How to think in Rust

Nick Cameron

RustConf 2018

@nrc @nick_r_cameron

New Zealand


moz://a

core team

tools

https://github.com/nrc/talks

https://github.com/nrc/talks

don’t fight the compiler

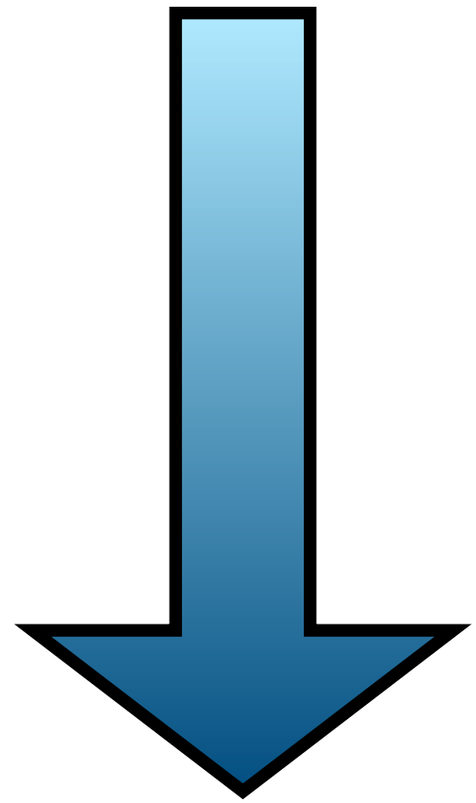
https://github.com/nrc/talks

the compiler is your ally

the plan

the plan

programming in the small



programming in the large

the plan

some key types

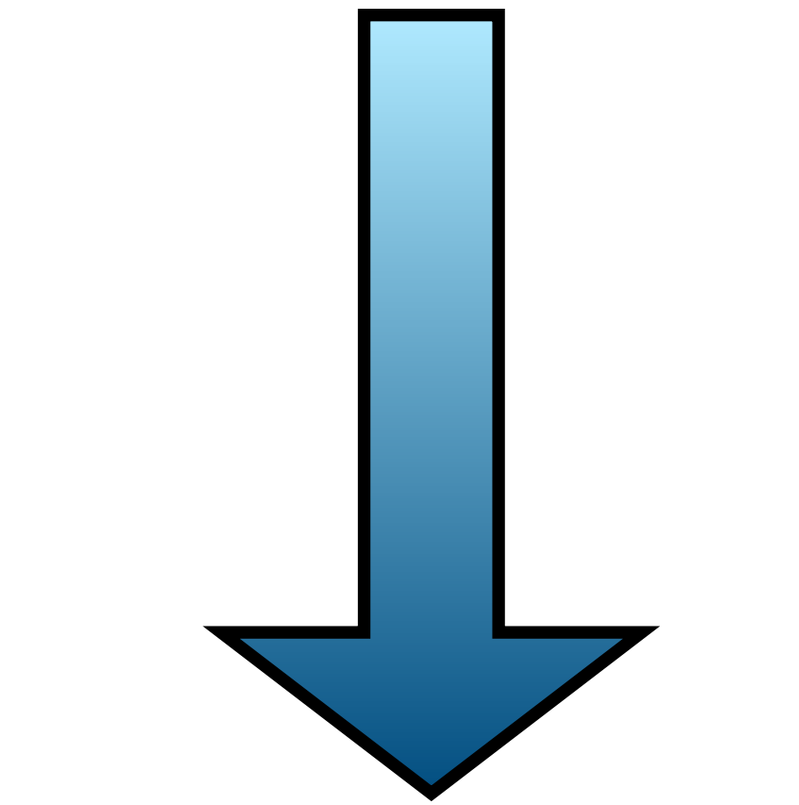
control flow

better control flow

error handling

ownership as a design principle

abstraction with traits



the plan

understanding ownership

some key types

control flow

better control flow

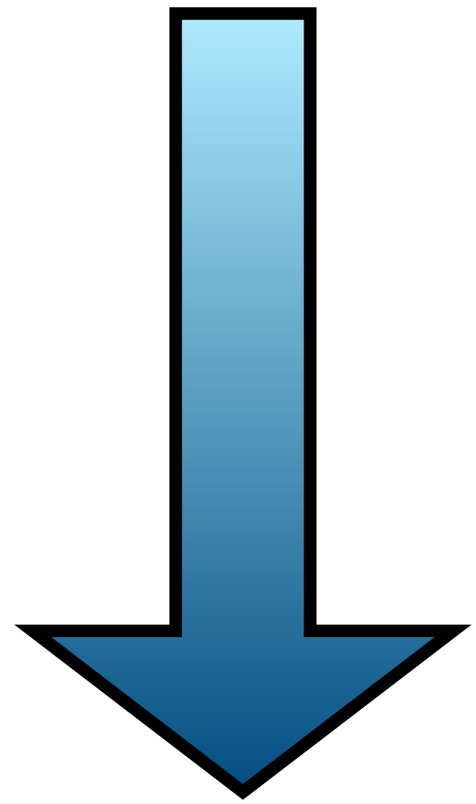
error handling

ownership as a design principle

abstraction with traits

getting more out of the compiler

programming in the small



programming in the large

https://twitter.com/nick_r_cameron/status/1014719625135714305

Josh Triplett @josh_triplett · Jul 5

Replying to @nick_r_cameron

Realizing I was *already* dealing with ownership and borrowing throughout my C code; Rust just does it all for me. Staring at libgit2's API and Python's API, full of statements like "free this when done with it" vs "returns a pointer to memory owned by another object, don't free"

2 7 48

JERRY BILLIONS @JarrettB · Jul 5

yeah, I feel like I was doing a lot of it in my head already; I didn't have a fully formed cohesive conception of it, and learning Rust was like learning words for something I couldn't describe

5

Shritesh Bhattarai @shritesh · Jul 5

Replying to @nick_r_cameron

Realizing that the borrow checker is not stupid and it's my fault.

4

Florian Gilcher @Argorak · Jul 5

Replying to @nick_r_cameron

a) Ownership is more important then borrowing.
b) Lifetimes are just descriptive.

1 1 18

Jonathan Pallant @therealjpster · Jul 5

Replying to @nick_r_cameron @rustlang

When I realised foo(bar* p) is hopelessly ambiguous. Does foo now own the bar? Will it call free(p)? Is it just borrowing it for the life of the call? Does it borrow it for an arbitrary period? C is now ruined for me.

1 8

Alfie John @alfiedotwtf · Jul 5

Replying to @nick_r_cameron

Why things wouldn't compile unless I fixed all of the annoying ownership issues. And then the whole topic blew my mind!

... and then I started to have an existential crisis thinking about all my non-Rust production code not taking into account ownership 😱😱😱

2 21

Laser Guided Kittens™ @RustDevLuke · Jul 5

Yeah I'm just going to nod furiously while agreeing with yours. Exactly my experience.
Definitely understanding ownership and all the associated things like immutable and mutable borrows, moves etc.

1 4

Oliver Schneider @oli_obk · Jul 5

Replying to @nick_r_cameron

lifetimes are descriptive, not prescriptive. I always tried to make inherently broken code work by making the lifetimes tell the code how to behave. At some point i realized I had it all wrong.

1 3 15

achtung bitte @ag_dubs · Jul 11

Replying to @nick_r_cameron @QEDunham

"lifetimes are part of the type"

1

ownership

Borrowing

Lifetimes

Lifetime parameters

Outlives bounds

Move semantics

Design

ownership

Unique or multiple

By reference or by value

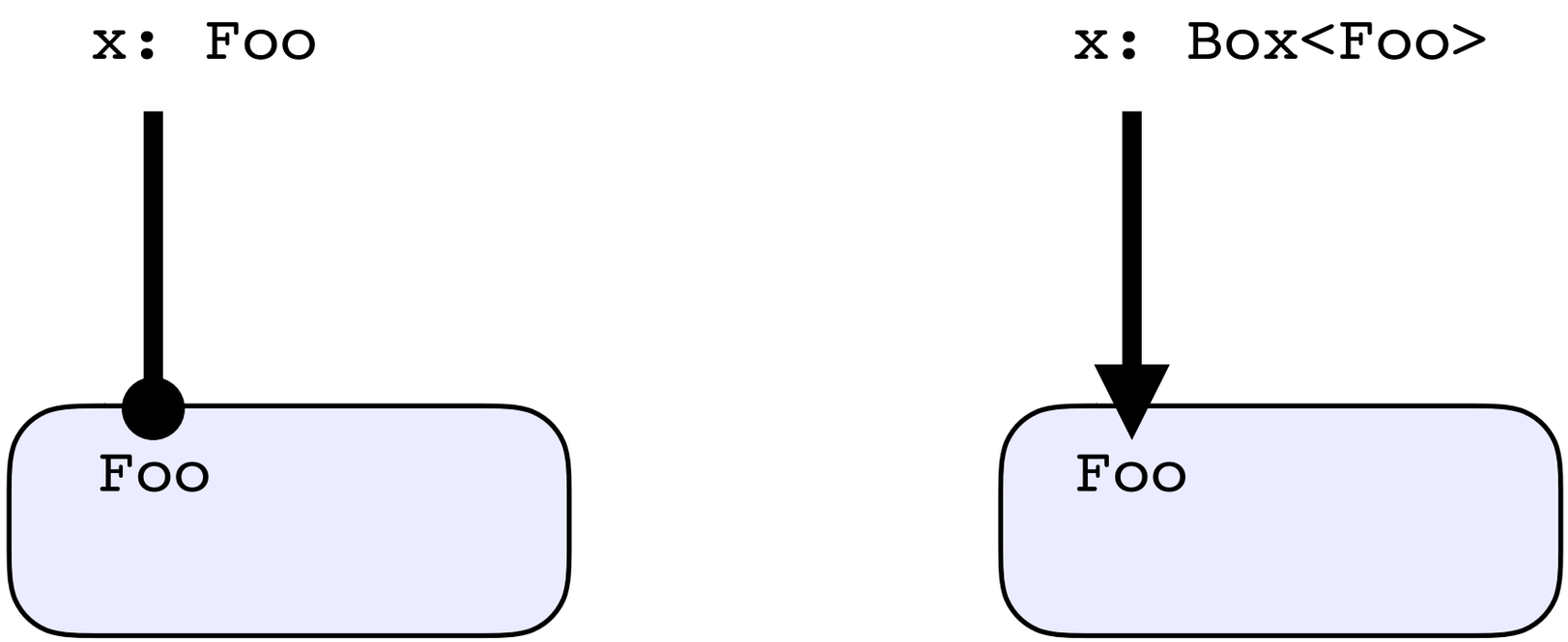
Heap or stack

Mutable or immutable

ownership

Who tidies up?

ownership

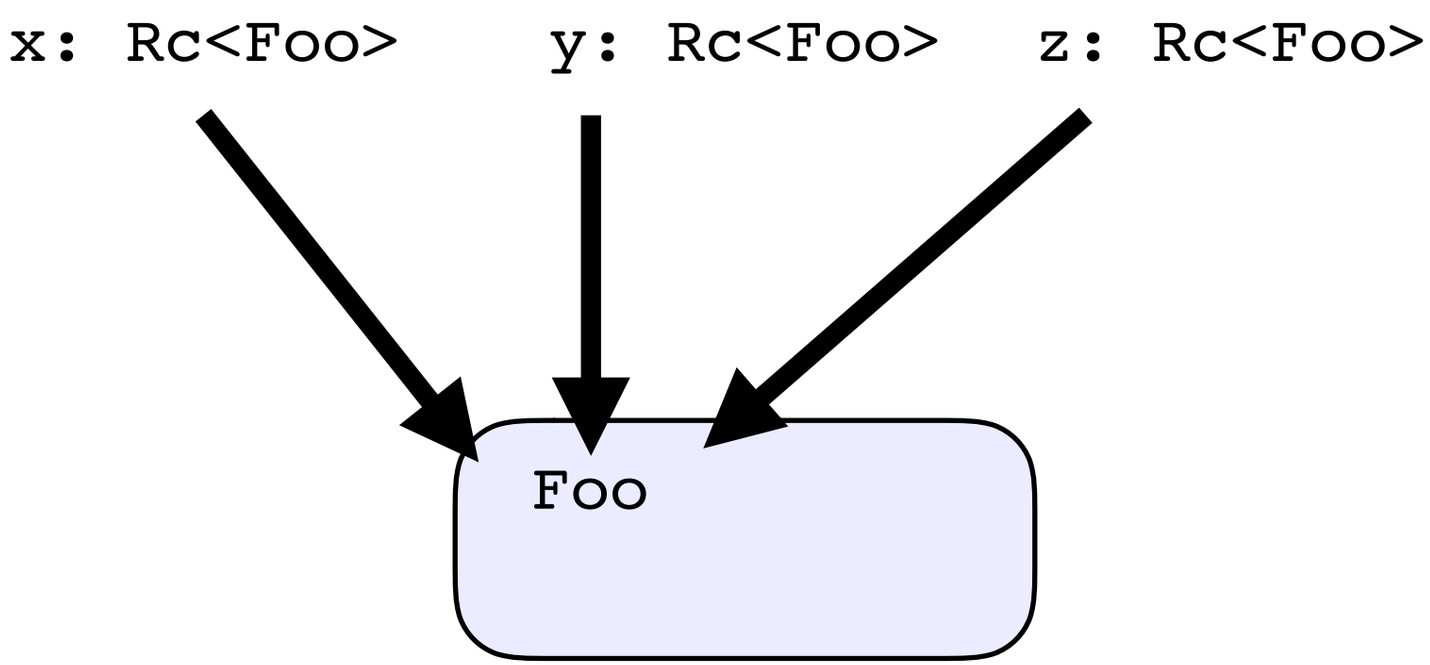



```
struct Foo { … }
```

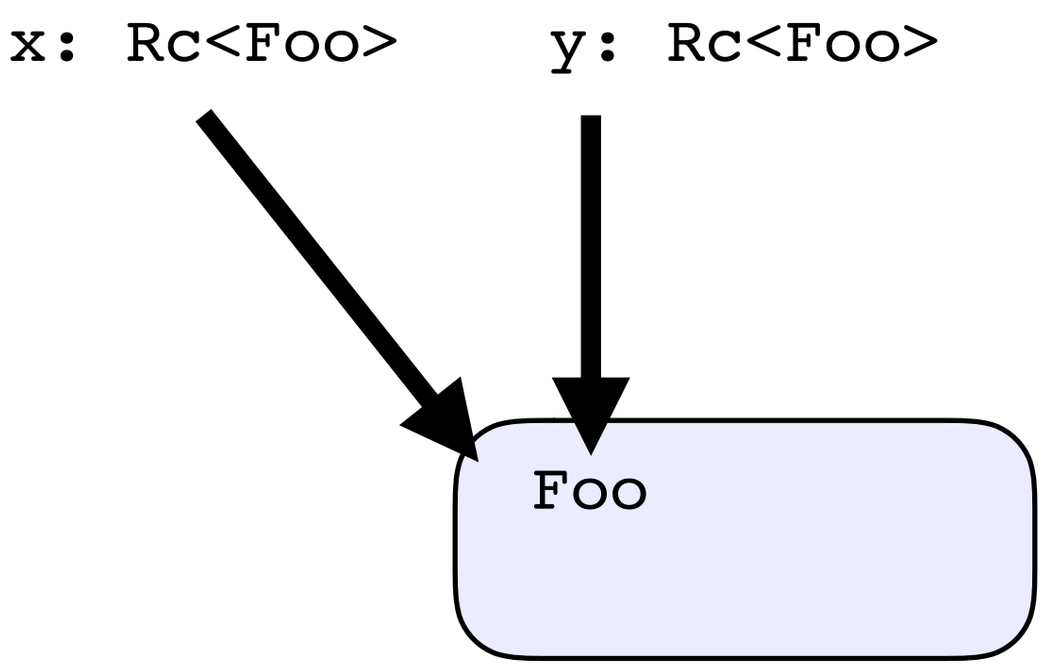
ownership

ownership

ownership



ownership



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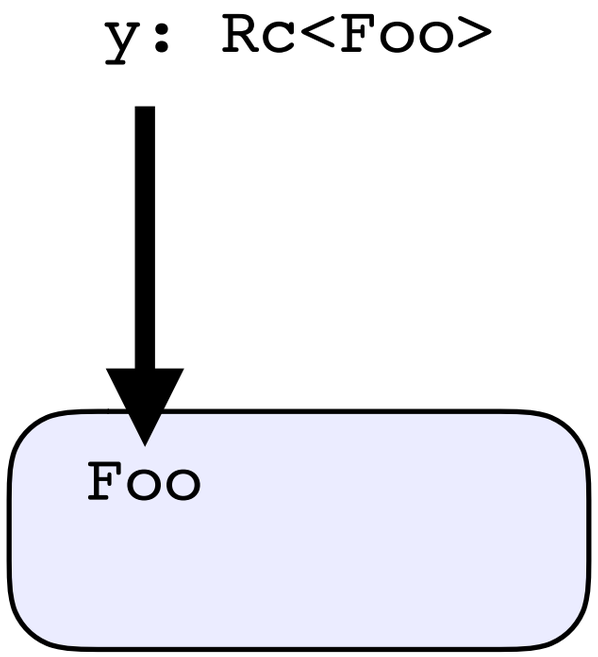
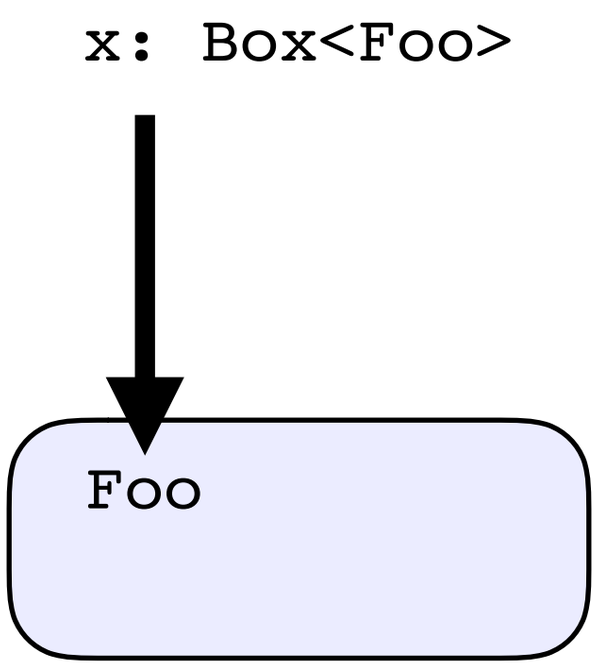


ownership

ownership

borrowing



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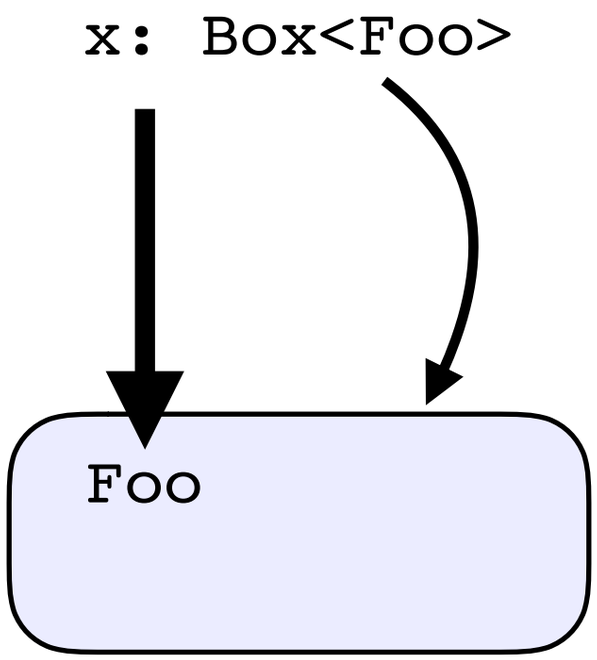

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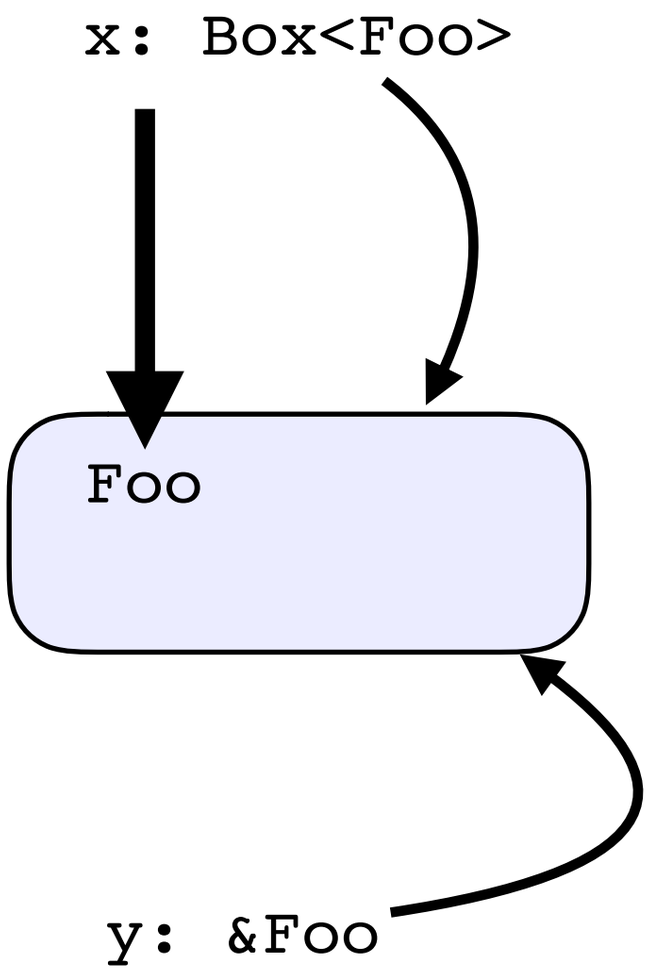
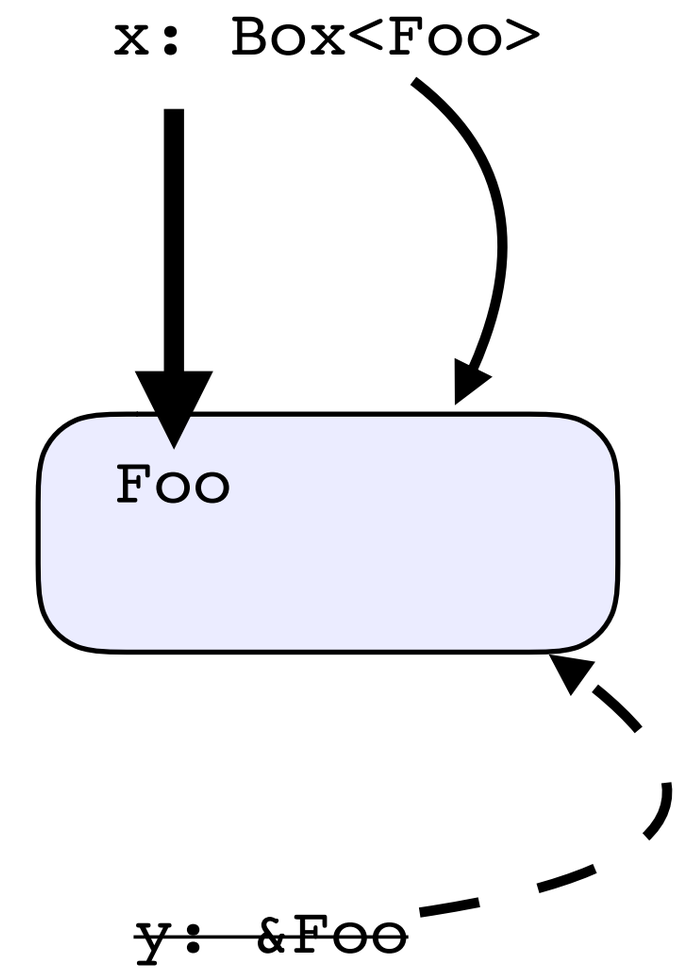
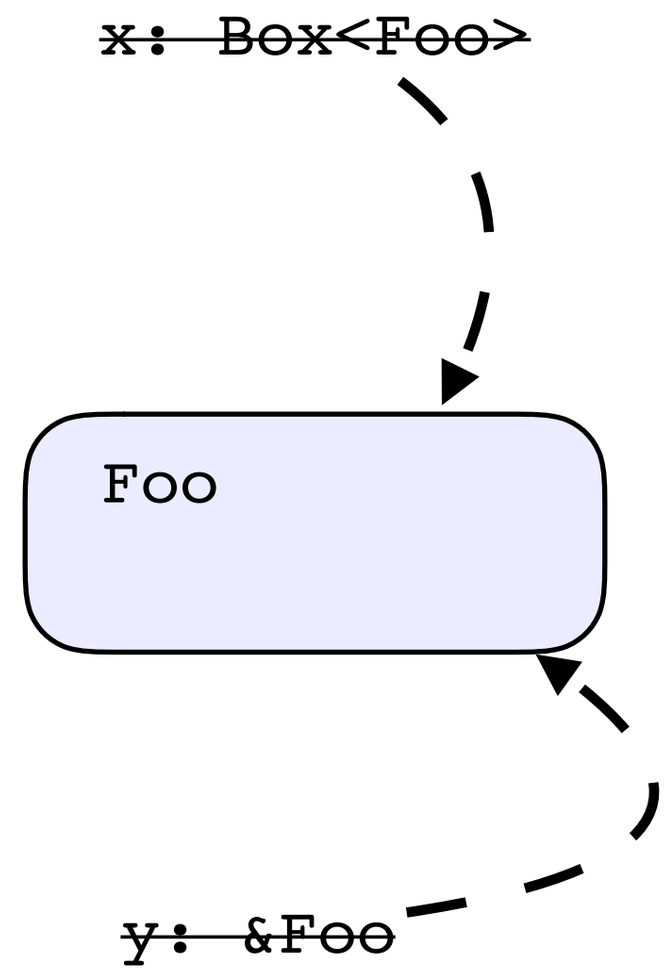


borrowing



borrowing



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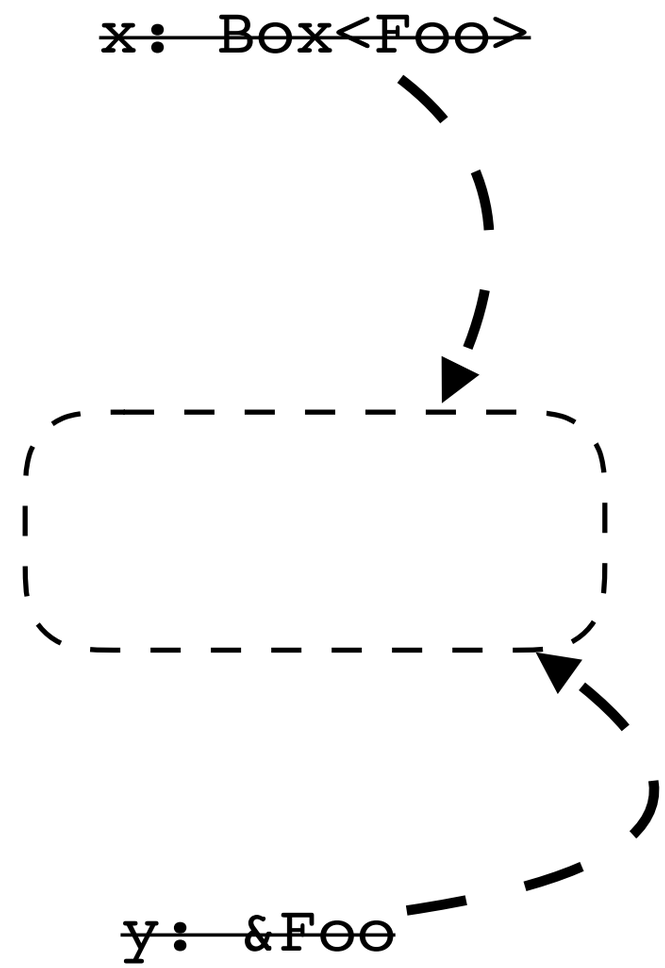

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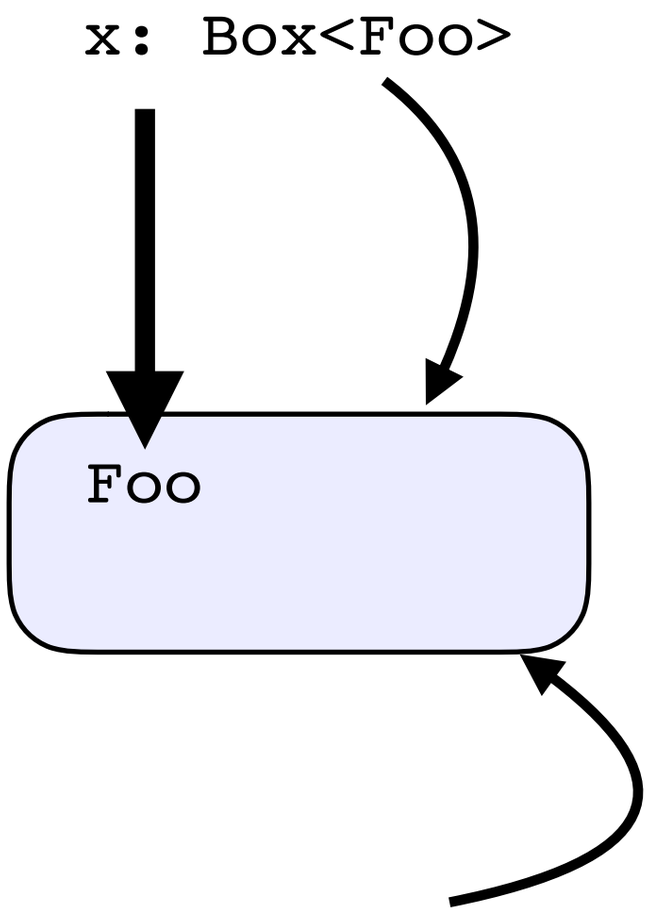

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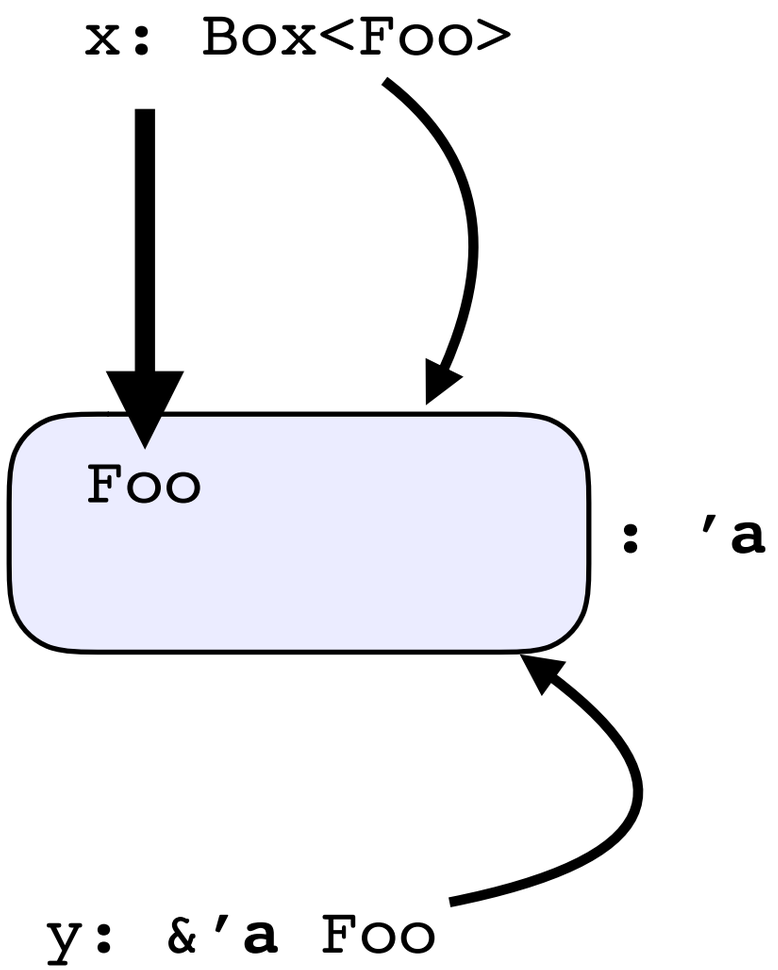


ownership

Owned

Borrowed

ownership

Owned

`Foo`

`Box<Foo>`

`[Foo; 3]`

`Vec<Foo>`

`Rc<Foo>`

Borrowed

ownership

Owned

```
Foo

Box<Foo>

[Foo; 3]

Vec<Foo>

Rc<Foo>
```

Borrowed

```
&Foo

&[Foo]

Vec<&Foo>

Bar<‘a>
```

cannot move out of borrowed context

cannot move out of borrowed context

```
struct Foo {
    s: String,
}
```

cannot move out of borrowed context

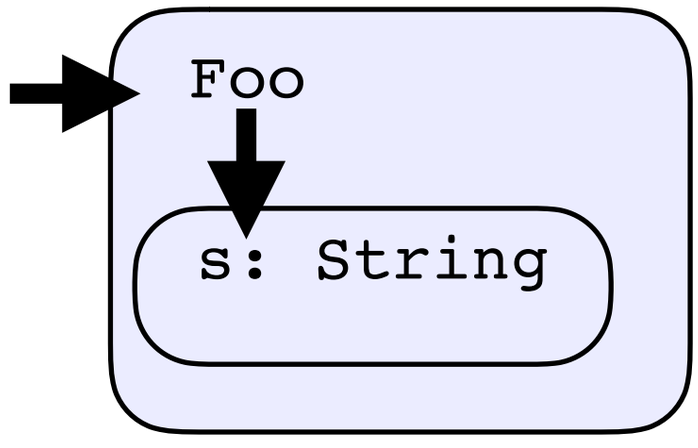
```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: String = f.s;
}
```

cannot move out of borrowed context

```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: String = f.s;
}
```



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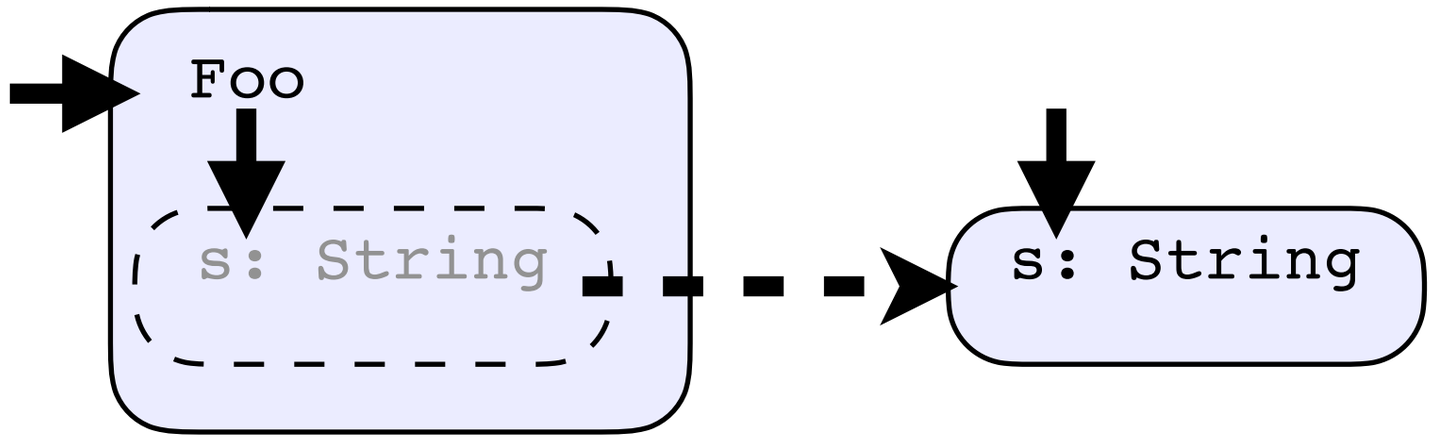

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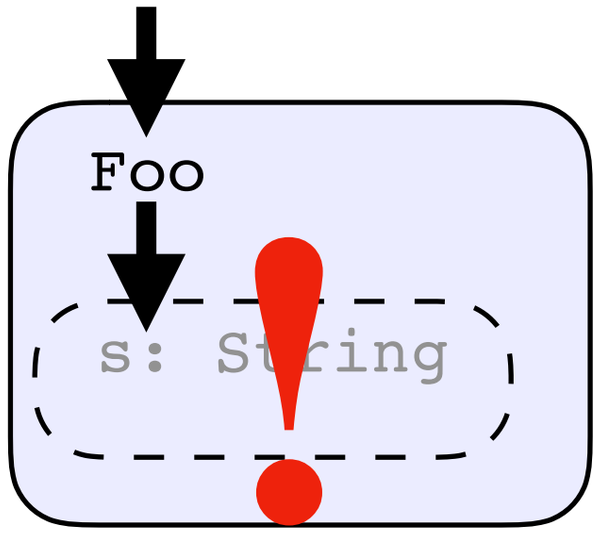
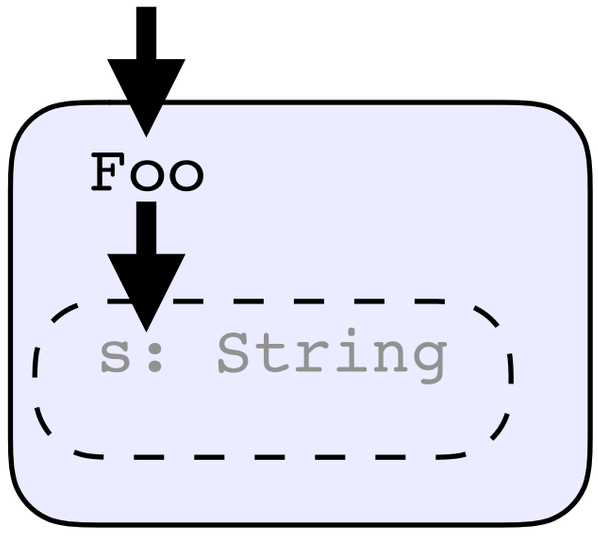


cannot move out of borrowed context

```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: String = f.s;
}
```



cannot move out of borrowed context

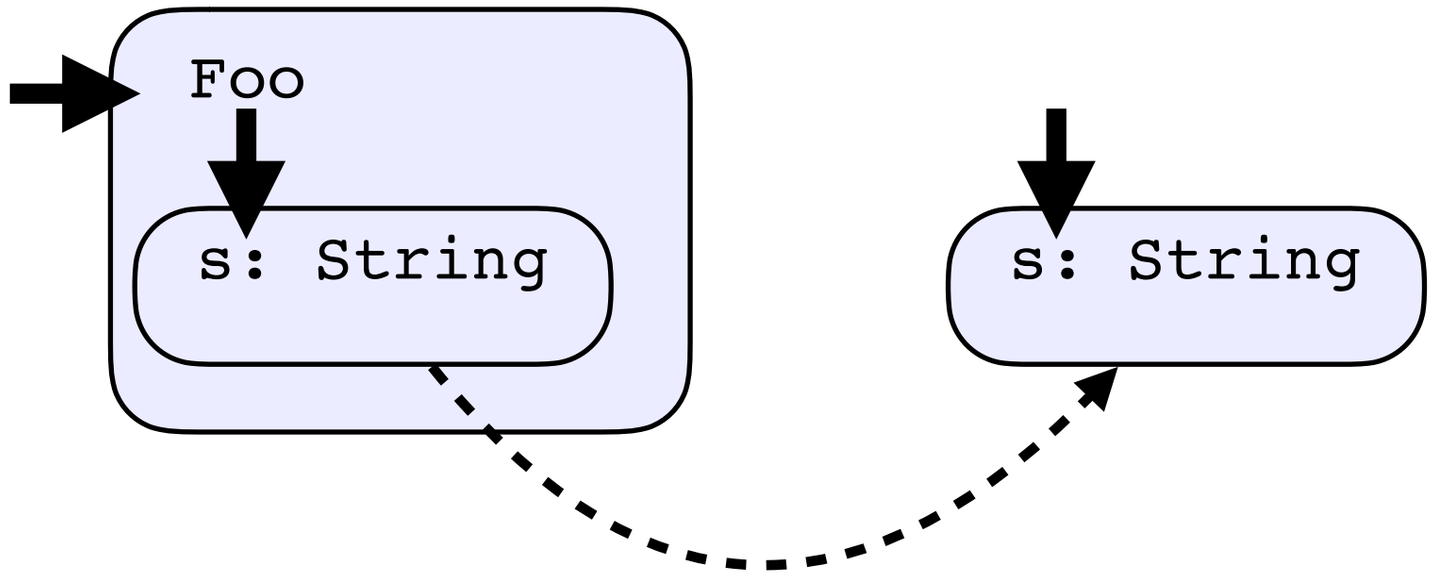
```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: String = f.s.clone();
}
```

cannot move out of borrowed context

```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: String = f.s.clone();
}
```



cannot move out of borrowed context

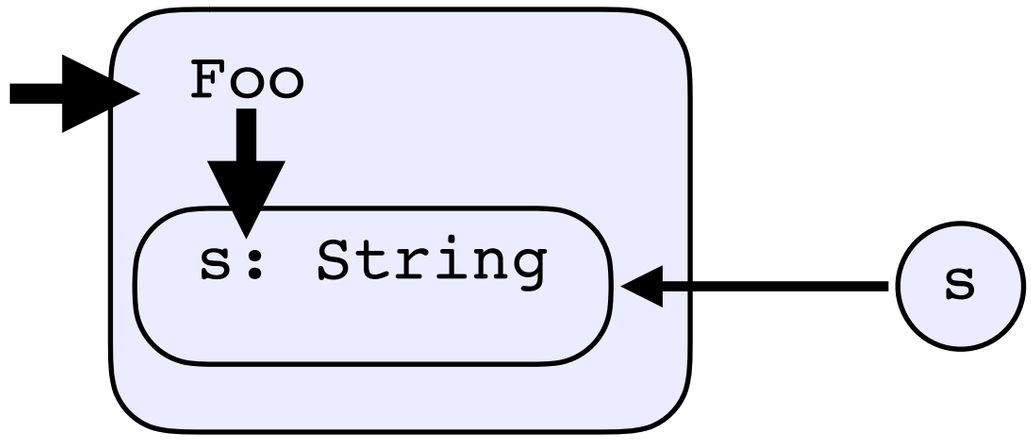
```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: &str = &f.s;
}
```

cannot move out of borrowed context

```
struct Foo {
    s: String,
}

fn bar(f: &Foo) {
    let s: &str = &f.s;
}
```



questions

Why don't **`Box`** (or other owning types) need a lifetime parameter?

Why is it an ownership graph and not a tree?

What is at the roots of the ownership graph?

How does ownership relate to mutability?

some types

Option

Result

Iterator

Option<T>

Result<T, E>

Iterator<Item = T>

?

for

Option<T>

Result<T, ()>

Option<()>

Result<(), ()>

bool

Option<T>
Option<T>
Option<T>
Option<T>
Option<T>
Option<T>

Iterator<Item = T>

Option

```
enum Option<T> {
    Some(T),
    None,
}
```

Result

```
enum Result<T, E> {
    Ok(T),
    Err(E),
}
```

if let

```
match h() {
     Ok(i) => {
          // do something with i
     }
     _ => {}
}
```

if let

```
if let Ok(i) = h() {
    // do something with i
}
```

?

```
match h() {
    Ok(i) => {
        // do something with i
    }
    err => return err,
}
```

?

```
let i = match h() {
    Ok(i) => i,
    err => return err,
};

// do something with i
```

?

```
let i = h()?;

// do something with i
```

?

```
let i = h()?.foo()?.bar;
```

some methods

some methods

```
fn add_four(x: i32) -> i32 {
    x + 4
}


fn maybe_add_four(y: Option<i32>) -> Option<i32> {
    match y {
        Some(yy) => Some(add_four(yy)),
        None => None,
    }
}
```

map

```
fn add_four(x: i32) -> i32 {
    x + 4
}


fn maybe_add_four(y: Option<i32>) -> Option<i32> {
    y.map(add_four)
}
```

map

```
fn maybe_add_four(y: Option<i32>) -> Option<i32> {
    y.map(|x| x + 4)
}
```

map

```
fn maybe_add_four(y: Result<i32, E>) -> Result<i32, E> {
    y.map(|x| x + 4)
}
```

map

```
fn maybe_add_four(y: Result<i32, E>) -> Result<i32, E> {
    y.map(|x| x + 4)
}
```

```
fn maybe_add_four(y: impl Iterator<Item = i32>)
    -> impl Iterator<Item = i32>
{
    y.map(|x| x + 4)
}
```

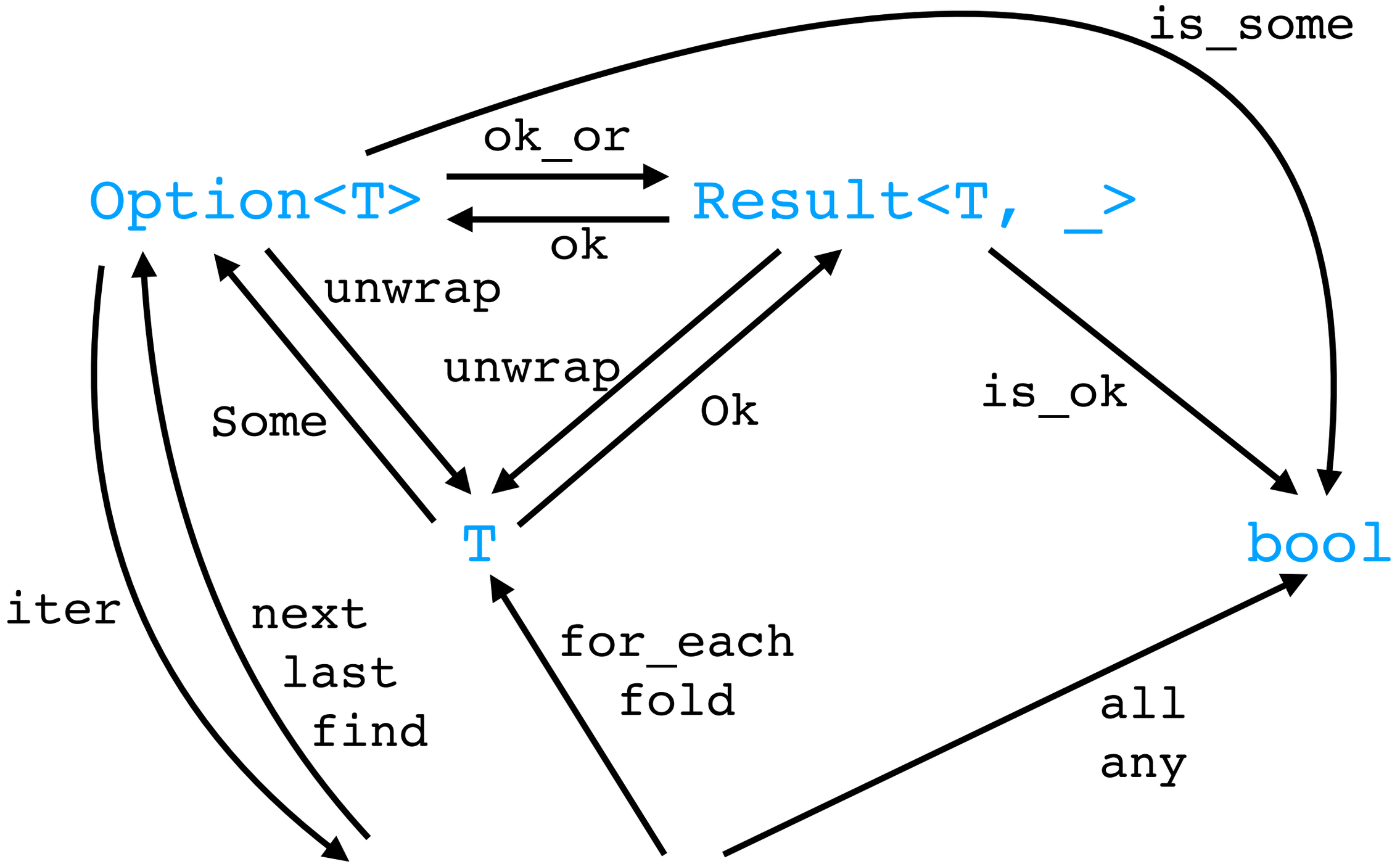
Option<T>

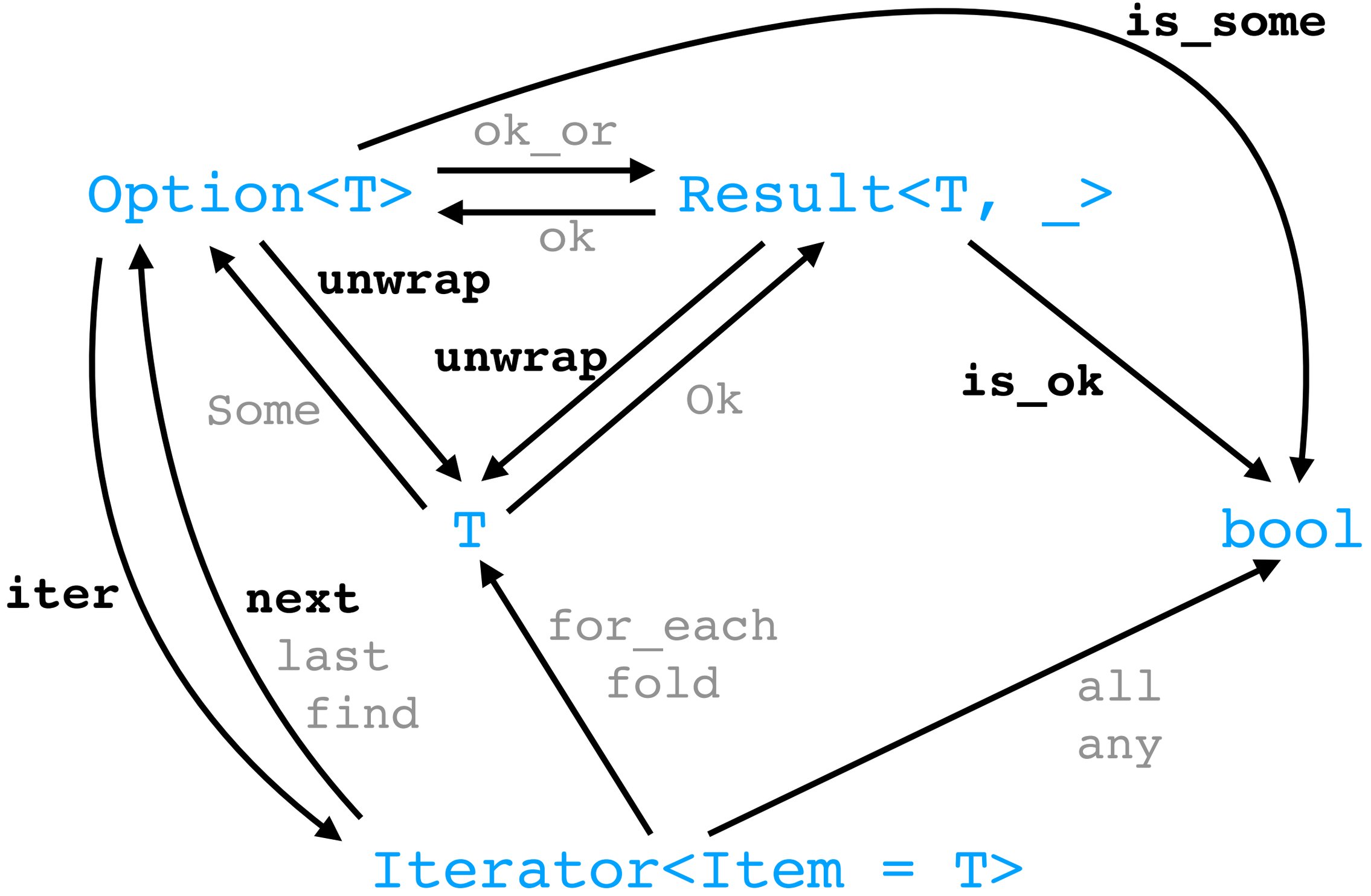
T

Result<T, _>

bool

Iterator<Item = T>


is_some
ok_or
Option<T>
Result<T, _>
ok
unwrap
unwrap
Some
Ok
is_ok
T
bool
iter
next
last
find
for_each
fold
all
any
Iterator<Item = T>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T
bool
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fold
all
any
Iterator<Item = T>

some methods

`unwrap`	`unwrap_or`	`unwrap_or_else`
`map`	`map_or`	`map_or_else`
	`or`	`or_else`
	`and`	`and_then`

some methods

O<T> -> T

unwrap	unwrap_or	unwrap_or_else
map	map_or	map_or_else
	or	or_else
	and	and_then

some methods

	T		
O<T> -> T	unwrap	unwrap_or	unwrap_or_else
	map	map_or	map_or_else
		or	or_else
		and	and_then

some methods

		T	**||/|T|**
O<T> -> T	unwrap	unwrap_or	unwrap_or_else
	map	map_or	map_or_else
		or	or_else
		and	and_then

some methods

		`T`		**`||/|T|`**
`O<T> -> T`		`unwrap`	`unwrap_or`	`unwrap_or_else`
`O<T> -> O<U>`	`map`	`map_or`	`map_or_else`	
		`or`	`or_else`	
		`and`	`and_then`	

some methods

		`T`	**`||/|T|`**
`O<T> -> T`	`unwrap`	`unwrap_or`	`unwrap_or_else`
`O<T> -> O<U>`	`map`	`map_or`	`map_or_else`
`O<T>, O<T> -> O<T>`		`or`	`or_else`
`O<T>, O<U> -> O<U>`		`and`	`and_then`

some methods

		T	**||/|T|**
O<T> -> T	unwrap	unwrap_or	unwrap_or_else
O<T> -> O<U>	map	map_or	map_or_else
O<T>, O<T> -> O<T>		or	or_else
O<T>, O<U> -> O<U>		and	and_then

https://doc.rust-lang.org

exercise

```
fn foo(input: Option<i32>) -> Option<i32> {
    if input.is_none() {
        return None;
    }

    let input = input.unwrap();
    if input < 0 {
        return None;
    }
    Some(input)
}

fn bar(input: Option<i32>) -> Result<i32, ErrNegative> {
    match foo(input) {
        Some(n) => Ok(n),
        None => Err(ErrNegative),
    }
}
```

https://doc.rust-lang.org

solution

```
fn foo(input: Option<i32>) -> Option<i32> {
    if input.is_none() {
        return None;
    }

    let input = input.unwrap();
    if input < 0 {
        return None;
    }
    Some(input)
}
```

solution

https://doc.rust-lang.org

```
fn foo(input: Option<i32>) -> Option<i32> {
    let input = input?;
    if input < 0 {
        return None;
    }
    Some(input)
}
```

solution

https://doc.rust-lang.org

```
fn foo(input: Option<i32>) -> Option<i32> {
    let input = input?;
    if input < 0 {
        return None;
    }
    Some(input)
}
```

https://doc.rust-lang.org

solution

```
fn foo(input: Option<i32>) -> Option<i32> {
    input.and_then(|i| {
        if i < 0 {
            None
        } else {
            Some(i)
        }
    })
}
```

https://doc.rust-lang.org

solution

```
fn foo(input: Option<i32>) -> Option<i32> {
    input.filter(|i| i >= 0)
}
```

solution

https://doc.rust-lang.org

```
fn bar(input: Option<i32>) -> Result<i32, ErrNegative> {
    match foo(input) {
        Some(n) => Ok(n),
        None => Err(ErrNegative),
    }
}
```

solution

https://doc.rust-lang.org

```
fn bar(input: Option<i32>) -> Result<i32, ErrNegative> {
    foo(input).ok_or(ErrNegative)
}
```

iterators

```
fn ping_all(foos: &[Foo]) {
    for f in foos {
        f.ping();
    }
}
```

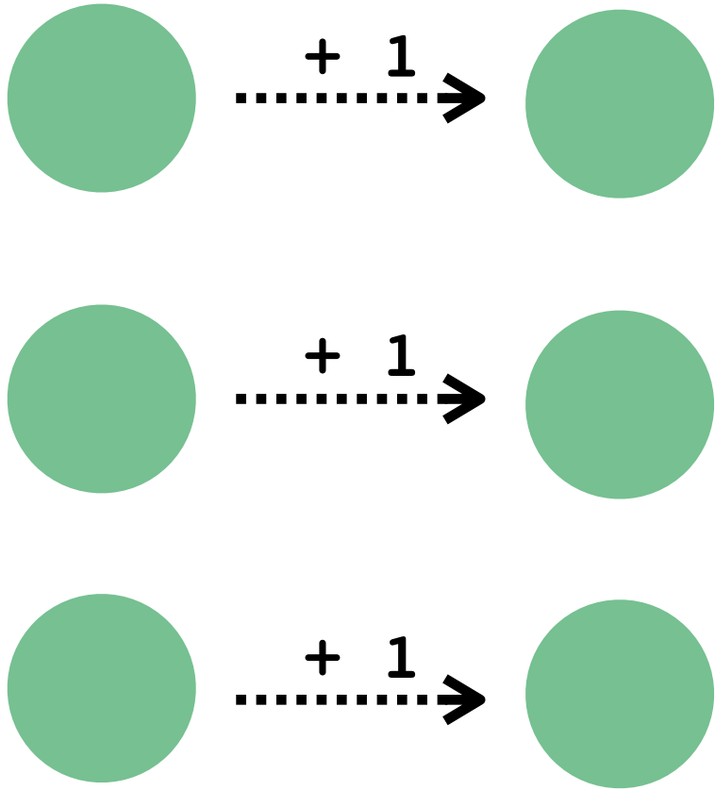
```
fn ping_all(foos: &[Foo]) {
    foos.iter().for_each(|f| f.ping());
}
```

map, filter, for_each

```
let vec = vec![…];
vec.iter()
    .map(|x| x + 1)
    .filter(|x| x > 1)
    .for_each(|x| println!("{}", x));
```

map, filter, for_each

```
let vec = vec![…];
vec.iter()
    .map(|x| x + 1)
    .filter(|x| x > 1)
    .for_each(|x| println!("{}", x));
```



map, filter, for_each

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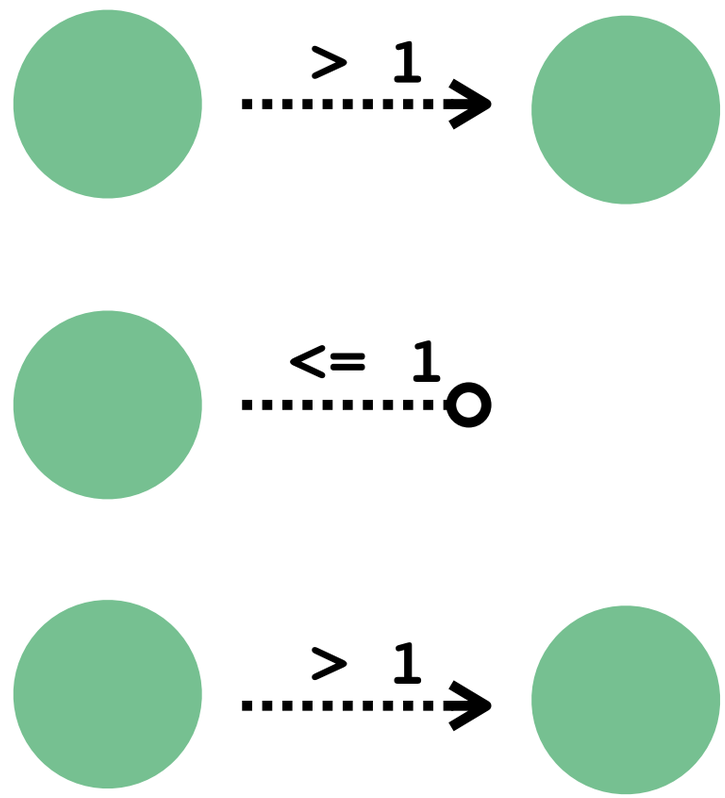

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let vec = vec![…];
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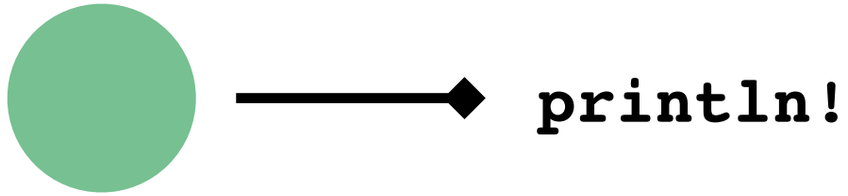

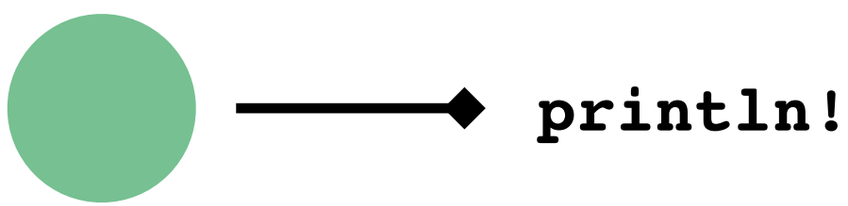

chain, enumerate

```
let vec = vec![…];
for (i, v) in vec.iter()
                 .chain(Some(42).iter())
                 .enumerate() {
    println!("{}: {}", i, v);
}
```

chain, enumerate

```
let vec = vec![…];
for (i, v) in vec.iter()
                 .chain(Some(42).iter())
                 .enumerate() {
    println!("{}: {}", i, v);
}
```

chain, enumerate

```
let vec = vec![…];
for (i, v) in vec.iter()
                 .chain(Some(42).iter())
                 .enumerate() {
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}
```
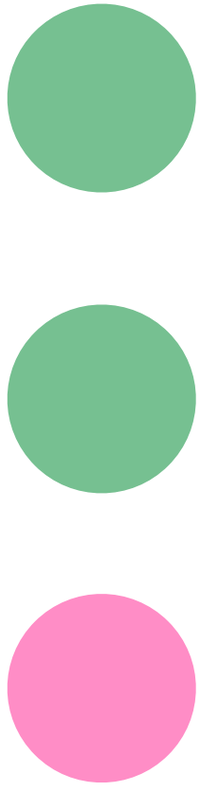
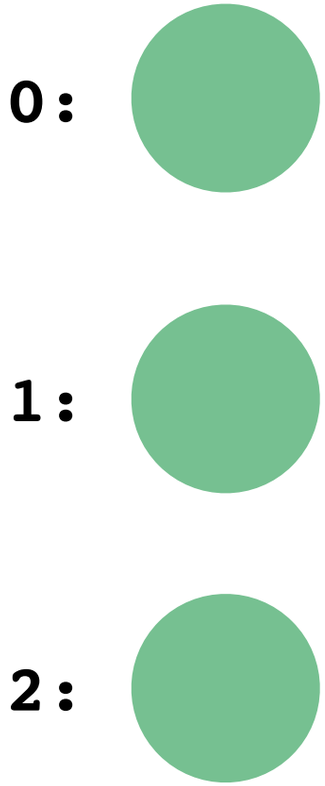



chain, enumerate

```
let vec = vec![…];
for (i, v) in vec.iter()
                 .chain(Some(42).iter())
                 .enumerate() {
    println!("{}: {}", i, v);
}
```



collect

```
let vec = vec![…];
let vec_2: Vec<_> = vec.iter().map(|x| x * 2).collect();
```

collect

```
let vec = vec![…];
let vec_2: Vec<_> = vec.iter().map(|x| x * 2).collect();
let map: HashMap<_, _> = vec.iter()
                            .map(|x| x * 2)
                            .enumerate
                            .collect();
```

```
let vec = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!("{}", v))

for v in &vec {
    println!("{}", v);
}
```

```
let vec: Vec<_> = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!("{}", v))

for v in &vec {
    println!("{}", v);
}
```

```
let vec: Vec<_> = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!(“{}”, v))

for v in &vec {
    println!(“{}”, v);
}
```

```
&Vec<T>: IntoIterator
```

```
let vec: Vec<_> = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!("{}", v))

for v in &vec {
    println!("{}", v);
}

&Vec<T>: IntoIterator
 Vec<T>: IntoIterator
```

```
let vec: Vec<_> = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!("{}", v))

for v in &vec {
    println!("{}", v);
}

&Vec<T>: IntoIterator

trait IntoIterator {
    fn into_iter() -> Iterator
}
```

```
let vec: Vec<_> = vec![0, 1, 2, 3];

vec.iter().for_each(|v| println!("{}", v))

for v in &vec {
    println!("{}", v);
}

&Vec<T>: IntoIterator

trait IntoIterator {
    fn into_iter() -> Iterator
}

trait Iterator {
    fn next() -> Option<Item>
}
```

```
let vec = vec![0, 1, 2, 3];


if let Some(v) = … {
    …
}
```

```
let vec = vec![0, 1, 2, 3];


while let Some(v) = … {
    …
}
```

```
let vec = vec![0, 1, 2, 3];

let mut iter = (&vec).into_iter();
while let Some(v) = iter.next() {
    println!("{}", v);
}
```

exercise

```
let vec = vec![0, 1, 2, 3];

let mut iter = (&vec).into_iter();
while let Some(v) = iter.next() {
    println!(“{}”, v);
}
```

loop {
    …
}

match
break

solution

```
let vec = vec![0, 1, 2, 3];

let mut iter = (&vec).into_iter();
while let Some(v) = iter.next() {
    println!(“{}”, v);
}
```

```
let mut iter = (&vec).into_iter();
loop {
    let v = match iter.next() {
        Some(v) => v,
        None => break,
    };
    println!(“{}”, v);
}
```

solution

```
let vec = vec![0, 1, 2, 3];

for v in &vec {
    println!(“{}”, v);
}

let mut iter = (&vec).into_iter();
while let Some(v) = iter.next() {
    println!(“{}”, v);
}

let mut iter = (&vec).into_iter();
loop {
    let v = match iter.next() {
        Some(v) => v,
        None => break,
    };
    println!(“{}”, v);
}
```

error handling

error handling is an architectural concern

Result

```
Result<T, E>
    Ok(…)
    Err(…)
```

Result

```
Result<T, E>
    Ok(…)
    Err(…)
```

```
fn foo(…) -> Result<i32, SomeErr>
```

what should I do with this `Err`?

what should I do with this `Err`?

Recover

Re-throw

Panic

what should I do with this `Err`?

Recover

what should I do with this `Err`?

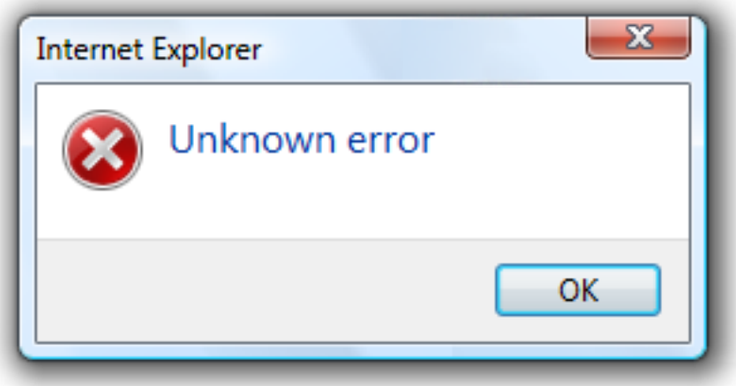
Recover

```
let n = match foo() {
    Ok(n) => n,
    Err(_) => 0,
};
```

what should I do with this `Err`?

Recover

```
let n = match foo() {
    Ok(n) => n,
    Err(_) => 0,
};

let n = foo().unwrap_or(0);
```


Internet Explorer
Unknown error
OK

what should I do with this `Err`?

Recover

Re-throw

what should I do with this `Err`?

Recover

Re-throw

```
let n = foo()?;
```

what should I do with this `Err`?

Recover

Re-throw

Panic

what should I do with this `Err`?

Recover

Re-throw

~~Panic~~ **expect**

```
let n = foo().expect(“Something unexpected happened”);
```

what should I do about errors?

Recover

Re-throw

} *Handle errors*

~~Panic~~ expect *Don't handle errors*

modularise your errors

Result - the error type

```
Result<T, E>
```

Result - the error type

Don’t use your own `Result` type

Result - the error type

Don’t use your own `Result` type

But:

```
type MyResult<T> = Result<T, MyErr>;
```

Result - the error type

```
()

1, 2, 3, …

String
```

Result - the error type

One error type or many?

Result - the error type

One error type or many?

```
pub enum MyError {
    Server(u8),
    User(String),
    Connection,
}
```

Result - the error type

One error type or many?

```
pub struct ServerError {
    code: u8,
    address: String,
}
```

```
pub enum ClientError {
    User(String),
    Connection,
    Unknown,
}
```

Failure

Failure

Handle multiple error types

Chain errors together

Backtraces

Interoperate with ecosystem

Failure

Handle multiple error types

Chain errors together

Backtraces

Interoperate with ecosystem

```
#[derive(Fail)]
pub enum MyError {
    Server(u8),
    User(String),
    Connection,
}
```

what should I do?

what should I do?

Library

App

what should I do?

Library

- Use your own error type
- Consider error boundaries
- Use Failure

App

what should I do?

Library

App

- Script
- Prototype
- Production

exercise

```
fn write_to_log() -> Result<(), DiskError> { ... }
fn open_port() -> Result<Port, NetworkError> { ... }

struct Server { ... }

impl Server {
    fn new() -> Server { ... }
}
```

exercise

```
fn read_config() -> ConfigFile {
    let file = { /* read file */ }.expect("could not open file");

    write_to_log().expect("could not write to log file");
    file
}

impl Server {
    fn startup(self) -> ListeningServer {
        let config = read_config();
        let port = open_port().expect("could not open port");
        self.configure(config, port)
    }
}

fn main() {
    let server = Server::new();
    let server = server.startup();
    while let Some(packet) = server.listen() {
        ...
    }
}
```

solution

```
enum ServerError {
    DiskError(DiskError),
    NetError(NetworkError),
}

impl From<DiskError> for ServerError {
    fn from(e: DiskError) -> ServerError {
        ServerError::DiskError(e)
    }
}

impl From<NetworkError> for ServerError {
    fn from(e: NetworkError) -> ServerError {
        ServerError::NetError(e)
    }
}
```

solution

```
fn read_config() -> Result<ConfigFile, DiskError> {
    let file = { /* read file */ }?;

    write_to_log()?;
    file
}
```

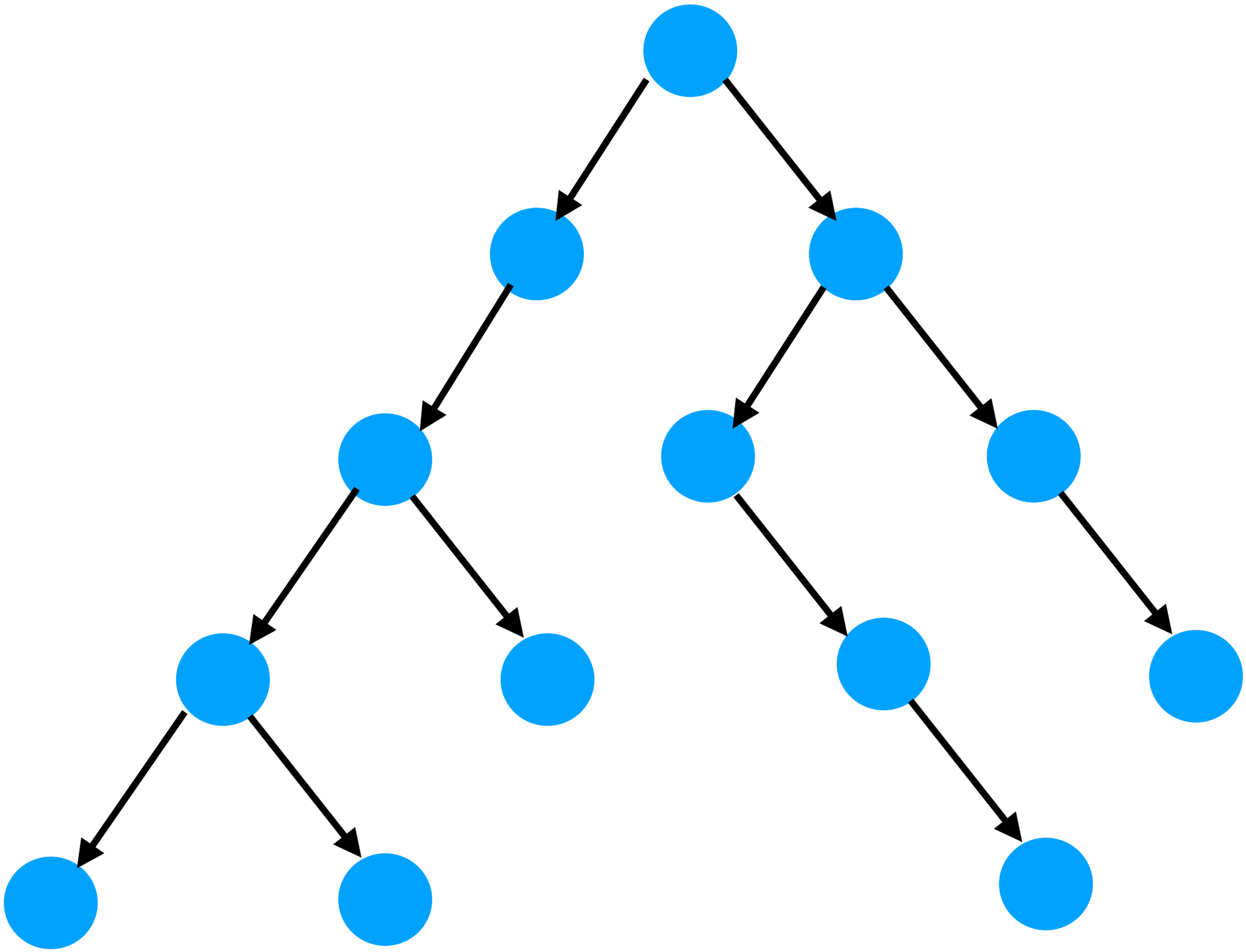
solution

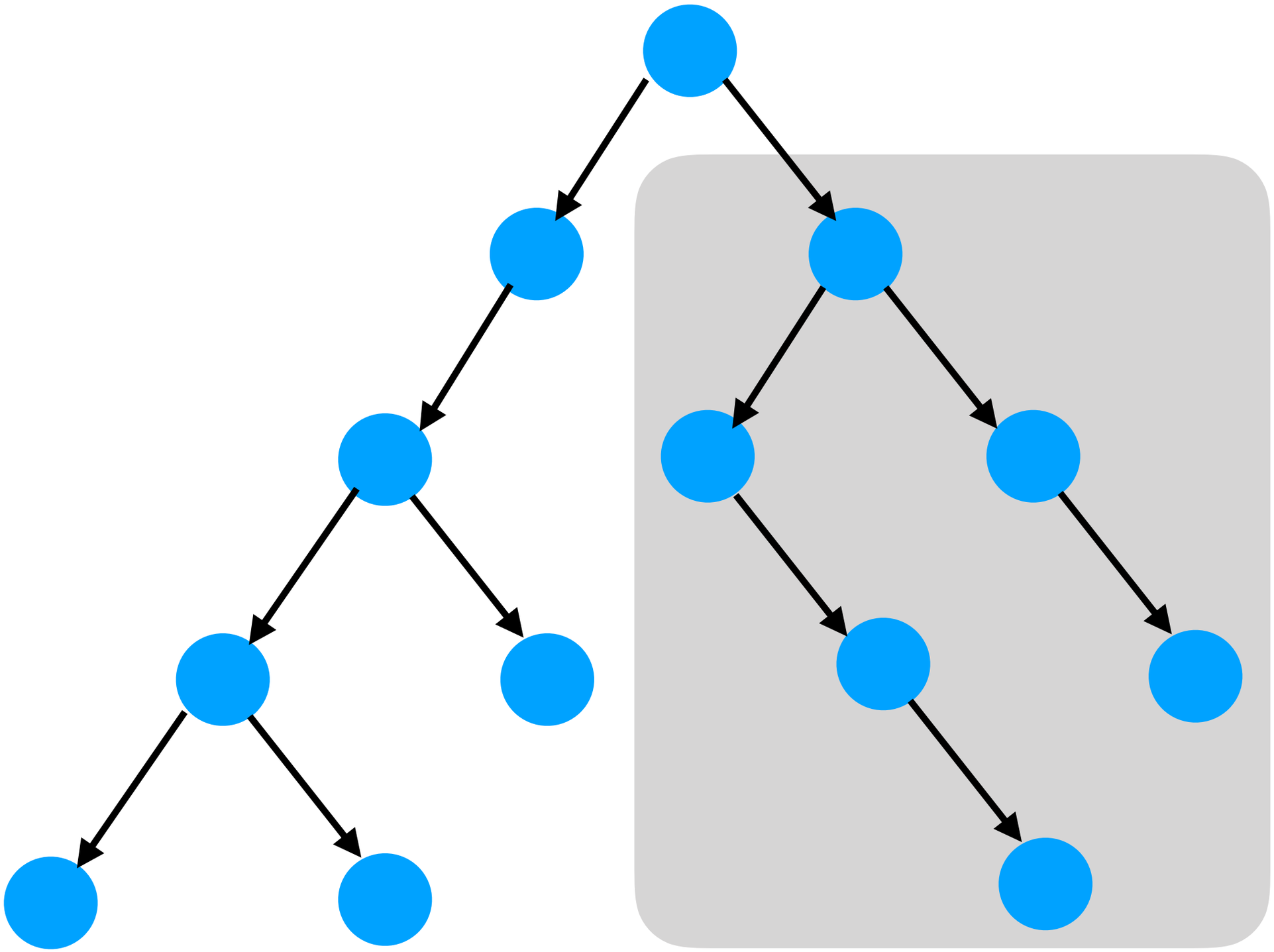
```
impl Server {
    fn startup(self) -> Result<ListeningServer, ServerError> {
        let config = read_config()?;
        let port = open_port()?;
        Ok(self.configure(config, port))
    }
}
```

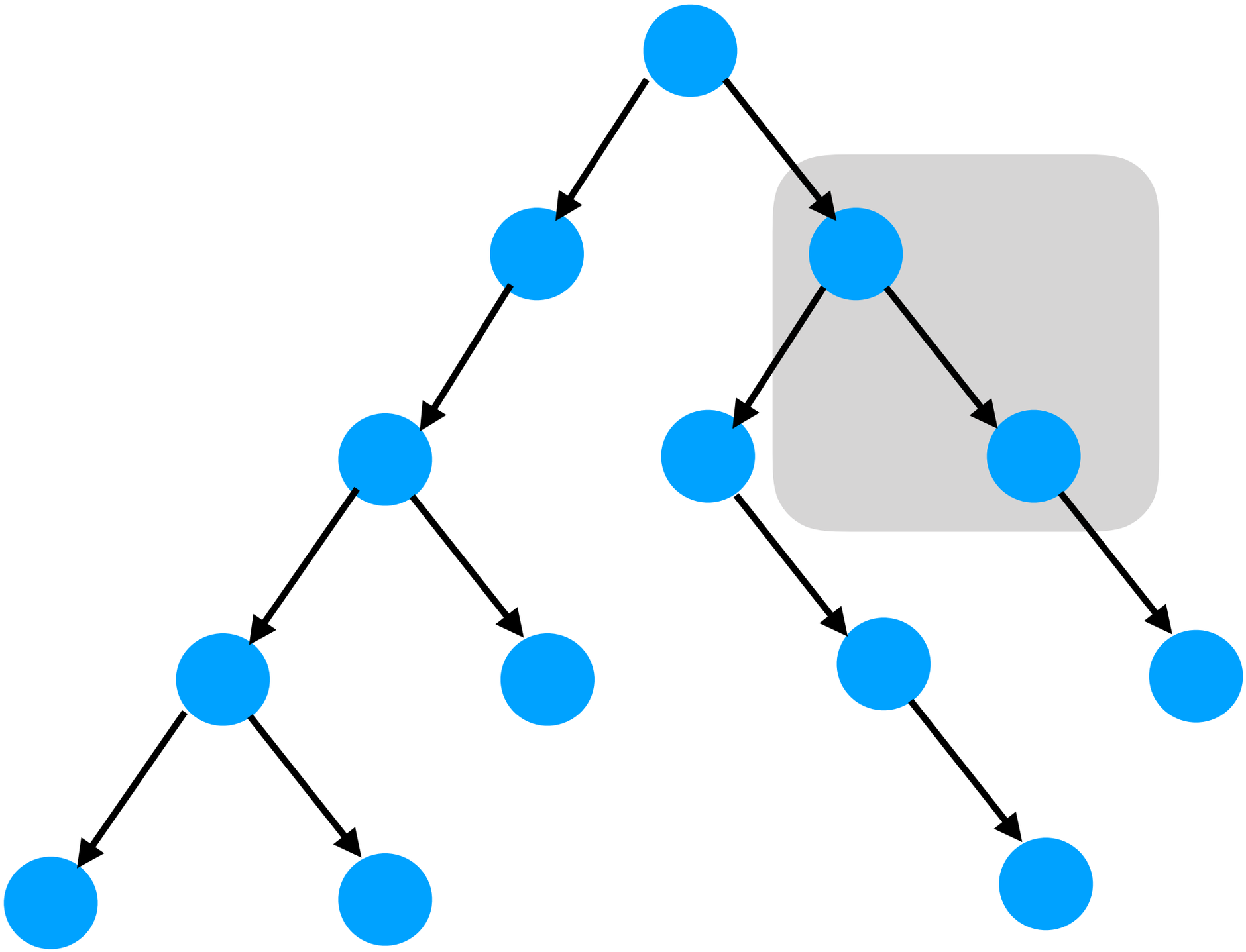
solution

```
fn main() {
    let server = Server::new();
    let server = match server.startup() {
        Ok(server) => server,
        Err(e) => {
            // Bad!
            eprintln!("...", e);
            exit(1);
        }
    };
    while let packet = server.listen() {
        ...
    }
}
```

ownership and design







functions

```
fn dispose(c: Chunk) { … }
```

functions

```
fn dispose(c: Chunk) { … }

fn lock(c: Chunk) -> LockedChunk { … }
```

functions

```
fn dispose(c: Chunk) { … }

fn lock(c: Chunk) -> LockedChunk { … }

fn count_bytes(s: &Chunk) -> usize { … }
```

functions

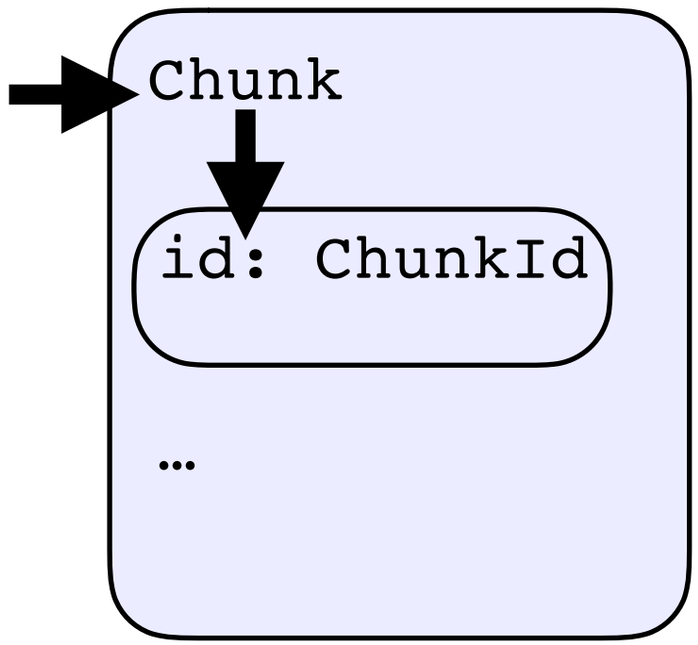
```
fn dispose(c: Chunk) { … }

fn lock(c: Chunk) -> LockedChunk { … }

fn count_bytes(s: &Chunk) -> usize { … }

fn clone(c: &Chunk) -> Chunk { … }
```

functions

```
fn dispose(c: Chunk) { … }

fn lock(c: Chunk) -> LockedChunk { … }

fn count_bytes(s: &Chunk) -> usize { … }

fn clone(c: &Chunk) -> Chunk { … }

fn get_id(c: &Chunk) -> &ChunkId { … }
```

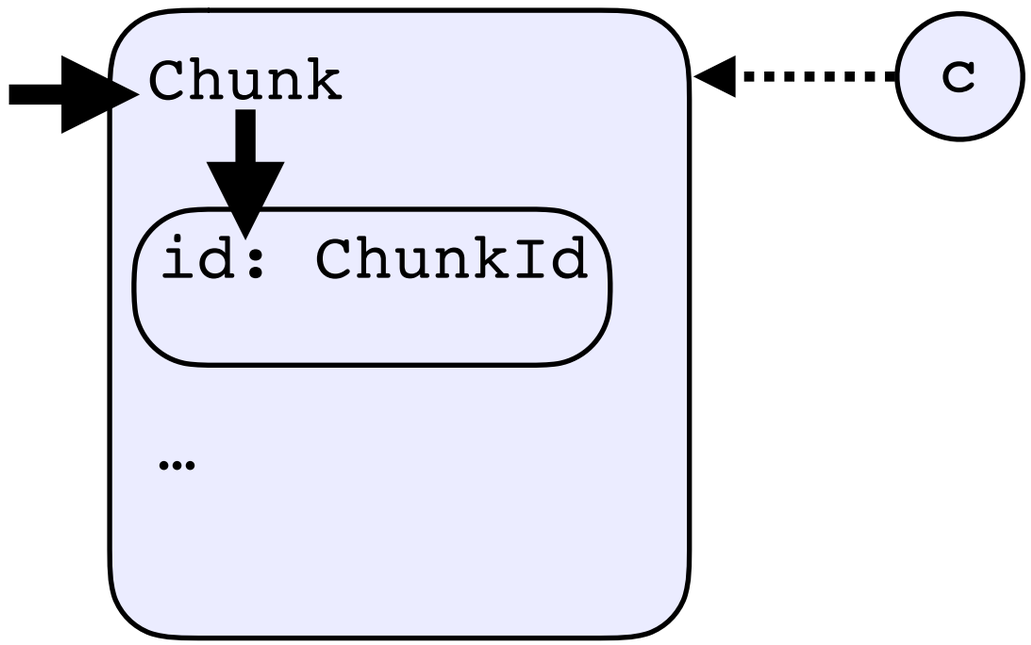
functions

```
fn get_id(c: &Chunk) -> &ChunkId { … }
```



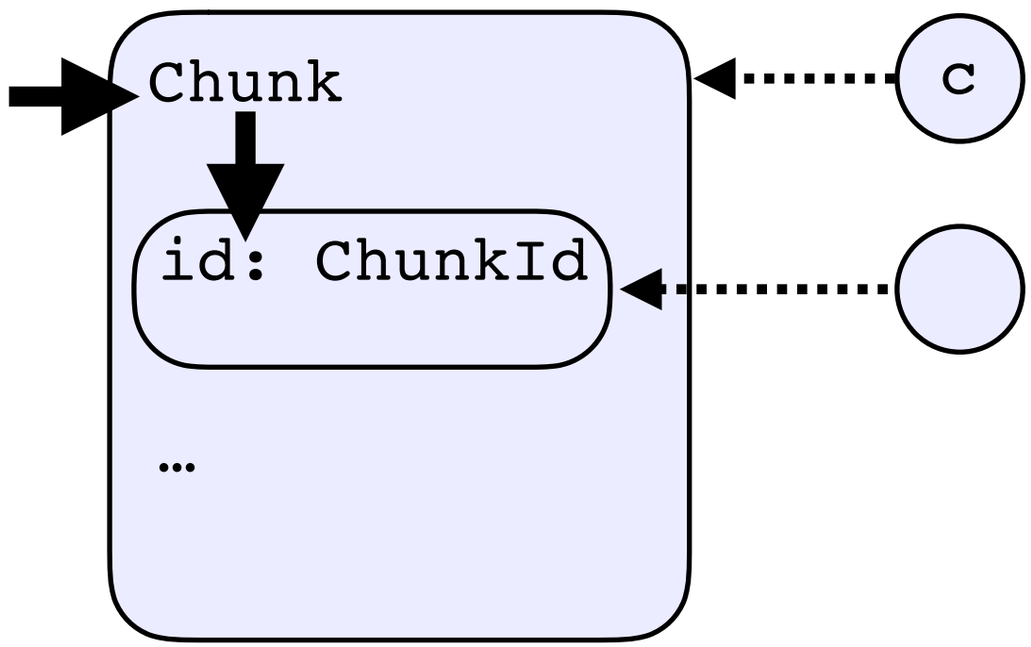
functions

```
fn get_id(c: &Chunk) -> &ChunkId { … }
```



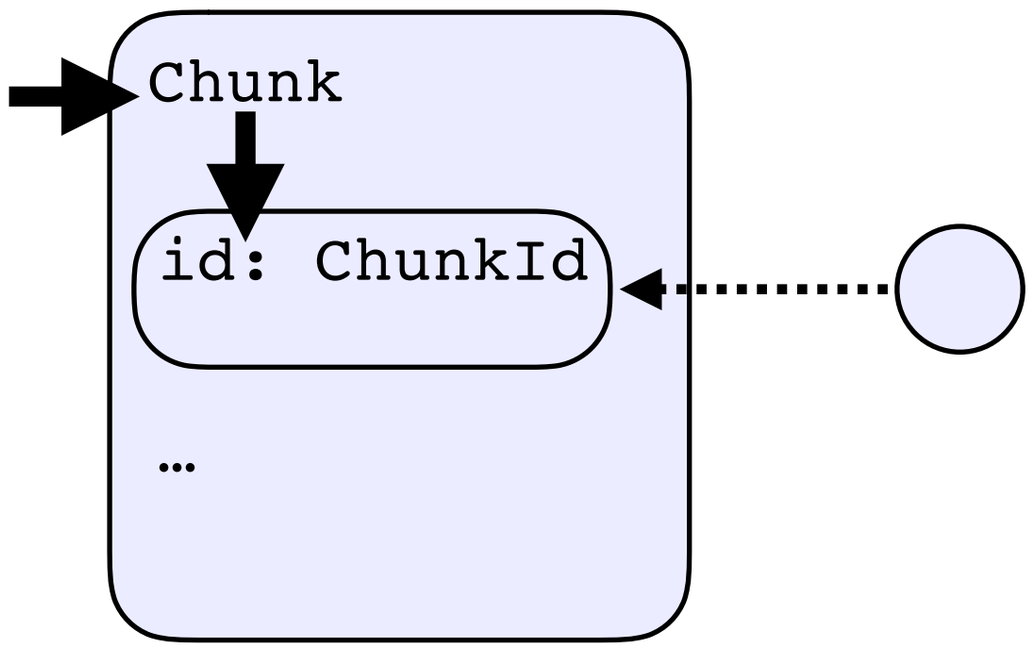
functions

```
fn get_id(c: &Chunk) -> &ChunkId { … }
```

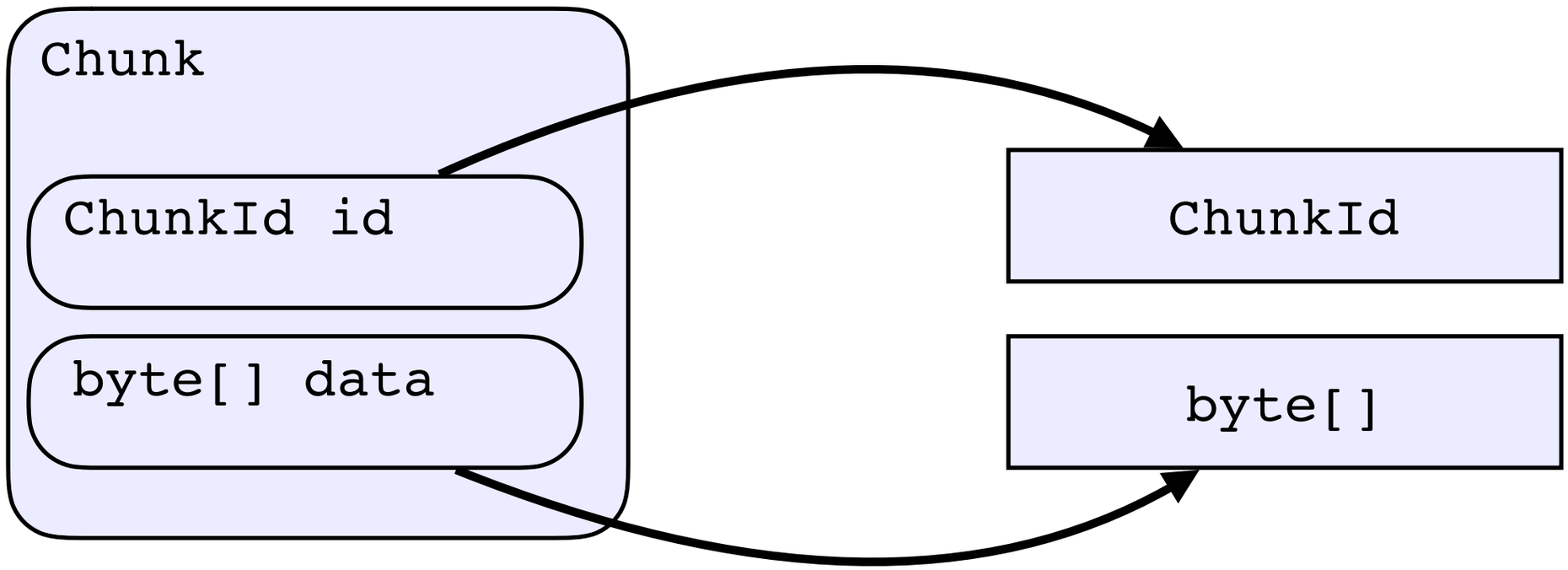


functions

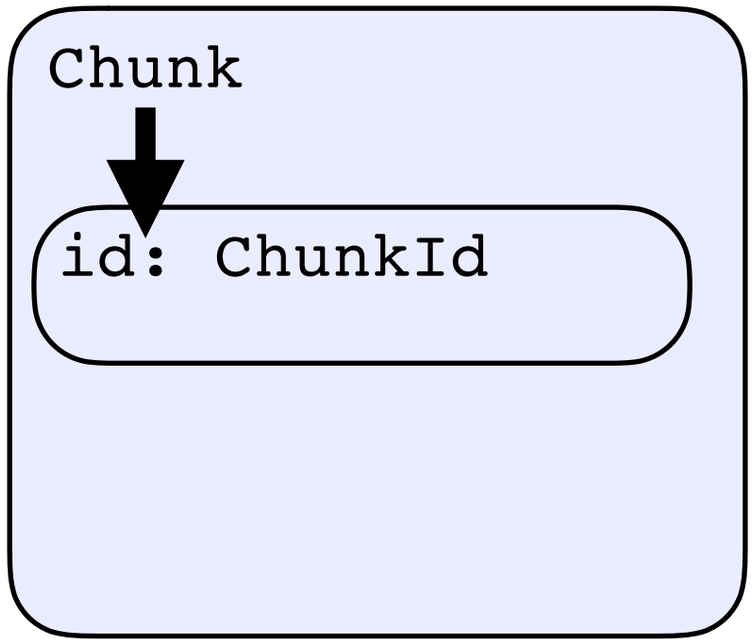
```
fn get_id(c: &Chunk) -> &ChunkId { … }
```



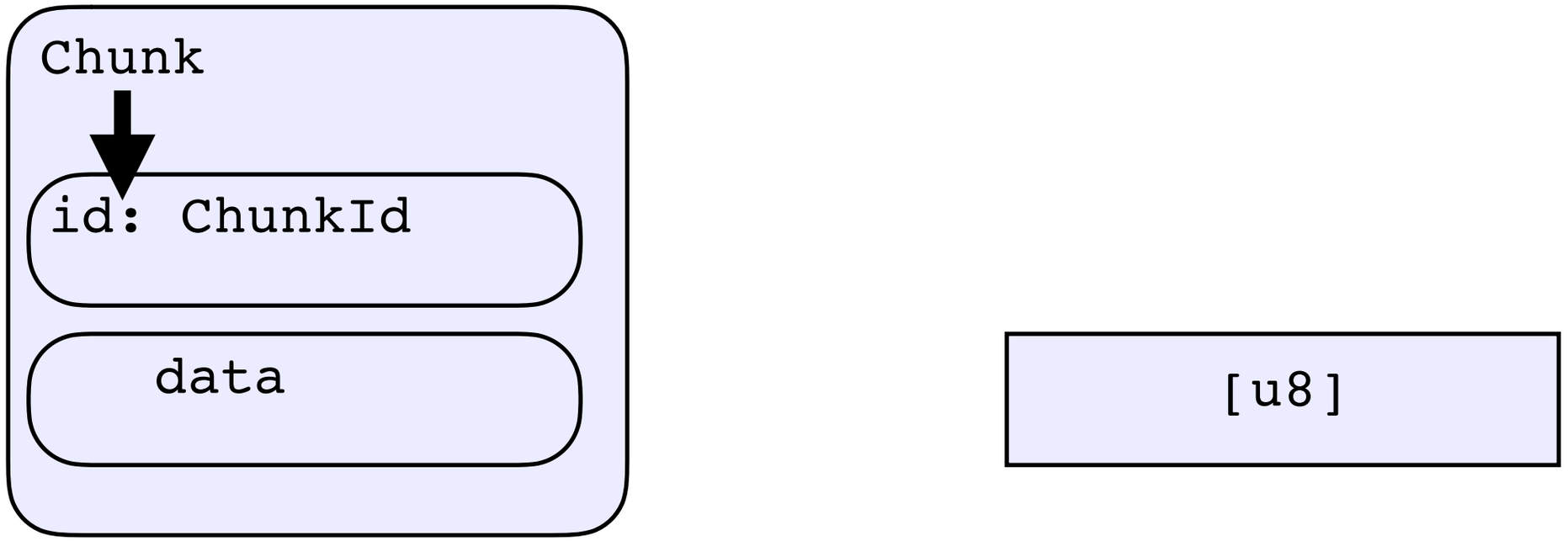
data



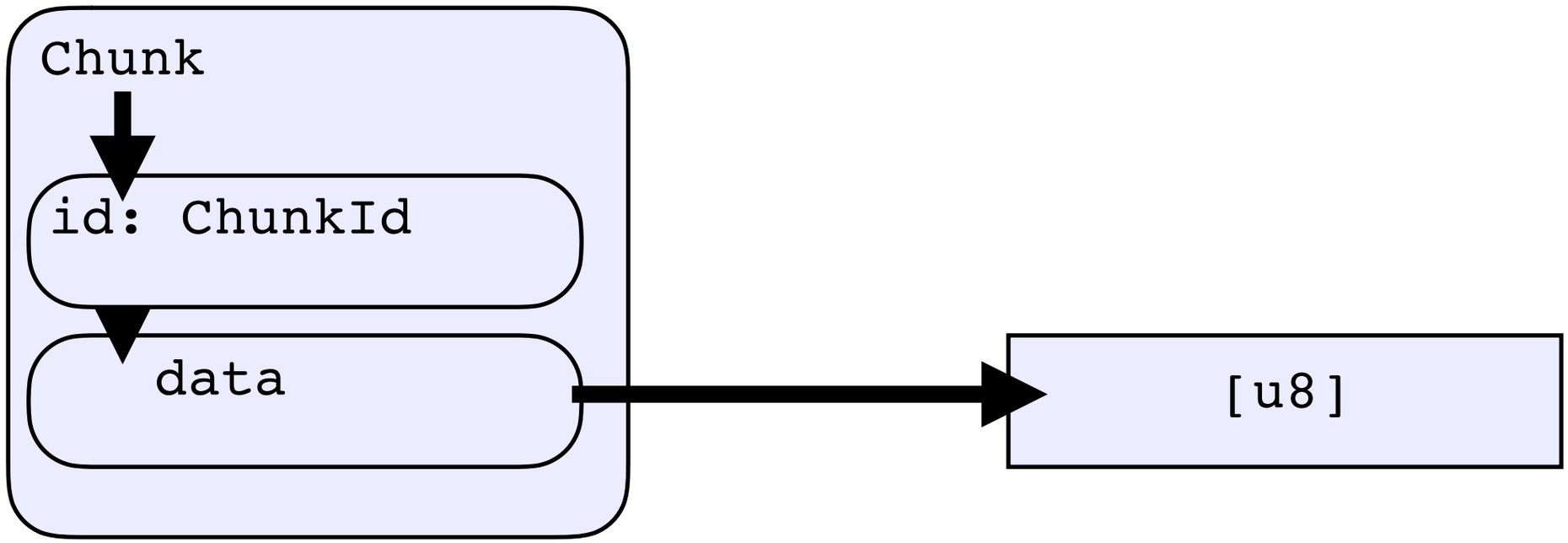
data



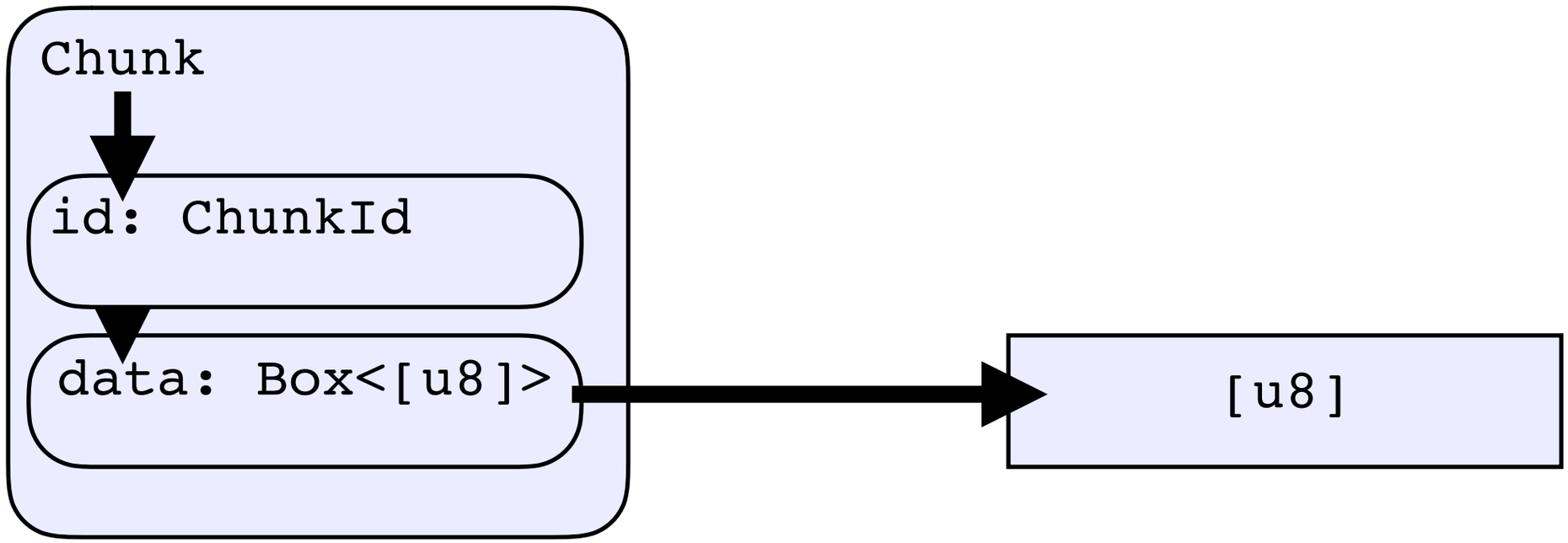
data



data



data



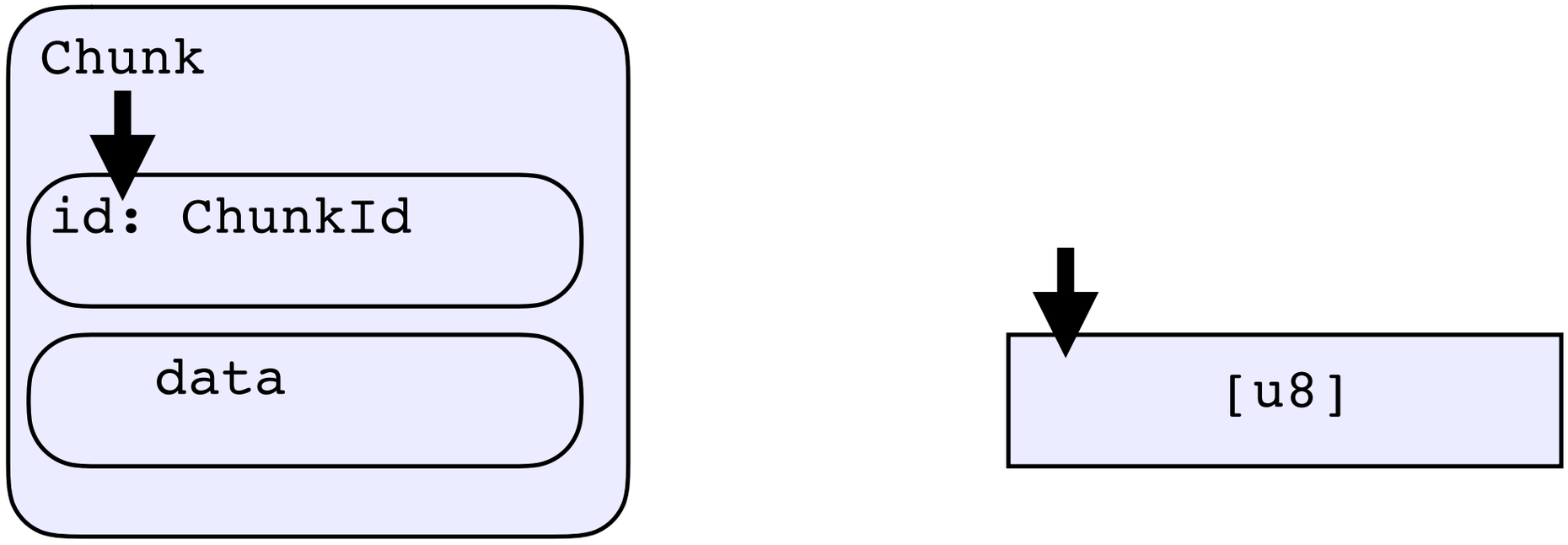
data

```
struct Chunk {
    id: ChunkId,
    data: Box<[u8]>,
}
```

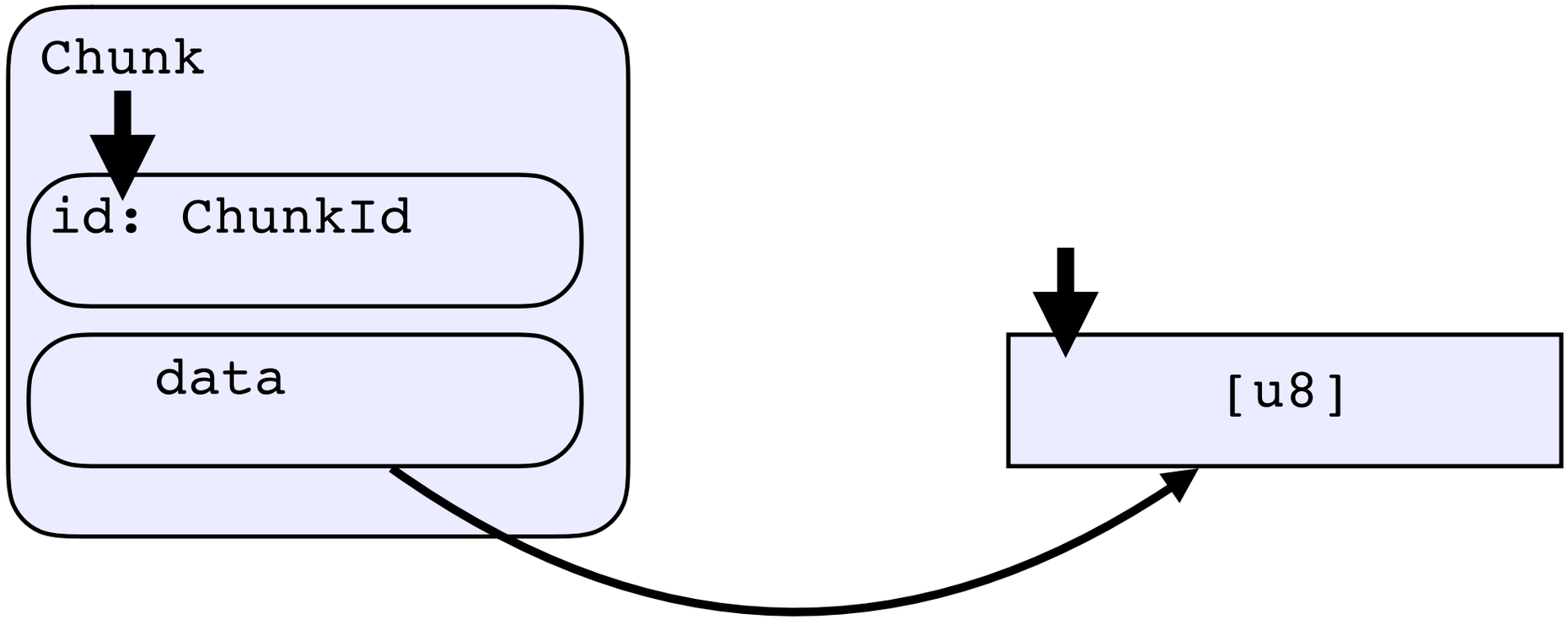
data

```
struct Chunk {
    id: ChunkId,
    data: Rc<[u8]>,
}
```

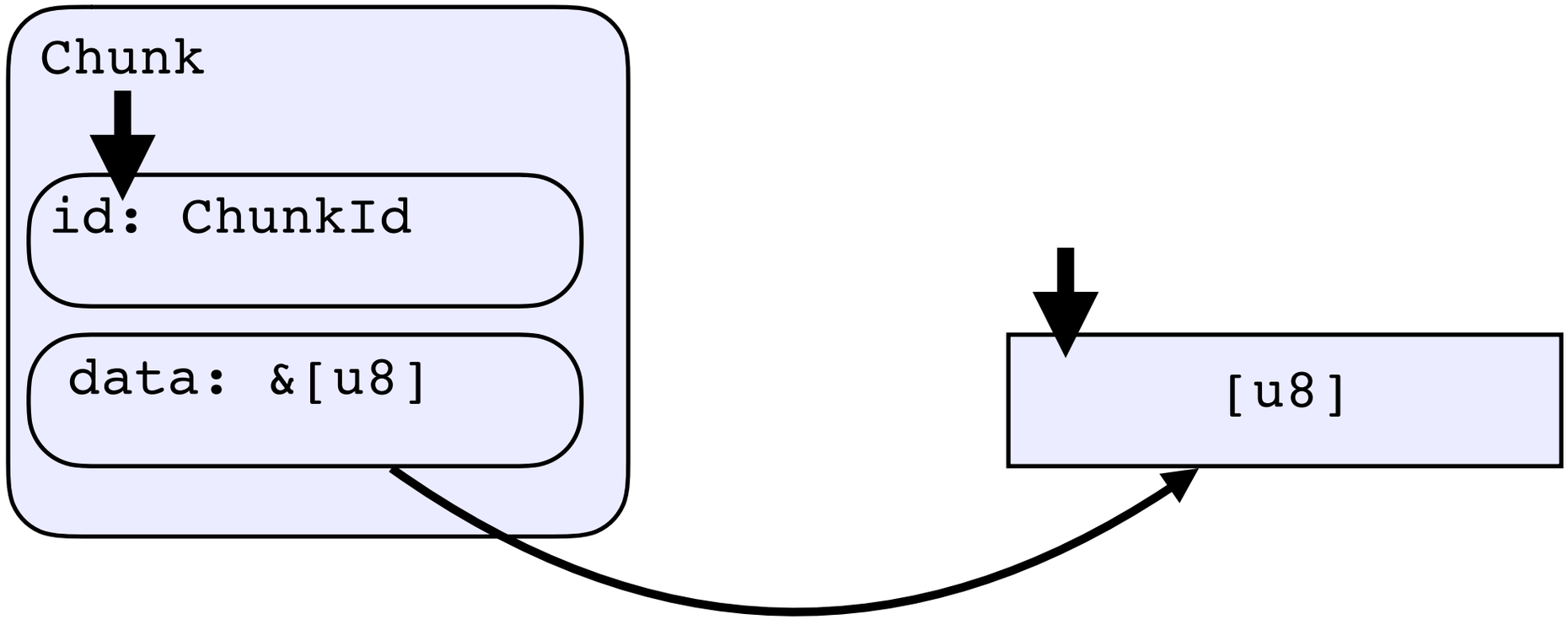
data



data



data



data

```
struct Chunk<'a> {
    id: ChunkId,
    data: &'a [u8],
}
```

example

```
class AsciiString {
    byte[] chars;
    int length;

    void append(AsciiSlice str) { ... }
    AsciiSlice slice(int start, int length) { ... }
}

class AsciiSlice {
    byte[] chars;
    int start;
    int length;
}
```

example

```
struct AsciiString {
    chars:              ,
    length: usize,
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}

struct AsciiSlice          {
    string:                      ,
    start: usize,
    length: usize,
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}

struct AsciiSlice<'str> {
    string: &'str AsciiString,
    start: usize,
    length: usize,
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}

struct AsciiSlice<'str> {
    string: &'str AsciiString,
    start: usize,
    length: usize,
}

impl AsciiString {
    fn append(&mut self, other: &AsciiSlice<‘o>)
    { ... }
    fn slice(&’s self, st: usize, len: usize)
        -> AsciiSlice<‘s>
    { ... }
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}
#[derive(Clone, Copy)]
struct AsciiSlice<'str> {
    string: &'str AsciiString,
    start: usize,
    length: usize,
}

impl AsciiString {
    fn append(&mut self, other: AsciiSlice<‘o>)
    { ... }
    fn slice(&'s self, st: usize, len: usize)
        -> AsciiSlice<‘s>
    { ... }
}
```

example

```
struct AsciiString {
    chars: Box<[u8]>,
    length: usize,
}

struct AsciiSlice<'str> {
    string: &'str AsciiString,
    start: usize,
    length: usize,
}

struct AsciiSlice<'str> {
    slice: *const u8,
    length: usize,
    _pd: PhantomData<&'str u8>,
}
```

exercise

```
struct SlabAllocator {
    unsigned char* data_start;
    int data_len;
    unsigned char* next;
}

*unsigned char allocate(SlabAllocator* slab, int bytes)
{ ... }

void deallocate(SlabAllocator* slab,
                unsigned char* data,
                int len)
{ ... }

void destroy(SlabAllocator* slab) { ... }
```

exercise

```
int main(int argc, char* argv[]) {
    SlabAllocator alloc = { ... };
    *unsigned char buf = allocate(&alloc, 64);
    // ...
    deallocate(&alloc, buf, 64);
    destroy(&alloc);
    return 0;
}
```

solution

```
struct SlabAllocator {
    data: Vec<u8>,
    next: usize,
}
```

```
#[derive(Clone)]
struct Allocation<'slab, T> {
    data: &'slab T,
    index: usize,
    slab: &'slab SlabAllocator,
}
```

solution

```
impl<‘slab, T> Deref for Allocation<‘slab, T> {
    type Target = T;
    fn deref(&self) -> &T {
        self.data
    }
}
```

```
impl<‘slab, T> Drop for Allocation<‘slab, T> {
    fn drop(&mut self) {
        self.slab.free(self.index, size_of::<T>())
    }
}
```

```
impl SlabAllocator {
    fn new() -> SlabAllocator { … }

    fn allocate<T>(&'a mut self)
        -> Allocation<‘a, T>
    {
        let start = self.next;
        self.next += size_of::<T>();
        assert!(self.next < self.data.len());
        let data = unsafe {
            transmute::<_, &T>(&self.data[start])
        };
        Allocation {
            data,
            index: start,
            slab: self,
        }
    }

    fn free(&self, index: usize, size: usize) { … }
}
```

solution

```
fn main() {
    let mut slab = SlabAllocator::new();
    let foo = slab.allocate::<Foo>();

    // …

    // foo goes out of scope
    // slab goes out of scope
}
```

abstraction with traits

classes are highly structured

traits are a soup of abstraction

```
impl MyTrait for Foo { … }
```

```
impl MyTrait for String { … }
```

```
impl Write for Vec<u8> { … }
```

```
impl<T: Hash> Hash for Vec<T> { … }
```

```
impl<T: From<U>, U> TryFrom<U> for T { … }
```

```
trait Copy: Clone { … }
```

use more traits!

use more traits!

testing

use more traits!

testing

extensibility

use more traits!

testing

extensibility

cleaner design

better traits

better traits

small

better traits

small

independent

better traits

small

independent

cohesive

using traits

```
impl Foo { … }
```

```
impl Bar for Foo { … }
```

using traits

```
fn qux(f: Foo) { … }
```

using traits

```
fn qux(f: Foo) { … }
```

```
fn qux(f: &dyn Bar) { … }
```

using traits

```
fn qux(f: Foo) { … }
```

```
fn qux(f: &dyn Bar) { … }
fn qux<T: Bar>(f: T) { … }
```

using traits

```
fn qux(f: Foo) { … }
```

```
fn qux(f: &dyn Bar) { … }
fn qux(f: impl Bar) { … }
```

learn more about traits

exercise

solution

https://github.com/nrc/graphql/blob/0a577fc765d450b5ddf8a82f5dfa401e8c320392/graphql/src/parser/parse_base.rs

```
trait Tokens<'a> {
    fn next_tok(&mut self) -> QlResult<&'a Token<'a>>;
    fn peek_tok(&mut self) -> Option<&'a Token<'a>>;

    // Default method impls...
}
```

solution

https://github.com/nrc/cargo-src/blob/master/src/file_controller/mod.rs

```
trait FileSystem {
    fn load_file(…);
    fn load_lines(…);
}

trait Cache { … }
```

make the compiler

more pedantic

Phantom types

Wrapper types

Marker traits

Unsafe traits

Different types for different states

example

```
fn cursor_at(row: u32, col: u32)
```

wrapper types

```
struct Row(u32);
struct Column(u32);
```

wrapper types

```
fn cursor_at(row: u32, col: u32)
```

```
fn cursor_at(row: Row, col: Column)
```

phantom types

```
pub struct Column<I: Indexed>(u32, PhantomData<I>);
```

phantom types

```
pub struct Column<I: Indexed>(u32, PhantomData<I>);

pub trait Indexed {}
```

phantom types

```
pub struct Column<I: Indexed>(u32, PhantomData<I>);

pub trait Indexed {}

pub struct ZeroIndexed;
impl Indexed for ZeroIndexed {}

pub struct OneIndexed;
impl Indexed for OneIndexed {}
```

phantom types

```
fn cursor_at(row: u32, col: u32)
```

```
fn cursor_at(row: Row, col: Column)
```

```
fn cursor_at(row: Row<ZeroIndexed>, col: Column<ZeroIndexed>)
```

the end

summary

summary

ownership

summary

ownership

`Option`, `Result`, `Iterator`

summary

ownership

`Option`, `Result`, `Iterator`

so many methods

summary

ownership

`Option`, `Result`, `Iterator`

so many methods

error handling

summary

ownership

`Option`, `Result`, `Iterator`

so many methods

error handling

modularise your errors

summary

ownership

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make the compiler do more work for you

Thank you!

nrc

@nick_r_cameron

nrc@mozilla.com

https://github.com/nrc/talks