A brief survey of functional parallelism

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What is *functional* programming?

Functional programming

- First-class functions
- Lexical closures
- Immutability / purity
- Equational reasoning
- Lazy evaluation

λ-calculus

λ-calculus (Church, 1928)

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- Minimalist, universal language

Alonzo Church

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- Three expression types:

v [variable]

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v [variable]

$e_1(e_2)$ [function application]

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λ-calculus (Church, 1928)

- Minimalist, universal language
- Three expression types:

v	[variable]
$e_1(e_2)$	[function application]
$\lambda v.e$	[anonymous function]

Alonzo Church

Lisp and Scheme

- $v \equiv$ `v`
- $f(e) \equiv$ `(f e)`
- $\lambda v.e \equiv$ `(lambda (v) e)`

Python

- $v \equiv$ `v`
- $f(e) \equiv$ `f(e)`
- $\lambda v.e \equiv$ `lambda v: e`

Ruby

- $v \equiv$ `v`
- $f(e) \equiv$ `f(e)`
- $\lambda v.e \equiv$ `lambda { |v| return e }`

JavaScript

- $v \equiv$ `v`
- $f(e) \equiv$ `f(e)`
- $\lambda v.e \equiv$ `function (v) { return e ; }`

Java

- $v \equiv$ `v`
- $f(e) \equiv$ `f.call(e)`
- $\lambda v.e \equiv$ `new Value () { public Value call (Value v) { return e ; } } ;`

λ-fortified

- Lisp
- SML
- Haskell
- Scala
- Java
- C#
- C++
- Python
- Ruby
- Smalltalk
- JavaScript
- PHP(!)

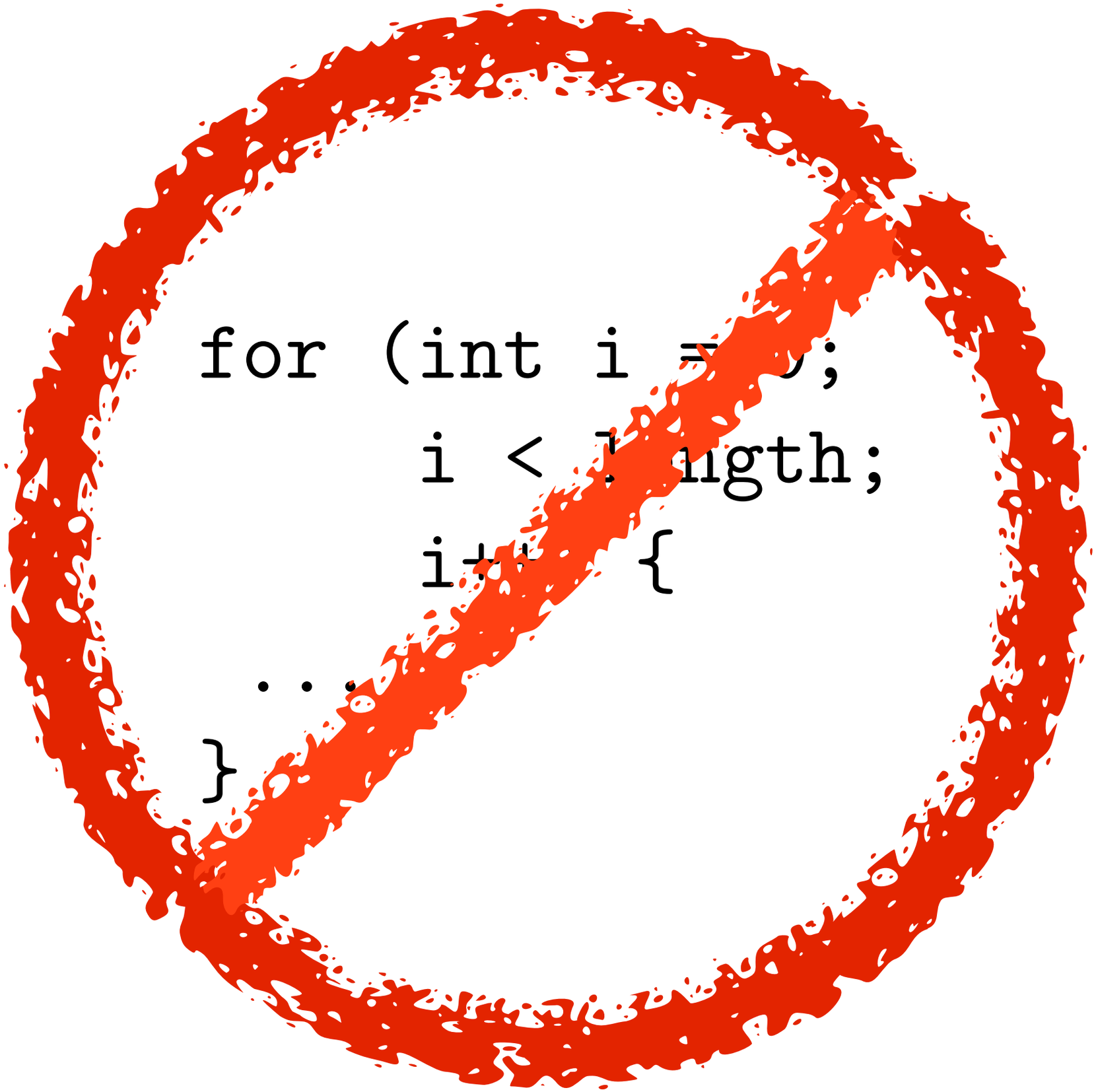
Today's menu

- Parallel iteration
- Futures
- Speculation
- Channels
- Transactions
- Autoparallelization

Parallel iteration

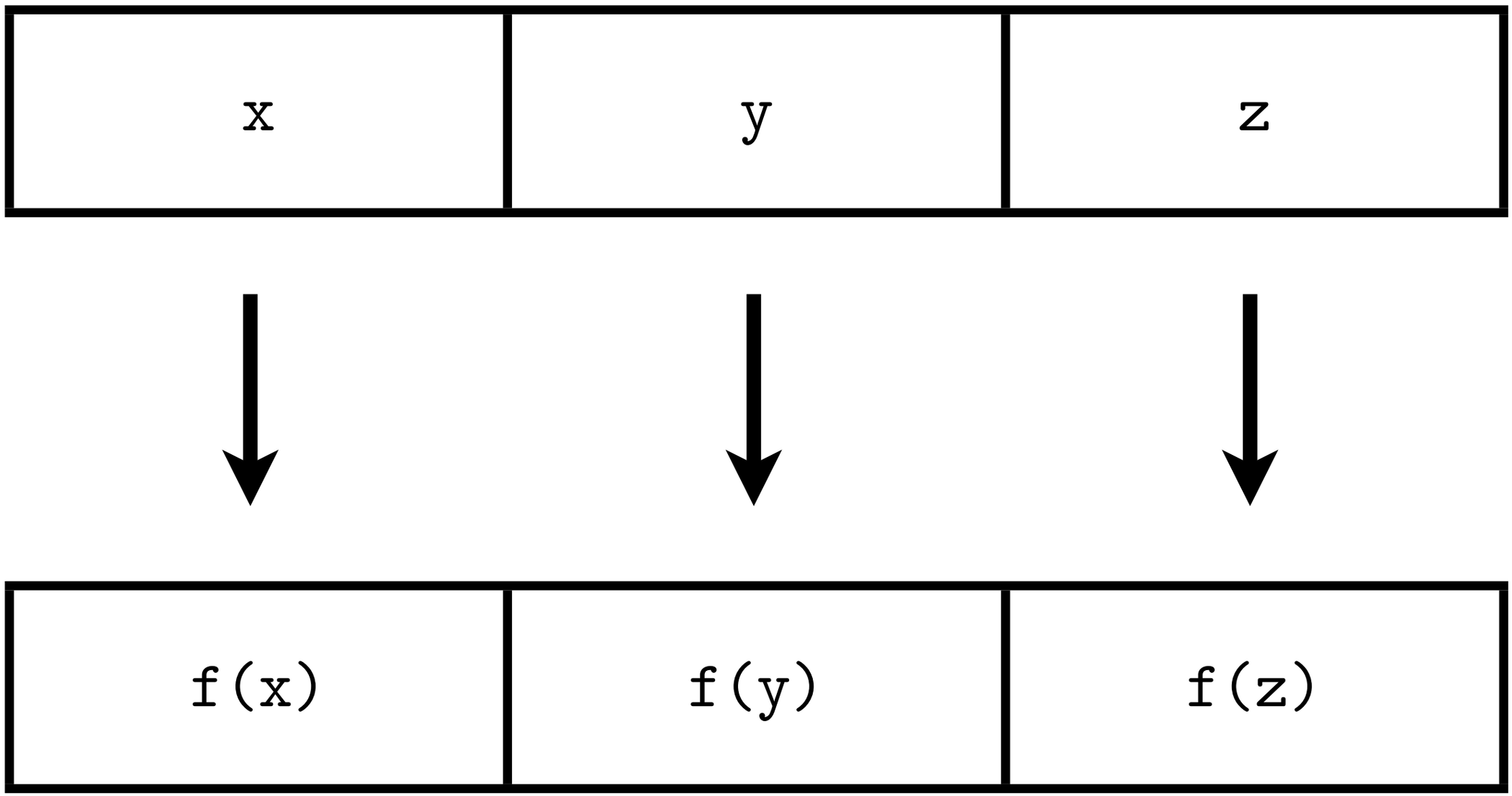
```
for (int i = 0;
     i < length;
     i++) {

  ...
}
```


for (int i = 0;
i < length;
i++) {
...
}

x	y	z

f(x)	f(y)	f(z)


x
y
z
f(x)
f(y)
f(z)

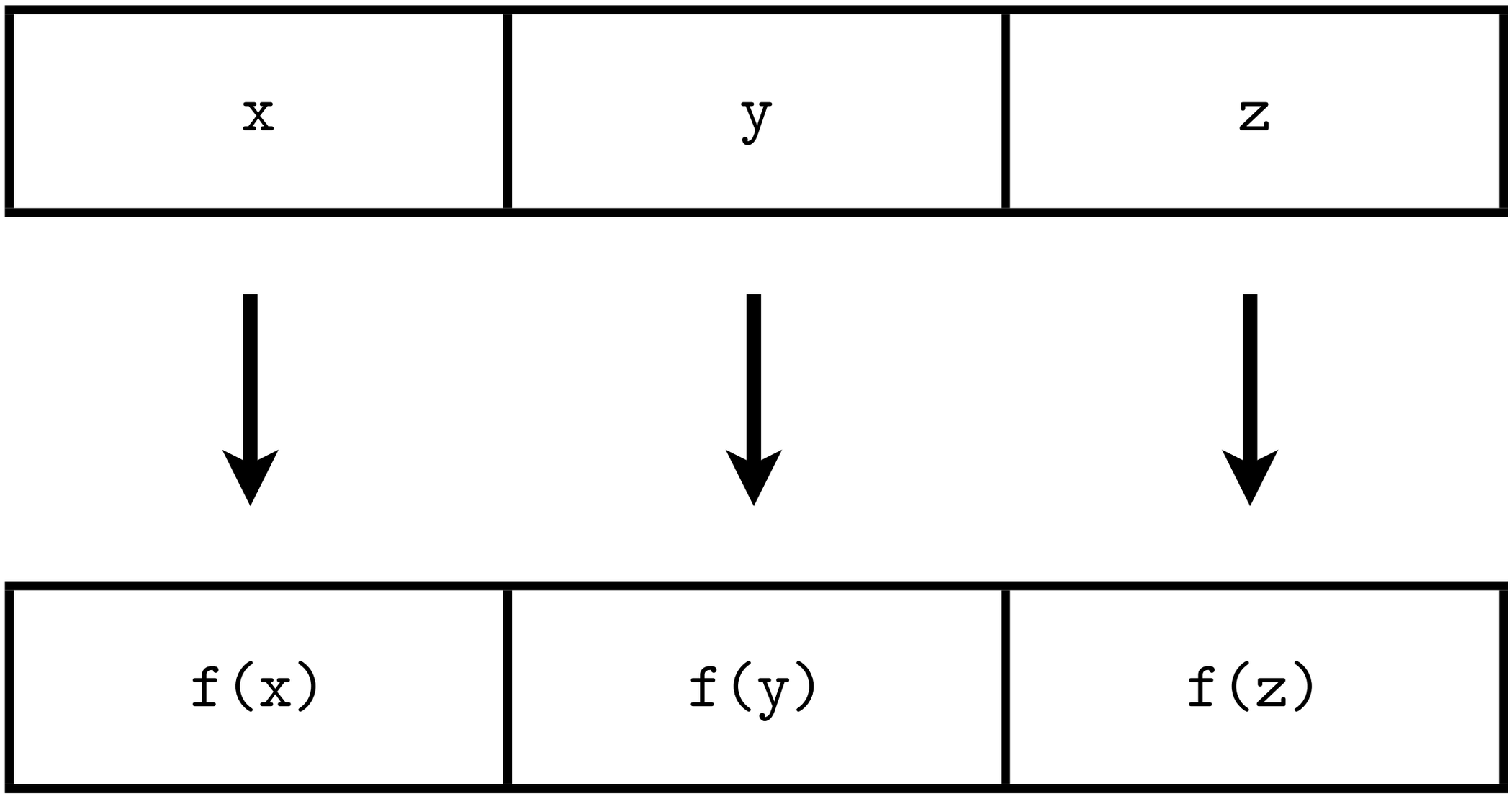
```
b = new T[a.length] ;
for (int i = 0; i < a.length; i++) {
 b[i] = f(a[i]) ;
}
```

```
b = map f a
```

```
b = map (x => x + 1) a
```

x	y	z

f(x)	f(y)	f(z)


x
y
z
f(x)
f(y)
f(z)

```
(pmap f a)
```

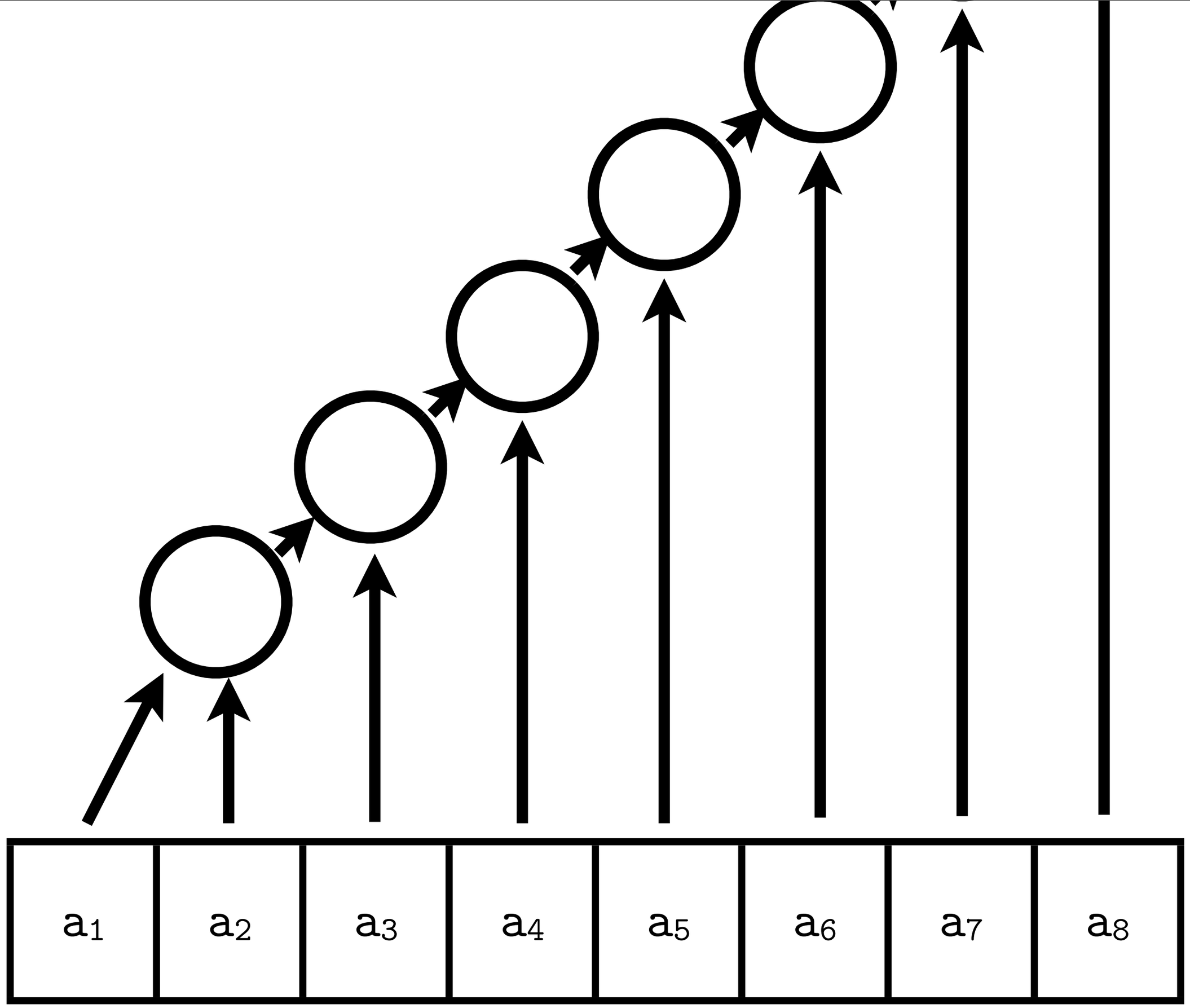
$$\sum_{i=1}^{8} a_i$$

$$a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 + a_8$$

```
c = 0 ;
for (int i = 0; i < a.length; i++) {
  c += a[i] ;
}
```

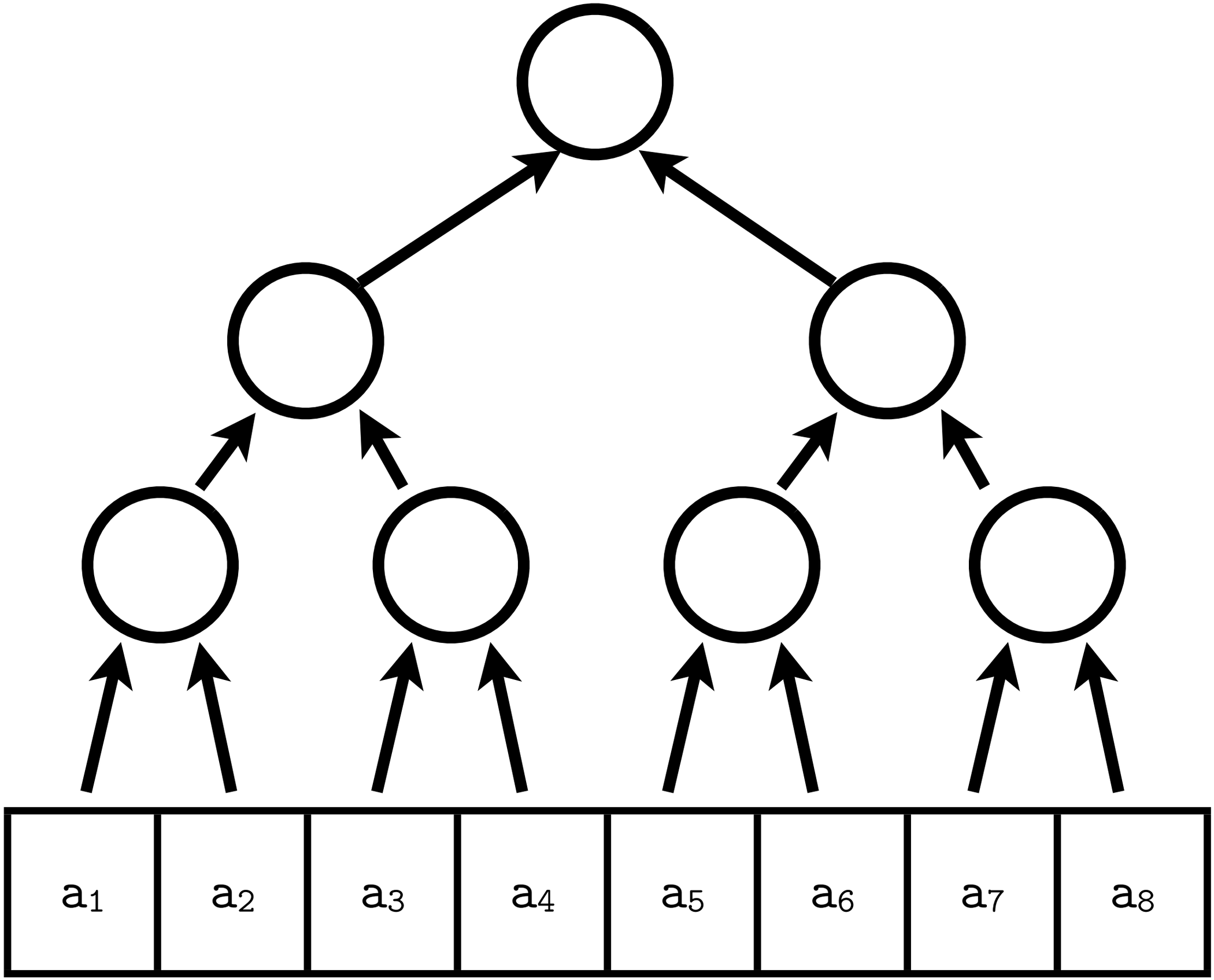
$$((((((a_1 + a_2) + a_3) + a_4) + a_5) + a_6) + a_7) + a_8$$

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8


a_1
a_2
a_3
a_4
a_5
a_6
a_7
a_8

$$((a_1 + a_2) + (a_3 + a_4)) + ((a_5 + a_6) + (a_7 + a_8))$$

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8


a_1
a_2
a_3
a_4
a_5
a_6
a_7
a_8

$$\texttt{reduce}\ (\oplus)\ \vec{a} = a_1 \oplus \cdots \oplus a_n$$

$$\sum = \texttt{reduce}\ (+)$$

preduce

assumes

associativity

Futures

```
a = f(x) ;
b = g(y) ;
return a + b;
```

```
pidf = spawn(f,&a,x) ;
pidg = spawn(g,&b,y) ;
join(pidf) ;
join(pidg) ;
return a + b ;
```

```
let a = f(x)
    b = g(y)
in a + b
```

```
let a = future f(x)
    b = future g(y)
in a + b
```

```
let a = future f(x)
    b = future g(y)
in h(a,b)
```

Speculation

immutability

=

no dependence

laziness

=

things to do

```
f(x,g(y))
```

```
f(a,b) =
  let z = BB(a)
  in z + b
```

Explicit speculation

```
par n f(x,n)
  where n = g(y)
```

```
f(a,b) =
 par b
   (let z = BB(a)
      in z + b)
```

Channels

Hard to reason about shared state.

Message-passing is reasonable.

π-calculus

```
P,Q ::= P | Q
      |  let v = c.receive() in P
      |  c.send(exp); P
      |  let c = new Channel() in P
      |  !P
      |  P + Q
      |  halt
```

Erlang example

```
ping(0, Pong_PID) ->
    Pong_PID ! finished,
    io:format("ping finished~n", []);

ping(N, Pong_PID) ->
    Pong_PID ! {ping, self()},
    receive
        pong ->
            io:format("Ping received pong~n", [])
    end,
    ping(N - 1, Pong_PID).
```

Erlang example

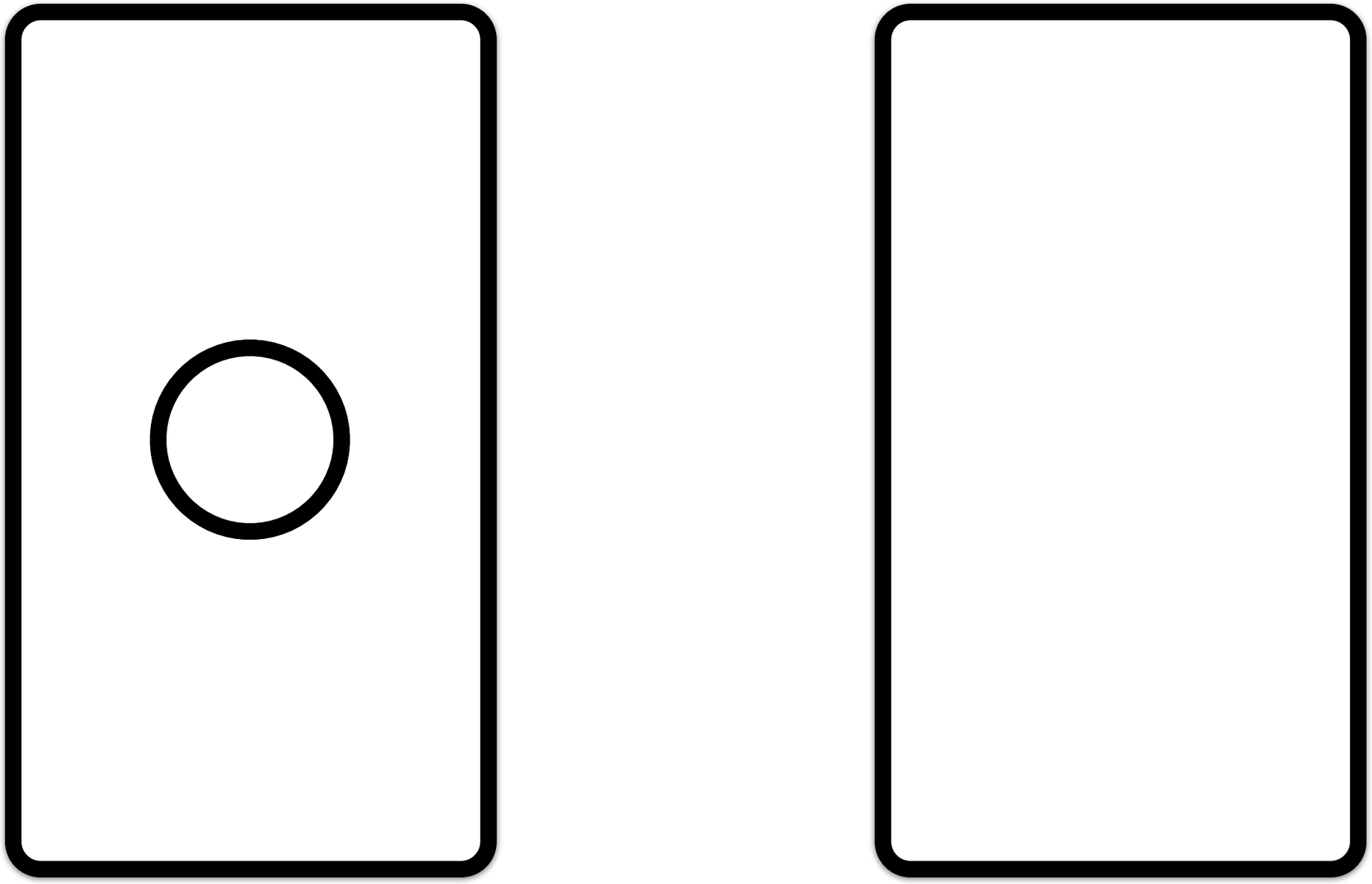
```
pong() ->
    receive
        finished ->
            io:format("Pong finished~n", []);
        {ping, Ping_PID} ->
            io:format("Pong received ping~n", []),
            Ping_PID ! pong,
            pong()
    end.
```

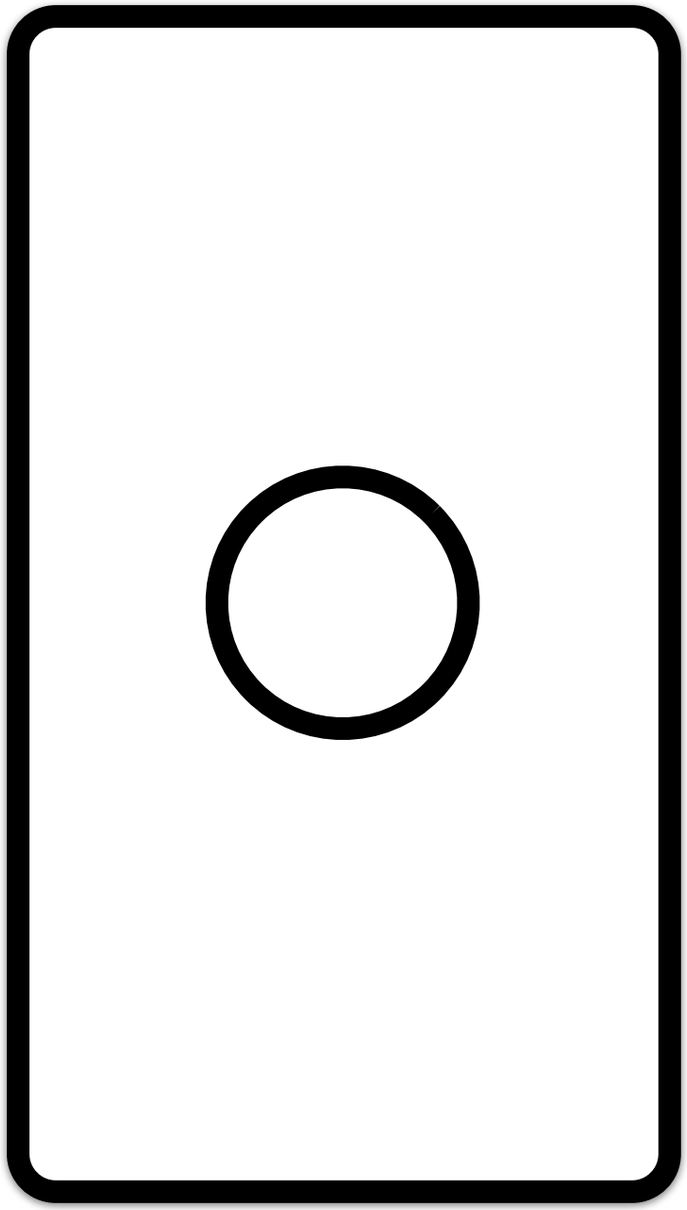
Erlang example

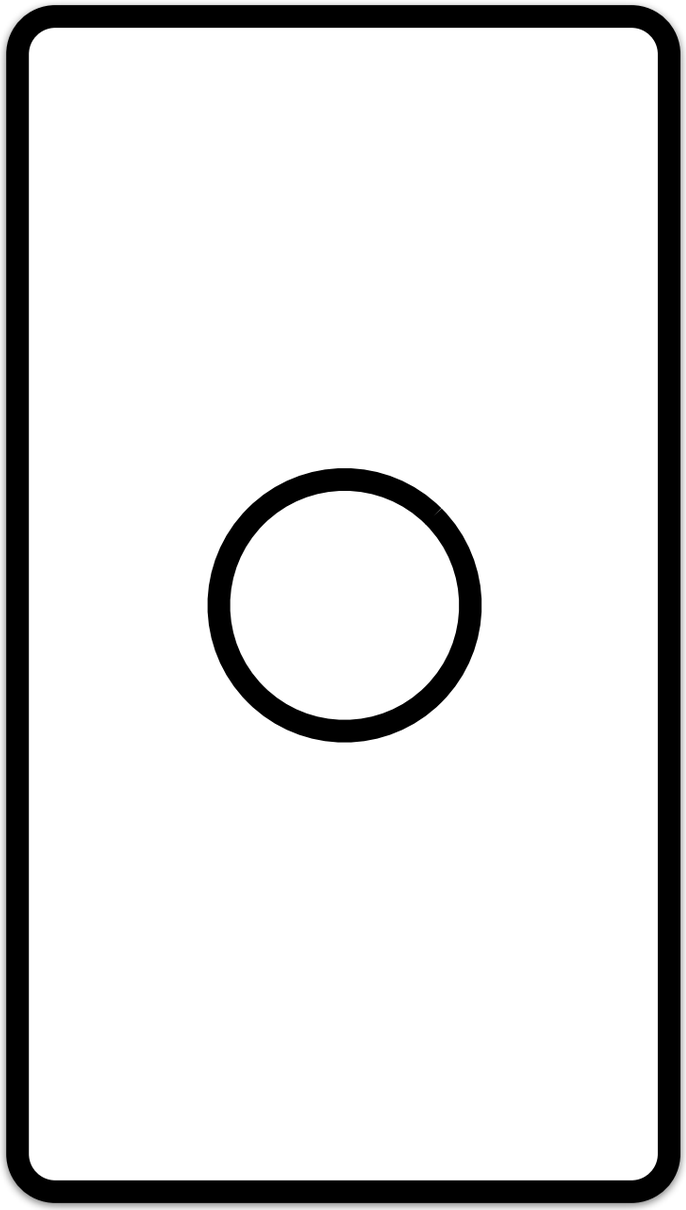
```
start() ->
    Pong_PID = spawn(tut15, pong, []),
    spawn(tut15, ping, [3, Pong_PID]).
```

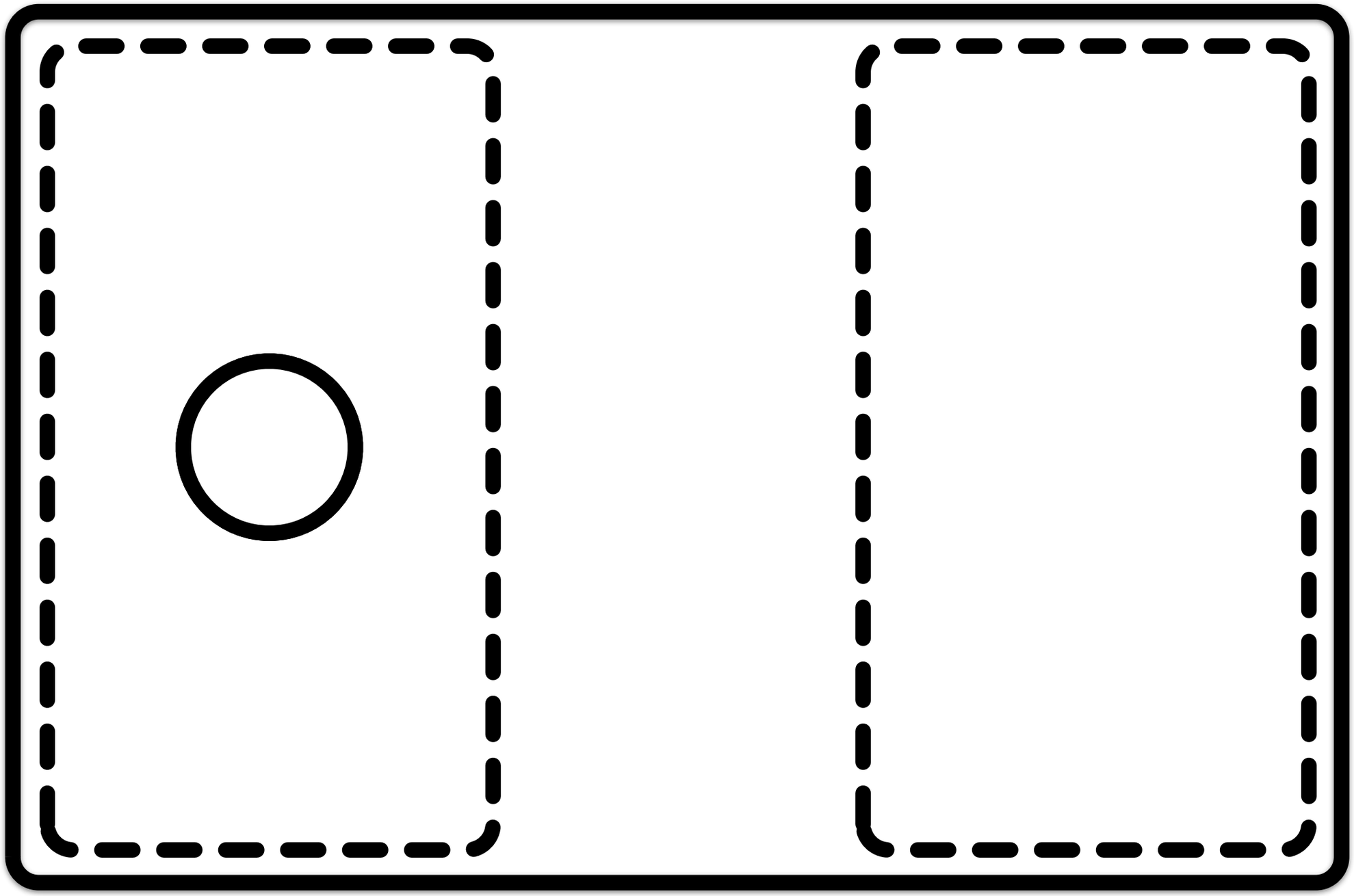
Is message-passing efficient?

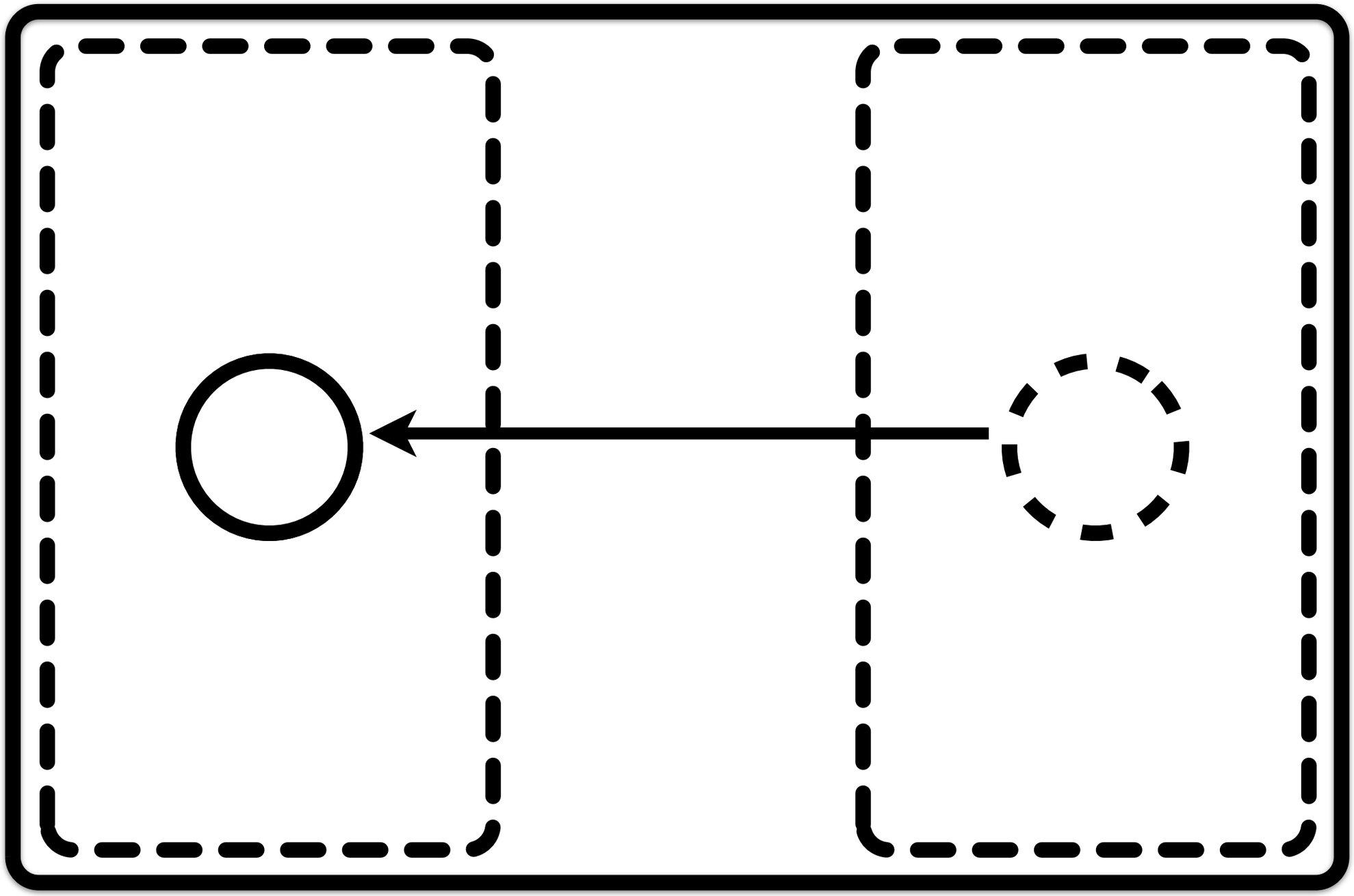
If data is immutable, message-passing can be implemented as shared memory.











Transactions

Locks are bad.

```
lock (mylock) ;
// do things
unlock (mylock) ;
```

```
atomic {
// do things
}
```

```
atomic {
 x += 1
}
```

```
atomic {
 x += 1
}
```

```
atomic {
 x += 1
}
```

```
atomic {
 x += 1
}
```

imperative: mutable by default

functional: immutable by default

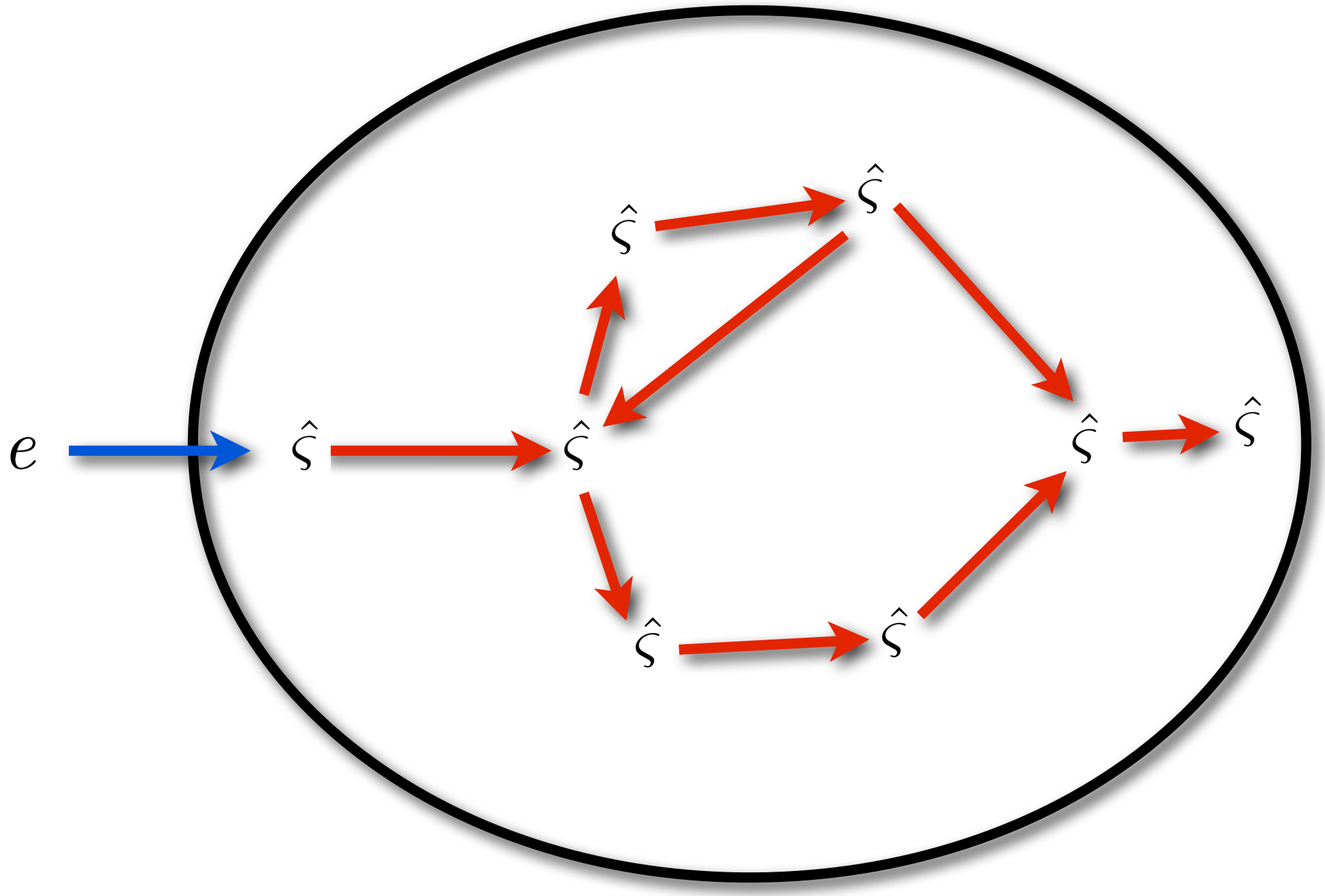
Automatic parallelization

```
f() ;

g() ;
```

Dependence analysis

Dependence analysis



Dependence analysis

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Dependence analysis

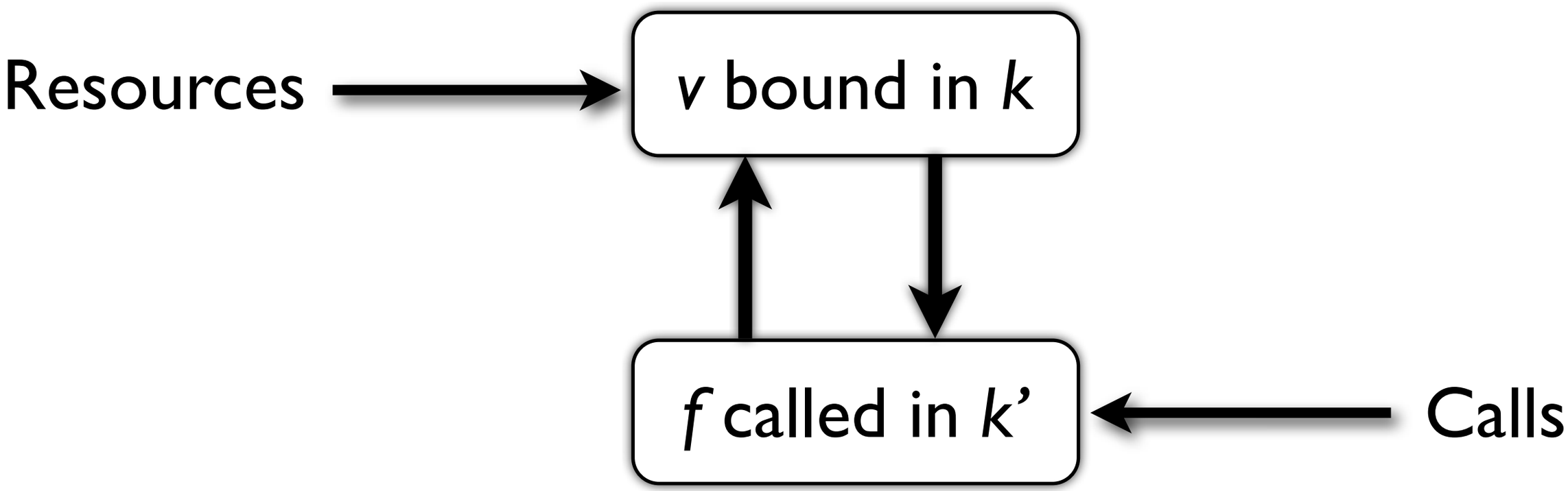
What resources are written?

What resources are read?

Which calling contexts are live on stack?

Context-sensitive dependence graphs

Context-sensitive dependence graphs



```
f()

g()
```

```
f() || g()
```

Questions?

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