

# Generics in Java



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## Motivating Example: Observations (1)



- In the `Book` class:
  - By declaring the attribute

```
Object[] records
```

We meant that each book instance may store any object whose *static type* is a **descendant class** of `Object`.

- Accordingly, from the return type of the `get` method, we only know that the returned record is an `Object`, but not certain about its *dynamic type* (e.g., `Date`, `String`, etc.).  
∴ a record retrieved from the book, e.g., `b.get("Yuna")`, may only be called upon methods in its *static type* (i.e., `Object`).
- In the tester code of the `Book` class:
  - In **Line 1**, the *static types* of variables `birthday` (i.e., `Date`) and `phoneNumber` (i.e., `String`) are **descendant classes** of `Object`.
  - So, **Line 5** and **Line 7** compile.

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## Motivating Example: A Book of Objects



```
1 class Book {  
2   String[] names;  
3   Object[] records;  
4   /* add a name-record pair to the book */  
5   void add (String name, Object record) { ... }  
6   /* return the record associated with a given name */  
7   Object get (String name) { ... } }
```

Question: Which line has a type error?

```
1 Date birthday; String phoneNumber;  
2 Book b; boolean isWednesday;  
3 b = new Book();  
4 phoneNumber = "416-67-1010";  
5 b.add ("Suyeon", phoneNumber);  
6 birthday = new Date(1975, 4, 10);  
7 b.add ("Yuna", birthday);  
8 isWednesday = b.get("Yuna").getDay() == 4;
```

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## Motivating Example: Observations (2)



Due to **polymorphism**, the *dynamic types* of stored objects (e.g., `phoneNumber` and `birthday`) need not be the same.

- Methods supported in the *dynamic types* (e.g., method `getDay` of class `Date`) may be new methods not inherited from `Object`.
- This is why **Line 8** would fail to compile, and may be fixed using an explicit **cast**:

```
isWednesday = ((Date) b.get("Yuna")).getDay() == 4;
```

- But what if the *dynamic type* of the returned object is not a `Date`?
- To avoid such a `ClassCastException` at runtime, we need to check its *dynamic type* before performing a cast:

```
if (b.get("Suyeon") instanceof Date) {  
    isWednesday = ((Date) b.get("Suyeon")).getDay() == 4;  
}
```

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## Motivating Example: Observations (2.1)



- It seems: combining *instanceof* check and *type cast* works.
- Can you see any potential problem(s)?
- **Hints:** What happens when you have a large number of records of distinct *dynamic types* stored in the book (e.g., Date, String, Person, Account, etc.)?

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## Motivating Example: Observations (2.2)



Imagine that the tester code (or an application) stores 100 different record objects into the book.

- All of these records are of *static type* Object, but of distinct *dynamic types*.

```
Object rec1 = new C1(); b.add(..., rec1);
Object rec2 = new C2(); b.add(..., rec2);
...
Object rec100 = new C100(); b.add(..., rec100);
```

where classes **C1** to **C100** are *descendant classes* of Object.

- **Every time** you retrieve a record from the book, you need to check “exhaustively” on its *dynamic type* before calling some method(s).

```
Object rec = b.get("Jim");
if (rec instanceof C1) { ((C1) rec).m1; }
...
else if (rec instanceof C100) { ((C100) rec).m100; }
```

- Writing out this list multiple times is tedious and error-prone!

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## Motivating Example: Observations (3)



We need a solution that:

- Saves us from explicit *instanceof* checks and type casts
- Eliminates the occurrences of *ClassCastException*

As a sketch, this is how the solution looks like:

- When the user declares a `Book` object `b`, they must *commit to the kind of record that `b` stores at runtime*.  
e.g., `b` stores either `Date` objects only or `String` objects only, but *not a mix*.
- When attempting to store a new record object `rec` into `b`, what if `rec`'s *static type* is not a **descendant class** of the type of book that the user previously commits to?  
⇒ A *compilation error*
- When attempting to retrieve a record object from `b`, there is *no longer a need to check and cast*.  
∴ *Static types* of all records in `b` are guaranteed to be the same.

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## Parameters



- In mathematics:
  - The same *function* is applied with different *argument values*.  
e.g.,  $2 + 3$ ,  $1 + 1$ ,  $10 + 101$ , etc.
  - We *generalize* these instance applications into a definition.  
e.g.,  $+: (\mathbb{Z} \times \mathbb{Z}) \rightarrow \mathbb{Z}$  is a function that takes two integer *parameters* and returns an integer.
- In Java programming:
  - We want to call a *method*, with different *argument values*, to achieve a similar goal.  
e.g., `acc.deposit(100)`, `acc.deposit(23)`, etc.
  - We generalize these possible method calls into a definition.  
e.g., In class `Account`, a method `void deposit(int amount)` takes one integer *parameter*.
- When you design a mathematical function or a Java method, always consider the list of *parameters*, each of which representing a set of possible *argument values*.

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## Java Generics: Design of a Generic Book



```
class Book<E> {
    String[] names;
    E[] records;
    /* add a name-record pair to the book */
    void add (String name, E record) { ... }
    /* return the record associated with a given name */
    E get (String name) { ... } }
```

Question: Which line has a type error?

```
1 Date birthday; String phoneNumber;
2 Book<Date> b; boolean isWednesday;
3 b = new Book<Date>();
4 phoneNumber = "416-67-1010";
5 b.add ("Suyeon", phoneNumber);
6 birthday = new Date(1975, 4, 10);
7 b.add ("Yuna", birthday);
8 isWednesday = b.get("Yuna").getDay() == 4;
```

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## Bad Example of using Generics



Has the following client made an appropriate choice?

```
Book<Object> book
```

**NO!!!!!!!!!!!!!!!!!!!!!!!!!!!!**

- It allows **all** kinds of objects to be stored.  
∴ All classes are descendants of **Object**.
- We can expect **very little** from an object retrieved from this book.  
∴ The **static type** of book's items is **Object**, root of the class hierarchy, has the **minimum** amount of features available for use.  
∴ Exhaustive list of casts are unavoidable.  
[ **bad** for extensibility and maintainability ]

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## Java Generics: Observations



- In class Book:
  - At the class level, we **parameterize the type of records** that an instance of book may store: `class Book<E>`  
where **E** is the name of a type parameter, which should be **instantiated** when the user declares an instance of Book.
  - Every occurrence of Object (the most general type of records) is replaced by **E**.
  - As soon as **E** at the class level is committed to some known type (e.g., Date, String, etc.), every occurrence of **E** will be replaced by that type.
- In the tester code of Book:
  - In **Line 2**, we commit that the book b will store Date objects only.
  - **Line 5** now fails to compile. [String is not a Date]
  - **Line 7** still compiles.
  - **Line 8** does **not need** any instance check and type cast, and does **not cause** any ClassCastException.  
∴ Only Date objects were allowed to be stored.

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## Generic Classes: Singly-Linked List (1)

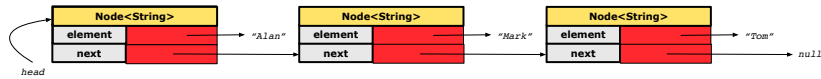


```
public class Node<E> {
    private E element;
    private Node<E> next;
    public Node(E e, Node<E> n) { element = e; next = n; }
    public E getElement() { return element; }
    public Node<E> getNext() { return next; }
    public void setNext(Node<E> n) { next = n; }
    public void setElement(E e) { element = e; }
}
```

```
public class SinglyLinkedList<E> {
    private Node<E> head;
    private Node<E> tail;
    private int size = null;
    public void addFirst(E e) { ... }
    Node<E> getNodeAt (int i) { ... }
    ...
}
```

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## Generic Classes: Singly-Linked List (2)



### Approach 1

```

Node<String> tom = new Node<>("Tom", null);
Node<String> mark = new Node<>("Mark", tom);
Node<String> alan = new Node<>("Alan", mark);
  
```

### Approach 2

```

Node<String> alan = new Node<>("Alan", null);
Node<String> mark = new Node<>("Mark", null);
Node<String> tom = new Node<>("Tom", null);
alan.setNext(mark);
mark.setNext(tom);
  
```

## Generic Stack: Interface

```

public interface Stack<E> {
    public int size();
    public boolean isEmpty();
    public E top();
    public void push(E e);
    public E pop();
}
  
```

## Generic Classes: Singly-Linked List (3)

Assume we are in the context of class SinglyLinkedList.

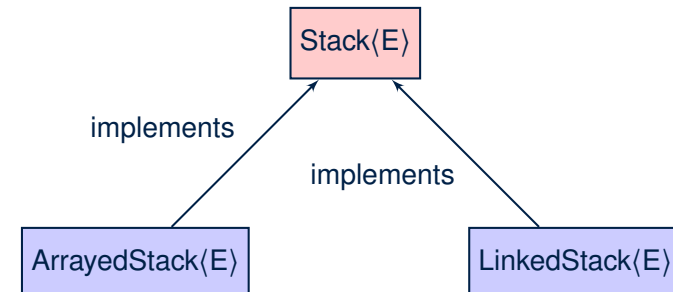
```

void addFirst (E e) {
    head = new Node<E>(e, head);
    if (size == 0) { tail = head; }
    size ++;
}
  
```

```

Node<E> getNodeAt (int i) {
    if (i < 0 || i >= size) {
        throw new IllegalArgumentException("Invalid Index"); }
    else {
        int index = 0;
        Node<E> current = head;
        while (index < i) {
            index ++; current = current.getNext();
        }
        return current;
    }
}
  
```

## Generic Stack: Architecture



## Generic Stack: Array Implementation



```
public class ArrayedStack<E> implements Stack<E> {
    private static final int MAX_CAPACITY = 1000;
    private E[] data;
    private int t; /* top index */
    public ArrayedStack() {
        data = (E[]) new Object[MAX_CAPACITY];
        t = -1;
    }
    public int size() { return (t + 1); }
    public boolean isEmpty() { return (t == -1); }
    public E top() {
        if (isEmpty()) { /* Error: Empty Stack. */
            else { return data[t]; } }
    }
    public void push(E e) {
        if (size() == MAX_CAPACITY) { /* Error: Stack Full. */
            else { t++; data[t] = e; } }
    }
    public E pop() {
        E result;
        if (isEmpty()) { /* Error: Empty Stack */
            else { result = data[t]; data[t] = null; t--; }
        }
        return result;
    }
}
```

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## Generic Stack: Testing Both Implementations



```
@Test
public void testPolymorphicStacks() {
    Stack<String> s = new ArrayedStack<>();
    s.push("Alan"); /* dynamic binding */
    s.push("Mark"); /* dynamic binding */
    s.push("Tom"); /* dynamic binding */
    assertTrue(s.size() == 3 && !s.isEmpty());
    assertEquals("Tom", s.top());

    s = new LinkedStack<>();
    s.push("Alan"); /* dynamic binding */
    s.push("Mark"); /* dynamic binding */
    s.push("Tom"); /* dynamic binding */
    assertTrue(s.size() == 3 && !s.isEmpty());
    assertEquals("Tom", s.top());
}
```

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## Generic Stack: SLL Implementation



```
public class LinkedStack<E> implements Stack<E> {
    private SinglyLinkedList<E> data;
    public LinkedStack() {
        data = new SinglyLinkedList<E>();
    }
    public int size() { return data.size(); }
    public boolean isEmpty() { return size() == 0; }
    public E top() {
        if (isEmpty()) { /* Error: Empty Stack. */
            else { return data.getFirst(); } }
    }
    public void push(E e) {
        data.addFirst(e);
    }
    public E pop() {
        E result;
        if (isEmpty()) { /* Error: Empty Stack */
            else { result = top(); data.removeFirst(); }
        }
        return result;
    }
}
```

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## Beyond this lecture ...



- Study <https://docs.oracle.com/javase/tutorial/java/generics/index.html> for further details on Java generics.

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Beyond this lecture ...