Programming Lanaugages (2)
Object-Oriented Programming Basics

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Classes and objects

- a *class* ≈ a data type definition + functions (*methods*) for it
- an *object* is a data instance created from a class definition

```
1  # define a class named rect
2  class rect:
3    def __init__(self, x, y, width, height):
4      self.x = x
5      self.y = y
6      self.width = width
7      self.height = height
8
9  r = rect(10,20,30,40) # create an instance (or an object) of rect
```

Methods

- ▶ ≈ functions
- ▶ unlike ordinary functions, a method of the same name can be defined for multiple classes (i.e., implemented differently)

```
1  class rect:
2    ...
3    # define a method named area
4    def area(self):
5      return self.width * self.height
6
7  class ellipse:
8    ...
9    # define another method named area
10   def area(self):
11     return self.radius * self.radius * math.pi
12
```

Dynamic dispatch

▶ when you call a method, which method gets called among many implementations is determined by the class argument(s) belong to

```
1  # shapes may have both rect and ellipse instances
2  for s in shapes:
3      ... s.area() ...
```

Language design points

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```

- ▶ in a code like the above, a variable s may take a value of different classes (types) over time *(polymorphism)*
- ▶ for languages that require type declarations, *how to declare/specify the type of* s *or* shapes*?*
- ▶ *does Go/Julia/OCaml/Rust require type declarations?*

Language design points

```
1  # shapes may have both rect and ellipse instances
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▶ more fundamentally, how can we guarantee, prior to execution, that *type errors (≈ application of non-existing methods) do not happen at runtime?*

▶ such property is called *type safety*

▶ an algorithm that checks type safety prior to execution is often called *static type checking*

▶ *does Go/Julia/OCaml/Rust guarantee type safety?*

Different approaches

- ▶ forgo static type checking and thus type safety (e.g., Python, javascript, Lisp, Smalltalk, …)
- ▶ disallow polymorphism altogether and make it (trivially) type-safe (e.g., Pascal)
- ▶ do some (loose) static type checking but allow polymorphism via unsafe casts between pointers (e.g., C/C++)
- ▶ allow polymorphism yet guarantee type safety via *subtypes*
  - ▶ *C is a subtype of P ($C \leq P$)* ≡ a value of C can be safely used wherever P is expected
  - ▶ allow $P \leftarrow C$ (assign a variable of type P a value of type C)

Different approaches to subtyping

- ▶ *subclass* vs. *interface*
  - ▶ a *subclass* that *inherits, extends or derives from* an existing class to make a subtype
  - ▶ an *interface* (or *trait, abstract class*, etc.) and a *(concrete) class* that *implements or conforms to* it
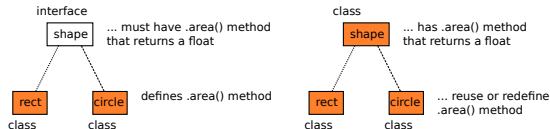
- ▶ *nominal (explicit)* vs. *structural* subtyping
  - ▶ nominal : subtype relation admitted only when so declared
  - ▶ structural : subtype relation admitted whenever appropriate (based on the structure)

How/if they guarantee type safety?

- following slides briefly explain how Go/Rust/OCaml guarantee *type safety*
- *type safety* $\equiv$ "no such methods" error never happens at runtime $\equiv$ when a program containing $o.m(\ldots)$ passes static type check, o always has method m at runtime
- recall that this is not the case for some languages (including Python, Julia, C++, etc.)

A common framework

- we (i.e., static type checker) like to guarantee that,
  - for any expression E whose *static type* is S,
  - any value E could take at runtime can be *safely put* in anywhere S is expected ($\approx$ any such value implements all the methods S specifies)
- for which we have to guarantee that, for any *assignment-like operations* $o = p$, any value p could take at runtime can be *safely put* in anywhere S is expected
- we want to check it by comparing p's static type (T) and o's static type (S)
- this is precisely what we like to capture by *subtype* relationship ($T \leq S$)

Note: assignment-like operations

▶ = any operation in which a value is stored to a
location of potentially different static type
   ▶ assignment to a variable/structure/array element
   ▶ function calls (passing values to parameters)
   ▶ function return (returning a value)

Subtype relationship

- T is a subtype of S ($T \leq S$)
- $\approx$ any value of T can be safely put anywhere S is expected
- $\approx$ T has all methods S has
- (this is not exactly correct, but suffices for now)

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- Q: when is a type T a subtype of another type S $(T \leq S)$?

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- ▶ A:
  - ▶ T has all the methods specified in S, and
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  2. when each of S and T is a function type ($S = a \rightarrow b$ and $T = a' \rightarrow b'$), then $b' \leq b$ and $a \leq a'$
  3. when each of S and T is an object type ($S = <m_0 : t_0, \ldots>$, $T = <m'_0 : t'_0, \ldots>$), then
     - ▶ $\{m_0, \ldots\} \subset \{m'_0, \ldots\}$ and
     - ▶ for each $m_i = m'_j$, $t'_j \leq t_i$