CMPT 373
Software Development Methods

Types, Polymorphisms, & Composition

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  - Easier readability
  - Better toolability
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  - Many languages have incorporated them: Python, Ruby, JavaScript, …
  - ***They limit what a program can do***
- To understand why the last point is good, let us consider what a type *is*

What are types?

- A *type* comprises
  - a set of values and
  - how those values may be used

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- In a *statically typed* language, we can describe the set of values ahead of time, without running the code
  - This enables problems to be found in advance
  - It also enables tools to provide better assistance

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  - One solution was through *polymorphism* – types comprising sets of types

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  - Coercion

There are more,
but we won’t discuss them

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Ad hoc

- *Universal polymorphisms* define types that can comprise an *infinite* number of other types with a *common* structure

Polymorphisms

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```
template<typename T>
T&
min(T& first, T& second) {
  return (first < second)
    ? first : second;
}
```

common structure

n (subtyping & inheritance)

sm (templates, generics, …)

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Polymorphisms

```
public class Cat
   extends Comparable<Cat> {
   ...
   @Override
   boolean compareTo(Cat other)
   ...
}
```

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```
public static <T extends Comparable<T>>
T
min(T first, T second) {
   return (first.compareTo(second) < 0)
     ? first : second;
}
```

common structure

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- *Ad hoc polymorphisms* define types that can comprise a *finite* set of explicitly specified types with *even disparate* structure

P

```
int
add(int first, int second) {
   return first + second;
}
```

```
String
add(const String& s1,
    const String& s2) {
  String result{s1};
  result.append(s2);
  return result;
}
```

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disparate structure

```
auto x = add(1, 2);
auto y = add(“hello”, “ world”);
```

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class string_view {
  string_view(const char *);

  string_view(const std::string&);

  template <size_t N>
  string_view(const char[N]);

  template <size_t N>
  string_view(const std::array<char,N>&);
  ...
```

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```
bool
endsInING(string_view view) {
  return view.ends_with(“ing”);
}
```

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One implementation,
coercion at the call site

```
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endsInING(string_view view) {
  return view.ends_with(“ing”);
}
```

```
endsInING(“reading”);
endsInING(std::string{“writing”});

std::array act = {‘a’,’c’,’t’,’i’,’n’,’g’};
endsInING(acting);
```

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- *Ad hoc polymorphisms* define types that can comprise a *finite* set of explicitly specified types with *even disparate* structure
- All forms of polymorphism have **benefits** & **costs**, but junior developers often struggle with *inheritance* vs *parametricity*

Runtime **vs** Parametric Polymorphism (commonly)

- Parametric polymorphism
  - Defines a fresh type for new parameters

std::array<int,5> != std::array<int,6>

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This means:
They may have different sizes.
They cannot be stored in a single collection.
...

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  - Hides the specific type from users of that type (decoupling)

```
void foo(Base&);
```

```
Derived1 d1;
foo(d1);
```

```
Derived2 d2;
foo(d2);
```

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  - Subtypes can be compiled separately (dynamically loaded, plug-in based, …)

Runtime & Parametric Polymorphism

- Combining them carefully leads to powerful results
  - Done *well*, you get the *strengths* of both (powerful good)
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- Parametric *derived* classes create a family of types satisfying an interface

```
class Base {
  virtual void foo() = 0;
};
```

```
template<typename T>
class Derived : public Base {
  void foo() override { ... }
};
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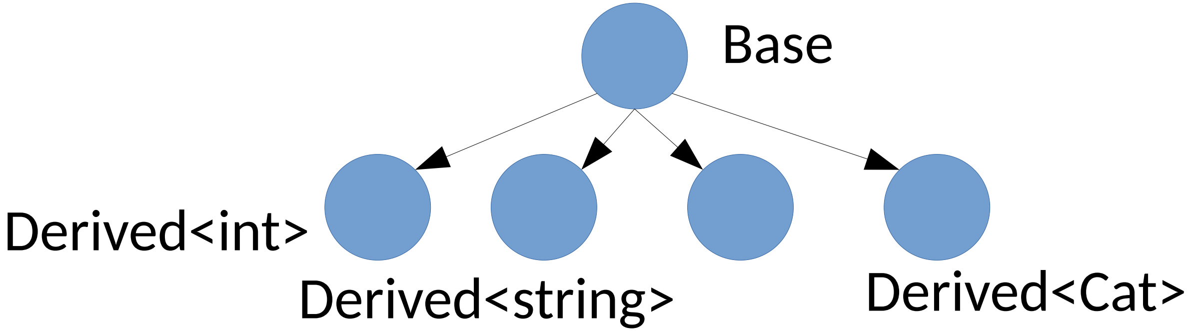

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This was just CRTP!

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  virtual void foo(Base&) = 0;
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What do the different sets of values mean?

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- Problems with poor inheritance usage are exacerbated by parametricity (significant additional overheads & complexity)

Runtime & Parametric Polymorphism

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    - Code should be
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```
class CrosswordGenerator {
  CrosswordGenerator(... clues)
    : clues{std::move(clues)}
      { }

private:
  std::unique_ptr<Clues> clues;
};
```

```
auto englishClues = ...
CrosswordGenerator cg{englishClues};
```

```
auto frenchClues = ...
CrosswordGenerator cg{frenchClues};
```

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```
template <typename WallCarver>
class MazeGenerator {
  MazeGenerator(WallCarver carver)
    : carver{std::move(carver)}
      { }

private:
  WallCarver carver;
};
```

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Polymorphism makes designing
around decisions easier!

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  - We have seen this before with higher order functions & lambdas!

Runtime & Parametric Polymorphism

```
bool
contains3(const Collection& c) {
  for (const auto& element : c) {
    if (c == 3) {
      return true;
    }
  }
  return false;
}
```

principle

to customize)

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```

```
template <typename Collection,
          typename Predicate>
bool
any_of(const Collection& c, Predicate p) {
  for (const auto& element : c) {
    if (p(c)) {
      return true;
    }
  }
  return false;
}
```

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```
any_of(elements,
  [](const auto& e) { return e == 3; });
```

Composition

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`char`

256 values

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∞ values

Composition

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```
char
```

256 values

```
struct Pair {
  char a;
  char b;
};
```

256^2=65536 values

```
class Base {
  virtual void foo() = 0;
};
```

∞ values

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```
enum Colors {
  RED,ORANGE,YELLOW,
  GREEN,BLUE,PURPLE
};
```

6 values

```
char
```

256 values

```
struct Pair {
  char a;
  char b;
};
```

256^2 =65536 values

```
class Base {
  virtual void foo() = 0;
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```

∞ values

Composition

- Plain composition is still simpler than polymorphism, but it makes satisfying the open/closed principle harder
- By thinking of types as sets of values it still offers some tactics

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enum Message {
  Quit,
  Move { x: i32, y: i32 },
  Write(String)
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[From the Rust Book]

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- ***Algebraic data types*** can be constructed through basic relational compositions of values
  - *product types* are records
  - *sum types* are discriminated unions
- Operations on sum types use ***pattern matching*** to require that all possible values are handled
  - This is even enforced by the compiler!

Composition

```
enum Message {
    Quit,
    Move { x: i32, y: i32 },
    Write(String)
}
let msg = Message::Quit;
match msg {
    Message::Quit => {
        println!("The Quit variant has no data to destructure.")
    },
    Message::Move { x, y } => {
        println!("Move {} and {}", x, y);
    },
    Message::Write(text) => println!("Text message: {}", text),
}
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[From the Rust Book]

Composition

- What do sum types look like in e.g. C++ or Java?

```
using Message =
  std::variant<Quit, Move, Write>;
```

```
struct Action {
  void operator()(const Quit&) {...}
  void operator()(const Move&) {...}
  void operator()(const Write&) {...}
};
...
  Message m = Quit{};
  std::visit(Action{}, m);
```

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  std::visit(Action{}, m);
```

```
public enum Message {
  QUIT,
  MOVE,
  WRITE {
    void bar() {...}
    @Override
    void foo() {...}
  };

  Message() {...}
  ...
  public void foo() {}
}
```

Composition

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  Message m = Quit{};
  std::visit(Action{}  m);
```

```
public enum Message {
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  MOVE,
  WRITE {
    void bar() {...}
    @Override
    void foo() {...}
  };

  Message() {...}
  ...
        c void foo() {}
```

But both languages are moving toward full pattern matching!

Composition

- What *may* pattern matching look like in e.g. C++ or Java?

```
Message m = ...
inspect (m) {
 <Quit> q:   ...;
 <Move> o:   ...;
 <Write> w:  ...;
}
```

```
int
get_area(const Shape& shape) {
  return inspect (shape) {
    <Circle>     [r]     => 3.14 * r * r,
    <Rectangle> [w, h] => w * h
  }
}
```

[Pattern Matching, p1371r0]

Composition

- What *may* pattern matching look like in e.g. C++ or Java?

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Message m = ...
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```
int
get_area(const Shape& shape) {
  return inspect (shape) {
                         => 3.14 * r * r,
               h] => w * h
```

```
Message m = ...
Result r = switch (m) {
   case QUIT q  -> ...;
   case MOVE o  -> ...;
   case WRITE w -> ...;
};
```

[Pattern Matching for Java]

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Summary

- By thinking of types as sets of values,
  we can carefully design types that help ensure
  correctness, flexibility, & performance
- Four(!) major forms of polymorphism have been in use for decades that give us significant power when designing our types
- Algebraic data types use composition of types to provide safe and convenient handling of finite sets of types
- All of these approaches have tradeoffs