Computer Programming: Skills & Concepts (CP)
Arrays

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What is an array?

An array is a collection of variables of the same type, grouped under a single name, with individual items being picked out via ‘indexing’.

Here is an example of *declaring* an array:

```
int a[8];
```

We can make a similar *declaration* for any standard (`int`, `float`, `double`, `char`) or user defined *type* (coming in week 8), for any **constant** size (8 is the size for this example).

More about arrays

The declaration of a creates 8 individual variables (“elements”, or “cells”) *organised at consecutive memory locations*, accessible via “indexing”

a	a[0]	a[1]	a[2]	a[3]	a[4]	a[5]	a[6]	a[7]
	0	1	2	3	4	5	6	7

(subscript or index)

To *access* the individual variables (“cells”) in the array:

- `a[0]` is the 0th cell of array `a`
  - life is less confusing if we always count from zero
- `a[1]` is the 1st (1th?) cell
- ...
- `a[7]` is the 7th (the final) cell
- `a[i]` is the `i`-th cell of `a`
  - assuming `i` is a variable of type `int` with value in the range 0 . . . 7

`fibonacci` with arrays

Remember the Fibonacci function $F(n)$ in lecture 6.

- Defined via the following recurrence

$$F(n) = \begin{cases} 0 & n = 0 \\ 1 & n = 1 \\ F(n-1) + F(n-2) & \text{otherwise} \end{cases}$$

- Programs `fibonacci.c`, `fibonacci-for.c` use variables `previous`, `current` and `next` to compute F(n).
  - (good) Efficient in terms of number of variables - we have `n`, an counting variable called `count`, and the 3 above.
  - (bad) Ungainly, and error-prone, in the details of updating `previous`, `current` and `next` within the loop.

There is, of course, a simpler way!

`fibonacci` with arrays

We can define an array (called `fib`) to store the various Fibonacci numbers F(n) up to a limit (say 100).

Advantages and Disadvantages

- (good) We won't have to do the delicate arranging of `previous`, `current` on each iteration of the loop.
- (bad) We will have an upper limit on the values of `n` we can handle, because arrays must be constant-size.
    - *In many languages, the size of an array can be assigned dynamically at run-time, but not in standard ANSI C. There is a way to get round it, but not until later.*

fibonacci-arr.c

"program design" - straight from the recursive definition of F(n)

```
....                      /* omitting header-files */
#define MAXFIB 100

int main(void) {
  int n, i;
  int fib[MAXFIB];

  fib[0]=0;
  fib[1]=1;
  ....                    /* omitting scanf for n */
  if ((n < 0) || (n > MAXFIB-1)) {
    printf("Not an appropriate integer.\n");
  } else {
    for(i=2; i <= n; i++) {
      fib[i] = fib[i-1]+fib[i-2];
    }
    printf("Fibonacci number %d is %d.\n", n, fib[n]);
  }
  return EXIT_SUCCESS;
}
```

Notes on `fibonacci-arr.c`

- The first element of `fib` has index 0, and the final element has index `MAXFIB - 1` (which is 99).
- We refer to the entire array as `fib`.
- All the *elements* (or *cells*) of the array have type `int`. We refer to these individual elements as `fib[0]`, `fib[1]`, and so on up to `fib[MAXFIB-1]` (or `fib[99]`).
- Array indices are **always** expressions of type `int`
- The advantage of arrays is greatest when we can/need-to *iterate through the arrays via the use of a changing index variable* (this 'index' is `i` in the case of `fibonacci-arr.c`)
- "Arrays are pointers" – `fib` is actually an address (of the first cell `fib[0]`) in memory).

More notes on `fibonacci-arr.c`

- Use of `#define`
  - `#define` just *substitutes* the value (100) for the identifier (`MAXFIB`) during `gcc`'s pre-processing step.
  - Can't use `const int` in Standard ANSI C if the identifier will be used for an array index.
  - A cleaner alternative is `enum { MAXFIB = 100 };` which we'll explain later – but `#define` is traditional.
- The bound on `n` that we can work with?
  - An artificial bound introduced because of array use **(unfortunately)**.
  - An entirely reasonable limit for Fibonacci numbers **as it happens**.
  - As i grows, the value of $F(i+1)/F(i)$ tends to $(1+\sqrt{5})/2$, roughly 1.61. So $F(i)$ grows *exponentially*.
  - The max value of an `int` in C on DICE is $2^{31}-1$.
  - **As it happens** $F(i)$ becomes greater than $2^{31}-1$ at 47
  - ... so we see negative numbers output ("wraparound" error) for 47 onwards
  - Even we use the '`long`' (64-bit integer on DICE) type for `fib`, we will exceed max size for '`long`' before $F(99) = 2.18 \times 10^{20}$.

Initializing arrays

If you want to initialize an array to specific values, you can write:

```
#define SIZE 8

/* initialize to the first 8 primes */
int a[SIZE] = { 2, 3, 5, 7, 11, 13, 17, 19 };
```

Warning: If you give too many values, gcc will complain; if you give too few, it will silently leave the last elements of the array uninitialized!

Where the power lies

An array index is a integer *expression*, not a *constant*, so its value isn't determined until the program is run. The precise array element referred to by a[i] depends on the current value of i

Example:

```
for (i = 0;  i < SIZE;  i++) { a[i] = 0; }
```

Effect: Initialise all elements of the array a to zero. Same as:

```
a[0] = 0;
a[1] = 0;
...
a[SIZE - 1] = 0;
```

Be careful NOT to access cells with a later index than defined (eg i taking the value SIZE +2). C does not check array index limits.

whatday with arrays

```
#include <stdio.h>

#define MONTHS_IN_YEAR 12
#define DAYS_IN_WEEK 7

int main(void) {
  int day, month, days, i;
      /* WARNING: arrays start at zero, so January has index 0 */
  int daysinmonth[MONTHS_IN_YEAR] = { 31, 28, 31, 30, 31, 30,
                                      31, 31, 30, 31, 30, 31 };
  char *daynames[DAYS_IN_WEEK] = {"Sunday","Monday", "Tuesday",
                                  "Wednesday", "Thursday",
                                  "Friday", "Saturday"};
  /* read the requested day and month in from user ... */
  printf("enter day and month\n"); scanf("%d%d",&day,&month);
  days = day-1;            /* first account for days since 1st */
  for (i=1; i < month; i++) {
    days = days + daysinmonth[i-1];
  }
  /* 1 Jan has days == 0, and was a Sunday */
  printf("It was a %s\n", daynames[(days)%DAYS_IN_WEEK]);
  return EXIT_SUCCESS;
}
```

Arrays of any type

We haven't discussed `typedef` or `struct` formally yet . . . though we will see, in Lab sheet 4, these words used to define a type for representing points in the plane.

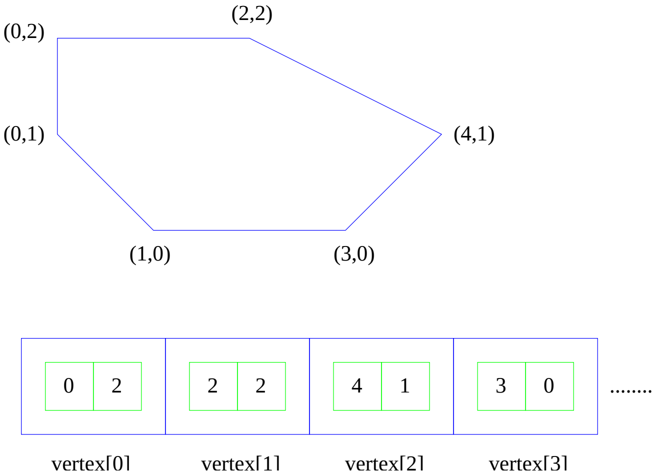
An array of points could be used to represent a polygon with up to `MAX` vertices.

```
typedef struct {
  int x, y;
} point_t;

point_t vertex[MAX];
```

Question: How do we deal with a polygon with fewer than `MAX` vertices?

Polygon as an array of vertices



Arrays as parameters

```
int Max(int b[], int n) {
/*  n is the number of elements in array b.  Max returns
 *  the maximum element of b.  NB:  We lose the size of
 *  the array when we pass it as a parameter              */

  int i, maxSoFar;
  maxSoFar = b[0];
  for (i = 1;  i < n;  ++i) {
    if (b[i] > maxSoFar) { maxSoFar = b[i]; }
  }
  return maxSoFar;
}
....
printf("The maximum value is %d.\n", Max(a, 8));
```

Arrays are 'pointers'

```
void Rotate(int b[], int n) {
/* Aim:  rotate the elements of an array cyclically. */
  int i;
  int temp;      /* Temporary storage (like in swap). */

  temp = b[n - 1];
  for (i = n - 1;  i > 0;  --i) { b[i] = b[i - 1]; }
  b[0] = temp;
}
....
Rotate(a, 8);
```

Question: Is a cyclically rotated or unchanged?

Arrays are ‘pointers’

The answer is that it *is* rotated.
The reason? Roughly it is because an array in C is a pointer (to its zeroth element).

- The actual parameter `a` is a pointer to an integer.
- The formal parameter `b[0]` is a synonym for `*b`.
- The formal parameter `b[i]` is a synonym for `*(b+i)`.

good: Means we don’t need to use `&` and `*` to get the effect of “call-by-reference” with array parameters (see `swap.c` in Lab 5).

bad: We always have to incorporate an extra parameter (eg, `n` in `Rotate`) to allow the length of the array to be passed into the function.

Arrays of arrays

Array elements can themselves be arrays. So, for example, a matrix with `N` rows and `M` columns could be defined as:

```
float matrix[N][M];
```

We'd then expect to be able to write a function that multiplies a vector `x` by a matrix `a` with header

```
void LinTransform(float a[][],
                  float x[],
                  float y[],
                  int n, int m);
```

However C does *not* allow this - declaration for `a` must instead be of the form `a[][10]` or `a[][8]` or similar.
To understand why, check out Kelley & Pohl [KP, §6.12].

Reading Material

Relevant sections of Chapter 6, Kelley and Pohl.

- Specifically, 6.1, 6.4, 6.6 and 6.12