

CSC 533: Programming Languages

Spring 2012

Language evolution: C → C++ → Java → JavaScript

- C
history, design goals, features, top-down design
- C++
history, design goals, features, object-based design
- Java
history, design goals, features, object-oriented design
- JavaScript
history, design goals, features, scripting

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C: early history

C was developed by Dennis Ritchie at Bell Labs in 1972

- designed as an in-house language for implementing UNIX
 - UNIX was originally implemented by Ken Thompson in PDP-7 assembly
 - when porting to PDP-11, Thompson decided to use a high-level language
 - considered the B language, a stripped-down version of BCPL, but it was untyped & didn't provide enough low-level machine access
 - decided to design a new language that provided high-level abstraction + low-level access
- the UNIX kernel was rewritten in C in 1973

became popular for systems-oriented applications, and also general problem solving (especially under UNIX)

- for many years, there was no official standard (other than Kernighan & Ritchie's 1978 book)
- finally standardized in 1989 (ANSI C or C89) and again in 1999 (C99)

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C design goals

wanted the language to support

- systems programming (e.g., the implementation of UNIX)
- applications programming

as a result, the language had to

- support low-level operations but also high-level abstractions
- be close to the machine but also portable
- yield efficient machine code but also be expressive/readable

the dominant paradigm of the time was imperative programming

- a program is a collection of functions
- statements specify sequences of state changes
- supported top-down design

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Program structure

a C program is a collection of functions

- libraries of useful functions can be placed in files and loaded using `#include`
- to be executable, a program must have a `main` method
- functions must call upward, or else place prototype above to warn the compiler

```
#include <stdio.h>
#include <string.h>

void oldMacVerse(char*, char*);

int main() {
    oldMacVerse("cow", "moo");
    return 0;
}

void oldMacVerse(char* animal, char* sound) {
    printf("Old MacDonald had a farm, E-I-E-I-O.\n");
    printf("And on that farm he had a %s, E-I-E-I-O.\n", animal);
    printf("With a %s-%s here, and a %s-%s there,\n",
        sound, sound, sound, sound);
    printf(" here a %s, there a %s, everywhere a %s-%s.\n",
        sound, sound, sound, sound);
    printf("Old MacDonald had a farm, E-I-E-I-O.\n");
}
```

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Built-in data types

integers

- to provide low-level access & control, multiple types: `short`, `int`, `long`
only guaranteed that $2 \text{ bytes} \leq \text{sizeof}(\text{short}) \leq \text{sizeof}(\text{int}) \leq \text{sizeof}(\text{long})$
- to support systems programming, can specify integers in octal & hexadecimal
- to make optimal use of limited memory, can declare type to be unsigned

floating-points (reals)

- similarly, a variety of floating-point: `float`, `double`, `long double`
- to support systems/scientific programming, can specify in scientific notation

characters

- `char` represents characters using ASCII codes (1 byte) – really another int type
`'A' + 1` → `'B'` `'4' - '0'` → 4
- no string type – strings are arrays of chars terminated by `'\0'` character

no boolean type

- fake it by declaring int constants (`TRUE = 1`, `FALSE = 0`)

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Bitwise operators & libraries

in addition to standard math & logical operators (`+` `-` `*` `/` `%` `&&` `||` `!`),
C has low-level bitwise operators

- `&` bitwise AND
- `|` bitwise OR
- `^` bitwise XOR
- `~` bitwise NOT (one's complement)
- `<<` left shift
- `>>` right shift

also has a variety of standard libraries

- `math.h` mathematical functions
- `stdio.h` input/output functions, including file processing
- `stdlib.h` various useful functions, including memory allocation,
system calls, random, searching & sorting, ...
- `string.h` functions for manipulating strings (char arrays)

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Variable bindings

types are bound statically

- all variable declarations must occur at the start of a block
- somewhat strongly typed, but loopholes exist

memory is bound...

- statically for global variables
- stack-dynamically for local variables
- heap-dynamically for malloc/free

for flexibility, assignments are expressions (evaluate to value assigned)

```
x = y = z = 0;
```

shorthand assignments save keystrokes

```
+=      -=      *=      /=
```

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Input & control

simple input via scanf

- must allocate space for the string
- can access chars using [] since an array

same control structures as C++/Java

- if/else, switch
- while, do-while, for
- break, continue

also has goto

- to support old-school programming

```
#include <stdio.h>
#include <string.h>

int isPalindrome(char*);

int main() {
    char input[20];
    printf("Enter a word: ");
    scanf("%s", &input);

    if (isPalindrome(input)) {
        printf("%s is a palindrome\n", input);
    }
    else {
        printf("%s is NOT a palindrome\n", input);
    }

    return 0;
}

int isPalindrome(char* word) {
    int len = strlen(word);

    int i;
    for (i = 0; i < len/2; i++) {
        if (word[i] != word[len-i-1]) {
            return 0;
        }
    }
    return 1;
}
```

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#define

you can define constants using #define

- this is a preprocessor directive
- the first step in compilation is globally replacing each constant with its value

note: constants are NOT the same as constants in Java

```
#include <stdio.h>
#include <string.h>

#define MAX_LENGTH 20
#define BOOLEAN int
#define TRUE 1
#define FALSE 0

BOOLEAN isPalindrome(char*);

int main() {
    char input[MAX_LENGTH];
    printf("Enter a word: ");
    scanf("%s", &input);

    if (isPalindrome(input)) {
        printf("%s is a palindrome\n", input);
    }
    else {
        printf("%s is NOT a palindrome\n", input);
    }

    return 0;
}

BOOLEAN isPalindrome(char* word) {
    int len = strlen(word);

    int i;
    for (i = 0; i < len/2; i++) {
        if (word[i] != word[len-i-1]) {
            return FALSE;
        }
    }
    return TRUE;
}
```

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Function parameters

all parameter passing is by-value

- but can achieve by-reference passing through pointers
- get the address of the variable using &
- pass the address to the function as parameter
- then dereference the address using *

```
#include <stdio.h>

void getValues(int*, int*);
void process(int*, int*);
void display(int, int);

int main() {
    int x, y;
    GetValues(&x, &y);
    Process(&x, &y);
    Display(x, y);

    return 0;
}

void getValues(int* a, int* b) {
    printf("Enter two numbers: ");
    scanf("%d%d", a, b);
}

void process(int* a, int* b) {
    if (*a > *b) {
        int temp = *a;
        *a = *b;
        *b = temp;
    }
}

void display(int a, int b) {
    printf("%d + %d = %d\n", a, b, (a+b));
}
```

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C arrays

by default, C array allocation is:

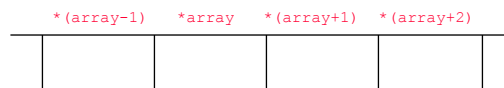
- static (allocated on the stack at compile time), if a global variable
- fixed stack-dynamic (size is fixed at compile time, memory is allocated on the stack during run time), if a local variable
- unlike Java, there is no length field associated with an array and no bounds checking – you must keep track!

arrays and pointers are linked in C

- can think of an array as a pointer to the first element

```
int counts[NUM_LETTERS];           // counts ≡ &counts[0]
```

- array indexing is implemented via pointer arithmetic: `array[k] ≡ *(array+k)`



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Array example

because of the size limit,
storing an arbitrary
number of items is ugly

- must set a max size
- as you read in items, must keep count and make sure don't exceed the limit
- must then pass the size around with the array in order to process

- note: could have written

```
int* nums
instead of
int nums[]
```

```
#include <stdio.h>
#define MAX_SIZE 20

void getNums(int[], int*);
int smallest(int[], int);

int main() {
    int numbers[MAX_SIZE];
    int count = 0;

    getNums(numbers, &count);
    printf("The smallest number is %d\n",
           smallest(numbers, count));

    return 0;
}

void getNums(int nums[], int* cnt) {
    int nextNum;

    printf("Enter numbers (end with -1): ");
    scanf("%d", &nextNum);
    while (nextNum != -1 && *cnt < MAX_SIZE) {
        nums[*cnt] = nextNum;
        (*cnt)++;
        scanf("%d", &nextNum);
    }
}

int smallest(int nums[], int cnt) {
    int small = nums[0];
    int i;
    for (i = 1; i < cnt; i++) {
        if (nums[i] < small) {
            small = nums[i];
        }
    }
    return small;
}
```

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Data structures

can define new, composite data types using `struct`

- `struct { ... }` defines a new structure
- `typedef ... NAME;` attaches a type name to the `struct`

note: a `struct` is NOT a class

- there is no information hiding (i.e., no `private`)
- there are no methods

```
#include <stdio.h>
#include <math.h>

typedef struct {
    int x;
    int y;
} Point;

double distance(Point, Point);

int main() {
    Point pt1;
    Point pt2;

    pt1.x = 0;
    pt1.y = 0;

    pt2.x = 3;
    pt2.y = 4;

    printf("Distance = %f\n",
           distance(pt1, pt2));

    return 0;
}

double distance(Point p1, Point p2) {
    return sqrt(pow(p1.x - p2.x, 2.0) +
               pow(p1.y - p2.y, 2.0));
}
```

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Dynamic memory

by default, data is allocated on the stack

- to allocate dynamic memory (from the heap), must explicitly call `malloc`
- `malloc` returns a `(void*)`
- must cast to the appropriate pointer type
- when done, must explicitly deallocate memory using `free`

```
#include <stdio.h>
#include <stdlib.h>

void getNums(int[], int);
int smallest(int[], int);

int main() {
    int* numbers;
    int count = 0;

    printf("How many numbers? ");
    scanf("%d", &count);
    numbers = (int *)malloc(count * sizeof(int));

    getNums(numbers, count);
    printf("The smallest number is %d\n",
           smallest(numbers, count));

    free(numbers);

    return 0;
}

void getNums(int nums[], int cnt) {
    int i;
    printf("Enter the numbers: ");
    for (i = 0; i < cnt; i++) {
        scanf("%d", &nums[i]);
    }
}

int smallest(int nums[], int cnt) {
    int i, small = nums[0];
    for (i = 1; i < cnt; i++) {
        if (nums[i] < small) {
            small = nums[i];
        }
    }
    return small;
}
```

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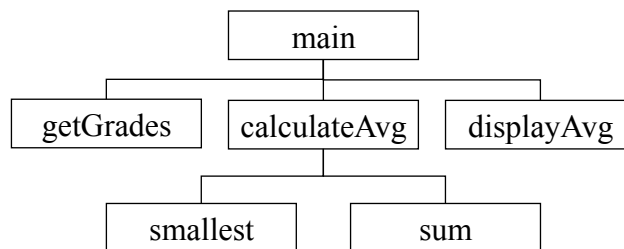
Top-down design

the dominant approach to program design in the 70's was top-down design

- also known as *iterative refinement*

general idea:

- focus on the sequence of tasks that must be performed to solve the problem
- design a function for each task
- if the task is too complex to be implemented as a single function, break it into subtasks and repeat as necessary



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C++ design

C++ was developed by Bjarne Stroustrup at Bell Labs in 1984

- C++ is a superset of C, with language features added to support OOP

design goals:

1. support object-oriented programming (i.e., classes & inheritance)
2. retain the high performance of C
3. provide a smooth transition into OOP for procedural programmers

backward compatibility with C was key to the initial success of C++

- could continue to use existing C code; learn and add new features incrementally

however, backward compatibility had far-reaching ramifications

- C++ did add many features to improve reliability & support OOP
- but, couldn't remove undesirable features
 - it is a large, complex, and sometimes redundant language

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Added reliability features: pass by-reference

in C, all parameter passing was by-value

```
void reset(int num) {           |           int x = 9;
    num = 0;                   |           reset(x);
}                               |           printf("x = %d", x);
```

- but, could get the effect of by-reference via pointers

```
void reset(int* num) {         |           int x = 9;
    *num = 0;                  |           reset(&x);
}                               |           printf("x = %d", x);
```

C++ introduced cleaner by-reference passing (in addition to default by-value)

```
void reset(int & num) {        |           int x = 9;
    num = 0;                   |           reset(x);
}                               |           cout << "x = " << x;
```

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Added reliability features: constants

in C, constants had to be defined as preprocessor directives

- weakened type checking, made debugging more difficult

```
#define MAX_SIZE 100
```

C++ introduced the `const` keyword

- can be applied to constant variables (similar to `final` in Java)
the compiler will catch any attempt to reassign

```
const int MAX_SIZE = 100;
```

- can also be applied to by-reference parameters to ensure no changes
safe since `const`; efficient since by-reference

```
void process(const ReallyBigObject & obj) {
    . . .
}
```

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Other reliability features

in C, there was no boolean type – had to rely on user-defined constants

- C++ `bool` type still implemented as an int, but provided some level of abstraction

```
#define FALSE 0
#define TRUE 1

bool flag = true;

int flag = TRUE;
```

in C, there was no string type – had to use char arrays & library functions

- C++ `string` type encapsulated basic operations inside a class

```
char* word = "foo";
printf("%d", strlen(word));

string word = "foo";
cout << word.length();
```

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Other reliability features

in C, memory was allocated & deallocated using low-level system calls

- C++ introduced typesafe operators for allocating & deallocating memory

```
int* a = (int*)malloc(20*sizeof(int));
...
free(a);

int* a = new int[20];
...
delete[] a;
```

in C, all variable declarations had to be at the beginning of a block

- C++ declarations can appear anywhere, can combine with initialization

```
if (inputOK) {
    int num1, num2;
    displayInstructions();
    num1 = getValue();
    num2 = getValue();
    ...
}

if (inputOK) {
    displayInstructions();
    int num1 = getValue();
    int num2 = getValue();
    ...
}
```

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ADT's in C++

in order to allow for new *abstract data types*, a language must provide:

1. encapsulation of data + operations (to cleanly localize modifications)
2. information hiding (to hide internal details, lead to implementation-independence)

Simula 67 was first language to provide direct support for data abstraction

- class definition encapsulated data and operations; but no information hiding

C++ classes are based on Simula 67 classes, extend C struct types

- data known as *fields*, operations known as *member functions*
- each instance of a C++ class gets its own set of fields (unless declared `static`)
- all instances share a single set of member functions

data fields/member functions can be:

- *public* visible to all
- *private* invisible (except to class instances)
- *protected* invisible (except to class instances & derived class instances)

can override protections by declaring a class/function to be a *friend*

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C++ classes

C++ classes followed the structure of structs (i.e., records)

- for backward compatibility, structs remained
- but only difference: in a struct, fields/functions are `public` by default
in a class, fields/functions are `private` by default

```
struct Point {  
    int x;  
    int y;  
};  
  
struct Point pt;  
pt.x = 3;  
pt.y = 4;
```

```
class Point {  
public:  
    Point(int xCoord, int yCoord) {  
        x = xCoord; y = yCoord;  
    }  
  
    int getX() const { return x; }  
  
    int getY() const { return y; }  
  
private:  
    int x;  
    int y;  
};  
  
Point pt(3, 4);
```

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Memory management

as in C, local variables in C++ are bound to memory stack-dynamically

- allocated when declaration is reached, stored on the stack
- this includes instances of classes as well as primitives

can use `new` & `delete` to create heap-dynamic memory

- requires diligence on the part of the programmer
- must explicitly delete any heap-dynamic memory, or else garbage references persist (there is no automatic garbage collection)
- in order to copy a class instance with heap-dynamic fields, must define a special copy constructor
- in order to reclaim heap-dynamic fields, must define a special destructor

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Example: card game

can separate class definition into 2 files

- allows for separate (smart) compilation

```
// Card.h
////////////////////////////////////
#ifndef _CARD_H
#define _CARD_H

using namespace std;

const string SUITS = "SHDC";
const string RANKS = "23456789TJQKA";

class Card {
public:
    Card(char r = '?', char s = '?');
    char GetSuit() const;
    char GetRank() const;
    int GetValue() const;
private:
    char rank;
    char suit;
};
#endif
```

```
// Card.cpp
////////////////////////////////////
#include <iostream>
#include <string>
#include "Card.h"
using namespace std;

Card::Card(char r, char s) {
    rank = r;
    suit = s;
}

char Card::GetRank() const {
    return rank;
}

char Card::GetSuit() const {
    return suit;
}

int Card::GetValue() const {
    for (int i = 0; i < RANKS.length(); i++) {
        if (rank == RANKS.at(i)) {
            return i+2;
        }
    }
    return -1;
}
```

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Example (cont.)

classes/functions can be templated

- idea later adopted by Java generics
- here, vector class is similar to Java ArrayList

```
// DeckOfCards.h
////////////////////////////////////

#ifndef _DECKOFCARDS_H
#define _DECKOFCARDS_H

#include <vector>
#include "Card.h"
using namespace std;

class DeckOfCards {
public:
    DeckOfCards();
    void Shuffle();
    Card DrawFromTop();
    bool IsEmpty() const;
private:
    vector<Card> cards;
};

#endif
```

```
// DeckOfCards.cpp
////////////////////////////////////

#include <string>
#include "Die.h"
#include "Card.h"
#include "DeckOfCards.h"
using namespace std;

DeckOfCards::DeckOfCards() {
    for (int suitNum = 0; suitNum < SUITS.length(); suitNum++) {
        for (int rankNum = 0; rankNum < RANKS.length(); rankNum++) {
            Card card(RANKS.at(rankNum), SUITS.at(suitNum));
            cards.push_back(card);
        }
    }
}

void DeckOfCards::Shuffle() {
    Die shuffleDie(cards.size());

    for (int i = 0; i < cards.size(); i++) {
        int randPos = shuffleDie.Roll()-1;
        Card temp = cards[i];
        cards[i] = cards[randPos];
        cards[randPos] = temp;
    }
}

Card DeckOfCards::DrawFromTop() {
    Card top = cards.back();
    cards.pop_back();
    return top;
}

bool DeckOfCards::IsEmpty() const {
    return (cards.size() == 0);
}
```

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Example (cont.)

following the convention from C:

main is a stand-alone function, automatically called if present in the file

```
#include <iostream>
#include <string>
#include "Card.h"
#include "DeckOfCards.h"
using namespace std;

int main() {
    DeckOfCards deck1, deck2;

    deck1.Shuffle();
    deck2.Shuffle();

    int player1 = 0, player2 = 0;
    while (!deck1.IsEmpty()) {
        Card card1 = deck1.DrawFromTop();
        Card card2 = deck2.DrawFromTop();

        cout << card1.GetRank() << card1.GetSuit() << " vs. "
              << card2.GetRank() << card2.GetSuit();

        if (card1.GetValue() > card2.GetValue()) {
            cout << ": Player 1 wins" << endl;
            player1++;
        }
        else if (card2.GetValue() > card1.GetValue()) {
            cout << ": Player 2 wins" << endl;
            player2++;
        }
        else {
            cout << ": Nobody wins" << endl;
        }
    }
    cout << endl << "Player 1: " << player1
          << " Player2: " << player2 << endl;

    return 0;
}
```

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Object-based programming

object-based programming (OBP):

- solve problems by modeling real-world objects (using ADTs)
- a program is a collection of interacting objects

when designing a program, first focus on the data objects involved, understand and model their interactions

advantages:

- natural approach
- modular, good for reuse
 - usually, functionality changes more often than the objects involved

OBP languages: must provide support for ADTs

e.g., C++, Java, JavaScript, Visual Basic, Object Pascal

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Object-oriented programming

OOP extends OBP by providing for inheritance

- can derive new classes from existing classes
- derived classes inherit data & operations from parent class, can add additional data & operations

advantage: easier to reuse classes,
don't even need access to source for parent class

pure OOP languages: all computation is based on message passing (method calls)

e.g., Smalltalk, Eiffel, Java

hybrid OOP languages: provide for interacting objects, but also stand-alone functions

e.g., C++, JavaScript

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C++ example: Person class

```
class Person {
public:
    Person(string nm, string id, char sex, int yrs) {
        name = nm; ssn = id; gender = sex; age = yrs;
    }

    void Birthday() {
        age++;
    }

    void Display() {
        cout << "Name: " << name << endl << "SSN : " << ssn << endl
            << "Gender: " << gender << endl << "Age: " << age << endl;
    }

private:
    string name, ssn;
    char gender;
    int age;
};
```

data: name
social security number
gender
age
...

operations: create a person
have a birthday
display person info
...

```
Person somePerson("Bjarne", "123-45-6789", 'M', 19);
somePerson.Birthday();
somePerson.Display();
```

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Student class: extending Person

```
class Student : public Person {
public:
    Student(string nm, string id, char sex, int yrs,
            string sch, int lvl) : Person(nm, id, sex, yrs) {
        school = sch; grade = lvl;
    }

    void Advance() {
        grade++;
    }

    void Display() {
        Person::Display();
        cout << "School: " << school << endl
            << "Grade: " << grade << endl;
    }

private:
    string school;
    int grade;
};
```

specifies that Student is derived from Person, public fields stay public

Student constructor initializes its own data fields, but must call the Person constructor to initialize inherited data

can override a function from the parent class, but still access using the scope resolution operator ::

Note: only new data fields and member functions are listed, all data/functions from Person are automatically inherited

```
Student someStudent("Bjarne", "123-45-6789", 'M', 19, "Creighton", 13);
someStudent.Birthday();
someStudent.Advance();
```

note: private data fields are hidden even from derived classes (e.g., name cannot be accessed in Person)

- can access if defined to be protected instead

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IS_A relationship

important relationship that makes inheritance work:

- an instance of a derived class is considered to be an instance of the parent class

```
a Student IS_A Person
an ifstream IS_A istream IS_A iostream
```

- thus, a pointer to a parent object can point to a derived object

```
Person * ptr =
    new Student("Terry", "222-22-2222", 'M', 20, "Creighton", 14);
```

- since by-reference parameters are really just pointers to objects, this means you can write generic functions that work for a family of objects

```
void Foo(Person & p) {           // can call with a Person or Student
    . . .
    p.Birthday();               // calls Person::Birthday on either
    . . .
}
```

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IS_A relationship & dynamic binding

BUT... for the IS_A relationship to work in general, member functions must be bound *dynamically*

- if the parent & derived classes both have member functions with the same name, how can the function know which type of object until it is passed in?

```
void Foo(Person & p)
{
    . . .
    p.Birthday();           // calls Person::Birthday
    . . .
    p.Display();           // calls ???
}

-----

Foo(somePerson);           // would like for Foo to call Person::Display
Foo(someStudent);         // would like for Foo to call Student::Display
```

UNFORTUNATELY... *by default* C++ binds member functions statically

- compiler looks at the parameter type in the function, `Person`, and decides that `p.Display()` must be calling `Person::Display`

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Dynamic binding & virtual

to specify dynamic binding, individual member functions in the parent class must be declared "virtual"

```
class Person
{
public:
    . . .

    virtual void Display() {
        cout << "Name: " << name << endl << "SSN : << ssn << endl
            << "Gender: " << gender << endl << "Age: " << age << endl;
    }

private:
    . . .
};

Foo(somePerson);          // calls Person::Display in Foo

Foo(someStudent);        // calls Student::Display in Foo
```

Serious drawback: when you design/implement a class, have to plan for inheritance

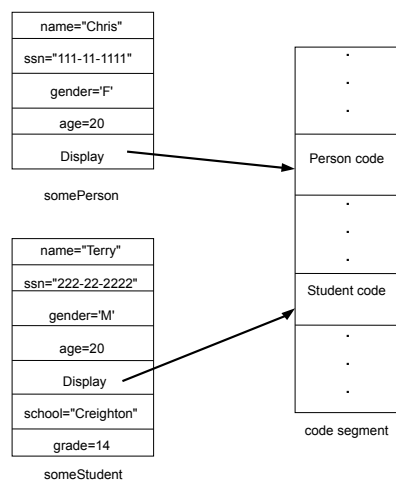
note: Java performs dynamic binding automatically

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Implementing virtual member functions

with static binding, the address of the corresponding code is substituted for the call

with dynamic binding, an extra pointer field must be allocated within the object



the pointer stores the address of the corresponding code for that class

when a virtual member function is called, the corresponding pointer in that object is dereferenced to find the correct version of the code

Note: each call to a virtual function implies one level of indirection

→ static binding more efficient

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Java

Java was developed at Sun Microsystems, 1995

- originally designed for small, embedded systems in electronic appliances
- initial attempts used C++, but frustration at limitations/pitfalls

recall: C++ = C + OOP features

the desire for backward compatibility led to the retention of many bad features

desired features (from the Java white paper):

simple	object-oriented	network-savvy
interpreted	robust	secure
architecture-neutral	portable	high-performance
multi-threaded	dynamic	

note: these are desirable features for any modern language (+ FREE)

→ Java has become very popular, especially when Internet related

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Language features

simple

- syntax is based on C++ (familiarity → easier transition for programmers)
- removed many rarely-used, confusing features
e.g., explicit pointers, operator overloading, multiple inheritance, automatic coercions
- added memory management (garbage collection)

object-oriented

- OOP facilities similar C++, but all member functions (methods) dynamically bound
- pure OOP – everything is a class, no independent functions*

network-savvy

- extensive libraries for coping with TCP/IP protocols like HTTP & FTP
- Java applications can access remote URL's the same as local files

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Language features (cont.)

robust

- for embedded systems, reliability is essential
- Java combines extensive static checking with dynamic checking
 - closes C-style syntax loopholes
 - compile-time checking more effective
 - even so, the linker understands the type system & repeats many checks
- Java disallows pointers as memory accessors
 - arrays & strings are ADTs, no direct memory access
 - eliminates many headaches, potential problems

secure

- in a networked/distributed environment, security is essential
- execution model enables virus-free*, tamper-free* systems
 - downloaded applets cannot open, read, or write local files
- uses authentication techniques based on public-key encryption

note: the lack of pointers closes many security loopholes by itself

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Language features (cont.)

architecture-neutral

- want to be able to run Java code on multiple platforms
- neutrality is achieved by mixing compilation & interpretation
 1. Java programs are translated into *byte code* by a Java compiler
 - byte code is a generic machine code
 2. byte code is then executed by an interpreter (Java Virtual Machine)
 - must have a byte code interpreter for each hardware platform
 - byte code will run on any version of the Java Virtual Machine
- alternative execution model:
 - can define and compile applets (little applications)
 - not stand-alone, downloaded & executed by a Web browser

portable

- architecture neutral + no implementation dependent features
 - size of primitive data types are set
 - libraries define portable interfaces

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Language features (cont.)

interpreted

- interpreted → faster code-test-debug cycle
- on-demand linking (if class/library is not needed, won't be linked)

does interpreted mean slow?

high-performance

- faster than traditional interpretation since byte code is "close" to native code
- still somewhat slower than a compiled language (e.g., C++)

multi-threaded

- a *thread* is like a separate program, executing concurrently
- can write Java programs that deal with many tasks at once by defining multiple threads (same shared memory, but semi-independent execution)
- threads are important for multi-media, Web applications

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Language features (cont.)

dynamic

- Java was designed to adapt to an evolving environment

e.g., the fragile class problem

in C++, if you modify a parent class, you must recompile all derived classes

in Java, memory layout decisions are NOT made by the compiler

- instead of compiling references down to actual addresses, the Java compiler passes symbolic reference info to the *byte code verifier* and the *interpreter*
- the Java interpreter performs name resolution when classes are being linked, then rewrites as an address
- thus, the data/methods of the parent class are not determined until the linker loads the parent class code
- if the parent class has been recompiled, the linker automatically gets the updated version

Note: the extra name resolution step is price for handling the fragile class problem

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ADTs in Java

recall: Java classes look very similar to C++ classes

- member functions known as *methods*
- each field/method has its own visibility specifier
- must be defined in one file, can't split into header/implementation
- javadoc facility allows automatic generation of documentation
- extensive library of data structures and algorithms
 - List: ArrayList, LinkedList
 - Set: HashSet, TreeSet
 - Map: HashMap, TreeMap
 - Queue, Stack, ...
- load libraries using `import`

```
public class Person {
    private String name;
    private String SSN;
    private char gender;
    private int age;

    public Person(string name, string SSN,
                  char gender, int age) {
        this.name = name;
        this.SSN = SSN;
        this.gender = gender;
        this.age = age;
    }

    public void birthday() {
        this.age++;
    }

    public String toString() {
        return "Name: " + this.name +
            "\nSSN : " + this.SSN +
            "\nGender: " + this.gender +
            "\nAge: " + this.age;
    }
}
```

recall: objects are heap-dynamic

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Inheritance in Java

achieve inheritance by "extending" a class

- can add new methods or override existing methods
- can even remove methods (but generally not considered good design – **WHY?**)

```
public class Student extends Person {
    private String school;
    private int level;

    public Student(String name, String SSN, char gender,
                  int age, String school, int level) {
        super(name, SSN, gender, age);
        this.school = school;
        this.level = level;
    }

    void advance() {
        this.level++;
    }

    public String toString() {
        return super.toString() +
            "\nSchool: " + this.school +
            "\nLevel: " + this.level;
    }
}
```

recall: Java uses "super" to call a constructor or method from the parent class

here, call the super constructor to initialize the private fields

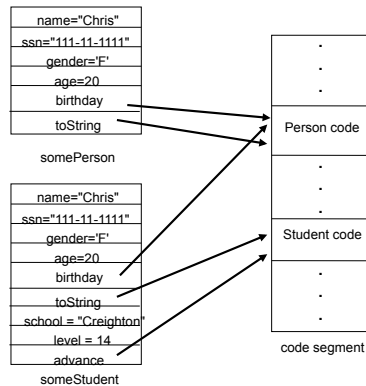
also, call the super.toString to print the private fields

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Dynamic (late) binding

in Java, all method calls are bound dynamically

- this was not the default in C++, required declaring methods to be "virtual"
- the implementation of dynamic binding is the same as in C++



since dynamic binding is used, each method call will refer to the most specific version

```
public void foo(Person p) {  
    . . .  
    p.birthday();  
    . . .  
    System.out.println(p);  
    . . .  
}
```

i.e., `foo(somePerson)` will call the `Person` version, while `foo(someStudent)` will call the `Student` version

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Abstract classes

there are times when you want to define a class hierarchy, but the parent class is incomplete (more of a placeholder)

- e.g., the `Statement` class from HW3
- want to be able to talk about a hierarchy of statements (including `Assignment`, `Output`, `If`), but there is no "Statement"

an *abstract class* is a class in which some methods are specified but not implemented

- can provide some concrete fields & methods
- the keyword "abstract" identifies methods that must be implemented by a derived class
- you can't create an object of an abstract class, but it does provide a framework for inheritance

note: you can define abstract classes in C++, but in a very kludgy way

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Statement class

```
public abstract class Statement {  
  
    public abstract void execute(VariableTable variables);  
    public abstract Statement.Type getType();  
    public abstract String toString();  
  
    public static enum Type {  
        OUTPUT, ASSIGNMENT, IF, QUIT  
    }  
  
    public static Statement getStatement(TokenStream input) throws Exception {  
        Token nextToken = input.lookAhead();  
  
        if (nextToken.toString().equals("output")) {  
            return new Output(input);  
        }  
        else if (nextToken.toString().equals("quit")) {  
            return new Quit(input);  
        }  
        else if (nextToken.toString().equals("if")) {  
            return new If(input);  
        }  
        else if (nextToken.getType() == Token.Type.IDENTIFIER) {  
            return new Assignment(input);  
        }  
        else {  
            throw new Exception("SYNTAX ERROR: Unknown statement type");  
        }  
    }  
}
```

Statement class provides framework for derived classes

- static enum `Type` and `getStatement` method are provided as part of the abstract class
- the other methods **MUST** be implemented exactly in a derived class

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Derived statement classes

derived classes define specific statements (assignment, output, if)

- each will have its own private data fields
- each will implement the methods appropriately
- as each new statement class is added, must update the `Type` enum and the `getStatement` code

```
public class Assignment extends Statement {  
    private Token t;   
    private Expression expr;  
  
    public void execute(VariableTable variables) { ... }  
    public Statement.Type getType() { ... }  
    public String toString() { ... }  
}
```

```
public class Output extends Statement {  
    private Expression expr;  
  
    public void execute(VariableTable variables) { ... }  
    public Statement.Type getType() { ... }  
    public String toString() { ... }  
}
```

```
public class If extends Statement {  
    private Expression expr;  
    private ArrayList<Statement> stmts;  
  
    public void execute(VariableTable variables) { ... }  
    public Statement.Type getType() { ... }  
    public String toString() { ... }  
}
```

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Interfaces

an abstract class combines concrete fields/methods with abstract methods

- it is possible to have no fields or methods implemented, only abstract methods
- in fact this is a useful device for software engineering
define the behavior of an object without constraining implementation

Java provides a special notation for this useful device: an *interface*

- an interface simply defines the methods that must be implemented by a class
- a derived class is said to "implement" the interface if it meets those specs

```
public interface List<E> {  
    boolean add(E obj);  
    void add(index i, E obj);  
    void clear();  
    boolean contains (E obj);  
    E get(index i);  
    int indexOf(E obj);  
    E set(index i, E obj);  
    int size();  
    . . .  
}
```

an interface is equivalent to an abstract class with only abstract methods

note: can't specify any fields, nor any private methods

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List interface

interfaces are useful for grouping generic classes

- can have more than one implementation, with different characteristics

```
public class ArrayList<T> implements List<T> {  
    private T[] items;  
    . . .  
}  
  
public class LinkedList<T> implements List<T> {  
    private T front;  
    private T back;  
    . . .  
}
```

- using the interface, can write generic code that works on any implementation

```
public numOccur(List<String> words, String desired) {  
    int count = 0;  
    for (int i = 0; i < words.size(); i++) {  
        if (desired.equals(words.get(i))) {  
            count++;  
        }  
    }  
}
```

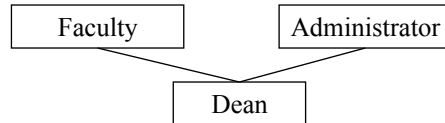
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Multiple interfaces

in Java, a class can implement more than one interface

e.g., `ArrayList<E>` implements `List<E>`, `Collection<E>`, `Iterable<E>`, ...

but can extend *at most* one parent class - **WHY?**



suppose a Dean class is defined that implements two interfaces

- the Dean class must implement the union of the listed methods – OK!

but if inheritance were used, conflicts could occur

- what if both parent classes had fields or methods with the same names?
- e.g., would `super.getRaise()` call the `Faculty` or the `Adminstrator` version?

C++ allows for multiple inheritance but user must disambiguate using `::`

- Java simply disallows it as being too tricky & not worth it

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Non-OO programming in Java

despite its claims as a pure OOP language, you can write non-OO code same as C++

- static methods can call other static methods

for large projects, good OO design leads to more reliable & more easily maintainable code

```
/**
 * Simple program that prints a table of temperatures
 *
 * @author    Dave Reed
 * @version   3/5/08
 */
public class FahrToCelsius {
    private static double FahrToCelsius(double temp) {
        return 5.0*(temp-32.0)/9.0;
    }

    public static void main(String[] args) {
        double lower = 0.0, upper = 100.0, step = 5.0;

        System.out.println("Fahr\t\tCelsius");
        System.out.println("----\t\t-----");

        for (double fahr = lower; fahr <= upper; fahr += step) {
            double celsius = FahrToCelsius(fahr);
            System.out.println(fahr + "\t\t" + celsius);
        }
    }
}
```

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Java vs. JavaScript

recall: Java took many features from C++, but removed/added features due to different design goals

- e.g., platform independence → interpreted+compiled execution model
- ease of development over efficiency → dynamic binding, garbage collection
- simplicity over expressivity → no goto, no implicit coercions, no operator overload
- security → no pointer access, byte code verifier

interesting to consider another variant: JavaScript

- designed to be a scripting language for execution in and enhancements of a Web browser
- developed at Netscape in 1995, integrated into Navigator
 - close variant added to IE under the name JScript
 - the core of both languages were standardized as ECMAScript
- as with Java, chose to keep basic syntax of C++ to aid learning
- different design goals yield different features

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JavaScript design

intended to be a scripting language for Web pages

- JavaScript code is embedded directly into HTML, interpreted by browser
- a.k.a., client-side scripting

scripting applications are more quick-and-dirty, relatively small

- variables are bound to type and address dynamically for flexibility
- do not need to declare variables, functions are not typed either
- code size is limited by the browser

not expected to develop large applications

- object-based: lots of useful classes predefined (Array, String, Math, ...)
- can define new classes but awkward, no info hiding

user security is important, script code security isn't

- like Java, JavaScript code can't access local files
- no way to hide the JavaScript source when download Web page

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JavaScript example

code is embedded in SCRIPT tags or within HTML event-handler attributes

- can declare local variables using var
- can access HTML elements such as text boxes & areas

```
<!doctype html>
<html>
  <head>
    <title> Substitution Cipher</title>
    <script type="text/javascript">
      function Encode() {
        var message = document.getElementById('messageArea').value;
        var key = document.getElementById('keyBox').value;
        var alphabet = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ';
        var coded = '';
        for (var i = 0; i < message.length; i++) {
          var ch = message.charAt(i);
          var index = alphabet.indexOf(ch);
          if (index == -1) {
            coded = coded + ch;
          }
          else {
            coded = coded + key.charAt(index);
          }
        }
        document.getElementById('outputDiv').innerHTML = coded;
      }
    </script>
  </head>
  <body>
    <h2>Substitution Cipher</h2>
    <p> Key: <input type="text" id="keyBox" size=26
      style="font-family:Courier,monospace"
      value="ZYXWVUTSRQPONMLKJIHGFEDCBA"> </p>
    <p> Enter your message below: <br>
    <textarea id="messageArea" rows=8 cols=30></textarea> <br>
    <input type="button" value="Encode the Message"
      onclick="Encode();" > </p>
    <hr> <div id="outputDiv"></div>
  </body>
</html>
```

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