A Whirlwind Tour of C++

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Part 1: 3 November 2000: Object Model
Part 2: 17 November 2000: Templates
Part 3: 15 December 2000: STL

Part 4: 30 March 2001
Exceptions and Exception Safety

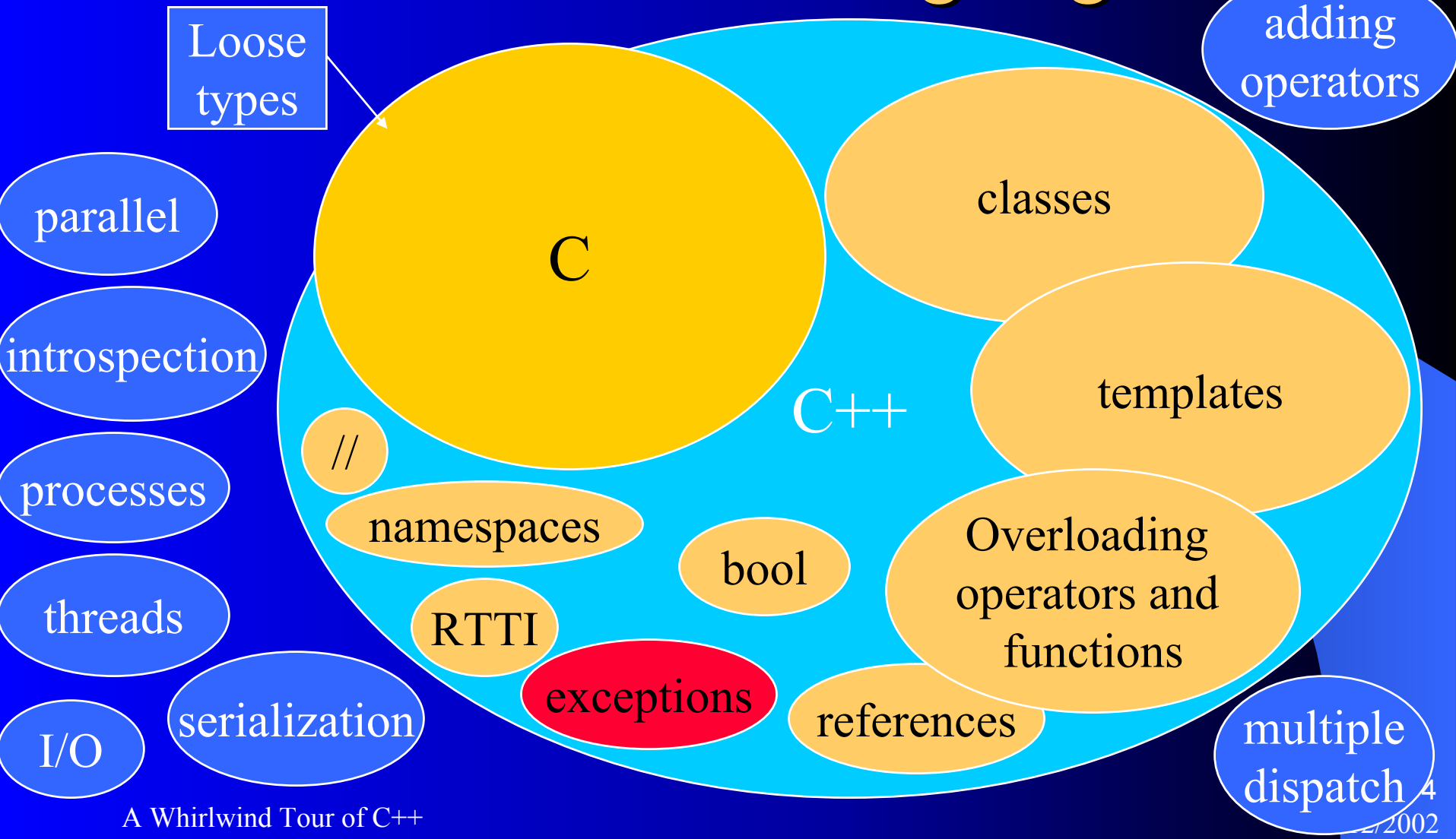
Introduction

- Scope: ISO/ANSI Standard C++ language and standard library
- Audience: Programmers. Some familiarity with basic C++ object model will help.
- Fast and shallow. It's simple on the surface, but the implications are complicated.

Series Agenda

- Overview of language features
- Overview of standard library
- Objectives of the language
- Classes and objects
- Templates
- Standard Template Library
- **Exceptions**
- I/O Streams
- Numerics
- etc.

Overview of the Language



Ways to Indicate Failure

- **Set a global error flag** like C math library. Not thread safe, universally ignored.
- **Return a status flag** like C stdio. Almost always ignored, OR error handling obscures normal logic. Useless for constructors, operators.
- **Set flag in object** like old iostreams. Usually ignored by client, slows member functions.
- **Print a message and exit().** Draconian.
- **Use assert().** Draconian, removed by NDEBUG.
- **Call longjmp().** Nonlocal go-to. Obscure, invisible, leaky (no destructor calls).
- **Throw an exception.** Imperfect but mandatory.

Throwing an Exception

```
#include "Complex.h"
#include <stdexcept>
class Complex::DivZero : public std::exception {
   const char *what() const    // override
       { return "Complex divide by zero"; }
};

Complex& Complex::operator/=(
   const Complex& den ) throw (Complex::DivZero)
{  if ( den == Complex(0.0,0.0) )
       throw ComplexDivZero();
   // ... do the calculation ...
   return *this;
}
```

Catching an Exception

```
#include <stdexcept>
void MyFun() {     // no exception specification
   try {
       // ... calculation involving Complex etc.
   }
   catch (Complex::DivZero& d) {
       // ... recover and carry on
   }
   catch (std::exception& e) { // base class
       cerr << "Caught: " << e.what() << endl;
       throw;       // re-throw same exception
   }
   catch (...) {    // anything else
       throw MyOwnException(); // different
   }
}
```

Exceptions Call Destructors for Local (Automatic) Variables

```
TypeB FunA() { // No exception spec: Can throw any
   TypeA a; // more code
   if ( goof )throw TypeX();
   return TypeB( a );    // Skipped on throw
       // a destructor always called here
}

void FunB() {
   TypeB b;
   TypeB bb = FunA();    //On throw, no bb
       // Destructor: bb if it exists
       // Destructor: b always
       // No catch: Exception propagates up
}
```

Exceptions Call Destructors 2

```
void FunC() {
   TypeA a;
   try {
       TypeC c;
       FunB();      // Might throw
       // c always destroyed here
   }
   catch (TypeX& x) {
       //... recover
   }           // Carry on
       // a destroyed here
}
```

Exceptions In Constructors

```
class TypeA {
   Type1 member1; Type2 member2; Type3 *pmember3;
public:      TypeA();     // constructor
}
TypeA::TypeA()
:  member1(),        // may be omitted
   member2( value2 ), pmember3( 0 )
{
   pmember3 = new Type3( value3 );
}
```

- If anything throws, previously constructed members are destroyed in reverse order. The TypeA object does not exist, never did exist, hence will not be destroyed.
- This example is exception safe (if destructor deletes #3) and exception neutral (propagates exceptions to caller).

Summary (surface)

- Throw at any level unwinds call stack until a matching catch is found. At each level, destructors for local variables are called before leaving function. No leaks (in principle).
- Any *copyable* type may be thrown & caught. Normally throw a special-purpose class, often based on **`std::exception`** hierarchy. Copied to special area (not on stack).
- Throw where error is discovered. Catch where you have enough context to recover.
- Throw by value, catch by reference.
- No time penalty unless exception is thrown.

Standard Exceptions

Name	Thrown by	Header
bad_alloc	*new*	*<new>*
bad_cast	*dynamic_cast*	*<typeinfo>*
bad_typeid	*typeid*	*<typeinfo>*
bad_exception	*exception specification*	*<exception>*
out_of_range	*at() (containers), bitset<>::operator[]()*	*<stdexcept>*
invalid_argument	*bitset constructor*	*<stdexcept>*
overflow_error	*bitset<>::to_ulong()*	*<stdexcept>*
ios_base::failure	*ios_base::clear()*	*<stdexcept>*

Exception Safety: 3 Levels

- **Basic Guarantee:** Operation doesn't leak resources. State remains consistent, but not necessarily predictable. Fairly easy.
- **Strong Guarantee:** Operation either succeeds or leaves state unchanged. Commit-Rollback semantics. Depends critically on class design.
- **Nothrow Guarantee:** Operation will never emit an exception. Overall safety is impossible unless *some* operations don't throw.

Basic Canonical Safety Rule

- Never allow an exception to escape from a destructor or from overloaded **`operator delete()`** or **`operator delete[]()`**.

- If destructor throws while another exception is uncaught, std::terminate() is called. The end.
- Fortunately, library destructors and deletes don't throw.

Leak Prevention 1: Try Blocks

```
void Fun1() {
  Type1 *p1 = new Type1();
  try {
     // do some stuff
  } catch ( ... ) {
     delete p1;
     throw;
  }
  delete p1;
}
```

- Verbose, repetitive, error prone.
- Multiple resources require nested try blocks.

Leak Prevention 2: auto_ptr

```
#include <memory>
void Fun1() {
  std::auto_ptr<Type1> p1( new
     Type1());
     // do some stuff
}
```

- **`auto_ptr`** destructor destroys and deletes its referenced object, whether or not an exception is thrown!
- Single objects only, not arrays. But...

Leak Prevention 3: STL Containers

```
#include <vector>
void Fun1(int size) {
  std::vector<Type1> v1(size);
     // Use v1 just like an array
}
```

- **`std::vector`** destructor destroys and deletes its contents, whether or not an exception is thrown!

Leak Prevention 4: Constructors

```
class TypeA {
  std::vector<Type1> vec1;
  std::auto_ptr<Type2> ptr2;
public:
  TypeA(int size)
  :  vec1( size ),
     ptr2( new Type2() ) {}
};
```

- This version is exception safe.
- No destructor is required! The one the system invents automatically does the right thing!

Resource Acquisition Principle

- Acquire resources in constructors.
- Release resources in destructors.
- Applies to memory, files, mutexes, locks, devices, ...
- If necessary, invent a tiny class whose only function is to acquire and release a resource (in constructor and destructor).
- The C++ library can often make it automatic.

Leak Prevention 5: swap()

```
doit( std::vector<TypeA>& v )
{
  std::vector<TypeA> w( v.size() );
  // Compute in w (may throw)
  v.swap( w );    // Doesn't throw
}
```

- This one satisfies strong guarantee: Success or no change in state.
- All STL containers and **`auto_ptr`** have swap().
- Consider adding swap() to your classes.

Leak Prevention 6: pimpl idiom

```
class TypeA {
  class Impl { // the guts }
  std::auto_ptr<Impl> pimpl;
public: // constructor etc...
}
```

- To satisfy strong guarantee: State changing operations construct new, temporary TypeA::Impl, do operation, then swap if successful. Temporary is destroyed on exit.

Where to Get More Information

- Book list posted at:

`http://staff.washington.edu/rpg3/booklist.html`

- Bjarne Stroustrup, *The C++ Programming Language*, Special (or 3rd) Edition, Addison-Wesley, 2000
- Herb Sutter, *Exceptional C++, 47 Engineering Puzzles, Programming Problems, and Solutions*, Addison-Wesley, 2000