Rust: Systems Programming for Everyone

Leo Testard, Mozilla

Why Rust…?

Why use Rust?

Fast code, low memory footprint

Go from bare metal (assembly; C FFI) ...

... to high-level (collections, closures, generic containers) ...

with *zero cost* (no GC, unboxed closures, monomorphization of generics)

Safety and *Parallelism*

Safety and Parallelism

Safety

No segmentation faults

No undefined behavior

No data races

Why would Mozilla sponsor Rust?

Hard to prototype research-y browser changes atop C++ code base

Rust ⇒ Servo, WebRender

Want Rust for next-gen infrastructure (services, IoT)

Where is Rust now?

1.0 release was back in May 2015

Rolling release cycle (up to Rust 1.8 as of May 2nd 2016)

Open source from the begining
`https://github.com/rust-lang/rust/`

Open model for future change (RFC process)
`https://github.com/rust-lang/rfcs/`

Awesome developer community (~1,000 people in `#rust`, ~250 people in `#rust-internals`, ~1,300 unique commiters to rust.git)

Talk plan

"Why Rust"

How we build safe abstractions in Rust:

ownership & borrowing

Example 1: Pointers and allocation

Example 2: Concurrency

Ownership: a metaphor

"Ownership is intuitive"

Let's buy a car

```rust
let money: Money = bank.withdraw_cash();
let my_new_car: Car = dealership.buy_car(money);
```

```rust
let second_car = dealership.buy_car(money); // <-- cannot reuse
```

money transferred into `dealership`, and car transferred to us.

"Ownership is intuitive"

Let's buy a car

```
let money: Money = bank.withdraw_cash();
let my_new_car: Car = dealership.buy_car(money);
// let second_car = dealership.buy_car(money); // <-- cannot reuse
```

money transferred into **`dealership`**, and car transferred to us.

```
my_new_car.drive_to(home);
garage.park(my_new_car);
```

```
my_new_car.drive_to(...) // now doesn't work
```

(can't drive car without access to it, e.g. taking it out of the garage)

"Ownership is intuitive"

Let's buy a car

```
let money: Money = bank.withdraw_cash();
let my_new_car: Car = dealership.buy_car(money);
// let second_car = dealership.buy_car(money); // <-- cannot reuse
```

money transferred into **`dealership`**, and car transferred to us.

```
my_new_car.drive_to(home);
garage.park(my_new_car);
// my_new_car.drive_to(...) // now doesn't work
```

(can't drive car without access to it, e.g. taking it out of the garage)

```
let my_car = garage.unpark();
my_car.drive_to(work);
```

...reflection time...

Ownership is important

Ownership enables:	which removes:
RsAll-style destructors	a source of memory leaks (or fd leaks, etc)
no dangling pointers	many resource management bugs
no data races	many multithreading heisenbugs

Do I need to take ownership here, accepting the associated resource management responsibility? Would temporary access suffice?

Good system developers ask this already!

"The pointer may subsequently be used as an argument to the function free(3)." STRDUP(2)

Rust forces function signatures to encode the answers, and they are checked by the compiler.

Problem: Ownership is intuitive, except for programmers ...

(copying data like integers, and characters, and .mp3's, is "free")

... and anyone else who *names* things

If ownership were all we had, car-purchase slide seems nonsensical

```
my_new_car.drive_to(home);
```

Does this transfer `home` into the car?

Do I lose access to my home, just because I drive to it?

We must distinguish an object itself from ways to name that object

`home` must be some kind of *reference* to a `Home`

So we will need references

We can solve any problem by introducing an extra level of indirection

-- David J. Wheeler

Sharing Data: Ownership and References

Rust types

Move	Copy	Copy if `T:Copy`
`Vec<T>`, `String`, …	`i32`, `char`, …	`[T; n]`, `(T1,T2,T3)`, …

```
struct Car { color: Color, engine: Engine }

fn demo_ownership() {
    let mut used_car: Car = Car { color: Color::Red,
                                  engine: Engine::BrokenV8 };
    let apartments = ApartmentBuilding::new();
```

references to data (`&mut T`, `&T`):

```
    let my_home: &Home;        // <-- an "immutable" borrow
    let christine: &mut Car; // <-- a "mutable" borrow
    my_home = &apartments[6]; //       (read `mut` as "exclusive")
    let neighbors_home = &apartments[5];
    christine = &mut used_car;
    christine.engine = Engine::VintageV8;
}
```

Why multiple **&**-reference types?

Distinguish *exclusive* access from *shared* access

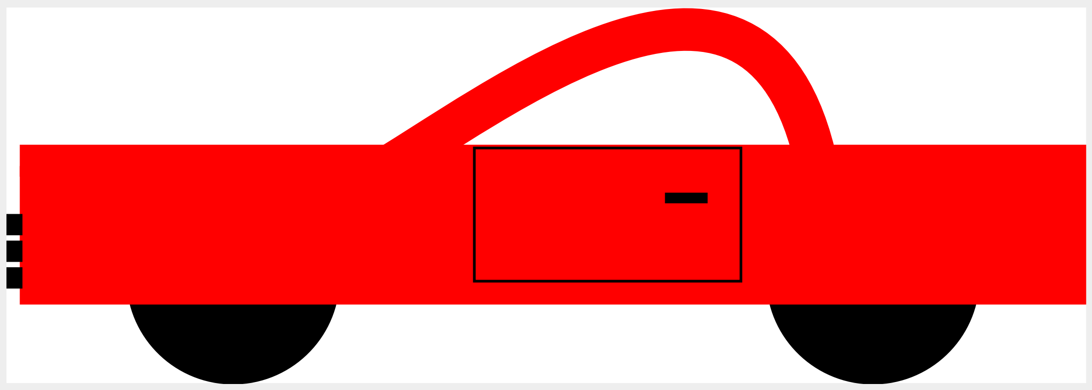
Enables **safe**, **parallel** API's

Borrowing: A Metaphor (continued)

(reminder: metaphors never work 100%)

```rust
let christine = Car::new();
```

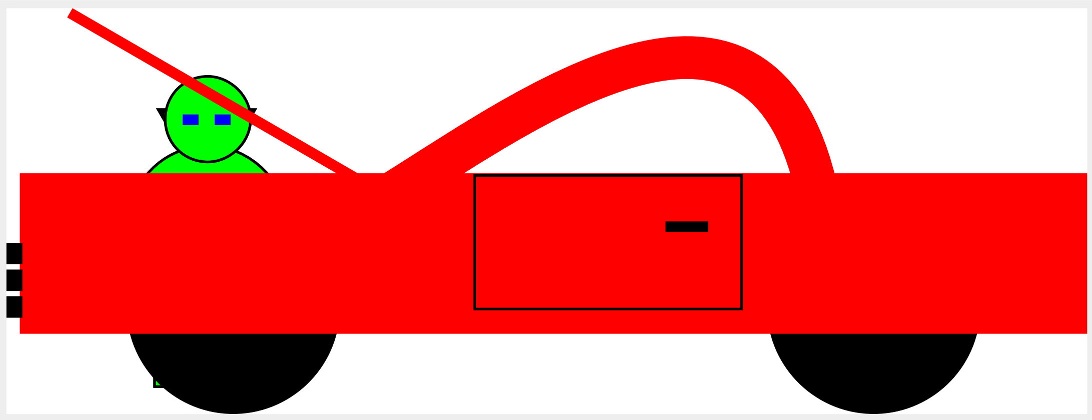
This is "Christine"



pristine unborrowed car

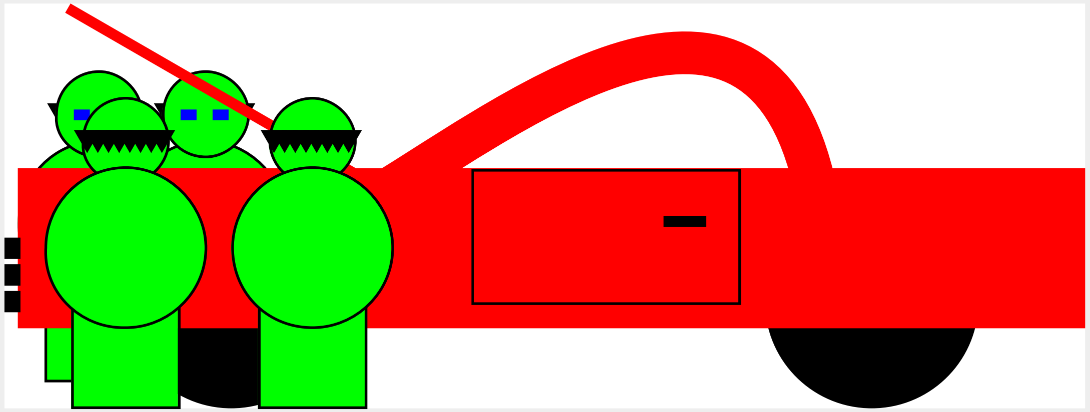
(apologies to Stephen King)

```
let read_only_borrow = &christine;
```



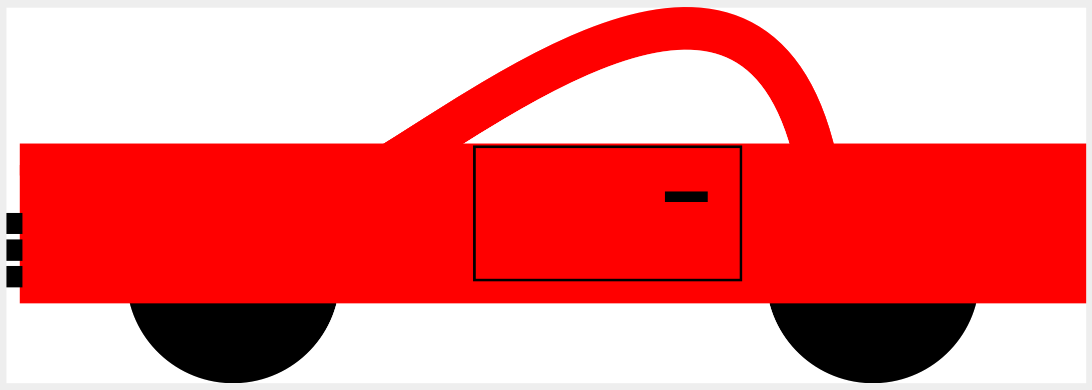
single inspector (immutable borrow)

```
read_only_borrows[2] = &christine;
read_only_borrows[3] = &christine;
read_only_borrows[4] = &christine;
```



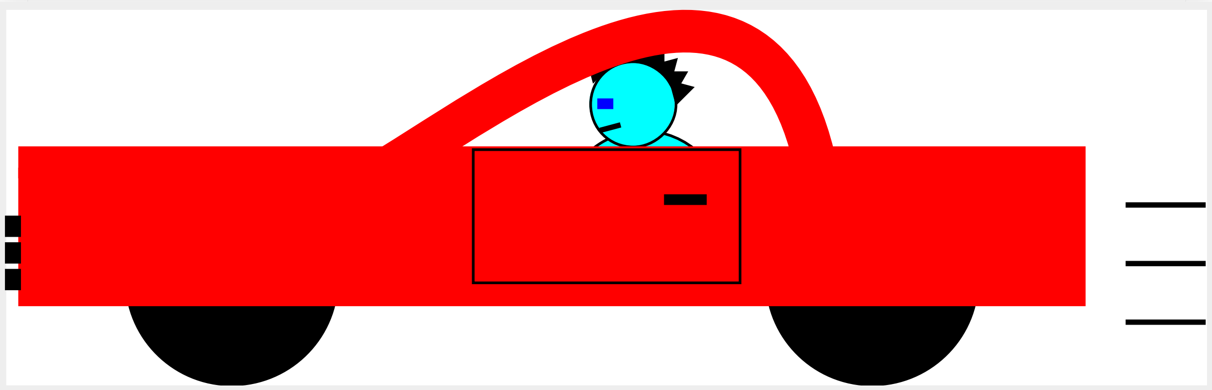
many inspectors (immutable borrows)

When inspectors are finished, we are left again with:



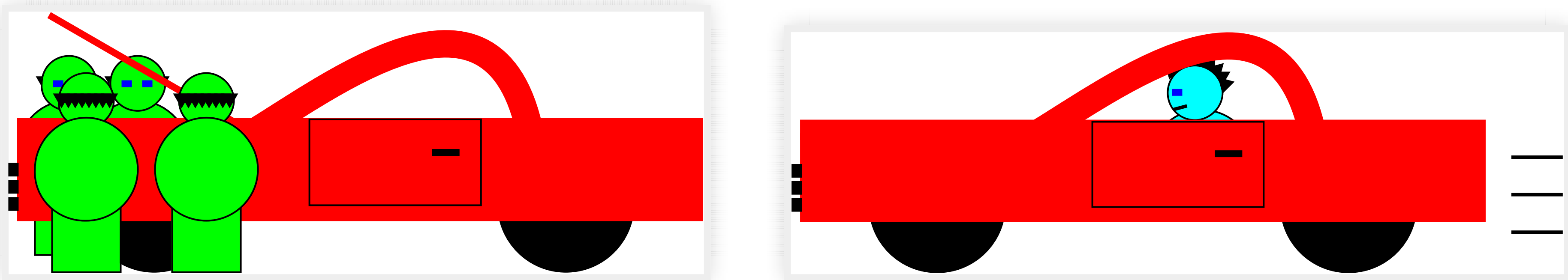
pristine unborrowed car

```
let mutable_borrow = &mut christine; // like taking keys ...
give_arnie(mutable_borrow); // ... and giving them to someone
```



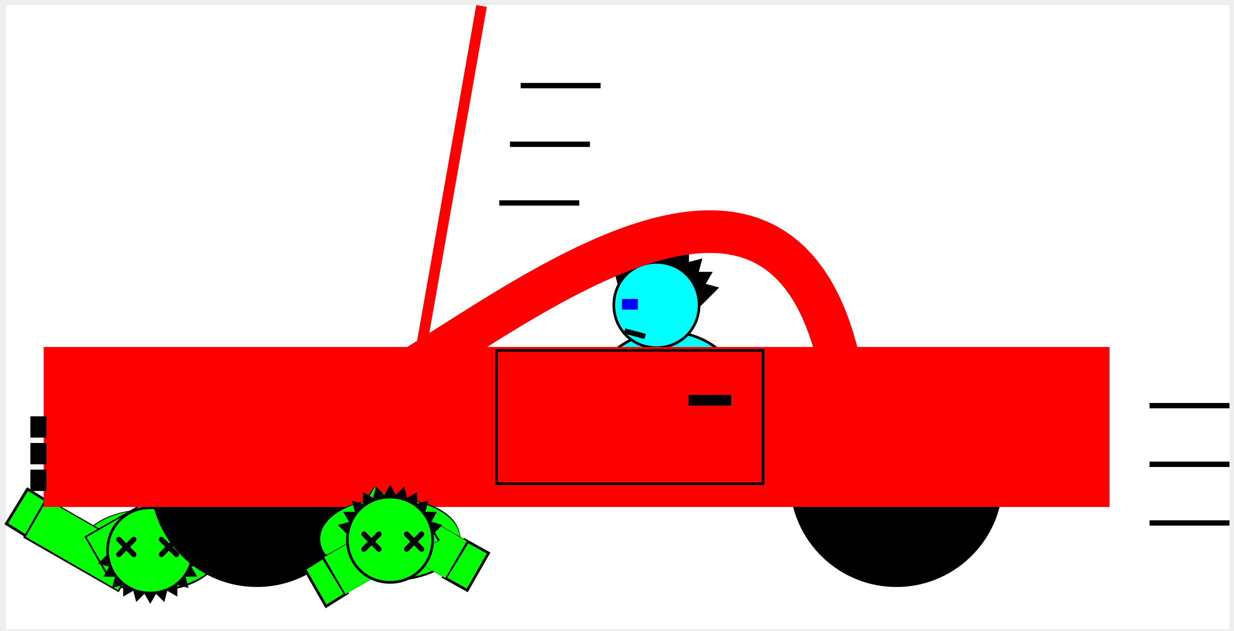
driven car (mutably borrowed)

Can't mix the two in safe code!



Otherwise: (data) races!

```rust
read_only_borrows[2] = &christine;
let mutable_borrow = &mut christine;
read_only_borrows[3] = &christine;
// ⇒ CHAOS!
```



mixing mutable and immutable is illegal

Mixing mutable and immutable is illegal

Reminder: this does not apply only to concurrency (iterator invalidation, etc.)

```
std::vector<int> v = {1};
int &i = v[0];
std::cout << i << std::endl; // prints 1

v.push_back(2);

std::vector<int> v2 = {2};
std::cout << i << std::endl; // prints 2
```

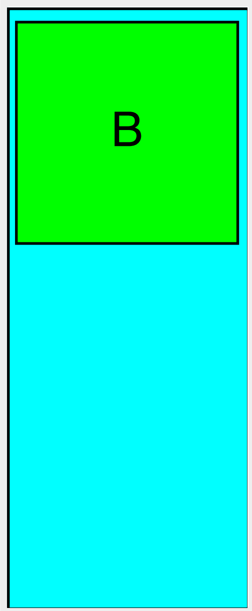
Ownership	`T`	
Exclusive access	`&mut T`	("mutable")
Shared access	`&T`	("read-only")

Now let's see how we can apply that to build safe abstractions

Pointers, Smart and Otherwise

Stack allocation

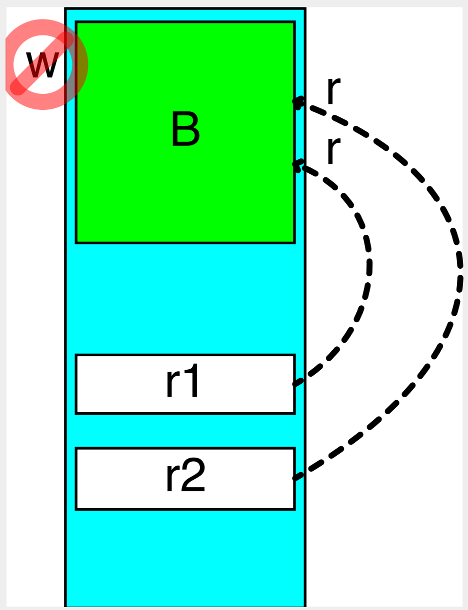
```
let b = B::new();
```



stack allocation

```
let b = B::new();

let r1: &B = &b;
let r2: &B = &b;
```

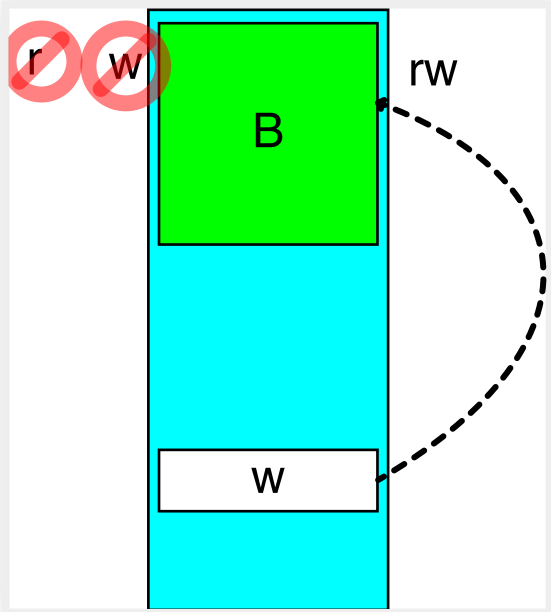


stack allocation and immutable borrows

(**b** has lost write capability)

```rust
let mut b = B::new();

let w: &mut B = &mut b;
```

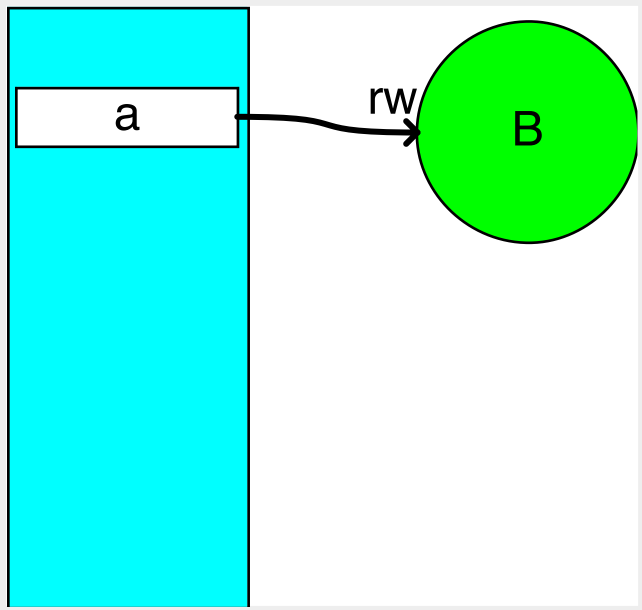


stack allocation and mutable borrows

(**b** has temporarily lost both read *and* write capabilities)

Heap allocation: **Box<B>**

```
let a = Box::new(B::new());
```



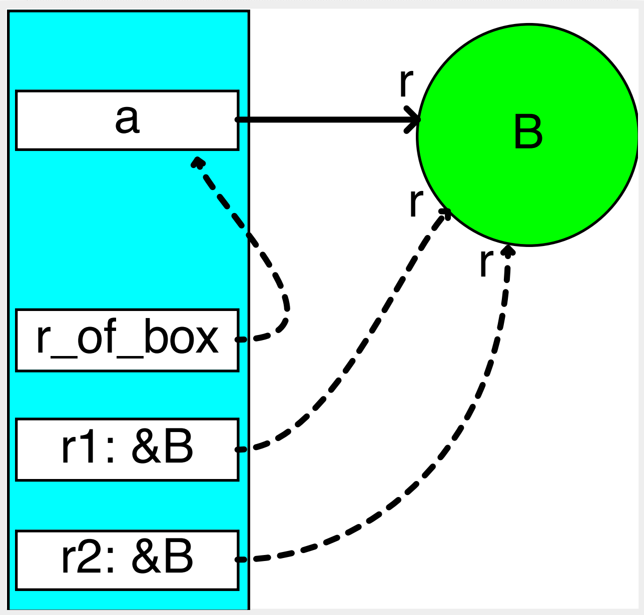
pristine boxed B

a (as owner) has both read and write capabilities

Immutably borrowing a box

```
let a = Box::new(B::new());
let r_of_box: &Box<B> = &a; // (not directly a ref of B)

let r1: &B = &*a;
let r2: &B = &a; // <-- coercion!
```

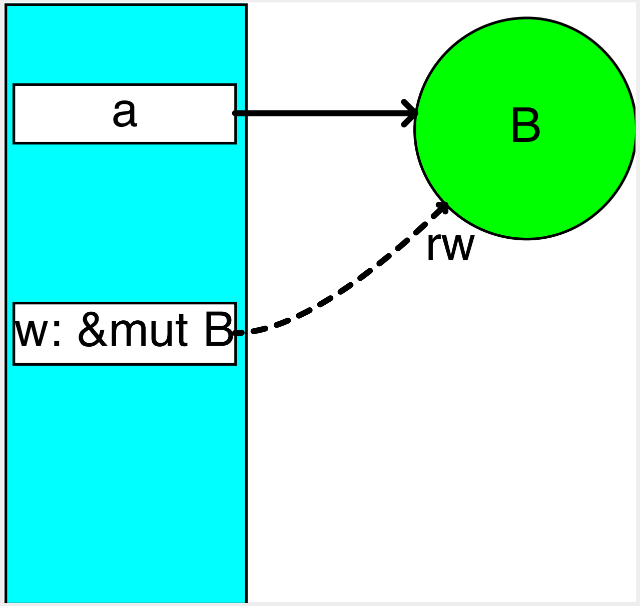


immutable borrows of heap-allocated B; a retains read capabilities (has temporarily lost write)

Mutably borrowing a box

```
let mut a = Box::new(B::new());

let w: &mut B = &mut a; // (again, coercion happening here)
```

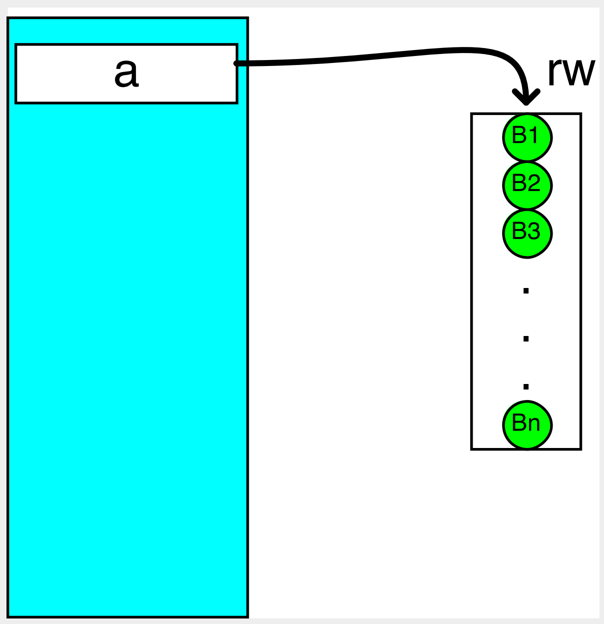


mutable borrow of heap-allocated B

a has temporarily lost *both* read and write capabilities

Heap allocation: **Vec<B>**

```
let mut a = Vec::new();
for i in 0..n { a.push(B::new()); }
```

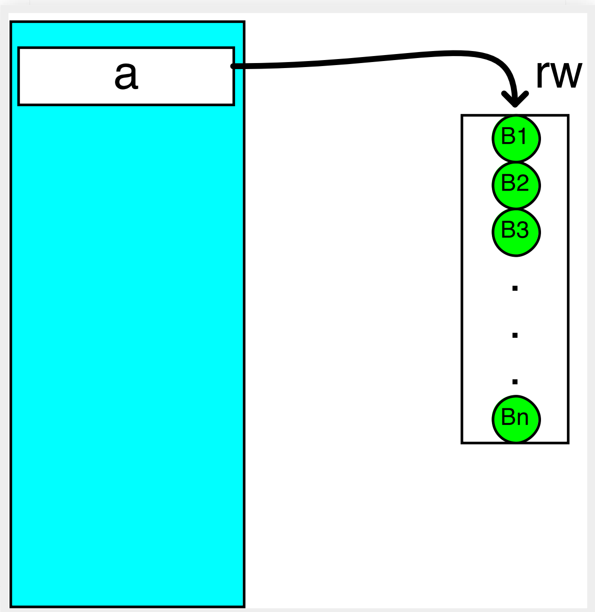


vec, filled to capacity

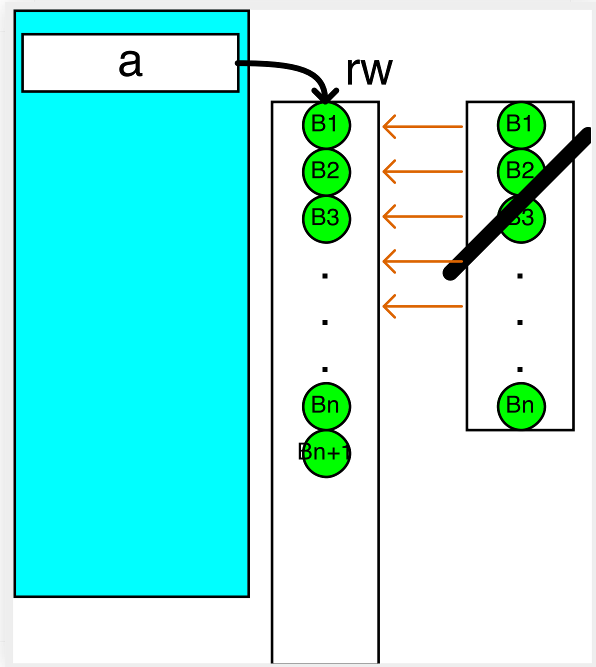
Vec Reallocation

```
...
a.push(B::new());
```

before



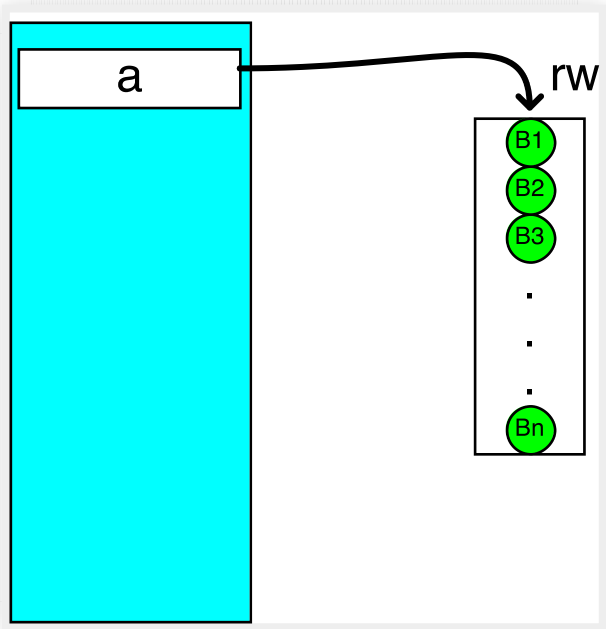
after



Slices: borrowing *parts* of an array

Basic **Vec<B>**

```
let mut a = Vec::new();
for i in 0..n { a.push(B::new()); }
```

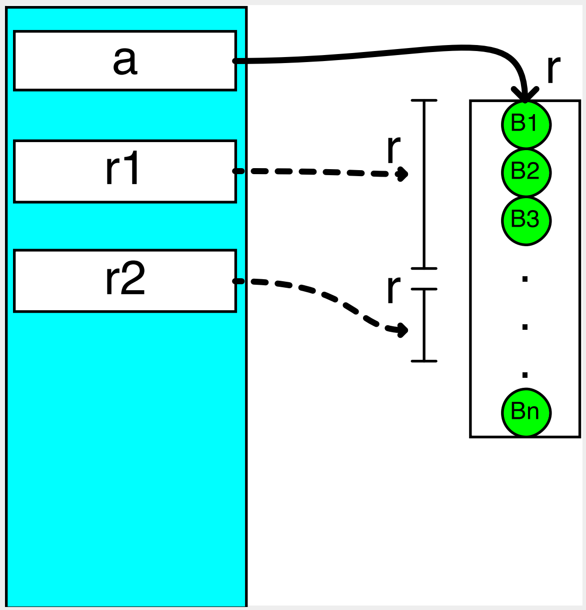


pristine unborrowed vec

(**a** has read and write capabilities)

Immutable borrowed slices

```
let mut a = Vec::new();
for i in 0..n { a.push(B::new()); }
let r1 = &a[0..3];
let r2 = &a[7..n-4];
```

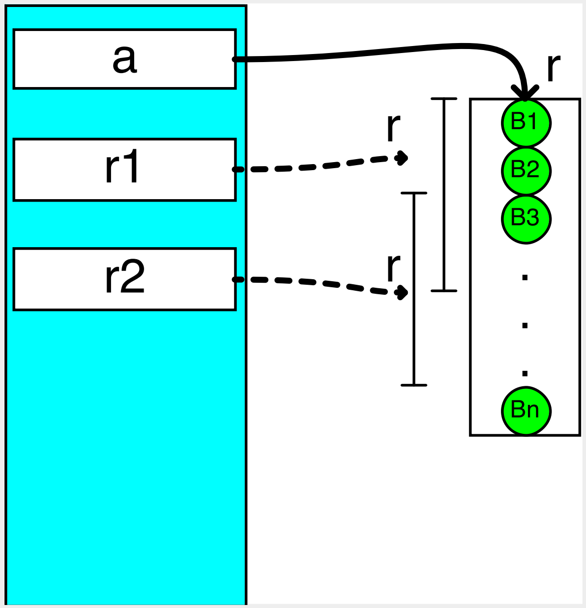


mutiple borrowed slices vec

(`a` has only read capability now; shares it with `r1` and `r2`)

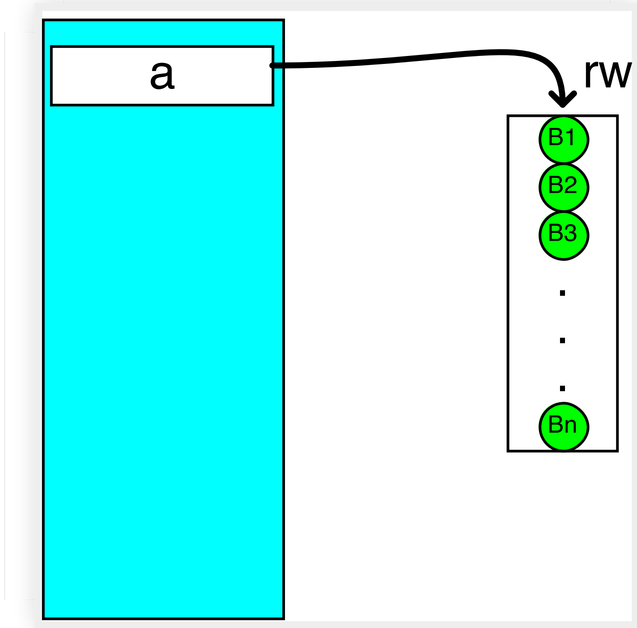
Safe overlap between `&[..]`

```
let mut a = Vec::new();
for i in 0..n { a.push(B::new()); }
let r1 = &a[0..7];
let r2 = &a[3..n-4];
```



overlapping slices

Basic **Vec<B>** again

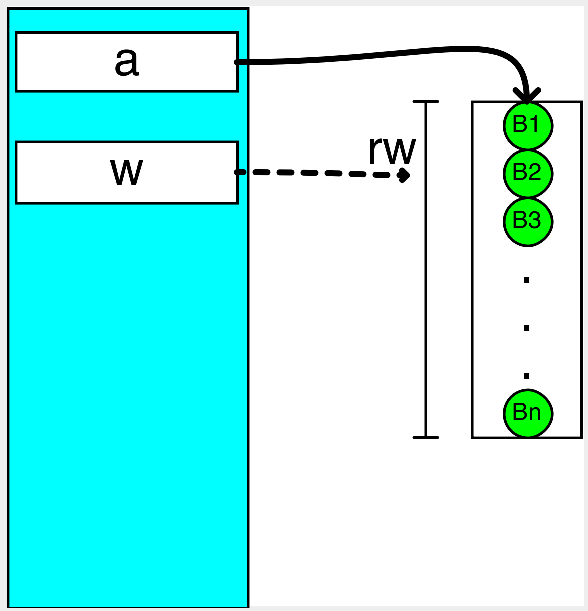


pristine unborrowed vec

(**a** has read and write capabilities)

Mutable slice of whole vec

```rust
let w = &mut a[0..n];
```

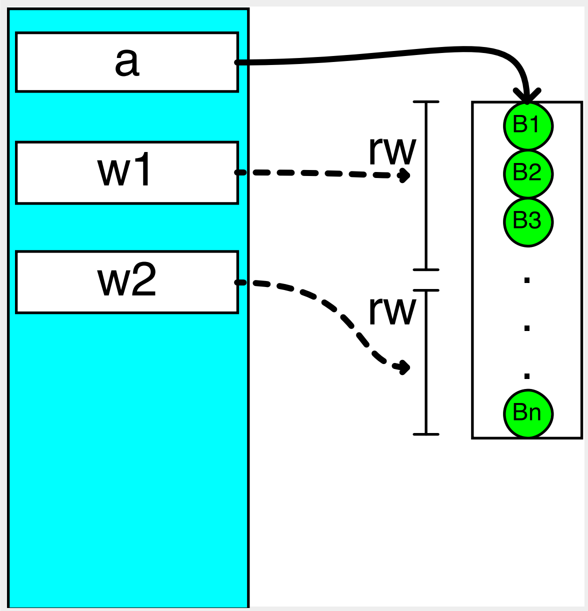


mutable slice of vec

(**a** has *no* capabilities; **w** now has read and write capability)

Mutable disjoint slices

```
let (w1,w2) = a.split_at_mut(n-4);
```



disjoint mutable borrows

(`w1` and `w2` share read and write capabilities for disjoint portions)

Sharing Work: Parallelism / Concurrency

Big Idea

3rd parties identify (and provide) *new abstractions* for (safe) concurrency and parallelism unanticipated in std lib.

Example: **rayon**'s scoped parallelism

rayon demo 1: map reduce

Sequential

```
fn demo_map_reduce_seq(stores: &[Store], list: Groceries) -> u32 {
    let total_price = stores.iter()
                            .map(|store| store.compute_price(&list))
                            .sum();
    return total_price;
}
```

Parallel (*potentially*)

```
fn demo_map_reduce_par(stores: &[Store], list: Groceries) -> u32 {
    let total_price = stores.par_iter()
                            .map(|store| store.compute_price(&list))
                            .sum();
    return total_price;
}
```

rayon demo 2: quicksort

```
fn quick_sort<T:PartialOrd+Send>(v: &mut [T]) {
    if v.len() > 1 {
        let mid = partition(v);
        let (lo, hi) = v.split_at_mut(mid);
        rayon::join(|| quick_sort(lo),
                    || quick_sort(hi));
    }
}
```

```
fn partition<T:PartialOrd+Send>(v: &mut [T]) -> usize {
    // see https://en.wikipedia.org/wiki/
    //     Quicksort#Lomuto_partition_scheme
    ...
}
```

rayon demo 3: buggy quicksort

```
fn quick_sort<T:PartialOrd+Send>(v: &mut [T]) {
    if v.len() > 1 {
        let mid = partition(v);
        let (lo, hi) = v.split_at_mut(mid);
        rayon::join(|| quick_sort(lo),
                    || quick_sort(hi));
    }
}
```

```
fn quick_sort<T:PartialOrd+Send>(v: &mut [T]) {
    if v.len() > 1 {
        let mid = partition(v);
        let (lo, hi) = v.split_at_mut(mid);
        rayon::join(|| quick_sort(lo),
                    || quick_sort(lo));
        //                       ~~ data race!
    }
}
```

(See blog post "Rayon: Data Parallelism in Rust" **`bit.ly/1IZcku4`**)

Threading APIs (plural!)

`std::thread`

`dispatch` : OS X-specific "Grand Central Dispatch"

`crossbeam` : Lock-Free Abstractions, Scoped "Must-be" Concurrency

`rayon` : Scoped Fork-join "Maybe" Parallelism (inspired by Cilk)

(Only the *first* comes with Rust out of the box)

Final Words

Thanks

`www.rust-lang.org`

Hack Without Fear