Beyond Arrays

An **array** is a collection of values, all of which have the **same data type**, and all of which have the **same essential meaning**:

```c
float* independent_variable = (float*)NULL;
```

In memory, the elements of the array are **contiguous**: they occur one after the other in memory.

What if, instead of having a collection of data that all have the same data type and meaning, we had a collection of data that had **different data types** and **different meanings**?
A Company and Its Employees #1

Suppose that we work for some company, and our boss tells us to write a program that tracks the company’s employees. What data will we need?

Well, we’ll probably need to know things like:

- first name;
- last name;
- pay rate;
- number of hours worked this week;
- social security number.

How could we implement this in C?
A Company and Its Employees #2

How could we implement this in C?

Well, we could simply set up a scalar variable to represent each of these values (and strings for the names):

```c
char* first_name;
char* last_name;
float pay_rate;
float hours_worked_this_week;
int social_security_number;
```

Of course, this arrangement would work if our company had exactly one employee.

But what if our company has **multiple employees**?
Multiple Employees #1

Okay, so suppose that the company has **multiple employees**. How could we store the data for them?

Well, we could have an **array for each** of the pieces of data:

```c
char* first_name[number_of_employees];
char* last_name[number_of_employees];
float pay_rate[number_of_employees];
float hours_worked_this_week[number_of_employees];
int   social_security_number[number_of_employees];
```
Multiple Employees #2

char* first_name[number_of_employees];
char* last_name[number_of_employees];
float pay_rate[number_of_employees];
float hours_worked_this_week[number_of_employees];
int social_security_number[number_of_employees];

This approach will work fine, but it’ll be unwieldy to work with. Why? Because it doesn’t match the way that we think about our employees.

That is, we don’t think of having several first names, several last names, several social security numbers and so on; we have several employees.
Multiple Employees #3

We don’t think of having several first names, several last names, several social security numbers and so on. Instead, we think of having several employees, each of whom has a first name, a last name, a social security number, etc. In general, it’s much easier to write a program if we can write it in a way that matches the way we think as much as possible. So: What if we could create a new data type, named Employee, that represented an employee?
A New Data Type #1

typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

The above declaration creates a new data type, named Employee.

This is known as a user-defined data type or a user-defined data structure.
A New Data Type #2

typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

The **user-defined data type** Employee consists of:
- a character string, first_name;
- a character string, last_name;
- a float scalar, pay_rate;
- a float scalar, hours_worked_this_week;
- an int scalar, social_security_number.
A New Data Type #3

typedef struct {
  char* first_name;
  char* last_name;
  float pay_rate;
  float hours_worked_this_week;
  int social_security_number;
} Employee;

In C, this construct is referred to as a structure definition, and (surprise!) it defines a structure. The general term for this is a user-defined data type.

NOTE: A structure definition, as above, only defines the new data type; it DOESN’T DECLARE any actual instances of data of the new data type.
Structure Definition Breakdown

typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

A structure definition consists of:

- a typedef struct statement and block open { ;
- a sequence of field definitions, which tell us the pieces of data that constitute an instance of the structure;
- a block close } and the name of the structure, followed by a statement terminator.
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

The above struct definition defines the struct named Employee, but DOESN’T DECLARE any instance of data whose data type is Employee.
Structure Instance Declaration #2

typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

To declare an instance of an Employee, we need to do like so:
Employee worker_bee;
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

The last statement above declares that worker_bee is an instance of type Employee.

The declaration statement tells the compiler to grab a group of bytes, name them worker_bee, and think of them as storing an Employee.
Structure Instance Declaration #4

typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

How many bytes?

That depends on the platform and the compiler, but the short answer is that it’s the sum of the sizes of the fields.
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

Okay, so now we have an instance of data type Employee named worker_bee.

But how can we use the values of its field data? For example, how do we get the social security number of worker_bee?
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

To use an individual field of a struct, we use the field operator, which is the period:

    worker_bee.social_security_number
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

For example, we can assign a value to the social security number of worker_bee:

    worker_bee.social_security_number = 123456789;

This is equivalent to using an index in an array:

    independent_variable[student] = 24.5;
typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
} Employee;

Employee worker_bee;

Likewise, we can output the social security number of worker_bee:
printf("%d\n", worker_bee.social_security_number);

This is equivalent to using an index in an array:
printf("%f\n", independent_variable[student]);
Structure Fields Like Array Elements #1

We said that we can use the field operator (period) to get an individual field of an instance of a struct:

```c
worker_bee.social_security_number = 123456789;
printf("%d\n", worker_bee.social_security_number);
```

Notice that this usage is analogous to the use of an index with an array:

```c
independent_variable[student] = 24.5;
printf("%f\n", independent_variable[student]);
```
In the case of arrays, we said that an individual element of an array behaves exactly like a scalar of the same data type. Likewise, a field of a struct behaves exactly like a variable of the same data type as the field.

For example:

- `worker_bee.social_security_number` can be used **exactly** like an `int` scalar;
- `worker_bee.first_name` can be used **exactly** like a character string.
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

int main ()
{
    typedef struct {
        char* first_name;
        char* last_name;
        float pay_rate;
        float hours_worked_this_week;
        int social_security_number;
    } Employee;

    const int maximum_name_length = 32;
    const int program_failure_code = -1;
    const int program_success_code =  0;
    Employee worker_bee;
    char dummy_name[maximum_name_length + 1];
    float worker_bee_pay;
printf("What is the first name of the employee?\n");
fgets(dummy_name, maximum_name_length, stdin);
if (dummy_name[strlen(dummy_name)-1] == '\n') {
    dummy_name[strlen(dummy_name)-1] = '\0';
} /* if (dummy_name[strlen(dummy_name)-1]=='\n') */
worker_bee.first_name =
    (char*)malloc(sizeof(char) * (strlen(dummy_name) + 1));
strcpy(worker_bee.first_name, dummy_name);
printf("What is the last name of the employee?\n");
fgets(dummy_name, maximum_name_length, stdin);
if (dummy_name[strlen(dummy_name)-1] == '\n') {
    dummy_name[strlen(dummy_name)-1] = '\0';
} /* if (dummy_name[strlen(dummy_name)-1]=='\n') */
worker_bee.last_name =
    (char*)malloc(sizeof(char) * (strlen(dummy_name) + 1));
Structure Example #3

```c
strcpy(worker_bee.last_name, dummy_name);
printf("What is %s %s's pay rate in $/hour?\n",
    worker_bee.first_name, worker_bee.last_name);
scanf("%f", &worker_bee.pay_rate);
printf("How many hours did %s %s work this week?\n",
    worker_bee.first_name, worker_bee.last_name);
scanf("%f", &worker_bee.hours_worked_this_week);
printf("What is %s %s's social security number?\n",
    worker_bee.first_name, worker_bee.last_name);
scanf("%d", &worker_bee.social_security_number);
```
Structure Example #4

worker_bee_pay =
    worker_bee.pay_rate * 
    worker_bee.hours_worked_this_week;
printf("Employee %s %s (%9.9d)\n",
    worker_bee.first_name,
    worker_bee.last_name,
    worker_bee.social_security_number);
printf("  worked %2.2f hours this week\n",
    worker_bee.hours_worked_this_week);
printf("  at a rate of $%2.2f per hour,\n",
    worker_bee.pay_rate);
printf("  earning $%2.2f.\n", worker_bee_pay);
return program_success_code;
} /* main */
Structure Example #5

```bash
% gcc -o employee_test employee_test.c
% employee_test
```

What is the first name of the employee? **Henry**

What is the last name of the employee? **Neeman**

What is Henry Neeman’s pay rate in $/hour? **12.5**

How many hours did Henry Neeman work this week? **22.75**

What is Henry Neeman’s social security number? **123456789**

Employee Henry Neeman (123456789) worked 22.75 hours this week at a rate of $12.50 per hour, earning $284.38.
Structure Array

When we started working on this task, we wanted to figure out a convenient way to store the many employees of the company.

So far, we’ve worked out how to define a structure, how to declare an individual instance of the `struct`, and how to use the fields of the instance.

So, how would we declare and use an array of instances of a struct?

```
Employee worker_bee_array[maximum_employees];
```
Structure Array: Static vs Dynamic

Employee worker_bee_array[maximum_employees];

Not surprisingly, an array whose elements are a struct can either be declared to be statically allocated (above) or dynamically allocatable (below):

Employee* worker_bee_array2 = (Employee*)NULL;
Structure Array: Dynamic Allocation

Employee* worker_bee_array2 = (Employee*)NULL;

If a struct array is declared to be dynamically allocatable, then allocating it looks just like allocating an array of a scalar data type:

worker_bee_array2 =
    (Employee*)malloc(sizeof(Employee) * number_of_employees);
Structure Array: Indexing

An individual element of an array of some struct data type can be accessed using indexing, exactly as if it were an element of an array of scalar data type:

```
worker_bee_array[index]
```
Structure Array: Element’s Field Access

Fields of an individual element of an array of a struct data type can be accessed thus:

```
worker_bee_array[index].pay_rate
```

For example:

```
worker_bee_array[index].pay_rate = 6.50;
printf("%f\n", worker_bee_array[index].pay_rate);
```
Structure Array Example #1

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

int main ()
{ /* main */
  typedef struct {
    char* first_name;
    char* last_name;
    float pay_rate;
    float hours_worked_this_week;
    int social_security_number;
  } Employee;
  const int maximum_name_length = 32;
  const int program_failure_code = -1;
  const int program_success_code = 0;
  Employee* worker_bee = (Employee*)NULL;
  float* worker_bee_pay = (float*)NULL;
  char dummy_name[maximum_name_length + 1];
  int number_of_worker_bees, index;
```
Structure Array Example #2

```c
printf("How many employees does the company have?\n");
scanf("%d", &number_of_worker_bees);
worker_bee =
    (Employee*)malloc(sizeof(Employee) * 
        number_of_worker_bees);
if (worker_bee == (Employee*)NULL) {
    printf("ERROR: can't allocate worker_bee array ");
    printf("of length %d Employees\n", 
        number_of_worker_bees);
    exit(program_failure_code);
}
worker_bee_pay = (float*)malloc(sizeof(float) * 
    number_of_worker_bees);
if (worker_bee_pay == (float*)NULL) {
    printf("ERROR: can't allocate worker_bee_pay ");
    printf("array of length %d floats", 
        number_of_worker_bees);
    exit(program_failure_code);
}
```

for (index = 0;
    index < number_of_worker_bees; index++) {
    /* I DO NOT UNDERSTAND WHY THIS IS NEEDED! */
    getchar();

    printf("What is the first name of ");
    printf("employee #\%d?\n", index);
    fgets(dummy_name, maximum_name_length, stdin);
    if (dummy_name[strlen(dummy_name)-1] == '\n') {
        dummy_name[strlen(dummy_name)-1] = '\0';
    } /* if (dummy_name[strlen(dummy_name)-1]...) */
    worker_bee[index].first_name =
        (char*)malloc(sizeof(char) *
                        (strlen(dummy_name) + 1));
    strcpy(worker_bee[index].first_name,
            dummy_name);
Structure Array Example #4

```c
printf("What is the last name of ");
printf("employee #\%d?\n", index);
fgets(dummy_name, maximum_name_length, stdin);
if (dummy_name[strlen(dummy_name)-1] == '\n') {
    dummy_name[strlen(dummy_name)-1] = '\0';
} /* if (dummy_name[strlen(dummy_name)-1]...) */
worker_bee[index].last_name =
    (char*)malloc(sizeof(char) *
        (strlen(dummy_name) + 1));
strcpy(worker_bee[index].last_name,
       dummy_name);
```

```
Structure Array Example #5

```c
printf("What is %s %s's pay rate in $/hour?\n",
    worker_bee[index].first_name,
    worker_bee[index].last_name);
scanf("%f", &worker_bee[index].pay_rate);
printf("How many hours did %s %s work ",
    worker_bee[index].first_name,
    worker_bee[index].last_name);
printf("this week?\n");
scanf("%f",
    &worker_bee[index].hours_worked_this_week);
printf("What is %s %s's ",
    worker_bee[index].first_name,
    worker_bee[index].last_name);
printf("social security number?\n");
scanf("%d",
    &worker_bee[index].social_security_number);
} /* for index */
```
Structure Array Example #6

```c
for (index = 0;
    index < number_of_worker_bees; index++) {
    worker_bee_pay[index] =
        worker_bee[index].pay_rate *
        worker_bee[index].hours_worked_this_week;
} /* for index */
```
Structure Array Example #7

for (index = 0;
    index < number_of_worker_bees; index++) {
    printf("Employee %s %s (%9.9d)\n",
            worker_bee[index].first_name,
            worker_bee[index].last_name,
            worker_bee[index].social_security_number);
    printf("  worked %2.2f hours this week\n",
            worker_bee[index].hours_worked_this_week);
    printf("  at a rate of $%2.2f per hour,\n",
            worker_bee[index].pay_rate);
    printf("  earning $%2.2f.\n",
            worker_bee_pay[index]);
} /* for index */
return program_success_code;
} /* main */
Structure Array Example #8

```bash
% gcc -o employee_array_test employee_array_test.c
% employee_array_test
How many employees does the company have?
2
What is the first name of employee #0?
Henry
What is the last name of the employee #0?
Neeman
What is Henry Neeman’s pay rate in $/hour?
12.5
How many hours did Henry Neeman work this week?
22.75
What is Henry Neeman’s social security number?
123456789
```
Structure Array Example #9

What is the first name of employee #1?
Lee
What is the last name of the employee #1?
Kim
What is Lee Kim’s pay rate in $/hour?
8.75
How many hours did Lee Kim work this week?
40
What is Lee Kim’s social security number?
987654321

Employee Henry Neeman (123456789)
worked 22.75 hours this week
at a rate of $12.50 per hour,
earning $284.38.

Employee Lee Kim (987654321)
worked 40.00 hours this week
at a rate of $8.75 per hour,
earning $350.00.