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Teuchos::RCP

An Introduction to the Trilinos Smart Reference-Counted Pointer Class for (Almost) Automatic Dynamic Memory Management in C++

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Outline

- Background on memory management in C++
- Simple motivating example using raw pointers
- Persisting and non-persisting associations
- Refactoring of simple example to use RCP
- RCP: Nuts & bolts and avoiding trouble
- Summary and RCP philosophy

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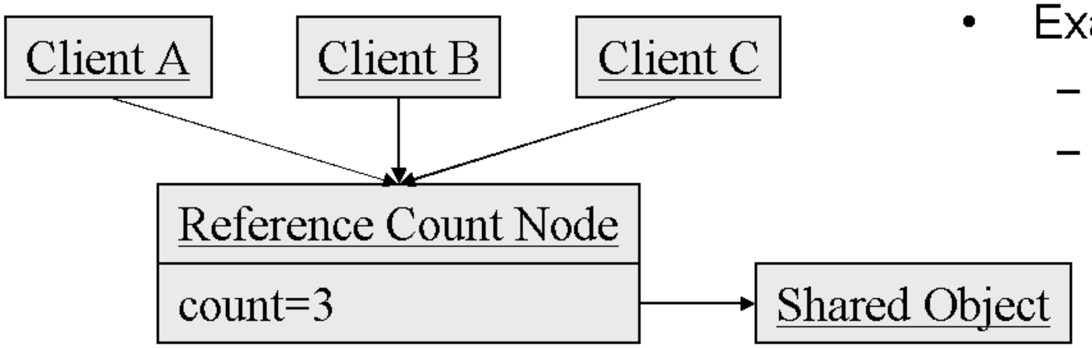
Dynamic Memory Management in C++

- C++ requires programmers to manage dynamically allocated memory themselves using operator new and operator delete
- Problems with using raw new and delete at application programming level
  - Very error prone (multiple deletes or memory leaks)
  - Difficult to know who's responsibility it is to delete an object
  - Creates memory leaks when exceptions are thrown
- Reference counting to the rescue?



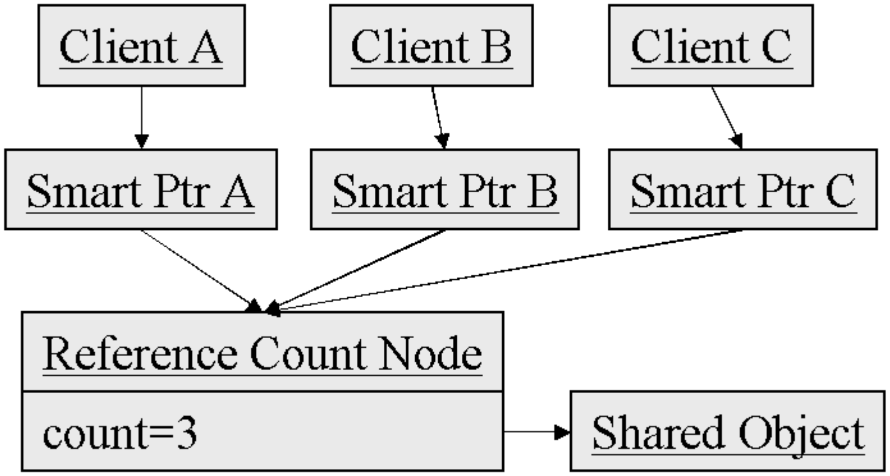
UML object diagram

- Examples (C++ and other):
  - CORBA
  - COM

  - How is the reference count updated and managed?
  - When is the object deleted?
  - How is the object deleted?

Smart Pointers : A C++ Reference Counting Solution

- C++ supports development of “smart” pointer classes that behave a lot like raw pointers
- Reference counting + smart pointers = smart reference counted pointers



Advantages of Smart Pointer approach:

- Access to shared object uses pointer-like syntax
  - (*ptr).f()   [operator*()]
  - ptr->f()   [operator->()]
- Reference counts automatically updated and maintained
- Object automatically deleted when last smart pointer is destroyed

- Examples of C++ smart reference counted pointer classes
  - boost::shared_ptr: Part of the Boost C++ class library (created in 1999?)
    - Being considered to go into the next C++ standard
    - Does not throw exceptions
  - Teuchos::RCP:
    - Originally developed as part of rSQP++ (Bartlett et. al.) in 1998
    - Does throw exceptions in some cases in debug mode and has addition features
    - Being used more and more extensively in many Trilinos packages such as Thyra, NOX/LOCA, Rythmos, Belos, Anasazi, ML, …

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Introduction of Simple Example Program

- Example program that is described in the Beginner's Guide (http://www.cs.sandia.gov/~rabartl/RefCountPtrBeginnersGuideSAND.pdf)
  - Complete program listings in Appendix E and F
- Uses basic object-oriented programming
- Demonstrates the basic problems of using raw C++ pointers and delete for high-level memory management
- Provides context for differentiating "persisting" and "non-persisting" object associations
- Show step-by-step process of refactoring C++ code to use RCP

Abstract Interfaces and Subclasses in Example Program

Utility interface and subclasses

```
class UtilityBase {
public:
  virtual void f() const = 0;
};
class UtilityA : public UtilityBase {
public:
  void f() const {…}
};
class UtilityB : public UtilityBase {
public:
  void f() const {…}
};
```

Utility “abstract factory” interface and subclasses (see “Design Patterns” book)

```
class UtilityBaseFactory {
public:
  virtual UtilityBase* createUtility() const = 0;
};
class UtilityAFactory : public UtilityBaseFactory {
public:
  UtilityBase* createUtility() const { return new UtilityA(); }
};
class UtilityBFactory : public UtilityBaseFactory {
public:
  UtilityBase* createUtility() const { return new UtilityB(); }
};
```

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Client Classes in Example Program

```
class ClientA {
public:
  void f( const UtilityBase &utility ) const { utility.f(); }
};

class ClientB {
  UtilityBase *utility_;
public:
  ClientB() : utility_(0) {}
  ~ClientB() { delete utility_; }
  void initialize( UtilityBase *utility ) { utility_ = utility; }
  void g( const ClientA &a ) { a.f(*utility_); }
};

class ClientC {
  const UtilityBaseFactory *utilityFactory_;
  UtilityBase              *utility_;
  bool                     shareUtility_;
public:
  ClientC( const UtilityBaseFactory *utilityFactory, bool shareUtility )
    :utilityFactory_(utilityFactory)
    ,utility_(utilityFactory->createUtility())
    ,shareUtility_(shareUtility) {}
  ~ClientC() { delete utilityFactory_; delete utility_; }
  void h( ClientB *b ) {
    if( shareUtility_ ) b->initialize(utility_);
    else                b->initialize(utilityFactory_->createUtility());
  }
};
```

Example Main Program

```
int main( int argc, char* argv[] )
{
  // Read options from the commandline
  bool useA, shareUtility;
  example_get_args(argc,argv,&useA,&shareUtility);
  // Create factory
  UtilityBaseFactory *utilityFactory = 0;
  if(useA) utilityFactory = new UtilityAFactory();
  else     utilityFactory = new UtilityBFactory();
  // Create clients
  ClientA a;
  ClientB b1, b2;
  ClientC c(utilityFactory,shareUtility);
  // Do some stuff
  c.h(&b1);
  c.h(&b2);
  b1.g(a);
  b2.g(a);
  // Cleanup memory
  delete utilityFactory;
}
```

This program has memory usage problems!

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Example Program Memory Usage Problem #1

```
class ClientC {
  …
public:
  ClientC( const UtilityBaseFactory *utilityFactory, bool shareUtility )
    :utilityFactory_(utilityFactory)
    ,utility_(utilityFactory->createUtility())
    ,shareUtility_(shareUtility) {}
  ~ClientC() { delete utilityFactory_; delete utility_; }
  …
};

int main( int argc, char* argv[] )
{
  …
  // Create factory
  UtilityBaseFactory *utilityFactory = 0;
  if(useA) utilityFactory = new UtilityAFactory();
  else     utilityFactory = new UtilityBFactory();
  // Create clients
  …
  ClientC c(utilityFactory,shareUtility);
  // Do some stuff
  …
  // Cleanup memory
  delete utilityFactory;
}
```

The `UtilityBaseFactory` object is deleted twice!

Example Program Memory Usage Problem #2

```
class ClientB {
  UtilityBase *utility_;
public:
  ~ClientB() { delete utility_; }
  void initialize( UtilityBase *utility ) { utility_ = utility; }
};

class ClientC {
  const UtilityBaseFactory *utilityFactory_;
  UtilityBase              *utility_;
  bool                     shareUtility_;
public:
  …
  ~ClientC() { delete utilityFactory_; delete utility_; }
  void h( ClientB *b ) {
    if( shareUtility_ ) b->initialize(utility_);
    else                b->initialize(utilityFactory_->createUtility());
  }
};

int main( int argc, char* argv[] )
{
  …
  ClientB b1, b2;
  ClientC c(utilityFactory,shareUtility);
  c.h(&b1);
  c.h(&b2);
  …
}
```

The `UtilityBase` object is deleted three times if `shareUtility_==true`!

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Problems with using raw pointers for memory management

Important points

- Fixing the memory management problems in this example program is not too hard
- However, writing complex OO software with independently developed modules without memory leaks nor multiple calls to delete is very hard!
  - Example: Epetra required major refactoring to address these problems!
- The designers of C++ never expected complex high-level code to rely on raw C++ memory management and raw calls to delete
- Almost every major C++ middleware software collection provides some higher-level support for dynamic memory management and wraps raw calls to delete
- Raw calls to delete are fragile and create memory leaks in the presents of exceptions

```
void someFunction() {
  A *a = new A;
  a->f();  // memory leak on throw!
  delete a;
}
```

```
void someFunction() {
  std::auto_ptr<A> a(new A);
  a->f();  // no leak on throw!
}
```

What is an alternative to using raw pointers for memory management?

- Smart Reference Counted Pointers! => Teuchos::RCP

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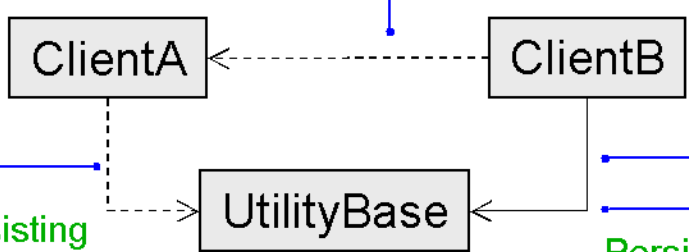
RCP: Persisting and Non-Persisting Associations

- Non-persisting association: An object association that only exists within a single function call and no “memory” of the object persists after the function exits
- Persisting association: An object association that exists beyond a single function call and where some “memory” of the object persists
- Examples:

```
class ClientA {
public:
  void f( const UtilityBase &utility ) const { utility.f(); }
};

class ClientB {
  UtilityBase *utility_;
public:
  ClientB() : utility_(0) {}
  ~ClientB() { delete utility_; }
  void initialize( UtilityBase *utility ) { utility_ = utility; }
  void g( const ClientA &a ) { a.f(*utility_); }
};
```



Non-persisting association

UML class diagram

Persisting association

- Non-persisting associations:
  - Use raw C++ references and pointers
- Persisting associations:
  - Use RCP

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Refactoring Example Program to use RCP : Part #1

Before Refactoring

```
class UtilityBaseFactory {
public:
  virtual UtilityBase* createUtility() const = 0;
};
class UtilityAFactory : public UtilityBaseFactory {
public:
  UtilityBase* createUtility() const { return new UtilityA(); }
};
class UtilityBFactory : public UtilityBaseFactory {
public:
  UtilityBase* createUtility() const { return new UtilityB(); }
};
```

After Refactoring

```
class UtilityBaseFactory {
public:
  virtual RCP<UtilityBase> createUtility() const = 0;
};
class UtilityAFactory : public UtilityBaseFactory {
public:
  RCP<UtilityBase> createUtility() const { return rcp(new UtilityA()); }
};
class UtilityBFactory : public UtilityBaseFactory {
public:
  RCP<UtilityBase> createUtility() const { return rcp(new UtilityB()); }
};
```

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Refactoring Example Program to use RCP : Part #2

Before Refactoring

```
class ClientA {
public:
  void f( const UtilityBase &utility ) const { utility.f(); }
};
```

After Refactoring (no change)

```
class ClientA {
public:
  void f( const UtilityBase &utility ) const { utility.f(); }
};
```

Before Refactoring

```
class ClientB {
  UtilityBase *utility_;
public:
  ClientB() : utility_(0) {}
  ~ClientB() { delete utility_; }
  void initialize( UtilityBase *utility ) { utility_ = utility; }
  void g( const ClientA &a ) { a.f(*utility_); }
};
```

After Refactoring

```
class ClientB {
  RCP<UtilityBase> utility_;
public:
  void initialize(const RCP<UtilityBase> &utility) { utility_=utility; }
  void g( const ClientA &a ) { a.f(*utility_); }
};
```

Constructor and Destructor are Gone!

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Refactoring Example Program to use RCP : Part #3

Before Refactoring

```
class ClientC {
  const UtilityBaseFactory *utilityFactory_;
  UtilityBase              *utility_;
  bool                     shareUtility_;
public:
  ClientC( const UtilityBaseFactory *utilityFactory, bool shareUtility )
    :utilityFactory_(utilityFactory)
    ,utility_(utilityFactory->createUtility())
    ,shareUtility_(shareUtility) {}
  ~ClientC() { delete utilityFactory_; delete utility_; }
  void h( ClientB *b ) {
    if( shareUtility_ ) b->initialize(utility_);
    else                b->initialize(utilityFactory_->createUtility());
  }
};
```

Destructor is Gone!

After Refactoring

```
class ClientC {
  RCP<const UtilityBaseFactory> utilityFactory_;
  RCP<UtilityBase>              utility_;
  bool                                      shareUtility_;
public:
  ClientC(const RCP<const UtilityBaseFactory> &utilityFactory, … )
    :utilityFactory_(utilityFactory)
    ,utility_(utilityFactory->createUtility())
    ,shareUtility_(shareUtility) {}
  void h( ClientB *b ) {…}
};
```

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Refactoring Example Program to use RCP : Part #4

Before Refactoring

```
int main( int argc, char* argv[] )
{
  // Read options from the commandline
  bool useA, shareUtility;
  example_get_args(argc,argv,&useA
                   ,&shareUtility);
  // Create factory
  UtilityBaseFactory *utilityFactory = 0;
  if(useA)
    utilityFactory=new UtilityAFactory();
  else
    utilityFactory=new UtilityBFactory();
  // Create clients
  ClientA a;
  ClientB b1, b2;
  ClientC c(utilityFactory,shareUtility);
  // Do some stuff
  c.h(&b1);
  c.h(&b2);
  b1.g(a);
  b2.g(a);
  // Cleanup memory
  delete utilityFactory;
}
```

After Refactoring

```
int main( int argc, char* argv[] )
{
  // Read options from the commandline
  bool useA, shareUtility;
  example_get_args(argc,argv,&useA
                   ,&shareUtility);
  // Create factory
  RCP<UtilityBaseFactory> utilityFactory;
  if(useA)
    utilityFactory = rcp(new UtilityAFactory());
  else
    utilityFactory = rcp(new UtilityBFactory());
  // Create clients
  ClientA a;
  ClientB b1, b2;
  ClientC c(utilityFactory,shareUtility);
  // Do some stuff
  c.h(&b1);
  c.h(&b2);
  b1.g(a);
  b2.g(a);
}
```

- New program runs without any memory problems
- New program will be easier to maintain

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Value Semantics vs. Reference Semantics

A. Value Semantics

```
class S {
public:
  S();                       // Default constructor
  S(const S&);               // Copy constructor
  S& operator=(const S&); // Assignment operator
  …
};
```

- Used for small, concrete datatypes
- Identity determined by the value in the object, not by its object address (e.g. obj==1.0)
- Storable in standard containers (e.g. std::vector<S>)
- Examples: int, bool, float, double, char, std::complex, extended precision …

B. Reference Semantics

```
class A {
public:
  // Pure virtual functions
  virtual void f() = 0;
  …
};
```

Important points!

- RCP class has value semantics
- RCP usually wraps classes with reference semantics

- Abstract C++ classes (i.e. has pure virtual functions) or for large objects
- Identity determined by the object's address (e.g. &obj1 == &obj2)
- Can not be default constructed, copied or assigned (not storable in standard containers)
- Examples: std::ostream, any abstract base class, …

Raw Pointers and RCP : const and non-const

Example:

```
A   a;
A* a_ptr = &a;
```

an address - - -> A's data

a_ptr   a

Important Point: A pointer object `a_ptr` of type `A*` is an object just like any other object with value semantics and can be const or non-const

Raw C++ Pointers		RCP
`typedef A* ptr_A;`	equivalent to	`RCP<A>`
`typedef const A* ptr_const_A;`	equivalent to	`RCP<const A>`

Remember this equivalence!

an address - - -> A's data

non-const pointer to non-const object

```
ptr_A          a_ptr;
A *            a_ptr;
```

equivalent to

```
RCP<A>              a_ptr;
```

an address - - -> A's data

const pointer to non-const object

```
const ptr_A    a_ptr;
A * const      a_ptr;
```

equivalent to

```
const RCP<A>        a_ptr;
```

an address - - -> A's data

non-const pointer to const object

```
ptr_const_A    a_ptr;
const A *      a_ptr;
```

equivalent to

```
RCP<const A>        a_ptr;
```

an address - - -> A's data

const pointer to const object

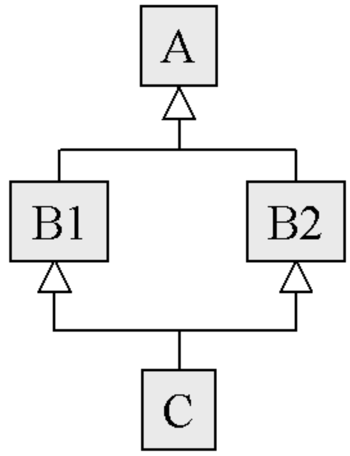
```
const ptr_const_A    a_ptr;
const A * const      a_ptr;
```

equivalent to

```
const RCP<const A> a_ptr;
```

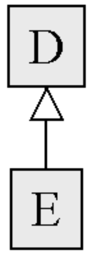
C++ Class Hierarchies used in Examples

```
// Abstract hierarchy
class A {
public:
  virtual ~A(){}
  virtual void f(){…}
};
class B1 : virtual public A {…};
class B2 : virtual public A {…};
class C : virtual public B1, virtual public B2 {…};
```



UML class diagram

```
// Non-abstract hierarchy (no virtual functions)
class D {…};
class E : public D {…};
```



- Assume all these classes have reference semantics

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Constructing RCP Objects

C++ Declarations for constructing an RCP object

```
template<class T>
class RCP {
public:
  RCP( ENull null_arg = null );
  explicit RCP( T* p, bool owns_mem = true );
  …
};
template<class T> RCP<T> rcp( T* p );
template<class T> RCP<T> rcp( T* p, bool owns_mem);
```

- Initializing an RCP<> object to NULL

```
RCP<C> c_ptr;          // Good for class data members!
RCP<C> c_ptr = null;   // May help clarity
```

- Creating an RCP object using new

```
RCP<C> c_ptr(new C);   // or c_ptr = rcp(new C);
```

- Initializing an RCP object to an object not allocated with new

```
C             c;
RCP<C> c_ptr = rcp(&c,false);
```

- Example

```
void foo( const UtilityBase &utility )  // Non-persisting with utility
{
  ClientB b;
  b.initialize(rcp(&utility,false));    // b lives entirely in foo()
  …
}
```

Commandment 1 : Give a 'new' object to just one RCP

Commandment 1: *Thou shall put a pointer for an object allocated with operator `new` into an RCP object only once. E.g.*

```
RCP<C> c_ptr(new C);
```

Anti-Commandment 1: *Thou shall never give a raw C++ pointer returned from operator `new` to more than one `RCP` object.*

Example:

```
A *ra_ptr = new C;
RCP<A> a_ptr1(ra_ptr); // Okay
RCP<A> a_ptr2(ra_ptr); // no, No, NO !!!!
```

- `a_ptr2` knows nothing of `a_ptr1` and both will call delete!

Anti-Commandment 2: *Thou shall never give a raw C++ pointer to an array of objects returned from operator `new[]` to an RCP object using `rcp(new C[n])`.*

Example:

```
RCP<std::vector<C> >
  c_array_ptr1(new std::vector<C>(N)); // Okay
RCP<C>
  c_array_ptr2(new C[n]);              // no, No, NO!
```

- `c_array_ptr2` will call `delete` instead of `delete []`!

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Reinitialization of RCP Objects

- The proper way to reinitialize an object with value semantics is to use the assignment operator! (`boost::shared_ptr` violates this principle!)

C++ Declarations for reinitializing an RCP Object

```
template<class T>
class RCP {
public:
  RCP<T>& operator=(const RCP<T>& r_ptr);
  …
};
```

- Resetting from a raw pointer

```
RCP<A> a_ptr;
a_ptr = rcp(new A());
```

- Resetting to null

```
RCP<A> a_ptr(new A());
a_ptr = null; // The A object will be deleted here
```

- Assigning from an RCP object

```
RCP<A> a_ptr1;
RCP<A> a_ptr2(new A());
a_ptr1 = a_ptr2; // Now a_ptr1 and a_ptr2 point to the same A object
```

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Access Underlying Reference-Counted Object

C++ Declarations for accessing referenced-counted object

```
template<class T>
class RCP {
public:
  T* operator->() const;    // Allows ptr->f();  [throws exception if NULL]
  T& operator*() const;     // Allows (*ptr).f() [throws exception if NULL]
  T* get() const;
  …
};
template<class T> bool is_null(const RCP<T>& p);
template<class T> bool operator==(const RCP<T>& p, ENull);
template<class T> bool operator!=(const RCP<T>& p, ENull);
```

- Access to object reference (debug runtime checked)

```
C &c_ref = *c_ptr; // Throws exception if c_ptr.get()==NULL
```

- Access to object pointer (unchecked, may return NULL)

```
C *c_rptr = c_ptr.get(); // Never throws an exception
```

- Access to object pointer (debug runtime checked, will not return NULL)

```
C *c_rptr = &*c_ptr; // Throws exception if c_ptr.get()==NULL
```

- Access of object's member (debug runtime checked)

```
c_ptr->f(); // Throws exception if c_ptr.get()==NULL
```

- Testing for null

```
if ( is_null(a_ptr) ) std::cout << "a_ptr is null\n";
if ( a_ptr==null ) std::cout << "a_ptr is null\n";
```

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Explicit Casting of RCP Objects : Template Functions

C++ Declarations for explicit casting of RCP Objects

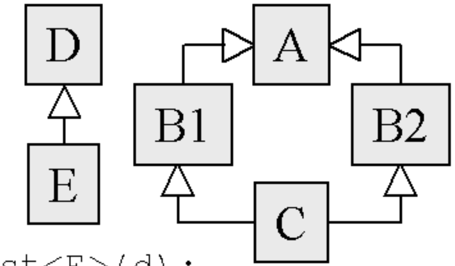
```
// implicit cast
template<class T2, class T1>
RCP<T2> rcp_implicit_cast(const RCP<T1>& p1);

// static cast
template<class T2, class T1>
RCP<T2> rcp_static_cast(const RCP<T1>& p1);

// const cast
template<class T2, class T1>
RCP<T2> rcp_const_cast(const RCP<T1>& p1);

// dynamic cast
template<class T2, class T1>
RCP<T2> rcp_dynamic_cast(const RCP<T1>& p1,
                         bool throw_on_fail = false );
```

Explicit Casting of RCP Objects : Examples



Raw C++ Pointers	RCP

Static cast (non-checked)

```
D*
  d = new E;
E*
  e = static_cast<E*>(d);
```

```
RCP<D>
  d  = rcp(new E);
RCP<E>
  e = rcp_static_cast<E>(d);
```

Constant cast

```
const A*
  ca = new C
A*
  a = const_cast<A*>(ca);
```

```
RCP<const A>
  ca = rcp(new C);
RCP<A>
  a = rcp_const_cast<A>(ca);
```

Dynamic cast (runtime check, can return NULL on fail)

```
A*
  a = new C;
B1*
  b1 = dynamic_cast<B1*>(a);
```

```
RCP<A>
  a = rcp(new C);
RCP<B1>
  b1 = rcp_dynamic_cast<B1>(a);
```

Dynamic cast (runtime check, can not return NULL on fail)

```
A*
  a = new B1;
B2*
  b2 = ( a ? &dynamic_cast<B2&>(*a)
           : (B2*)NULL              );
```

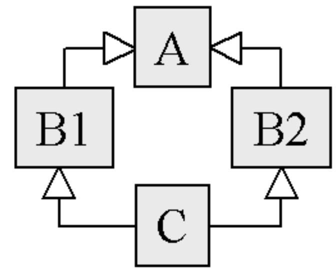
```
RCP<A>
  a = rcp(new B1);
RCP<B2>
  b2 = rcp_dynamic_cast<B2>(a,true);
```

Note: In last dynamic cast, rcp_dynamic_cast<B2>(a,true) throws exception with much better error message than dynamic_cast<B2&>(*a). See Teuchos::dyn_cast<>()!

Commandment 4 : Casting RCP Objects

Commandment 4: *Thou shall only cast between `RCP` objects using the default copy constructor (for implicit conversions) and the nonmember template functions `rcp_implicit_cast<>(...)`, `rcp_static_cast<>(...)`, `rcp_const_cast<>(...)` and `rcp_dynamic_cast<>(...)`.*

Anti-Commandment 5: *Thou shall never convert between `RCP` objects using raw pointer access.*



Example:

```
RCP<A>      a_ptr   = rcp(new C);
RCP<B1>     b1_ptr1 = rcp_dynamic_cast<B1>(a_ptr);            // Yes :-)
RCP<B1>     b1_ptr2 = rcp(dynamic_cast<B1*>(a_ptr.get())); // no, No, NO !!!
```

- `b1_ptr2` knows nothing of `a_ptr` and both will call delete!

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  - Implicit casting
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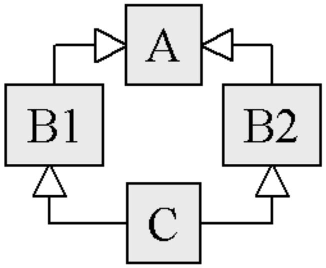
Implicit Casting in Function Calls : Raw C++ Pointers




```
// Typedefs
typedef A*         ptr_A;
typedef const A*   ptr_const_A;

// Takes pointer to A (by value)
void foo1( ptr_A a_ptr );

// Takes pointer to const A (by value)
void foo2( ptr_const_A a_ptr );

// Takes pointer to A (by const reference)
void foo3( const ptr_A &a_ptr );

// Takes pointer to A (by non-const reference)
void foo4( ptr_A &a_ptr );

void boo1()
{
  C* c = new C;
  A* a = c;
  foo1(c); // Okay, implicit cast to base class
  foo2(a); // Okay, implicit cast to const
  foo2(c); // Okay, implicit cast to base class and const
  foo3(c); // Okay, implicit cast to base class
  foo4(a); // Okay, no cast
  foo4(c); // Error, can not cast from (C&*) to (A&*)!
}
```

Compiler can perform implicit conversions on arguments passed by value or const reference!

Compiler can not perform implicit conversions on arguments passed by non-const reference!

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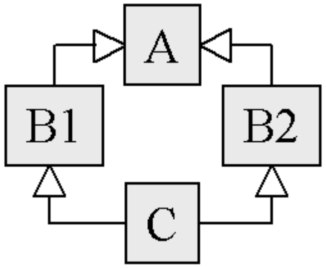
Implicit Casting of RCP Objects

C++ Declarations for implicit casting

```
template<class T>
class RCP {
public:
  template<class T2>
  RCP(const RCP<T2>& r_ptr); // Templated copy constructor!
  …
};
template<class T2, class T1>
RCP<T2> rcp_implicit_cast(const RCP<T1>& p1);
```



Raw C++ Pointers	RCP

Implicit cast to base class

Raw C++ Pointers	RCP
`C*   c_rptr = new C;`	`RCP<C> c_ptr = rcp(new C);`
`A*   a_rptr = c_rptr;`	`RCP<A> a_ptr = c_ptr;`

Implicit cast to const

Raw C++ Pointers	RCP
`A*         a_rptr  = new A;`	`RCP<A>         a_ptr  = rcp(new A);`
`const A*   ca_rptr = a_rptr;`	`RCP<const A> ca_ptr = a_ptr;`

Implicit cast to base class and const

Raw C++ Pointers	RCP
`C*         c_rptr  = new C;`	`RCP<C>         c_ptr  = rcp(new C);`
`const A*   ca_rptr = c_rptr;`	`RCP<const A> ca_ptr = c_ptr;`

Note: Templated copy constructor allows implicit conversion of RCP objects in almost every situation where an implicit conversion with raw C++ pointers would be allowed

Implicit Casting : Raw C++ Pointers verses RCP

Raw C++ Pointers

```
typedef A*       ptr_A;
typedef const A* ptr_const_A;

void foo5(ptr_A a_ptr);

void foo6(ptr_const_A a_ptr);

void boo2()
{
  C* c = new C;
  A* a = c;
  foo5(c); // Okay, cast to base
  foo6(a); // Okay, cast to const
  foo6(c); // Okay, to base+const
}
```

RCP

```
void foo5(const RCP<A> &a_ptr);

void foo6(const RCP<const A> &a_ptr);

void boo3()
{
  RCP<C> c = rcp(new C);
  RCP<A> a = c;
  foo5(c); // Okay, cast to base
  foo6(a); // Okay, cast to const
  foo6(c); // Okay, to base+const
}
```

- Implicit conversions for RCP objects to satisfy function calls works almost identically to implicit conversions for raw C++ pointers and raw C++ references except for a few unusual cases:
  - Implicit conversions to call overloading functions (see example on next page)
  - ???

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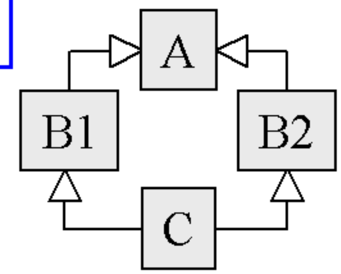
Implicit Casting with RCP : Common Problems/Mistakes

Passing RCP by non-const reference instead of by const reference

```
void foo7(RCP<A> &a);
void foo7(const RCP<A> &a);

void boo4() {
  RCP<C> c(new C);
  RCP<A> a = c;
  foo7(a); // Okay, no cast
  foo7(c); // Error, can not cast involving non-const reference
  foo7(c); // Okay, implicit case involving const reference okay
}
```

Programming mistake!



Failure to perform implicit conversion with overloaded functions

```
RCP<A>       foo9(const RCP<A>       &a);
RCP<const A> foo9(const RCP<const A> &a);

RCP<A> boo5() {
  RCP<C> c(new C);
  return foo9(c);          // Error, call is ambiguous!
  RCP<A> a = c;
  return foo9(a);          // Okay, calls first foo9(…)
  return foo9(rcp_implicit_cast<A>(c)); // Okay, calls first foo9(…)
}
```

A deficiency of smart pointers over raw pointers

Calls `foo9(A* a)` when using raw C++ pointers!

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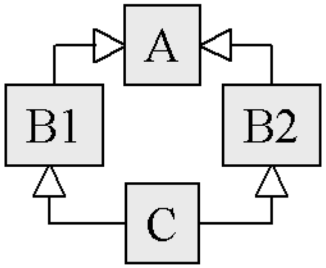
Summary of RCP and Advanced Features Overview

- RCP combines concepts of “smart pointers” and “reference counting” to build an imperfect but effective “garbage collection” mechanism in C++



- Smart pointers mimic raw C++ pointer usage and syntax
  - Value semantics: i.e. default construct, copy construct, assignment etc.
  - Object dereference: i.e. `(*ptr).f()`
  - Pointer member access: i.e. `ptr->f()`
  - Conversions :
    - Implicit conversions using templated copy constructor: i.e. `C*` to `A*`, and `A*` to `const A*`
    - Explicit conversions: i.e. `rcp_const_cast<T>(p)`, `rcp_static_cast<T>(p)`, `rcp_dynamic_cast<T>(p)`
- Reference counting
  - Automatically deletes wrapped object when last reference (i.e. smart pointer) is deleted
  - Watch out for circular references! These create memory leaks!
    - Tip: Call `Teuchos::setTracingActiveRCPNodes(true)` (with --enable-teuchos-debug)
- RCP<T> is not a raw C++ pointer!
  - Implicit conversions from T* to RCP<T> and visa versa are not supported!
  - Failure of implicit casting and overload function resolution!
  - Other problems …
- Advanced Features (not covered here)
  - Template deallocation policy object
    - Allows other an delete to be called to clean up
    - Allows one smart pointer (e.g., `boost::shared_ptr`) to be embedded in an RCP
  - Extra data
    - Allows RCP to wrap classes that do not have good memory management (e.g. old Epetra)
    - Allows arbitrary events to be registered to occur before or after the wrapped object is deleted

The Philosophy of RCP

- Using RCP for only persisting associations increases the vocabulary of the C++ language and makes in more self documenting.

```
void foo( const A &a, const RCP<C> &c );
```

- Responsibilities of code that generates shared objects (e.g. factories)
  - Create and initialize the concrete object to be given away
  - Define the deallocation policy that will be used to deallocate the object

```
RCP<BaseClass>
SomeFactory::create() const {
  ConcreteSubclass  *instance; InitializeObject(&instance); // Initialize!
  new rcp(instance,DeallocConcreteSubclass(),true); // Define destruc. policy!
}
```

- Responsibilities of code that maintains persisting associations with shared objects
  - Accept RCP objects that wrap shared objects
  - Maintain RCP objects to shared objects while in use
  - Destroy or assign to null RCP objects when it is finished using shared object

```
class SomeClient {
  RCP<A> a_;                                       // Maintain A
public:
  void accept(const RCP<A> &a)  { a_ = a; } // Accept A
  void clearOut() { a_ = null; }                   // Forget/release A
};
```

- RCP allows radically different types of software to be glued together to build a correct and robust memory management system
  - Use RCP to wrap objects not currently wrapped with RCP and use customized deallocation policies
  - Combine different smart pointer objects together (e.g., boost::shared_ptr, …)

A Truism

Ben Parker once said to Peter Parker:

"With great power comes great responsibility"

and the same can be said of the use of RCP and of C++ in general