

CMSC 330: Organization of Programming Languages

Smart Pointers in Rust

Smart Pointers

- A **smart pointer** is a **reference plus metadata**, to provide additional capabilities
 - Originated in C++
 - Examples seen so far: **String**, **Vec<T>**
- Usually implemented as **structs**
 - Which must implement the **Deref** and **Drop** traits
- New ones we will see: **Box<T>**, **Rc<T>**
 - There are several others, such as **Ref<T>**
 - And you can make your own; see the book!

Box<T> Smart Pointers

- **Box<T>** values point to heap-allocated data
 - The **Box<T>** value (the pointer) is on the stack, while its pointed-to **T** value is allocated on the heap
 - Has **Deref** trait – can be treated like a reference
 - More later
 - Has **Drop** trait – will drop its data when it dies
- Uses?
 - **Reduce copying** (via an ownership move)
 - Create **dynamically sized objects**
 - Particularly useful for recursive types

Quiz 1

A `Box<T>` value points to heap-allocated data. Therefore, it cannot be dropped when the owner goes out of scope.

- A. True
- B. False

Quiz 1

A `Box<T>` value points to heap-allocated data. Therefore, it cannot be dropped when the owner goes out of scope.

- A. True
- B. False

Example: Linked List

- Naïve attempt doesn't work

- Compiler complains that it can't know the size of `List`
- The `Cons` case is “inlined” into the `enum`

```
enum List {  
    Nil,  
    Cons(i32, List)  
}
```

- Since a `List` is recursive, it could be basically any size

- Use a `Box` to add an indirection

- Now the size is fixed
 - `i32` + size of pointer
 - `Nil` tag smaller

```
enum List {  
    Nil,  
    Cons(i32, Box<List>)  
}
```

Creating a LinkedList

```
enum List {
  Nil,
  Cons(i32, Box<List>)
}

use List::{Cons, Nil};

fn main() {
  let list = Cons(1,
    Box::new(Cons(2,
      Box::new(Nil)))));
  ... // data dropped at end of scope
}
```

Deref Trait

- If **x** is an **int** then **&x** is a **&{int}**
 - Can use ***** operator to dereference it, extracting the underlying value
 - ***(&x) == x**
- Can use ***** on **Box<T>** types
 - **Deref** trait requires **deref (&self) -> &T** method
 - So that ***x** translates to ***(x.deref())**
- **deref** returns type **&T** and **not T** so as not to relinquish ownership from inside the **Box** type

Deref Coercion

- The Rust compiler automatically inserts one or more calls to `x.deref()` to get the right type
 - When `&T` required but value `x : U` provided, where `U` implements `Deref` trait
 - In particular, at function and method calls
- Also a `DerefMut` trait
 - Deref coercion works with this too (see Rust book)

Example

```
fn hello(x:&str) {
    println!("hello {}",x);
}
fn main() {
    let m = Box::new(String::from("Rust"));
    hello(&m); //same as hello(&>(*m)[..]);
}
```

- **&m** should have type **&str** to pass it to **hello**
- So, compiler calls **m.deref()** to get **&String**, and then **deref()** again to get **&str**

Drop Trait

- Provides the method `fn drop (&mut self)`
 - Called when the value implementing the trait dies
 - Should be used to **free the underlying resources**, e.g., heap memory
- **May not call drop method manually**
 - Would lead to a **double free** when Rust calls the method again at the end of a scope
 - Can call `std::mem::drop` function in some circumstances

Multiple Pointers to a Value

- What's wrong with this code?

```
fn main() {  
    let a = Cons(5,  
        Box::new(Cons(10,  
            Box::new(Nil)))) ;  
    let b = Cons(3, Box::new(a)) ;  
    let c = Cons(4, Box::new(a)) ; // fails  
}
```

- **Box::new** takes ownership of its argument, so the second **Box::new(a)** call fails since **a** not owned
- How to allow something like this code?

Rc<T> to the Rescue

- Smart Pointer that associates a **counter** with the underlying reference
- Calling **clone** copies the pointer, not the pointed-to data, and bumps the counter by one
 - By convention, call `Rc::clone(&a)` rather than `a.clone()`, as a visual marker for future performance debugging
 - In general, calls to `x.clone()` are possible issues
- Calling **drop** reduces the counter by one
- When the counter hits **zero**, the data is **freed**

Rc::clone “Shares” Ownership

```
enum List {
    Nil,
    Cons(i32, Rc<List>)
}

use List::{Cons, Nil};

fn main() {
    let a = Rc::new(Cons(5,
        Rc::new(Cons(10,
            Rc::new(Nil)))));
    let b = Cons(3, Rc::clone(&a));
    let c = Cons(4, Rc::clone(&a)); //ok
}
```

Nb. `Rc::strong_count` returns the current ref count

Quiz 2

`Rc::clone` produces a new pointer to the same value in the heap. Because it shares the reference, programmer has to destroy the pointed-to value.

- A. True
- B. False

Quiz 2

`Rc::clone` produces a new pointer to the same value in the heap. Because it shares the reference, programmer has to destroy the pointed-to value.

- A. True
- B. False

More

- See the Rust book for
 - How to get **more flexible borrowing** rules using `Ref<T>` and `RefCell<T>` types
 - Allows for **mutability**
 - How to use such pointers to make **useful tree-based datastructures**
 - With lifetimes that may extend beyond the creating scope
 - How you can end up with **reference cycles** leading to a **memory leak**
 - And how you can use `Weak<T>` types to prevent them
- Check out ***The Rustonomicon*** for how to implement your own smart pointers!
 - <https://doc.rust-lang.org/stable/nomicon/>