

# CMSC 330: Organization of Programming Languages

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Box Smart Pointer, Trait Objects

# Box<T> Smart Pointers

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- **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

# Example: Linked List

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- 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

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```
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

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- 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

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- 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, for when object is mutable
  - `Deref` coercion works with this too (see Rust book)

# Example

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```
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

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- Provides the method `fn drop (&mut self)`
  - Called when the value implementing the trait goes out of scope
  - 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



# Another Place Where Size Matters

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- Recall **Summarizable**

```
pub trait Summarizable {  
    fn summary(&self) -> String {  
        String::from("none")  
    }  
}  
  
impl Summarizable for i32 {...}
```

- Let's make a **general summary-printing function**
- First attempt: **fn print\_summary(s: Summarizable) {...}**
  - This means the caller *moves* (or copies, if `s` is `Copy`) the argument to the function when calling it (`s` is not a reference)
  - This means the *data* in the argument needs to be moved/copied
  - How many bytes long is the data? Don't know; **won't work**

# Still Not Right

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- Recall **Summarizable**

```
pub trait Summarizable {
    fn summary(&self) -> String {
        String::from("none")
    }
}

impl Summarizable for i32 {...}
```

- Second attempt, also **wrong**:

```
fn print_summary(s: &Summarizable) {
    print!("{}", s.summary());
}
```

- There are lots of implementations of **summary**
- Which one should be invoked?

# What's Missing: Receiver Type

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- This code was OK; why?

```
let x:i32 = 42;  
x.summarize();
```

- The compiler knows which `summarize` to call, since it knows `x:i32`

# Dynamic Dispatch

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```
fn print_summary(s: &Summarizable) {  
    print!("{}", s.summary());  
}
```

- Object oriented languages, like Java, accept code like the above because they have **dynamic dispatch**
  - The correct method is determined at run time
- To implement dispatch in Rust, we use **trait objects**
- A trait object **pairs data with runtime type information**
  - Think: `(42, "I am an i32!")`

# Trait Objects

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- Use type `dyn Summarizable`, wrapped in a `Box`

```
fn print_summarizable(s: Box<dyn Summarizable>) {  
    println!("{}", s.summary());  
}
```

- Callers simply use `Box` to put the data on the heap

```
pub fn main() {  
    let b = Box::new(42);  
    print_summarizable(b);  
}
```

# Why the Box?

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- Could we do this instead?

```
fn print_s(s: dyn Summarizable) {  
    println!("{}", s.summary());  
}
```

- **Error!**

```
17 | fn print_s(s: dyn Summarizable) {  
    |           ^ doesn't have a size known at compile-time  
    |  
    = help: the trait `Sized` is not implemented for `(dyn  
Summarizable + 'static)`  
help: function arguments must have a statically known size,  
borrowed types always have a known size
```

**Lesson: `dyn Summarizable` has different sizes; `Box<T>` has one**

# Box and Size

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- `Box<i32>` is a **pointer** to a heap-allocated `i32`
- `Box<dyn Summarizable>` is a **fat pointer** to a heap-allocated `Summarizable`
  - That is: (type information, pointer to data on the heap)

```
struct Enormous { // 512 bytes (4 * 128)
    a: [i32; 128],
}
```

```
impl Summarizable for Enormous {...}
```

```
println!("{}", std::mem::size_of::<Enormous>());
println!("{}", std::mem::size_of::<Box<Enormous>>());
println!("{}", std::mem::size_of::<Box<Summarizable>>());
println!("{}", std::mem::size_of::<Box<dyn Summarizable>>());
```

Example

512  
8  
Error  
16

# Box: a Kind of Smart Pointer

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- A **smart pointer** is a **reference plus metadata**, to provide additional capabilities
  - Originated in C++
  - Examples seen so far: **String**, **Vec<T>**, **Box<T>**
- Usually implemented as **structs**
  - Which must implement the **Deref** and **Drop** traits
- New ones we will see: **Cell<T>**, **Rc<T>**, **Ref<T>**, ...
- Check out *The Rustonomicon* for how to implement your own smart pointers!
  - <https://doc.rust-lang.org/stable/nomicon/>



# Summary

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- Use **Box**<*T*> to heap-allocate data, and reduce copying (via an ownership move)
  - Useful for non cyclic, immutable data structures
- Use **trait objects**, of type **Box**<dyn *Trait*>, to implement **dynamic dispatch**
  - For any trait type *Trait*
  - **Box** lets you use *fat pointers* for **dyn** trait objects, to provide runtime type information to enable dynamic dispatch
  - If you try to pass traits without **Box**, you may get errors about **Sized** because the compiler doesn't know how big things are