

CS100

Introduction to Programming

Lecture 12. C summary & Object-Oriented Programming

Review on what we have learned

- **Variables**

- A name given to a continuous range of memory
- Data type
 - How many memory cells are reserved
 - In what format the data are represented and stored
 - The operations that can be performed on it

char:	1 byte
int:	4 bytes
long:	8 bytes
float:	4 bytes
double:	8 bytes

Review on what we have learned

- **Pointers**

- Variables which store the **addresses** of memory locations of some data objects
- Pointer type
 - How to increment/decrement the pointer address
 - How to retrieve the data value pointed by the pointer

<code>int *ptrI;</code>	<code>/* Variable ptrI is a pointer. It stores the address of a memory location for an integer */</code>
<code>float *ptrF;</code>	<code>/* Variable ptrF is a pointer. It stores the address of a memory location for a float */</code>
<code>char *ptrC;</code>	<code>/* Variable ptrC is a pointer. It stores the address of a memory location for a char */</code>

Review on what we have learned

- **Structures**

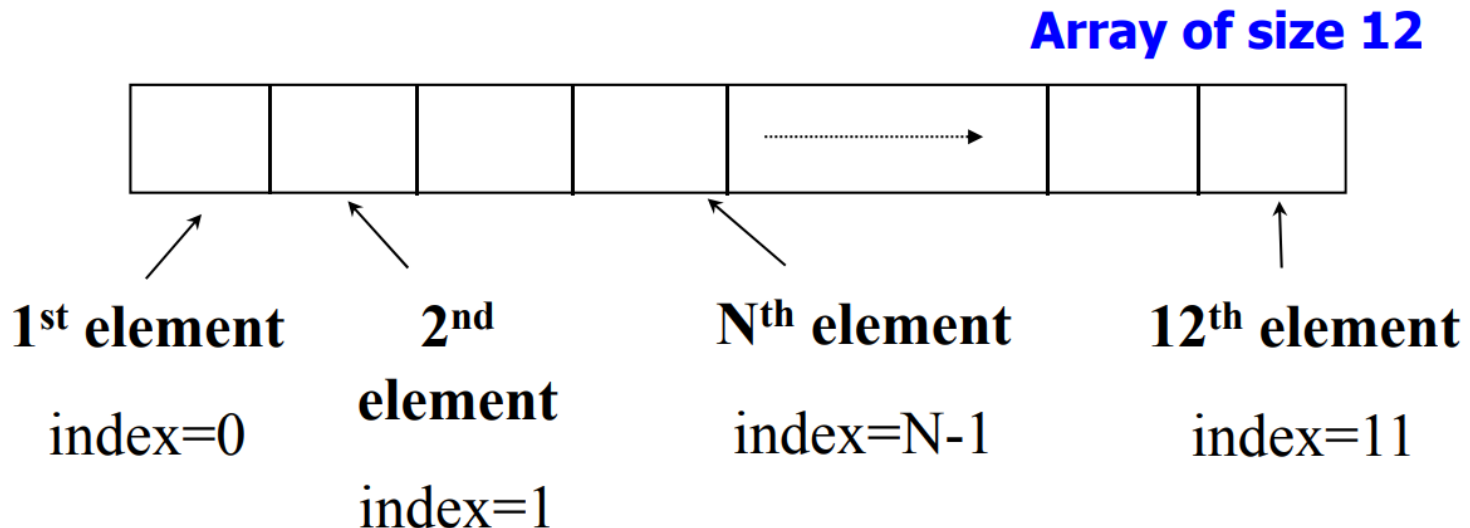
- An aggregate of values
- Can contain members with different types

```
typedef struct
{
    int shipClass;
    char *name;
    int speed, crew;
} warShip;
```

- Structure can allow the lowest level of data abstraction

Review on what we have learned

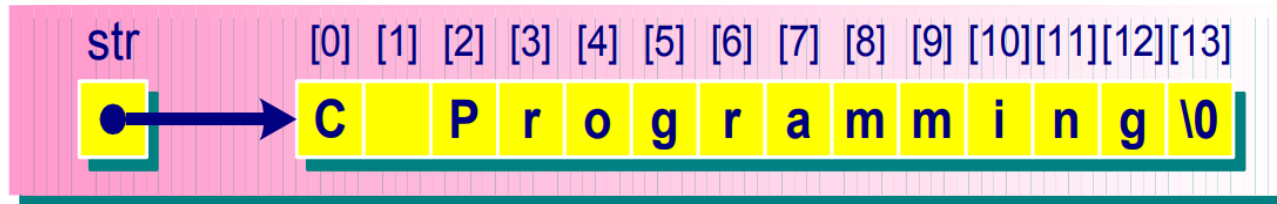
- **Array**
 - A continuous range of data values in memory
 - Zero-based index in C
 - Static v.s. dynamic array



Review on what we have learned

- **Strings**

- An array of characters ended by '\0'
- Static v.s. dynamic strings



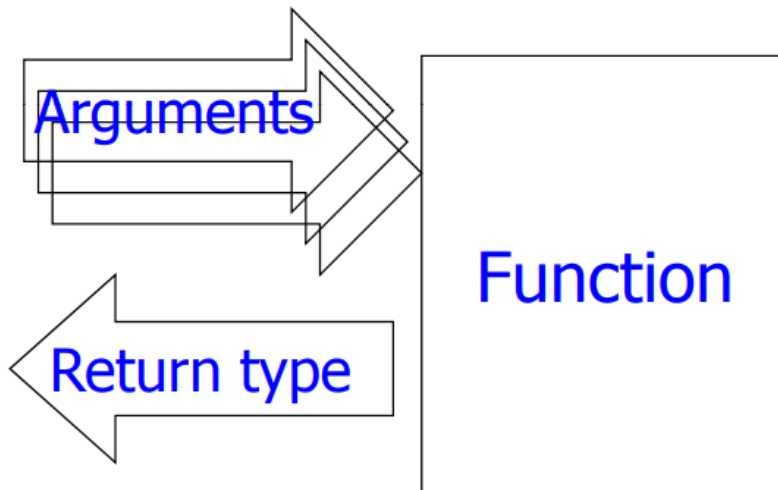
- String operations
 - length/concatenation/comparison...

Review on what we have learned

- **Functions**

- A function is a self-contained unit of code to carry out a specific task

- Input argument list
 - Return value



```
float findMaximum
    (float x, float y)
{
    // variable declaration
    float maxnum;

    // find the max number
    if (x >= y)
        maxnum = x;
    else
        maxnum = y;

    return maxnum;
}
```

Review on what we have learned

- **Passing arguments to a function**

- Call by value

- The arguments of a function have a local copy of variable value

```
int num1 = 5, num2=10;  
int r=add(num1, num2); //int add(int, int);
```

- Call by pointer

- The arguments of a function have a local copy of pointer variable value (the address)

```
int num1 = 5, num2=10;  
int r=add(&num1, &num2); //int add(int*, int*);
```

- Call by reference

- The arguments of a function do not have a local copy; only another name of the same memory

```
int num1 = 5, num2=10;  
int r=add(num1, num2); //int add(int&, int&);
```


Review on what we have learned

- **Memory copy**

- You can use loops to copy one by one
 - Not recommended unless necessary (slow)
- Use memory copy functions
 - `memcpy(...)/strcpy(...)`

```
float* data=(float*)malloc(sizeof(float)*100);  
...  
float* data_new[100];  
memcpy(data_new, data, sizeof(float)*100);
```

Practical Example 1: Vector

- **Recall what is a vector in linear algebra?**
 - A 1D arrangement (array) of variables/numbers

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

- There are several mathematical operations on vectors

Practical Example 1: Vector

- **Vector operations**

- Element-wise addition / subtraction / multiplication / division

$$\mathbf{x} = \begin{bmatrix} 1 \\ 2 \end{bmatrix}, \mathbf{y} = \begin{bmatrix} 3 \\ 4 \end{bmatrix}$$

$$\mathbf{x} + \mathbf{y} = \begin{bmatrix} 1 \\ 2 \end{bmatrix} + \begin{bmatrix} 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 1 + 3 \\ 2 + 4 \end{bmatrix} = \begin{bmatrix} 4 \\ 6 \end{bmatrix}$$

- Scaling

$$2\mathbf{x} = 2 \begin{bmatrix} 1 \\ 2 \end{bmatrix} = \begin{bmatrix} 2 * 1 \\ 2 * 2 \end{bmatrix} = \begin{bmatrix} 2 \\ 4 \end{bmatrix}$$

Practical Example 1: Vector

- **Vector operations**

- Norm

$$\|\mathbf{x}\| = \sqrt{\sum_{i=1}^n x_i^2} = \sqrt{x_1^2 + x_2^2 + x_3^2 + \dots + x_n^2}$$

- Dot product

$$\mathbf{x} \cdot \mathbf{y} = x_1 y_1 + x_2 y_2 + \dots + x_n y_n$$

Practical Example 1: Vector

- How to define a vector

```
struct VECTOR
{
    int dim;
    float* data;
};
```



Used for vector presentation

```
struct VECTOR_FILE_HEADER
{
    int dim;
    int data_element_size; //size in byte
};
```



Used for writing/reading vector data onto hard disk

Practical Example 1: Vector

- What functions are needed for a vector?

```
bool create_vector(int, VECTOR*);
```

```
void destroy_vector(VECTOR*);
```

```
bool vector_assign(VECTOR*, const VECTOR*);
```

```
int get_vector_dim(const VECTOR*);
```

```
float& get_vector_element(int, const VECTOR*);
```

```
void set_vector_element(int, float, VECTOR*);
```

```
float* get_vector_data(const VECTOR*);
```

Practical Example 1: Vector

- What functions are needed for a vector?

```
bool vector_add(VECTOR*, const VECTOR*);  
bool vector_sub(VECTOR*, const VECTOR*);  
bool vector_mul(VECTOR*, const VECTOR*);  
bool vector_div(VECTOR*, const VECTOR*);  
float vector_dot(const VECTOR*, const VECTOR*);  
  
float get_vector_norm(const VECTOR*);  
  
void print_vector(const VECTOR*);  
  
bool write_vector(const char*, const VECTOR*);  
bool read_vector(const char*, const VECTOR*);
```

Practical Example 1: Vector

- Create a vector dynamically

```
bool create_vector(int dim, VECTOR* p_vec_out)
{
    if (dim <= 0)
    {
        printf("invalid vector dimension!\n");
        return false;
    }

    if (p_vec_out != NULL)
    {
        p_vec_out->data = (float*)malloc(sizeof(float) * dim);
        if (p_vec_out->data != NULL)
        {
            memset(p_vec_out->data, 0, sizeof(float) * dim);
            p_vec_out->dim = dim;

            return true;
        }
        else
        {
            ...
        }
    }
}
```


Practical Example 1: Vector

- Create a vector dynamically

```
bool create_vector(int dim, VECTOR* p_vec_out)
{
    ...

    else
    {
        printf("unable to allocate vector data!\n");
        p_vec_out->dim = 0;

        return false;
    }
}
else
    return false;
}
```

Practical Example 1: Vector

- Destroy a vector

```
void destroy_vector(VECTOR* p_vec)
{
    if (p_vec != NULL)
    {
        if (p_vec->data != NULL)
            free(p_vec->data);
        p_vec->dim = 0;
    }
}
```

Practical Example 1: Vector

- Assign one vector to another

```
bool vector_assign(VECTOR* p_vec1, const VECTOR* p_vec2)
{
    if (p_vec1 != NULL && p_vec2 != NULL)
    {
        if (p_vec1->dim != p_vec2->dim)
        {
            if (p_vec1->data != NULL)
                free(p_vec1->data);
            p_vec1->data = (float*)malloc(sizeof(float) * p_vec2->dim);
            if (p_vec1->data == NULL)
                return false;
            memcpy(p_vec1->data, p_vec2->data, sizeof(float) * p_vec2->dim);
            p_vec1->dim = p_vec2->dim;
        }
        else
        {
            memcpy(p_vec1->data, p_vec2->data, sizeof(float) * p_vec2->dim);
        }
        return true;
    }
    else
        return false;
}
```

Practical Example 1: Vector

- Get relevant data in a vector

```
int get_vector_dim(const VECTOR* p_vec)
{
    return p_vec->dim;
}
```

```
float& get_vector_element(int i, const VECTOR* p_vec)
{
    return p_vec->data[i];
}
```

```
void set_vector_element(int i, float data_value, VECTOR* p_vec)
{
    p_vec->data[i] = data_value;
}
```

```
float* get_vector_data(const VECTOR* p_vec)
{
    return p_vec->data;
}
```

Practical Example 1: Vector

- Element-wise addition / subtraction / multiplication / division

```
bool vector_add(VECTOR* p_vec1, const VECTOR* p_vec2)
{
    if (p_vec1->dim != p_vec2->dim)
        return false;
    if (p_vec1->data == NULL || p_vec2->data == NULL)
        return false;

    for (int i = 0; i < p_vec1->dim; i++)
        p_vec1->data[i] += p_vec2->data[i];

    return true;
}
```

Practical Example 1: Vector

- Dot product between two vectors

```
float vector_dot(const VECTOR* p_vec1, const VECTOR* p_vec2)
{
    if (p_vec1->dim != p_vec2->dim)
        return false;
    if (p_vec1->data == NULL || p_vec2->data == NULL)
        return false;

    float dot_ret = 0;
    for (int i = 0; i < p_vec1->dim; i++)
        dot_ret += p_vec1->data[i] * p_vec2->data[i];

    return dot_ret;
}
```

Practical Example 1: Vector

- Print the vector onto the screen

```
void print_vector(const VECTOR* p_vec)
{
    for (int i = 0; i < get_vector_dim(p_vec) - 1; i++)
        printf("%f, ", get_vector_element(i, p_vec));
    printf("%f\n", get_vector_element
            (get_vector_dim(p_vec) - 1, p_vec));
}
```

Practical Example 1: Vector

- Write a vector to a file

```
bool write_vector(const char* path, const VECTOR* p_vec)
{
    FILE* p_file = fopen(path, "wb");
    if (p_file == NULL)
        return false;

    VECTOR_FILE_HEADER header;
    header.dim = p_vec->dim;
    header.data_element_size = sizeof(float);

    if (fwrite(&header, sizeof(VECTOR_FILE_HEADER), 1, p_file) != 1)
    {
        printf("writing vector header error!\n");
        return false;
    }
    ...
}
```


Practical Example 1: Vector

- Write a vector to a file

```
bool write_vector(const char* path, const VECTOR* p_vec)
{
    ...

    if (fwrite(get_vector_data(p_vec),
               header.data_element_size, header.dim, p_file) != header.dim)
    {
        printf("writing vector data error!\n");
        return false;
    }

    fclose(p_file);

    return true;
}
```

Practical Example 1: Vector

- Read a vector from a file

```
bool read_vector(const char* path, const VECTOR* p_vec)
{
    FILE* p_file = fopen(path, "rb");
    if (p_file == NULL)
        return false;

    VECTOR_FILE_HEADER header;
    memset(&header, 0, sizeof(VECTOR_FILE_HEADER));
    if (fread(&header, sizeof(VECTOR_FILE_HEADER), 1, p_file) != 1)
    {
        printf("reading vector header error!\n");
        return false;
    }

    if (fread(get_vector_data(p_vec), header.data_element_size, header.dim, p_file) != header.dim)
    {
        printf("reading vector data error!\n");
        return false;
    }

    fclose(p_file);

    return true;
}
```

Practical Example 1: Vector

- Use the vector functions for computation

...

```
printf("v1 dot v2 is: %f\n", vector_dot(&v1, &v2));
```

```
printf("saving vectors...\n");  
write_vector("D:\\v1.dat", &v1);  
write_vector("D:\\v2.dat", &v2);
```

```
destroy_vector(&v1);  
destroy_vector(&v2);
```

Can we do things better?

- **Procedural programming in C**
 - The programs are organized in terms of functions
 - Function design plays a central role
- **Problem for procedural programming**
 - The logic is not consistent to human thinking
 - Data abstraction is relatively poor
 - Code sharing is difficult

Encapsulation

- **Encapsulation in C**

- Look at structure again

```
struct Person
{
    char* name;
    int age;
    float height;
    float weight;
};
```

- What we lack for structure in C

- The related operations in a structure variable (object)

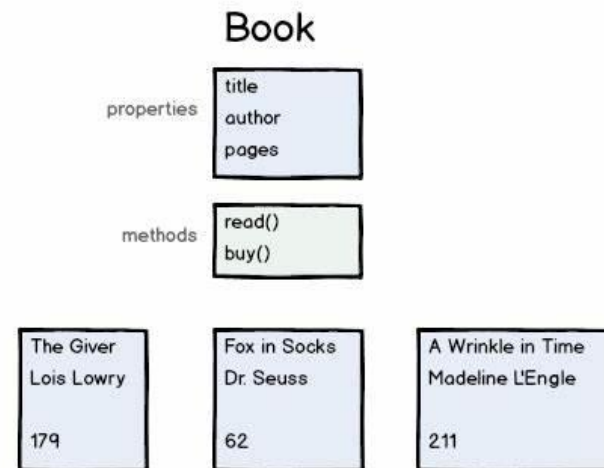
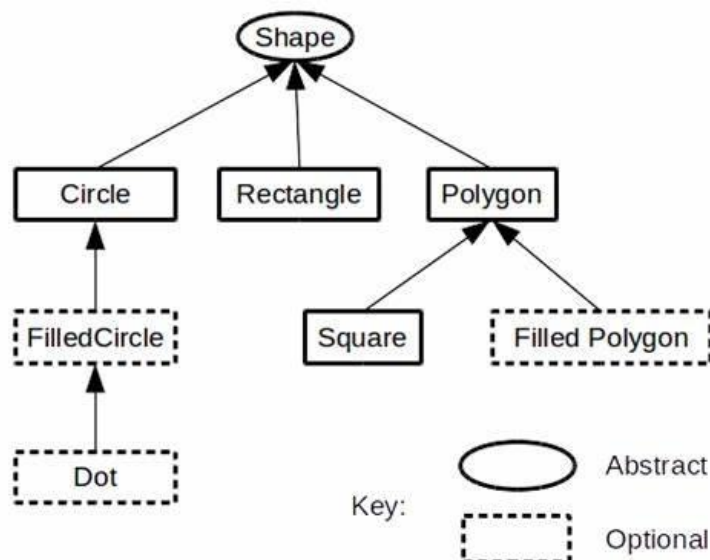
```
struct Person
{
    char* name;
    int age;
    float height;
    float weight;
    void increase_age_by(int age_increment = 1);
};
```

Object-Oriented Programming

- now that we start using C++, we can start taking advantage of ***object-oriented programming***
- adding OOP to C was one of the driving forces behind the creation of C++ as a language
 - C++'s predecessor was actually called “C with Classes”

Object-Oriented Programming

- **A programming language model**
 - programs are organized around objects
 - identify all of the objects to manipulate and how they relate to each other



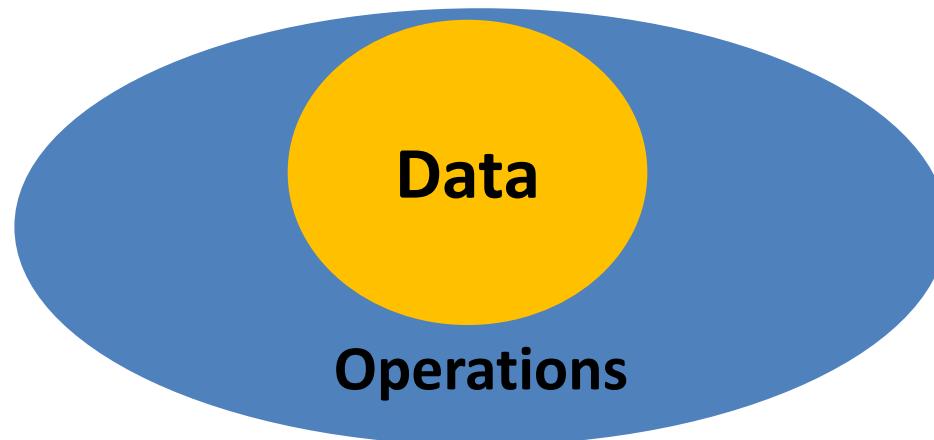
OOP: C++ Language

- **An object-oriented programming language**
 - A significant extension of C: $C + \text{OOP} = C++!$
 - Code C++ in a "C" with "object-oriented" style.
 - Invented by Bjarne Stroustrup
 - Classes and objects
 - Function overloading
 - Inheritance
 - Polymorphism
 - Templates



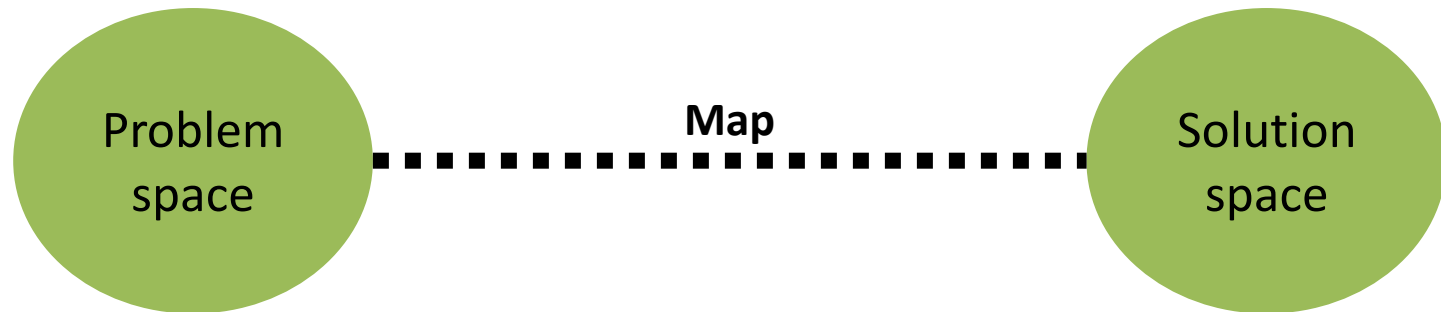
OOP: What is an object

- Object = Entity
- Object maybe visible or invisible
- Object is variable in programming language
- Objects = Attributes + Services
 - Data: the properties or status
 - Operations: the functions



Mapping

- From the problem space to the solution space



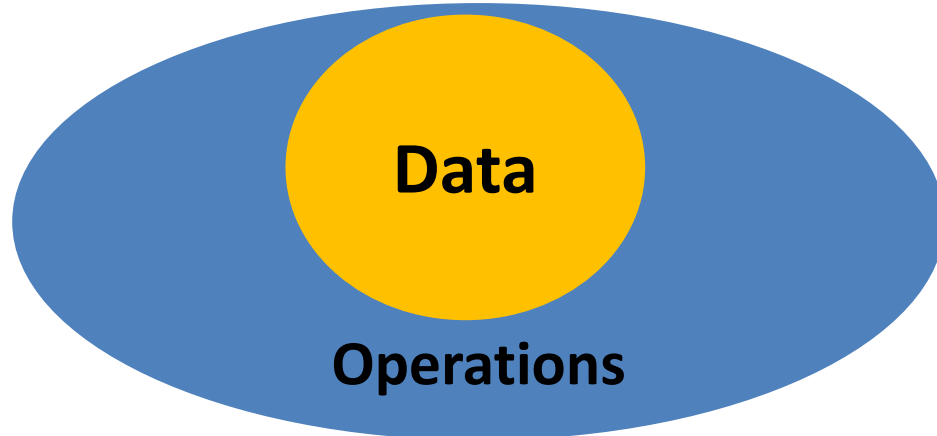
Procedural Languages in C

- C doesn't support relationship between data and functions

```
typedef struct point3d {  
    float x;  
    float y;  
    float z;  
} Point3d;  
  
void Point3d_print(const Point3d* pd);  
  
Point3d a;  
a.x = 1; a.y = 1; a.z = 3;  
Point3d_print(&a);
```

C++ version

```
class Point3d{  
public:  
    Point3d(float x, float y, float z);  
    print();  
private:  
    float x;  
    float y;  
    float z;  
};  
Point3d a(1, 2, 3);  
a.print();
```



C vs. C++

```
typedef struct point3d {  
    float x;  
    float y;  
    float z;  
} Point3d;  
  
void Point3d_print  
    (const Point3d* pd);  
  
Point3d a;  
a.x = 1;  
a.y = 1;  
a.z = 3;  
Point3d_print(&a);
```

```
class Point3d{  
public:  
    Point3d(float x, float y,  
            float z);  
  
    print();  
private:  
    float x;  
    float y;  
    float z;  
};  
  
Point3d a(1, 2, 3);  
a.print();
```

Procedural Programming

- In C, everything we've been doing has been *procedural programming*
- code is divided into multiple procedures
 - procedures operate on data (structures), when given correct number and type of arguments
 - program calls the procedures in sequence
- Example:
 - `printf(<character array>, <parameters>)`

Object-Oriented Programming

- in OOP, code and data are combined into a single entity called a ***class***
 - each ***instance*** of a given class is an ***object*** of that class type
- principles of Object-Oriented Programming
 - encapsulation
 - inheritance
 - polymorphism

OOP: Encapsulation

- *encapsulation* is a form of information hiding and abstraction
- data and functions that act on that data are grouped together (inside a class)
- *ideal*: separate the interface/implementation so that you can use the former without any knowledge of the latter

OOP: Inheritance

- ***inheritance*** allows us to create and define new classes from an existing class (i.e. sub-classes)
- this allows us to re-use code
 - faster implementation time
 - fewer errors
 - easier to maintain/update

OOP: Polymorphism

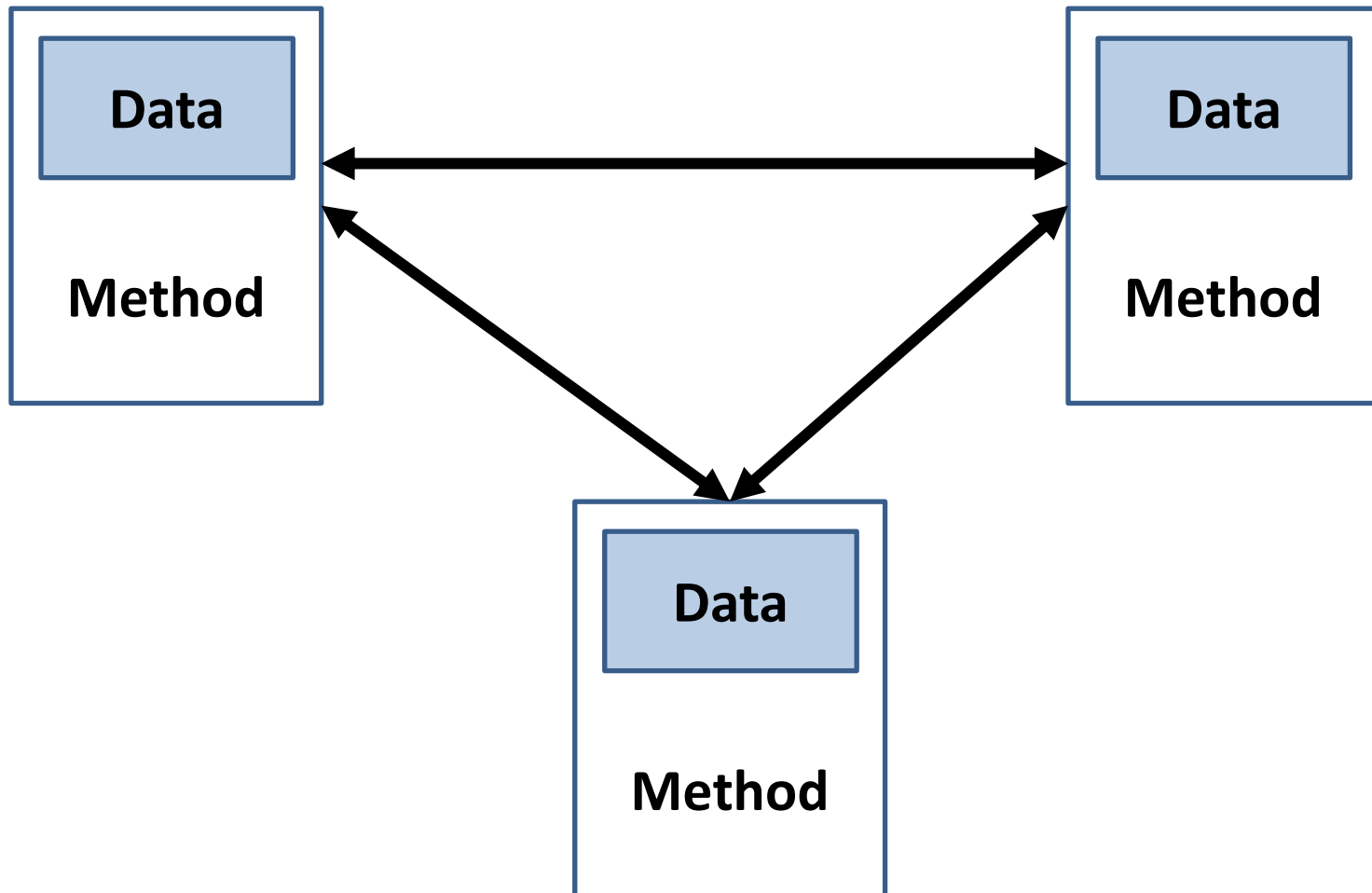
- *polymorphism* is when a single name can have multiple meanings
 - normally used in conjunction with inheritance
 - ability to decide at runtime what will be done
- We'll look at one form of polymorphism today:
 - overloading functions

OOP: What is an object-oriented

- A way to organize
 - Design
 - Implementation
- Objects, not control of data flow, are the primary focus of the design and implementation.
- To focus on things, not operations.

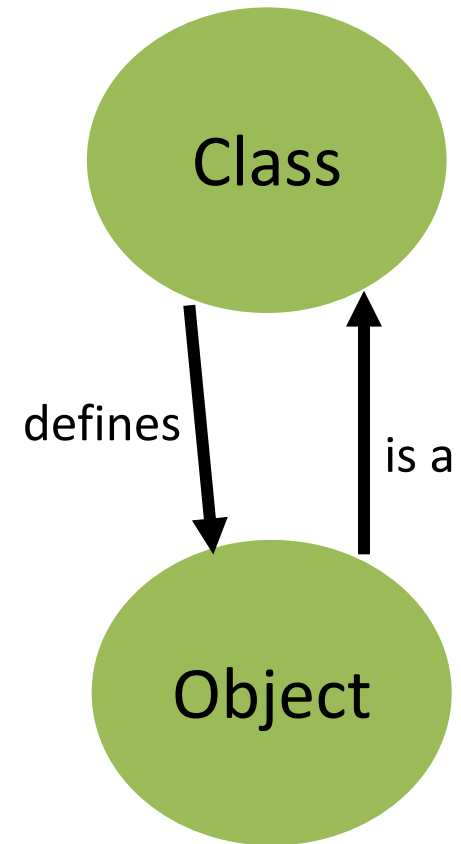
Object-Oriented Programming

- Objects send and receive messages (objects do things!)



Object vs. Class

- Objects (cat)
 - Represent things, events, concepts
 - Respond to messages at run-time
- Classes (cat class)
 - Define properties of instances
 - Act like types in C++



OOP: Characteristics

1. Everything is an object.
2. A program is a bunch of objects telling each other what to do by sending messages.
3. Each objects has its own memory made up by other objects.
4. Every object has a type.
5. All objects of a particular type can receive the same messages.

An objects has interfaces

- The interface is the way to receive messages
- It is defined in the class that the object belongs to
- Functions of the interfaces
 - Communication
 - Protection

The Hidden Implementation

- Inner part of an object, data members to present its state, and the actions it takes when messages is received are hidden
- Class creators vs. Client programmers
 - Keep client programmers' hands off portions they should not touch.
 - Allow the class creator to change the internal working of the class without worrying about how it will affect the client programmer.

OOP: Encapsulation

- *encapsulation* is a form of information hiding and abstraction
- Bundle data and methods dealing with these data together in an objects
- Hide the details of the data and the action
- Restrict only access to the publicized methods

Example: Ticket Machine

- Ticket machines print a ticket when a customer inserts the correct money for their fare.
- They work by customers `inserting' money into them, and then requesting a ticket to be printed. A machine keeps a running total of the amount of money it has collected throughout its operations

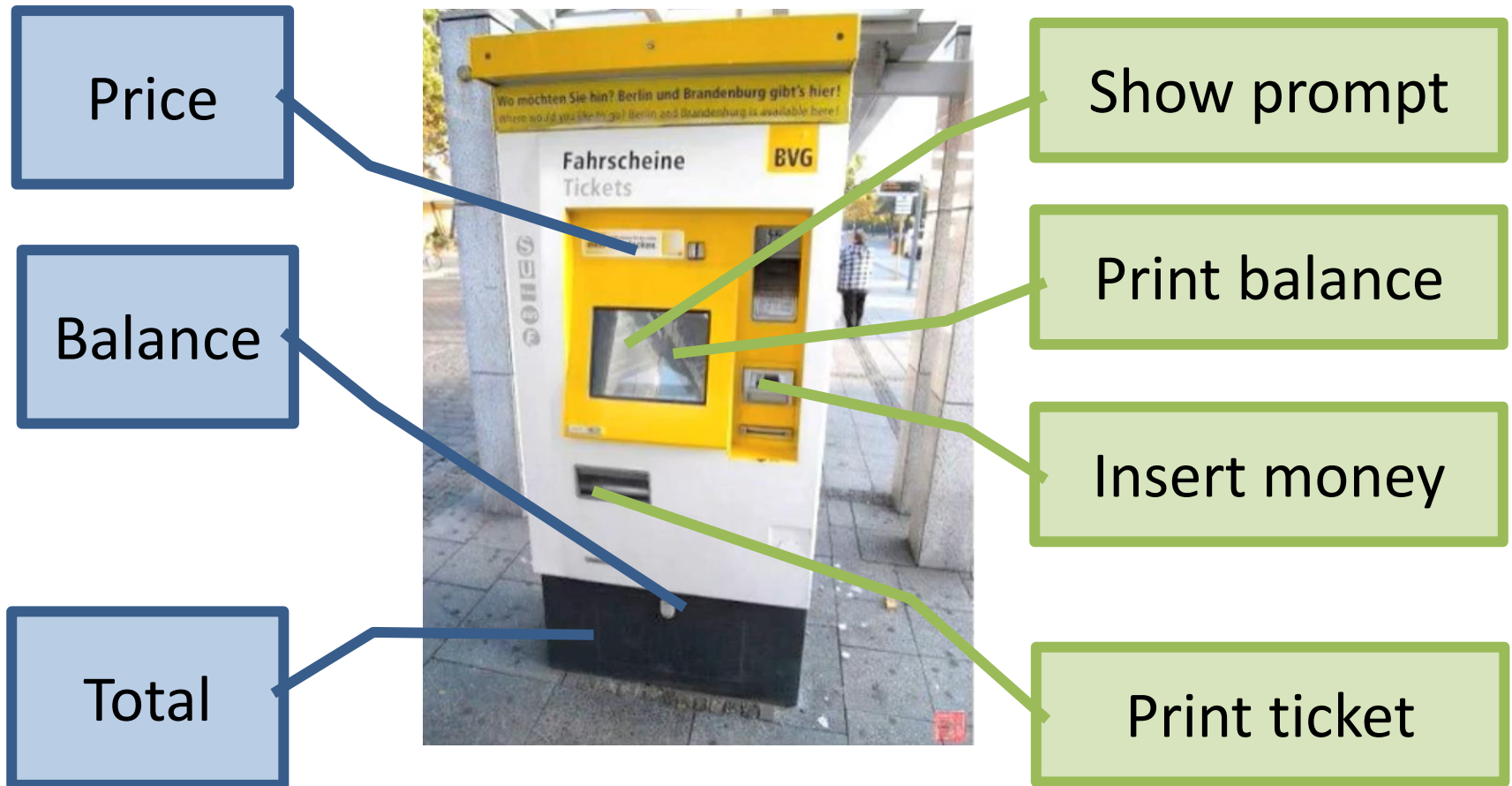


Ticket Machine: Procedure-Oriented

- Step to the machine
- Insert money into the machine
- The machine prints a ticket
- Take the ticket and leave



Ticket Machine: Something is there



Ticket Machine: Something is there

TicketMachine

PRICE
balance
total

ShowPrompt
getMoney
printTicket
showBakance
printError

ticketMachine 1:
TicketMachine

price

balance

total

:: resolver

- <Class Name>::<function name>
- ::<function name>

```
Void S::f( ) {  
    ::f( );    // Would be recursive otherwise  
    ::a++;    // Select the global a  
    a--;      // The a at class scope  
}
```