

CSC 447 - Concepts of Programming Languages

Parametric Polymorphism

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Learning Objectives

- ❓ Inheritance for container classes?
 - Compare inheritance and type parameters



Monomorphic Linked Lists (C)

- Implement a linked list

```
1 typedef struct Node Node;
2 struct Node {
3     int* item;
4     Node* next;
5 };
6
7 int* get_last (Node* xs) {
8     while (xs->next != NULL) {
9         xs = xs->next;
10    }
11    return xs->item;
12 }
```

- ❗ Code duplication

```
1 typedef struct FloatNode FloatNode;
2 struct FloatNode {
3     float* item;
4     FloatNode* next;
5 };
6
7 float* get_last (FloatNode* xs) {
8     while (xs->next != NULL) {
9         xs = xs->next;
10    }
11    return xs->item;
12 }
```

- ❓ Benefits? Downsides?



Generic Linked Lists (C)

- Use type `(void*)` in C

```
1 typedef struct Node Node;
2 struct Node {
3     void* item;
4     Node* next;
5 };
6
7 void* get_last (Node* xs) {
8     while (xs->next != NULL) {
9         xs = xs->next;
10    }
11    return xs->item;
12 }
```

- ! No static protection against casts

```
1 int main () {
2     int p      = (int*) malloc (sizeof(int));
3     *p         = 2123456789;
4     Node* xs   = (Node*) malloc (sizeof(Node));
5     xs->next    = NULL;
6     xs->item    = p;           // store pointer
7     double* q  = get_last(xs); // alias of p
8     printf ("q=%f\n", *q);    // unsafe access
9 }
```

```
1 $ clang -m32 parametric-03.c && ./a.out
2 q=96621069057346178268049192388430659584.000000
```

- ? Benefits? Downsides?



Generic Linked Lists (Java)

- Generic list using subtype polymorphism

```
1 static class Node {
2     Object item;
3     Node next;
4 }
5
6 static Object getLast (Node xs) {
7     while (xs.next != null) {
8         xs = xs.next;
9     }
10    return xs.item;
11 }
```

`ClassCastException` at runtime, but no unsafe memory access

```
1 public static void main (String[] args) {
2     Integer p = Integer.valueOf(2123456789);
3     Node xs = new Node();
4     xs.next = null;
5     xs.item = p; // store Integer
6     Double q = (Double) getLast(xs); // ClassCastException
7     System.out.printf ("d=%f\n", q); // unsafe access
8 }
```

```
1 $ javac Parametric2.java
2 $ java Parametric2
3 java.lang.ClassCastException: Integer cannot be cast to Double
```

? Benefits? Downsides?



Can Inheritance Solve This?

- Container base class

```
1 abstract class Node {
2     Object item;
3     Node next;
4     Object getLast() {
5         Node xs = this;
6         while (xs.next != null) xs = xs.next;
7         return xs.item;
8     }
9 }
```

- Implementations reuse `getLast`

```
1 class IntNode extends Node {
2     int getLastItem() {
3         return (int)getLast(); // cast
4     }
5 }
```

❗ static casts shifted into library, but problem not solved

❓ How to adapt a class?

💡 Need type parameters

```
1 class Node {
2     ??? item;
3     Node next;
4     ??? getLast() {
5         Node xs = this;
6         while (xs.next != null) xs = xs.next;
7         return xs.item;
8     }
9 }
```

❓ Benefits? Downsides?



Generic Linked Lists (Java)

- Generic list using parametric polymorphism

```
1 class Node<X> {  
2     X      item;  
3     Node<X> next;  
4     X getLast () {  
5         Node<X> xs = this;  
6         while (xs.next != null) xs = xs.next;  
7         return xs.item;  
8     }  
9 }
```

- Create a list of Integer

```
1 public static void main (String[] args) {  
2     Node<Integer> xs = new Node<>();  
3     xs.next      = null;  
4     xs.item      = Integer.valueOf(37);  
}
```

- Incompatible read: compile error

```
1 Double q = (Double) getLast(xs); // compiler error  
2 System.out.printf ("d=%f\n", q); // unsafe access  
3 }
```

```
1 $ javac Parametric1.java  
2 error: incompatible types: Integer cannot be converted to Double  
3     Double q = (Double) getLast(xs);    // compiler error  
4                                ^
```



Generic Linked Lists (Scala)

- Generic list using parametric polymorphism

```
1 class Node[X](val item: X, val next: Node[X]):  
2   def getLast () : X =  
3     var xs = this  
4     while xs.next != null do xs = xs.next  
5     xs.item
```

- Recursive

```
1 class Node[X](val item: X, val next: Node[X]):  
2   def getLast () : X =  
3     if next == null then item  
4     else next.getLast ()
```



Java Type Parameter Erasure

- Java type parameters are not part of runtime type information

```
1 static class ArrayList<X> {  
2     X[] a;  
3  
4     ArrayList(int n) {  
5         a = new X[n];  
6     }  
7  
8     void put (int i, X item) { a[i] = item; }  
9     X      get (int i)       { return a[i]; }  
10 }
```

```
1 $ javac Parametric3.java  
2 error: generic array creation  
3     a = new X[n];  
4             ^
```



Java Type Parameter Erasure

- Cast is not checked at runtime

```
1 static class ArrayList<X> {  
2     X[] a;  
3  
4     ArrayList(int n) {  
5         a = (X[]) new Object[n];  
6     }  
7  
8     void put (int i, X item) { a[i] = item; }  
9     X      get (int i)      { return a[i]; }  
10 }
```

```
1 $ javac -Xlint:unchecked Parametric4.java  
2 warning: [unchecked] unchecked cast  
3     a = (X[]) new Object[n];  
4           ^
```

❓ Why is cast not checked at runtime?



Java Type Parameter Erasure

- ? Why is `@SuppressWarnings` ok?
- ? What are the entries of `a` before any item is placed in it?

```
1 static class ArrayList<X> {  
2     X[] a;  
3  
4     @SuppressWarnings("unchecked")  
5     ArrayList(int n) {  
6         a = (X[]) new Object[n];  
7     }  
8  
9     void put (int i, X item) { a[i] = item; }  
10    X      get (int i)      { return a[i]; }  
11 }
```

```
1 $ javac -Xlint:unchecked Parametric4.java
```

- Okay to ignore, since all references in array are `null` (can be assigned to any reference type)



Java Type Parameter Erasure

- Not possible to check casts when writing to unparameterized list

```
1 ArrayList<String> ss = new ArrayList<>(10);
2 ArrayList os = ss;
3 os.put (1, 2123456789);
4
5 // ClassCastException when reading
6 String s = ss.get (1);
```

```
1 $ javac Parametric6.java
2 Note: Parametric6.java uses unchecked or unsafe operations.
3 Note: Recompile with -Xlint:unchecked for details.
```

```
1 $ java Parametric6
2 ClassCastException: Integer cannot be cast to class String
3   at Parametric.main(Parametric6.java:6)
```



Arrays Checked When Assigned

- Java stores types with arrays

```
1 String[] ss = new String[10];
2 Object[] os = ss;
3
4 // ArrayStoreException when writing
5 os[1] = 2123456789;
6 String s = ss[1];
```

```
1 $ javac Parametric7.java
2 // no warnings
```

```
1 $ java Parametric7
2 ArrayStoreException: Integer
3     at Parametric.main(Parametric7.java:5)
```



C++ Templates

- C++ class templates are instantiated with concrete types
- Compiler checks that types fit to all used operations

```
1 template <class T> class Node {
2     public:
3         T item;
4         Node<T>* next;
5         T getLast() {
6             Node<T>* c = this;
7             while (c->next != nullptr)
8                 c = c->next;
9             return c->item;
10        }
11 }
```

```
1 int main(int argc, char* argv[]) {
2     Node<int>* n = new Node<int>();
3     n->item = 5;
4     n->next = new Node<int>();
5     n->next->item = 6;
6     cout
7         << "Last item: "
8         << n->getLast() << endl;
9 }
```



C++ Templates Challenge

! Problems in template not noticed until instantiated

```
1 template <class T> class Node {
2     public:
3         T item;
4         Node<T>* next;
5         // ...
6         void printCout() {
7             Node<T>* c = this;
8             cout << c->item;
9             while (c->next != nullptr) {
10                 c = c->next;
11                 cout << "," << c->item;
12             }
13             cout << endl;
14         }
15 }
```

- Works fine

```
1 int main(int argc, char* argv[]) {
2     Node<int>* n = new Node<int>();
3     n->item = 5;
4     n->printCout();
5 }
```

```
1 typedef struct { int a; int b; } Pair;
2
3 int main(int argc, char* argv[]) {
4     Node<Pair>* n = new Node<Pair>();
5     n->item = (Pair) { .a=2, .b=3 };
6     n->printCout();
7 }
```

- Compile error: cannot print Pair



Summary

- Parametric polymorphism allows independence between container class and types of contained objects
- Type safety when reading from and writing to containers
- Not all languages retain type parameters at runtime (Java: compiler knows generics, JVM does not)
- C++ templates are different
 - Template itself has no executable form: `List<T>`
 - Executable generated for each instantiation: `List<int>`, `List<string>`
 - Compile problems hidden until template gets instantiated