Where do we go from here?

- **C++ (3-4 lectures)**
  - classes and objects again, with all the moving parts visible
  - operator overloading
  - templates, STL
- **Visual Basic**
  - user interfaces
  - component-based software
  - viruses ?
- **C#, .NET**
- **XML and friends**
  - SOAP, XSLT, WSDL, ...
- **Guest lectures**

  April 1: Chris Karr '02, Northwestern University

  "I have a $150,000 computer science degree. Now what?"

  April 15: Sean Dorward '91, Google

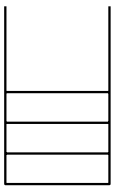
  April 22: Clayton Marsh '85, General Counsel's Office

Stacks in C: a single stack

```
int stack[100];
int *sp = stack;  /* first unused */

#define push(n) (*sp++ = (n))
#define pop()   (*--sp)

for (i = 0; i < 10; i++)
    push(i);
```



Stacks in C: a stack type

```
typedef struct {
  int stk[100];
  int *sp;
} stack;

int push(stack s, int n) {
    return *s.sp++ = n;
}

int pop(stack s) {
    return *--s.sp;
}

stack s1, s2;
for (i = 0; i < 10; i++)
  push(s1, i);
```

Another stack implementation

```
typedef struct {
  int *stk;   // allocated dynamically
  int *sp;
} stack;

int push(stack *s, int n) {
    return *s->sp++ = n;
}
int pop(stack *s) {
    return *--s->sp;
}

stack *s1, *s2;   not initialized

s1 = (stack *) malloc(sizeof(stack));
s1->stk = (int *) malloc(100*sizeof(int));
                  ugly

for (i = 0; i < 10; i++)
    push(*s1, i);
```

Problems

- **representation is visible, can't be protected (e.g., s1->stk)**
- **creation and copying must be done very carefully**
  - and you don't get any help with them
- **no initialization**
  - you have to remember to do it
- **no help with deletion**
  - you have to recover the memory when not in use
- **weak argument checking between declaration and call**
  - easy to get inconsistencies

- **the real problem: no abstraction mechanisms**
  - complicated data structures can be built, but access to the representation can't be controlled
  - you can't change your mind once the first implementation has been done

- **abstraction and information hiding are**
  nice for small programs
  absolutely necessary for big programs

C++

- **designed & implemented by Bjarne Stroustrup**
  Bell Labs (1979-95) -> AT&T Labs (1995-) -> TAMU (2003)
  - began ~ 1980; ISO standard 1998

- **a better C**
  - more checking of interfaces (ANSI C)
  - other features for easier programming
- **data abstraction**
  - you can hide HOW something is done in a program,
  - reveal only WHAT is done
  - HOW can be safely changed as program evolves
- **object-oriented programming**
  - *inheritance* -- new types can be defined that inherit properties from previous types
  - *polymorphism* or dynamic binding -- function to be called is determined by data type of specific object at run time
- **parameterized types**
  - define families of related types, where the type is a parameter
  - templates or "generic" programming

C++ classes

- **data abstraction and protection mechanism derived from Simula 67** **(Kristen Nygaard, Norway)**

```
class thing {
  public:
    methods -- functions that define what operations can
    be done on this kind of object
  private:
    variables and functions that  implement the operations
};
```

- **defines a data type 'thing'**
  - can declare variables and arrays of this type, create pointers to them, pass them to functions, return them, etc.
- **object: an instance of a class variable**
- **method: a function defined within the class**

- **private variables and functions are not accessible from outside the class**
- **it is not possible to determine HOW the operations are implemented, only WHAT they do.**

C++ synopsis

- **data abstraction with classes**
  - a class defines a type that can be used to
    declare variables of that type,
    control access to representation

- **operator and function name overloading**
  - all C operators (including assignment, **( )**, **[ ]**, **->**, argument passing and function return) can be overloaded so they apply to user-defined types
- **control of creation and destruction of objects**
  - initialization of class objects
  - recovery of resources on destruction
- **inheritance: derived classes built on base classes**
  - virtual functions override base functions
  - multiple inheritance: inherit from more than one class
- **exception handling**
- **namespaces for separate libraries**
- **templates (generic types)**
- **Standard Template Library**
  - generic algorithms on generic containers

- **compatible (almost) with C**
  - except for new keywords

Stack class in C++

```
// stk1.c: stack of ints, 1st draft;  no checking!!!

class stack {
  private:      // this is the default
        int stk[100];
        int *sp;        // next free place
   public:
        int push(int);
        int pop();
};

int stack::push(int n)  // push n onto stack
{
        return *sp++ = n;
}

int stack::pop()        // pop top element
{
        return *--sp;
}
```

Testing stk1.c

```
#include <stdio.h>

main()
{
        stack s;
        int i;

        for (i = 0; i < 10; i++)
                s.push(i);
        for (i = 0; i < 10; i++)
                if (s.pop() != 9-i)
                        printf("oops: %d\n", i);
}


$ g++ -g stk1.c
$ a.out
```

Constructors: making a new object

```
// stk2.c:   constructors

class stack {
   private:
        int stk[100];
        int *sp;        // next free place
   public:
        stack();        // constructor
        int push(int);
        int pop();
};

stack::stack() { sp = stk; }

int stack::push(int n)  // push n onto stack
{
        return *sp++ = n;
}
int stack::pop()        // pop top element
{
        return *--sp;
}
```

Testing stk2.c

```
main()
{
        stack s1, s2;
        int i;

        for (i = 0; i < 10; i++)
                s1.push(i);
        for (i = 0; i < 10; i++)
                s2.push(s1.pop());
        for (i = 0; i < 10; i++)
                if (s2.pop() != i)
                        printf("oops: %d\n", i);
}
```

Constructors and destructors

- **constructor:**
  creating a new object (including initialization)
  - implicitly, by entering the scope where it is declared
  - explicitly, by calling **new**
- **destructor:**
  destroying an existing object (including cleanup)
  - implicitly, by leaving the scope where it is declared
  - explicitly, by calling **delete** on an object created by **new**
- **construction includes initialization, so it may be parameterized**
  - by multiple constructor functions with different args
  - an example of function overloading
- **new can be used to create an array of objects**
  - in which case **delete** can delete the entire array

Implicit and explicit

- **implicit:**

```
f() {
    stack s;
         // calls constructor stack::stack()
    …
    // calls stack::~stack() implicitly
}
```

- **explicit:**

```
f() {
    stack *sp = new stack;
         // calls stack::stack()
    …
    delete sp; // calls stack::~stack()
    …
}
```

Implicit and explicit

- **implicit:**

```
f() {
    int i;
    stack s;
         // calls constructor stack::stack()
    …
    // calls stack::~stack() implicitly
}
```

- **explicit:**

```
f() {
    int *ip = new int;
    stack *sp = new stack;
                // calls stack::stack()
    …
    delete sp; // calls stack::~stack()
    delete ip;
    …
}
```

Memory allocation: new and delete

- **new is a type-safe alternative to malloc**
  - **delete** is the matching alternative to free
- **new T allocates an object of type T, returns pointer to it**

```
stack *sp = new stack;
```

- **new T[n] allocates array of T's, returns pointer to first**

```
int *stk = new int[100];
```

  - by default, throws exception if no memory
- **delete p frees the single item pointed to by p**

```
delete sp;
```

- **delete [ ] p frees the array beginning at p**

```
delete [ ] stk;
```

- **new uses T's constructor for objects of type T**
  - need a default constructor for array allocation
- **delete uses T's destructor ~T()**

- **use new/delete instead of malloc/free**
  - malloc/free provide raw memory but no semantics
  - this is inadequate for objects with state
  - **never** mix new/delete and malloc/free

Overloaded functions; constructors

- **two or more functions can have the same name if the number and/or types of arguments are different**

```
abs(int);   abs(double);   abs(complex)
atan(double x);    atan(double y, double x);

int abs(int x) { return x >= 0 ? x : -x; }
double abs(double x) { return x >= 0 ? x : -x; }
...
```

- **multiple constructors for a class are a common instance**

```
stack::stack( );
stack::stack(int stacksize);

stack s;            // default stack::stack()
stack s1(100);    // stack::stack(100)
stack s2 = 100;  // also stack::stack(100)
```

Dynamic stack with new, delete

```
// stk3.c:  new, destructors, delete; explicit size

class stack {
  private:
        int *stk;        // allocated dynamically
        int *sp;         // next free place
  public:
        stack();       // constructor
        stack(int n);    // constructor
        ~stack();        // destructor
        int push(int);
        int pop();
};

stack::stack()
{
        stk = new int[100];  sp = stk;
}

stack::stack(int n)
{
        stk = new int[n];  sp = stk;
}

stack::~stack() { delete [ ] stk; }
```

Where are we?

- **a class is a user-defined type**
- **an object is an instance (variable or value) of that type**
- **public part defines interface it supports**
  - member functions in the public part define legal operations on an object
- **private part defines implementation**
  - functions and data values that implement interface
- **constructors are members that define how to create new instances**
- **destructor is a member that defines how to destroy an instance (e.g., how to recover its resources)**

- **there's more to constructors**
  - show up implicitly in declarations, function arguments, return values, assignment
  - the meaning of explicit and implicit copying must be part of the representation

Inline definitions, default arguments

```
// stk4.c:  inline definitions, default size

class stack {
        int *stk;       // allocated dynamically
        int *sp;        // next free place
   public:
        stack(int n);
        ~stack()        { delete [ ] stk; }
        int push(int n) { return *sp++ = n; }
        int pop()       { return *--sp; }
        int top()       { return sp[-1]; }
};
inline stack::stack(int n = 100)
{                       // ^ default argument
        stk = new int[n];
        sp = stk;
}

main() {
        stack s1(10), s2;

// could use 2 constructors instead of default arg
//      stack();  stack(int n);
```

Overloaded functions / default args

- default arguments: syntactic sugar for a single function
  ```
  stack::stack(int n = 100);
  ```
- declaration can be repeated if the same

- explicit size in call
  ```
  stack s(500);
  ```
- omitted size uses default value
  ```
  stack s;
  ```

- overloaded functions: different functions, distinguished by argument types
- these are two different functions:
  ```
  stack::stack(int n);
  stack::stack();
  ```

Change of representation

```
// stk5.c:  change of representation  (no checking)

class stack {
   private:
        struct blk {    // private to this class
                int n;
                blk *nb;
                blk(int sz = 0, blk *next = 0);
        };
        blk *sp;        // top == head of the list

   public:
        stack(int = 0)  { sp = 0; }
        ~stack()        { while (sp) pop(); }
        int push(int n);
        int pop();
        int top()       { return sp->n; }
};
```

Representation as linked list

```
stack::blk::blk(int sz, blk *next)
{
        n = sz;
        nb = next;
}

int stack::push(int n)
{
        blk *bp = new blk(n, sp);
        sp = bp;
        return n;
}

int stack::pop()
{
        blk *bp = sp;
        int n = sp->n;
        sp = sp->nb;
        delete bp;
        return n;
}
```

Aside on implementation

- **a class is just a struct**
  - no overhead
  - no "class Object" that everything derives from
  - member functions are just names
  - definition is such that C++ can be translated into C
  - original C++ compiler was a C++ program ("cfront") that generated C

```
struct stack {  /* sizeof stack == 8 */
int *stk__5stack ;
int *sp__5stack ;
};
...
struct stack __1s1 ;
struct stack __1s2 ;
int __1i ;
 ...
```

Cfront output, continued...

```
main() {
        stack s1(10), s2;
        int i;
        for (i = 0; i < 10; i++)
                s1.push(i);
        for (i = 0; i < 10; i++)
                s2.push(s1.pop());
        for (i = 0; i < 10; i++)
                if (s2.pop() != i)
                        printf("oops: %d\n", i);
}
```

```
( (( ((& __1s1 )-> stk__5stack = (((int *)__nw__FUi (
  (sizeof (int ))* 10 ) ))), ((& __1s1 )-> sp__5stack =
  (& __1s1 )-> stk__5stack )) ), (((& __1s1 )))) ;
( (( ((& __1s2 )-> stk__5stack = (((int *)__nw__FUi (
  (sizeof (int ))* 100 ) ))), ((& __1s2 )-> sp__5stack =
  (& __1s2 )-> stk__5stack )) ), (((& __1s2 )))) ;
for(__1i = 0 ;__1i < 10 ;__1i ++ )
( (((*((& __1s1 )-> sp__5stack ++ )))= __1i )) ;
for(__1i = 0 ;__1i < 10 ;__1i ++ )
( (__2__X1 = ( ((*(-- (& __1s1 )-> sp__5stack )))) ), (
  (((*((&__1s2 )-> sp__5stack ++ )))= __2__X1 )) ) ;
for(__1i = 0 ;__1i < 10 ;__1i ++ )
if (( ((*(-- (& __1s2 )-> sp__5stack )))) != __1i )
printf ( (char *)"oops: %d\n",__1i ) ;
( (( ( __dl__FPv ( (char *)(& __1s2 )-> stk__5stack ) ,
  (( (( 0 ) ), 0 ))) , 0 ) )) ;
( (( ( __dl__FPv ( (char *)(& __1s1 )-> stk__5stack ) ,
  (( (( 0 ) ), 0 ))) , 0 ) )) ;
```

Where are we now?

- **hiding representation with <u>private</u>**
- **member functions for public interface**
  - classname :: member()
- **constructors to make new instances and initialize them**
- **destructors to delete them cleanly**
- **change of representation**
  - as long as the public part doesn't change
- **nothing magic about implementation**

What we have ignored (besides error checking):

- **implications of assignment and initialization**
  - declarations, function arguments, function return values
  - if we don't do anything, will get memberwise assignment and initialization

The meaning of explicit and implicit copying MUST be part of the representation