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 **`struct`s**
  - 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

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

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

- 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

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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/