Advanced Rust

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Themes of the day

1. Lifetimes across functions
2. Lifetimes are part of types
3. Successful borrowing
4. Lifetimes in structs
5. Mutability
6. Open questions

Lifetimes across functions

```rust
pub struct Map<K: Eq, V> {
  elements: Vec<(K, V)>
}

impl<K: Eq, V> Map<K, V> {
  pub fn new() -> Self {
    Map { elements: vec![] }
  }

  pub fn insert(&mut self, key: K, value: V) {
    self.elements.push((key, value));
  }

  pub fn get(&self, key: &K) -> Option<&V> {
    self.elements.iter().rev().find(|pair| pair.0 == *key)
                          .map(|pair| &pair.1)

  }
}
```

Indicates that method will **mutate** the map.

Returns a **reference** to data owned by **self**

```rust
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

reference still valid when map dropped

map dropped here

```
error: `map` does not live long enough
24 |         p = map.get(&'a');
   |             ^^^ does not live long enough
25 |     }
   |     - borrowed value only valid until here
26 |     println!("key for 'a' is {:?}", p);
27 | }
   | - borrowed value must be valid until here
```

https://is.gd/tvOrjf

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

'l

's

Lifetime ('l): span of code where reference is in scope.

must be less than

Scope ('s) of data being borrowed (here, `map`)

How do we **know** that map is borrowed while p is in scope?

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

Take references to
data owned by caller

Returns a reference…
but **to what**?

```
pub fn get(&self, key: &K) -> Option<&V>
```

```
pub fn get<'a>(&'a self, key: &K) -> Option<&'a V>
```

Returns a reference **borrowed from** `self`

Implies:

- as long as the return value is in use,
- `self` is still borrowed.

Lifetime Elision

In the **return type of a function**:

- one argument of reference type? ➡ borrowed from that argument.
- `&self` or `&mut` self method? ➡ borrowed from self.
- otherwise? ➡ error.

```
fn foo(count: usize, data: &[u32]) -> &u32
```

```
    fn foo<'a>(count: usize, data: &'a [u32]) -> &'a u32
```

```
fn bar(&self, count: usize, data: &[u32]) -> &u32
```

```
    fn bar<'a>(&'a self, count: usize, data: &[u32]) -> &'a u32
```

```
fn baz(count: usize, data: &[u32], more: &[u32]) -> &u32
```

```
    error: missing lifetime specifier
```

(play)

```rust
impl<K, V> Map<K, V> {

  pub fn get_or(&self, key: &K, value: &V) -> &V {
    match self.get(key) {
      Some(from_map) => from_map,
      None => value,
    }
  }

}
```

```
error[E0495]: cannot infer an appropriate lifetime
   |
19 |         match self.get(key) {
   |         ^
```

https://is.gd/42ZEWL

```rust
pub fn get_or(&self, key: &K, value: &V) -> &V
```

```rust
pub fn get_or<'a>(&'a self, key: &K, value: &V) -> &'a V {
    match self.get(key) {
      Some(from_map) => from_map, ✅
      None => value, 🚫
    }
}
```

Signature declares that it returns a reference **borrowed from** `self`

But does it?

```
impl<K, V> Map<K, V> {

  pub fn get_or<'a>(&'a self, key: &K, value: &'a V) -> &'a V {
    self.get(key).unwrap_or(value)
  }

}
```

Returns a reference borrowed **either** from `self` **or** from `value`

Implies:

- as long as the return value is in use,
- `self` **and** `value` are still borrowed.

https://is.gd/I2yBr4

```
fn main() {
    let mut map = Map::new();
    map.insert('a', format!("alpha"));
    let v = format!(“fallback”);
    let p = map.get_or('a', &v);
    …
}
```

https://is.gd/qI7c5i

```
fn main() {
    let mut map = Map::new();
    map.insert('a', format!("alpha"));
    let p;
    let v = format!("fallback");
    p = map.get_or('a', &v);
    …
}
```

'l

's

```
error: `v` does not live long enough
30 |     p = map.get_or(&'a', &v);
   |                           ^ does not live long enough
31 |     println!("p={:?}", p);
32 | }
   | - borrowed value dropped before borrower
```

https://is.gd/WfIgHv

Key concept: **Modularity**

```
impl<K, V> Map<K, V> {
  pub fn get_or<'a>(&'a self, key: &K, value: &V) -> &'a V {
    panic!(“signature writing cheques body can't cash”) 😿
  }
}

fn main() {
    let mut map = Map::new();
    map.insert('a', format!(“alpha"));
    let p;
    let v = format!(“fallback”);
    p = map.get_or('a', &v);
    …
}
```

💯

Exercise: **named lifetimes**

http://rust-tutorials.com/exercises/

Cheat sheet:

```
fn foo<'a>(…)  // declare a named lifetime parameter
&'a i32        // reference with lifetime 'a
```

http://doc.rust-lang.org/std

Lifetimes are part of types

```rust
pub fn get(&self, key: &K) -> Option<&V>
```

```rust
pub fn get<'a>(&'a self, key: &K) -> Option<&'a V>
```

```rust
pub fn get<'a,'b>(&'a self, key: &'b K) -> Option<&'a V>
```

Every reference type `&T` is short for `&'lt T` for some lifetime.

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

reference still valid when map dropped

map dropped

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

What is lifetime of this type?

Expression has type `&char`. What lifetime?

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        Map::insert(&mut map, 'a', format!(“alpha"));
        p = Map::get(&map, &'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

Method calls are actually “syntactic sugar” for **function calls**.

Every method can be named via a **fully qualified path**.

The `.` operator also adds **implicit borrows**.

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        Map::insert(&mut map, 'a', format!(“alpha"));
        p = Map::get(&map, &'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

All of these lifetimes must be inferred.

http://www.rockyhorror.com/participation/timewarp.php

$$X + Y = 22$$
$$X - Y = 10$$

$$X = 16$$
$$Y = 6$$

$$X \geq Y$$
$$Y \geq 10$$

$$X = 10$$
$$Y = 10$$

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        Map::insert(&mut map, 'a', format!(“alpha"));
        p = Map::get(&map, &'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

1. Assign each lifetime a variable.
2. Determine **constraints** on those variables.
3. **Solve** the constraints — or try, at least.

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!(“alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

{call to Map::insert}

{use of format!}

{scope of `p`}

1. Assign each lifetime a variable.

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!(“alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

Type of variable must outlive its scope:

```
Option<&'W String>: {scope of `p`}
&'W String: {scope of `p`}
'W: {scope of `p`}
```

2. Determine **constraints** on those variables.

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!("alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

Types of arguments must outlive a call:

```
&'X mut Map<char, String>: {call of Map::insert}
'X: {call of Map::insert}
…
'Y: {call of Map::get}
…
```

2. Determine **constraints** on those variables.

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!(“alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

Linking of lifetime from argument to return value:

'Y: 'W

2. Determine **constraints** on those variables.

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!("alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

```
'W: {scope of `p`}
'X: {call of Map::insert}
'Y: 'W
'Z: {call of Map::get}
…
```

```
'W = {scope of `p`}
'X = {call of Map::insert}
'Y = {scope of `p`}
'Z = {call of Map::get}
```

3. **Solve** the constraints — or try, at least.

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        Map::insert(&mut map, 'a', format!("alpha"));
        p = Map::get(&{scope of `p`} map, &'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

{scope of `map`}

{scope of `p`}

'Y = {scope of `p`}

```
fn main() {
    let p: Option<&'W String>;
    {
        let mut map = Map::new();
        Map::insert(&'X mut map, 'a', format!(“alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

Linking of lifetime from argument to return value:

```
'Y: 'W
```

How did we come by this again?

2. Determine **constraints** on those variables.

```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        Map::insert(&mut map, 'a', format!("alpha"));
        p = Map::get(&'Y map, &'Z 'a');
    }
    println!("key for 'a' is {:?}", p);
}
```

```
impl<K,V> Map {
  pub fn get<'a,'b>(&'a self, key: &'b K) -> Option<&'a V>
}
```

```
p = Map::<char, String>::get::<'U, 'V>(&'Y map, &'a');
```

```
p = Map::<char, String>::get::<'U, 'V>(&'Y map, &'a');
```

Expected type of this argument: `&'U Map<char, String>`

Actual type of this argument: `&'Y Map<char, String>`

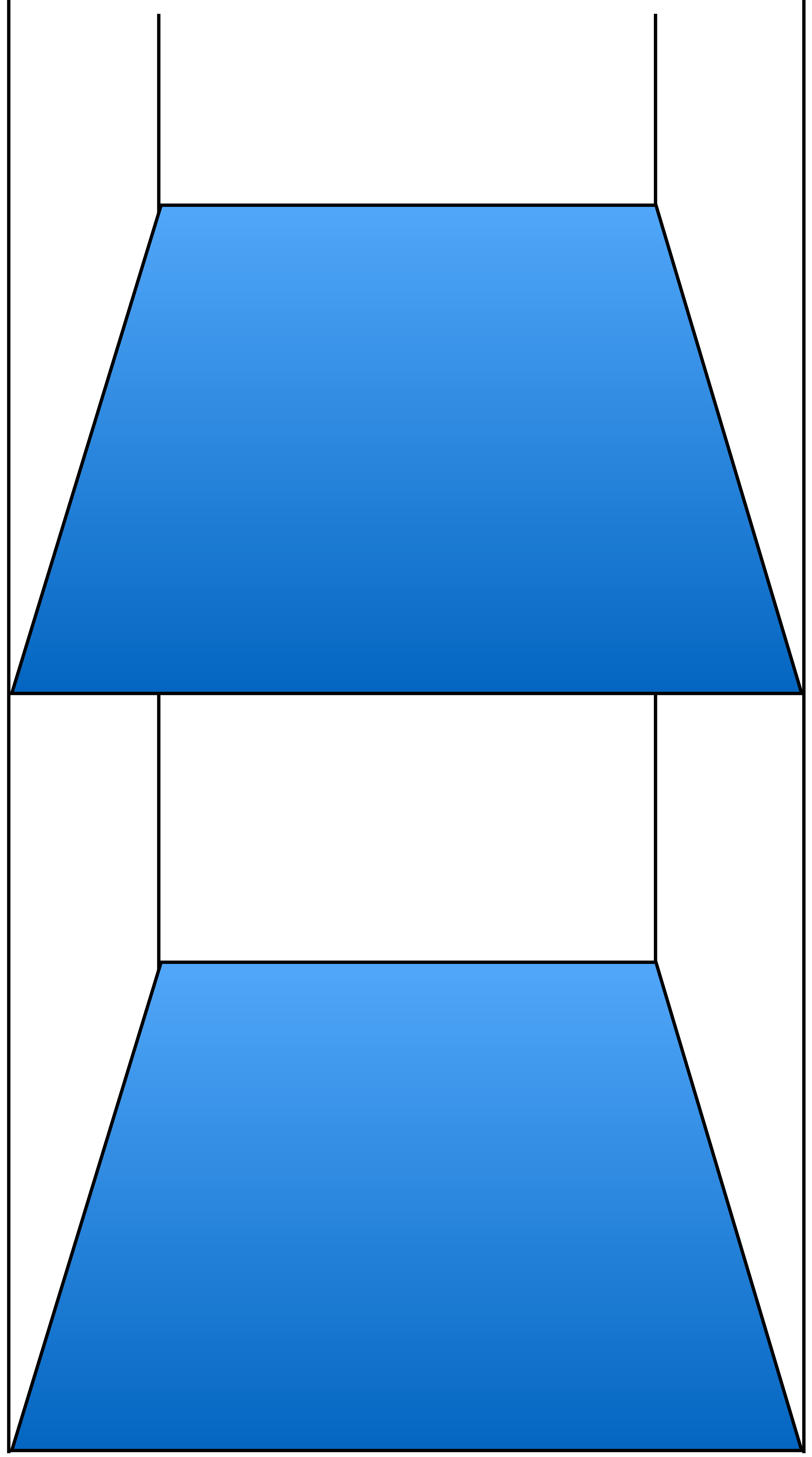
Resulting constraint: `'Y: 'U`

Return type of `Map::get`: `Option<&'U String>`

Type of `p`: `Option<&'W String>`

Resulting constraint: `'U: 'W`

`'Y: 'W`



```
fn main() {                    {scope of `p`}
    let p: Option<&String>;
    {
        …
        p = Map::get(&map, &'a');
    }
    …
}

impl<K,V> Map<K,V> {
  pub fn get<'a, 'b>(&'a self, key: &'b K)
                           -> Option<&'a V> {…}
}
```

```
pub fn get_or<'a>(&'a self, key: &K, value: &’a V) -> &'a V {
    match self.get(key) {
      Some(from_map) => from_map,
      None => value,
    }
}

pub fn get_or<‘a, ‘b>(&'a self, key: &K, value: &’b V) -> &'a V
  where ‘b: ‘a
{
    match self.get(key) {
      Some(from_map) => from_map,
      None => value,
    }
}
```

Overkill in this scenario.
Sometimes useful.

Exercise: **lifetimes as part of types**

http://rust-tutorials.com/exercises/

Cheat sheet:

```
fn foo<‘a, ‘b>(…)  // declare a named lifetime parameter
  where ‘b: ‘a     // ‘b outlives ‘a
```

http://doc.rust-lang.org/std

Successful borrowing

reference still valid when map dropped

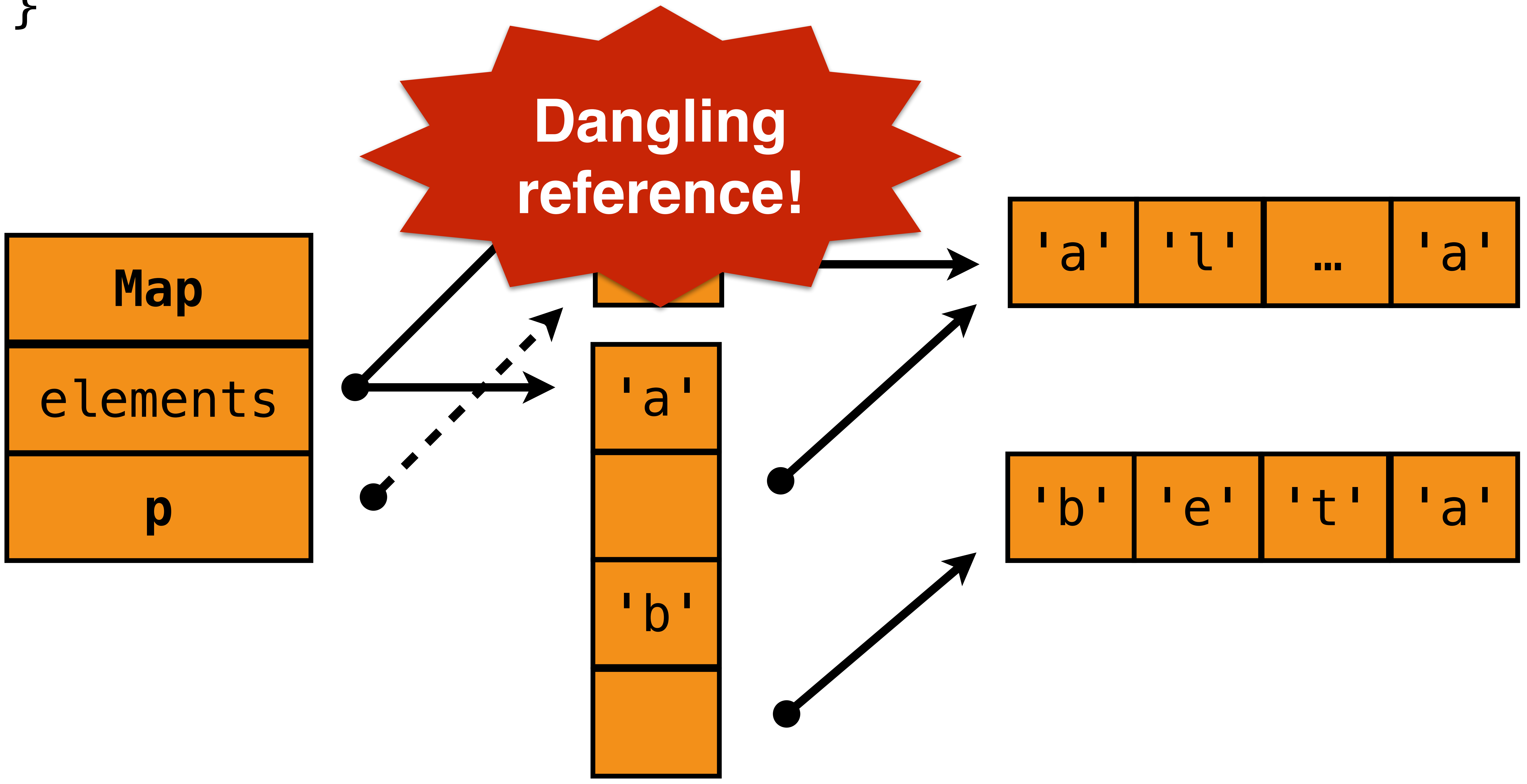
```
fn main() {
    let p: Option<&String>;
    {
        let mut map = Map::new();
        map.insert('a', format!("alpha"));
        p = map.get(&'a');
    }
    println!(“key for 'a' is {:?}”, p);
}
```

map dropped

Tracking lifetimes ensures that values are not dropped while there is a live reference.

But mutation can cause memory to be freed early.

```rust
fn main() {
    let mut map = Map::new();
    map.insert('a', format!("alpha"));
    let p = map.get(&'a');
    map.insert('b', format!("beta"));
}
```



Rust solution

Compile-time read-write-lock:

Shared borrow of X **“read locks”** X.
- Other readers OK.
- No writers.
- Lock lasts for lifetime of borrow.

Mutable borrow of X **“writes locks”** X.
- No other readers or writers.
- Lock lasts for lifetime of borrow.

Never have a reader/writer at same time.

```
fn main() {
    let mut map = Map::new();
    Map::insert(&mut map, 'a', format!("alpha"));
    let p = Map::get(&map, &'a');
    Map::insert(&mut map, 'b', format!("beta"));
}
```

Shared borrow of map

Lifetime of shared borrow

Mutable borrow of map

```
error[E0502]: cannot borrow `map` as mutable because
              it is also borrowed as immutable
22 |     let p = map.get(&"a");
   |             --- immutable borrow occurs here
23 |     map.insert("a", format!("alpha"));
   |     ^^^ mutable borrow occurs here
24 | }
   | - immutable borrow ends here
```

https://is.gd/lyi2ru

```
pub fn remove(&mut self, key: &K) {
  for (index, pair) in self.elements.iter().enumerate() {
    if pair.0 == *key {
      self.elements.remove(index);
      return;
    }
  }
}
```

Lifetime of shared borrow

Mutable borrow of map

Shared borrow of map

https://is.gd/AxhTUo

```rust
pub fn remove(&mut self, key: &K) {
  let mut found = None;
  for (index, pair) in self.elements.iter().enumerate() {
    if pair.0 == *key {
      found = Some(index);
      break;
    }
  }

  if let Some(index) = found {
    self.elements.remove(index);
  }
}
```

Lifetime of shared borrow

Mutable borrow

```rust
fn index_of(&self, key: &K) -> Option<usize> {
  self.elements.iter().position(|pair| pair.0 == *key)
}

pub fn remove(&mut self, key: &K) {
  match self.index_of(key) {
    Some(index) => self.elements.remove(index),
    None => ()
  }
}
```

Takeaway:

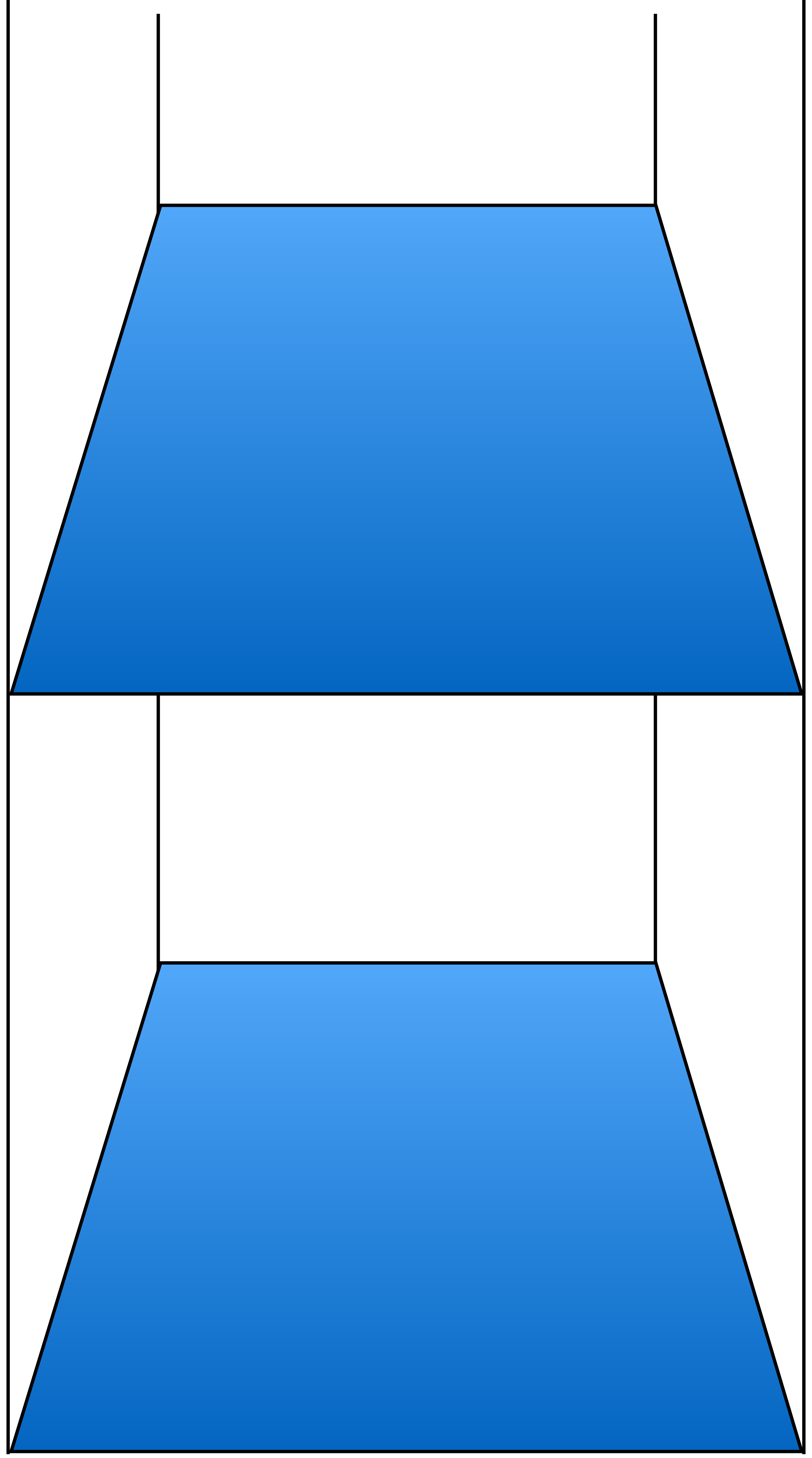
Separate **queries**, which read state, from **actions**.

Create **re-usable helpers** for queries.

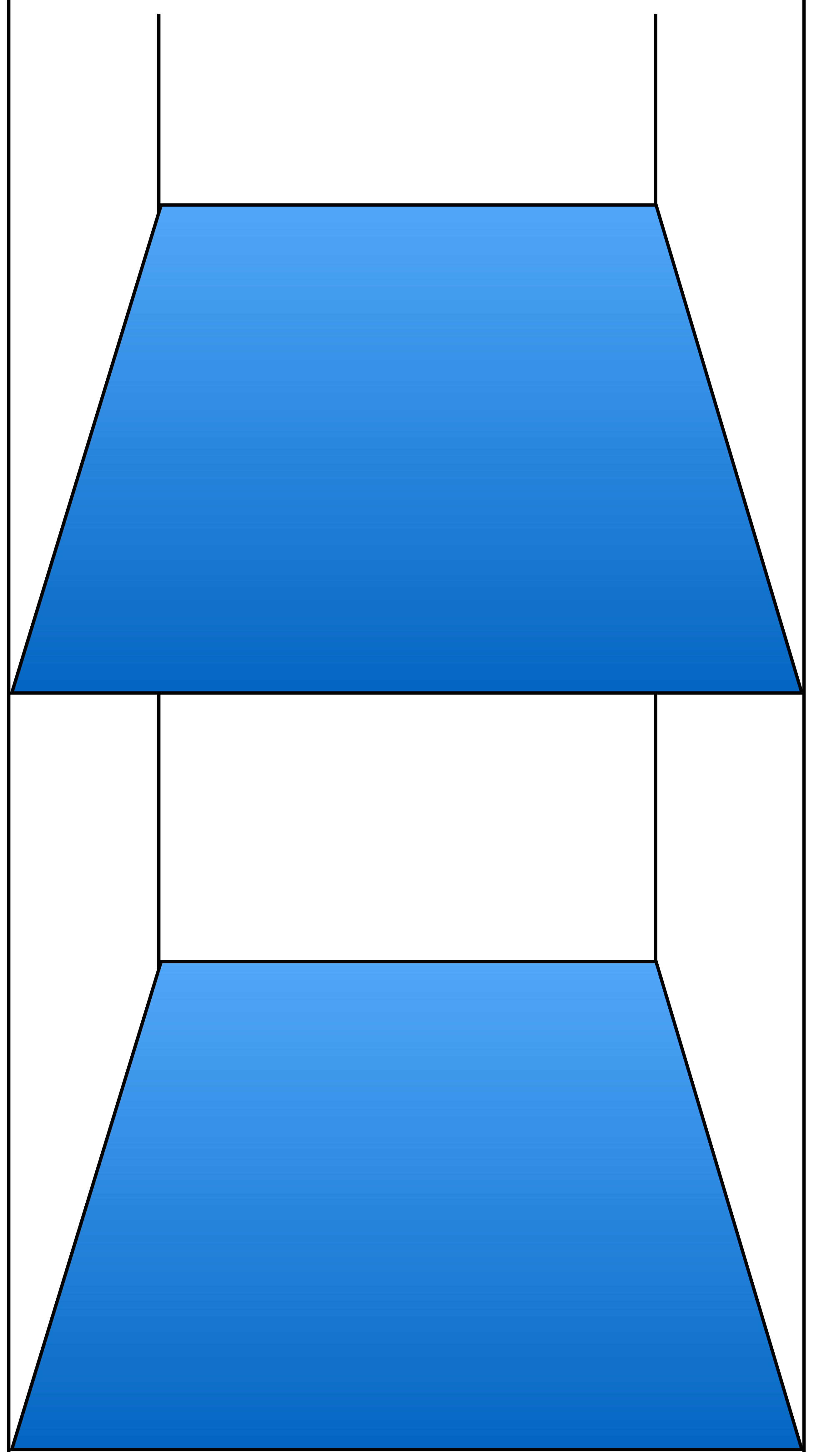
```rust
pub fn get_or_insert(&mut self, key: K, value: V) -> &V {
  for pair in &self.elements {
    if pair.0 == key {
      return &pair.1;
    }
  }

  self.elements.push((key, value));
  &self.elements.last().unwrap().1
}
```

```rust
pub fn get_or_insert<'a>(&'a mut self, key: K, value: V) -> &'a V {
  for pair in &'a self.elements {
    if pair.0 == key {
      return &'a pair.1;
    }
  }

  self.elements.push((key, value));
  &self.elements.last().unwrap().1
}
```

https://is.gd/fmWUQh



```
fn caller() {
    …
    let p = map.get_or_insert(…);
    …
}
impl<K,V> Map<K,V> {
  pub fn get_or_insert<'a>(…) -> &'a V {
    for pair in &'a self.elements {
      if pair.0 == key {
        return &'a pair.1;
      }
    }

    self.elements.push((key, value));
    &self.elements.last().unwrap().1
  }
}
```



```
fn caller() {
    …
    let p = map.get_or_insert(…);
    …
}

impl<K,V> Map<K,V> {
  pub fn get_or_insert<'a>(…) -> &'a V {
    match self.get(key) {
      Some(value) => return value,
      None => (),
    }

    self.elements.push((key, value));
    &self.elements.last().unwrap().1
  }
}
```

```rust
pub fn get_or_insert<'a>(&'a mut self, key: K, value: V) -> &'a V {
  if let Some(index) = self.index_of(&key) {
    return self.get(&key).unwrap();
  }

  self.elements.push((key, value));
  &self.elements.last().unwrap().1
}
```

Takeaway:

Separate **queries**, which read state, from **actions**.

Create **re-usable helpers** for queries.

Careful across fn boundaries.

```rust
pub struct Categorizer {
  categories: HashMap<String, String>,
  histogram: HashMap<String, usize>,
}

impl Categorizer {
  pub fn category(&self, class: &str) -> &str {
    self.categories.get(class)
  }

  pub fn histogram(&mut self, class: &str) {
    let category = self.category(class);
    *self.histogram.get_mut(category) += 1;
  }
}
```

```rust
pub struct Categorizer {
  categories: HashMap<String, String>,
  histogram: HashMap<String, usize>,
}

impl Categorizer {
 …
 pub fn histogram(&mut self, class: &str) {
    let category = self.categories.get(class);
    *self.histogram.get_mut(category) += 1;
  }
}
```

Takeaway:

Factor distinct state into subtypes.

Exercise: **successful borrowing**

http://rust-tutorials.com/exercises/

Takeaway:

Separate **queries**, which read state, from **actions**.

Create **re-usable helpers** for queries.

Careful across fn boundaries.

http://doc.rust-lang.org/std

Lifetimes in Structs

Previous section we had:

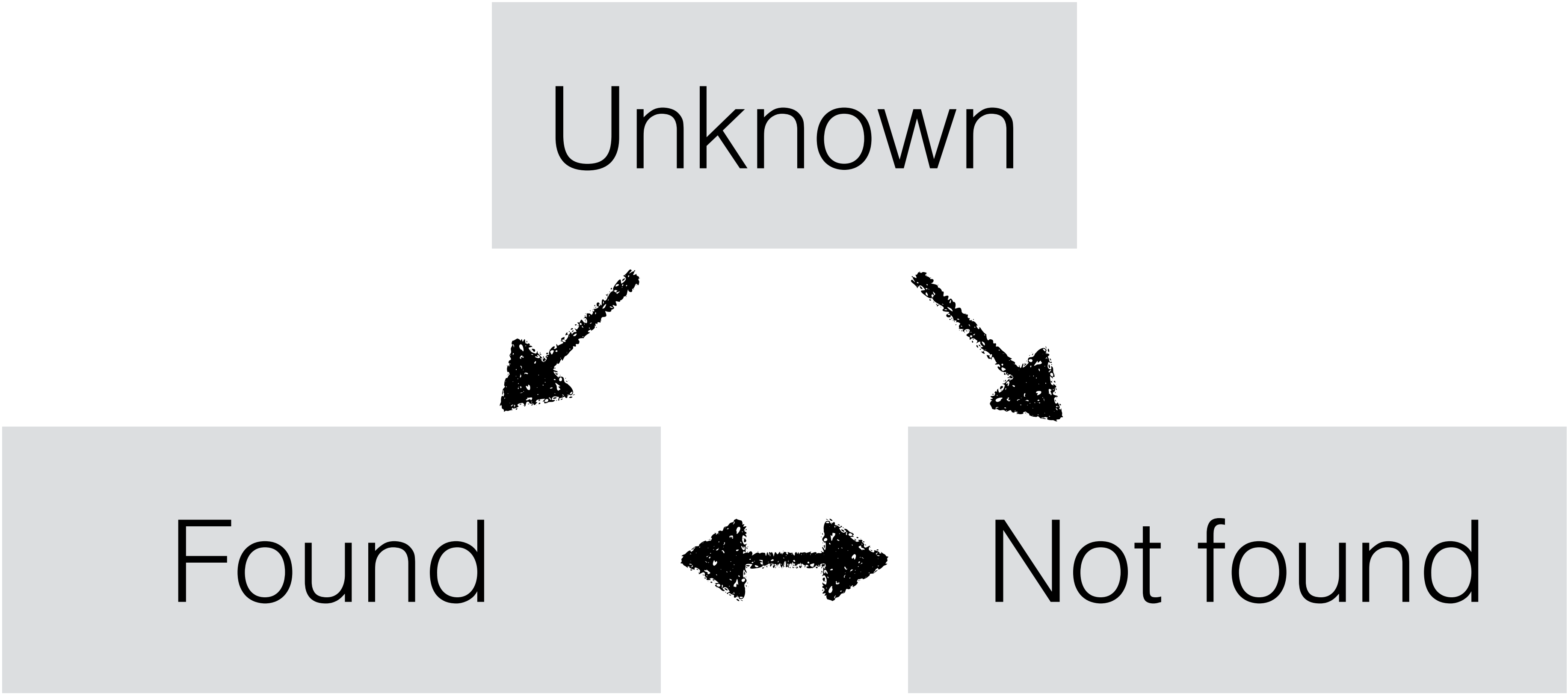
```
*map.get_or_insert(key, 0) += 1
```

But standard library does:

```
*map.entry(key).or_insert(0) += 1
```

Let's do that!

```
pub enum Entry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  Found(FoundEntry<'map, K, V>),
  NotFound(NotFoundEntry<'map, K, V>),
}
```




```
pub struct FoundEntry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  index: usize,
  elements: &'map mut Vec<(K,V)>
}
```

```
pub struct NotFoundEntry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  key: K,
  elements: &'map mut Vec<(K,V)>
}
```

```
enum Entry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  Found(FoundEntry<'map, K, V>),
  NotFound(NotFoundEntry<'map, K, V>),
}
```

Interpretation #1:

Lifetime of the reference to the map (or parts of the map).

Interpretation #2:

Lifetime of the entry itself.

```
fn main() {
    let mut map = Map::new();
    …
    {                                     'X = {scope of `entry`}
      let entry: Entry<'X, _, _> = map.entry(key);
      entry.or_insert(value);
    }
    map.insert(another_key, another_value);
}
                                             {scope of `map`}
```

Observation:

`Entry` has a “write-lock” for the duration of **‘X**.

```rust
enum Entry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  Found(FoundEntry<'map, K, V>),
  NotFound(NotFoundEntry<'map, K, V>),
}

struct FoundEntry<'map, K, V>
  where K: Eq, K: 'map, V: 'map
{
  index: usize,
  elements: &'map mut Vec<(K,V)>
}
```

Safe to borrow K, V for ‘map

```
impl<K, V> Map<K, V>
  where K: Eq
{
  pub fn entry<'map>(&'map mut self, key: K) -> Entry<'map, K, V> {
    …
  }
}
```

Caller gives us unique access to the map for the lifetime 'map.

Lifetime 'map continues as long as entry is in use.

BTW: This style also works. Not recommended.

```
pub fn entry(&mut self, key: K) -> Entry<K, V>
```

```
impl<K, V> Map<K, V>
  where K: Eq
{
  pub fn entry<‘map>(&’map mut self, key: K) -> Entry<‘map, K, V> {
    let pos = self.index_of(&key);
    match pos {
      Some(index) =>
        Entry::Found(FoundEntry {
          index: index,
          elements: &mut self.elements,
        }),

      None => …
    }
  }
}
```

Lifetime will be ‘map,
because of return type.

```rust
impl<K, V> Map<K, V>
  where K: Eq
{
  pub fn entry<'map>(&'map mut self, key: K) -> Entry<'map, K, V> {
    let pos = self.elements.iter().position(|pair| pair.0 == key);
    match pos {
      Some(index) => …,

      None =>
        Entry::NotFound(NotFoundEntry {
          key: key,
          elements: &mut self.elements,
        }),
    }
  }
}
```

```
impl<‘map, K, V> FoundEntry<'map, K, V>
  where K: Eq
{
  fn get(self) -> &’map mut V {
    &mut self.elements[self.index]
  }
}
```

`K: ‘map` implied in impls and fns

How do we know data.index is still valid?

```
impl<‘map, K, V> NotFoundEntry<'map, K, V>
  where K: Eq
{
  fn insert(self, value: V) -> &’map mut V {
    self.elements.push((self.key, value));
    &mut self.elements.last_mut().unwrap().1
  }
}
```

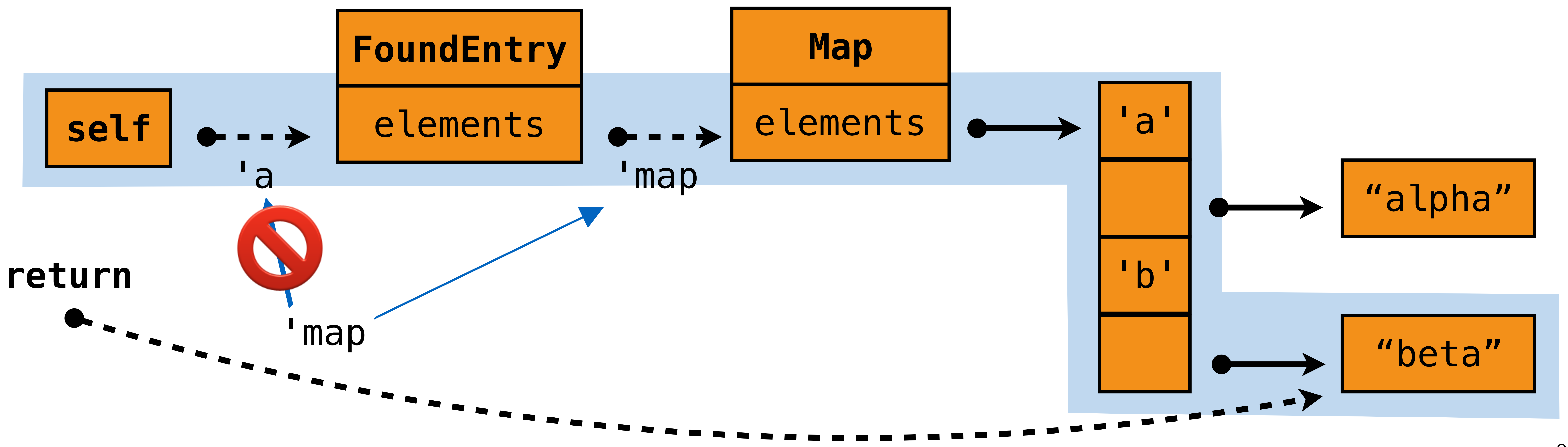
Would `insert()` make sense on `FoundEntry`?

```
impl<‘map, K, V> Entry<'map, K, V>
  where K: Eq
{
  fn or_insert(self, value: V) -> &’map mut V {
    match self {
      Entry::Found(data) => data.get(),
      Entry::NotFound(data) => data.insert(value),
    }
  }
}
```

```
impl<‘map, K, V> FoundEntry<'map, K, V>
  where K: Eq
{
  fn get(&mut self) -> &’map mut V {
    &mut self.elements[self.index]
  }
}
```

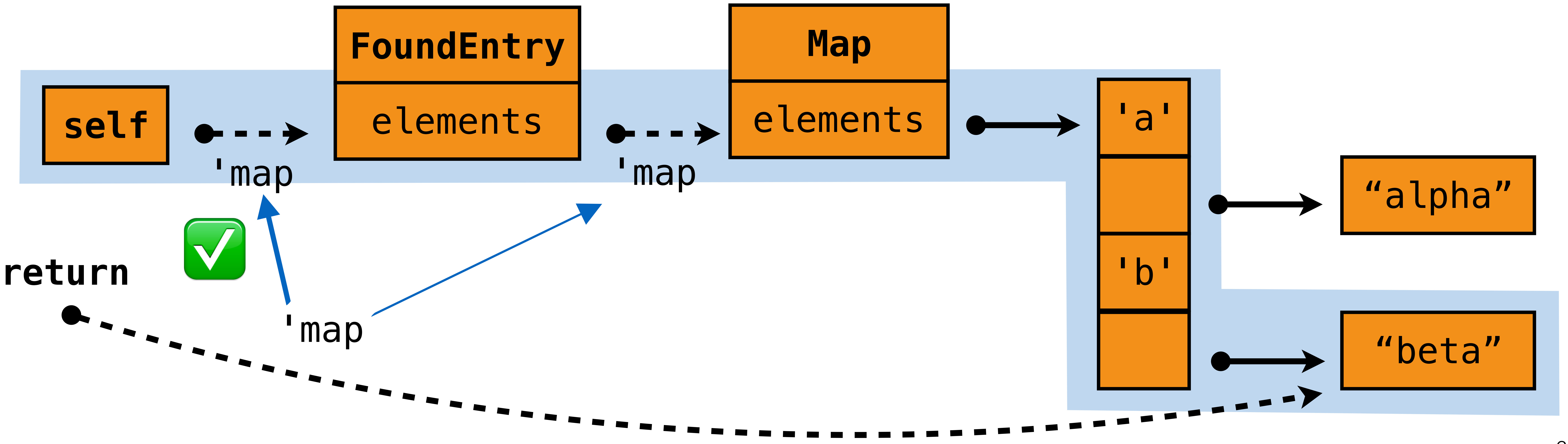
Why not this?

```
impl<‘map, K, V> FoundEntry<'map, K, V>
  where K: Eq
{
  fn get<‘a>(&’a mut self) -> &’map mut V {
    &mut self.elements[self.index]
  }
}
```



```
impl<‘map, K, V> FoundEntry<'map, K, V>
  where K: Eq
{
  fn get(&’map mut self) -> &’map mut V {
    &mut self.elements[self.index]
  }
}
```

OK, why not **this**?



Why not **this**?

```
fn or_insert(&'map mut self) -> &'map mut V
```

```
fn helper<'a>(map: &'a mut Map<K,V>) -> &'a mut V {
  map.entry(some_key()).or_insert(value)
}
```

```
fn helper<'a>(map: &'a mut Map<K,V>) -> &'a mut V {
  let mut entry = map.entry(some_key());
  Entry::or_insert(&mut entry, value)
}
```

What is **lifetime** of this borrow?
What is **scope** of entry?

`'a` 🚫

Takeaway:

- Structs can store references too
- Reference gives a “lock” on borrowed value
- Can encode a state machine
  - type per state, **fn**(self) -> [new state]

Exercise: **lifetimes in structs**

http://rust-tutorials.com/exercises/

Takeaway:

Separate **queries**, which read state, from **actions**.

Create **re-usable helpers** for queries.

Careful across fn boundaries.

http://doc.rust-lang.org/std

Sharing and mutability

Mutable reference in Rust:

really a **unique reference.**

Shared references can permit mutation:

but caution is required.

“Mutation is the root of all evil.”
— Strawman functional programmer

Don’t buy it.

```
let mut counter = 0;
counter += 1;
```

And yet…

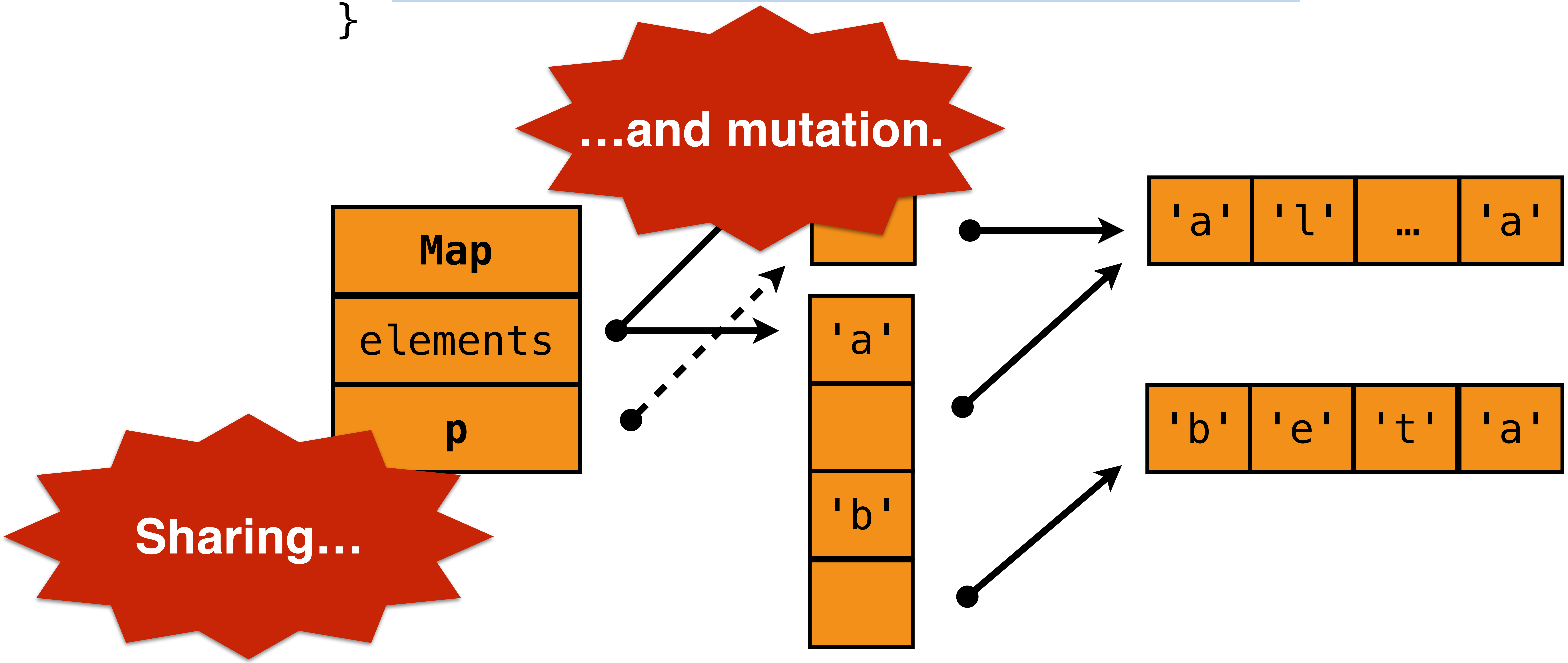
```
mod backend {
  fn search(…) {
    for entry in &context.big_map {
      process(entry);
    }
  }
}
```

Sharing…

```
mod middle {
  fn lazy_fill(…) {
    if !context.big_map.contains(&key) {
      context.big_map.insert(key, …);
    }
```

…and mutation.

```
fn main() {
    let mut map = Map::new();
    map.insert('a', format!("alpha"));
    let p = map.get(&'a');
    map.insert('b', format!("beta"));
}
```



Shared == Immutable*

```
fn helper(name: &String) {
  println!("{}", name);
}
```

OK. Just reads.

```
fn helper(name: &String) {
  name.push_str("foo");
}
```

Error. Writes.

```
error: cannot borrow immutable borrowed content `*name`
       as mutable
    name.push_str("s");
    ^~~~
```

* **Actually:** mutation only in **controlled circumstances**.

If you have a mutable reference `&mut T`…

- You have **unique access** for the lifetime of that reference.
- No other references to T.

If we have a shared reference `&Foo<T>`…

- The API of `Foo` can enforce that same guarantee!
  - *…and thus we can make mutation safe.*

```rust
struct Cell<T> {…}

impl<T: Copy> Cell<T> {
  fn new(value: T) -> Self {…}

  fn get(&self) -> T {…}

  fn set(&self, value: T) {…}
}
```

```rust
let counter = Cell::new(0);
let value = counter.get();
counter.set(value + 1);
```

```rust
let counter = Rc::new(Cell::new(0));
let counter2 = counter.clone();

let value = counter.get(); // 0
counter.set(value + 1);

let value = counter2.get(); // 1
```

```rust
use std::cell::UnsafeCell;

struct Cell<T> {
  data: UnsafeCell<T>
}

impl<T: Copy> Cell<T> {
  …

  fn set(&self, value: T) {
    unsafe {
      let ptr: *mut T = self.data.get();
      *ptr = value;
    }
  }
}
```

Why is this safe?

- API offers no way to get a reference to T.
- Not safe to pass between threads.
  - (The default for UnsafeCell)

Great for Cell<u32>, but Cell<Vec<u32>>…

```rust
use std::cell::UnsafeCell;

struct Cell<T> {
  data: UnsafeCell<T>
}

impl<T: Clone> Cell<T> {
  …

  fn set(&self, value: T) {
    unsafe {
      let ptr: *mut T = self.data.get();
      *ptr = value.clone();
    }
  }
}
```

```rust
impl Clone for MyType {
  fn clone(&self) {
    // may have access to the cell!
  }
}
```

What could go wrong?

```
let vec = RefCell::new(vec![]);

{
  let mut p = vec.borrow_mut();         ← Acquires “write lock”.
  // let mut q = vec.borrow();          ← Would panic.
  p.push(format!(“data”));              ← Mutation permitted.
}  ← Release “read locks”.

{
  let p = vec.borrow();
  let q = vec.borrow();                 ← Acquires “read lock”.
  assert_eq!(&p[0], &q[0]);
}  ← Release “read locks”.
```

Unlike entry, `borrow` takes `&self`:

- Guarantees `RefCell` will not be moved
- Does **not** guarantee unique access

```
struct RefCell<T> {…}

struct Ref<‘b, T: ‘b> {…}

impl<T> RefCell<T> {
  fn borrow<‘b>(&’b self) -> Ref<‘b, T> {
    // twiddle bits to acquire lock
    Ref { … } // return a Ref that contains `self`
  }
}


impl<‘b, T> Deref for Ref<‘b, T: ‘b> {
  type Target = T;
  …
}
```

```
{
  let vec = RefCell::new(vec![]);

  let mut p = vec.borrow_mut();
  p.push(format!(“data”));

  let p = vec.borrow();
  let q = vec.borrow();
  assert_eq!(&p[0], &q[0]);
}
```

```
{
  let mut vec = vec![];

  let mut p = &mut vec;
  p.push(format!(“data”));

  let p = &vec;
  let q = &vec;
  assert_eq!(&p[0], &q[0]);
}
```

```
mod backend {
  fn search(…) {
    for entry in context.big_map.borrow() {
      process(entry);
    }
  }
}
```

```
mod middle {
  fn lazy_fill(…) {
    …
    context.big_map.borrow_mut()
                   .insert(key, …);
  }
}
```

```rust
pub struct Context {
  pub big_map: RefCell<Map<…>>
}
```

Open-ended access is error-prone.

```rust
pub struct Context {
  big_map: RefCell<Map<…>>
}

impl Context {
  pub fn find_entry(&self, key: &K) -> V {
    self.big_map.borrow().get(key).cloned()
  }

  pub fn add_entry(&self, k: K, v: V) {
    self.big_map.borrow_mut().insert(k, v);
  }
}
```

Controlled accessors can be audited, but less flexible and repetitive.

No best answer yet.

What about threads?

- Cell and RefCell cannot be shared across threads.
- AtomicU32 and Mutex can but offer similar usability tradeoffs.

Some alternatives to explore:

- Avoid using shared/mutability:
  - often you can replace a `&T` with an index into a vector
- Persistent data structures.

Your experiences?

Exercise: **aliasing and mutability**

http://rust-tutorials.com/exercises/

Takeaway:

Separate **queries**, which read state, from **actions**.

Create **re-usable helpers** for queries.

Careful across fn boundaries.

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Open questions