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:

```c
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"

```
   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`
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!
We can define an array (called $\text{fib}$) 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.
void fibonacci_arr(void) {
    "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;
    }
}

CP Lect 9 – slide 6 – Monday 16 October 2017
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 (“wraparoun”” 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:

```c
#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:

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

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

```c
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.
#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 ... */
    days = day-1; /* first account for days since 1st */
    for (i=1; i < month; i++) {
        days = days + daysinmonth[i-1];
    }
    printf("It was a %s\n", daynames[(days+5)%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


0 2 2 4 1 3 0
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));
void Rotate(int b[], int n) {
    /* Aim: rotate the elements of a 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)`.

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

**−ve:** 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:

```c
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

```c
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