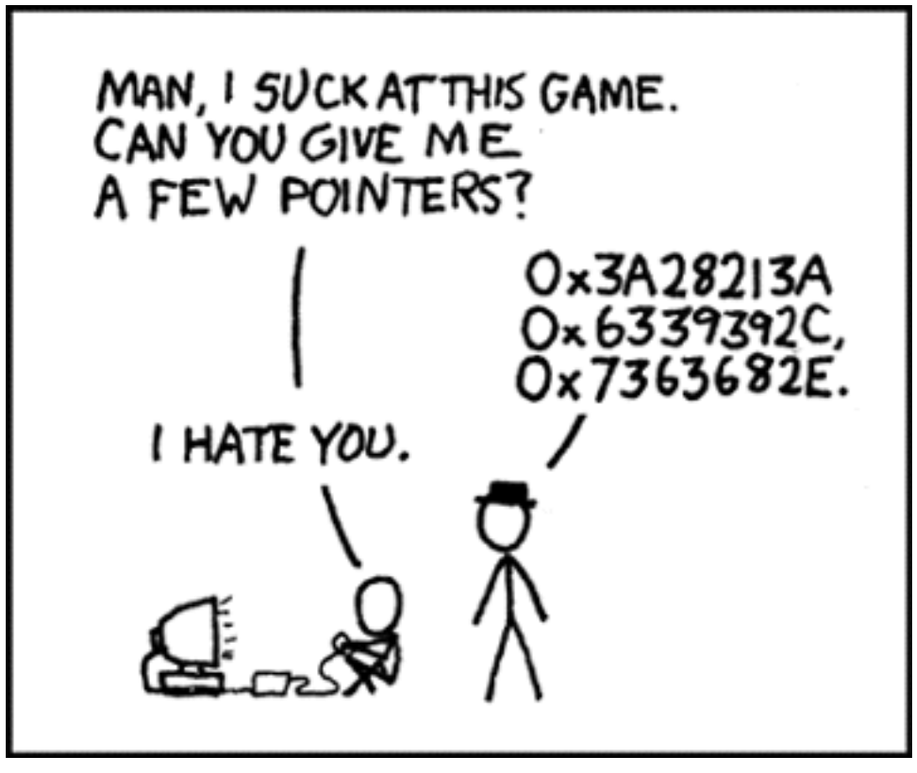



# C++

Gordon Erlebacher
++ Peter Beerli

http://xkcd.com/138/

# C++

- Typed language
  - every variable must be declared
  - every variable has a type (int, string, etc.)
  - C++ is compiled to object code (contains information about symbols and relative locations in memory)
  - Multiple object files are linked into an executable (machine code)

# Program Structure

- int main(char* argc, char** argv) {}
  - main function is a requirement
- main() calls other functions, defines, classes, etc.
- structure of C++ program is very similar to structure of a python program
- C++ is less general and less powerful than Python
- C++ is often much faster than Python (unless modules like numpy and scipy are used, which are optimized and use underlying C/C++ code)

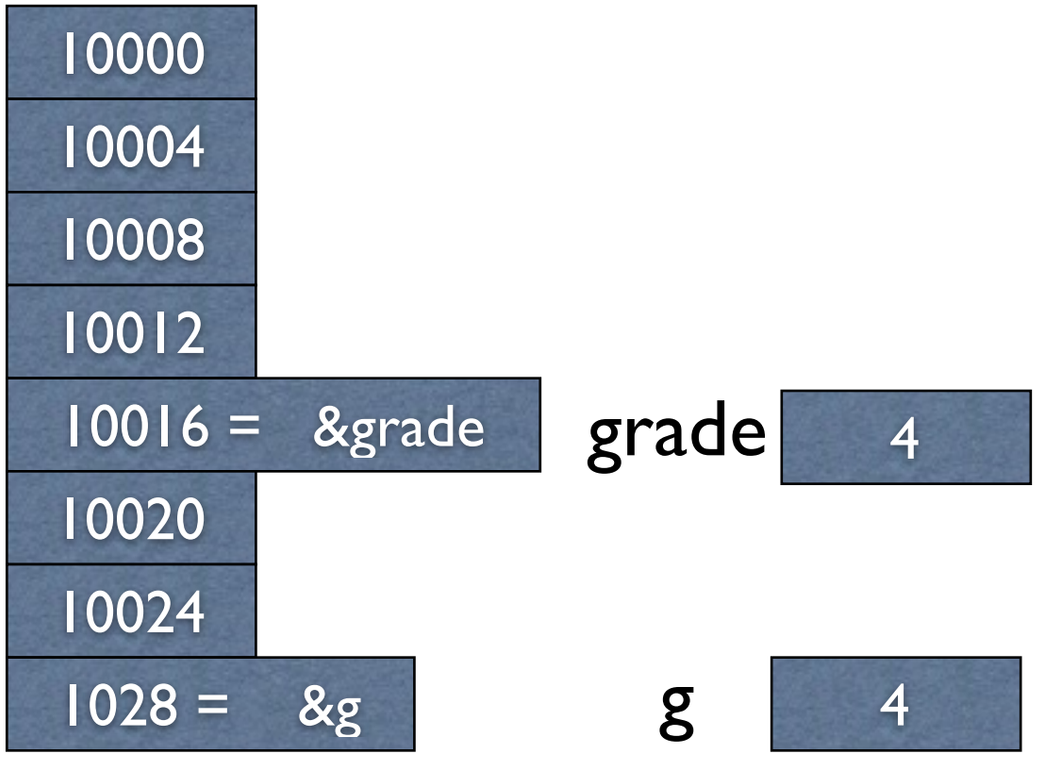
# Second half of course

- You all know Java or C++, therefore, we will concentrate on:
  - use of pointers and references
  - use of preprocessing macros
  - function and operator overloading
  - templates
  - STL library
  - wrapping C++/C functions with Python

# Pointers

- What is a pointer?
  - a pointer is a memory address
  - ```
    int grade;     // semi-colon necessary
    int* grade_p;  // pointer
    // comment
    /*  another comment */
    ```
    ```

# Pointer




```
int grade = 4;
int* grade_ptr = &grade;

// grade_ptr = 10016

int g = *grade_ptr;    // 4
int* gp = &g;
```

```
int* p; // pointer to an integer
int i; // integer value
```

You turn a pointer into a value with `*`:

```
int i2 = *p; // integer value
```

You turn a value into a pointer with `&`:

```
int* p2 = &i; // pointer to an integer
```

Edit: In the case of arrays, they are treated very much like pointers. If you think of them as pointers, you'll be using `*` to get at the values inside of them as explained above, but there is also another, more common way using the `[]` operator:

```
int a[2];  // array of integers
int i = *a; // the value of the first element of a
int i2 = a[0]; // another way to get the first element
```

To get the second element:

```
int a[2]; // array
int i = *(a + 1); // the value of the second element
int i2 = a[1]; // the value of the second element
```

So the `[]` indexing operator is a special form of the `*` operator, and it works like this:

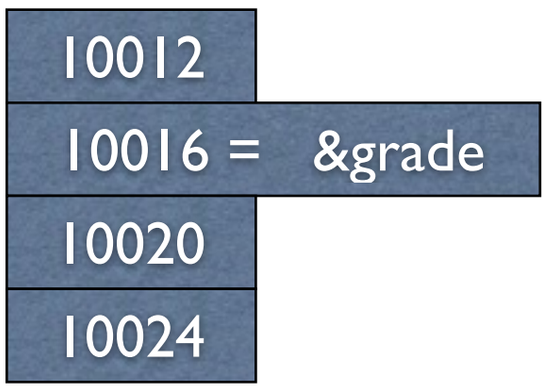
```
a[i] == *(a + i);  // these two statements are the same thing
```

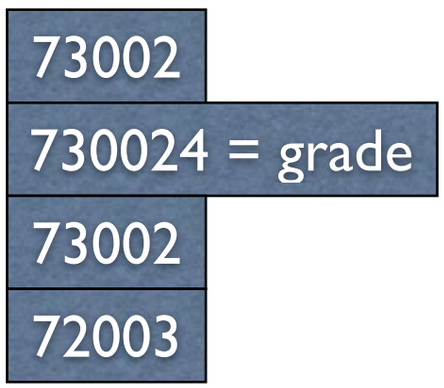
```c
#include <stdio.h>

// or
// int main(int argc, char** argv)
int main()
{
    int grade = 4;
    int* grade_p = &grade;

    printf("grade= %d\n", grade);
    printf("&grade= %ld\n", (long) grade_p);
    printf("sizeof(grade_p)= %d\n", (int) sizeof(grade_p));

    int g = *grade_p;
    int* gp = &g;
    printf("g= %d\n", g);
    printf("&g= %ld\n", (long) &g);

    return 0;
}
```

```
nagal:examples>ls
gugus.cpp  gugus.h
nagal:examples>g++ -o gugus gugus.cpp
nagal:examples>gugus
grade= 4
&grade= 140734634980712
sizeof(grade_p)= 8
g= 4
&g= 140734634980700
```

# new operator

- float* grade = new float;
  - allocates memory for a float
  - float takes sizeof(float) bytes (8 on modern macOSX)
  - the address



# Sizes

- int grade // uses up 4 bytes of memory
  int* grade_p // uses up 8 bytes of memory

- How many bytes are used by grade?
  Answer: 4 (sizeof(grade)=4)

- How many bytes are used by &grade?
  Answer: 8 (sizeof(grade_p)=8)

# Double pointer

- float a;
- float* b;  // pointer to b
- float** c;  // pointer to pointer to b

# 1D Arrays

- float* a = new float [10];
- float a[10];
- float b[]; // illegal (unknown size)
- float c[] = {1.,32.,-2.5};  // ok

- What are the differences?

# float* a

- float* a;
  a = new float [10];
- float* b = new float [10];
- &a : address of a
- a : address of a[0]
- a[0] : content of a
- *a : content of a
- *(&a) : content of &a = content of a

```
&a = 140473360469568
a = 140473360469568
a[0] = 45.000000, *a= 45.000000
a[1] = -145.000000
&a[0] = 140473360469568
&a[1] = 140473360469572
```

**4 bytes per float**

```
#include <stdio.h>

int main()
{
  float* a;
  a = new float [10];
  a[0] = 45.;
  a[1] = -145.;

  float* b = new float [10];

  printf("&a = %ld\n", (long) a);
  printf("a = %ld\n", (long) a);
  printf("a[0] = %f, *a= %f\n", a[0], *a);
  printf("a[1] = %f\n", a[1]);
  printf("&a[0] = %ld\n", (long) &a[0]);
  printf("&a[1] = %ld\n", (long) &a[1]);
}
```

# float** a

- Pointer to pointer to float
- **float** a** or
  float **a
- Both are admissible
- The second is preferred by me, but some people like
  - float** can be considered as a new type, but see this [!!!!]
  - float **a, **b;  // two float** variables
  - float** a, b;  // a is float**, but b is float.
  - float** is not really a type
  - Way out: typedef

# Typedef

```
#include <stdio.h>

typedef float** FLOAT_PP;

FLOAT_PP a, b;  // two float**
float** c, d;       // one float** and one float

int main()
{
    a = new float* [10];
    b = new float* [10];

    c = new float* [10];
    d = new float* [10];  // ILLEGAL (d is a float)
}
```

typedef is very useful to create new types

Most useful when using the Standard Template Library

```
int main()
{
        float** a;
        a = new float* [4];
        a[0] = new float [5];
        a[1] = new float [6];

        a[0][0] = 45.;
        a[0][1] = -145.;
        a[1][0] = 32.;
        a[1][1] = 35.;

        printf("sizeof(float)= %d\n", (int) sizeof(float));
        printf("&a= %ld\n", (long) a);
        printf("a= %ld\n", (long) a);
        printf("*a= %ld\n", (long) *a);
        printf("**a= %f, a[0][0]= %f\n", (float) **a, (float) a[0][0]);
        printf("*a[0]= %f\n", (float) *a[0]);
        printf("a[0]= %ld, a[1]= %ld\n", (long) a[0], (long) a[1]);
        printf("&a[0]= %ld\n", (long) &a[0]);
        printf("&a[1]= %ld\n", (long) &a[1]);
        printf("&a[0][0]= %ld\n", (long) &a[0][0]);
        printf("&a[1][0]= %ld\n", (long) &a[1][0]);
}
```

```
./a.out
sizeof(float)= 4
&a= 4296016000
a= 4296016000
*a= 4296016032
**a= 45.000000, a[0][0]= 45.000000
*a[0]= 45.000000
a[0]= 4296016032, a[1]= 4296016064
&a[0]= 4296016000
&a[1]= 4296016008
&a[0][0]= 4296016032
&a[1][0]= 4296016064
```

# Creation of a triangular matrix

- Assume n rows
- row 1: 1 column
- row 2: 2 columns
- ...
- row n: n columns

```
float** triangular(int n)
{
    float** tri = new float* [n]; // n rows

    for (int i=0; i < n; i++) {
        tri[i] = new float [i];
    }

    return tri;
}
```

Memory used:

- n rows
- 1+2+...+n = n*(n+1)/2 elements
- n pointers of 8 bytes

nb floats: n*(n+1)/2

nb pointers: n

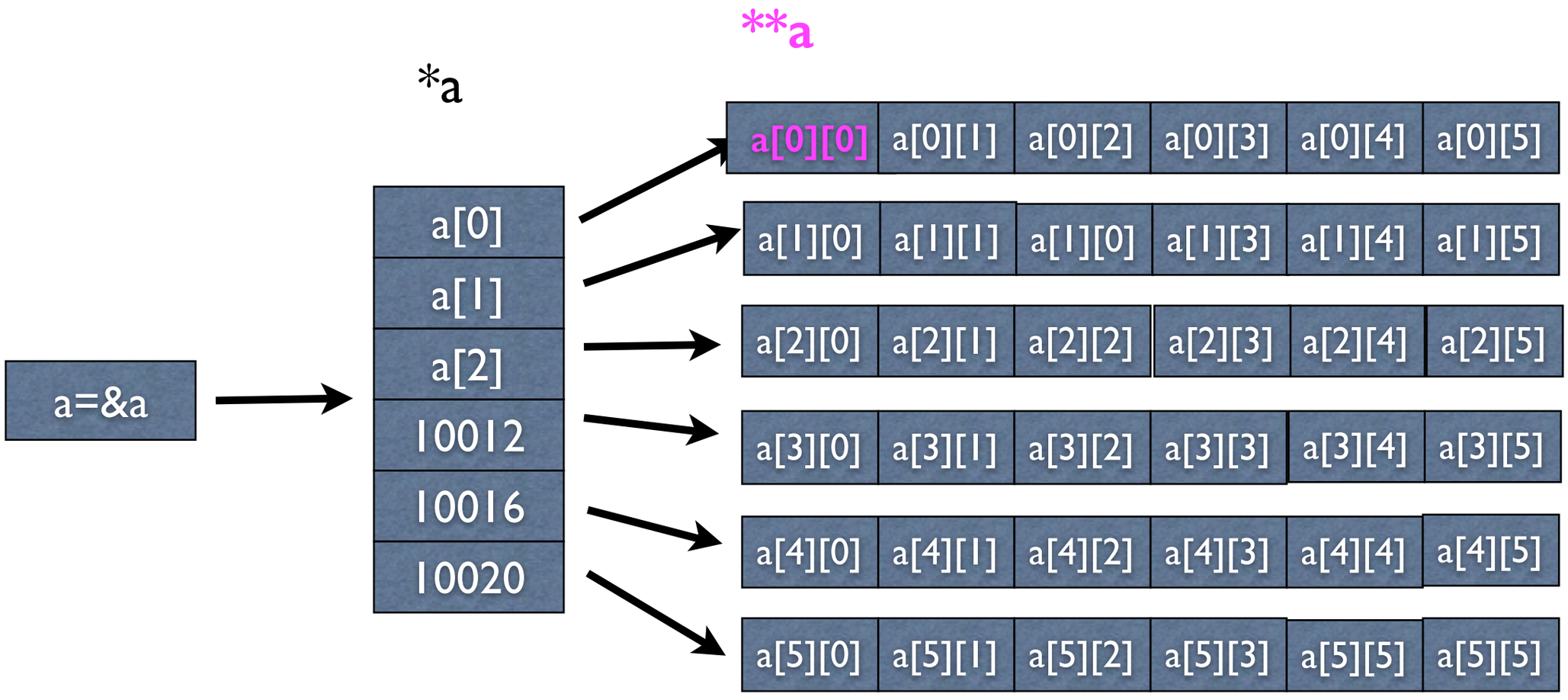
total bytes: 8n+4*n(n+1)/2

= 2n*n+10n

Regular nxn matrix of floats:

- uses: 4*n*n (higher memory usage for large n)

# Square 6x6 Matrix with float** a



# Square 6x6 Matrix with float a[6][6]


All elements are contiguous in memory.
addr(a[5][5])-addr(a[0][0]) = (6*6-1)*4
(four bytes in every float)

```
int main()
{
    float a[10][10];
    printf("sizeof(a)= %d\n", (int) sizeof(a));

    printf("&a= %ld, a= %ld\n", (long) &a, (long) a);
    printf("&a[0][0]= %ld\n", (long) &a[0][0]);
    printf("a[0]= %ld\n", (long) a[0]);
    printf("&a[0]= %ld\n", (long) &a[0]);

    printf("&a[1]= %ld\n", (long) a[1]);
    printf("&a[1][0]= %ld\n", (long) &a[1][0]);
    printf("&a[2][0]= %ld\n", (long) &a[2][0]);
    printf("&a[0][1]= %ld\n", (long) &a[0][1]);
    printf("&a[0][2]= %ld\n", (long) &a[0][2]);

    printf("&a[0][0]= %ld, &a[9][9]= %ld\n",
           (long) &a[0][0], (long) &a[9][9]);

    int nb_elem = &a[9][9]-&a[0][0] + 1;
    printf("nb_elem= %d\n", nb_elem);

    return 0;
}
```

```
./a.out
sizeof(a)= 400
&a= 140734799801232,
  a= 140734799801232
&a[0][0]= 140734799801232
      a[0]= 140734799801232
&a[0]= 140734799801232
&a[1]= 140734799801272
&a[1][0]= 140734799801272
&a[2][0]= 140734799801312
&a[0][1]= 140734799801236
&a[0][2]= 140734799801240
&a[0][0]= 140734799801232,
&a[9][9]= 140734799801628
nb_elem= 100
```

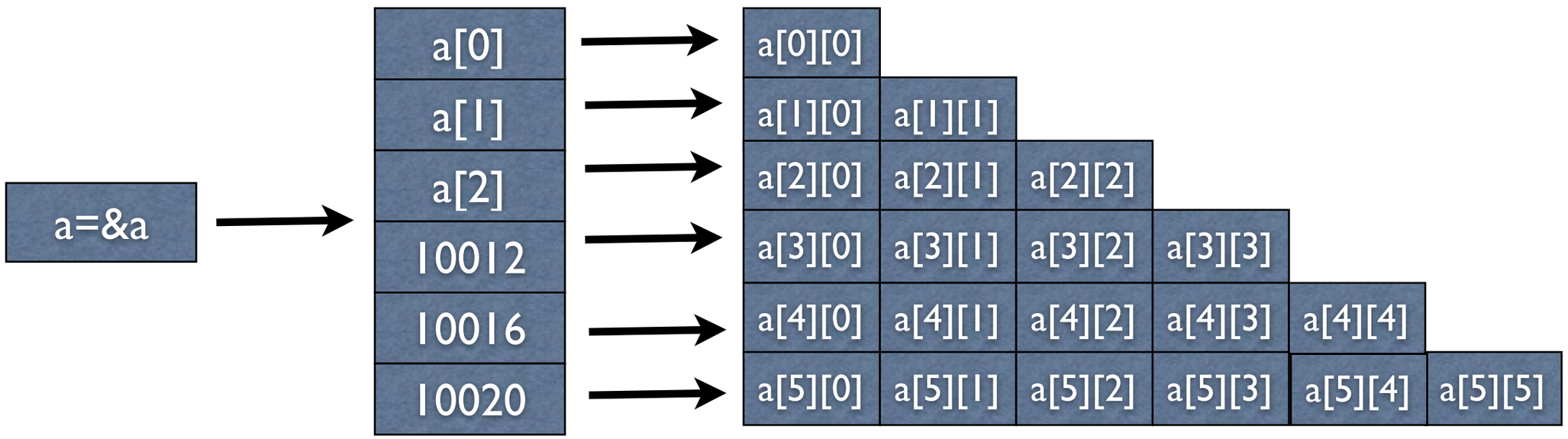
**All identical addresses**

**40** bytes

**4** bytes

**400-4**
**=396** bytes

Triangular Matrix with float** a



# Pointer Arithmetic

```
int main()
{
	float* a;
	printf("a= %ld\n", (long) a);

	a = new float [10];
	printf("a= %ld\n", (long) a);

	float* b = a + 1;
	printf("b= %ld\n", (long) b);

	float** c = new float* [10];
	float** d = c + 1;
	printf("c= %ld\n", (long) c);
	printf("d= %ld\n", (long) d);
}
```

```
./a.out
a= 0
a= 4296016000
b= 4296016004
c= 4296016048
d= 4296016056
```

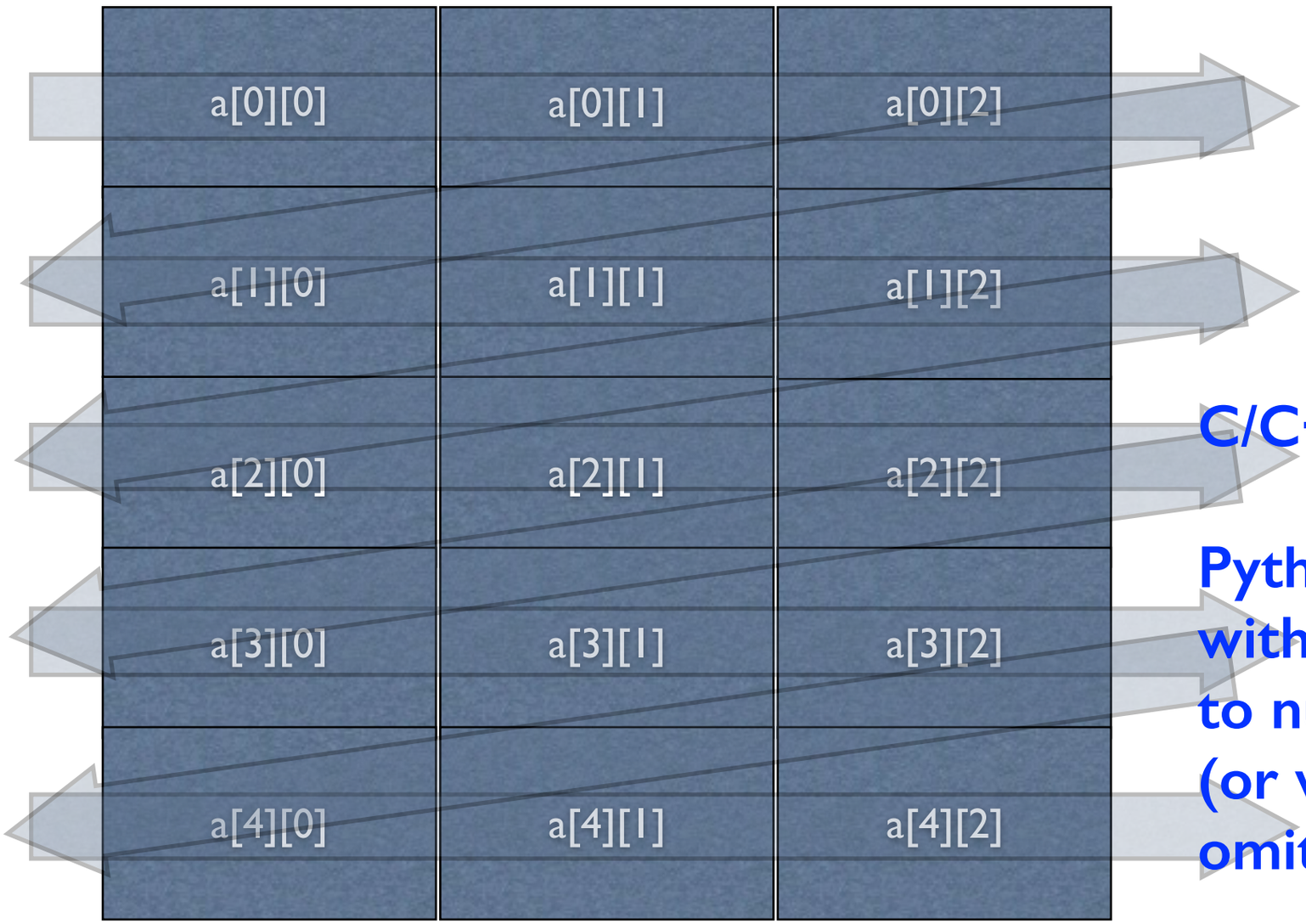
Adding one to a pointer updates the address by the size of the underlying type

# 2D to 1D

- float a[5][3]
  - 15 floats contiguous in memory
  - What order are they stored?
  - a[0][0], a[0][1], ..., a[0][2], a[1][0], a[1][1],a[1][2], a[2][0], a[2][1], a[2][2], a[3][0], ...

# Rowise Ordering

- a[0][0], a[0][1], ..., a[0][2], a[1][0], a[1][1],a[1][2], a[2][0], a[2][1], a[2][2], a[3][0], ...

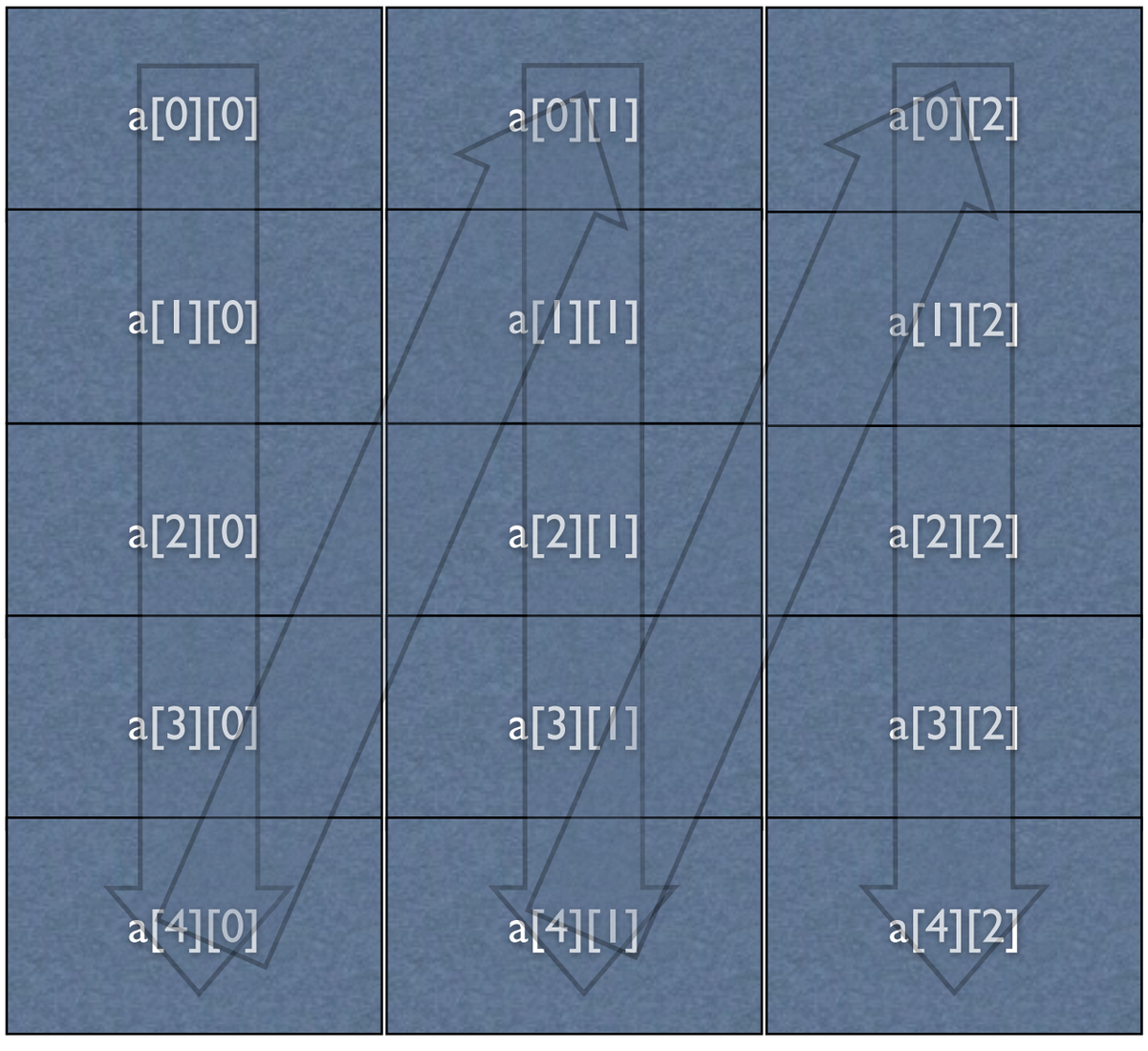



**C/C++/Java**

**Python when using numpy with 'row' as second argument to numpy array constructor (or when 2nd argument omitted)**

# Column Ordering

- The ordering is
  a[0][0], a[1][0], a[2][0], ...., a[0][1], a[1][1], ...




**Fortran**

**Python when using numpy with 'col' as second argument to numpy array constructor**

# 2D to 1D

- a[n][m] : in C++: 2nd index varies the fastest in memory
- Equivalent 1D array in memory:

a[j][i] equiv b[i+m*j]

if &a[0][0] == &b[0]

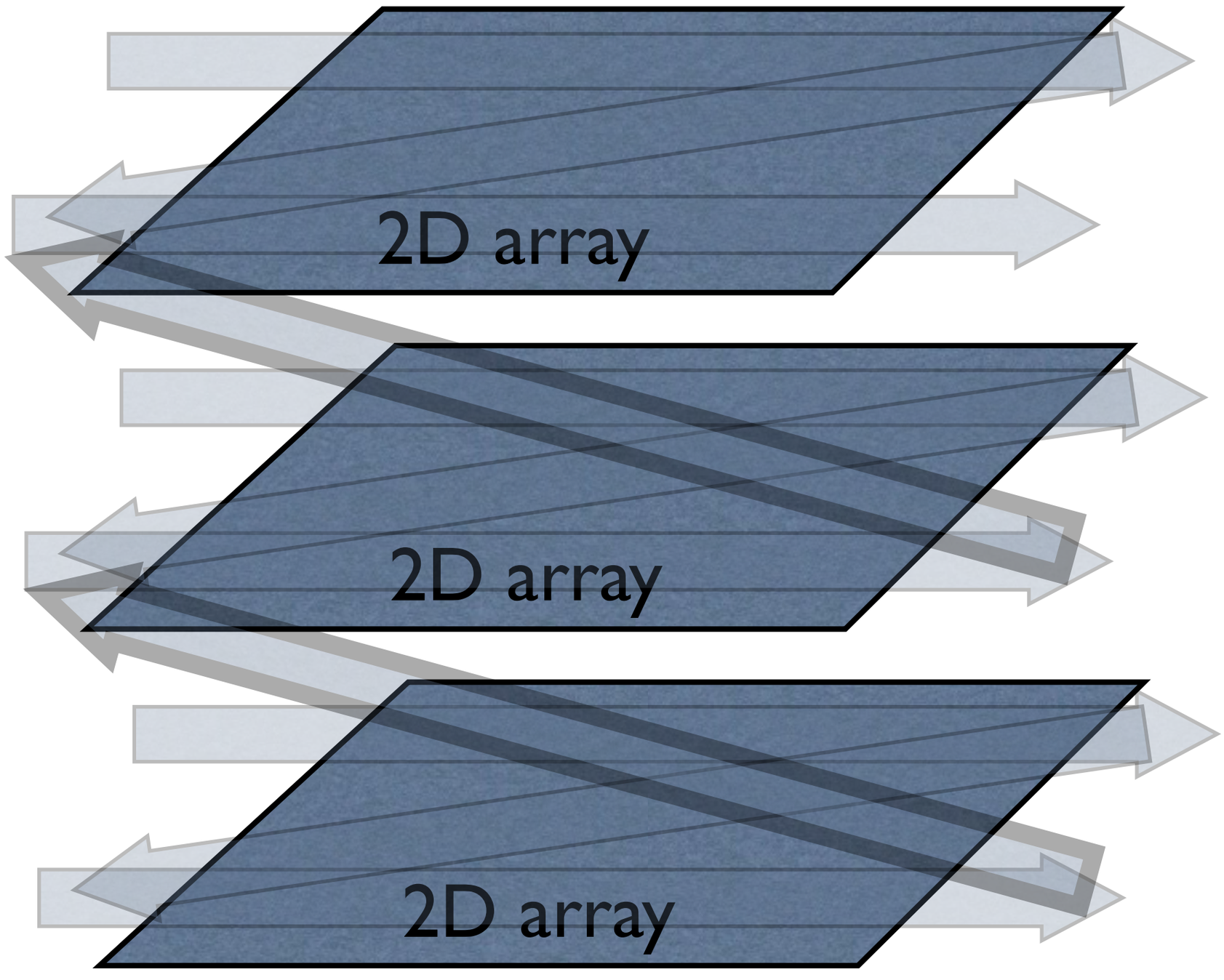
# 3D to 1D

- a[n][m][p] : in C++: 3rd index varies the fastest in memory
- Equivalent 1D array in memory:

a[k][j][i] equiv b[i+p*j+p*m*k]

if &a[0][0][0] == &b[0][0]

# a[m][n][k]




row

column

plane

# arrays_2d_to_1d.cpp

```
int main()
{
    int n = 3;
    int m = 2;
    int a[n][m]; // a[slowest][fastest]

    for (int i=0; i < n; i++) {
    for (int j=0; j < m; j++) {
        a[i][j] = 10*i+j;
        printf("a[%d][%d]= %d\n", i,j,a[i][j]);
    }}

    int* b = new int [n*m];
    int* c = new int [n*m];

    int* ptr = &a[0][0];
    int count = 0;

    for (int i=0; i < n; i++) {
    for (int j=0; j < m; j++) {
        b[j+m*i] = a[i][j]; // 2D -> 1D
        // equiv (*ptr; ptr++)
        c[count++] = *ptr++;  // alternative
    }}

    for (int k=0; k < n*m; k++) {
        // \t  : tab
        printf("b[%d]= %d,\t c[%d]= %d\n",
            k,b[k], k,c[k]);
    }

    delete [] b;   // avoid memory leaks
    delete [] c;

    return 0;
}
```

# Pointers and Functions

- pointers can be used as arguments
- pointers can be returned from functions
- Treat each in turn

# Pointer as argument

Memory allocated in **called method**

```
void change(float** p, float* q)
{
    *p = new float [10];
    (*p)[0] = 5;

    q = new float [10];
    q[0] = 5;
}
//-------------------------------
int main()
{
    float* p;
    float* q;
    change(&p, q);

    // p[0]=5, q[0] not allocated
    printf("p[0]= %f, q[0]= %f\n", p[0], q[0]);
}
```

Arguments are all passed by value.
Interpretation: p and q are passed by value.

This value is the same before and after the call.

The address is passed by value. Therefore, the method *cannot change* this address

While q changes in the function, **the value is not returned** to the main program.

# Pointer as argument

Memory allocated in **calling method**

```
void change(float* p)
{
      p[0] = 5.;
}
//---------------------------------------
int main()
{
      float* p = new float[10];
      p[0] = 3.;
      change(p);

      // pointer value has changed to 5
      printf("p[0]= %f\n", p[0]);
}
```

# Returning a pointer

```
//-----------------------------------------------------
float*  change()
{
    float* p = new float [10];
    p[0] = 5;
    return p;
}
//-----------------------------------------------------
int main()
{
    float* p = change();

    // pointer value changes to 5 in the function
    printf("p[0]= %f\n", p[0]);  // prints 5
}
//-----------------------------------------------------
```

# returning_static_array.cpp AVOID!!

```
//-----------------------------------------
float*  change()
{
    float p[10];
    p[0] = 5;
    return p;
}
//-----------------------------------------
int main()
{
    float* p = change();

    // pointer value changes to 5 in the function
    printf("p[0]= %f\n", p[0]);
}
//-----------------------------------------
```

```
returning_static_array.cpp: In function
'float* change()':
returning_static_array.cpp:6: warning:
address of local variable 'p' returned
```

p is deallocated before the function returns