Programming and Algorithms II

Lecture 6: Abstract Data Types

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Abstract Data Types

Abstract Data Types

- An abstract data type (ADT) provides some abstract mathematical object
- The specification is in terms of properties with respect to that object
- Despite their name, these are closer to interfaces than abstract classes

Abstract Data Types

- To model an ADT in Java, we need a *state* and some *operations*, which we *specify* in terms of some mathematical object
- The specification is in the form of *comments* before the class, and before each method
- We must specify the initial state, for the class and the preconditions, postconditions, and return value for each method

Stacks

Stacks

- A *stack* is an abstract data type that comes up very often
- It allows elements to be put onto and removed from the top of the stack
- The natural model for this is to think of a stack as a *list* with a suitably limited vocabulary

Stacks

- First we give the state space and initial value of the ADT

```
// state:  xs : [int]
// init:   xs = []
interface IntStack {
  …
}
```

A Haskell-like notation is a fine tool for specifications

- With these in place, we define each of the operations we want to model by making reference to this state both before and after execution of the method

Stacks

- We provide *preconditions* and *postconditions* before methods as comments

```
// pre: true
// post: xs = x:xs0
public void push(int x);
```

- The preconditions are things that *must* be true before we enter the code
- The postconditions are promises we make about the state after the code executes
- Variables subscripted with 0 are the value of the variable *before* the code is executed

Q. What happens if the pre is false and we run the method anyway?

Stacks

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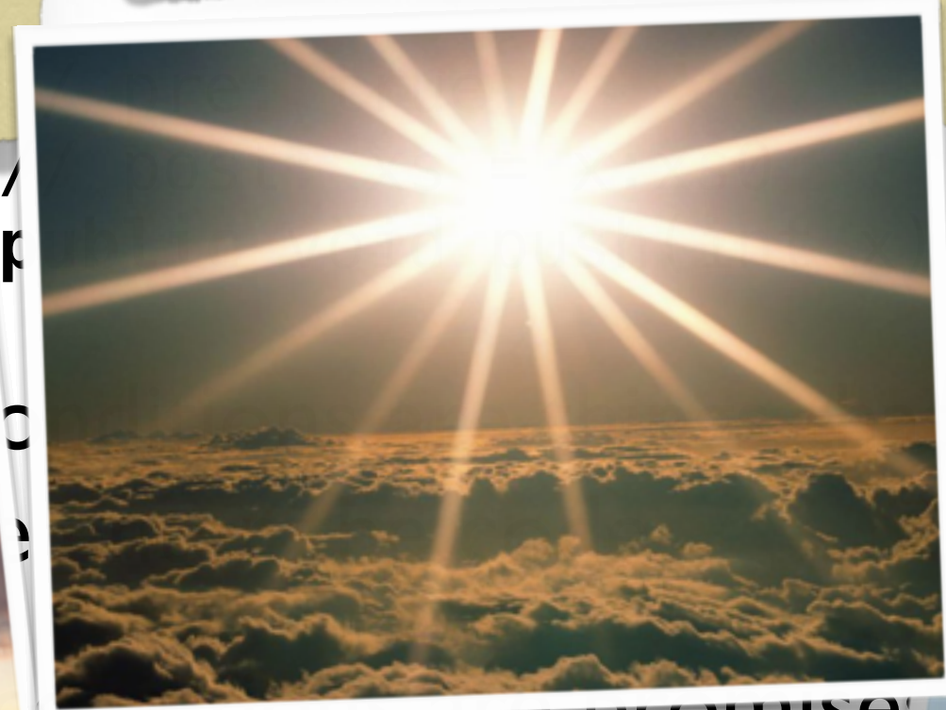
Q. What if a post condition is always false?

A. Then we are claiming our code is miraculous: it makes true become false

Q. What if the post condition is always true?

A. Then our code can do anything we want it to. Missiles could get launched.



- We provide
- Conditions are promise
- state after the code e

Variables subscripted with 0 are the value of the variable *before* the code is executed

Stacks

- The *peek* operation returns the element at the top, without affecting the stack

```
// pre:  xs ≠ []
// post: xs = xs0
// return: head xs
public int peek();
```

- The *pop* operation returns the element at the top, and removes it from the stack

```
// pre:    xs ≠ []
// post:   x:xs = xs0
// return: x
public int pop();
```

x was introduced in the post step and reused in return

Stacks

- The *empty* operation returns true when the stack is empty

```
// pre: true
// post: xs = xs0
// return: xs ≡ []
public boolean empty();
```

- When the precondition is *true* it is customary to remove it
- Similarly, if the return value is void, it is usually left empty

Stacks

```
// state: xs : [int]
// init:  xs = []
interface IntStack {

  // post: xs = x:xs0
  public void push(int x);

  // pre:    xs ≠ []
  // post:   x:xs = xs0
  // return: head xs
  public int pop();

  // pre:  xs ≠ []
  // post: xs = xs0
  // return: head xs
  public int peek();

  // post: xs = xs0
  // return: xs ≡ []
  public boolean empty();
}
```

Concrete Stacks

Concrete Stacks

- So far we have only described what a stack ADT should be
- We haven't implemented a concrete stack
- Many different implementations exist
- We need to tie the abstract and concrete together with an *abstraction function (ABS)*
- Concrete implementations have limitations set out by the *data type invariant (DTI)*

Concrete Stacks

- The abstraction function is a function from the concrete state to the abstract state

```
abs : ArrayIntStack → [int]
abs this = [ this.values[this.size - i]
           | i <- [1 .. this.size] ]
```

- Constraints on the concrete are given by the datatype invariant

```
dti : ArrayIntSet → Bool
dti this = this.size < this.N
```

Concrete Stacks

- Implement an ArrayIntStack based on the Stack ADT, using the abstraction function and datatype invariant

Concrete Stacks

```
// abs : (int[], int, int) → [int]
// abs (stack, size, N) = [ stack[size - i] | 0 < i ≤ size ]
// dti (stack, size, N) = stack.length ≡ N ∧ size ≤ N
class ArrayStack implements Stack {
  int[] stack;
  int size;
  final int N;

  ArrayStack() {
    N     = 100;
    stack = new int[N];
    size  = 0;
  }

  public void push(int x) {
    assert (size > 0);
    stack[size] = x;
    size = size + 1;

  }

  public int pop() {
    assert (size > 0);
    int result = stack[size];
    size = size - 1;
    return result;
  }

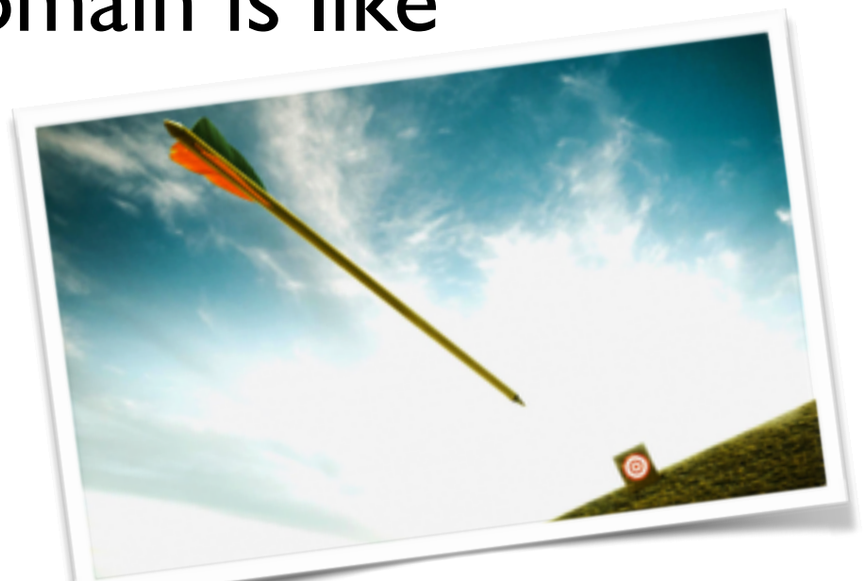
  public int peek() {
    int result = stack[size];
    return result;
  }

  public boolean empty() {
    return (size == 0);
  }
}
```

NB. We use assert() to ensure the preconditions hold. Assertions can get erased at runtime

Concrete Stacks

- This might all have seemed far-fetched
- But if we don't model our datatypes on mathematical objects, what else is there?
- Mathematical objects give us a *semantic domain*: they give *meaning* to our computation
- Hacking without a semantic domain is like shooting without a target



Downcasting

Downcasting

- The IntStack we introduced was very rigid in its values: it could only contain ints

```
IntStack stack = new IntArrayStack();
stack.push(42);
stack.push(314);
int n = stack.pop();
```

- In general, we want to deal with objects

Downcasting

- All objects in Java inherit from Object

```
class Object {
   protected Object clone();
   boolean equals(Object obj);
   …
}
```

- We could use this idea to give a broader definition of Stacks

Downcasting

Q. How would we modify this code?

```
// state: xs : [int]
// init:  xs = []
interface IntStack {

  // post: xs = x:xs0
  public void push(int x);

  // pre:    xs ≠ []
  // post:   x:xs = xs0
  // return: head xs
  public int pop();

  // pre:  xs ≠ []
  // post: xs = xs0
  // return: head xs
  public int peek();

  // post: xs = xs0
  // return: xs ≡ []
  public boolean empty();
}
```

Downcasting

Q. How would we modify this code?

```
// state: xs : [int]
// init:  xs = []
interface IntStack {

  // post: xs = x:xs0
  public void push(int x);
  // pre:    xs ≠ []
  // post:   x:xs = xs0
  // return: head xs
  public int pop();

  // pre:  xs ≠ []
  // post: xs = xs0
  // return: head xs
  public int peek();

  // post: xs = xs0
  // return: xs ≡ []
  public boolean empty();
}
```

A. Replace int with Object

```
// state: xs : [Object]
// init:  xs = []
interface ObjectStack {

  // post: xs = x:xs0
  public void push(Object x);
  // pre:    xs ≠ []
  // post:   x:xs = xs0
  // return: head xs
  public Object pop();

  // pre:  xs ≠ []
  // post: xs = xs0
  // return: head xs
  public Object peek();

  // post: xs = xs0
  // return: xs ≡ []
  public boolean empty();
}
```

Downcasting

- Using the ObjectStack is now very similar to before
- We just need to do some *downcasting* to turn an Object into an Integer

```
ObjectStack stack = new ObjectArrayStack();
stack.push(42);
stack.push(314);
Integer n = (Integer)stack.pop();
```

Downcasting

- Let's see how we can abuse downcasting

```
ObjectStack stack = new ObjectArrayStack();
stack.push(new Dog("Milou"));
```

So far, so good ...

Downcasting

- Let's see how we can abuse downcasting

```
ObjectStack stack = new ObjectArrayStack();
stack.push(new Dog("Milou"));
Integer number = (Integer)stack.pop()
```

Milou is not a number

Downcasting

- Downcasting allowed us to turn an *Object* into an *Integer*
- But it only works when the *Object* really was an *Integer*!
- We must rely on the programmer to make sure that the downcasting is applied sensibly
- Unfortunately, if a mistake is made we can only see this problem at runtime
- Furthermore, downcasting costs time!

Generics

Generics

- The downcasting problem was solved by the introduction of *generics* in Java 5
- Generics allow the *compiler* to keep track of object types at *compile time*, rather than relying on the programmer
- With generics, we can parameterise classes with *types*, which removes the need for downcasting for the consumer of ADTs

Generics

- Generics allow us to replace this code:

```
ObjectStack stack = new ObjectArrayStack();
stack.push(314);
Integer n = (Integer)stack.pop();
```

- With something more sensible:

```
Stack<Integer> stack = new ArrayStack<Integer>();
stack.push(314);
Integer n = stack.pop();
```

No more downcasting!

Generics

- Show the generic version of Stack and ArrayStack

Generics

- Making the generic version of Stack involves sprinkling a type parameter
- This is clean!

```
// state: xs : [V]
// init:  xs = []
interface Stack<V> {
  // post: xs = x:xs0
  public void push(V x);

  // pre:    xs ≠ []
  // post:   x:xs = xs0
  // return: head xs
  public V pop();

  // pre:  xs ≠ []
  // post: xs = xs0
  // return: head xs
  public V peek();

  // post: xs = xs0
  // return: xs ≡ []
  public boolean empty();
}
```

Generics

```
// abs : (Object[], int, int) → [V]
// abs (stack, size, N) = [ stack[size - i] | 0 < i ≤ size ]
// dti (stack, size, N) = stack.length ≡ N ∧ size ≤ N
class ArrayStack<V> implements Stack<V> {
  private Object[] stack;
  private int size;
  private final int N;

  ArrayStack() {
    N     = 100;
    stack = new Object[N];
    size  = 0;
  }

  public void push(V x) {
    assert (size > 0);
    stack[size] = x;
    size = size + 1;
  }

  public V pop() {
    assert (size > 0);
    @SuppressWarnings("unchecked")
    V result = (V) stack[size];
    size = size - 1;
    return result;
  }

  public V peek() {
    @SuppressWarnings("unchecked")
    V result = (V) stack[size];
    return result;
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  public boolean empty() {
    return (size == 0);
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}
```

Q. Did you spot the fishy bit of code?

Generics

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// abs : (Object[], int, int) → [V]
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  public boolean empty() {
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  }
}
```

Q. Did you spot the fishy bit of code?

A. There's a downcast!

Generics

- We just got hit with a downcast again, but was it problematic?
- Well, it was *ugly*
- However, it wasn't unsafe: we did not expose the underlying Object[] to the world, nor did the downcast leak out
- But it *was* ugly
- Yes, generics do have limitations, in fact, there's a whole list of them

Generics

- While generics seem like a magical solution, there are a number of sometimes painful restrictions:
  - No primitive type instantiation of generic type
  - No new instances of type parameters
  - No static fields with type parameters
  - No arrays of parameterized types
  - No generic exceptions
  - No overloading to common raw type

http://docs.oracle.com/javase/tutorial/java/generics/restrictions.html