Structures Lesson Outline

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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* list1_input_value = (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?
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.

(Here, “user” means the programmer, not the person running the program, just as in “user-defined function.”)
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.
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.
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.
Fields of a Structure Instance #1

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?
Fields of a Structure Instance #2

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:

    list1_input_value[element] = 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", list1_input_value[element]);
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
list1_input_value[element] = 24.5;
printf("%f\n", list1_input_value[element]);
```
Structure Fields Like Array Elements #2

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.pay_rate` can be used exactly like a `float` scalar;
- `worker_bee.first_name` can be used exactly like a character string.
# Structure Example #1

```c
#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;
}
```
Structure Example #2

```c
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';
}

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';
}

worker_bee.last_name =
    (char*)malloc(sizeof(char) * (strlen(dummy_name) + 1));
```

Huh?
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

```c
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

% 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);
```
#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 = (Employee*)NULL;
    float* worker_bee_pay = (float*)NULL;
    char dummy_name[maximum_name_length + 1];
    int number_of_worker_bees, index;
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);
}
/* if (worker_bee == (Employee*)NULL) */
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);
} /* if (worker_bee_pay == (float*)NULL) */
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

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

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 */
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

% 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.