A Whirlwind Tour of C++

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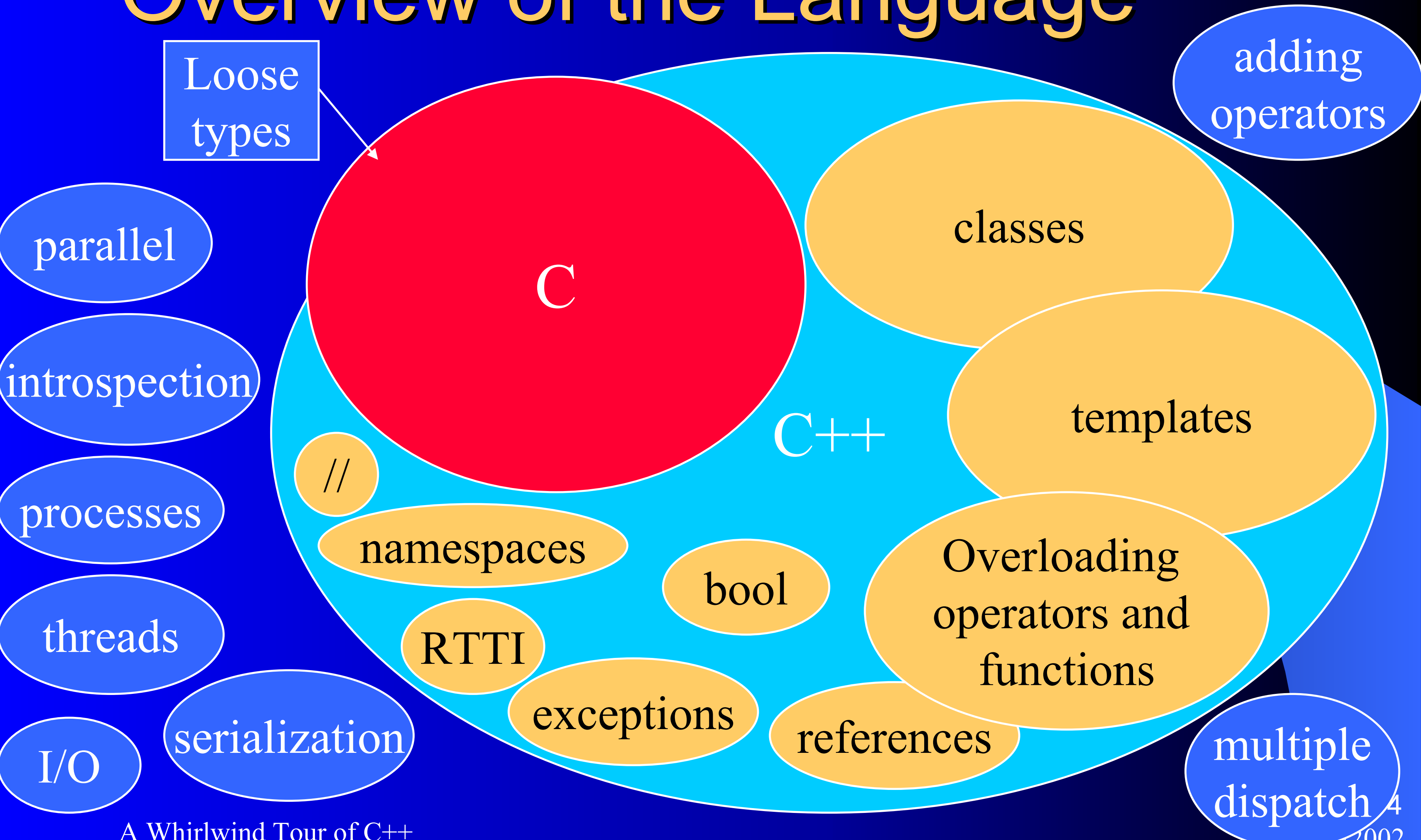
Introduction

- Scope: ISO/ANSI Standard C++ language and standard library
- What is in it, what isn't, and why?
- Emphasis is on objectives of language, and compromises made to achieve them.
- Audience: Programmers. Some familiarity with C, and concepts like object, class, and type will be helpful.
- Fast and shallow

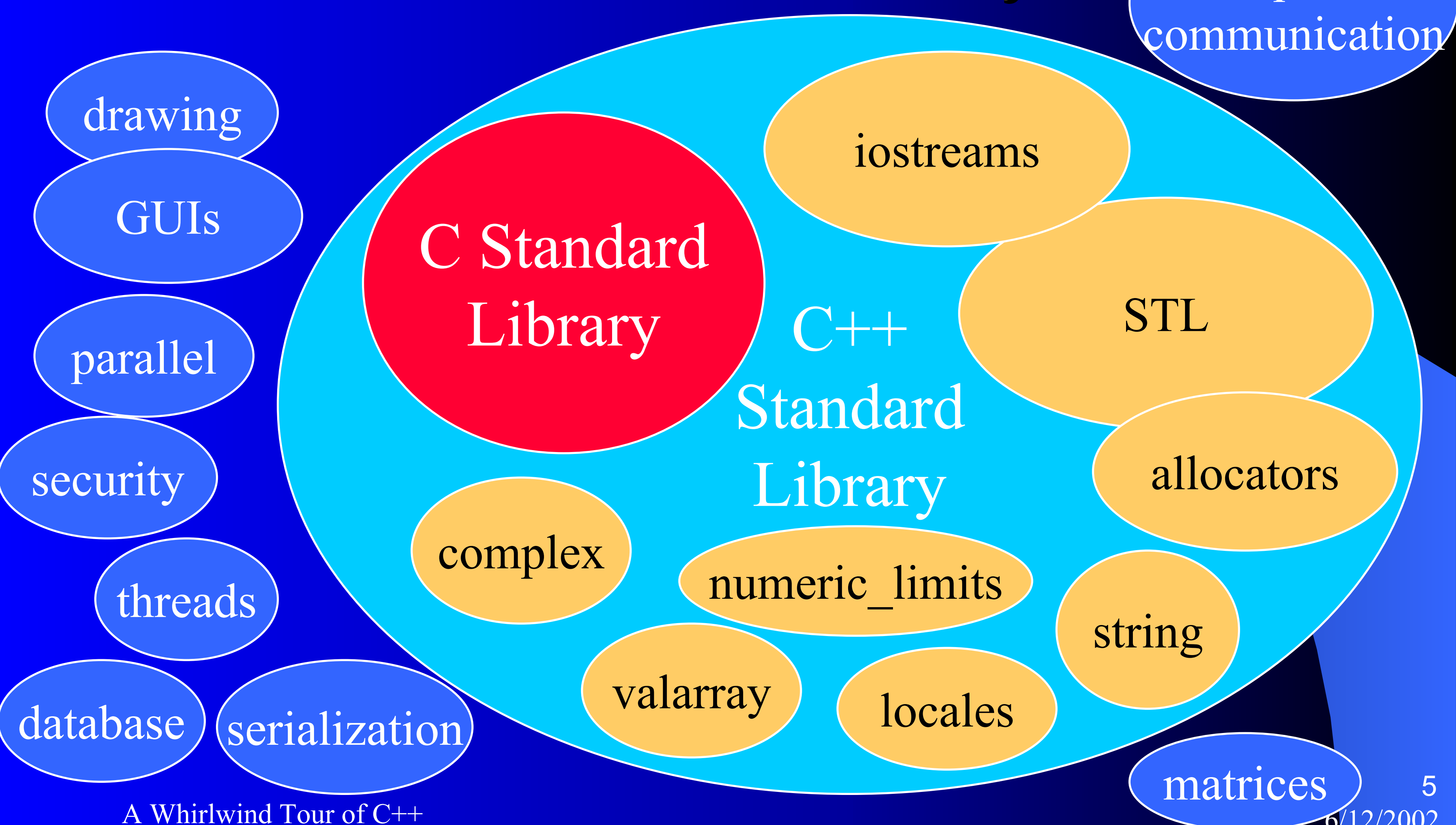
Agenda

- 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



Overview of the Library



Aims of the Language

- C++ makes programming more enjoyable for serious programmers.
- C++ is a general-purpose programming language that
  - is a better C
  - supports data abstraction
  - supports object-oriented programming
  - *supports generic programming

(Stroustrup, *Design and Evolution of C++*, + *)

General Rules

- C++'s evolution must be driven by real problems.
- Don't get involved in a sterile quest for perfection.
- C++ must be useful *now*.
- Every feature must have a reasonably obvious implementation.
- Always provide a transition path.
- C++ is a language, not a complete system.
- Provide comprehensive support for each supported style.
- Don't try to force people.

Design Support Rules

- Support sound design notions.
- Provide facilities for program organization.
- Say what you mean.
- All features must be affordable.
- It is more important to allow a useful feature than to prevent every misuse.
- Support composition of software from separately developed parts.

Language-technical Rules

- No implicit violations of the static type system.
- Provide as good support for user-defined types as for built-in types.
- Locality is good.
- Avoid order dependencies.
- If in doubt, pick the variant of a feature that is easiest to teach.
- Syntax matters (often in perverse ways).
- Preprocessor usage should be eliminated.

Low-level Programming Support Rules

- Use traditional (dumb) linkers.
- No gratuitous incompatibilities with C.
- Leave room for lower-level language below C++ (except assembler).
- What you don't use, you don't pay for (zero-overhead rule).
- If in doubt, provide means for manual control.

C++ Is a Better C

- C code compiles and runs as C++, *except*:
  - All functions must be declared (with prototype) before used.
  - No old-style (K&R) function headers.
  - No implicit int.
  - New keywords.
  - Use extern "C" for C linkage (default C++ linkage includes signatures for overloading).
- All but last can be fixed and remain C.

Features Inherited From C

- Built-in types (float, int, etc.), operators, expressions.
- Syntax for pointers, arrays, structures, const, etc.
- Syntax for functions (C prototypes from C++).
- Syntax for decisions and control.
- File organization: header (.h), source (.c, .cc, .C, .cpp, .cxx, etc.).
- Preprocessor (but used less).
- External linkage model.
- Standard conversions (including narrowing).
- Efficiency: You pay only for what you use.

Concrete Data Type Usage: “Just like built-in types”

```
#include "Complex.h"
#include <iostream>
using namespace std;
int main()
{
   const Complex x( 1.0, 2.0 );
   Complex y( 3.0 );
   Complex z = x*y + exp( z );
   y *= x;
   z.imag( x.real() );
   cout << "w=" << w << "  z=" << z << endl;
}
```

Concrete Data Type: Class Definition

```
   // In Complex.h:
class Complex {
   double _re, _im;  // private
public:
   Complex( double r, double i=0) //default
        : _re(r), _im(i){}
   Complex() : _re(0), _im(0) {}
   double real() const { return _re; }   //inline
   double imag() const { return _im; }   //inline
   void real(double r) {_re = r; }       //inline
   void imag(double i) {_im = i; }       //inline
        // Declarations of member functions
   Complex& operator+=( const Complex& );
   Complex& operator*=( const Complex& );
};
```

Concrete Data Type: Extended Interface

```
   // Complex.h continued:
inline Complex& Complex::operator+=( // Member operator
       const Complex& rhs )
{  _re += rhs._re;
   _im += rhs._im;
   return *this;
}
inline Complex operator+(  // Non-member operator
       const Complex& lhs, const Complex& rhs )
{  Complex result( lhs );  // invokes copy constructor
   result += rhs;
   return result;
}
Complex exp( const Complex& ); // Non-member declaration
ostream& operator<<( ostream&, const Complex& );
```

Concrete Data Type: External Definitions

```
   // In Complex.cc:
#include <Complex.h>
#include <cmath>
   // Member operator
Complex& Complex::operator*=( const Complex& rhs )
{  double temp = _re*rhs._re - _im*rhs._im;
   _im = _re*rhs._im + _im*rhs._re;
   _re = temp;
   return *this;
}
   // Non-member function (overloaded)
Complex exp( const Complex& x )
{  using std::exp, std::cos, std::sin;
   double mag = exp( x.real() );
   return Complex( mag*cos(x.imag()), mag*sin(x.imag()) );
}
```

Concrete Data Type: External Definitions cont.

```
  // In Complex.cc, continued:
#include <iostream>
  // Overloaded inserter for text output
ostream& operator<<( ostream& s, const Complex& x )
{
  s << "(" << x.real() << "," << x.imag() << ")";
  return s;
}
```

Polymorphism: Usage

```
  // A client of abstract class Shape,
  // which has derived classes Circle,
  // Rectangle, etc.
#include "Shape.h"
void drawAllShapes( Shape *first,
     Shape *last )
{
  for ( Shape *s = first; s != last; ++s )
     s->draw();// Which draw() gets called?
}
```

Polymorphism Via Inheritance

```
class Shape { // abstract class, in Shape.h
public:
   virtual void rotate(int) = 0;
   virtual void draw() const = 0; // pure virtual
};     // Abstract class cannot be instantiated.

   // In Circle.h:
#include "Shape.h"
class Circle : public Shape {
public:
   Circle( const Point& p, int r );      // constructor
   void rotate(int) { };   // overrides
   void draw() const;      // definition is in Circle.cc
private:
   Point center; int radius;
};
   // etc. for Rectangle, ...
```

Polymorphism Via Inheritance: How it works

- **For each class that has any virtual functions, there is a list of addresses (*vtbl*) of v. f. implementations.**
- **Each derived class inherits the vtbl of its base class, but it substitutes its own v.f. implementations.**
- **Each object of a class having a virtual function contains a pointer (*vptr*) to the *vtbl* for the object's class.**
- **A v.f. call is doubly indirect, through *vptr* and an address in the *vtbl* .**

Inheritance Rules of Thumb

- Public inheritance means "is a". Must obey the Liskov Substitution Principle.
- Private or protected inheritance means "is implemented in terms of". Rarely a good idea.
- Cleanest form of public inheritance: Pure abstract base class ("interface"). No state, pure virtual functions.
- Inheritance implies tight coupling from derived class to base class. When in doubt, choose containment instead.
- Polymorphism requires client access via references or pointers. Passing by value will "slice" objects back to base class part.
- Multiple inheritance is useful but tricky. It helps if base classes are "interfaces" (except perhaps one).

Inheritance Rules of Thumb (2)

- **Consider refactoring if "bad smells" detected:**
  - **Inheritance more than 3 levels deep.**
  - **Clients fall into categories that use different interfaces.**
  - **Class has too many responsibilities, or not enough.**
  - **Code is duplicated, with only minor changes.**
  - **Parameter list, class, or method too big or too small.**
  - **Switch statements.**
  - **Inappropriate intimacy with another class.**
  - **Divergent changes for different causes.**
  - **Changes require editing many classes.**

  (Lots more: See Fowler, *Refactoring: Improving the Design of Existing Code*)

Special Member Functions

```
class Foo {
public:
   Foo();     // Default Constructor
   Foo( const Foo& );    // Copy Constructor
   Foo& operator=( const Foo& );     //Assignment
   ~Foo();   // Destructor
}
```

- **These 4 are created by compiler if you don't.**
- **Default versions call same operator for base classes and all data members.**
- **Destructor must release any resources held in object.**
- **Assignment must release resources held by target.**
- **To disable one of these, declare it private.**

Template Class: Usage

```
// Use by client:
#include "Complex.h"     // Complex<T>, next slide
#include <algorithm>     // for std::transform
void client_fun()
{
  Complex<double> cd( 1.0, 3.0 );
  Complex<float> cf;    // = 0
  Complex<double> ecd = exp( cd );
  Complex<double> cdarray[10];      // all 0
      // ... set cdarray values
      // Substitute exp(x) for x in cdarray
  std::transform( cdarray, cdarray+10, cdarray,
      exp );
}
```

Template Class Definition

```
// T can be double, float, long double, Rational, ...
template <class T>
class Complex {
   T _re, _im;        // private
public:
   Complex( const T& r=0, const T& i=0)  // 0,1,2 args
        : _re(r), _im(i){}
   T real() const { return _re; } // getters
   T imag() const { return _im; }
   void real( const T& r ) { _re = r; }  // setters
   void imag( const T& i ) { _im = i; }
        // Constraint: operator+= is defined for T
   Complex& operator+=( const Complex& )
        {_re += rhs._re; im += rhs._im; return *this; }
   Complex& operator*=( const Complex& );
};
```

Template Function Definition

```
// Template Function:
template<class T>
Complex<T> operator+(
      const Complex<T>& lhs, const Complex<T>& rhs )
{  Complex<T> result( lhs );       // copy constructor!
   result += rhs;    // member operator+=
   return result;
}
```

- T must be copy constructible and must define operator +=.
- Such constraints are implicit. C++ has no syntax to specify them, but compilation fails if they aren't met.

Template Specialization

```
// Assume double version requires an algorithm
// that differs from that for float etc.
#include "Complex.h"

template<>
Complex<double> exp( const Complex<double>& x )
{ Complex<double> result;
      // Set it using code specific to T=double
  return result;
}
```

Templates: When To Use

- to express algorithms that apply to many argument types
- to express containers (and iterators)
- to specify policy
- instead of inheritance when run-time efficiency is at a premium
- instead of inheritance when no common base class can be defined

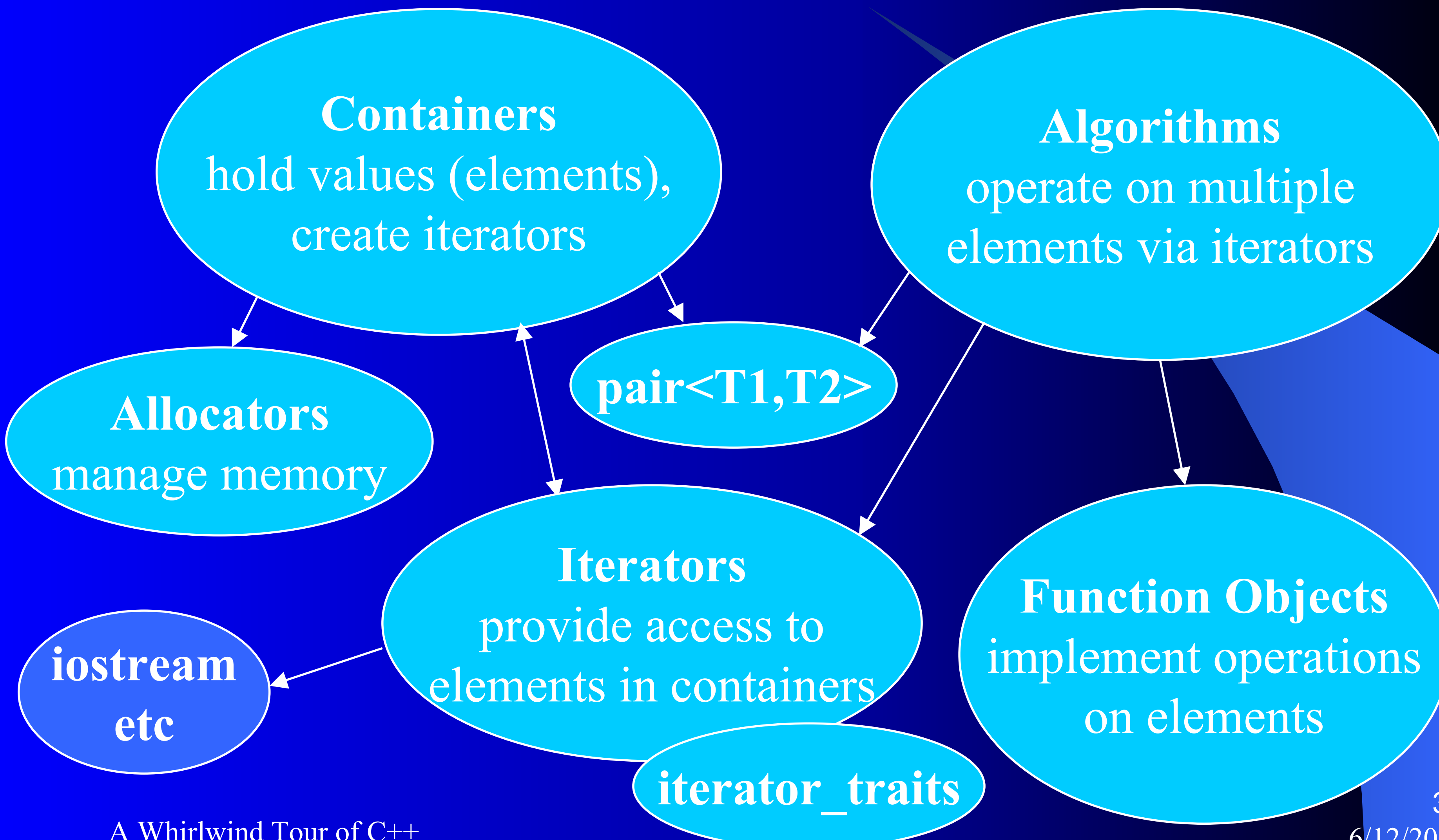
Polymorphism via Virtual Functions vs. Templates

Virtual Functions	Templates
Run-time selection	Compile-time selection
Common base class	Any type or constant
Object contains vptr	No memory overhead
Call is indirect	No run-time overhead
Cannot be in-line	Can be in-line
One copy of each method	Can cause code bloat
Client knows interface (base class and signature)	Client must know actual type and template

Templates: Other Topics

- Member templates
- Partial specialization
- Non-type template arguments
- Default template parameters
- Using templates to specify policy (traits etc.)
- Recursive templates vs. iteration
- Order of specializations (how compiler chooses)
- When and how are specializations generated?

Standard Template Library (STL)



STL Example: Read a File 1

```
// This version uses vector as expandable int[]
#include <fstream>
#include <vector>
void ReadIntegers( const char *filename,
      std::vector<int>& result )
{ ifstream s( filename );
  int val;
  while ( s >> val )
      result.push_back( val );      // It grows!
} // ifstream destructor closes file
```

- Vector access is like an array: **`result[i]`**.
- Memory is released by destructor.

STL Example: Read a File 2

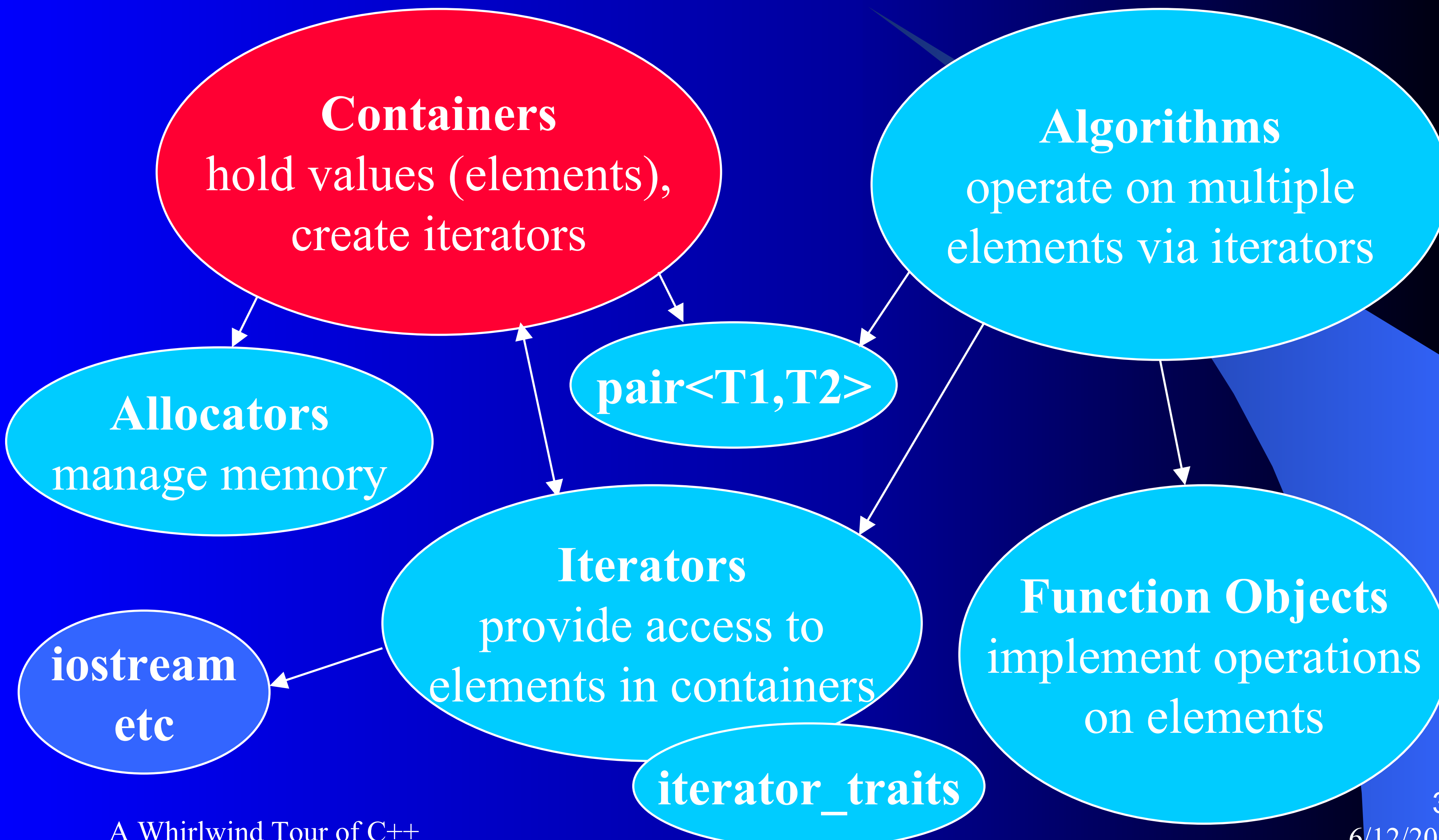
```
// This version uses iterators, STL copy
#include <fstream>
#include <vector>
#include <algorithm>
using namespace std;
void ReadIntegers2( const char *filename,
      vector<int>& result )
{ ifstream s( filename );
  copy( istream_iterator<int>( s ),
      istream_iterator<int>(),
      back_inserter(result) );
}
```

STL Example: Read a File 3

```
// Generalize contained type and container type
// #include & using as before

template < class T, template<class> class C >
void ReadAny( const char *filename,
      C<T>& result )
{ ifstream s( filename );
  copy( istream_iterator<T>( s ),
      istream_iterator<T>(),
      back_inserter(result) );
}
```

Standard Template Library (STL)



STL Sequence Containers

- vector<T>: Random access, grows at back. Use this instead of arrays.
- list<T>: Bidirectional access, grows anywhere.
- deque<T>: Random access, grows at front or back.
- queue<T> (adapter): Grow at back, access and remove at front.
- stack<T> (adapter): Push, pop, top at front.
- priority_queue<T> (adapter): Add anywhere, access and remove highest priority. T ordered.

STL Associative Containers

- map<Key,T>: Access unique T by specifying key; add or remove anywhere. Key must be ordered. Holds pair<const Key,T>.
- multimap<Key,T>: Like map, allowing duplicate keys (equivalence classes).
- set<T>: Unique values with order. Add or remove anywhere, query for presence. T must be ordered.
- multiset<T>: Like set, allowing duplicate values (equivalence classes).

Almost STL Containers

- basic_string<C>: String of character type
- valarray<T>: Vector optimized for numeric computation
- bitset: Fixed-size packed array of booleans
- built-in arrays: Can be used with most STL algorithms. Iterator is pointer.
- iostreams: STL provides **`istream_iterator`**, **`ostream_iterator`**.

STL vector: Array-like Access

```
template <class T, class A=allocator<T> >
class std::vector {
public:
  typedef T& reference;
  typedef const T& const_reference;
  typedef long size_type;      // maybe
  reference operator[]( size_type n ); // unchecked
  const_reference operator[]( size_type n ) const;
  reference at( size_type n); // checked
  const_reference at( size_type n) const;
  reference front(); reference back(); // + const
  // ...
};
```

STL vector: Iterator Access

```
template <class T, class A=allocator<T> >
class std::vector {
public:
  typedef T* iterator;    // maybe
  iterator begin();
  iterator end();    // to one past last

  typedef const T* const_iterator; // maybe
  const_iterator begin() const;
  const_iterator end() const;
  // etc. for reverse_iterator
};
```

STL Containers: Member Types

- **`value_type`, `reference`, `const_reference`**: Behave like T, T*, const T*.
- **`size_type`, `difference_type`**: Type of subscripts, difference between iterators.
- **`iterator`, `const_iterator`, `reverse_iterator`, `const_reverse_iterator`**: Each container defines a set of iterator types.
- **`key_type`, `mapped_type`, `key_compare`**: Associative containers only.

STL Containers: Access

- **`begin()`**: Iterator for first element.
- **`end()`**: Iterator for one-past-last element.
- **`rbegin()`, `rend()`**: Reverse iterators.
- **`front()`, `back()`**: Reference to first and last elements
- **`operator[](size_type)`**: Subscripting, unchecked.
- **`at(size_type)`**: Subscripting, checked.
- All return const version if container is const.

STL Containers: Modification

- **`push_back(T&), pop_back()`**: Add or remove from end.
- **`push_front(T&), pop_front()`**: Add or remove at front (list, deque only).
- **`insert(iterator& p, T& x); template <class iterator2> insert(iterator& p, iterator2& first, iterator2& last)`**: Add value(s) before p.
- **`erase (iterator& p), erase(iterator& first, iterator& last)`**: Remove element(s).
- **`clear(): erase( begin(), end() )`**

STL Containers: Other ops

- **`size()`, `empty()`, `max_size()`:** Cardinality.
- **`capacity()`, `reserve(size_type)`:** vector only.
- **`resize(size_type, T val=T())`:** vector, list, deque.
- **`swap()`:** Swap elements of 2 containers.
- **`==`, `!=`, `<`:** Lexographic comparisons.

STL Containers: Constructors

- **`container():`** Empty container.
- **`container(size_t n, const T& x=T())`**: n copies (not associative containers)
- **`template <class iterator2> container(iterator2 first, iterator2 last)`**: Copy elements from a range.
- **`container(const container& c):`** Copy elements from another container.
- **`~container():`** Destroy container and all elements.

STL Containers: Assignments

- **`operator=(const container& x)`**: Copy all elements from x.
- **`assign( size_t n, T& x )`**: Assign n copies of x (not for associative containers).
- **`template <class iterator2> assign( iterator2& first, iterator2& last )`**: Assign from range.
- All assignments destroy existing elements.

STL Containers: Associative

- **`operator[](k)`**: Reference to element with unique key k.
- **`find(k)`**: Iterator to element with key k.
- **`lower_bound(k), upper_bound(k)`**: Iterators to first and last+1 elements with key k.
- **`equal_range(k)`**: pair(lower_bound(k), upper_bound(k)).
- **`key_comp()`**: Copy of key comparison object.
- **`value_comp()`**: Copy of *mapped_value* comparison object.

Container Summary

	[]	List Operations	Front Operations	Back (Stack) Operations	Iterators
vector ***list*** ***deque***	const const	O(n)+ const O(n)	 const const	const+ const const	Ran Bi Ran
stack ***queue*** ***priority_queue***			 const O(log(n))	const const O(log(n))	
map ***multimap*** ***set*** ***multiset***	O(log(n))	O(log(n))+ O(log(n))+ O(log(n))+ O(log(n))+			Bi Bi Bi Bi
string ***array*** ***valarray*** ***bitset***	const const const const	O(n)+	O(n)+	const+	Ran Ran Ran

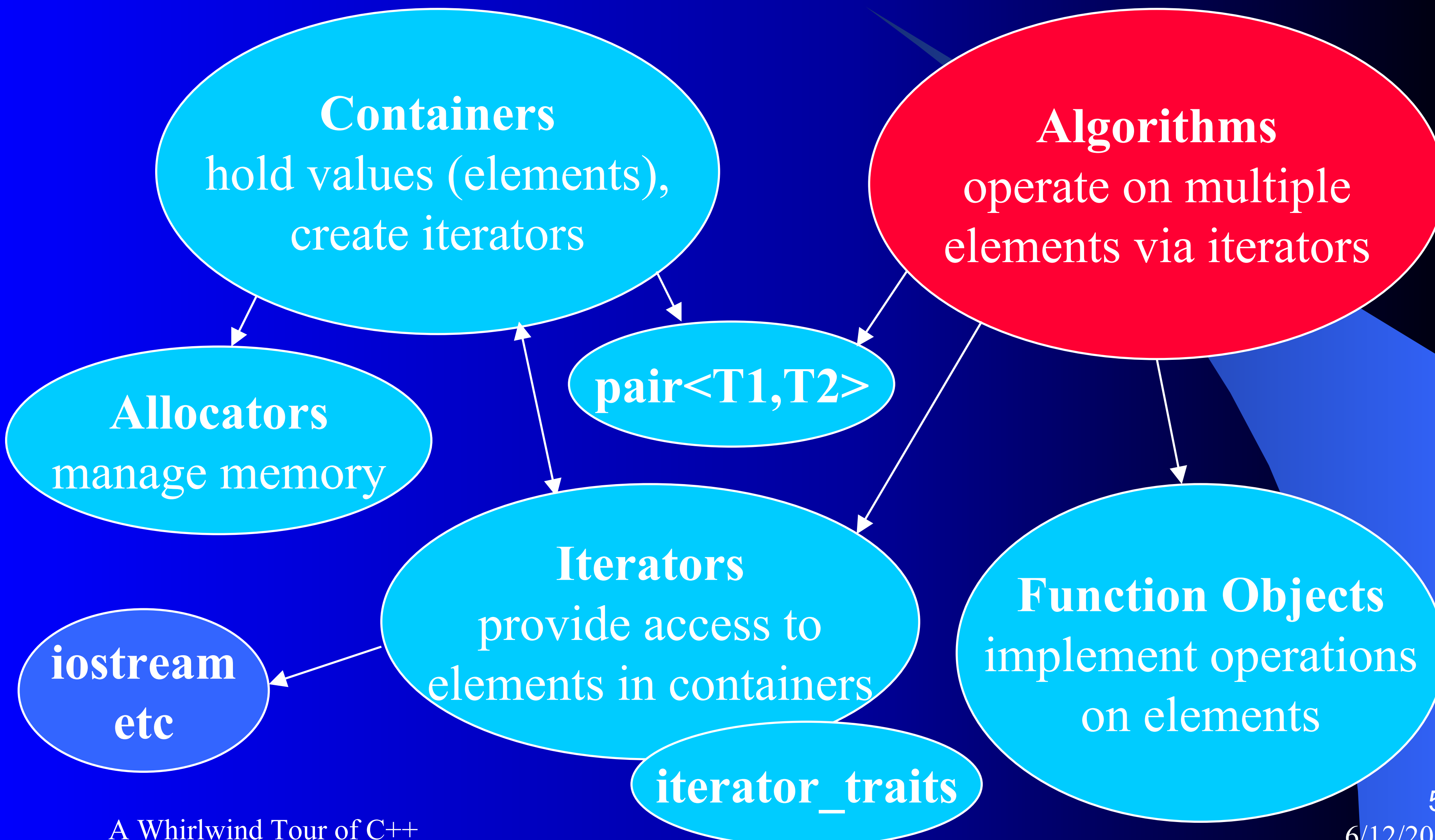
STL Contained Type Concepts

- *Regular Type*: Assignable, Default Constructible, Equality Comparable. Required for many algorithms, generally a good idea for elements of containers.
- *Ordering*: Less Than Comparable, Strict Weakly Comparable (refinement). Required for some algorithms & roles, e.g. as key in associative container.
- Built-in numeric types are *models* of all of these, plus Totally Ordered (further refinement).

STL Container Concepts

- Hold any "regular type" as copies.
- Responsible for construction & destruction of elements.
- Responsible for memory management via plug-in allocators.
- Const correct, exception safe.
- Uniform access syntax via iterators.
- Associated types declared via member typedefs.
- Array-like access syntax where it makes sense.
- Common syntax for adding and removing elements (subsets depending on container type).

Standard Template Library (STL)



STL Algorithms: Definitions

- The STL algorithms are template function that operate on ranges of values.
- All are defined in header <algorithm>.
- Ranges are specified using *iterators*.
- For some algorithms, operations on individual elements are specified using *function objects*, which behave like unary or binary functions.
- Each algorithm requires a specific class of iterator and may constrain the value type.

STL Algorithms: Example Use

```
#include "Club.h"    // my own class
#include <list>
#include <algorithm>
#include <iostream>
#include <string>
using namespace std;
   // Club has a member function of the form
string Club::name() const { ... }

void printClubNames( const list<Club>& lc )
{  transform( lc.begin(), lc.end(),
        ostream_iterator<string>( cout, "\n" ),
        mem_fun_ref( &Club::name ) );
}
```

STL transform Specification

```
template <class In, class Out, class Op>
Out transform( In first, In last, Out res, Op op );

template <class In, class In2, class Out, class Op>
Out transform( In first, In last, In2 first2, Out res,
   Op op );
```

- **For each element in the range [*first*,*last*) , apply the operation and place the result in the range starting at *res*.**
- **Two-input form: Second argument of op comes from range starting at in2.**
- **Op defines function call operator of the form**
  `*res = op( *first )` **or**
  `*res = op( *first, *first2 )`

STL transform Implementation

```
template <class In, class Out, class Op>
Out transform( In first, In last, Out res, Op op )
{
   while ( first != last )
        *res++ = op( *first++ );
   return res;
}

template <class In, class In2, class Out, class Op>
Out transform( In first, In last, In2 first2, Out res,
   Op op )
{
   while ( first != last )
        *res++ = op( *first++, *first2++ );
   return res;
}
```

STL Algorithms: Nonmodifying Sequence Ops

- for_each
- find
- find_if
- find_first_of
- adjacent_find
- count
- count_if
- mismatch
- equal
- search
- find_end
- search_n

STL Algorithms: Modifying Sequence Ops

copy	replace_copy	remove_copy
copy_backward	replace_copy_if	remove_copy_if
swap	fill	unique
iter_swap	fill_n	unique_copy
swap_ranges	generate	reverse
replace	generate_n	reverse_copy
transform	remove	rotate
replace_if	remove_if	rotate_copy
		random_shuffle

STL Algorithms: Sorted Sequence Ops

sort
stable_sort
partial_sort
partial_sort_copy
nth_element
lower_bound
upper_bound
equal_range

binary_search
merge
inplace_merge
partition
stable_partition

STL Algorithms: Set and Heap Operations

- includes
- set_union
- set_intersection
- set_difference
- set_symmetric_difference

- make_heap
- push_heap
- pop_heap
- sort_heap

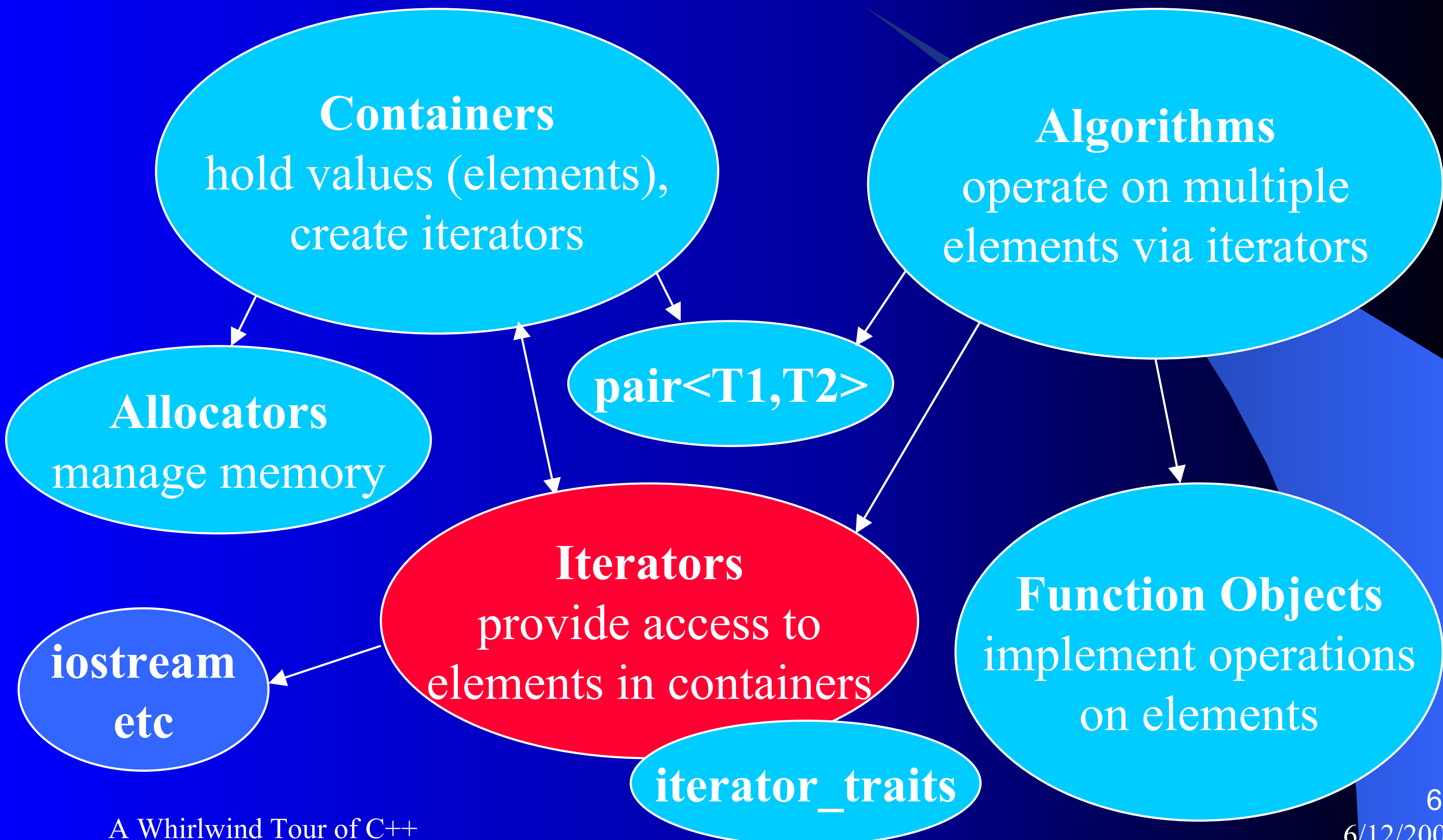
STL Algorithms: Extrema and Permuations

- min
- max
- min_element
- max_element
- lexicographical_compare
- next_permutation
- prev_permutation

STL Algorithm Concepts

- Input and output sequences accessed via iterators.
- Iterator types required (forward, bidirectional, random access, etc.) depend on algorithm.
- Element types required (Less Than Comparable, etc.) depend on algorithm.
- Operations on elements specified via function object: Function address, object with operator() defined, or adapter.
- Decisions specified via predicate: Function object returning bool.

Standard Template Library (STL)



Iterator Operations and Categories

Category	Out	In	For	Bi	Ran
Read		=*p	=*p	=*p	=*p
Access		->	->	->	-> []
Write	*p=		*p=	*p=	*p=
Iterate	++	++	++	++ --	++ -- + - += -=
Compare		== !=	== !=	== !=	== != < > >= <=

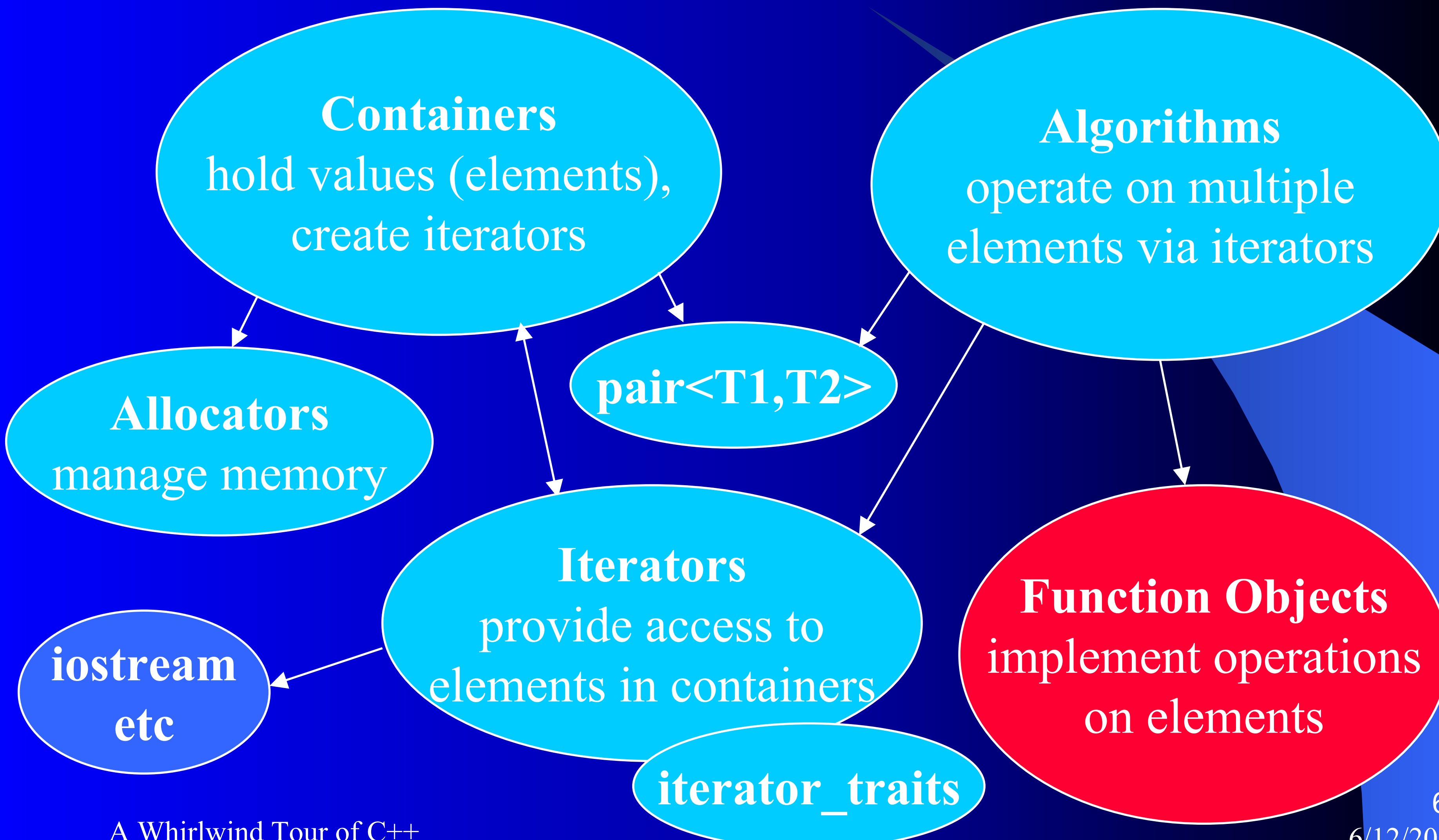
Iterator Sources

- Container operations: **`begin()`**, **`end()`**, etc.
- Operations on other iterators: **`=`**, **`++`**, **`--`**, **`+`**, **`-`**
- Results of some STL algorithms: **`find`** etc.
- Many STL modifying algorithms return iterator just past last modification.
- Pointers into arrays are valid iterators.
- Template classes defined in **`<iterator>`**: **`back_inserter`**, **`front_inserter`**, **`inserter`**.
- Stream iterators: **`ostream_iterator`**, **`istream_iterator`**, **`ostreambuf_iterator`**, **`istreambuf_iterator`**
- Your own, e.g. checked iterators.

STL Iterator Concepts

- Iterator Categories: Input, Output, Forward, Bidirectional, Random Access
- Assignable, Default Constructible, Equality Comparable. Random Access iterators are also Strict Weakly Comparable.
- Associated types (value_type, pointer, reference, etc.) defined as typedefs in iterator_traits template class.
- Dereference via unary * – unless iterator is "singular" (e.g. past end of container).
- Increment via ++. Maybe --, +, - too.
- Reading or writing through iterator might do other things, e.g. I/O, appending.

Standard Template Library (STL)



STL Function Objects

- Passed as input argument to some STL algorithms to specify operation on individual elements of ranges.
- Behave like a unary or binary function.
- Most commonly, use the address of a function.
- OR, define an object that defines operator().
- OR, use an adapter that constructs a function object for you.
- STL's function objects and adapters are in <functional>.

Function Object Implementation

```
template <class T>
struct logical_not: public unary_function<T,bool> {
   bool operator()( const T& x ) const
   { return !x; }
};

template <class T>
struct less: public binary_function<T,T,bool> {
   bool operator()(const T& x, const T& y) const
   { return x < y; }
};
```

- These are *predicates* (return bool) defined in STL.
- Base classes define types.
- Similar ones for operators == != > >= <= && || !

Function Object Usage

- Example: Compare two sequences, looking for the first element of one that is less than the corresponding element of the other.

```
void f( vector<int>& vi, list<int>& li )
{  typedef list<int>::iterator LI;
   typedef vector<int>::iterator VI;
   pair<VI,LI> pl = mismatch(
       vi.begin(), vi.end(), li.begin(),
       less<int>() );
   // ...
}
```

STL Function Objects: Predicates and Arithmetic

equal_to
not_equal_to
greater
less
greater_equal
less_equal
logical_and
logical_or
logical_not

plus
minus
multiplies
divides
modulus
negate

STL Function Objects: Binders, Adapters, Negaters

- bind2nd()
- bind2st()
- mem_fun()
- mem_fun_ref()
- ptr_fun()
- not1()
- not2()

Each of these adapter functions is a template function that returns a function object as its result. Typically the call to an adapter function is placed in-line in the argument list of a call to an STL algorithm.

STL Adapters: Example Use

```
// Count the number of clubs whose name
// contains a given string (e.g. "National")
bool contains( const string& outer,
       const string& inner )
{  return outer.find( inner ) != string::npos; }

int countClubsNamed( const list<Club>& lc,
   const string& namepart )
{  return count_if( lc.begin(), lc.end(),
     bind_second( ptr_fun(contains), namepart ) );
}
```

- Adapters support composition of function objects.
- An adapter is a high-order function: Takes function argument and produces a new function.

Exceptions

```
#include <stdexcept>
class Complex::DivZero : public std::exception {
   const char *what() const    // override
       { return "Complex divide by zero"; }
}
Complex& Complex::operator/=(
   const Complex& den )
{  if ( den == Complex(0.0,0.0) )
       throw ComplexDivZero();
   // ... do the calculation ...
   return *this;
}
```

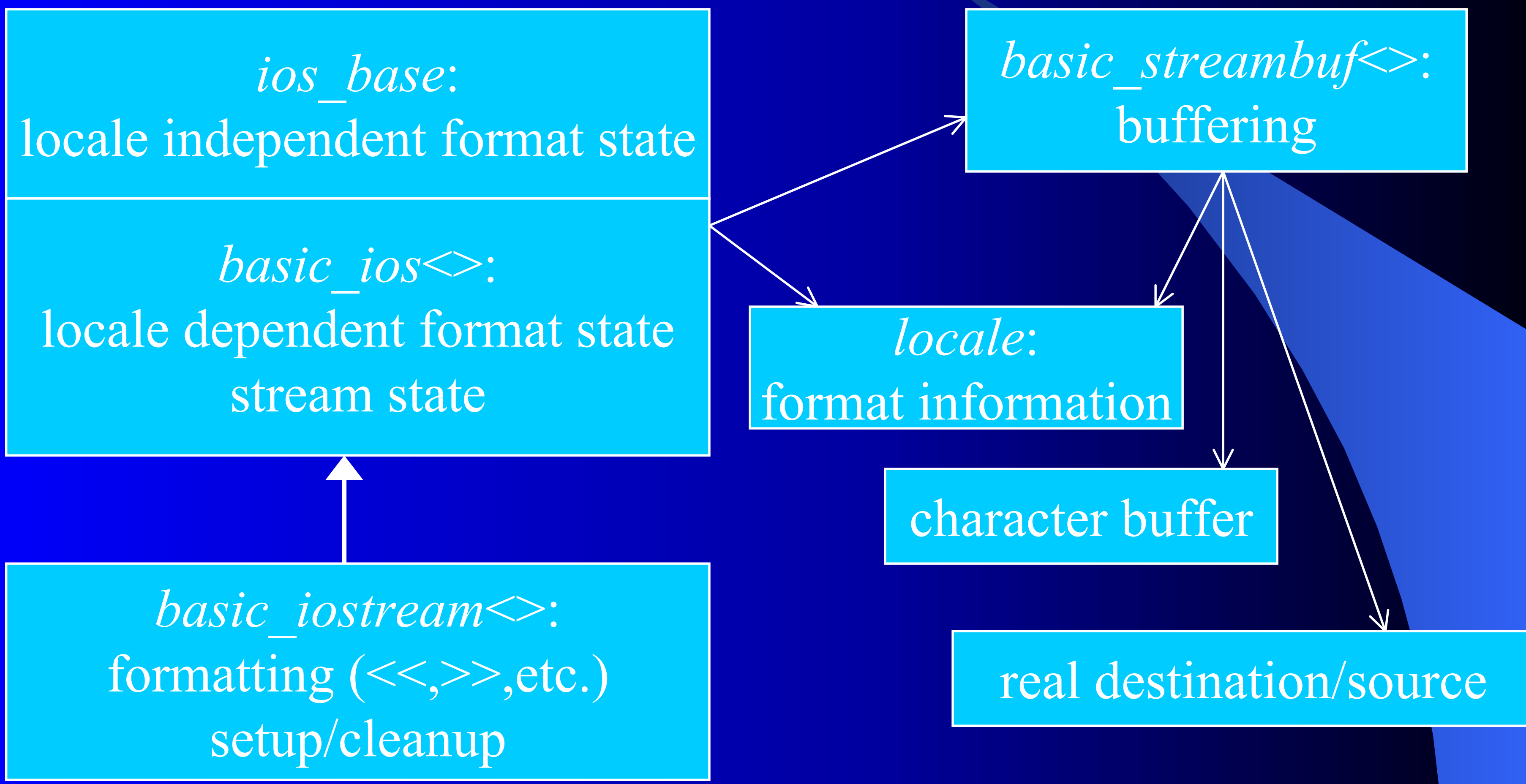
Exceptions (2)

```
// Client code
#include <stdexcept>
...
  try {
      // ... calculation involving Complex etc.
  }
  catch ( std::exception& e ) {
      cerr << "std::exception caught"
            << e.what() << endl;
      throw;      // re-throw same exception
  }
```

Exceptions (3)

- 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.
- Any type may be thrown & caught. Normally throw a special-purpose class, often based on std::exception hierarchy.
- Use only for bona fide errors, not for control.
- Advantage over status flag: Cannot be ignored.
- Advantage over longjump: Calls destructors.
- But: Writing exception-safe code is hard.

Streams: Class Relationships



Streams

- Template arguments are character type and character traits (default char_traits<Ch>).
- ostream, istream, iostream are typedefs for basic_ostream<char> etc.
- Predefined ostream's: cout, cerr, clog.
- Predefined istream: cin.
- File I/O: ifstream, ofstream, fstream.
- String I/O: istringstream, ostringstream, stringstream.

Streams: Example Usage

```
#include "Date.h" // Date with operator<<
#include <iostream>
using namespace std;
      // Inserter usage
  float score; Date today;
  cout << "The score on << today
      << " is " << setprecision(3) << score
      << endl;
      // Extractor usage
  string answer;
  cin >> answer;
```

Streams: Advantages over C

- **Type safe.**
- **Extensible to I/O of user-defined types.**
- **Extensible to I/O to/from any destination.**
- **Buffering strategy can be modified via plug-in.**

Numerics

- complex<T>: Concrete type, same rep as Fortran, the usual library functions and operations, template is underlying numeric type.
- Standard math functions: Same as C but includes float, long double versions + convenience stuff like min, max.
- numeric_limits<T>: Machine dependencies.
- valarray, slice, slice_array, gslice: Vectors optimized for numeric computation.

Where to Get More Information

- Book list posted at:

`http://staff.washington.edu/aganse/staffmtg.html`