Part III Synchronization

A bit of C++ and *ThreadMentor*

I don't know what the programming language of the year 2000 will look like, but I know it will be called FORTRAN.

Charles Anthony Richard Hoare

iostream *and* namespace

- Include `iostream` for input/output.
- Then, add `using namespace std`;

```
#include <iostream>
using namespace std;

int  main(…)
{
   // other C/C++ statements
}
```

Input with `cin` *and* `>>`

- Use `cin` and `>>` to read from `stdin`.
- For example, `cin >> n` reads in a data item from `stdin` to variable `n`.
- One more example: `cin >> a >> b` reads in two data items from `stdin` to variables `a` and `b` in this order.
- Thus, `cin` is easier to use than `scanf`.

Output with `cout` *and* `<<` *: 1/2*

- Use `cout` and `<<` to write to `stdout`.
- For example, `cout << n` writes the content of variable `n` to `stdout`.
- One more example: `cout << a << b` writes the values of variables `a` and `b` to `stdout` in this order.
- Thus, `cout` is easier to use than `printf`.
- Formatted output with `cout` is very tedious.

Output with `cout` *and* `<<` *: 2/2*

- **The `\n` is `endl`: `cout << a << endl` prints the value of `a` and follows by a newline.**
- **You may want to add spaces to separate two printed values.**
- **`cout << a << ' ' << b << endl` is better than `cout << a << b << endl`.**

cin/cout *Example 1*

hello.cpp

```
#include <iostream>

using namespace std;

int main(void)
{
    cout << "Hello, world." << endl;
    return 0;
}
```

cin/cout Example 2

factorial.cpp

```
#include  <iostream>
using namespace std;

int main(void)
{
   int  i, n, factorial;

   cout << "A positive integer --> ";
   cin  >> n;
   factorial = 1;
   for (i = 1; i <= n; i++)
      factorial *= i;
   cout << "Factorial of " << n << " = "
        << factorial << endl;
   return 0;
}
```

What Is a `class`? : 1/2

- A `class` is a type similar to a `struct`; but, a `class` type normally has member functions and member variables.

```
class Sum_and_Product
{
   public:
      int a, b;
      void Sum(), Product();
      void Reset(int, int), Display();
   private:
      int MySum, MyProduct;
};
```

Constructors : 1/2

- Constructors are member functions and are commonly used to initialize member variables in a class.
- A constructor is called when its class is created.
- A constructor has the same name as the class.
- A constructor definition ***cannot*** return a value, and no type, not even `void`, can be given at the beginning of the function or in the function header.

Constructors : 2/2

- **Constructors are commonly used to initialize member variables in a class.**

```
class MyClass
{
    public:
        MyClass(int n);   // constructor
    // …
};

MyClass::MyClass(int Input) // function
{
    // …
}
```

Member Functions

- **Member functions are just functions.**

```
class MyClass
{
   public:
      MyClass(int n);   // constructor
      void Display(…); // member function
   // …
};

MyClass::Display(…)     // function
{
   // ……
}
```

Example: 1/5

account.cpp

```
#include  <iostream>
using namespace std;

class MyAccount
{
   public:
      MyAccount(int Initial_Amount); // constructor
      int  Deposit(int);             // member funct
      int  Withdraw(int);            // member funct
      void Display(void);            // member funct

   private:
      int  Balance;                  // private variable
};
```

Example: 2/5

account.cpp

```
MyAccount::MyAccount(int initial)
{
   Balance = initial;  // constructor initialization
}

int MyAccount::Deposit(int Amount)
{
   cout << "Deposit Request  = " << Amount << endl;
   cout << "Previous Balance = " << Balance << endl;
   Balance += Amount;
   cout << "New Balance      = " << Balance << endl
        << endl;
   return Balance;
}
```

Example: 3/5

account.cpp

```
int MyAccount::Withdraw(int Amount)
{
   cout << "Withdraw Request = " << Amount << endl;
   cout << "Previous Balance = " << Balance << endl;
   Balance -= Amount;
   cout << "New Balance      = " << Balance << endl
        << endl;
   return Balance;
}

void MyAccount::Display(void)
{
   cout << "Current Balance  = " << Balance << endl
        << endl;
}
```

Example: 4/5

account.cpp

```
int main(void)
{
   MyAccount  NewAccount(0); // initial new account

   NewAccount.Display();     // display balance
   NewAccount.Deposit(20);   // deposit 20 (Bal=20)
   NewAccount.Deposit(35);   // deposit 35 (Bal=55)
   NewAccount.Withdraw(40);  // withdraw 40 (Bal=15)
   NewAccount.Display();     // current balance
   return 0;
}
```

Example: 5/5

account-1.cpp

```
int main(void)
{
    MyAccount  *NewAccount;          // use pointer

    NewAccount = new MyAccount(0);  // create account
    NewAccount->Display();           // now use ->
    NewAccount->Deposit(20);
    NewAccount->Deposit(35);
    NewAccount->Withdraw(40);
    NewAccount->Display();
    return 0;
}
```

initial value here

This version uses a pointer.
The `new` operator creates an object and returns a pointer to it.
It is similar to `malloc()` in C. Use `delete` to deallocate.

Constructors : The Initialization Section

- There is a faster way, actually maybe a preferable way, to initialize member variables.

```
class Numbers
{
   public:
      int Lower, Upper;
      Numbers(int a, int b);    // constructor
   // …
};

Numbers::Numbers(int a, int b)
          : Lower(a), Upper(b)  // init. section
{ // function body is empty
}
```

Derived Classes: 1/6

- **Deriving a class from an existing one is called *inheritance* in C++.**
- **The newly created class is a *derived* class and the class from which the derived class is created is a *base* class.**
- **The constructor (and destructor) of a base class is not inherited.**

Derived Classes: 2/6

- **A derived class is just a class with the following syntax:**

```
class derived-class-name : public base-class-name
{
      public:
         // public member declarations
         derived-class-constructor();
      private:
         // private member declarations
};
```

Derived Classes: 3/6

derived-1.cpp

```
class Base
{
   public:
      int  a;
      Base(int x=10):a(x)   // use x to init a
         { cout << "Base has " << a << endl; }
};

class Derived: public Base
{
   public:
      int x;
      Derived(int m=20):x(m) // use m to init x
         { cout << "Derived has " << x << endl; }
};
```

Derived Classes: 4/6

derived-1.cpp

```
int main(void)
{
   Base    X, *XX;
   Derived Y, *YY;

   cout << "Base's value    = " << X.a << endl;
   cout << "Derived's value = " << Y.x << endl;
   cout << endl;
   XX = new Base(123);
   YY = new Derived(789);
   cout << "Base's value    = " << XX->a << endl;
   cout << "Derived's value = " << YY->x << endl;

   return 0;
}
```

X.a = 10, Y.x = 20

XX->a = 123, YY->x = 789

Derived Classes: 5/6

derived-2.cpp

```
class Base
{
   public:
      int  a;
      char name[100];
      Base(int);
};

Base::Base(int x = 10) : a(x)
{
   char  buffer[10];
   strcpy(name, "Class");     // requires string.h
   sprintf(buffer, "%d", a);  // requires stdio.h
   strcat(name, buffer);      // requires string.h
   cout << "Base has " << a << ' ' << name << endl;
}
```

This is not the best way;
but, it works!

Derived Classes: 6/6

derived-2.cpp

```
class Derived: public Base
{
   public:
      Derived(int m=20): Base(m) {   }
};
```

use m to call constructor Base

```
int main(void)
{
   Base     X(23);
   Derived  Y(789);

   cout << "Base's name    = " << X.name << endl;
   cout << "Derived's name = " << Y.name << endl;

   return 0;
}
```

"Class23"

"Class789"

Organization & Compilation: 1/4

- **Normally, the specification part and the implementation part of a class are saved in `.h` and `.cpp` files, respectively.**

MyAccount.h

```
class MyAccount
{
   public:
      MyAccount(int Initial_Amount);
      int  Deposit(int);
      int  Withdraw(int);
      void Display(void);

   private:
      int  Balance;
};
```

Organization & Compilation: 2/4

MyAccount.cpp

```
#include  <iostream>
#include  "MyAccount.h"

using namespace std;

MyAccount::MyAccount(int initial)
             : Balance(initial)
{ /* function body is empty */ }

int MyAccount::Deposit(int Amount)
{
   cout << "Deposit Request  = " << Amount << endl;
   cout << "Previous Balance = " << Balance << endl;
   Balance += Amount;
   cout << "New Balance      = " << Balance
        << endl << endl;
   return Balance;
}
// other member functions
```

Organization & Compilation: 3/4

account-3.cpp

```
#include  <iostream>
#include  "MyAccount.h"

using namespace std;

int main(void)
{
   MyAccount  *NewAccount;

   NewAccount = new MyAccount(0);
   NewAccount->Display();
   NewAccount->Deposit(20);
   NewAccount->Deposit(35);
   NewAccount->Withdraw(40);
   NewAccount->Display();
   return 0;
}
```

Organization & Compilation: 4/4

- **Now we have the specification file `MyAccount.h`, the implementation file `MyAccount.cpp`, and the main program `account-3.cpp`.**
- **Compile the whole thing this way**

```
g++ MyAccount.cpp account-3.cpp -o account-3
```

- **Or, we may compile `MyAccount.cpp` to `MyAccount.o` and use it later:**

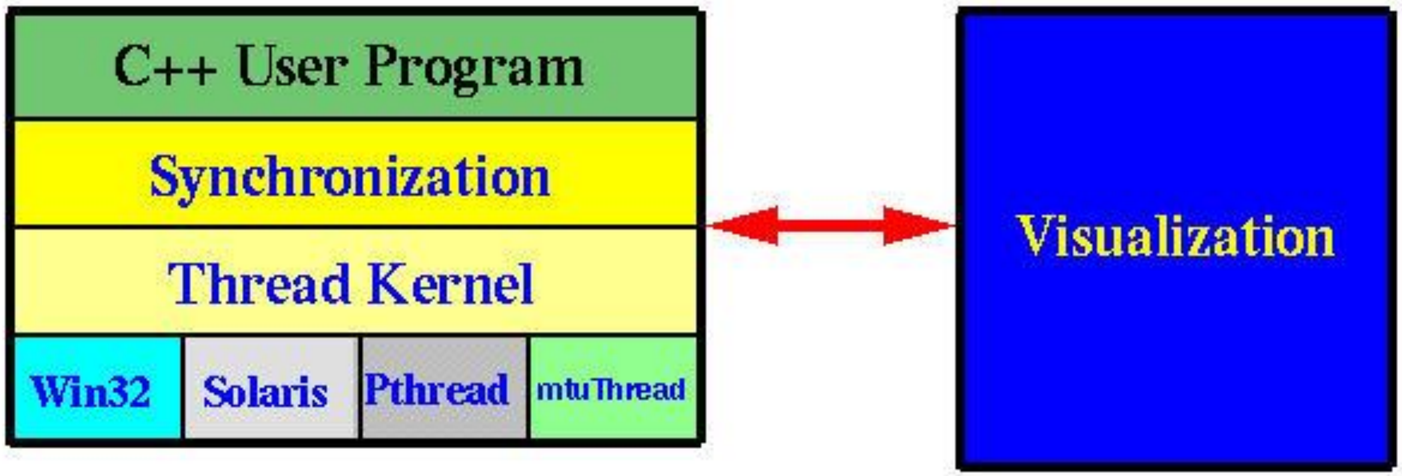
```
g++ MyAccount.cpp -c
g++ account-3.cpp MyAccount.o -o account-3
```

ThreadMentor Basics

ThreadMentor Architecture

- ***ThreadMentor*** consists of a class library and a visualization system.
- The class library provides all mechanisms for thread management and synchronization primitives.
- The visualization system helps visualize the dynamic behavior of multithreaded programs.

ThreadMentor Architecture



Basic Thread Management

- **Thread creation**: creates a new thread
- **Thread termination**: terminates a thread
- **Thread join**: waits for the completion of another thread
- **Thread yield**: yields the execution control to another thread
- **Suspend/Resume**: suspends or resumes the execution of a thread.

How to Define a Thread?

- A thread should be declared as a derived class of `Thread`.
- All executable code must be in function `ThreadFunc()`.
- A thread may be assigned a name with a constructor.
- Method `Delay()` may be used to delay the thread execution for a random time.

```
#include "ThreadClass.h"
class test : public Thread
{
   public:
      test(int i){n=i;};
   private:
      int n;
      void  ThreadFunc(int);
};
void test::ThreadFunc(int n)
{
   Thread::ThreadFunc();
   for (int i=0; i<10; i++)
      cout << n << i << endl;
   // other stuffs
}
```

may not be thread safe!

Create and Run a Thread

- **Declare a thread just like declaring an `int` variable.**
- **Then, use method `Begin()` to run a thread.**

```
int main(void)
{
   test* Run[3];
   int   i;
   for (i=0;i<3;i++) {
      Run[i] = new test(i) ;
      Run[i]->Begin() ;
   }
   // other stuffs
}
```

A Few Important Notes

- **Before calling method `Begin()`, the created thread *does not* run.**
- **Function `ThreadFunc()` *never* returns. When it reaches the end or executes a return, it *disappears*!**
- **Do not use `exit()`, as it terminates the whole system. See next slide.**

Terminating a Thread

- Use method `Exit()` of the thread class `Thread`.
- Do not use system call `exit()` as it terminates the whole program.

```
void test::ThreadFunc(int n)
{
    Thread::ThreadFunc() ;

    for (int i=0;i<10;i++)
        cout << n << i << end;
    Exit() ;  // terminates
}
```

Thread Join

- **Sometimes, a thread must wait until the completion of another thread so that the results computed by the latter can be used.**
- **The parent must wait until all of its child threads complete. Otherwise, when the parent exits, all of its child threads exit.**

The `Join()` *Method*

- **Use the `Join()` method of a thread to join with that thread.**
- **Suppose thread A must wait for thread B's completion. Then, do the following in thread A:**

```
B->Join()
```

or

```
B.Join()
```

Thread Join Semantics

Suppose thread A wants to join with thread B, we have two cases:

1. **If A reaches the `Join()` call before B exits, A waits until B completes.**
2. **If B exits before A can reach the `Join()` call, then A continues as if there is no `Join()`.**

A Simple Example

```
#include "ThreadClass.h"
class test : public Thread
{
   public:
      test(int i){n = i;};
   private:
      int n;
      void  ThreadFunc();
};
void test::ThreadFunc(int n)
{
   Thread::ThreadFunc();
   for (int i=0; i<10; i++)
    cout << n << i << endl;
   Exit();
}
```

```
#include "ThreadClass.h"

int main(void)
{
   test* Run[3];

   for (int i=0;i<3;i++){
         Run[i] = new test(i);
         Run[i]->Begin();
   }
   for (i = 0; i<3; i++)
         Run[i]->Join() ;
   Exit();
}
```

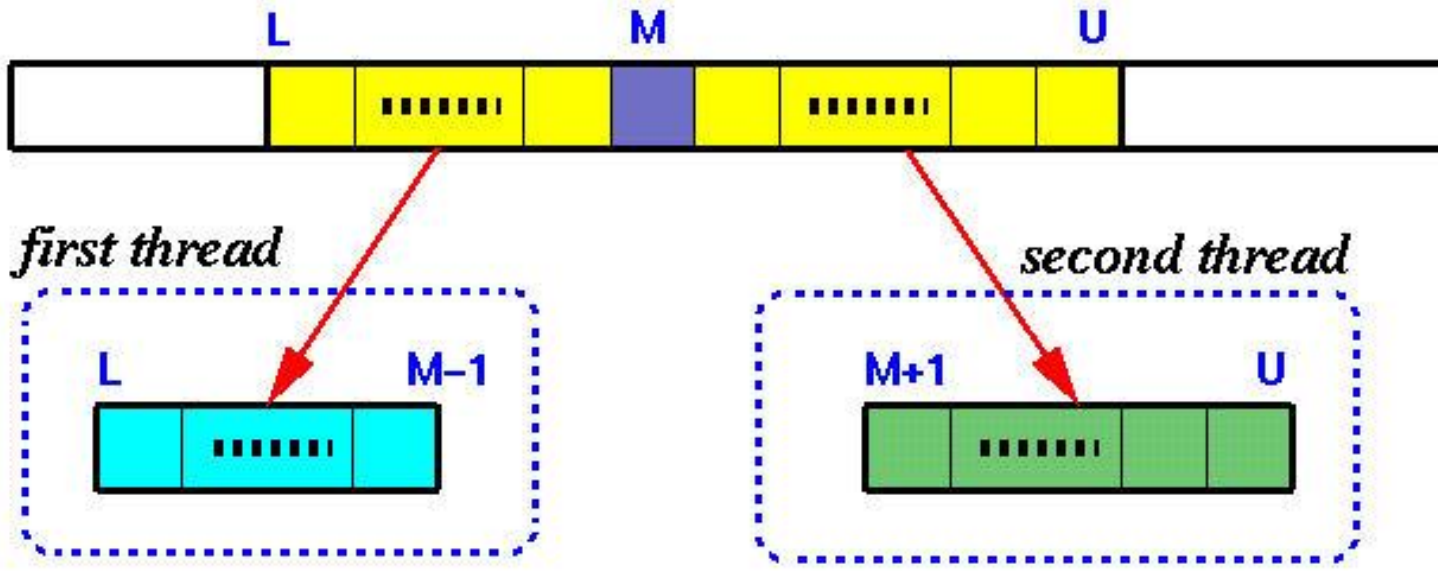
May not be thread safe.
Why?

Threaded Quicksort: 1/3

- **In each recursion step, the quicksort cuts the given array segment `a[L:U]` into two with a pivot element `a[M]` such that all elements in `a[L:M-1]` are less than `a[M]` and all elements in `a[M+1:U]` are greater than `a[M]`. Then, `a[L:M-1]` and `a[M+1:U]` are sorted independently and recursively.**
- **Since `a[L:M-1]` and `a[M+1:U]` are sorted independently, we may use a thread for each segment!**

Threaded Quicksort: 2/3

- A thread receives the array segment `a[L:U]` and partitions it into `a[L:M-1]` and `a[M+1:U]`.
- Then, creates a thread to sort `a[L:M-1]` and a second thread to sort `a[M+1:U]`.



Threaded Quicksort: 3/3

Thus, our strategy looks like the following:

1. **A thread receives array `a[L:R]`.**
2. **It finds the pivot element `a[M]`.**
3. **Creates a child thread and provides it with `a[L:M-1]`.**
4. **Creates a child thread and provides it with `a[M+1:R]`.**
5. **Issues two thread `Join()`s waiting for both child threads.**

Class `Quicksort`: Definition

```
class Quicksort : public Thread
{
    public:
        Quicksort(int L, int U, int a[]);
    private:
        int  low;
        int  up;
        int  *a;
        void ThreadFunc();
};
```

quicksort.h

Class Quicksort: Implementation

```
Quicksort::Quicksort(int L, int U, int A[])
           :low(L), up(U), a(A)
{
     ThreadName = // set a thread name;
}

Void Quicksort::ThreadFunc()
{
   Thread::ThreadFunc();  // required
   Quicksort  *Left, *Right;
   int        M;
   M = // compute the pivot element;
   Left = new Quicksort(low, M-1, a); Left->Begin();
   Right = new Quicksort(M+1, up, a); Right->Begin();
   Left->Join(); Right->Join();
   Exit();
}
```


quicksort.cpp

Class Quicksort: Main Program

The main program is easy:

```
int  main(void)
{
    Quicksort   *thread;
    int          a[MAXSIZE], L, U, n;
    // read in array a[] and # of elements n
    L = 0; U = n-1;
    thread = new Quicksort(L, U, a);
    thread->Begin();
    thread->Join();
    Exit();
}
```

quicksort-main.cpp

What If We Have the Following?

```
Quicksort::Quicksort(int L, int U, int A[])
           :low(L), up(U), a(A)
{
     ThreadName = // set a thread name;
}

Void Quicksort::ThreadFunc()
{
   Thread::ThreadFunc();
   Quicksort  *Left, *Right;
   int         M;
   M = // compute the pivot element;
   Left = new Quicksort(low, M-1, a);
     Left->Begin();  Left->Join();
   Right = new Quicksort(M+1, up, a);
     Right->Begin(); Right->Join();
   Exit();
}
```

`Join()` are moved to right after `Begin()`. Is this a correct program? Does it fulfill the maximum concurrency requirement?

Compilation with ThreadMentor

- ***ThreadMentor*** **adds all visualization features in its class library so that you don't have to do anything in your program to use visualization.**
- **But, you need to recompile your program properly so that a correct library will be used.**
- **There are two versions of *ThreadMentor* library: Visual and non-Visual.**

`Makefile` for ThreadMentor: 1/4

Define some names.
Don't touch this portion.

visual library

```
CC        = c++
CFLAGS    = -g -O2
DFLAGS    = -DPACKAGE=\"threadsystem\" ......
IFLAGS    = -I/local/eit-linux/apps/ThreadMentor/include
TMLIB     = /local/eit-linux/apps/ThreadMentor/Visual/...
TMLIB_NV  = /local/eit-linux/apps/ThreadMentor/NoVisual/...

OBJ_FILE  = quicksort.o quicksort-main.o
EXE_FILE  = quicksort
```

non-visual library

This is the executable file

List the `.o` files here

`Makefile` *for ThreadMentor: 2/4*

generate executable file with visual

```
${EXE_FILE}: ${OBJ_FILE}
  tab  ${CC} ${FLAGS} -o ${EXE_FILE} ${OBJ_FILE} ${TMLIB} -lpthread

quicksort.o: quicksort.cpp
        ${CC} ${DFLAGS} ${IFLAGS} ${CFLAGS} -c quicksort.cpp

quicksort-main.o: quicksort-main.cpp
        ${CC} ${DFLAGS} ${IFLAGS} ${CFLAGS} -c quicksort-main.cpp

noVisual: ${OBJ_FILE}
        ${CC} ${FLAGS} -o ${EXE_FILE}  ${OBJ_FILE} ${TMLIB_NV} -lpthread

clean:
        rm -f ${OBJ_FILE} ${EXE_FILE}
```

clean up

generate executable file without visual

`Makefile` *for ThreadMentor: 3/4*

- **By default, the above `Makefile` generates executable with visual. The following generates executable `quicksort`:**

  ```
  make
  ```

- **If you do not want visualization, use the following:**

  ```
  make noVisual
  ```

- **To clean up the `.o` and executable files, use**

  ```
  make clean
  ```

`Makefile` *for ThreadMentor: 4/4*

- **Add the following line to your `.cshrc`, which is in your home directory. Then, logout and login again to make it effective:**

```
set path=($path /local/eit-linux/apps/ThreadMentor/bin)
```

- **More *ThreadMentor* examples are available at the *ThreadMentor* tutorial site:**

http://www.cs.mtu.edu/~shene/NSF-3/e-Book/index.html

The End