Introduction

Madhavan Mukund, S P Suresh

Programming Language Concepts

Lecture 1, 5 January 2023

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  Swift, Go, Rust, . . .

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  - Declarative — what is to be done
  - Imperative — how to do it

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Sum a list of numbers

Declarative

```
sum [] = 0
sum (x:xs) = x + sum xs
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Declarative

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sum (x:xs) = x + sum xs
```

Imperative

```
sum = 0
for x in l:
  sum = sum + x
```

Imperative programming

- Variables — types, storage allocation

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- Control flow

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- Control flow
- Abstraction
  - Control flow — functions and procedures
  - Data — complex data structures

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Abstract datatypes

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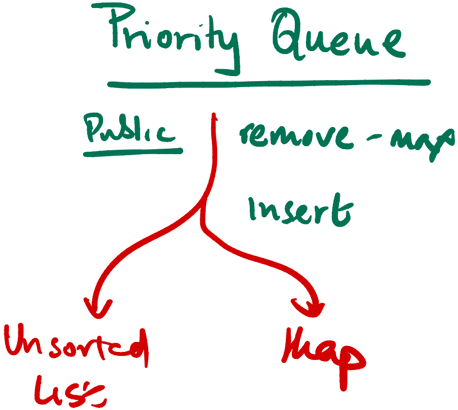
Abstract datatypes

- Public interface
- Private implementation



Course outline

Imperative programming

- Object oriented programming

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- Concurrent programming
  - Language support for concurrency

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Declarative programming

- Haskell and relatives
- Foundations — λ calculus

Alonzo Church

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Declarative programming

- Haskell and relatives
- Foundations — λ calculus
- Types and type inference

Abstraction, modularity, object-oriented programming

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Stepwise refinement

- Begin with a high level description of the task

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  print first thousand prime numbers
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- Refine the task into subtasks

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begin
  declare table p
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  integer array p[1:1000]
  for k from 1 through 1000
    make p[k] equal to the kth prime number
  for k from 1 through 1000
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- Program refinement — focus on code, not much change in data structures

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Data refinement

- Banking application
  - Typical functions: `CreateAccount()`, `Deposit()/Withdraw()`, `PrintStatement()`

Balances of all accounts

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- How do we represent each account?
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  - Overall, an array of balances
- Refine `PrintStatement()` to include `PrintTransactions()`
  - Now we need to record transactions for each account
  - Data representation also changes
  - Cascading impact on other functions that operate on accounts

Modular software development

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- Simplest example of a component: a function
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- Main challenge: suitable language to write specifications
  - Balance abstraction and detail, should not be another programming language!
  - Cannot algorithmically check that specification is met (halting problem!)

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- Object-oriented programming
  - Organize ADTs in a hierarchy
  - Implicit reuse of implementations — subtyping, inheritance

Objects

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- Distinguishing features of object-oriented programming
  - Abstraction
  - Subtyping
  - Dynamic lookup
  - Inheritance

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  - Use a generic simulation operation across different types of events
    - Avoid elaborate checking of cases

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- Data-centric view of programming
  - Focus on what data we need to maintain and manipulate
- Recall that stepwise refinement could affect both code and data
  - Tying methods to data makes this easier to coordinate
  - Refining data representation naturally tied to updating methods that operate on the data

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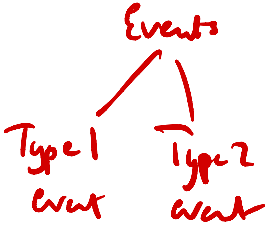

- Arrange types in a hierarchy
  - A subtype is a specialization of a type
  - If `A` is a subtype of `B`, wherever an object of type `B` is needed, an object of type `A` can be used
    - Every object of type `A` is also an object of type `B`
    - Think subset — if $X \subseteq Y$, every $x \in X$ is also in Y

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- If `f()` is a method in `B` and `A` is a subtype of `B`, every object of `A` also supports `f()`
  - Implementation of `f()` can be different in `A`

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- Dynamic lookup
  - A variable `v` of type `B` can refer to an object of subtype `A`
  - Static type of `v` is `B`, but method implementation depends on run-time type `A`

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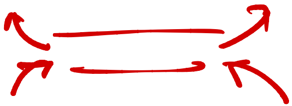
- Usually one hierarchy of types to capture both subtyping and inheritance
  - `A` can inherit from `B` iff `A` is a subtype of `B`
- Philosophically, however the two are different
  - Subtyping is a relationship of interfaces
  - Inheritance is a relationship of implementations

Subtyping vs inheritance

- A deque is a double-ended queue
  - Supports `insert-front()`, `delete-front()`, `insert-rear()` and `delete-rear()`



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- `Stack` and `Queue` inherit from `Deque` — reuse implementation

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- `Stack` and `Queue` inherit from `Deque` — reuse implementation
- But `Stack` and `Queue` are not subtypes of `Deque`
  - If `v` of type `Deque` points an object of type `Stack`, cannot invoke `insert-rear()`, `delete-rear()`
  - Similarly, no `insert-front()`, `delete-rear()` in `Queue`

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- `Stack` and `Queue` inherit from `Deque` — reuse implementation
- But `Stack` and `Queue` are not subtypes of `Deque`
  - If `v` of type `Deque` points an object of type `Stack`, cannot invoke `insert-rear()`, `delete-rear()`
  - Similarly, no `insert-front()`, `delete-rear()` in `Queue`
- Interfaces of `Stack` and `Queue` are not compatible with `Deque`
  - In fact, `Deque` is a subtype of both `Stack` and `Queue`

Summary

- Solving a complex task requires breaking it down into manageable components
  - Top down: refine the task into subtasks; Bottom up: combine simple building blocks
- Modular description of components — interface and specification
  - Build prototype implementation to validate design
  - Reimplement the components independently, preserving interface and specification
- PL support for abstraction
  - Control flow: functions and procedures
  - Data: Abstract data types, object-oriented programming
- Distinguishing features of object-oriented programming
  - Abstraction: Public interface, private implementation, like ADTs
  - Subtyping: Hierarchy of types, compatibility of interfaces
  - Dynamic lookup: Choice of method implementation is determined at run-time
  - Inheritance: Reuse of implementations