References as class members

- Declared without initial value

References as class members

- Declared without initial value
- Must be initialized using constructor initializer list

```
class X {
public:
    int& m_y;
    X(int& a);
};
X::X(int& a) : m_y(a) { }
```

code & demo

Returning references

- Functions can return references
  - But they should refer to non-local variables!

```
#include <cassert>
const int SIZE = 32;
double myarray[SIZE];
double& subscript(const int i) {
    return myarray[i];
}
```

Example

```
main() {
    for (int i = 0; i < SIZE; i++) {
        myarray[i] = i * 0.5;
    }
    double value = subscript(12);
    subscript(3) = 34.5;
}
```

const in functions arguments

- Passing by const value – don't do it
- Passing by const reference

```
Person(const string& name, int weight);
```

  - won't change the string object
  - more efficient than pass by value (copy)
  - const qualifier protects from change

const reference parameters

- What if you don't want to change the argument
- Use ***const*** modifier

```
// y is a constant! Can't be modified
void func(const int& y, int& z) {
    z = z * 5; // ok
    y += 8; // error!
};
```

Temporary values are const

- What you type

```
void func(int &);
func(i * 3); // Generates warning or error!
```

- What the compiler generates

```
void func(int &);
const int _tmp_ = i * 3;
func(_tmp_); // Problem - binding non-const ref
             // to const argument!
```

The temporary is constant, since you can't access it

const in function returns

- return by const value
  - basically it means nothing
- return by const pointer or reference
  - depends on what you want your client to do with the return value

code & demo

Copy Ctor

Object-Oriented Programming with C++

Problem

- For the code below

```
void f() {
    Stash students();
    …
}
```

Which statement is RIGHT for the line in function f()?

1. This is a variable definition, while students is an object of Stash, initialized with default ctor.
2. This is a function prototype, while students is a function returns an object of Stash.
3. This is a function call.
4. This is illegal in C++.

Copying

- Create a new object from an existing one
  - For example, when calling a function

```
// Currency as pass-by-value argument
void func(Currency p) {
  cout << "X = " << p.dollars();
}
...
Currency bucks(100, 0);
func(bucks); // bucks is copied into p
```

Example: HowMany.cpp

The copy constructor

The copy constructor

- Copying is implemented by the ***copy constructor***

The copy constructor

- Copying is implemented by the ***copy constructor***
- Has the unique signature

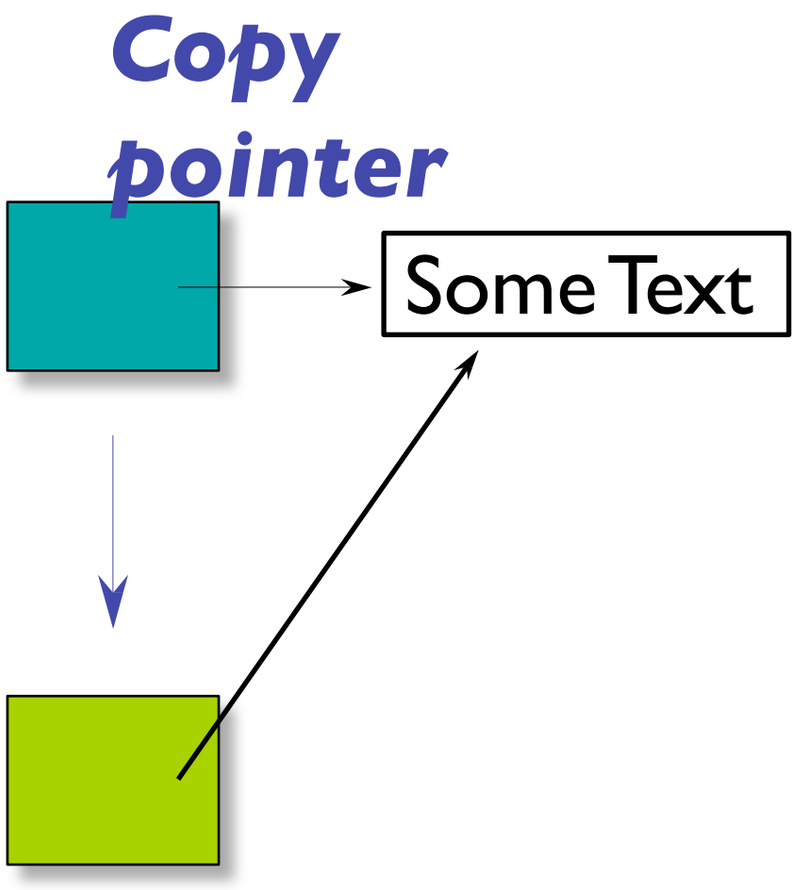
```
T::T(const T&);
```

  – Call-by-reference is used for the explicit argument
- C++ builds a copy ctor for you if you don't provide one!
  – Copies each member variable
    - Good for numbers, objects, arrays
  – Copies each pointer
    - Data may become shared!

What if class contains pointers?

```
class Person {
public:
    Person(const char *s);
    ~Person();
    void print();
    // ... accessor functions
private:
    char *name;   // char * instead of string
    //... more info e.g. age, address, phone
};
```

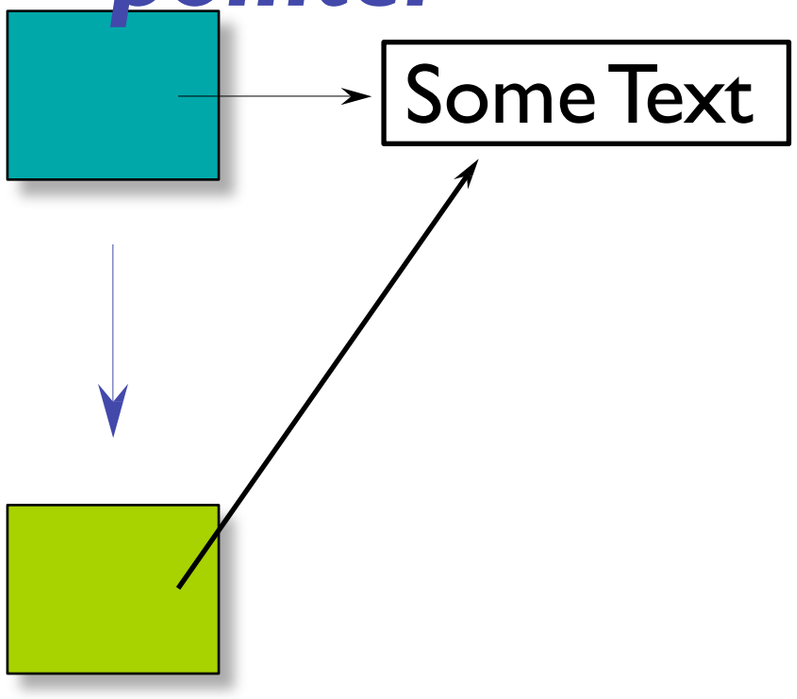
Choices



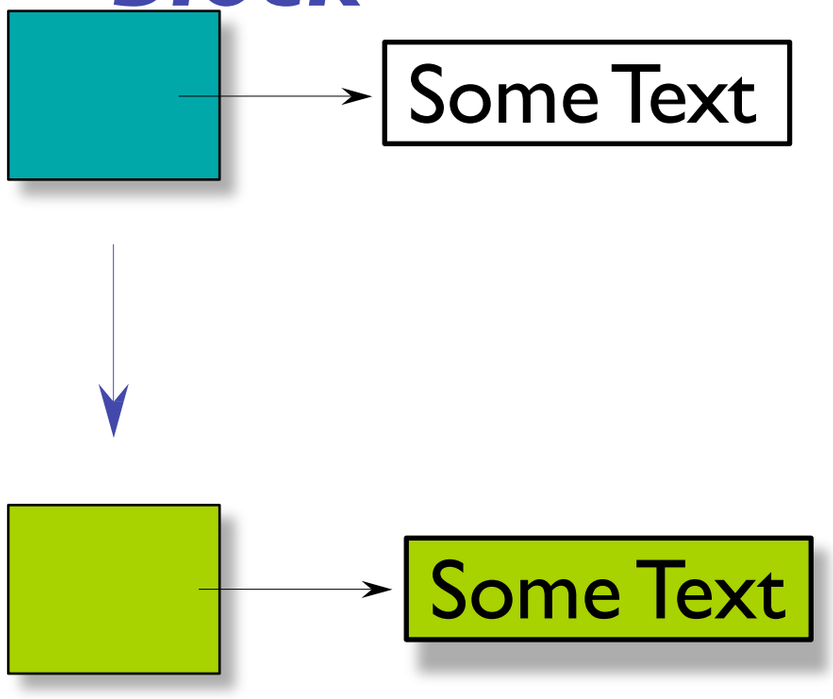
code & demo

Choices

Copy pointer

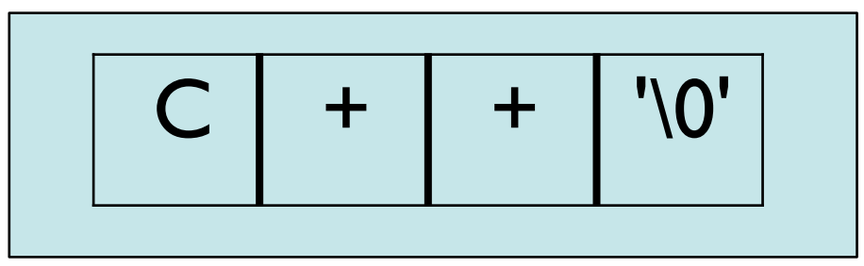


Copy entire block



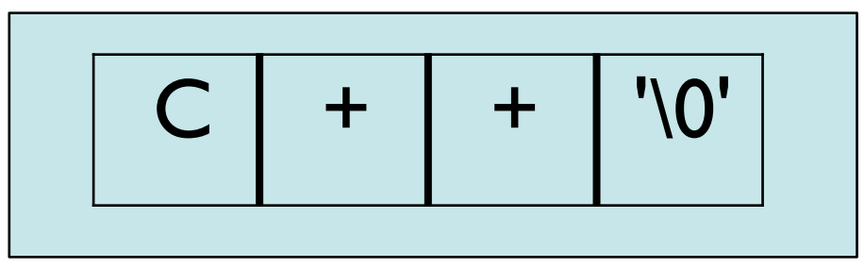
code & demo

Character strings



Character strings

- In C++, a character string is
  - An array of characters
  - With a special terminator — '\0' or ASCII null
- The string "C++" is represented, in memory, by an array of four (4, count'em) characters



Standard C library String fxns

- Declared in `<cstring>`

Standard C library String fxns

- Declared in `<cstring>`

```
size_t strlen(const char *s);
```

  - s is a null-terminated string
  - returns the length of s
  - length does not include the terminator!

```
char *strcpy (char *dest, const char *src);
```

  - Copies src to dest stopping after the terminating null-character is copied. (src should be null-terminated!)
  - dest should have enough memory space allocated to contain src string.
  - Return Value: returns dest

Person (char*) implementation

```
#include <cstring>      // #include <string.h>
using namespace std;

Person::Person( const char *s ) {
  name = new char[::strlen(s) + 1];
   ::strcpy(name, s);
}

Person::~Person() {
   delete [] name;      // array delete
}
```

Person copy constructor

Person copy constructor

- To Person declaration add copy ctor prototype:

```
Person( const Person& w );   // copy ctor
```

- To Person .cpp add copy ctor defintion:

```
Person::Person( const Person& w ) {
    name = new char[::strlen(w.name) + 1];
    ::strcpy(name, w.name);
}
```

Person copy constructor

- To Person declaration add copy ctor prototype:

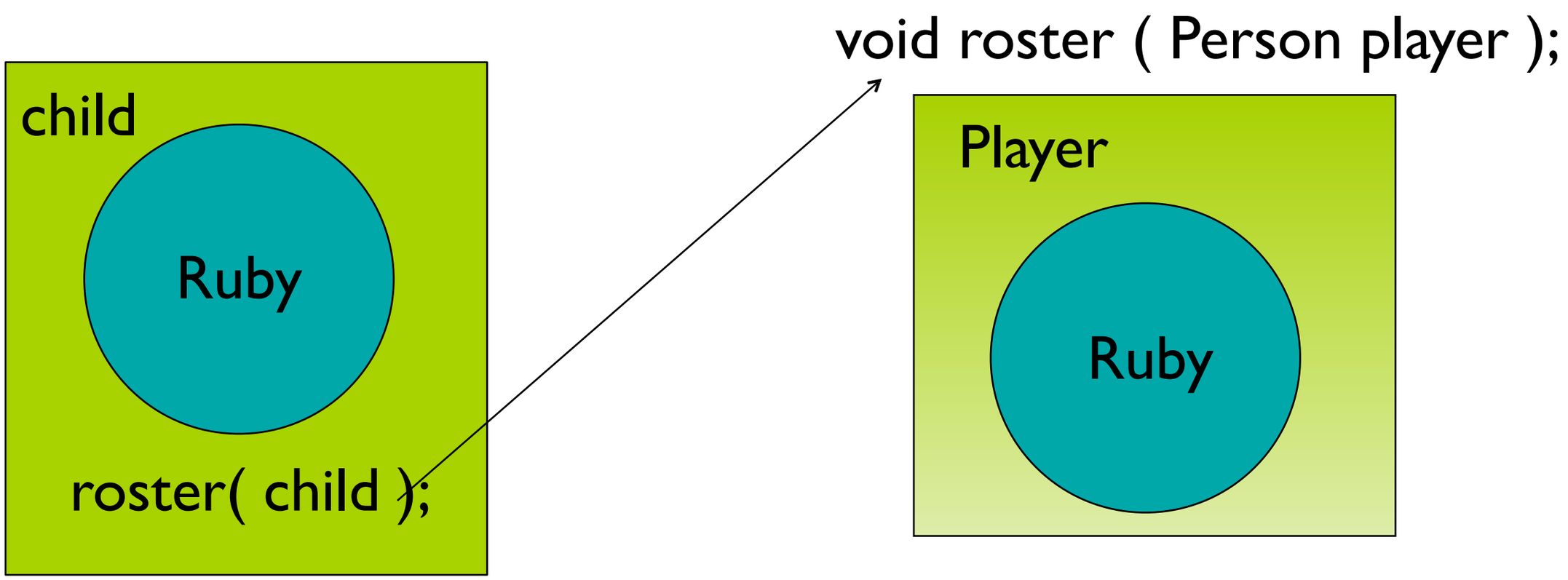
```
Person( const Person& w );   // copy ctor
```

- To Person .cpp add copy ctor defintion:

```
Person::Person( const Person& w ) {
    name = new char[::strlen(w.name) + 1];
    ::strcpy(name, w.name);
}
```

- No value returned
- Accesses w.name across client boundary
- The copy ctor initializes uninitialized memory

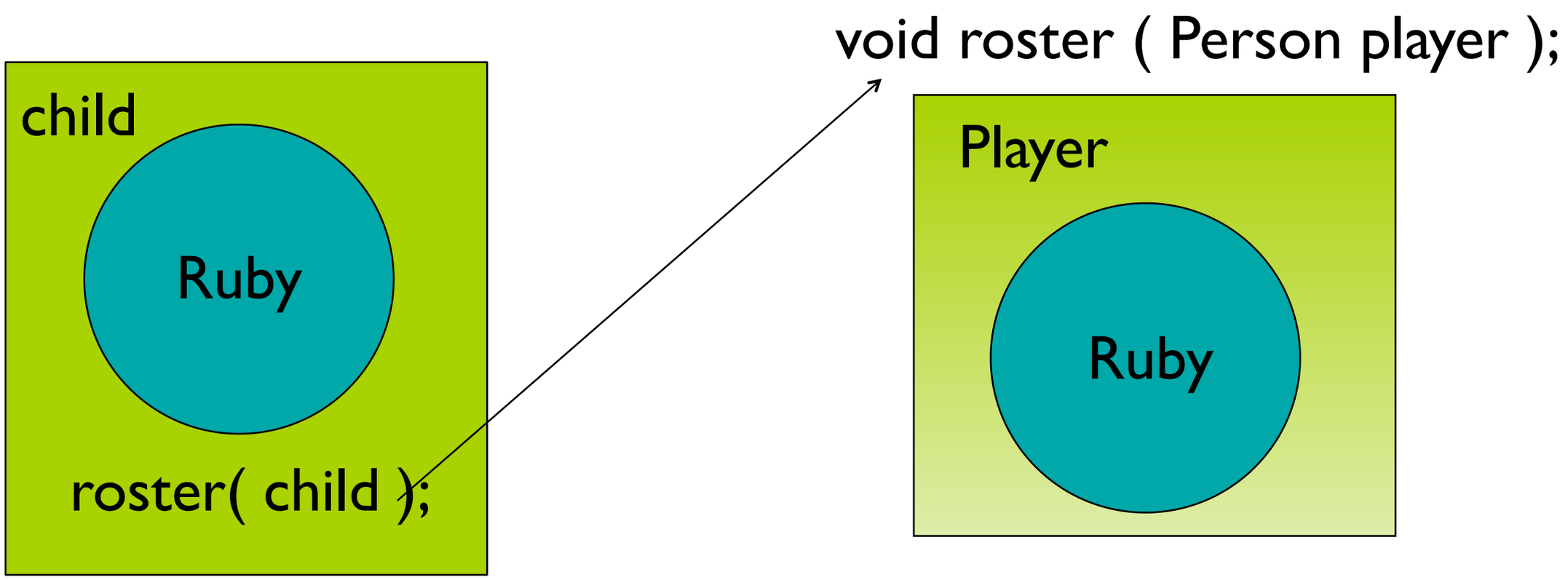
When are copy ctors called?



When are copy ctors called?

- During call by value

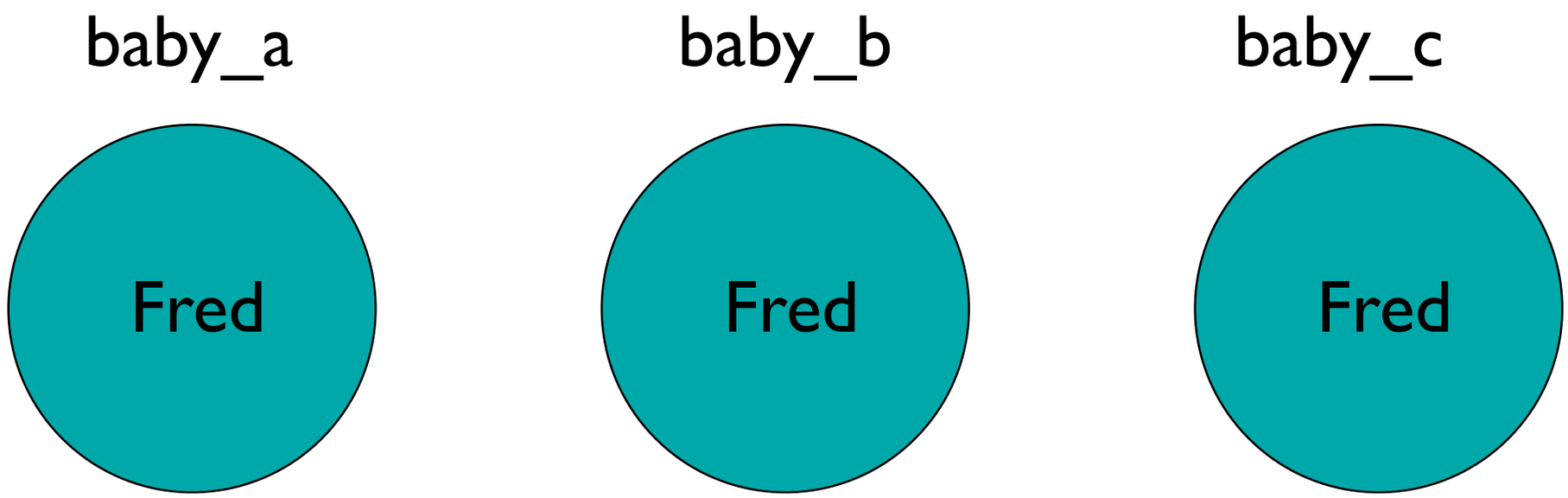
```
void roster( Person );          // declare function
Person child( "Ruby" );         // create object
roster( child );   // call function
```



When are copy ctors called?

- During initialization

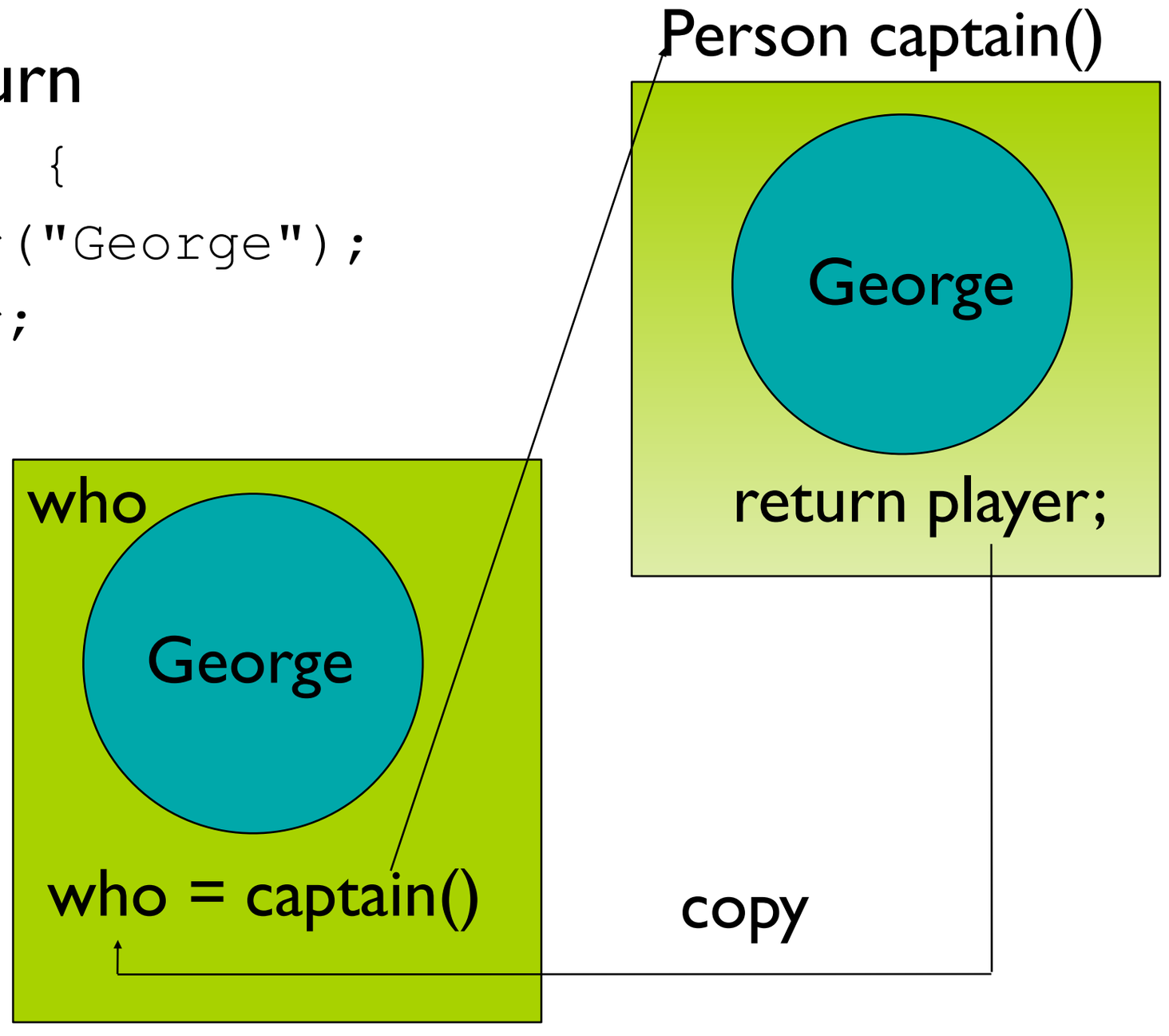
```
Person baby_a("Fred");
// these use the copy ctor
Person baby_b = baby_a;   // not an assignment
Person baby_c( baby_a );  // not an assignment
```



When are copy ctors called?

- During function return

```
Person captain() {
    Person player("George");
    return player;
}
...
Person who
    = captain();
...
```



Copies and overhead

Copies and overhead

- Compilers can "optimize out" copies when safe!

Copies and overhead

- Compilers can "optimize out" copies when safe!
- Programmers need to
  - Program for “dumb” compilers
  - Be ready to look for optimizations

Example

```
Person copy_func( Person p ) {
    p.print();
    return p; // copy ctor called!
}
```

```
Person nocopy_func( char *who ) {
    return Person( who );
}  // no copy needed!
```

code & demo

Constructions vs. assignment

- Every object is constructed once
- Every object should be destroyed once
  - Forget to invoke `delete`
  - Invoke `delete` more than once
- Once an object is constructed, it can be the target of many assignment operations

Person: string name

- What if the name was a string (and not a char*)

```
#include <string>
class Person {
public:
    Person( const string& );
    ~Person();
    void print();
    // ... other accessor fxns ...
private:
    string name;     // embedded object (composition)
    // ... other data members...
};
```

Person: string name…

Person: string name…

- In the default copy ctor, the compiler recursively calls the copy ctors for all member objects (and base classes).

Person: string name…

- In the default copy ctor, the compiler recursively calls the copy ctors for all member objects (and base classes).
- default is memberwise initialization

Copy ctor guidelines

Copy ctor guidelines

- In general, be explicit when necessary
  - –Create your own copy ctor
- If you don't need one declare a private copy ctor
  - – prevents creation of a default copy constructor
  - – generates a compiler error if try to pass-by-value
  - – don't need a definition

Copy ctor guidelines

- In general, be explicit when necessary
  - –Create your own copy ctor
- If you don't need one declare a private copy ctor
  - – prevents creation of a default copy constructor
  - – generates a compiler error if try to pass-by-value
  - – don't need a definition
  - – use "`Person(const Person &rhs)` **`= delete;`**" (since C++11)

static

Static in C++

Two basic meanings

- Static storage
  - allocated once at a fixed address
- Visibility of a name
  - internal linkage

Uses of "static" in C++

Static free functions	Internal linkage
Static global variables	Internal linkage
Static local variables	Persistent storage
Static member variables	Shared by all instances
Static member function	Shared by all instances, can only access static member variables

Global static hidden in file

File1

```
int g_global;
static int s_local;

void
func() {
...
}

static
void
hidden() { ...}
```

?

File2

```
extern int g_global;
void func();

extern int s_local;
int myfunc() {

   g_global += 2;
   s_local *= g_global;
   func();
}
```

Static inside functions

Static inside functions

- Value is remembered for entire program

Static inside functions

- Value is remembered for entire program
- Initialization occurs only once

Static inside functions

- Value is remembered for entire program
- Initialization occurs only once
- Example:
  - count the number of times the function has been called

```
void f() {
    static int num_calls = 0;
    ...
    num_calls++;
}
```

Static applied to objects

- Suppose you have a class

```
class X {
    X(int, int);
    ~X();
    ...
};
```

- And a function with a static X object

```
void f() {
    static X my_X(10, 20);
    ...
}
```

Static applied to objects…

Static applied to objects…

- Construction occurs when definition is encountered
  - Constructor called at-most once
  - The constructor arguments must be satisfied
- Destruction takes place on exit from *program*
  - Compiler assures LIFO order of destructors

Conditional construction

- Example: conditional construction

```
void f(int x) {
    if (x > 10) {
        static X my_X(x, x * 21);
        ...
    }
}
```

- `my_X`
  - is constructed once, if f() is ever called with x > 10
  - retains its value
  - destroyed only if constructed

Global objects

Global objects

- Consider

```
#include "X.h"
static X global_x(12, 34);
static X global_x2(8, 16);
```

- Constructors are called before main() is entered
  - Order controlled by appearance in file
  - In this case, `global_x` before `global_x2`
  - main() is "no longer" the *first* function called
- Destructors called when
  - main() exits
  - exit() is called

Static initialization dependency

Static initialization dependency

- Order of construction within a file is known

Static initialization dependency

- Order of construction within a file is known
- Order between files is unspecified!

Static initialization dependency

- Order of construction within a file is known
- Order between files is unspecified!
- Problem when static objects in different files have dependencies.

Can we apply static to members?

Can we apply static to members?

- Static means
  - Hidden
  - Persistent
- Hidden: *A static member is a member*
  - Obeys usual access rules
- Persistent: *Independent of instances*

Can we apply static to members?

- Static means
  - Hidden
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- Hidden: *A static member is a member*
  - Obeys usual access rules
- Persistent: *Independent of instances*
- Static members are class-wide
  - variables or
  - functions

Static members

Static members

- Static member variables
  - –Global to all class member functions
  - –*Initialized once, at file scope*
  - –provide a place for this variable and init it in .cpp
    - –No ‘static’ in .cpp

- Example: StatMem.h, StatMem.cpp

Static members

- Static member functions
  - –Have no implicit receiver ("this")
    - (why?)
  - –*Can access only static member variables*
    - (or other globals)
  - –No ‘static’ in .cpp
  - –Can’t be dynamically overridden

- Example: StatFun.h, StatFun.cpp

To use static members

- <class name>::<static member>
- <object variable>.<static member>