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C++ Basics and Applications in technical Systems

Lecture 8 - Polymorphism, template classes and exeptions

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University of Bremen

14th December 2012 / Bremen

WiSe 2012/2013

VAK 01-036

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Overview

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Lecture schedule

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Time schedule

- HK **26. Oct.** - Introduction / Simple Program / Datatypes ...
- HK **02. Nov.** - Flow control / User-Defined Data types ...
- CF **09. Nov.** - Simple IO / Functions/ Modular Design ...
- CF **16. Nov.** - C++ Pointer
- CF **23. Nov.** - Object oriented Programming / Constructors
- AL **30. Nov.** - UML / Inheritance / Design principles
- AL **07. Dec.** - Namespace / Operators
- AL **14. Dec.** - Polymorphism / Template Classes / Exceptions
- HK **11. Jan.** - Design pattern examples

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Important dates

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Submission of exercises

1-3 **16. Nov.** - Deadline for submission of Exercise I, 13:00

4-6 **07. Dec.** - Deadline for submission of Exercise II, 13:00

For admission to final exam you need at least 50% of every exercise sheet.

Final project

1-9 **15. Feb.** - Deadline for submission of final project, 13:00

1-9 **21. Feb.** - Student presentations of their final projects, 10:00 - 12:00, 14:00 - 17:00

Final exam

1-9 **06. Feb.** - Final exam, 10:00-12:00, H3

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Example usage of namespaces

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Example

```
namespace DevLayer
{
  static int GetDevID(void);
}
```

usage version #1

```
int main()
{
  using namespace DevLayer;
  devID = GetDevID();
}
```

usage version #2

```
int main()
{
  using DevLayer::GetDevID;
  devID = GetDevID();
}
```

usage version #3

```
int main()
{
  devID = DevLayer::GetDevID();
}
```

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Misc on namespaces

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Attention

The usage of `using namespace ...` at global scope destroys the concept of namespaces!

Classes as namespace for static members

For static members of classes (they are not bound to a specific instance of that class) the class name builds a namespace:

```
class Device
{
public:
  static void Shutdown(void);
}
```

```
int main()
{
  Device::Shutdown();
}
```

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Introduction

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Definiton

Within a method `this` is a pointer to the current object and `*this` is the object itself.

Example

```
class MyClass
{
  MyClass()
  {
    std::cout << "Address of this instance: 0x"
              << static_cast<long>(this)
              << std::endl;
  }
};
```

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Operators

handling of 'operator-like' methods

Example

```
Matrix a(3,3);
...                   // Set elements of a
Matrix b(3,3);
...                   // Set elements of b
a.Assign(b);          // 'Operator-like' method
```

more intuitive: `a = b;` or `Matrix a = b + c/2;`

Global vs. Element-function

By means of the output operator `<<` and the class `MyClass`

- Objective: `cout << MyClassObject;`
- Syntax:
  - 1st possibility:

    ```
    cout.operator<< (MyClassObject);
    ```

  - 2nd possibility:

    ```
    operator<< (cout, MyClassObject);
    ```

Conclusion

Only the 2nd version is really possible, i.e., the operator has to be declared as a global function.

Polymorphism

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Polymorphism is:

Operations with identical names, belonging to different objects, may behave differently. Objective $\rightarrow$ Treat an object of a derived class as an object of the base class within a certain context.

You already know about one kind of polymorphism:

Static polymorphism

Overloading of functions, methods and operators.

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Dynamic polymorphism

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Another kind of polymorphism is:

Dynamic polymorphism

Delayed linkage
E.g. the decision which function/method call is associated with the operation will be known during runtime only. This is called runtime or dynamic polymorphism.

- In C++ polymorph methods can be used only in **inherited class hierarchies.**
- All polymorph methods must have **identical signatures.**
- A method that will be selected during runtime is called **virtual method.**

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Virtual methods

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The keyword `virtual`

Virtual methods of a (base) class, can be reimplemented / redefined in each derived class.

- usage of virtual methods is called run-time polymorphism
- statement: `virtual <method declaration>;`

Example

```
class Point
{
public:
  virtual void Move(int iX,
                    int iY);
};
```

Example

```
class Rectangle
  : public Point
{
public:
  void Move(int iX, int iY);
};
```

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Usage example

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Example

```
class Point
{
public:
  virtual void Move(int iX,
                    int iY);
};

class Rectangle
  : public Point
{
public:
  void Move(int iX, int iY);
};
```

During runtime the correct method is called automatically!

Example

```
Point * pElement;
Rectangle newRectangle(...);
Point newPoint(...);

pElement = &newPoint;
pElement->Move(...);

pElement = &newRectangle;
pElement->Move(...);
```

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Virtual method background

- Type-informations are stored for each object internally.
- Difference between „normal“ and „virtual“ method is only observable if pointer or reference to base class is used for access.
- Call to non-virtual methods depends on the type of the pointer or reference, virtual method calls depend on the object type.
- A method declared as virtual is used as **interface definition** for all derived classes.

Rule-to-Remember

Non-virtual member functions should not be overloaded within derived classes.

Example **without** `virtual` method

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Example

```
class Vehicle {
public:
  void Travel() {
    std::cout << "no vehicle"
    " specified" << std::endl;
  }
};
```

Example

```
class Car : public Vehicle {
public:
  void Travel() {
    std::cout << "we travel"
    " by car" << std::endl;
  }
};
```

Example

```
Car newCar;
Vehicle *pVehicle(&newCar);
pVehicle->Travel(); // output: no vehicle specified
```

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Example with `virtual` method

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Example

```
class Vehicle {
public:
  virtual void Travel() {
    std::cout << "no vehicle"
    " specified" << std::endl;
  }
};
```

Example

```
class Car : public Vehicle {
public:
  void Travel() {
    std::cout << "we travel"
    " by car" << std::endl;
  }
};
```

Example

```
Car newCar;
Vehicle *pVehicle(&newCar);
pVehicle->Travel(); // output: we travel by car
```

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Usage of polymorphism for containers

```
// vehicle park
class Aircraft : public Vehicle { ... };
class Ship : public Vehicle { ... };
class Balloon : public Vehicle { ... };
```

```
// storing all vehicles in a std::vector with pointer to base class
std::vector<Vehicle*> vehiclePark;
```

```
// fill vector
vehiclePark.push_back(new Car);
vehiclePark.push_back(new Aircraft);
vehiclePark.push_back(new Ship);
vehiclePark.push_back(new Balloon);
```

```
// access elements of vector
vehiclePark[0]->Travel(); // output: we travel by car
vehiclePark[1]->Travel(); // output: we travel by aircraft
vehiclePark[2]->Travel(); // output: we travel by ship
vehiclePark[3]->Travel(); // output: we travel by balloon
// do not forget to delete all elements of vehiclePark ...
```

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Use a `virtual` destructor

Example

```
class Vehicle {
public:
  virtual ~Vehicle() {
    std::cout << "vehicle"
    " destroyed" << std::endl;
  }
};
```

Example

```
class Car : public Vehicle {
public:
  ~Car() {
    std::cout << "car"
    " destroyed" << std::endl;
  }
};
```

Example

```
Car * pCar(new Car);
Vehicle * pVehicle(pCar);
delete pVehicle; // output: car destroyed
                 //         vehicle destroyed
```

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Dynamic Cast

Sometimes it is necessary to access the derrived class from an interface. This is possible by dynamic casting the pointer to the derrived class.

Usage

```
DerrivedClass* pDerrivedClass =
    dynamic_cast< DerrivedClass* >( pBaseClass );
```

If pBaseClass is not a pointer to a DerrivedClass object, the dynamic_cast returns a NULL pointer.
Warning: static_cast does not type check the cast. Returned pointer may be invalid and can crash the program on using!

Example

```
Car* pCar = dynamic_cast< Car* >( pVehicle ) ;
```

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Summarization

Remember

- Every class, from which should be inherited, should have a virtual destructor.
- Every class, which has at least one virtual method (incl. the destructor) is called polymorphic type.
- A virtual and overridden method is only accessible from its derivatives. E.g.:

```
void Aircraft::Travel() { Vehicle::Travel(); }
```

- The `virtual` statement is only used in the declaration / header file.
- A method that was declared `virtual` should also be declared `virtual` in all derived children to improve readability.

Abstract classes

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Sometimes it is necessary to declare a method in a base class, which must be implemented in each derived class, but not in the base class itself.

Pure virtual method declaration syntax:

```
virtual <method declaration> = 0;
```

Example

```
class Plugin {
public:
  virtual Icon * GetIcon(void) = 0;
};
```

Classes with at least one pure virtual method are called abstract classes.

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Example

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Example

```
class Vehicle {
public:
   virtual void Travel() = 0;
   // Method is pure virtual,
   //  no implementation
   //  definition here!
};
```

Example

```
class Car : public Vehicle {
public:
   void Travel()
   // This method must be
   // implemented here!
   {
      std::cout << "we travel"
      " by car" << std::endl;
   }
};
```

Example

```
Car newCar; // OK, does compile
Vehicle newVehicle; // NOT OK, error from compiler!
```

Remember...

- A class with at least one pure virtual method cannot be instantiated directly, only their derivatives.
- An abstract class with only pure virtual methods is normally used for **interfaces**.

Usage...

Abstract classes are often used as common interfaces in class hierarchies.

Small exercise

Create a class hierarchy with a base class for 2-dimensional shapes: rectangle, triangle and circle:

- The base class should be an interface (abstract class).
- Create a class for each shape.
- Each class for a shape should have a `Draw()` method, which outputs „Drawing <shape type>“.
- Store different objects of shapes in one `std::vector` and test the `Draw()` method within a `main()` function.

General idea of templates

A template:

- enables to construct methods without defining parameter types.
- is easier to write.
- is easier to understand.
- is type-safe.

Your already know about function templates (lecture 3):

```
template <class tType> void Swap(tType &A, tType &B);
```

Repetition: function-templates

- Function templates for unspecified data types
- Generic usable algorithms can be made available
- **Declaration and definition must be in the header-file!**

Definition

```
template <class tType>
void Swap(tType &A, tType &B)
{
  tType Temp = A;
  A = B;
  B = Temp;
}
```

Example

```
int iNumber1;
int iNumber2;
iNumber1 = 1;
iNumber2 = 2;

Swap(iNumber1, iNumber2);
```

Class templates

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Beside function templates it is also possible to create class templates and method templates.

Usage for abstract data-types like:

- graphs
- sets
- queues
- lists
- trees
- matrices

You already know two template classes: `std::vector` and `std::complex`. The first with one and the second with two template arguments.

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Example template class

```
#ifndef SIMPLE_STACK_H
#define SIMPLE_STACK_H
#include <vector>                  // std::vector to store elements
```

```
template <class T>
class SimpleStack
{
```

```
public:
        SimpleStack();                  // Constructor
        const T& Top(void) const;       // Method to get top element
        void Pop(void);                 // Method to remove top element
        void Push(const T & x);         // Method to add element
```

```
private:
        std::vector<T> m_Array;         // std::vector for stack
```

```
};
```

```
#endif
```

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Usage of template class

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Example

```
SimpleStack< unsigned int > SStack ; // Constructs SimpleStack
                                     //  with type unsigned int

SStack.Push( 1 ) ;                   // Fills stack
SStack.Push( 2 ) ;
SStack.Push( 3 ) ;

cout << SStack.Top() << endl ;      // Print out top element
SStack.Pop() ;                      // Removes from stack
```

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Code organization with templates I

Problem:

Datatype in template only specified during instantiation.
$\rightarrow$ Declaration + definition have to be included in compilation unit (impl/cpp-file) of template-instantiation.

Solution 1:

Declaration + definition in header-file:

- Normal approach
- Attention: code bloat in large projects!!

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Code organization with templates II

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Solution 2:

Separate declaration „Stack.h“ and definition „Stack.cpp“ and inline implementation in separate file e.g. „Stack.inl“.

Example

```
// Stack.h
template<class T>
class Stack
{
  void Push(T & value);
};

#include "Stack.inl"
```

Example

```
// Stack.inl
template<class T>
void Stack<T>::Push(T & value)
{
  // ...
}
```

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Templates and polymorphism

You already know:

Run-time (dynamic) polymorphism

Polymorphism with virtual methods is called **run-time polymorphism.**

With respect to templates a new type of polymorphism is:

Compile-time polymorphism

Polymorphism with templates is called parametric or **compile-time polymorphism.**

Small exercise

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- Create a simple stack template class with methods to add, remove and get elements from the top of the stack.
- Create a test application to test your stack template class.

Example

```
template <class T>
class SimpleStack
{
public:
  const T& Top(void) const;      // Method to get top element
  void Pop(void);              // Method to remove top element
  void Push(const T & x);           // Method to add element
private:
  std::vector<T> m_Array;           // std::vector for stack
};
```

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Exception handling

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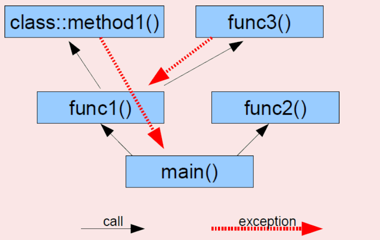
- Exception can / shall not be handled within the scope of its occurrence.
- Program abort in case of exception is often unnecessary and not user-friendly.

Call graph



Concept: Parent scope is informed about error:

- and does exception handling.
- forwards exception notification to own parent scope.

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Usage of exceptions for error handling I

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Exception handling is mainly used for error handling.

- Code for error handling can be separated from „normal“ code.
- Complexity in code is reduced.

statement for callee

```
throw (<exception object>);
throw (); // no exceptions
```

Without the throw statement any class can be thrown ⇒ unexpected for caller.

statement for caller

```
try {
  // error prone code
}
catch (<exception type>
        [object name])
{
  // error handling
}
```

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Usage of exceptions for error handling II

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Declaration

```
class MyClass {
public:
  void Method(void)
    throw (ExceptionType1,
           ExceptionType2);
};
```

Hint: Don't forget the exception specification in your declaration and definition!

Definition

```
void MyClass::Method(void)
  throw (ExceptionType1,
         ExceptionType2)
{
  // ...
  if (bVeryBad)
    throw ExceptionType1;
  if (bVeryVeryBad)
    throw ExceptionType2;
  // ...
  return;
}
```

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Example

Example

```
double Div(double dDividend,
           double dDivisor)
{
  std::string Exception(
    "division by 0");

  if (dDivisor == 0.0)
  {
    // throw exception
    throw (Exception);
  }

  // return result
  return dDividend
         / dDivisor;
}
```

Example

```
double dNumberA;
double dNumberB;
std::cin >> dNumberA;
std::cin >> dNumberB;

try {
  std::cout << Div(dNumberA,
                   dNumberB)
            << std::endl;
}
catch (std::string error) {
  std::cout << error
            << std::endl;
}
```

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Summarization

Rules to remember

- Enclose each function / method that can throw an exception in a `try`-block.
- Catch each kind of exception and handle it or forward it using throw again.
- Use `catch(...){}` to catch all exceptions anonymously.
- If there is no object type given for `throw`, no exception can be thrown.
- Without the throw statement any class can be thrown $\Rightarrow$ unexpected for caller.

Uncaught exceptions

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- If an exception is thrown, but not caught, the application will be terminated!
- Take care for standard exceptions thrown by the `new`-operator: `std::bad_alloc`.

Example

```
double * pValue(NULL);
try {
  pValue = new double(0.0);
}
catch (std::bad_alloc) {
  std::cout << "not enough memory available"
            << std::endl;
}
```

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Grouping exceptions

Often it is useful to group exceptions depending on the occurred error. A possible and good approach is to use inheritance for own exception types.

Example

```
// General error/exception type
class MathErr { };

// Exception type for division by zero
class DivisionZeroErr : public MathErr { };
// Exception type for overflow
class OverflowErr : public MathErr { };
// Exception type for underflow
class UnderflowErr : public MathErr { };
```

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Catch different exceptions

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Be careful: The order of `catch()`-statements is important when using exceptions based on an inheritance hierarchy.

Example

```
try {
  // execute Div() with arbitrary values
  dResult = Div(dNumberA, dNumberB)
}
catch (DivisionZeroErr) {
  // handle division by zero errors
}
catch (OverflowErr) {
  // handle overflow errors
}
catch (MathErr) {
  // handle all math errors
}
```

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Transporting data with exceptions

Using classes enables to add further functionality to exception types.

Example

```
class Error_T {
  int m_iErrNum;
  std::string m_sError;
public:
  Error_T(int iErrNum,
          std::string sError)
    : m_iErrNum(iErrNum),
      m_sError(sError) {}
  void PrintMessage(void) {}
};
```

Example

```
if ( ... very bad things ...)
{
  throw Error_T(13, "Friday");
}
```

Example

```
try
{
  // ...
}
catch (const Error_T& error)
{
  error.PrintMessage();
}
```

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Small exercise

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Extend the class `Rational` from lecture #7 about exceptions for error cases (e.g. division by zero):

- create own exception types
- use exception specifications
- test for error cases the behavior with and without catching the exceptions

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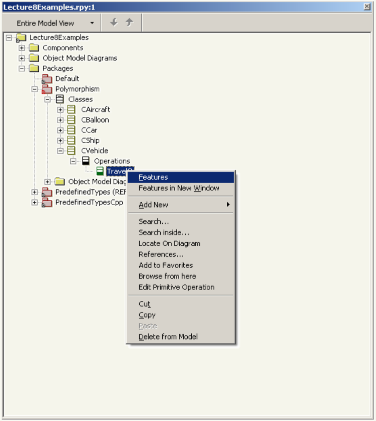
Polymorphism (XI) – Rhapsody



- Creating virtual methods:
  - Select a method (in Rhapsody: operation) with right click
  - Choose “**Features**”

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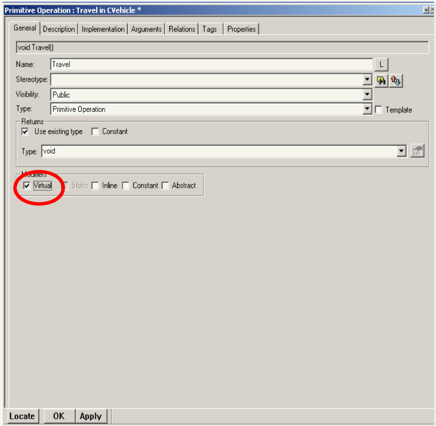
Polymorphism (XII) – Rhapsody



– Select the “**virtual**” modifier under “**General**”

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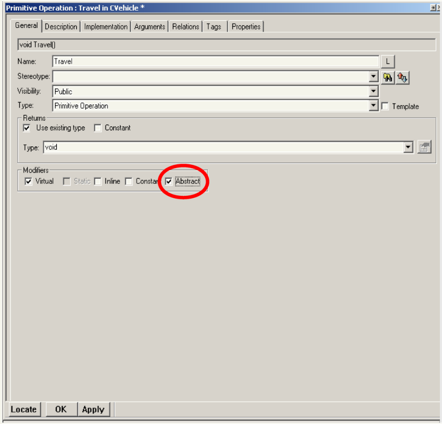
Polymorphism (XII) – Rhapsody



- Creating pure virtual methods:
  - additionally select the “**Abstract**” modifier under “**General**”

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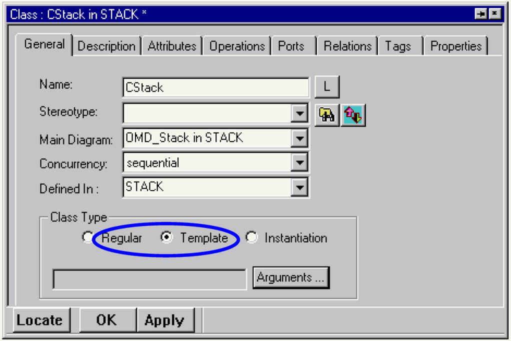
Definining template classes



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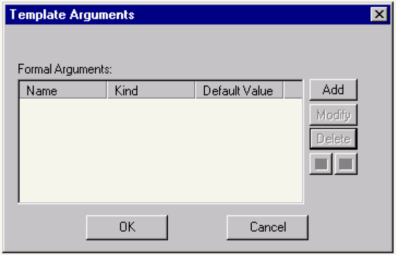
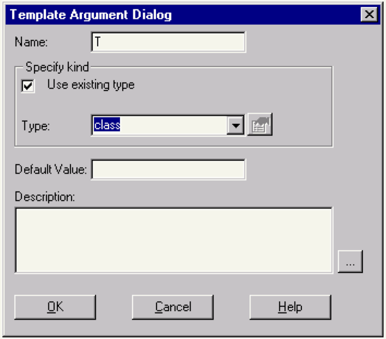
Settings for template arguments





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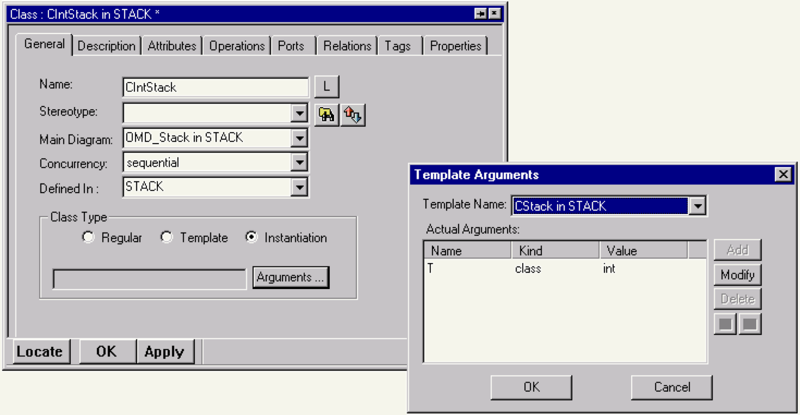
Template instantiation



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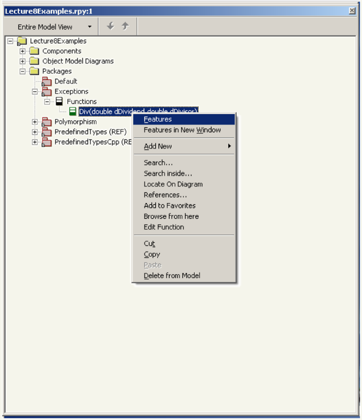
Exception Handling (XII) – Rhapsody



- Adding exception specifications to methods / functions
  - Select a method or function with right click
  - Choose “**Features**”

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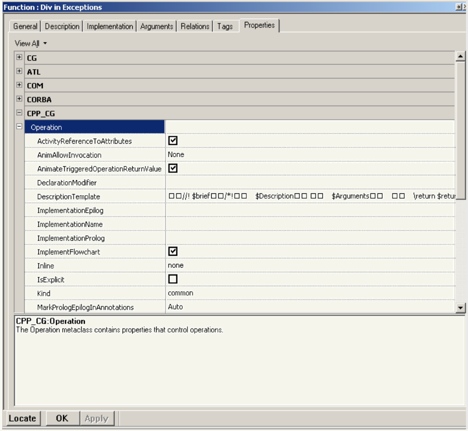
Exception Handling (XIII) – Rhapsody



- Under "Properties" select category "**CPP_CG**"
- Select "**Operation**"

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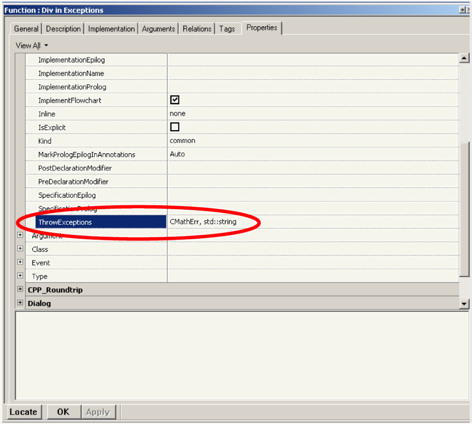
Exception Handling (XIIV) – Rhapsody



– Enter in the property **“ThrowExceptions”** a list of coma separated exception types

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