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
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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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
    - 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

```rust
enum List {
    Nil,
    Cons(i32, Box<List>)
}
```
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 \textit{int} then \&\( x \) is a \&\{\textit{int}\}
  – Can use \* operator to dereference it, extracting the underlying value
    • \(*(\& x) == x\)

• Can use \* on \textbf{Box<T>} types
  – \textit{Deref} trait requires \texttt{deref(&self) \rightarrow &T} method
  – So that \*\( x \) translates to \*\( (x\texttt{.deref}()) \)

• \texttt{deref} returns type \&\( T \) and \texttt{not} \( T \) so as not to relinquish ownership from inside the \textbf{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

```rust
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?

```rust
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` is 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

```rust
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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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 \texttt{Ref<T>} and \texttt{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 \texttt{Weak<T>} types to prevent them

- Check out \textit{The Rustonomicon} for how to implement your own smart pointers!
  - \url{https://doc.rust-lang.org/stable/nomicon/}