CMSC 330: Organization of Programming Languages

Reference Counting
and Interior Mutability

Rust Ownership and Mutation

- Recall Rust ownership rules
  - Each value in Rust has a variable that's called its *owner*; there can be only one
  - When the owner goes out of scope, the value will be dropped

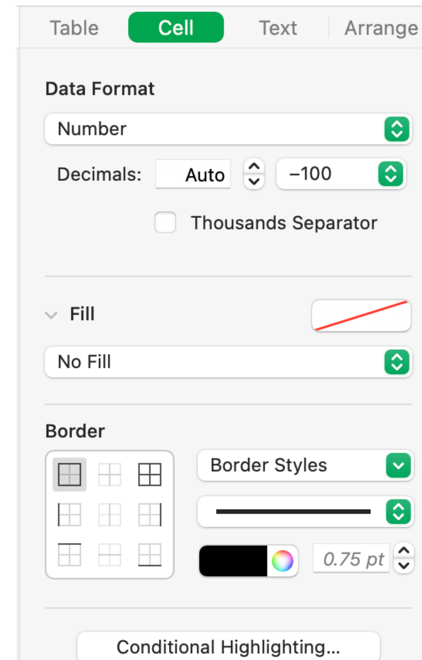
- Recall Rust mutability rules
  - Mutation can occur only through mutable variables (e.g., the owner) or references
  - Rust permits only one borrowed mutable reference (and no immutable ones at the same time)

But: Mutation and Sharing is Useful

- Example: a simple spreadsheet

```
struct CellStyle { fontSize: f64 }
struct Cell { style: CellStyle }
struct Table { cells: [Cell; 128] }
```

  - So: a `Table` *owns* its `Cells`



- But: a format inspector needs to read *and write* the cell data
  - Ensuring only one borrowed mutable reference would be awkward
  - Easier if the inspector has its own reference

Another Example

- Suppose you have a multiplayer chess game
  - Local data structures record the board state
  - Maybe the board is owned by the window that contains it

- What happens when a new move comes in from the network?
  - That's handled by a different software component, not the window

- Simplest design is to have multiple (mutable) references to the board
  - But Rust doesn't allow that

Relaxing Rust's Restrictions

- Architecturally, designating one owner that all accesses must go through can be awkward
  - We might end up wanting shared mutable access to the owner!

- Rust provides APIs by which you can get around the compiler-enforced restrictions against multiple mutable references
  - Use reference counting to manage lifetimes safely
  - Track borrows at run-time to overcome limited compiler analysis
  - Discipline is called interior mutability
  - But: extra checks at space and time overhead; some previous compile-time failures now occur at run-time

Multiple Pointers to a Value

- What's wrong with this code?

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

```
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 no longer the owner

- How to allow something like this code?
  – Problem: Managing lifetime

Managing Lifetimes Dynamically

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

- Benefit of ownership: compiler knows when to free memory

```
{
  let nil_box = Box::new(List::Nil);
  // free memory HERE (nil_box is going out of scope)
}
```

- Suppose **`Box`** *didn't* own its data:

```
let nil_box = Box::new(List::Nil);
let one_list = List::Cons(1, nil_box);
{
    let two_list = List::Cons(2, nil_box);
    // two_list is going out of scope; free nil_box too?
}
```

```
error[E0382]: use of
moved value: `nil_box`
```

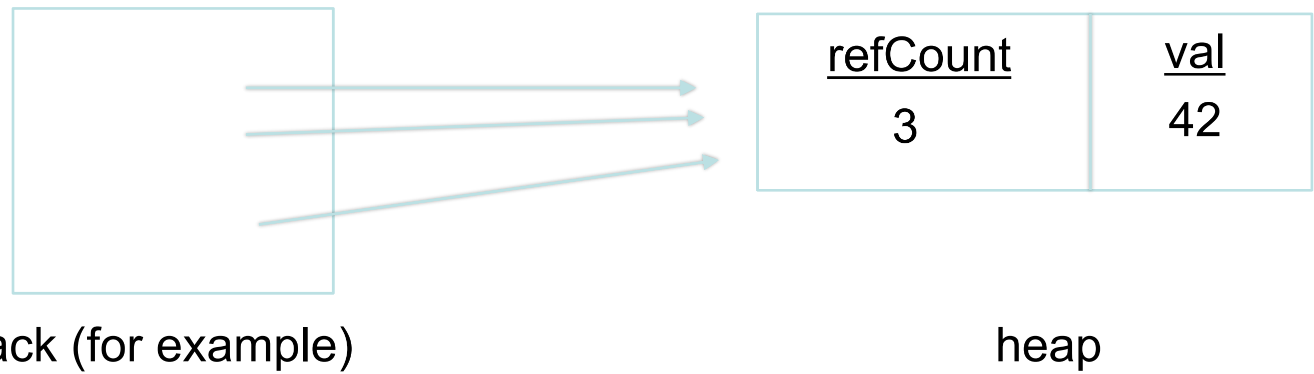
- (**`Box`** does own its data so the above pattern is not allowed.)

Rc<T>: Multiple Owners, Dynamically

- This is a *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

- **`Rc`** associates a refCount with the value



- **`let x = Rc::new(42);`**
- **`let y = Rc::clone(x);`**
- **`let z = Rc::clone(x);`**

does heap allocation, like Box::new, but uses reference counting

clone() increments reference count

clone() increments reference count

Lists with Sharing

```
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

Reference Counting: Summary

- To *create*: **`let r = Rc::new(...);`**
- To *copy* a pointer: **`let s = Rc::clone(&r);`**
  - Increments the reference count
- To *move* a reference: **`let t = s;`**
  - Does *not* increment reference count; **`s`** no longer the owner
- To *free* is automatic: **`drop`** is called when variables go out of scope, reducing the count; freed when 0

- See docs:
  - https://doc.rust-lang.org/book/ch15-04-rc.html
  - https://doc.rust-lang.org/std/rc/index.html