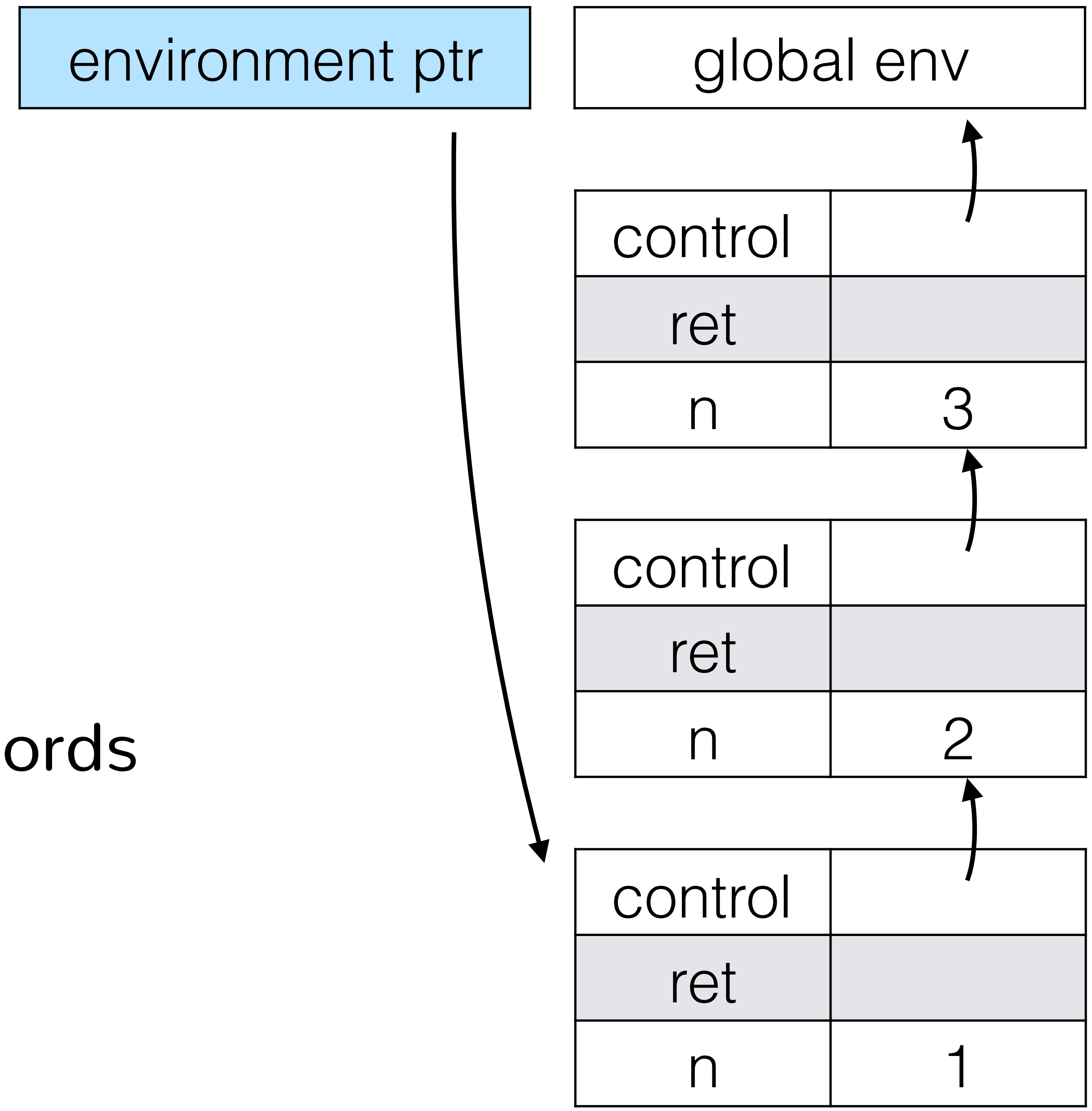

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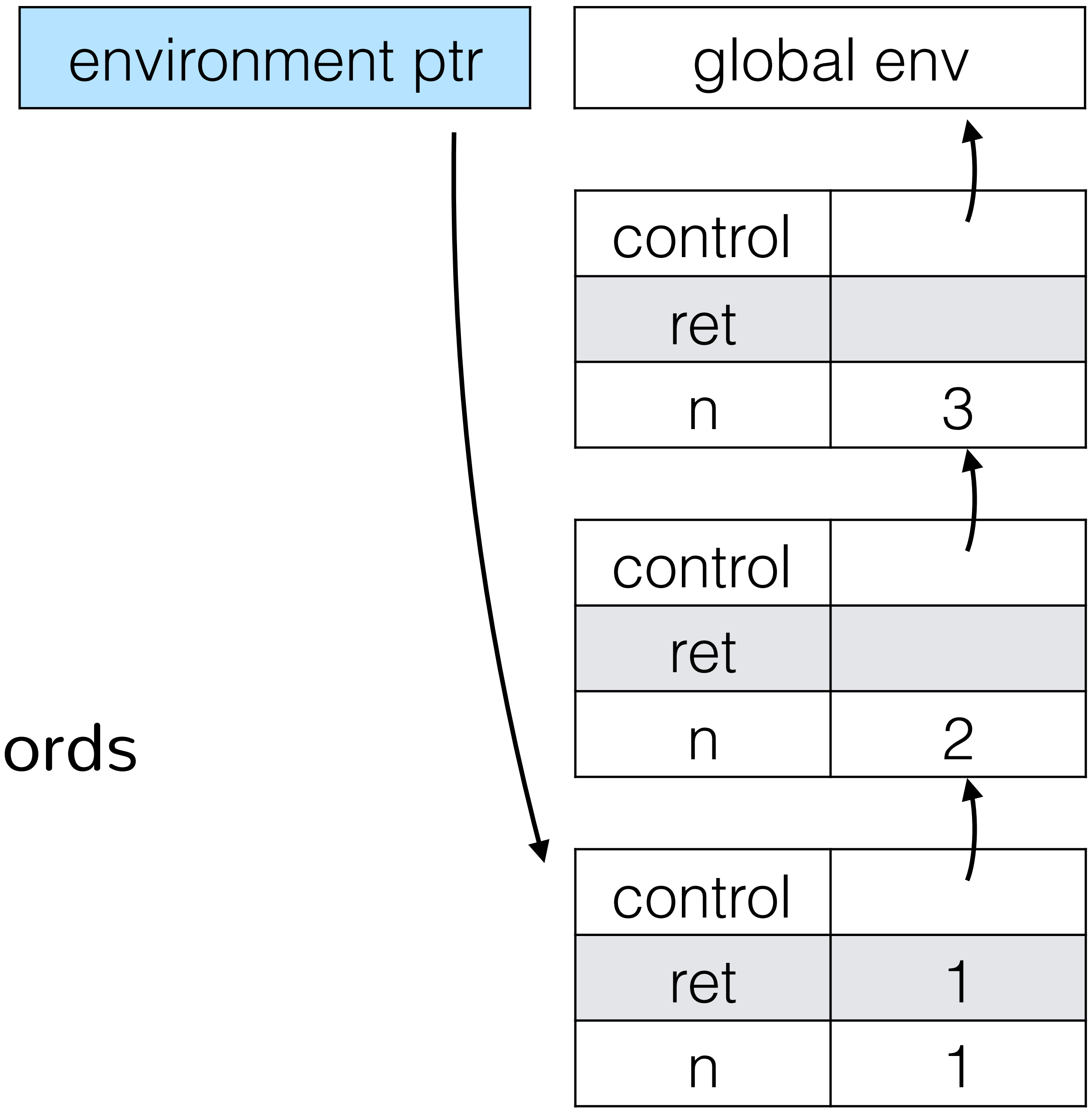

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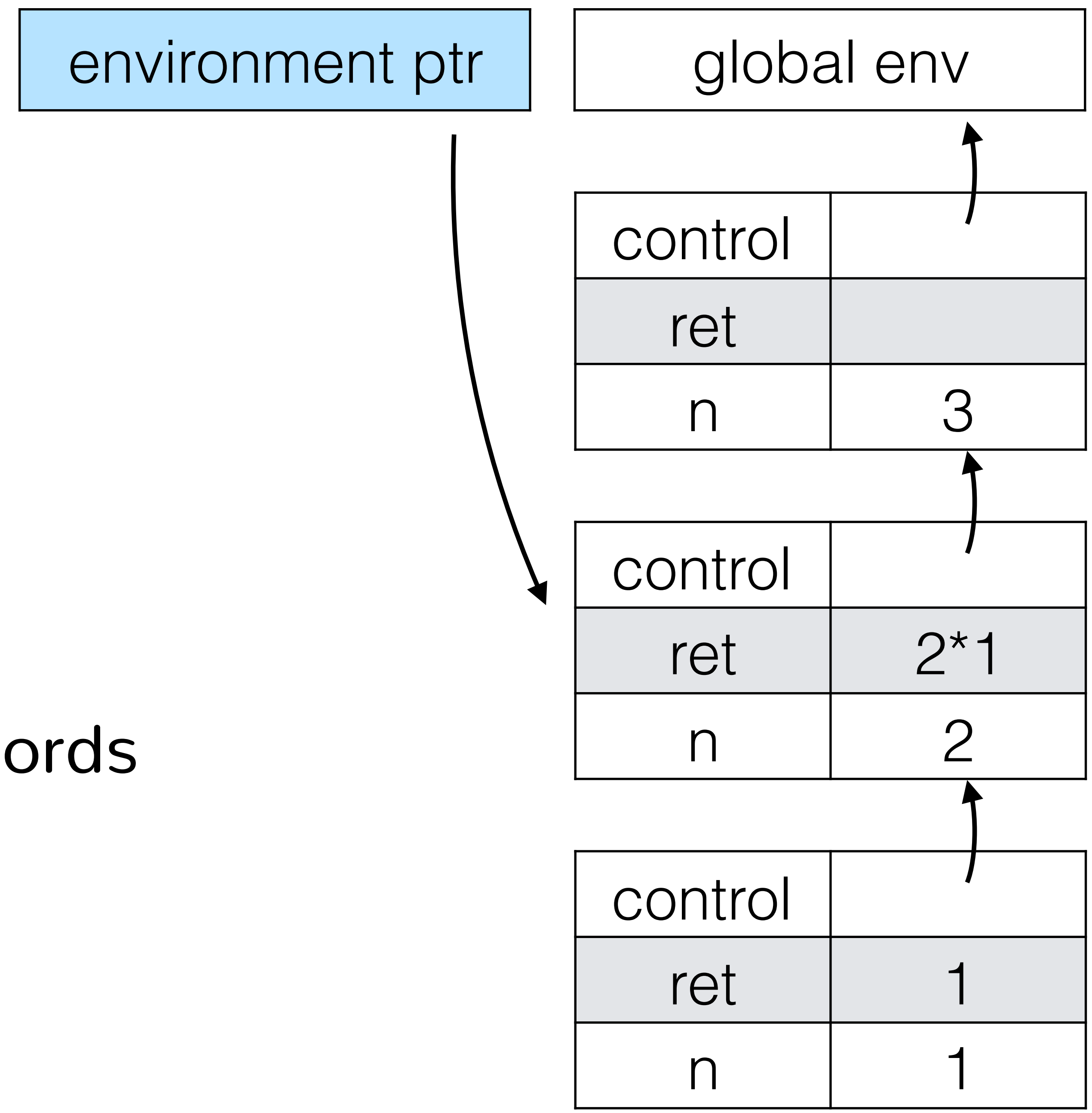

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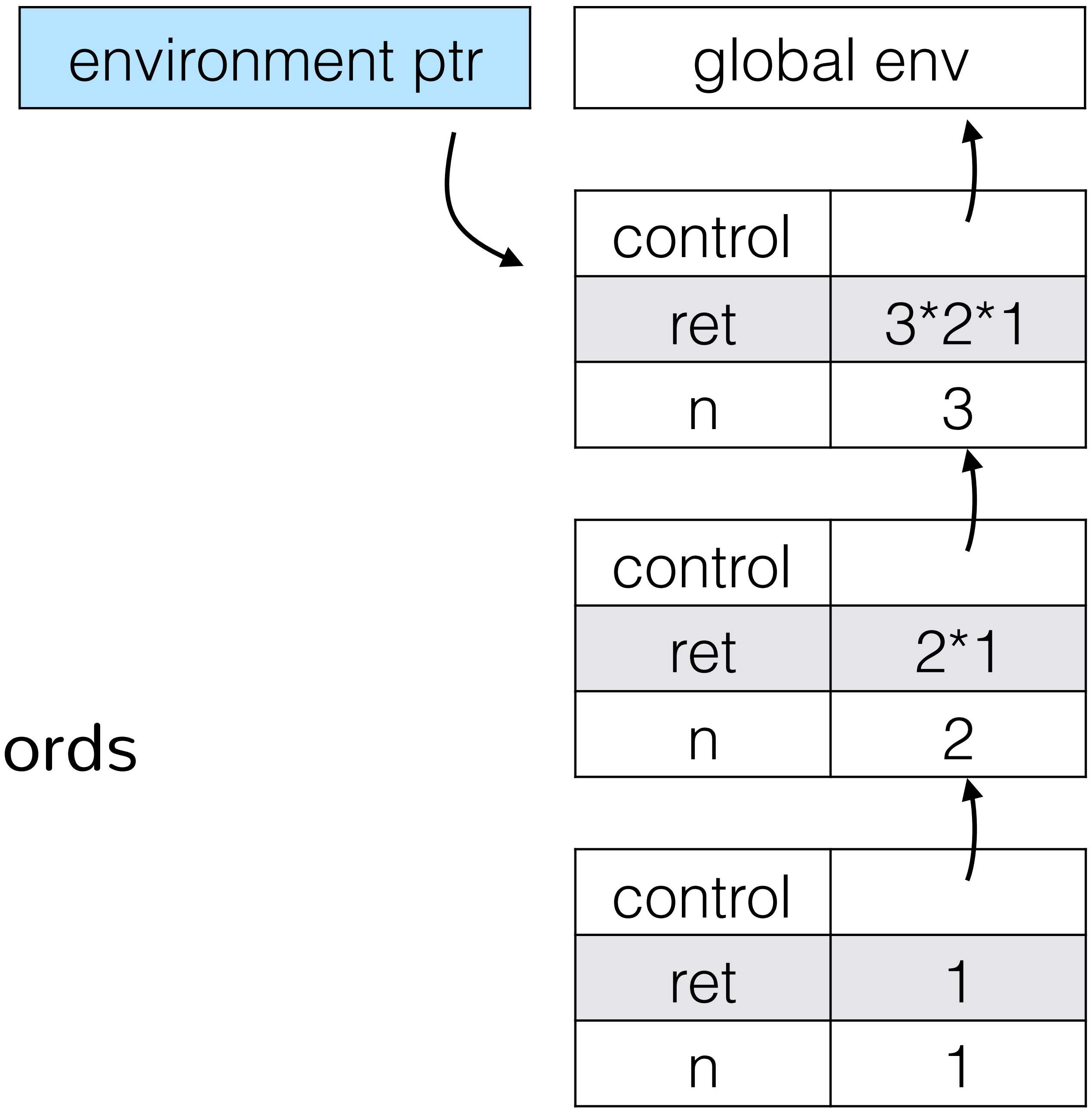


- Do we keep the activation records on the stack after evaluation?

  A: yes, **B: no**

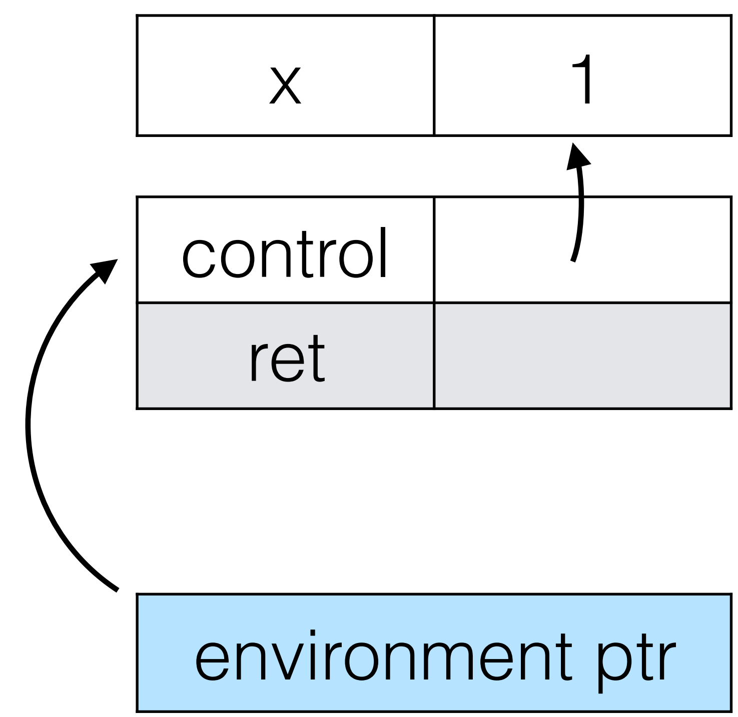
The environment model (by example)

- Anatomy of a scope ✓
- First-order functions ✓
- Free variables
- High-order functions (bonus)

Free variables

- Consider activation records when calling f:

```
let x = 1;
function f() {
 console.log(x)
}
f();
```



- Should we lookup x via the control link?
    - A: yes
    - B: no

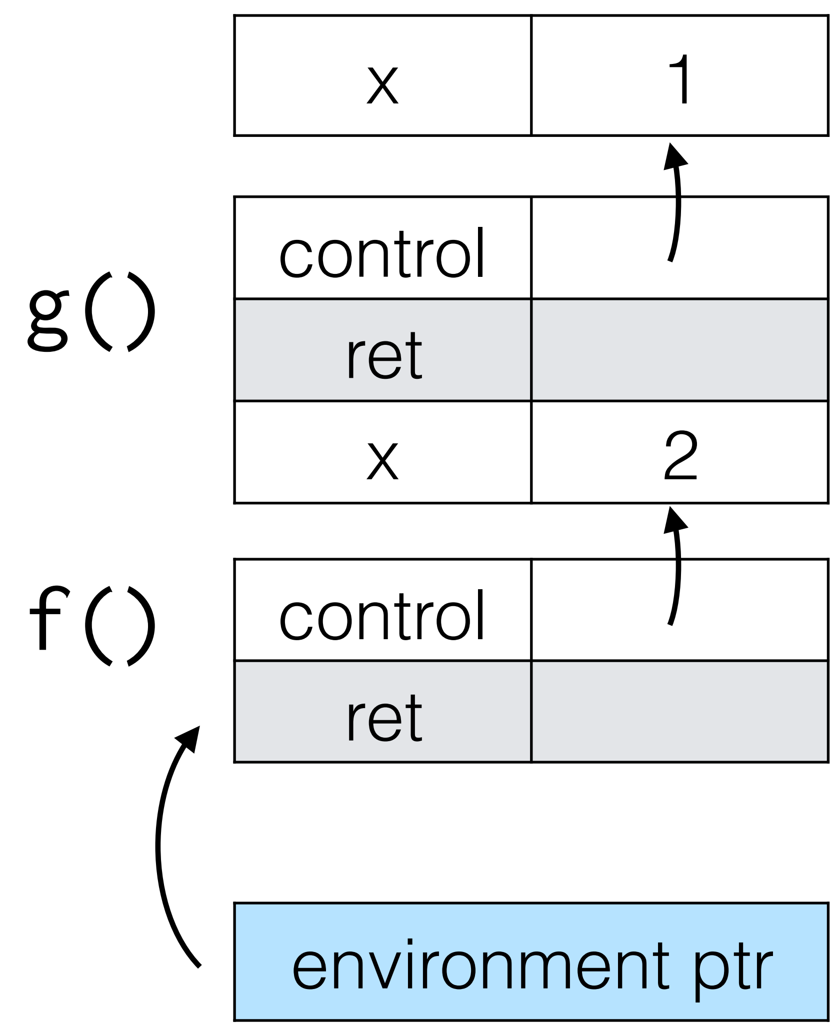
Free variables

- Consider activation records when calling g:

```
let x = 1;
function f() {
 console.log(x)
}

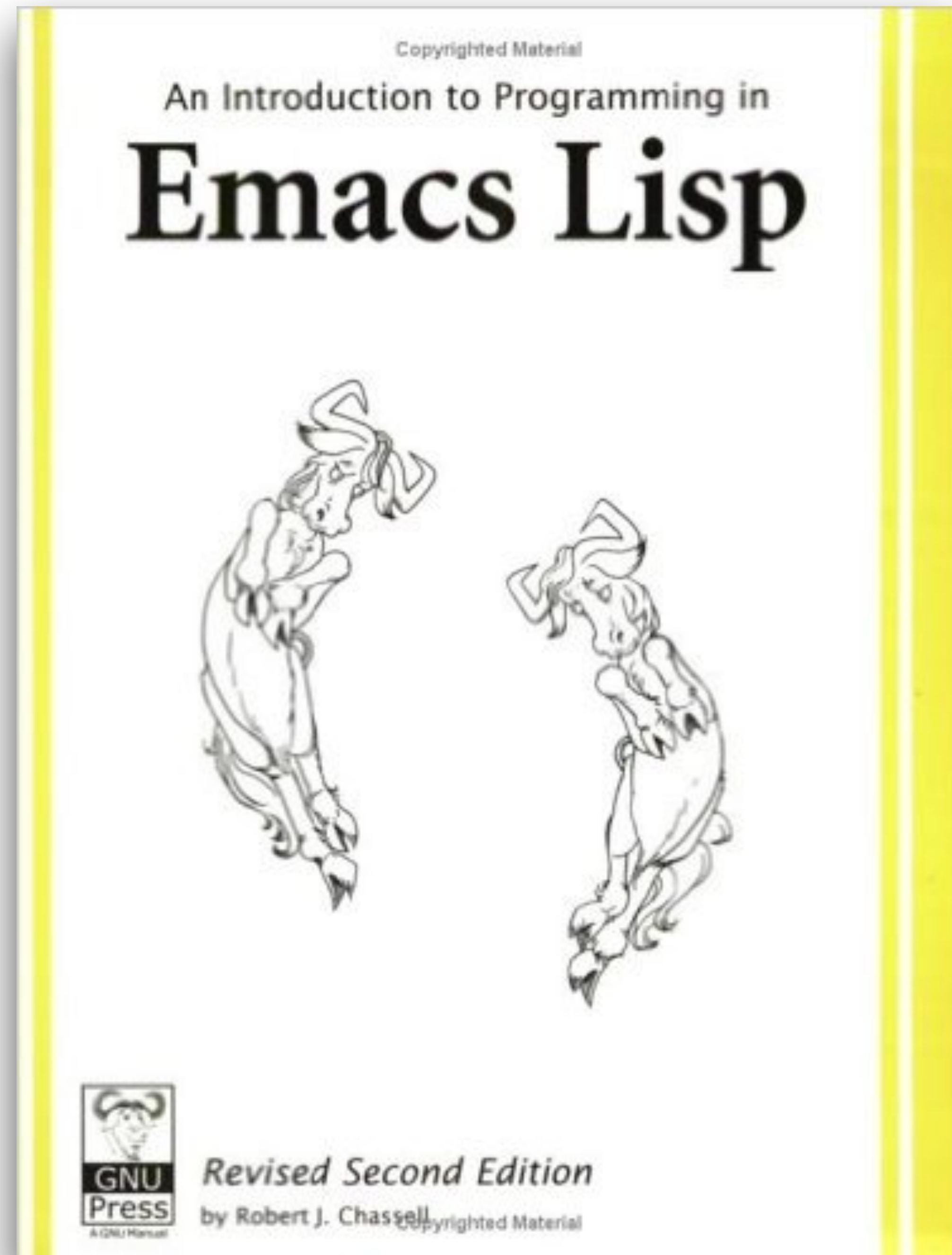
function g() {
 let x = 2;
 f();
}

g();
```



- What happens when we follow the control link?

Congrats, you did it!



You invented dynamic scoping!

How do we “fix” this?

- We need more bookkeeping!
  - <u>access link:</u> reference to activation record of closest enclosing lexical scope
- Modify our lookup algorithm:
  - Find the current environment
  - Check to see if variable being reference is in env
  - If not, follow the access link and repeat

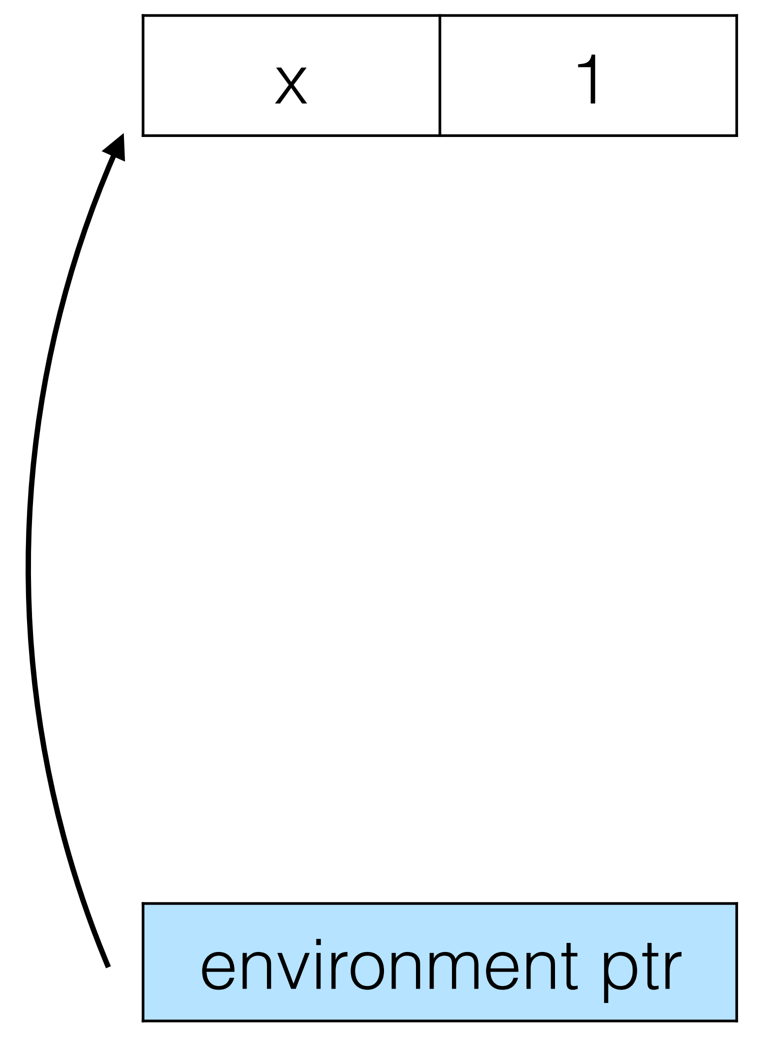
Retry with access links

- Consider activation records when calling g:

```
let x = 1;
function f() {
 console.log(x)
}

function g() {
 let x = 2;
 f();
}

g();
```



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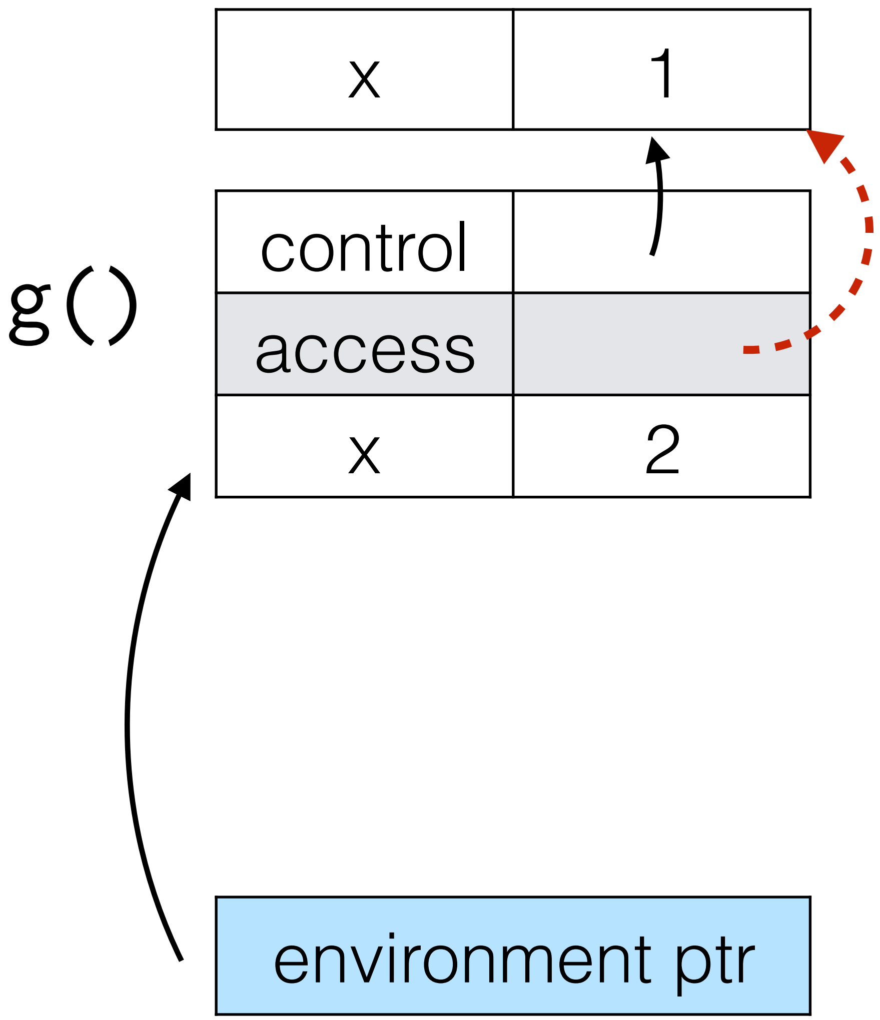

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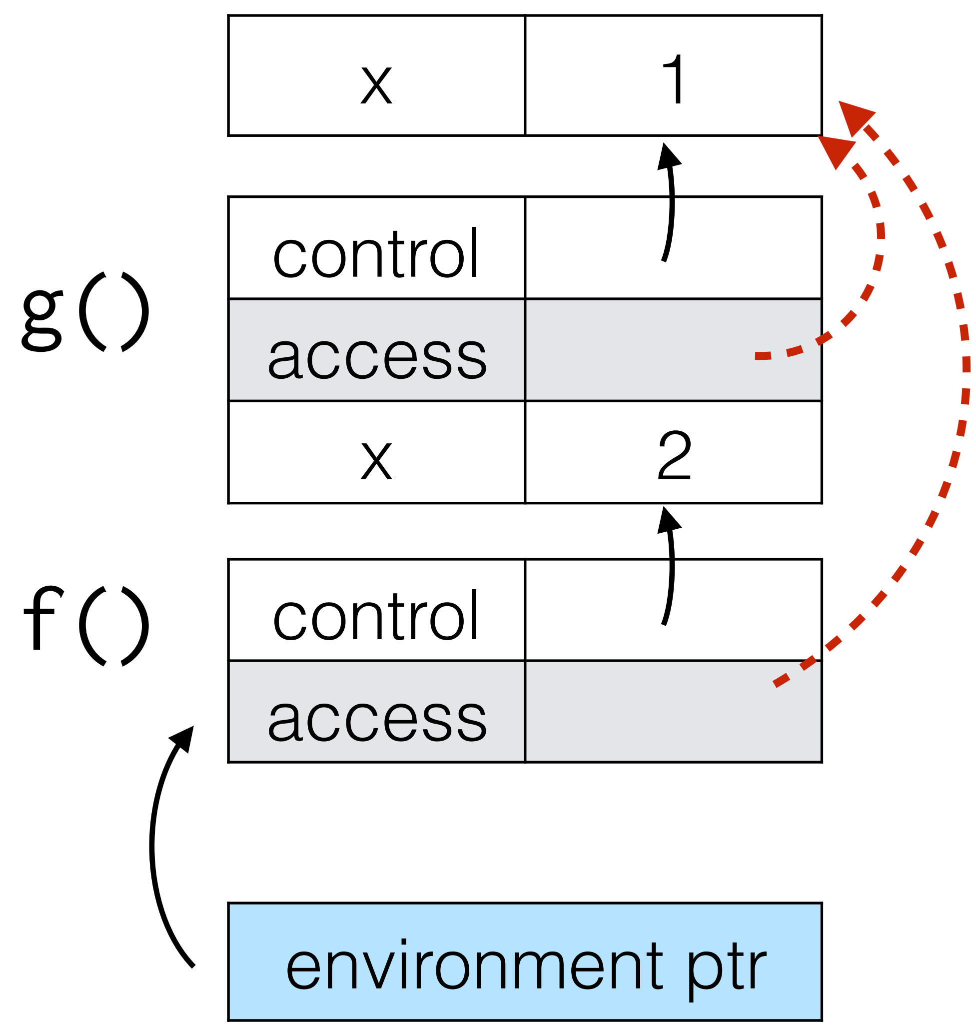

Wait, there is some magic here

- How do we know how to wire up the access links?

```
let x = 1;
function f() {
 console.log(x)
}

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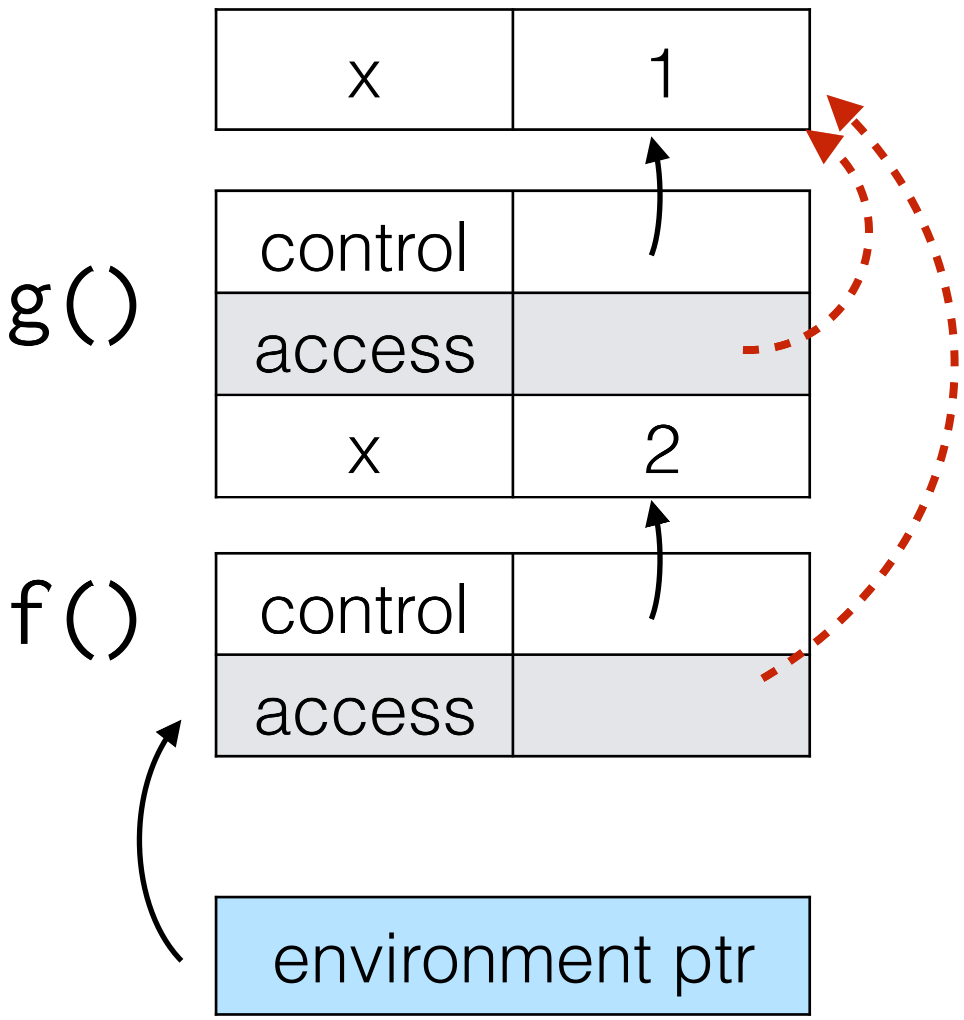
 let x = 2;
 f();
}

g();
```



Functions are data!

The act of defining a function should include the act of recording the access link associated with the function

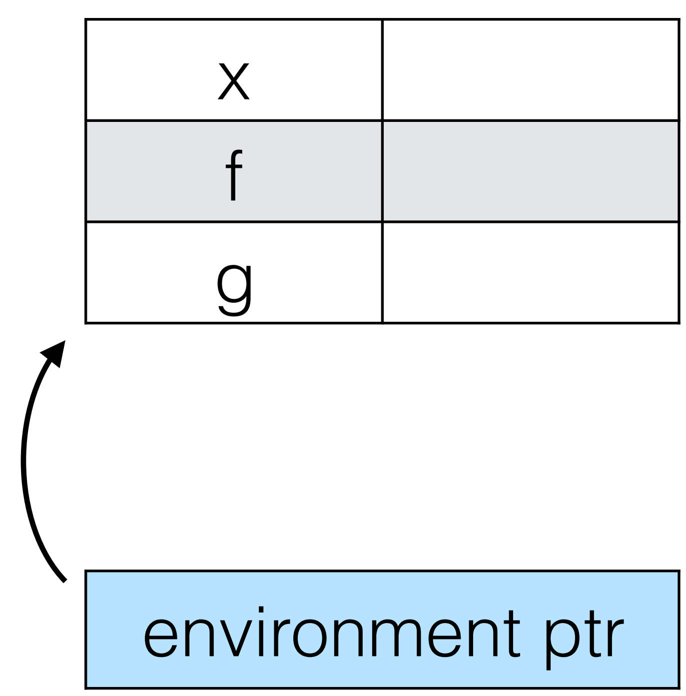
Treating functions as data

- Let's look at the example again, with minor rewrite

```
let x = 1;
let f = () => {
 console.log(x)
}

let g = () => {
 let x = 2;
 f();
}

g();
```



- Function as data = closures = (current env ptr, code pointer)

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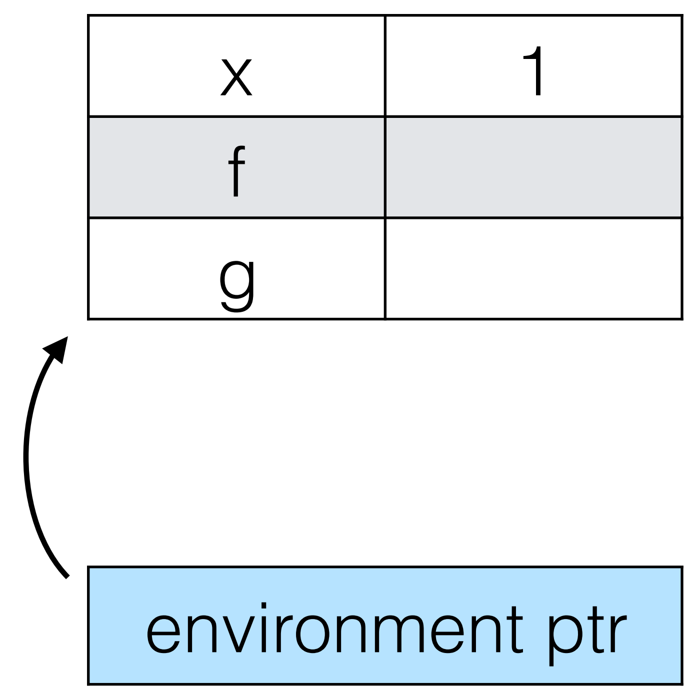

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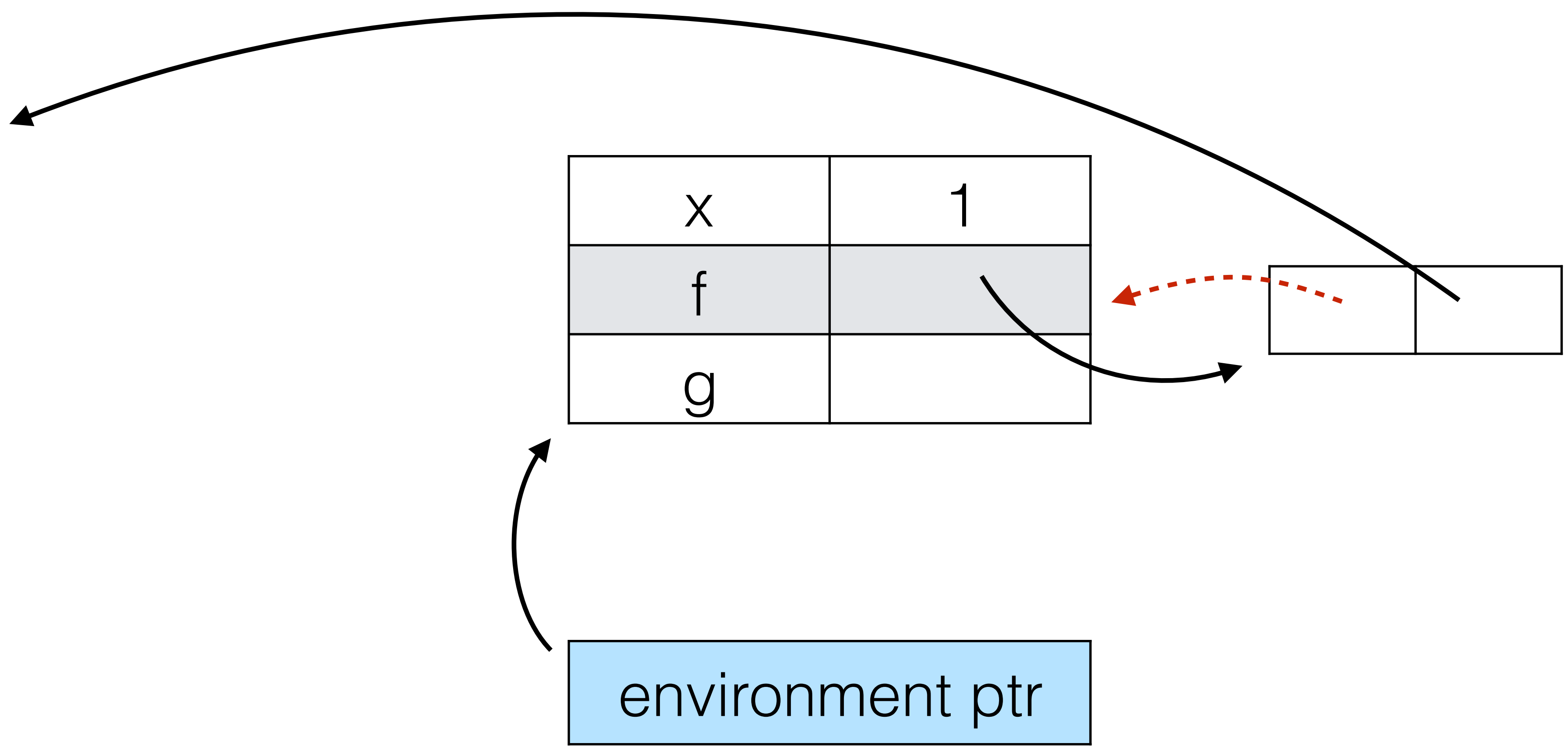

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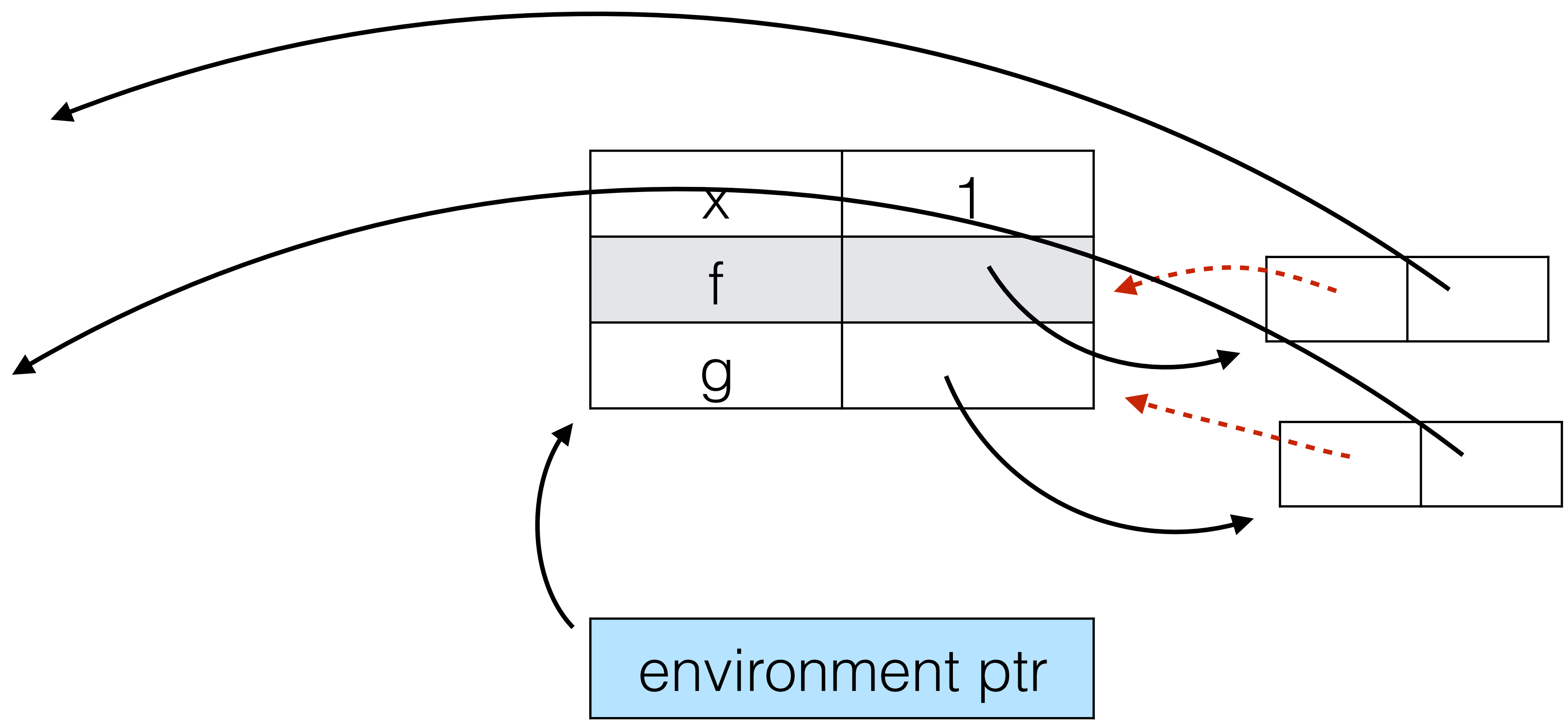

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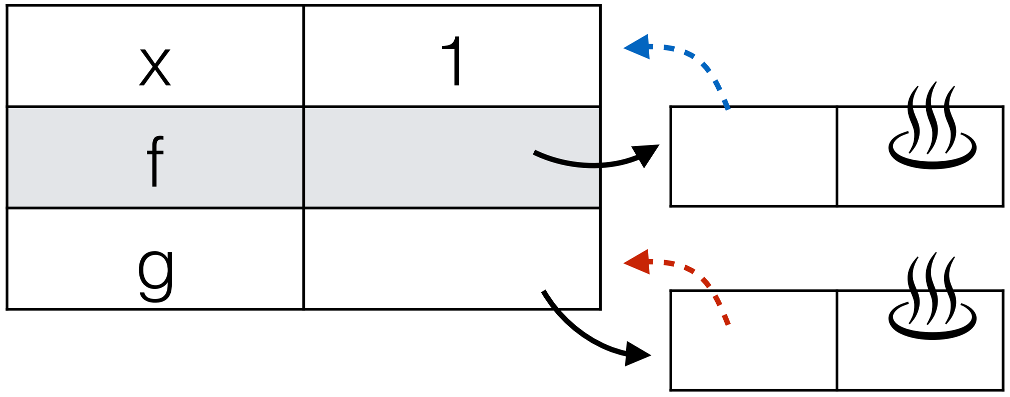
Treating functions as data

- When we evaluate function, the access link is set to the pointer in the closure

environment ptr

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 f();
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g();
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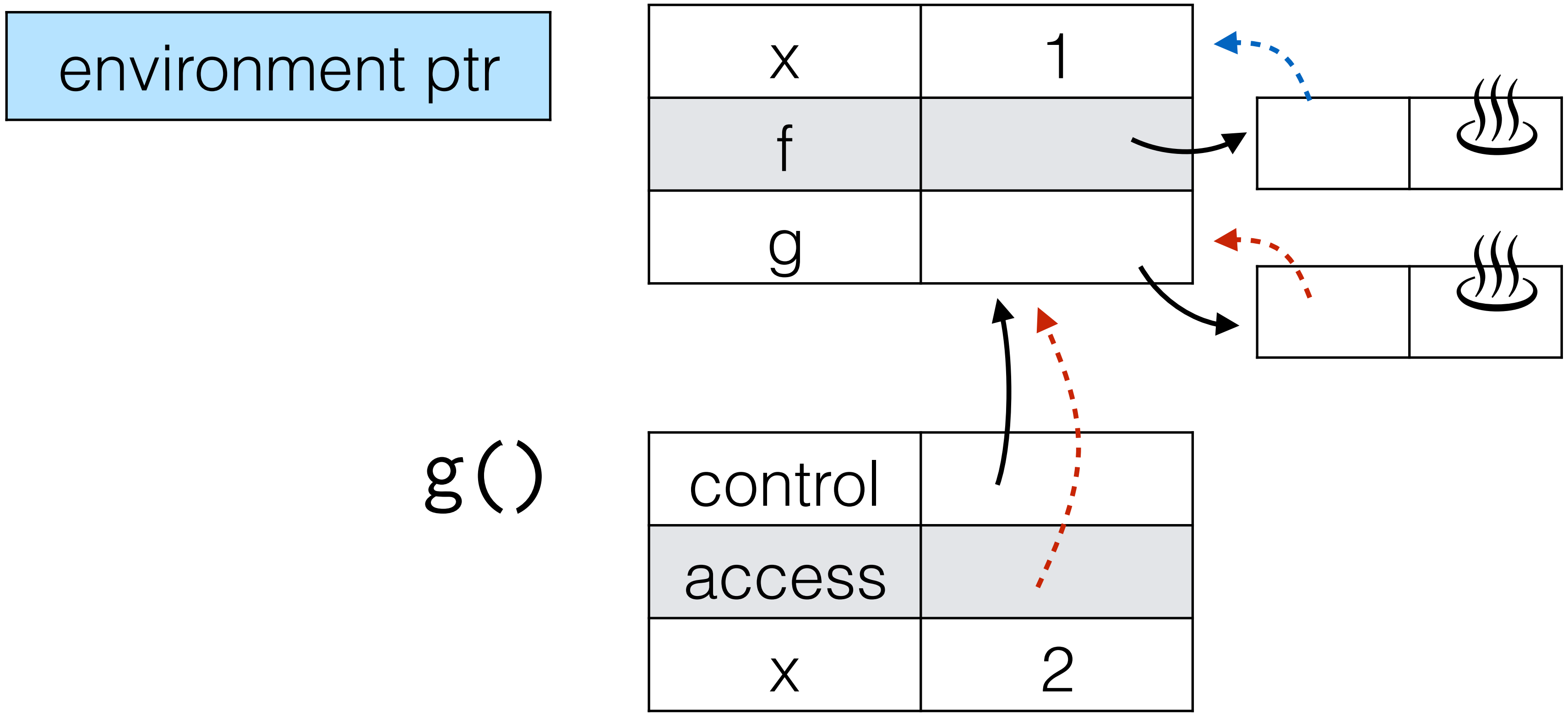

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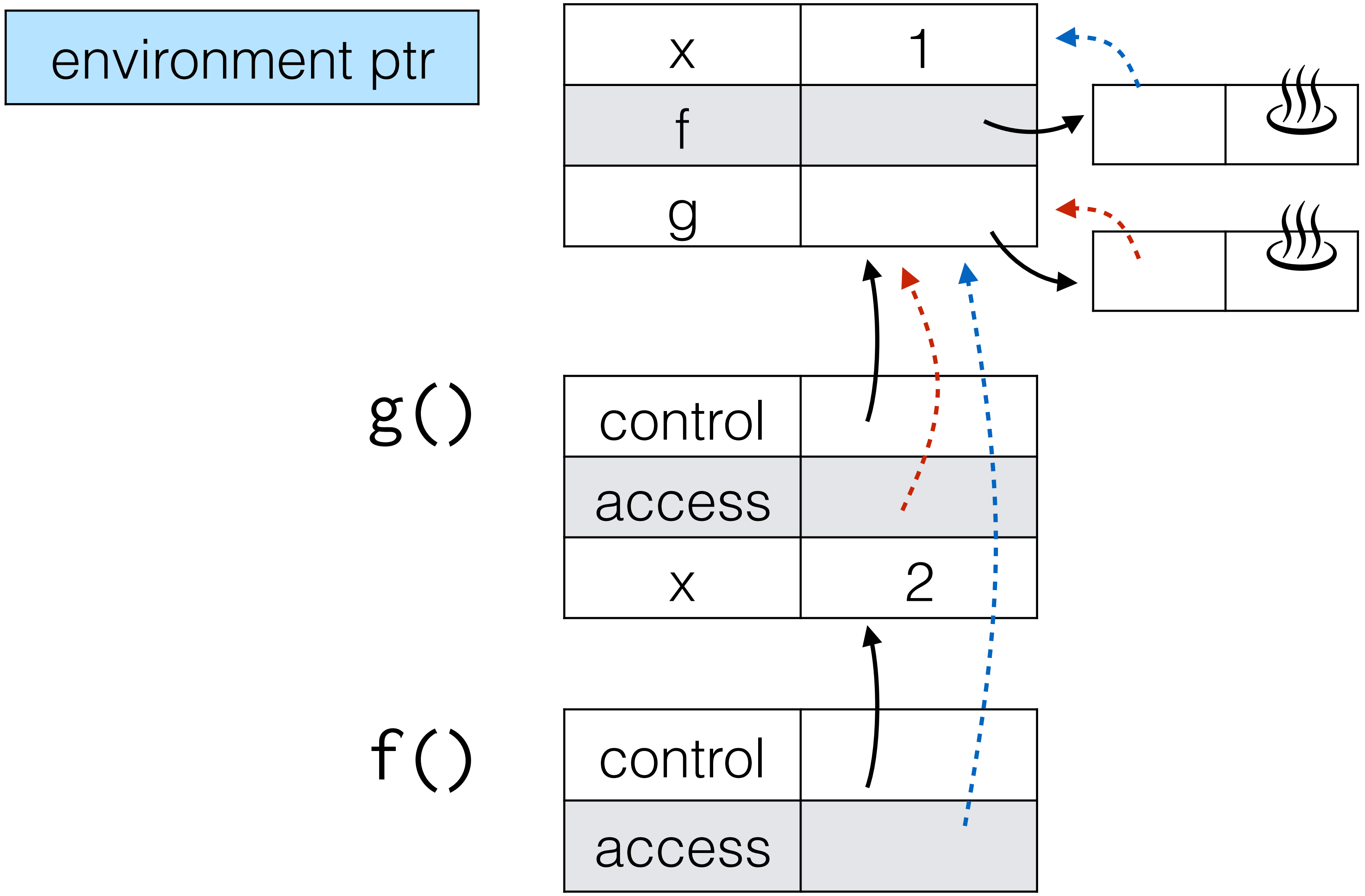


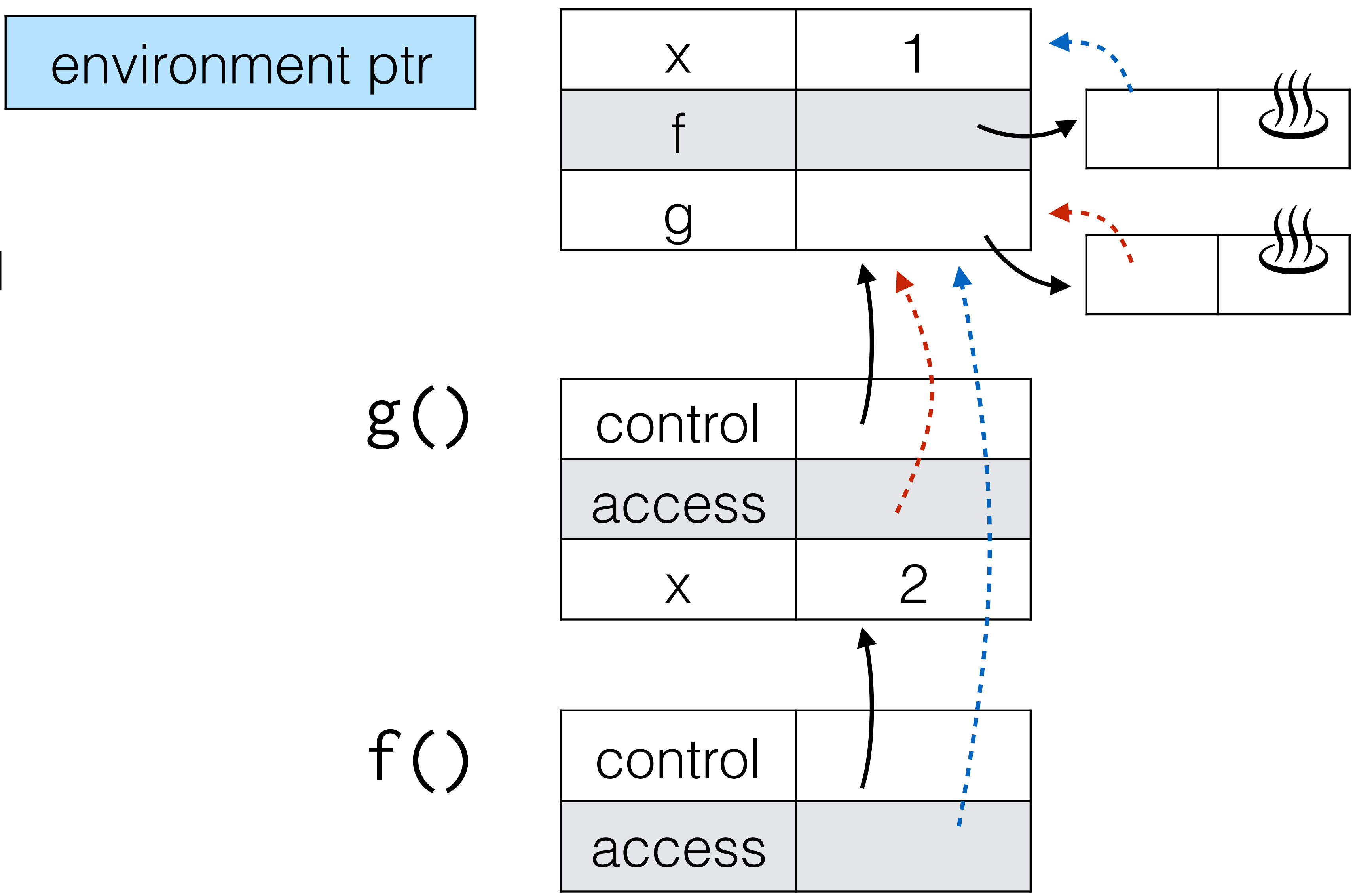
Treating functions as data

- When we evaluate function, the access link is set to the pointer in the closure

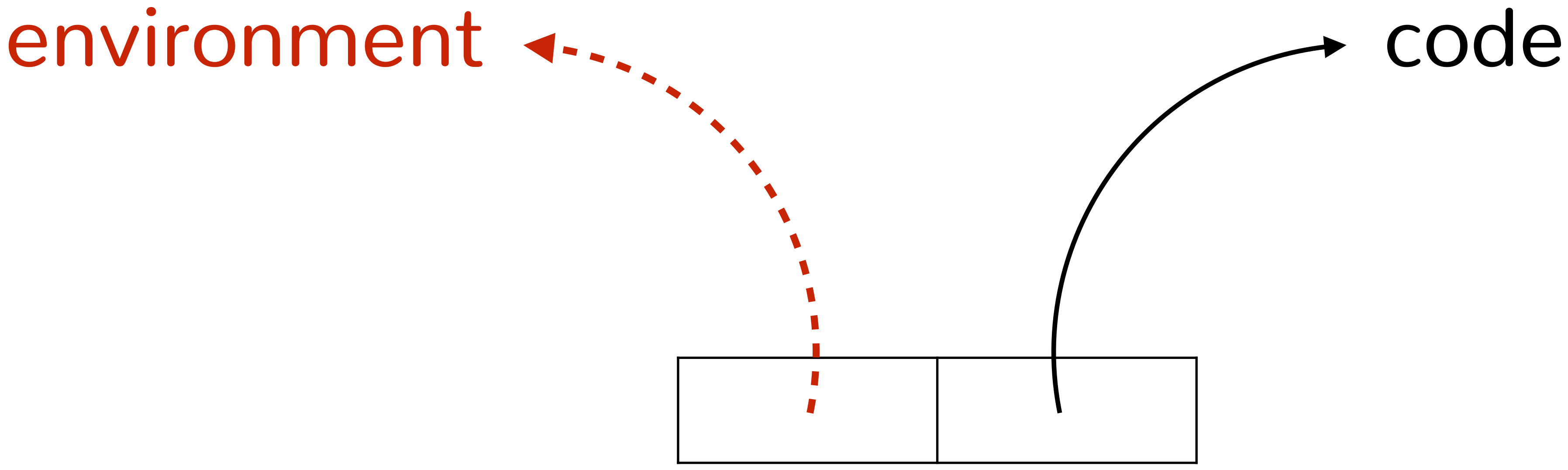
```
let x = 1;
let f = () => {
 console.log(x) // 1
}

let g = () => {
 let x = 2;
 f();
}

g();
```



Closures



The environment model (by example)

- Anatomy of a scope ✓
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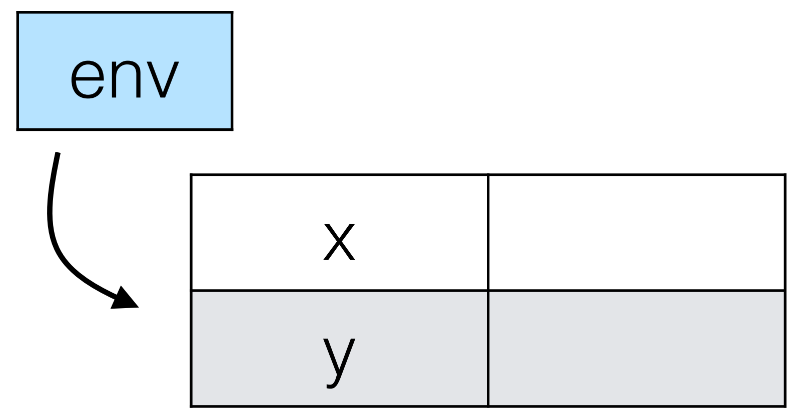
Higher-order functions

- Consider the use of high-order mkCounter function

```
function mkCounter(c) {
  return () => {
     return c++;
  };
}

let x = mkCounter(0);
let y = mkCounter(2);
console.log(x());
```



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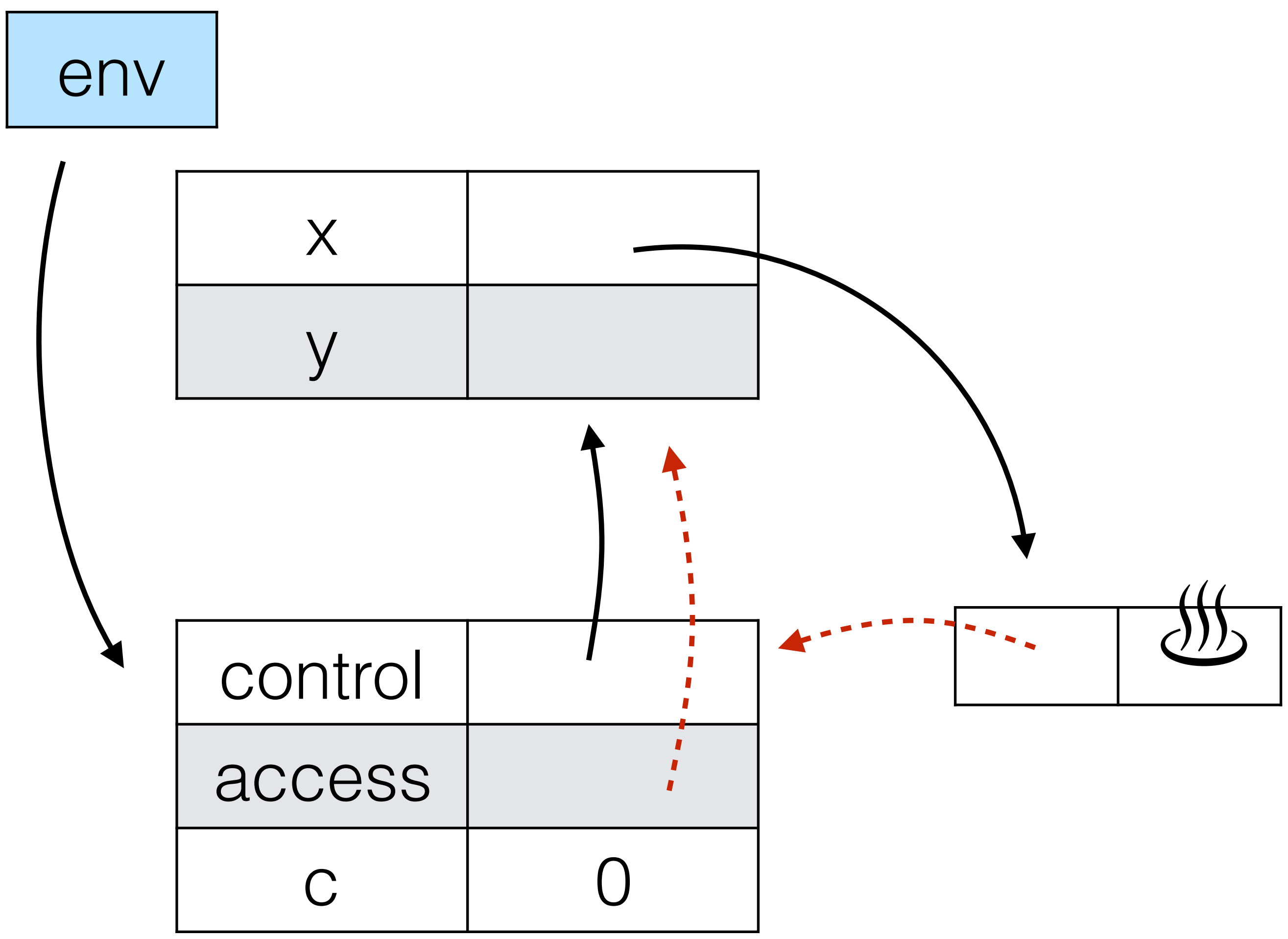

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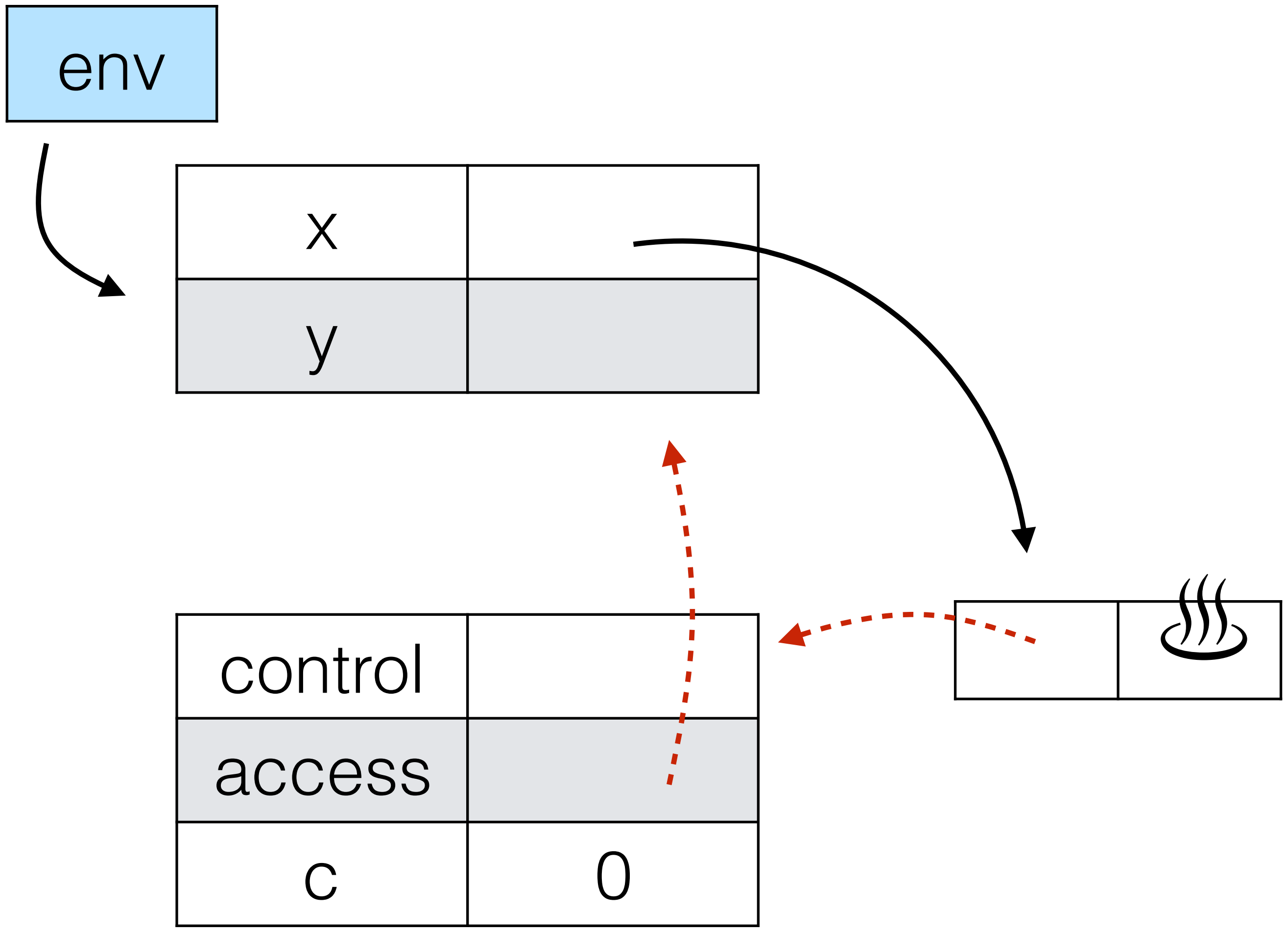

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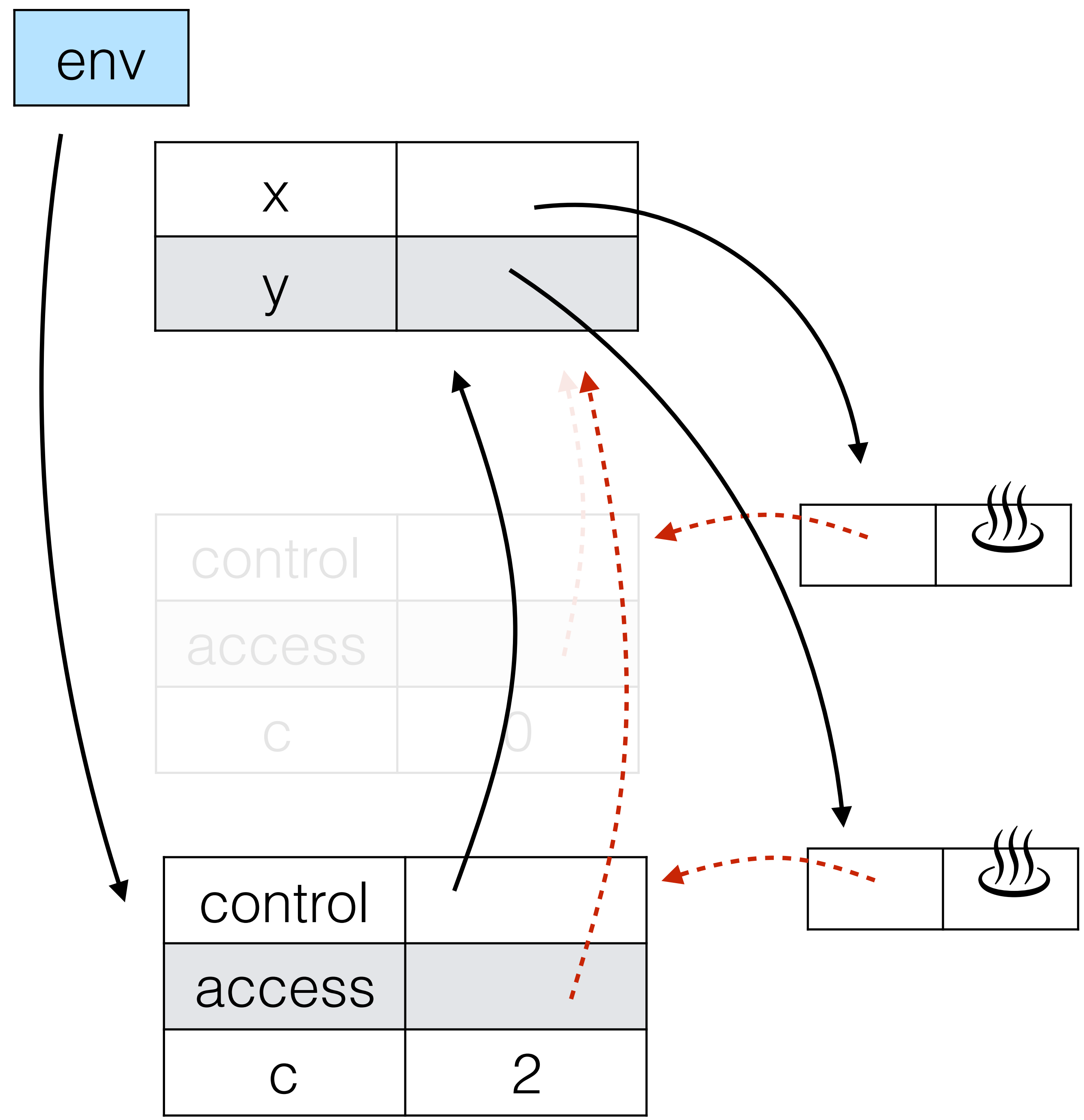

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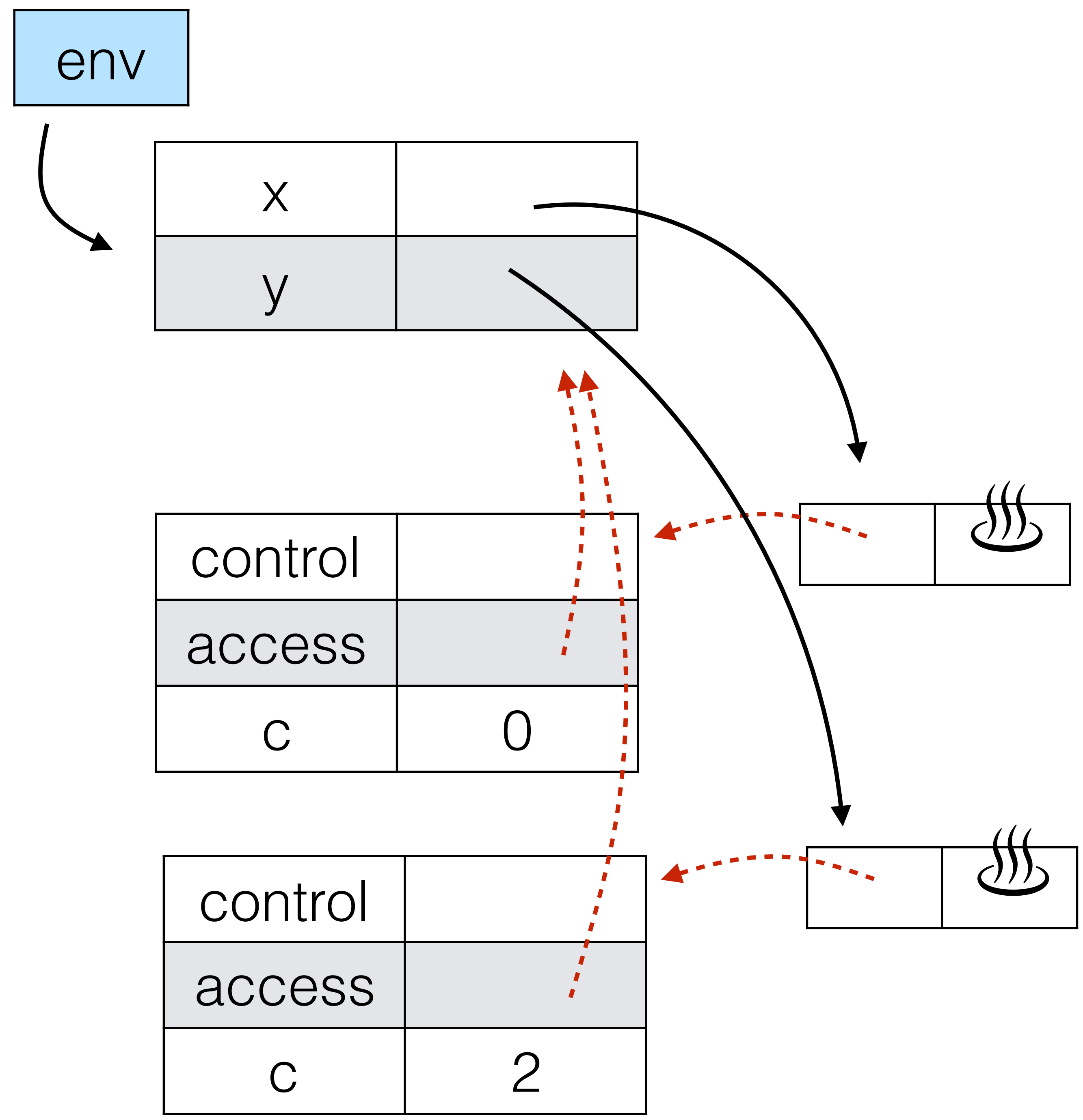

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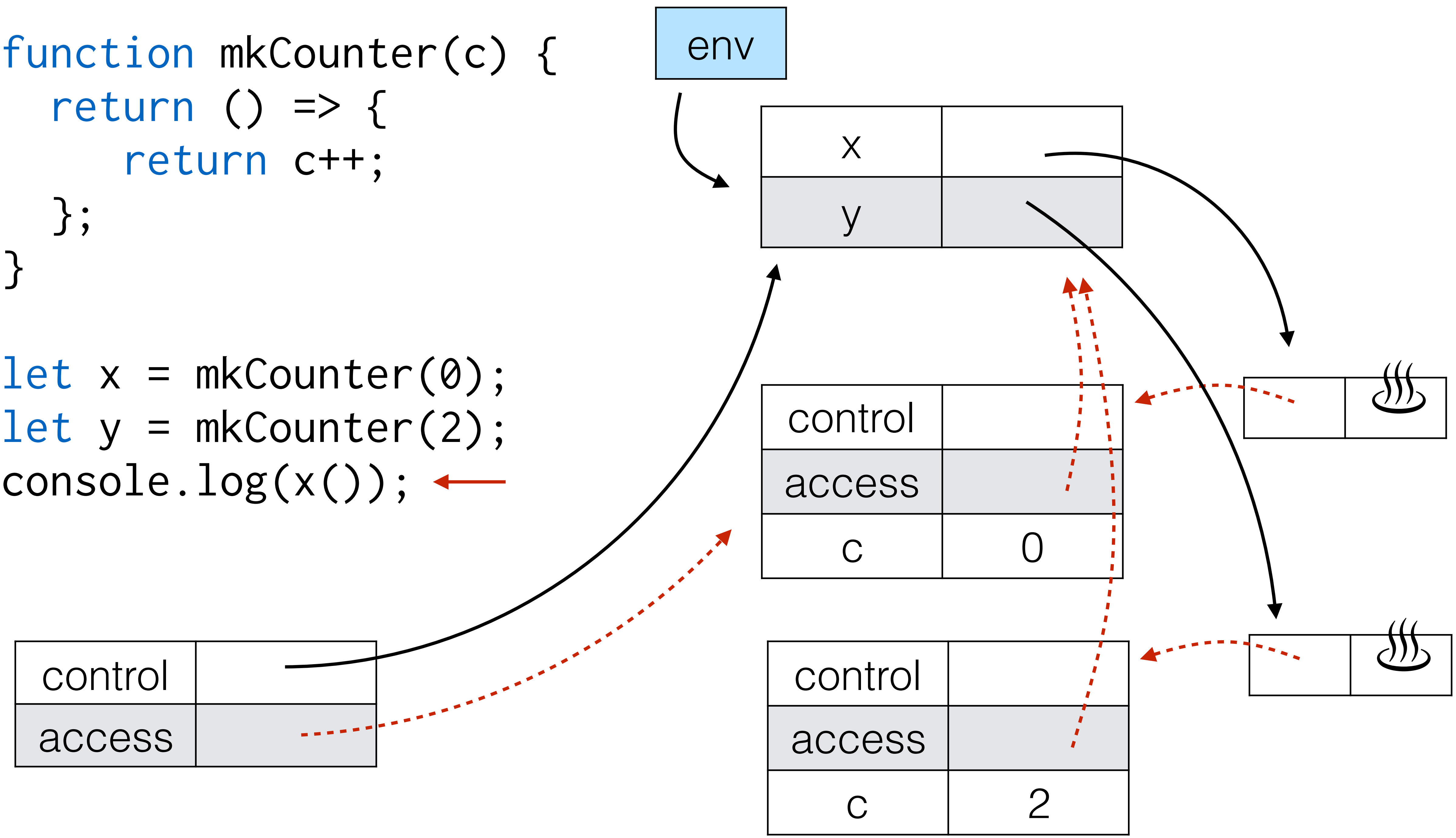

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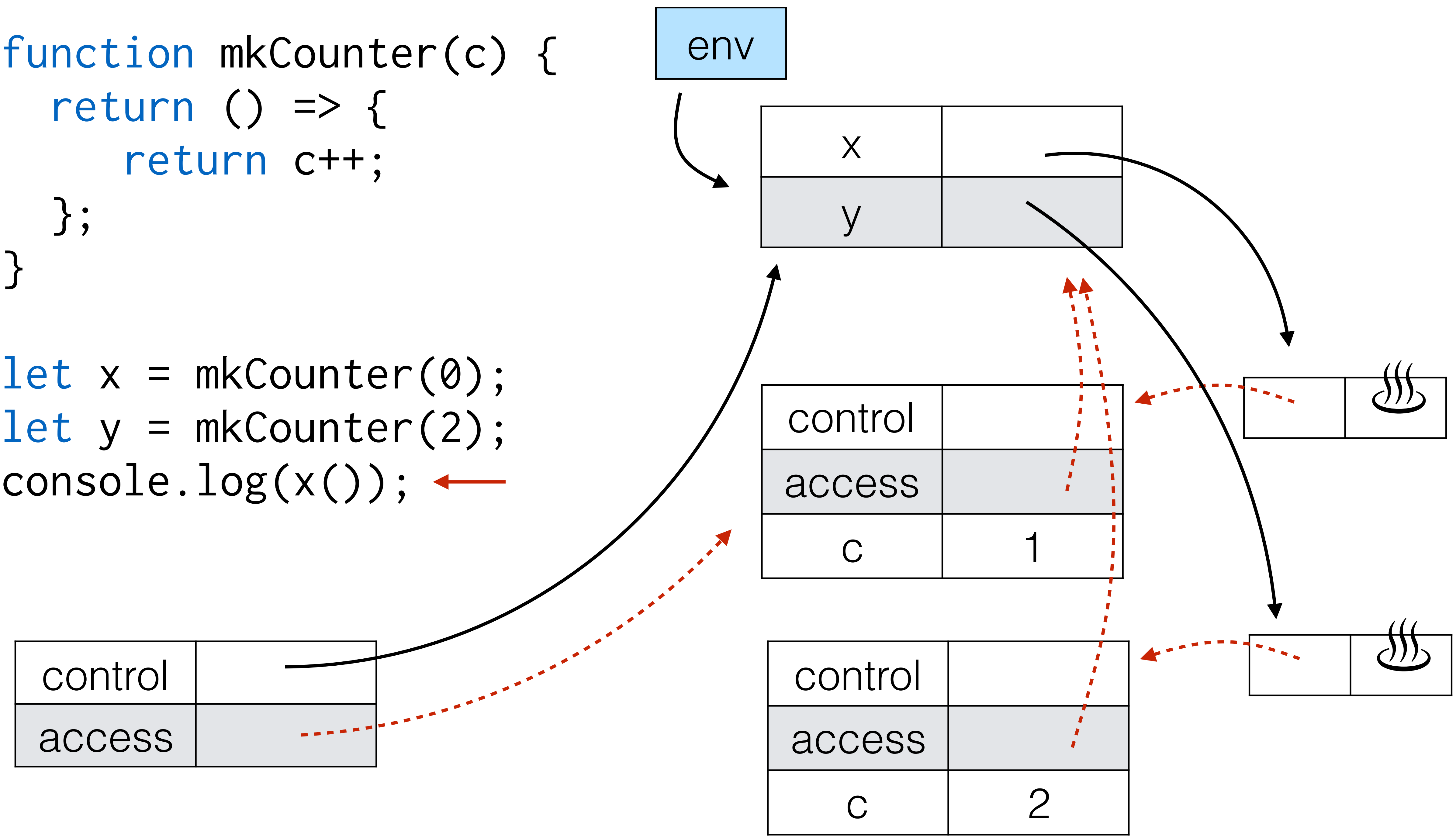

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