a systems language
pursuing the trifecta
safe, concurrent, fast

mozilla

Motivation

- To implement next-gen browser, Servo ...

  ⇒ **`http://github.com/mozilla/servo`**

- ... Mozilla is using (& implementing) Rust

  ⇒ **`http://rust-lang.org`**

- **Part I: Motivation**

  Why Mozilla is investing in Rust

- **Part II: Rust syntax and semantics**
- **Part III: Ownership and borrowing**

Systems Programming

- Resource-constrained enviroments, direct control over hardware
- C and C++ dominate this space
- Systems programmers care about the last 10-15% of potential performance

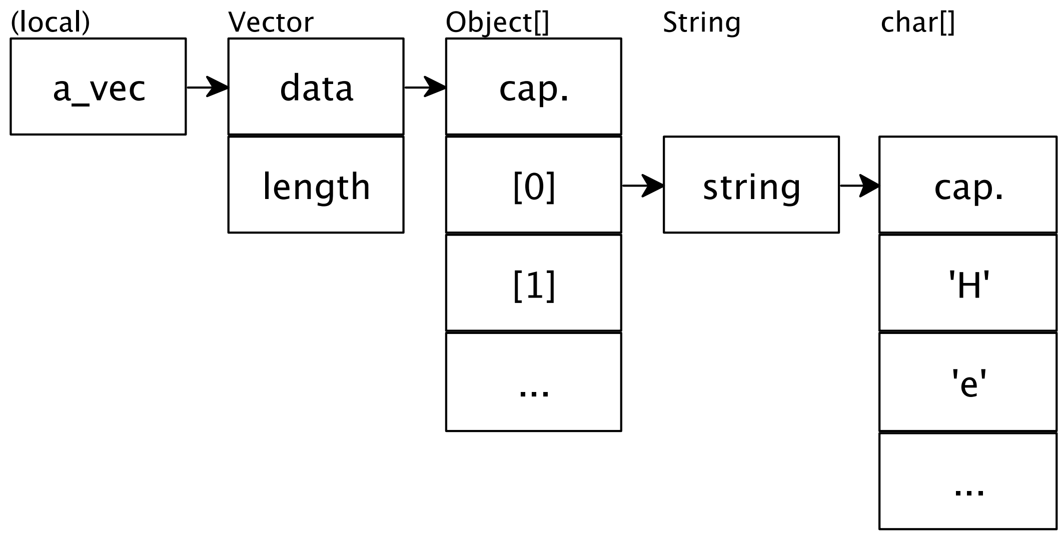
Zero-cost abstractions

Express abstractions that completely optimize away at compile-time

- Memory representation
- Monomorphized Generics
    - (aka template expansion)
- etc
    - (static method dispatch, inlining)

Zero-cost abstraction: Memory Representation

Java heap:



Unsafe aspects of C/C++

- Dangling pointers
- Null pointer dereferences
- Buffer overflows, array bounds errors
- Format string and argument mismatch
- Double frees

Rust has none of the above

Safety: Consider C/C++

```
// (example due to Stepan Koltsov)
std::string get_url() {
    return "http://www.mozilla.com";
}

string_view get_scheme_from_url(string_view url) {
    unsigned colon: url.find(':');
    return url.substr(0, colon);
}

int main() {
    auto scheme = get_scheme_from_url(get_url());
    std::cout << scheme << "\n";
    return 0;
}
```

Safety: C/C++ is busted

```
// (example due to Stepan Koltsov)
std::string get_url() {
    return "http://www.mozilla.com";
}

string_view get_scheme_from_url(string_view url) {
    unsigned colon: url.find(':');
    return url.substr(0, colon);
}

int main() {
    auto scheme;
    {    std::string temp = get_url();
         scheme = get_scheme_from_url(temp); }
    std::cout << scheme << "\n";
    return 0;
}
```

Tool: Sound Type Checking

Milner, 1978

- "Well-typed programs can't go wrong."
- More generally: identify classes of errors ...
  - ... then use type system to remove them
  - (or at least isolate them)
- Eases reasoning; adds confidence

Tobin-Hochstadt 2006, Wadler 2009

- Well-typed programs help assign blame.
  - (**`unsafe`** code can still "go wrong")
  - and even safe code can **`fail`**

Simple source ⇔ compiled code relationship

- A reason C persists to this day
- Programmer can mentally model machine state
  - can also control low-level details (e.g. memory layout)
- Goal for Rust: preserve this relationship ...
  - ... while **retaining** memory safety ...
  - ... and data-race freedom, etc ...
  - ... without runtime cost.
  - Do not box everything; do not GC-manage everything.

No GC?

- Unpredictable; hard to **control** at best
- Requires a **runtime**
- **Insufficient** for aliasing-related problems
    - iterator invalidation, data races

- **Part I: Motivation**
- **Part II: Rust syntax and semantics**

  Systems programming under the influence of FP

- **Part III: Ownership and borrowing**

Scala / Rust: basic syntax

Scala:

```
var y = { var x = 2 + 3; x > 5 };
if (y) z + 6 else z + 7
```

Rust:

```
let y = { let x = 2 + 3; x > 5 };
if y { z + 6 } else { z + 7 }
```

Scala / Rust: functions

Scala:

```
def add3(x:Int) = x + 3;
var y = add3(7) > 5;
```

Rust:

```
fn add3(x:int) -> int { x + 3 }
let y = add3(7) > 5;
```

Scala / Rust: generics, pattern binding

Scala:

```
def add3_left[A](t: Tuple2[Int, A]): Tuple2[Int, A]
    = { val (x,y) = t; (x+3, y) }

import scala.math.Ordering.Implicits._;
var y = add3_left(7,"hi") > (10,"lo")
```

Rust:

```
fn add3_left<A>((x,y):(int, A)) -> (int, A) {
    (x + 3, y)
}
let y = add3_left((7,"hi")) > (10,"lo");
```

playpen (**http://is.gd/FgtM0y**)

Scala / Rust: pattern matching

Scala:

```
abstract class Lonely[A];
case class One[A](a:A) extends Lonely[A]
case class Two[A](l: A, r: A) extends Lonely[A]
def combined(l: Lonely[Int]) = l match {
  case One(a) => a; case Two(a,b) => a + b
}
```

Rust:

```
enum Lonely<A> { One(A), Two(A, A) }
fn combined(l: Lonely<int>) -> int {
    match l {
        One(a)    => a,
        Two(a, b) => a + b,
    }
}
```

playpen (http://is.gd/gd2tDG)

Rust: Bounded Polymorphism

playpen (http://is.gd/J7hH2a)

```
enum Lonely<A> { One(A), Two(A, A) }
trait Plus { fn plus(self, rhs: Self) -> Self; }
fn combined<N:Plus>(l: Lonely<N>) -> N {
    match l {
        One(a)    => a,
        Two(a, b) => a.plus(b),
    }
}
```

- Note: Rust traits not equiv to Scala traits

Rust: Bounded Polymorphism

```
// "struct" is Rust's record syntax.
struct Dollars { amt: int }
struct Euros { amt: int }
trait Currency {
    fn render(&self) -> String;
    fn to_euros(&self) -> Euros;
}
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}
```

Trait Impls

```
impl Currency for Dollars {
    fn render(&self) -> String {
      format!("${}", self.amt)
    }
    fn to_euros(&self) -> Euros {
      let a = ((self.amt as f64) * 0.79);
      Euros { amt: a as int }
    }
}

impl Currency for Euros {
    fn render(&self) -> String {
      format!("€{}", self.amt)
    }
    fn to_euros(&self) -> Euros { *self }
}
```

Static Resolution (1)

```
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

     let eu100 = Euros { amt: 100 };
     let eu200 = Euros { amt: 200 };
     println!("{:?}", add_as_euros(&eu100, &eu200));
```

⇒ `Euros{amt: 300}`

Static Resolution (2)

```
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

    let us100 = Dollars { amt: 100 };
    let us200 = Dollars { amt: 200 };
    println!("{:?}", add_as_euros(&us100, &us200));
```

⇒ `Euros{amt: 237}`

Static Resolution (!)

```
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

    let us100 = Dollars { amt: 100 };
    let eu200 = Euros { amt: 200 };
    println!("{:?}", add_as_euros(&us100, &eu200));
```

⇒

Static Resolution (!)

```
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

     let us100 = Dollars { amt: 100 };
     let eu200 = Euros { amt: 200 };
     println!("{:?}", add_as_euros(&us100, &eu200));
```

```
error: mismatched types: expected `&Dollars`
       but found `&Euros` (expected struct Dollars
       but found struct Euros)
      println!("{:?}", add_as_euros(&us100, &eu200));
                                            ^~~~~~
```

Dynamic Dispatch

```
fn add_as_euros<C:Currency>(a: &C, b: &C) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

fn accumeuros(a: &Currency, b: &Currency) -> Euros {
    let sum = a.to_euros().amt + b.to_euros().amt;
    Euros{ amt: sum }
}

let us100 = Dollars { amt: 100 };
let eu200 = Euros { amt: 200 };
println!("{:?}", accumeuros(&us100 as &Currency,
                            &eu200 as &Currency));
```

⇒ `Euros{amt: 279}`

Scala / Rust: value model (move semantics)

- In JVM-based languages, one holds references to heap-allocated values.
- Passing one parameter == copy one word
  - (a word-sized atom, or a tagged pointer to block on heap)
- Things are different in Rust.

Inlined representations

playpen (http://is.gd/pzY6p9)

```
use std::mem::size_of;
enum Lonely<A> { One(A), Two(A, A) }
let size =
    size_of::<Lonely<(int,int,int,int,int)>>();
let word_size = size_of::<int>();
println!("words: {}", size / word_size);
```

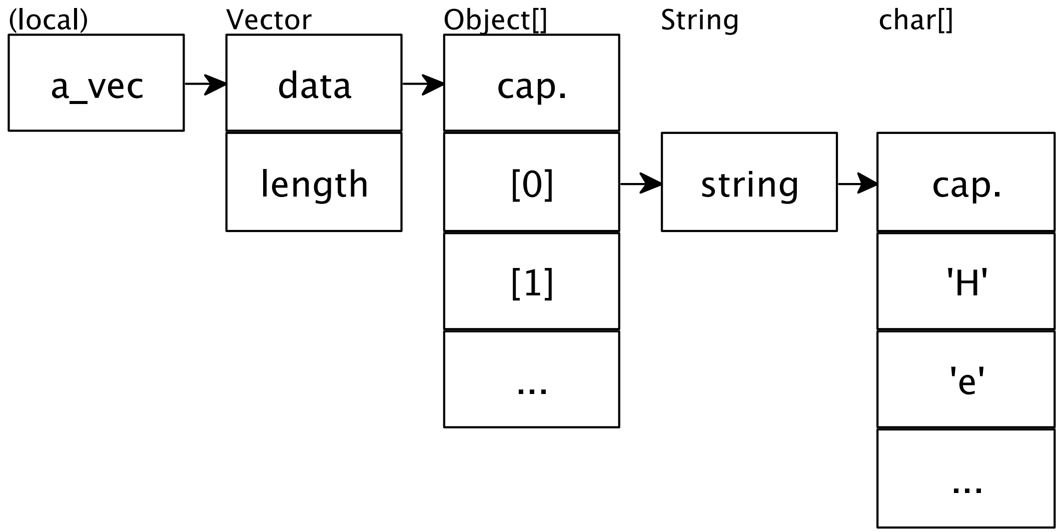
- Prints `words: 11`
- Here is how Rust represents a `Two`

(Two)	1	2	3	4	5	1	2	3	4	5

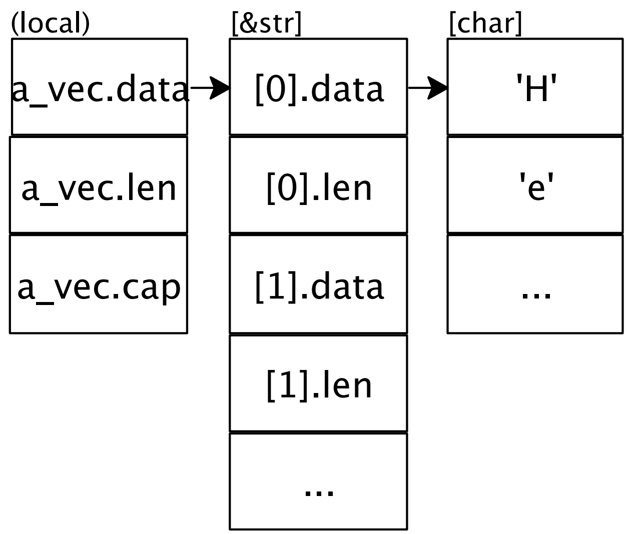
- Here is how Rust represents a `One`

(One)	1	2	3	4	5					

Zero-cost abstraction: Memory Representation



Java heap:



Rust heap:

Implications

To Move or To Copy?

can't build: playpen (http://is.gd/kYJQzk)

```
fn twice<T:Show>(x: T, f: fn (T) -> T) -> T {
    let w = f(x);
    println!("temp w: {}", w);
    let y = f(x);
    println!("temp y: {}", y);
    let z = f(y); return z;
}
```

```
error: use of moved value: `x`
let y = f(x);
          ^
note: `x` moved here because it has non-copyable
      type `T` (perhaps use clone()?)
let w = f(x);
          ^
```

What sleight of hand is this?

- "You said ’move semantics’; looks like linear or affine types."
- Did we not see a bunch of examples earlier like:

```
let y = { let x = 2 + 3; x > 5 };
if y { x + 6 } else { x + 7 }
```

- Obviously `x` is not being used linearly there
- Magic?

Clarke's third law

- It's not magic; it's the type system

Clarke’s third law

- It’s not magic; ~~it's the type system~~ it’s the type + trait system
- The **`Copy`** bound expresses that a type is freely copyable
  - and it is checked by the compiler
- Many built-in types implement **`Copy`**...
- ... but a type parameter with no given bounds does not.

To Move or To Copy? (II)

"Works": `playpen` (`http://is.gd/fOEE4C`)

```
fn twice<T:Show+Copy>(x: T, f: fn (T) -> T) -> T {
             // ^~~~~ new code here
    let w = f(x);
    println!("temp w: {}", w);
    let y = f(x);
    println!("temp y: {}", y);
    let z = f(y); return z;
}
```

but that's not the point.

- (Cannot generally just add **`Copy`** bounds)

Why all the fuss about move semantics?

Part I: Motivation

Part II: Rust syntax and semantics

Part III: Ownership and borrowing

How Rust handles pointers

Rust: Values and References

Life outside of ref-cells

There are three core types `T` to think about.

- `T` owned value
- `&T` shared reference
- `&mut T` mutable unaliased reference

okay there is `*T` too, aka `unsafe` pointers

  - (and library smart pointers like `Box<T>` or `Rc<T>`, but those are not core)

&T : shared reference

playpen (http://is.gd/aJ1TZx)

```
let x: int = 3;
let y: &int = &x;
assert!(*y == 3);
// assert!(y == 3); /* Does not type-check */

struct Pair<A,B> { a: A, b: B }
let p = Pair { a: 4, b: "hi" };
let y: &int = &p.a;
let (z1, z2) = (y, y); // &T impl's Copy for any T.
assert!(*y == 4);
```

&mut T : mutable unaliased reference

playpen (http://is.gd/sqVUIa)

```
let mut x: int = 5;
{
    let y = &mut x;
    increment(y);
}
assert!(x == 6);

fn increment(r: &mut int) {
    *r = *r + 1;
}

let y = &mut x;
// let (z1, z2) = (y, y); /* Does not type-check */
```

pattern matching and refs: Why

playpen (http://is.gd/O05OXc)

```
struct Pair<A,B> { a: A, b: B }
fn add_b_twice<T>(p: Pair<int,T>,
                  f: fn (&T) -> int) -> int {
  match p {
    Pair{ a, b } => {
        //   ^ `p.b` is moved into `b` here, so
        // cannot compile: use of moved value: `p.b`
        a + f(&b) + f(&p.b)
    }
  }
}
```

pattern matching and refs: How

playpen (http://is.gd/Npbf17)

```
struct Pair<A,B> { a: A, b: B }
fn add_b_twice<T>(p: Pair<int,T>,
                  f: fn (&T) -> int) -> int {
  match p {
    Pair{ a, ref b } => {
        //   ^ now `p.b` is left in place, and
        // `b` is bound to a `&T` instead of a `T`.
        // (even happens when `p` is Copy!)
        a + f(b) + f(&p.b)
    }
  }
}
```

Why all the fuss about aliasing?

It is for type soundness

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/jPR99P)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* WATCH: */ *p2 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

- (punchline: above is fine; `rustc` accepts it)

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/8WqUji)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* was p2 */ *p1 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/CAO0LG)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* was p2 */ *p1 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

- (punchline: above is badness; `rustc` rejects it)

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/ql9yce)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            unsafe { *(p1 as *mut E)=B(7); }
            println!("{}", (*adder)(14));
} } }
```

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/TxPLzy)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);           let mut b = B(17);
let m1 = &mut a;               let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            unsafe { *(p1 as *mut E)=B(7); }
            println!("{}", (*adder)(14));
} } }
```

- Emphasis: `unsafe` means "can crash."

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/Kbyb9z)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m2);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* watch? */ *p2 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

- (reminder: above is fine; **`rustc`** accepts it)

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/RoHtew)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);              let mut b = B(17);
let m1 = &mut a;                  let m2 = &mut b;
foo(m1, m1);

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* watch? */ *p2 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

- what changed, nothing in `foo`...

mutable aliasing ⇒ soundness holes

playpen (http://is.gd/4MQeii)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let mut a = A(add3);            let mut b = B(17);
let m1 = &mut a;                let m2 = &mut b;
foo(m1, m1); // <~~ AHHHHH

fn foo(p1: &mut E, p2: &mut E) {
    match p1 {
        &B(..) => fail!("cannot happen"),
        &A(ref adder) => {
            /* watch? */ *p2 = B(0xBadC0de);
            println!("{}", (*adder)(14));
} } }
```

- (punchline: above is badness; **rustc** rejects it)

Why all the fuss about move semantics?

Allows us to reason about aliasing

Mutable aliasing ⇒ dynamic errors

```
import java.util.Stack;
import java.util.Iterator;

def push_all[A](i: Iterator[Int], s: Stack[Int]) {
  while (i.hasNext) {
    var e = i.next(); s.push(e);
  }
}
var s1 = new Stack[Int]();
var s2 = new Stack[Int]();
for (i <- 1 to 4) { s1.push(i) }
push_all(s1.iterator(), s2);
println("s1: " + s1 + " s2: " + s2);
```

(This works)

```
s1: [1, 2, 3, 4] s2: [1, 2, 3, 4]
```

Mutable aliasing ⇒ dynamic errors

```
import java.util.Stack;
import java.util.Iterator;

def push_all[A](i: Iterator[Int], s: Stack[Int]) {
  while (i.hasNext) {
    var e = i.next(); s.push(e);
  }
}
var s1 = new Stack[Int]();
var s2 = new Stack[Int]();
for (i <- 1 to 4) { s1.push(i) }
push_all(s1.iterator(), s1);
println("s1: " + s1 + " s2: " + s2);
```

(This breaks, at runtime)

`java.util.ConcurrentModificationException`

Iterator invalidation in Rust

playpen (http://is.gd/pQC2en)

```
fn push_all<'a,I>(i: I, s: &mut Vec<int>)
    where I:Iterator<&'a int> {
    let mut i = i;
    for e in i {
        s.push(*e);
    }
}
let mut s1 : Vec<int> = Vec::new();
let mut s2 : Vec<int> = Vec::new();
for i in iter::range_inclusive(1, 4) { s1.push(i); }
push_all(s1.iter(), &mut s2);
println!("s1: {} s2: {}", s1, s2);
```

(Again, this works)

```
s1: [1, 2, 3, 4] s2: [1, 2, 3, 4]
```

Iterator invalidation in Rust

playpen (http://is.gd/IJN14m)

```
fn push_all<'a,I>(i: I, s: &mut Vec<int>)
    where I:Iterator<&'a int> {
    let mut i = i;
    for e in i {
        s.push(*e);
    }
}
let mut s1 : Vec<int> = Vec::new();
let mut s2 : Vec<int> = Vec::new();
for i in iter::range_inclusive(1, 4) { s1.push(i); }
push_all(s1.iter(), &mut s1);
println!("s1: {} s2: {}", s1, s2);
```

```
error: cannot borrow `s1` as mutable because it is
also borrowed as immutable
```

Lifetimes

- Earlier claim: **`&T`** is shared reference
- Does this mean you can copy it anywhere you like?
- Of course not; must disallow dangling pointers

Reality of types

- Core types are not really **`&T`** and **`&mut T`**
- They are really **`&'a T`** and **`&'b mut T`**
  - **`'IDENT`** is distinguished syntax for lifetime parameters
  - (similar to "regions" used by Tofte/Talpin 1994)
- **`x: &'a T`** means x is a reference that will survive at *least* as long as **`'a`** and perhaps longer
  - implicitly, **`T`** itself must also live that long

Reality of functions

A function

```
fn foo(x: &int, y: &int)
```

is really sugar for the more explicit form

```
fn foo<'a,'b>(x: &'a int, y: &'b int)
```

You can also put in bounds:

```
fn baz<'a,'b:'a>(x: &'a int, y: &'b int)
```

meaning `'b` lives at least as long as `'a` (and perhaps longer)

Reality of structs / enums

- Did you notice that none of the examples put references inside structs?
- Rust requires explicit lifetimes on reference-types in fields.
  - which effectively means such structs need to be lifetime-parametric

```
let y : int = 3;
struct S<'a> { x: &'a int }
let z : S    = S { x: &y };
```

playpen (http://is.gd/xCt1tX)

Is every kind of mutability forced into a linearly passed type?

There two kinds of mutatibility in Rust:

- Inherited
- Interior

(remember: goal is to prevent data-races; not to hamstring developers)

Inherited mutability

playpen (http://is.gd/ZUj4Jg)

```
struct S { x: int, y: int }
let a = S { x: 3, y: 4 }; // a.x and a.y *immutable*
let mut b = a;            // b.x and b.y are mutable
let mut c = b;            // c.x and c.y are mutable
b.x = 5; b.y = 6;

struct T<'l> { p: &'l S,
               q: &'l mut S }
let u;
u = T { p: &b, q: &mut c };
u.p.x = 7;
```

Inherited mutability

playpen (http://is.gd/Yb0Zg2)

```
struct S { x: int, y: int }
let a = S { x: 3, y: 4 }; // a.x and a.y *immutable*
let mut b = a;            // b.x and b.y are mutable
let mut c = b;            // c.x and c.y are mutable
b.x = 5; b.y = 6;

struct T<'l> { p: &'l S,
               q: &'l mut S }
let u;
u = T { p: &b, q: &mut c };
u.p.x = 7;
```

you can't mutate `u.p.x` this way; `u` is not marked `mut`

Inherited mutability

playpen (http://is.gd/qqlCfu)

```
struct S { x: int, y: int }
let a = S { x: 3, y: 4 }; // a.x and a.y *immutable*
let mut b = a;            // b.x and b.y are mutable
let mut c = b;            // c.x and c.y are mutable
b.x = 5; b.y = 6;

struct T<'l> { p: &'l S,
               q: &'l mut S }
let mut u;
u = T { p: &b, q: &mut c };
u.p.x = 7;
```

Inherited mutability

playpen (**http://is.gd/1CtD1D**)

```
struct S { x: int, y: int }
let a = S { x: 3, y: 4 }; // a.x and a.y *immutable*
let mut b = a;              // b.x and b.y are mutable
let mut c = b;              // c.x and c.y are mutable
b.x = 5; b.y = 6;

struct T<'l> { p: &'l S,
               q: &'l mut S }
let mut u;
u = T { p: &b, q: &mut c };
u.p.x = 7;
```

you can't mutate **`u.p.x`** this way; **`u.p`** is not **`&mut`**

Inherited mutability

playpen (http://is.gd/BlhZ4O)

```
struct S { x: int, y: int }
let a = S { x: 3, y: 4 }; // a.x and a.y *immutable*
let mut b = a;            // b.x and b.y are mutable
let mut c = b;            // c.x and c.y are mutable
b.x = 5; b.y = 6;

struct T<'l> { p: &'l S,
               q: &'l mut S }
let mut u;
u = T { p: &b, q: &mut c };
u.q.x = 7;
```

(this one works; path all way down **`u.q.x`** is marked **`mut`**)

Inherited mutability in summary

Inherited mutability: if you own something or have exclusive access to it, you can modify it.

- You just might need to move it into a local slot marked **`mut`** first.
- But the inverse does not hold!

Interior mutability

Library types **`Cell`** and **`RefCell`** can be modified via shared references

- **`Cell<T>`**: provides **`get`** and **`set`** methods
  - easy access, but only usable for **`T : Copy`**
  - for other types, must use ...
- **`RefCell<T>`**: you claim temporary exclusive access.
  - Compiler does not check your claim!
  - Dynamically checked; task failure if you broke rules.

Demo of Cell<T>

playpen (http://is.gd/NamYS4)

```
enum E { A(fn (int) -> int), B(int) }
fn add3(x:int) -> int { x + 3 }
let a = Cell::new(A(add3)); let b = Cell::new(B(17));
let c1 = &a;                let _c2 = &b;
foo(c1, c1);

fn foo(p1: &Cell<E>, p2: &Cell<E>) {
    match p1.get() {
        B(ref _val) => fail!("cannot happen"),
        A(ref adder) => {
            println!("{:X}", p1.get());
            p2.set(B(0xBadC0de));
            println!("{:d}", (*adder)(14));
            println!("{:X}", p1.get());
        }
    }
}
```

(this is fine!)

Back to inherited vs interior

So what does the **`mut`** marker actually mean?

- **`mut`** does not mark all and only "mutable things".
  - It marks the items for which, at some point, someone wants *exclusive access* to do some operation (often mutation).

Topics not covered

- subtype relation of `&'a T` and `&'b T` induced by `'b:'a`
- borrow-checking static analysis rules
- Rust and closures

Join the Fun!

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community chat: **`irc.mozilla.org :: #rust`**

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