# Type and class parameters

- A program unit that uses a type can also become a generic program unit, with a type parameter
- Ada, C++, and Java have generic units with type parameters



# Type parameters in C++

- A C++ generic unit may be parameterized wrt any type or calls on which it depends
  - Encapsulation of homogeneous lists

```
template <class Element>
class List is
private:
  const int capacity = …;
  int length;
  Element elems[capacity];

public:
  List();
  void append(Element e);
  … //other methods
}
```



# Type parameters in C++

- `<class Element>` states that `Element` is a formal parameter of the generic class and denotes an unknown type
  - generic class constructor and methods:

```
template <class Element>
List<Element>::List () {
  length = 0;
 }
template <class Element>
void List<Element>::append(Element e) {
  elems[length++] = e;
}
```

  - instantiated via `typedef List<char> Phrase`
  - or `struct Trans { …};`
    `typedef List<Trans> Trans_List;`



# Type parameters in C++

- Encapsulation of sequences, i.e., sortable lists

```
template <class Element>
class List is
private:
  const int capacity = …;
  int length;
  Element elems[capacity];

public:
  sequence();
  void append(Element e);
  void sort();
  … //other methods
}
```

# Type parameters in C++

- **Generic class constructor and methods:**

```
template <class Element>
void Sequence<Element>::sort() {
  Element e;
  …
  if (e < elems[i]) …
  …
  }
```

- **Note the use of the "<" operator in the `sort` method**



# Type parameters in C++

- The argument type `<class Element>` should be equipped with a "<" operation
  - A proper instantiation is:

```
typedef Sequence<float> Number_Sequence;
Number_Sequence readings;
…
readings.sort();
```

  - A seemingly proper instantiation is:

```
typedef char* String;
typedef Sequence<String> String_Sequence;
```

    - however "<" operation compares pointers instead of lexicographically
  - An incorrect instantiation is:

```
struct Trans { … };
typedef Sequence<Trans> Trans_Sequence;
```

    - `Trans` type is not equipped with "<" operation



# Type parameters in C++

- **Operations used for T in the generic unit $\subseteq$ operations with which the argument type is equipped**
- **The C++ compiler cannot completely type-check the definition of a generic unit**



# Class parameters in Java

- Since 2004 Java supports generic abstraction in the form of *generic classes*, parameterized with other classes
  - encapsulation of homogeneous lists

```
class List <Element> {
  private length;
  private Element[] elems;
  public List() { … }
  public void append(Element e) { … }
}
```

  - heading states that `Element` is a formal parameter of the generic class `List`

## Class parameters in Java

- **Generic class can be instantiated with:**

```
List<Character> sentence;
List<Transaction> sentence;
```

- **Argument must be a class, not a primitive type**

```
List<char> sentence; // illegal!
```



## Class parameters in Java

- **If the generic Java class must be equipped with particular operations, the class parameter must be specified as an interface**
- **The class parameter is *bounded* by the interface**
  - **Java generic class with a bounded class parameter**

```
interface Comparable <Item> {
  public abstract int compareTo(Item that);
}
```



## Class parameters in Java

- **Following Java generic class encapsulates sequences equipped with a sort operation**

```
class Sequence
  <Element implements Comparable<Element>> {
  private length;
  private Element[] elems;
  public Sequence() { … }
  public void append() { … }
  public void sort() {
    Element e;
    …
    if (e.compareTo(elems[i]) < 0 ) …
    …
  }
}
```



## Class parameters in Java

- **A Java generic unit is to have a class parameter C of the form** `class C implements Interface`
- **The compiler checks the generic unit to ensure**
  - **operations used for *C* in the generic unit**
    **⊆ operations declared for *Interface***
  - **operations declared in *Interface***
    **⊆ operations with which the argument class is equipped**
- **Java generic units are based on type theory:**
  - **compiler can type-check the declarations of each generic unit**
  - **separately type-check every instantiation**
- **Weakness of Java generic classes: only classes as parameter**

# Generic abstraction

- Built-in templates: generics as in Java, C++ OCaML
- Add-on templates



# Intermezzo: Software templates

## Software templates

- Object code with holes
- Holes contain instructions for the evaluator
  - meta code
- Separation of object code and evaluator code
  - code for interpreting meta language is invisible
  - code for file handling is invisible
- Meta programming in concrete object code (WYSIWYG)
  - template represents structure and layout of result

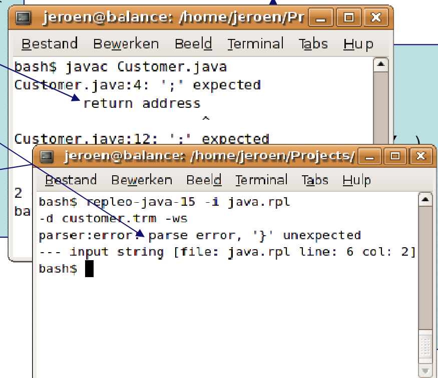


# Intermezzo: Software templates

```
public class Customer{
 private String address;
 public String getaddress(){
        return address
 }
 public void setaddress
        (String address){
   this.address=address;
 }
 private int age;
 public int getage(){
        return age
 }
 public void setage
        (int age){
   this.age=age;
 }
}
```

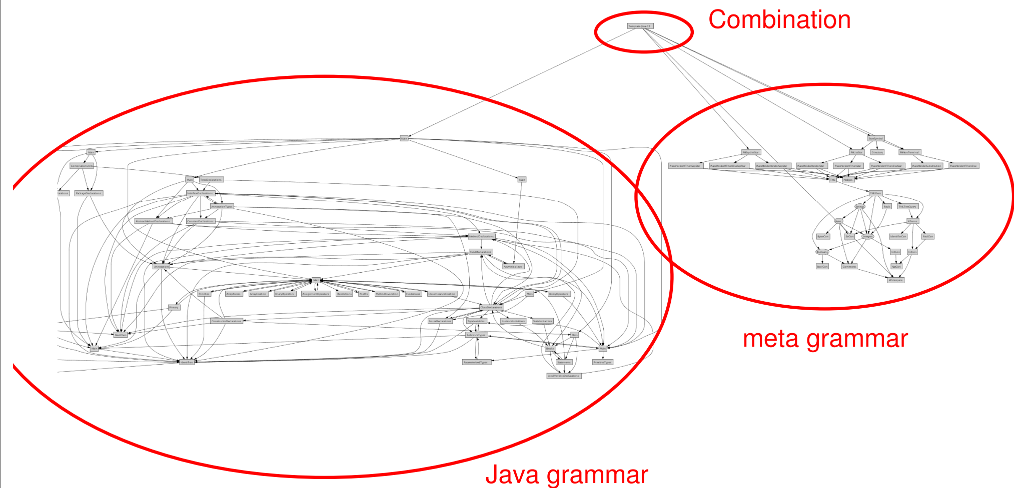
**Customer**

- address : String
- age : int

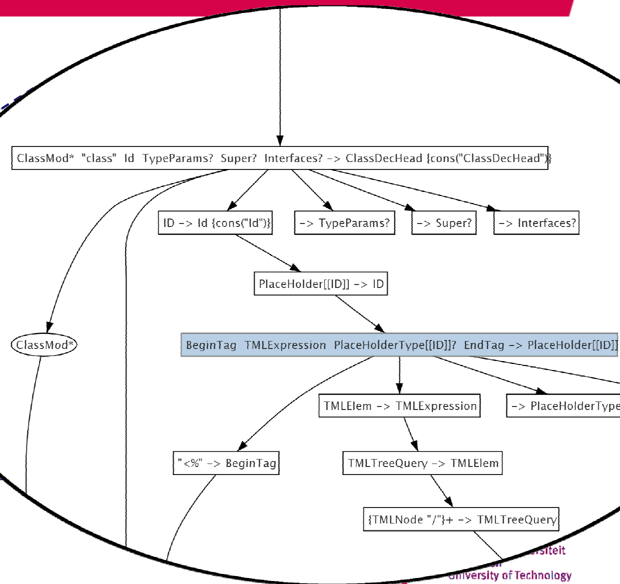





# Intermezzo: Software templates



# Intermezzo: Software templates




- Traverse the syntax tree to finding the placeholders



# Intermezzo: Software templates

- **Evaluation of placeholders**

  `public class <%class/name%>{`

  BeginTag TMLExpression PlaceHolderType[[ID]]? EndTag -> PlaceHolder[[ID]]

  - Lookup in input data
  - Return value: "Customer"
- **Before replacing the placeholder:**
  - Parse result of expression as ID
  - Replace placeholder with parse tree of the result of the expression

```
class(
  name("Customer"),
  attribute(
    name( "address" ),
  )
  attribute(
    name( "age" ),
    type( "int" )
  )
)
```



# Intermezzo: Software templates

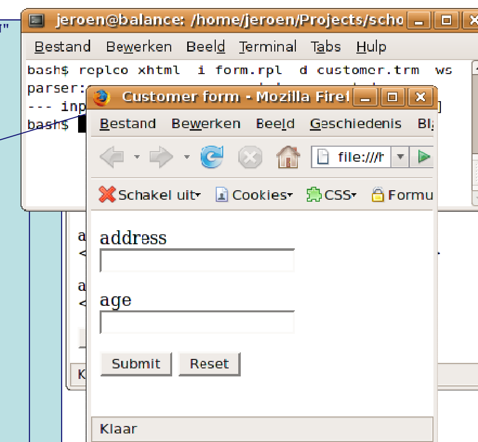
- **Better than using the compiler errors**
  - Detection of syntax errors in branches
  - More accurate error message
- **Generation of code not necessary**
  - Syntax checking without input data
- **However, can this technology be applied to other languages?**



# Intermezzo: Software templates

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
 "http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html>
 <head>
  <title>Customer form</title>
 </head>
 <body>
  <form action="/commit" method="post">
   <p>
    address <br>
    < input type="text"
      name="address" size="20">
   </p><p>
    age <br>
    < input type="text"
      name="age" size="20">
   </p>
   <p>
    <input type="submit" value="Submit">
    <input type="reset" value="Reset">
   </p>
  </form>
 </body>
</html>
```

jeroen@balance: /home/jeroen/Projects/scho
Bestand Bewerken Beeld Terminal Tabs Hulp
bash$ replco xhtml i form.rpl d customer.trm ws
parser:
--- inp
bash$



## Intermezzo: Software templates

- Syntax safe templates
  - Early detection of syntax errors
  - Generated code is syntax correct
- Generic
  - Combination of object language grammar with meta language grammar
- More Grammar, More Checking
  - More detailed object language grammar implies more syntax safety



## Ch.8: Type systems

- Older languages had very simple type systems
  - C's type system is too weak
  - Pascal's type system is too rigid
- Modern languages more powerful type systems:
  - subtypes
  - polymorphism
  - overloading



## Inclusion polymorphism

- *Inclusion polymorphism* is a type system where types may have subtypes
- A type T is a set of values equipped with some operations
- A subtype of T is a subset of values equipped with the same operations as T
- If we know that a variable only ranges over a subset of values of T, it is better to allow a subtype declaration
  - C has rudimentary subtypes:
    - char and int are subtypes of long
    - float is a subtype of double



## Inclusion polymorphism

- General properties of subtypes
  - S is subtype of T if every value of S is also a value of T: $S \subseteq T$
  - subtype S inherits the operations of type T
  - $T_1$ is compatible with $T_2$
    - $T_1$ is a subtype of $T_2$
    - $T_2$ is a subtype of $T_1$
    - $T_1$ and $T_2$ are subtypes of some other type

# Inclusion polymorphism

- If $T_1$ is compatible with $T_2$
  - $T_1$ is a subtype of $T_2$, no run-time check is necessary
  - $T_1$ is not a subtype of $T_2$
    - some of the values of $T_1$ are values of $T_2$
    - A run-time check is needed to check whether a value of $T_1$ is also a value of $T_2$
- This kind of run-time check is cheaper the full run-time checking as for dynamic languages

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# Classes and subclasses

- Class S is a subclass of class C
  - a class C is a set of objects with variable components and operations
  - each object of class S inherits all variable components and operations, but may add extra ones
- Subclasses are not exactly analogous to subtypes
  - objects of class S may be used wherever objects of class C are expected
  - S may have additional components, so the objects of S are not a subset of the objects of C

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# Parametric polymorphism

- *Monomorphic* procedures can only operate on arguments of a fixed type
- *Polymorphic* procedures can operate uniformly on arguments of a family of types
- *Parametric polymorphism* is a type system in which we can write polymorphic procedures
  - functional languages, ML, Haskell, etc., provide parametric polymorphism

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# Parametric polymorphism

- A type variable is an identifier that stands for a family of types
  - monomorphic
    `second(x : Int, y : Int) = y`
  - polymorphic
    `second(x : δ, y : τ) = y`
- A polytype derives a family of similar types
  `δ × τ → τ`
  includes
  - `Integer × Boolean → Boolean`
  - `String × String → String`

  but not
  - `Boolean × Integer → Boolean`
  - `Integer → Integer`

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## Parameterized types

- A *parameterized type* takes other type(s) as parameter(s)
  - In C array types `τ []` are parameterized types:
    - `char[]`
    - `float[]`
- All programming languages have built-in parameterized types
- ML and Haskell allow programmer to define their own parameterized types
  - `type Pair τ = (τ, τ)`
  - `data List τ = Nil | Cons(τ, List τ)`
    - plus polymorphic functions head, tail, length on these lists



## Type inference

- Statically type programming languages insist on explicit declaration of the type of entity in programs
  - `integer I := E`
- In Haskell we can write a definition `I = E` where type of I is not explicitly stated, but inferred from `E`
- *Type inference* is a process where the type of a declared entity is inferred instead of explicitly stated
  - monotype, if strong clues, e.g., if a monomorphic operator is used
  - polytype in case of polymorphic operators



## Type inference

- `even n = (n ‘mod’ 2 = 0)`
  type of `even` is: `Integer → Integer → Integer`
- `id x = x`
  type of `id` is: $\tau \to \tau$
- `f . g = \x -> f(g(x))`
  - types of `f` and `g` are $\beta \to \gamma$ and $\alpha \to \beta$, respectively
  - variable `x` must be of type $\alpha$
  - subexpression `f(g(x))` is of type $\gamma$
  - expression `\x -> f(g(x))` is of type $\alpha \to \gamma$
  - “`.`” is of type $(\beta \to \gamma) \to (\alpha \to \beta) \to (\alpha \to \gamma)$



## Type inference

- Type inference may lead to programs that are difficult to understand
- Explicitly declaring (redundant) types is good programming practice

## Overloading

- An identifier is *overloaded* of it denotes two or more distinct procedures in the same scope
- In older programming languages (e.g. C) identifiers and operators for certain built-in functions are overloaded
  - C "-" operator:
    - integer negation (`Integer` → `Integer`)
    - floating-point negation (`Float` → `Float`)
    - integer subtraction (`Integer×Integer` → `Integer`)
    - floating-point subtraction (`Float×Float` → `Float`)



## Overloading

- C++, Java allow programmers to define overloaded identifiers and operators
- Identifier F denotes
  - function ($f_1$) of type $S_1 \to T_1$
  - function ($f_2$) of type $S_2 \to T_2$
  - *context-independent overloading* requires $S_1$ and $S_2$ are non-equivalent
    - if actual parameter `E` of `F(E)` is of type $S_1$ then `F` denotes $f_1$
    - if `E` is of type $S_2$ then `F` denotes $f_2$
  - with context-independent overloading the function can be uniquely identified by the type of the actual parameter



## Overloading

- Identifier F denotes
  - function ($f_1$) of type $S_1 \to T_1$
  - function ($f_2$) of type $S_2 \to T_2$
  - *context-dependent overloading* requires $S_1$ and $S_2$ are non-equivalent or $T_1$ and $T_2$ are non-equivalent
    - if $S_1$ and $S_2$ are non-equivalent, see previous slide
    - if $S_1$ and $S_2$ are equivalent, but $T_1$ and $T_2$ are non-equivalent the context must be taken into consideration
      - if the context `F(E)` is of type $T_1$ then `F` denotes $f_1$
      - if the context is of type $T_2$ then `F` denotes $f_2$
  - with context-dependent overloading, it is possible to formulate expressions which cannot be uniquely identified
    - the programming language should prohibit this



## Type conversions

- A *type conversion* is a mapping from the values of one type to corresponding values of a different type
  - integers to real numbers
  - real numbers to integers involve rounding and truncation
- A *cast* is an explicit type conversion
  - In C, C++, Java: `(T)E`
- A coercion is an implicit type conversion
  - C allows very restricted coercions: from integers to real number, from narrow-range to wide-range integers
  - modern programming languages minimize or eliminate coercions altogether because of conflicts with polymorphism and overloading