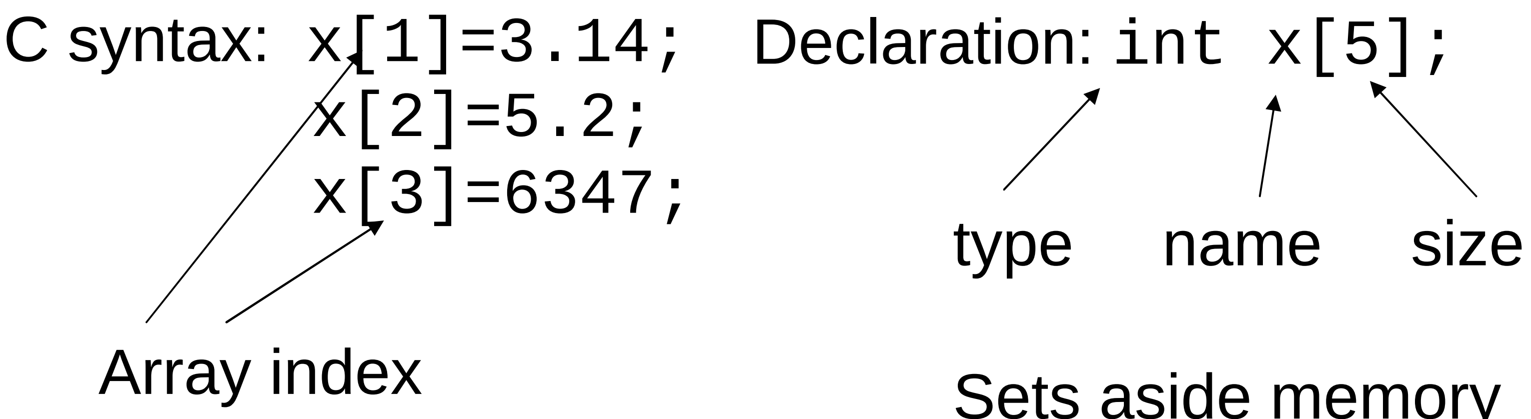
Arrays and Pointers. Lecture Plan.

- *Intro into arrays.*
  definition and syntax
  declaration & initialization
  major advantages
  multidimensional arrays
  examples
- *Intro into pointers.*
  address and indirection operators
  definition of pointers
  pointers and arrays – comparison
  pointer arithmetic

Arrays and Pointers

Array is a group of elements that share a common name, and that are different from one another by their positions within the array.



C syntax:

```
x[1]=3.14;
x[2]=5.2;
x[3]=6347;
```

Array index

Declaration: `int x[5];`

type name size

Sets aside memory for the array

Arrays and Pointers

Initialization:

```
  int grade[]={100,99,85};
  int grade[3]={100,99,85};
  int grade[100]={1,3,5,7};
```

– grade[4]-grade[99] will be zeros.

```
  grade[36] = 87;
```

Multidimensionality:

Scalar variable	a
Vector variable (1D)	$a_0, a_1, a_2, ...$
Matrix variable (2D)	$a_{00}, a_{01}, a_{02}, ...$
	$a_{10}, a_{11}, a_{12}, ...$
	$a_{20}, a_{21}, a_{22}, ...$
	$...$

Arrays and Pointers

Declaration: `int L=100, M=100, N=100;`

```
float a[L][M][N];
```

Initialization: `alpha[2][2]={1,2,3,4};`

```
alpha[2][2]={{1,2},{3,3}};
alpha[0][1]=3;
alpha[1][1]=2;
```

NB: Array size is fixed at declaration.

```
#define L 100
#define M 100
#define N 100
...
int a[L][M][N]
```

Arrays and Pointers

NB: In C numbers of array elements start form zero:
x[0], x[1], x[2], x[3], x[4]. There is no x[5].

NB: If x[5] is accessed, no error will result!

Utility: simplify programming of repetitive operations
improve clarity
improve modularity
improve flexibility

Arrays and Pointers

Example: a program to compute the class average of the midterm.

Scalar form:

```
int main(void){
 float average;
 int sum=0,grade1,
  grade2,..;
 scanf(“%d”,&grade1);
 scanf(“%d”,&grade2);
       ...
 sum += grade1;
 sum += grade2;
       ...
 average = sum/95.0;
}
```

Vector (array) form:

```
int main(void){
 float average;
 int i,n,sum=0,grade[100];
 scanf(“%d”,&n);
 for(i=0;i<n,&n;i++){
  scanf(“%d”,&grade[i]);
  sum += grade[i];
 }      ...
 average = (float)sum/n;
}
```

Arrays and Pointers

Example: Integration using Composite Trapezoid Rule

$$I = \int_a^b f(x)\,dx$$

Continuous function f(x), x belongs to [a,b]

a set of discrete values f(x_i), x_i belong to [a,b].

$$I = \sum_{i=1}^{N} \frac{h}{2}\left[f(x_{i-1}) + f(x_i)\right] = h\left[\frac{f(a)+f(b)}{2} + \sum_{i=1}^{N-1} f(x_i)\right]$$

Arrays and Pointers

Given a function y=f(x) to integrate

form x=a to x=b:

```
int main(void) {
   ...
   h=(b-a)/n;
   integral =0.5*(func(a)+func(b));
   for(i=1;i<n;i++)
   integral += func(a+i*h);
   integral *=h;
   ...
   return(0);
}
```

Arrays and Pointers

Given discrete data y_i = f(x_i) integrate form x=a to x=b:

```
int main(void) {
   ...
   for (i=0; i<=n; i++)
     scanf(“%f”,&y[i]);  /*reading f(xi)*/
   integral =0.5*(y[0]+y[n]);
   for(i=1; i<n; i++){
     scanf(“%f”,&y);   /*summing f(x[i])*/
     integral += y;
   }
   scanf(“%f”, &a)
   scanf(“%f”, &b)
   integral *= (b-a)/n;
   ...
   return(0);
}
```

Arrays and Pointers

Calculating the average. Version 1. `/*No arrays.*/`

```
#include <stdio.h>
int main(void)
{
  float ave;
  int sum=0;
  int data1, data2, data3;
  scanf(“%d”, &data1);
  scanf(“%d”, &data2);
  scanf(“%d”, &data3);
  sum == data1;
  sum += data2;
  sum += data3;
  ave = sum/3.0;
  ...
}
```

- inefficient coding
- only works for a fixed number of data points

Arrays and Pointers

Calculating the average. Version 2.

```
/* no arrays, scalar “for” loop */

#include <stdio.h>
int main(void)
{
  float ave;
  int i, n, datai, sum=0;
  scanf(“%d”, &n);
  for (i=0;i<n;i++){
     scanf(“%d”, &datai);
     sum += datai;
  }
  ave = (float) sum/n;
  ...
}
```

Arrays and Pointers

Calculating the average. Version 3. `/* with arrays */`

```
#include <stdio.h>
#include <math.h>
#define NMAX 100
int main(void)
{
  float ave;
  int i, n, data[NMAX], sum=0;
  scanf(“%d”, &n);
  if(n>NMAX) printf(“number of pts > NMAX);
  for (i=0; i<n; i++)
     scanf(“%d”, &data[i]);
     sum += data[i];
  }
  ave = float(sum)/n;
  ...
}
```

- array size is fixed at declaration
- use #define to have some flexibility

Arrays, Summing up

- The name identifies the location in memory, big enough to store the whole array.
- a[k] refers to the k-th element of the array, the indexing starting from 0.
- The memory allocation happens when the array is declared: use # to set the dimensions.
- Advantages: clear and compact coding, better modularity, take advantage of loops for repetitive operations.

Arrays and Pointers

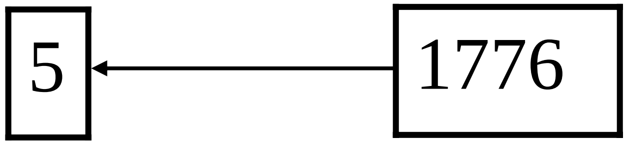
Intro into pointers.

`&` - address operator, unary, right to left precedence

`v` – variable   `&v` – location (address) of `v` in the memory

The special type of variable to operate with the address is needed: POINTER   `pv = &v;`

Identifier	`v`	`pv`
Memory address	1776	1997
Value	5	1776



Arrays and Pointers

Declaration: `int *p;`   `p` – pointer to integer variable.

Value range: zero or NULL address and a set of positive integers.

Assignment: `p=0; p=NULL; p=&i; p=(int *)1776;`

address of i   cast as “pointer to int”

Indirection (dereferencing) operator `*` - “inverse” to &. Gives the value of the variable pointed to by the pointer.

`p = &i;      i = *p;` *We can access any variable, if know the variable’s address!*

`&i = p;` illegal, addresses are allocated by declarations.

`p = &3; p = &(i+j);` illegal: constants and expressions do not have addresses.

Arrays and Pointers

Relationship between arrays and pointers:

- Array name is a pointer **constant**, it’s value is the address of the first element of the array.
- Pointers can be subscribed

`a[i] = *(a + i)`   `a` – address of `a[0]`
(base address or the array)

`a[i] = *(p + i)` points to i-th element of the array

NB: a is a constant pointer, `a=p,   ++a,   &a` are illegal.

Arrays and Pointers

Pointer arithmetic is equivalent to array indexing:

```
p = a + 1        p = &a[1]
p = a + m        p = &a[m]
```

Summing the array using pointers:

```
for (p = a; p < &a[N]; ++p)
    sum += *p;
           or
for (i = 0; i < N; ++i)
    sum  +=  *(a + i);
```

Arrays and Pointers

Pointer arithmetic:

```
    p + 1   ++p    p + i    p += i
```

However, pointers and numbers are not quite the same:

```
double      a[2], *p, *q;
p = a;
q = p + 1;
printf(“%d\n”, q – p);                 /* 1 is printed  */
printf(“%d\n”,(int) q – (int) p);      /* 8 is printed  */
```

The difference in terms of array elements is 1, but the difference in memory locations is 8!

Arrays and Pointers

Arrays and pointers as function arguments:

“call by value” – “call by reference”

- Variables themselves are passed as function arguments.
- The variables are copied to be used by the function.
- Dealing directly with variables, which are are not changed in calling environment.

- Pointers are used in the argument list: addresses of variables are passed as arguments.
- Variables are directly accessed by the function.
- The variables may be changed inside the function and returned.

Arrays and Pointers

Passing arrays to functions:

As individual scalars: `x=sum(grade[k],grade[k+1]);`

prototype:
```
int sum(x,y)
{
     int x, y;
     ...
```

Using pointers:
```
     x = sum(grade,n)
```

prototype:
```
int sum(int *grade, int n);
{
     int res, *p;
     res =0;
     for (p=grade;p<&grade[N];++p)
          res += *p;
     return(res);
}
```

Arrays and Pointers

The function swaps two variables, using “call by reference”.

```
void swap(int *p, int *q)
{
    int tmp;
    tmp = *p;
    *p = *q;
    *q = tmp;
}
```

Arrays and Pointers

Checking how “`swap`” works:

```
#include <stdio.h>
void swap(int *, int *)
{
    int  i = 3, j = 5;
    swap(&i, &j);
    printf(“%d %d\n”, i, j);
    return 0;
}   /* 5  3 is printed */
```

Arrays and Pointers

Pointer arithmetic summed up:

1. Assignment: `ptr = &a;`
2. Value finding: `*ptr = a;`
3. Taking pointer address: `&ptr` – address of `ptr` in the memory (pointer to pointer).
4. Addition/subtratction: `ptr2 = ptr1 +1;` `ptr2-ptr2;`
5. Increment: `ptr1++`   `ptr1 + 1`

NB Increment does not work for pointer constants.

6. Indexing – like arrays: `ptr[i] = a[i];`

NB Pointers and arrays are almost the same:

....[i]   *(….+i)

Arrays and Pointers

Automatic memory allocation happens when the array is declared: `int data[100];`

Dynamic memory allocation:

- function `calloc( )` takes 2 unsigned integers: number of elements in the array and number of bytes in each element, returns a pointer to the base element of the array and sets all the array elements to zero:

```
    a = calloc(n, sizeof(int));
```

To clear (return) the allocated space the “free” command is used:

```
    free(a);
```

Arrays and Pointers

The other option is function `malloc():` it takes one unsigned integer - required number of bytes of memory desired.

Both `calloc` and `malloc` return pointer to void and the result will be casted automatically.

```
int main(void) {
     float *a;
     int k;
     scanf(“%d,&k);
     a = (float *)malloc(k*sizeof(float);
     …
     a[0] = …
     …
     free(a);
}
```

Arrays and Pointers

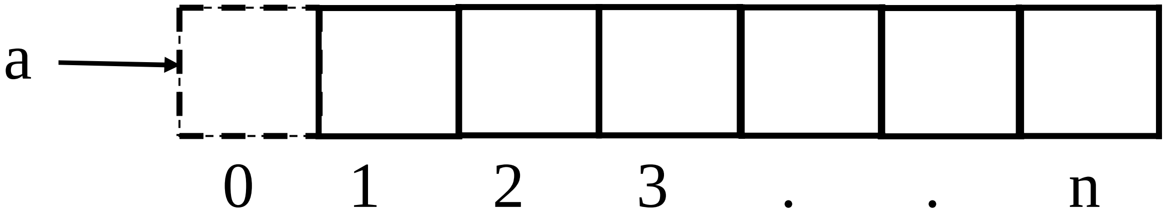
Offsetting the pointer for the array to start form the element 1 instead of 0.

```
int   n;
double *a;
a = calloc(n+1, sizeof(double));
```

or

```
a = calloc(n, sizeof(double));
--a;      /* offset the pointer */
```

a[1] is the first accessible storage element.



Multidimensional Arrays and Pointers

```
int a[3][5]; /* 3 rows, 5 columns */
```

Some differences form vector arrays:

a - pointer to the base **address** &a[0][0] (not to a[0][0])

a + i - pointer to the **address** of the *i*th row &a[i][0]

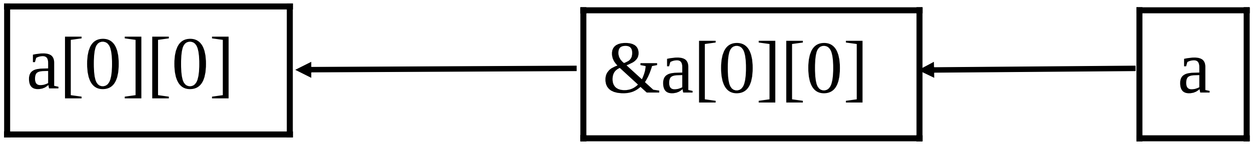
Both a and a+i are pointers to pointers.

*a - row addess for a (1st row), **a - value of a[0][0].

We need to dereference twice to get form a to the values.

a[i] - pointer to the *i*th row

```
a[i][j]      *(&a[0][0] + 5*i + j)
```



Multidimensional Arrays and Pointers

Prove that each of the following four expressions is equal to a[i][j]:

```
     *(a[i] + j)
     (*(a + i))[j]
*((*(a + i)) + j) /* NOTE 2 dereferencing operations */
     *(&a[0][0] + 5*i +j)
```

Some more pointer arithmetic:

`*(a + 1)`	address of the second row
`*(a + j) + k`	address of `a[j][k]`
`*(*(a + j) + k)`	value of `a[j][k]`
`*(*(a + j) + k)`	`a[j][k] + m`

Storage mapping - finding the array element using a pointer:

```
a[i][j] = *(&a[0][0] + 5*i + j)
```

NB need the number of columns (5), not just pointer to a[0][0]!

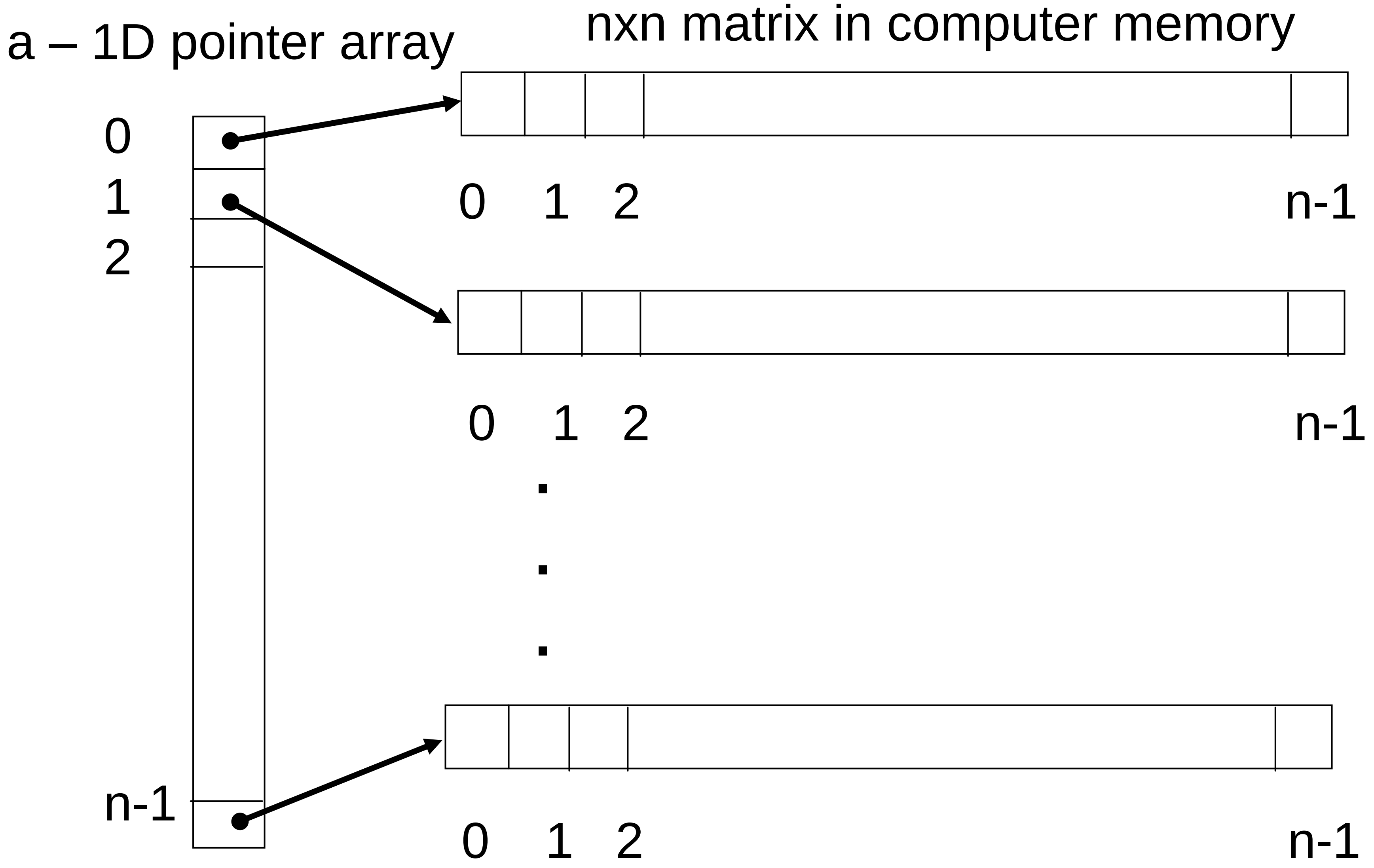
Multidimensional Arrays and Pointers

To pass an nD array to the function we need to set (n-1) dimensions of the array outside the function. For n>1 programming becomes much less flexible: no dynamic memory allocation, etc.

It may be avoided by using arrays of pointers. Let’s build a matrix of an arbitrary size starting form *pointer to pointer to double:*

```
int  i,  n;
double **a,  det;    /* NB **a declared, not an array */
…...            /* getting n */
a = calloc(n, sizeof(double *)); /* a-array of pointers to double */
for (i = 0;  i < n;  ++i)
      a[i] = calloc(n, sizeof(double));
      …...
```

Multidimensional Arrays and Pointers



Multidimensional Arrays and Pointers

Now we can easily pass a to a function, say one summing diagonal elements of the matrix:

```
double trace(double **a, int n)
{
        int             i;
        double          sum = 0.0;
        for (i = 0; i < n; ++i);
                sum += a[i][j];
        return sum;
}
```

Pointers to Functions

What if we need to do the same calculation for several functions?

Example: $\sum_{k=m}^{n} f^2(k)$

The summing routine:

```
double sum_square(double  f(double),  int m,  int n) {
int k;
double sum = 0.0;
for (k = m; k <= n; ++k)
        sum += f(k) * f(k);
return sum;
}
```

The first argument is a pointer to function f, which takes double and returns double.

Pointers to Functions

f can either be treated as a function or as a pointer with dereferencing:

```
sum += (*f)(k) * (*f)(k);          sum += f(k)*f(k)
```

f	the pointer to function
*f	the function itself
(*f)(k)	the call to the function

Pointer to array: points to the first memory cell containing the element of the array in the **data segment** of computer memory.

Pointer to function: points to the first memory cell containing the function in the **code segment** of computer memory.