INHERITANCE & TEMPLATES: TWO KINDS OF GENERALIZATION

LECTURE 12-2

JIM FIX, REED COLLEGE CS2-S20

TODAY'S PLAN

- FINISH INHERITANCE
  - ACCOUNT EXAMPLES
  - DYNAMIC DISPATCH WITH `virtual`
  - SHAPE EXAMPLE
- TEMPLATES
- A SURVEY OF THE C++ STANDARD TEMPLATE LIBRARY (or ***C++ STL***)

CS FACULTY CANDIDATES THIS/NEXT WEEK…

- **Today/Wednesday @4:30pm over Zoom:**

  Tanya Amert, University of North Carolina

  "Enabling Real-Time Certification of Autonomous-Driving Applications"

- **Next Monday @4:30pm over Zoom:**

  Sonia Roberts, University of Pennsylvania

  (Title forthcoming; will be on her robotics research.)

CLASS ACCOUNT AND ITS DERIVED CLASSES

- The full class hierarchy we'll flesh out...

- **Savings** accounts accrue 2% interest. They charge a penalty for withdrawal.

```
class Savings : public Account { ... }
```

- .

```
class Checking : public Account { ... }
```

- .

```
class Promotional : public Checking { ... }
```

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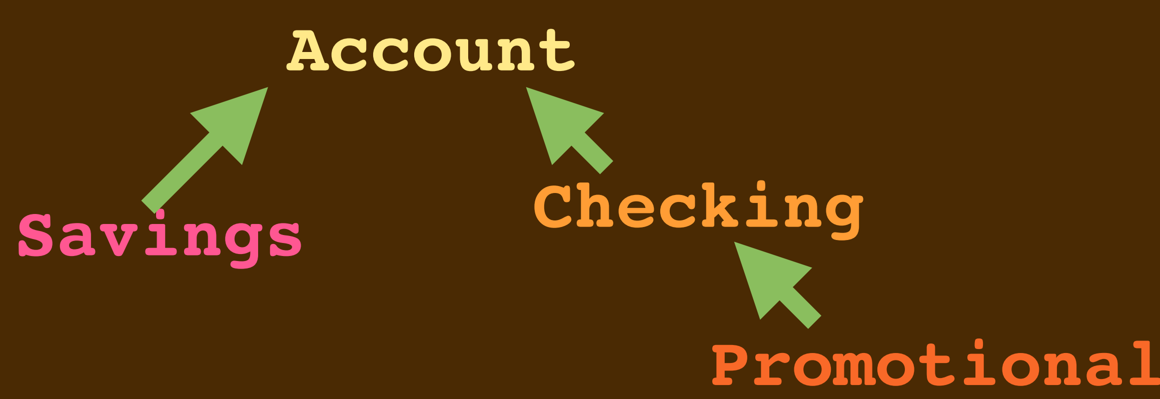

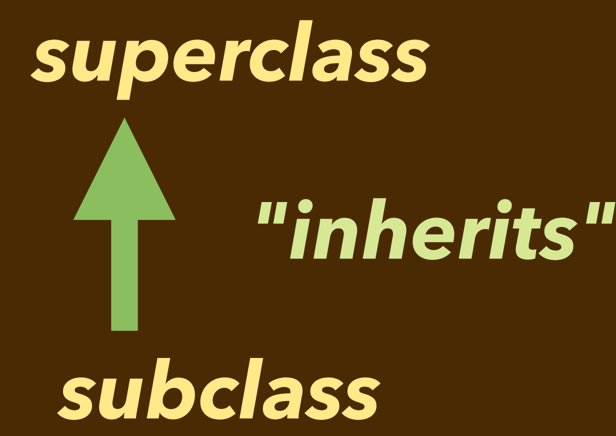

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class Checking : public Account { ... }
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- **Promotional** checking accounts accrue 0.7% interest, but give you $100 to open the account. You must stay above $100 to earn that interest.

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class Promotional : public Checking { ... }
```

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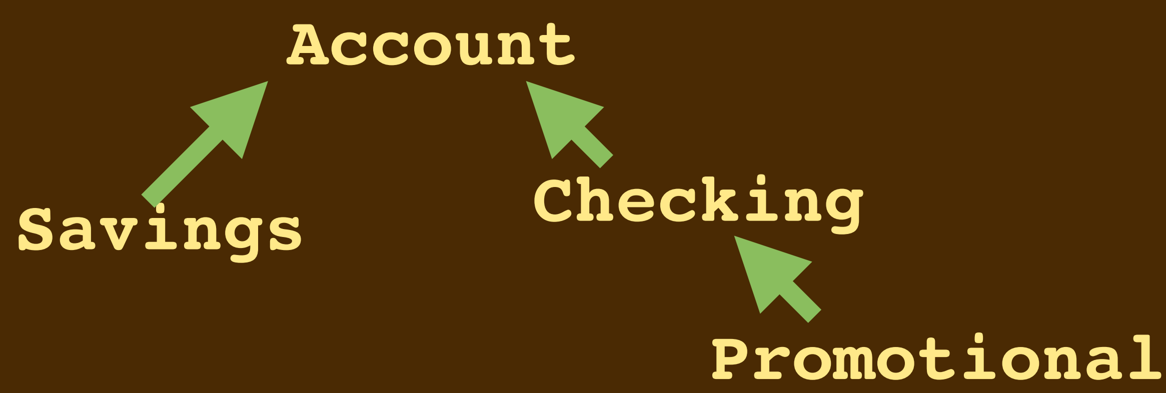

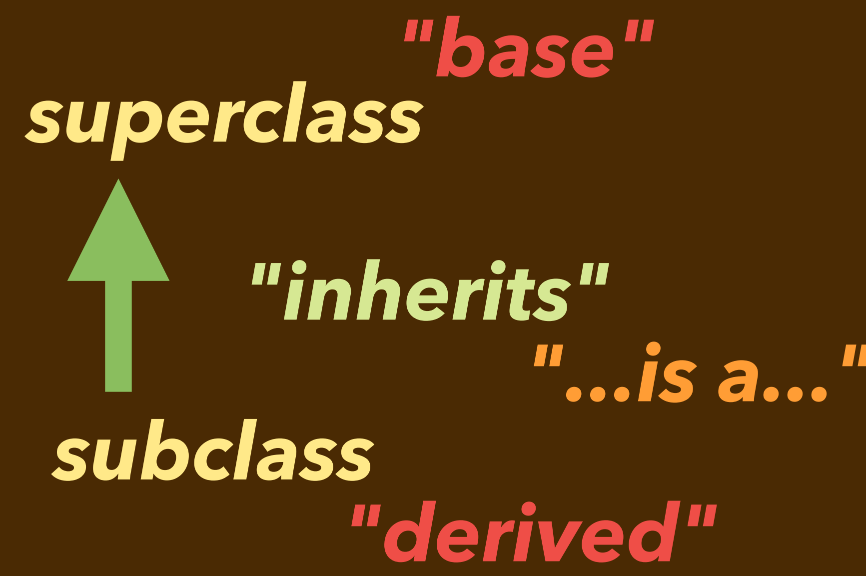

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```
class Promotional : public Checking { ... }
```

ACCOUNT CLASS, READIED FOR DERIVING

```
class Account {
private:
  static long gNextNumber; // used to generate account nos.
protected:
  // instance variables
  std::string name;          // description of the account
  long number;               // account no.
  double balance;            // money held
  double rate;               // monthly interest
public:
  ...
};
```

ACCOUNT CLASS, READIED FOR DERIVING

```
class Account {
private:
  static long gNextNumber;
protected:
  // instance variables
  std::string name;
  long number;
  double balance;
  double rate;
public:
  // methods
  ...
};
```

Not publicly accessible, but accessible to any derived class.

ACCOUNT CLASS, READIED FOR DERIVING

```
class Account {
private:
  static long gNextNumber;
protected:
  // instance variables
  ...
public:
  // methods
  Account(std::string name, double amount, double interest);
  virtual double getBalance() const;
  virtual std::string getName() const;
  virtual long getNumber() const;
  virtual double getRate() const;
  virtual void deposit(double amount);
  virtual void gainInterest();
  virtual double withdraw(double amount);
};
```

Virtual keyword indicates that the code of overriding methods in subclass will get called.

ACCOUNT CLASS IMPLEMENTATION (MISSING GETTERS)

```
Account::Account(std::string name, double amount, double
interest) : name {name},
            balance {amount},
            rate {interest},
            number {Account::gNextNumber++}
{ }

void Account::deposit(double amount) {
  balance += amount;
}
void Account::gainInterest() {
  deposit(rate * balance);
}
double Account::withdraw(double amount) {
  if (amount > balance) {
    amount = balance;
    balance = 0.0;
  } else {
    balance -= amount;
  }
  return amount;
}
```

SUBCLASSES OF ACCOUNT

- Example of a subclass **`Savings`** deriving from a base **`Account`**:

```
class Savings : public Account { ... }
```

- The keyword **`public`** means that...

SUBCLASSES OF ACCOUNT

- Example of a subclass **`Savings`** deriving from a base **`Account`**:

```
class Savings : public Account { ... }
```

- The keyword **`public`** means that
  - all public members are accessible as public in the derived class,
  - all protected members are accessible as protected in the derived class,
  - private members are only accessible if that subclass is a **`friend`**.

EXTENSIONS AND OVERRIDES

```
class Savings : public Account {
protected:
  double penalty;  // Savings accounts have a withdrawal penalty.
public:
  Savings(std::string name, double amount);
  double withdraw(double amount);  // Charges a penalty.
};

class Checking : public Account {
protected:
  double level;
public:
  Checking(std::string name, double amount);
  void gainInterest();
};

class Promotional : public Checking {
public:
  Promotional(std::string name, double amount);
};
```

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  double penalty;  // Savings accounts have a withdrawal penalty.
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class Promotional : public Checking {
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  Promotional(std::string name, double amount);
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EXTENSIONS AND OVERRIDES

```
class Savings : public Account {
protected:
  double penalty;
public:
  Savings(std::string name, double amount);
  double withdraw(double amount);
};

class Checking : public Account {
protected:
  double level; // Checking accounts gain interest above a level
public:
  Checking(std::string name, double amount);
  void gainInterest(); // Checks that level
};

class Promotional : public Checking {
public:
  Promotional(std::string name, double amount);
};
```

EXTENSIONS AND OVERRIDES

```
class Savings : public Account {
protected:
  double penalty;
public:
  Savings(std::string name, double amount);
  double withdraw(double amount);
};

class Checking : public Account {
protected:
  double level;
public:
  Checking(std::string name, double amount);
  void gainInterest();
};

class Promotional : public Checking {
public: // Promotional accounts are a special kind of checking
  Promotional(std::string name, double amount);     // account
};
```

SAVINGS ACCOUNT

Savings accounts accrue 2% interest. They charge a penalty for withdrawal.

- We add a **`penalty`** instance variable.

```
class Savings : public Account {
protected:
  double penalty;
public:
  Savings(std::string name, double amount);
  double withdraw(double amount);
};

Savings::Savings(std::string name, double amount) :
  Account {name,amount,0.02}, penalty {50.0}
{ }

double Savings::withdraw(double amount) {
  double howmuch = Account::withdraw(amount);
  Account::withdraw(penalty);
  return howmuch;
}
```

SAVINGS ACCOUNT

Savings accounts accrue 2% interest. They charge a penalty for withdrawal.

- We *override* the **withdraw** method to charge that penalty.

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class Savings : public Account {
protected:
  double penalty;
public:
  Savings(std::string name, double amount);
  double withdraw(double amount);
};

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SAVINGS ACCOUNT

Savings accounts accrue 2% interest. They charge a penalty for withdrawal.

- We rely on **`Account`**'s implementation in several places.

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  Account::withdraw(penalty);
  return howmuch;
}
```

CHECKING ACCOUNT

Checking accounts accrue 1% interest, but only if balance is above $1000.

- We add a `level` instance variable.

```
class Checking : public Account {
protected:
  double level;
public:
  Checking(std::string name, double amount);
  void gainInterest();
};

Checking::Checking(std::string name, double amount) :
  Account {name, amount, 0.01}, level {1000.0}
{ }

void Checking::gainInterest() {
  if (balance >= level) {
    Account::gainInterest();
  }
}
```

CHECKING ACCOUNT

Checking accounts accrue 1% interest, but only if balance is above $1000.

- We *override* the **`gainInterest`** method to check that level.

```
class Checking : public Account {
protected:
  double level;
public:
  Checking(std::string name, double amount);
  void gainInterest();
};

Checking::Checking(std::string name, double amount) :
  Account {name, amount, 0.01}, level {1000.0}
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void Checking::gainInterest() {
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CHECKING ACCOUNT

Checking accounts accrue 1% interest, but only if balance is above $1000.

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class Checking : public Account {
protected:
  double level;
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  Checking(std::string name, double amount);
  void gainInterest();
};

Checking::Checking(std::string name, double amount) :
  Account {name, amount, 0.01}, level {1000.0}
{ }

void Checking::gainInterest() {
  if (balance >= level) {
    Account::gainInterest();
  }
}
```

PROMOTIONAL (CHECKING) ACCOUNT

Promotional accrues less interest, has an opening gift, has lower threshold.

- It derives from **`Checking`**. There are no extensions or overrides.

```
class Promotional : public Checking {
public:
  Promotional(std::string name, double amount);
};


Promotional::Promotional(std::string name, double amount) :
  Checking {name, amount + 100.0}
{
  rate = 0.07;
  level = 100.0;
}
```

VIRTUAL METHODS: DISPATCH ACCORDING TO CONTENTS

- Consider these two class definitions

```
class A {
    ...
    virtual void m(...); // yes virtual
    ...
}
class B : public A {
    ...
    void m(...);
    ...
}
```

- Consider this client code

```
A *b = new B();
b->m(x);
```

- Since **`m`** is marked virtual, the code for **`B::m`** runs like we'd normally expect.
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    - This is sometimes called "***dynamic dispatch***" of the "message" **`m`**.

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  - Code run for **m** is determined by the **contents at b**, i.e. *at run time*.

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A *b = new B();
b->m(x);
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- Since **m** is marked virtual, the code for **B::m** runs like we'd normally expect. *dynamic!!*
  - Code run for **m** is determined by the **contents at b**, i.e. *at run time*.

NON-VIRTUAL METHODS: DISPATCH ACCORDING TO TYPE

- Consider these two class definitions

```
class A {
    ...
    void m(...); // NOTE: not virtual!!!
    ...
}
class B : public A {
    ...
    void m(...);
    ...
}
```

- Consider this client code

```
A *b = new B();
b->m(x);
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- Since **m** is not marked virtual, the code for **A::m** runs instead.
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    ...
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}
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- Consider this client code

```
A *b = new B();
b->m(x); //
```

- Since **m** is not marked virtual, the code for **A::m** runs instead*!!!!!!!*
  - This is sometimes called "***static dispatch***" of the "message" **m**.

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- Consider this client code

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A *a = new B();
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- Since **m** is not marked virtual, the code for **A::m** runs instead!!!!!!!
  - Code run for **m** is determined by the **type of b**, i.e. *at compile time*.

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- Consider this client code

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A *a = new B();
a->m(x);
```

- Since **m** is not marked virtual, the code for **A::m** runs instead!!!!!!! *static.*
  - Code run for **m** is determined by the **type of b**, i.e. *at compile time*.

WHY YOU WANT DYNAMIC DISPATCH

- Imagine We have the following hierarchy:

```
class Shape { virtual void draw(); ... };
class Oval : public Shape { void draw(); ... };
class Rectangle : public Shape { void draw(); ... };
```

- Consider this client code that has a linked list **`shapes`**:

```
ShapeNode* current = shapes->first;
while (current != nullptr) {
  current->shape->draw();
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-

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- Consider this client code that has a linked list of **`shapes`**:

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- In the above code, **`current->shape`** is of type **`Shape*`**.
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  - When the list node points to an **`Oval`** instance, **`Oval::draw`** is called.

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- In the above code, **`current->shape`** is of type **`Shape*`**.
- Because the **`draw`** method is **`virtual`**, dynamic dispatch is used.
  - When the list node points to an **`Oval`** instance, **`Oval::draw`** is called.
  - When it points to a **`Rectangle`**, **`Rectangle::draw`** is called.

ABSTRACT CLASSES

- Note that the **`Account`** class probably shouldn't have an instance.
  - Nonetheless, it does define a few methods useful to subclass instances:
    - ➡The **`deposit`** and **`withdraw`** methods as defined in **`Account`** provide a default behavior that subclasses may use, or override.

- Classes not meant to be instantiated are called ***abstract***.

"PURELY VIRTUAL" METHODS IN AN ABSTRACT BASE

- Can't always provide a "default" method behavior in an abstract base...
- In C++ we can designate methods as "purely virtual" with a value of 0:

```
class A {
   ...
   virtual T m(T1 v1, T2 v2, ...) = 0;
   ...
};

class B : public A {
   ...
   T m(T1 v1, T2 v2, ...) { ... /* actual behavior on B */ }
   ...
};
```

➡ Method **m** must be defined by classes that derive from abstract **A**.

"PURELY VIRTUAL" METHODS IN AN ABSTRACT BASE

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class B : public A {
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  ...
};
```

➡Method **m** must be defined by classes that derive from abstract **A**.

EXAMPLE: SHAPE HIERARCHY

```
class Shape {
public:
  virtual double perimeter(void) const = 0;
  virtual double area(void) const = 0;
  virtual void print(void) const = 0;
  virtual double getHeight(void) const = 0;
  virtual double getWidth(void) const = 0;
  Rectangle bounds(void);
};
```

CIRCLE SUBCLASS DERIVED FROM SHAPE

```
class Circle : public Shape {
private:
  double radius;
public:
  Circle(double r) : radius(r) { }
  double perimeter(void) { return 2.0 * M_PI * radius; }
  double area(void) { return M_PI * radius * radius; }
  void print(void); // This one's many lines long.
  double getHeight(void) { return 2.0 * radius; }
  double getWidth(void) { return 2.0 * radius; }
};

void Circle::print(void) const {
  cout << "A circle with radius " << radius << ":\n" << endl;
  int w = static_cast<int>(ceil(getWidth()));
  if (w == 1) {
    std::cout << "+" << std::endl;
    return;
  }
  ...
```

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    return;
  }
  ...
```

RECTANGLE SUBCLASS DERIVED FROM SHAPE

```
class Rectangle : public Shape {
private:
  double width;
  double height;
  void depict(void);
public:
  Rectangle(double w,double h) : width(w), height(h) { }
  double perimeter(void) { return 2.0 * (width + height); }
  double area(void) { return width * height; }
  void print(void);
  double getHeight(void) { return height; }
  double getWidth(void) { return width; }
  friend class Square;
};
```

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  void depict(void);
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  Rectangle(double w,double h) : width(w), height(h) { }
  double perimeter(void) { return 2.0 * (width + height); }
  double area(void) { return width * height; }
  void print(void);
  double getHeight(void) { return height; }
  double getWidth(void) { return width; }
  friend class Square;
};
void Rectangle::print(void) const {
  std::cout << "Here is a " << width << "x" << height;
  std::cout << " rectangle:\n" << std::endl;
  depict();
}
```

RECTANGLE SUBCLASS DERIVED FROM SHAPE

```
class Rectangle : public Shape {
private:
  double width;
  double height;
  void depict(void) const;
public:
  Rectangle(double w,double h) : width(w), height(h) { }
  double perimeter(void) { return 2.0 * (width + height); }
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SQUARE SUBCLASS DERIVED FROM RECTANGLE

```
class Rectangle : public Shape {
private:
  void depict(void);
public:
  ...
  friend Square;
}

class Square : public Rectangle {
public:
  Square(double s) : Rectangle {s, s} { }
  void print(void);
};

void Square::print(void) const {
  std::cout << "Here is a " << getWidth() << "x" << getHeight();
  std::cout << " square:\n" << std::endl;
  Rectangle::depict();
}
```

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}
```

SHAPE PROGRAM OUTPUT

```
Here is a circle with radius 5:

  ++++++
 ++++++++
++++++++++
++++++++++
++++++++++
++++++++++
++++++++++
++++++++++
 ++++++++
  ++++++

Here is a 7x3 rectangle:

+++++++
+++++++
+++++++

Here is a 1x1 square:

+
```

POLYMORPHISM IN PROGRAMMING LANGUAGES

- Some people say that subclassing provides ***polymorphism***
  - ***We can have a list of shapes, but the shapes can be of different types.***
  - ***poly*** **"multiple/many" + *morph* "shape/form"**

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- In general, a language construct that is "***polymorphic***" allows you to write one piece of code that handles many types of data.
  - Object-oriented languages typically have ***subtype polymorphism***.
  - C (with void*) and Python have ***ad hoc polymorphism***.

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  - Object-oriented languages typically have ***subtype polymorphism***.
  - C (with void*) and Python have ***ad hoc polymorphism***.
  - Many modern programming languages have ***parameterized polymorphism***.

CONTAINER POLYMORPHISM?

- **Recall:** our container classes have had to fixate their element type:

```
class IntStck { int* elements; ... };
class StringStck { std::string* elements; ...};
class ShapeStck { Shape** elements; ... };
```

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class Stck<T> { T* elements; ... };
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- ***Wouldn't it be nice*** if we could define `Stck` once to take many forms?

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class Stck<T> { T* elements; ... };
```

- ***That is:*** what if this one class definition could describe all these types???
  - `Stck<int>               // a stack of integers`
  - `Stck<std::string>       // a stack of strings`
  - `Stck<Shape*>            // a stack of shapes`

TEMPLATE CLASSES

- C++ also provides an ability to "abstract away" the defining types of a class:
- We can define a **`class A`** with type parameters **`T1,T2,...`** :

```
class A<T1, T2...> {
   ...
   // T1 and T2 used as type names throughout its definition
   ...
};
```

- Then the client code can stamp out different **`A`** types, like so:

```
A<int,std::string> a1 = ...;
A<char,bool> a2 = ...;
```

- The definition of **`class A`** provides a ***template*** for *different forms* of **`A`**.

EXAMPLE: TEMPLATE STACK CLASS (SEE STCK_T.HH)

```
template <class X>
class Stck {

private:
  int capacity;
  int num_elements;
  X *elements;

public:
  Stck(const int size);
  const bool is_empty() const;
  void push(const X value);
  X pop();
  const X top() const;
  const std::string to_string() const;
  ~Stck();
};
```

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};
```

SOME SAMPLE TEMPLATE METHODS (ALSO IN STCK_T.HH)

```
template <class X>
Stck<X>::Stck(const int size) :
  capacity {size},
  num_elements{0},
  elements {new X[size]}
{ }

template <class X>
void Stck<X>::push(const X value) {
  elements[num_elements] = value;
  num_elements++;
}

template <class X>
X Stck<X>::pop() {
  num_elements--;
  return elements[num_elements];
}
```

USE OF TEMPLATE BY CLIENT: A NEW DC.CC

```
#include <iostream>
#include <string>
#include "Stck_T.hh"

int main() {

  Stck<int> s(100);

  std::string entry;
  do {
    std::cin >> entry;
    if (entry == "+") {
      int v1 = s.pop();
      int v2 = s.pop();
      int v = v1 + v2;
      s.push(v);
    } else if (entry == "-") {
      int v1 = s.pop();
      int v2 = s.pop();
      int v = v1 - v2;
      s.push(v);
  ...
```

USE OF TEMPLATE BY CLIENT: A DIFFERENT DC.CC

```
#include <iostream>
#include <string>
#include "Stck_T.hh"

int main() {

  Stck<double> s(100);

  std::string entry;
  do {
    std::cin >> entry;
    if (entry == "+") {
      double v1 = s.pop();
      double v2 = s.pop();
      double v = v1 + v2;
      s.push(v);
    } else if (entry == "-") {
      double v1 = s.pop();
      double v2 = s.pop();
      double v = v1 - v2;
      s.push(v);
  ...
```

NOTES ON TEMPLATES

- Templates provide something like "***generics***" (term used in **Java**).
- Comes from the *functional programming language* community (e.g. **CaML**):
  - ➡ ***parameterized polymorhism***, e.g. `T list`
- Separate compilation in C++ makes templates tricky:
  - You must put *everything* (spec'n and impl'n) into a header file.
  - Client code **`#include`**s the full definition, class and methods.
  - Compiler stamps out different code, code *for each* type parameterization.
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  …but generics/parametrized types are a very useful and elegant concept.

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