CMSC 330: Organization of Programming Languages

Closures and Iterators
In Rust

Closures

- Syntax
  - `|x1[:t1]? , …, xn[:tn]?| [-> u]? e`
    - Type annotations are optional – will be inferred if absent
- Evaluation
  - A closure is a value
- Type checking
  - has type `(t1, … ,tn) -> u`

    when `e` : `u` under assumptions `x1` : `t1`, …, `xn` : `tn`
    - Not curried

Using Closures/Functions Locally

- Rust has local functions, and closures

```
fn moveit(l:bool,x:i32) -> i32 {
  let left = |x| x - 1;
  fn right(x:i32) -> i32 { x+1 };
  if l { left(x) }
  else { right(x) }
}
```

Closure (may have an environment)

Local function (no environment)

- OCaml local functions/closures

```
let moveit l x =
  let left =  fun x -> x - 1 in
  let right = fun x -> x + 1 in
  if l then   left x
  else        right x
```

Limits of Type Inference

- Rust infers non-polymorphic types

```
let id = |x| x;
let x = id(1); //infers x:i32
let y = id("hi"); //fails: &str ≠ i32
```

- OCaml infers polymorphic types

```
let f = fun x -> x in (* 'a -> 'a *)
let x = id 1 in
let y = id "hi" in (* OK *) …
```

- We'll see polymorphically typed closures shortly

Passing Closures as Arguments

- Each closure has a distinct type
  - Even if two closures have the same signature, their types are considered different
    - Such types are called *generative* types
- To specify the type of a closure (for a function parameter, say), use generics with trait bounds
  - **`Fn`** *t* *(will describe later)*
  - **`FnMut`** *t*
  - **`FnOnce`** *t*
- Functions (defined with **`fn f`**…) implement the above trait bounds too

Using the Fn Trait

Trait bound on **`T`** to specify type of **`f`**

```
fn app_int<T>(f:T,x:i32) -> i32
     where T:Fn(i32) -> i32
{
  f(x)}
fn main() {
  println!(“{}”,app_int((|x| x-1),1));
}
```

– But cannot write

```
fn app_int(f:(i32) -> i32,x:i32) -> i32
{ f(x) }
```

- Can also use function trait bounds in struct, enum, etc. definitions

Using the Fn Trait Polymorphically

```
fn app<T,U,W>(f:T,x:U) -> W
    where T:Fn(U) -> W
{
   f(x)
}
fn main() {
   println!("{}",app((|x| x-1),1));//i32
   let s = String::from("hi ");
   println!("{}",app(|x| x+"there",s));//String
}
```

Capturing Free Variables

```
fn main() {
    let x = 4;
    let equal_to_x = |z| z == x;
    let y = 4;
    assert!(equal_to_x(y))
} // true
```

Closure env captures **x**

- Note: fails if **equal_to_x** defined as a local function
  - Local functions do not have an environment

- Complication: What if **x** is owned?
  - Capturing it could move it or borrow (mut or immut)
  - Use various **Fn*X*** traits to specify what to do

Distinguishing Fn Trait Bounds

- **`FnOnce`** ***`t`*** *(where* ***`t`*** *is a func type)*
  - Consumes the variables it captures from its enclosing scope (i.e., moves or copies them)
  - Thus can only be called once
    - The call consumes ownership
- **`FnMut`** ***`t`***
  - Borrows captured variables mutably
- **`Fn`** ***`t`***
  - Borrows captured variables immutably, or copies
    - **`equal_to_x`** copied **`x`** due to its **`Copy`** trait
  - In general, try this first, and follow the compiler's advice if it doesn't work

Example use of FnOnce

```
let x = String::from("hi");
let add_x = |z| x+z; //captures x; is FnOnce
println!("x = {}",x); //fails
let s = add_x(" there");//consumes closure
let t = add_x(" joe");//fails, add_x consumed
```

Iteration using the `Iterator` Trait

- Recall an earlier example:

```
let a = vec![10, 20, 30, 40, 50];
for e in a.iter() {
  println!("the value is: {}", e); }
```

- The **`iter()`** method returns an *iterator*, i.e., a value with the **`Iterator`** trait

```
trait Iterator {
  type Item; //this is an associated type
  fn next(&mut self) -> Option<Self::Item>;
  … //default method impls
}
```

Unpacking the **`for`** syntax

- Each call to **`next`** advances the iterator
  - So it has to be **`mut`**

```
let a = vec![10, 20];
let mut iter = a.iter();
assert_eq!(iter.next(), Some(&10));
assert_eq!(iter.next(), Some(&20));
assert_eq!(iter.next(), None);
```

- calls to **`next`** produce immutable references to the values in **`a`**
  - else may call **`into_iter`** or **`iter_mut`** on **`a`** to get different sorts of references

`Iterator` Adaptors

- We can make one iterator from another
  - An iterator is consumed as it used; it is *lazy*
- This is a pattern for higher order programming
  - **`i.map(f)`** produces an iterator returning **`f(e)`** for each of **`i`**'s elements **`e`**
  - **`i.filter(f)`** produces iterator for **i**'s elements **`e`** such that **`f(e) == true`**
  - **`i.collect()`** converts an iterator into a vector
  - **`i.fold(a,f)`** is like OCaml's **`fold_right`**
    - **`fold_right f a v`** where **`v`** is the list corresponding to **`i`**
  - **`zip`**, **`sum`**, …

Examples

```
let a = vec![10,20];
let i = a.iter();
let j = i.map(|x| x+1).collect(); //[11,21]
let k = a.iter().fold(0,|a,x| x-a); //10
for e in a.iter().filter(|&&x| x == 10) {
  println!("{}",e);
} //prints 10
```

Quiz 1: Output of the following code

```
fn main(){
  let a = [0, 1, 2, 3, 4, 5];
  let mut iter2 = a.iter().map(|x| 2 * x);
  iter2.next();
  let t2 = iter2.next();
  println!("{:?}", t2)
}
```

A. Some(0)
B. Some(1)
C. Some(2)
D. Some(4)

Quiz 1: Output of the following code

```
fn main(){
  let a = [0, 1, 2, 3, 4, 5];
  let mut iter2 = a.iter().map(|x| 2 * x);
  iter2.next();
  let t2 = iter2.next();
  println!("{:?}", t2)
}
```

A. Some(0)
B. Some(1)
C. Some(2)
D. Some(4)

Notes

- You can make your own iterators too
  - Implement the Iterator trait
  - Several examples in the Rust Book
- Iterators perform extremely well
  - Better that for loops with explicit indexes!
  - This is because Rust aggressively optimizes the code it generates, e.g., by unrolling the iteration loop
  - So feel free to program using map, fold, zip, etc.