Lecture 16 - Structures, Unions and Enumerations

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Introduction

- C allows us to perform arithmetic—addition and subtraction—on pointers to array elements.
- This leads to an alternative way of processing arrays in which pointers take the place of array subscripts.
- The relationship between pointers and arrays in C is a close one.
- Understanding this relationship is critical for mastering C.

Structure Variables

- The properties of a ***structure*** are different from those of an array.
  - The elements of a structure (its ***members***) aren't required to have the same type.
  - The members of a structure have names; to select a particular member, we specify its name, not its position.
- In some languages, structures are called ***records,*** and members are known as ***fields.***

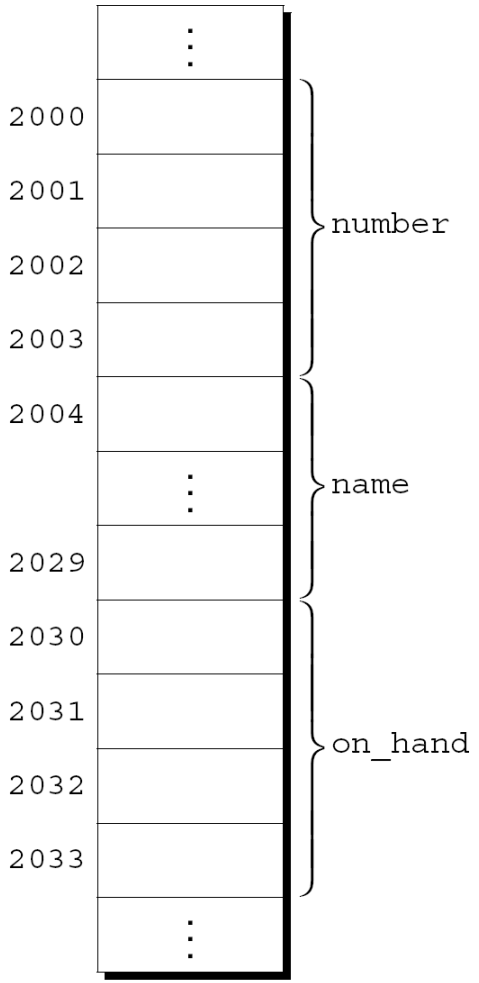
Declaring Structure Variables

- A structure is a logical choice for storing a collection of related data items.
- A declaration of two structure variables that store information about parts in a warehouse:

```
struct {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} part1, part2;
```

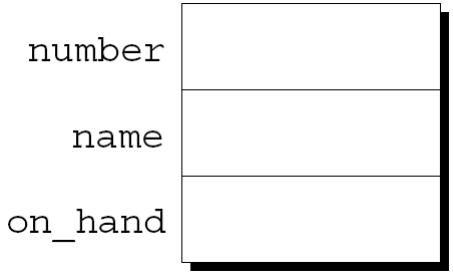
Declaring Structure Variables (cont.)

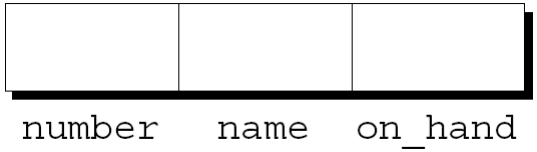
- The members of a structure are stored in memory in the order in which they're declared.
- Appearance of `part1` 
- Assumptions:
  - `part1` is located at address 2000.
  - Integers occupy four bytes.
  - `NAME_LEN` has the value 25.
  - There are no gaps between the members.



Declaring Structure Variables (cont.)

- Abstract representations of a structure:





- Member values will go in the boxes later.

Declaring Structure Variables (cont.)

- Each structure represents a new scope.
- Any names declared in that scope won't conflict with other names in a program.
- In C terminology, each structure has a separate ***name space*** for its members.

Declaring Structure Variables (cont.)

- For example, the following declarations can appear in the same program:

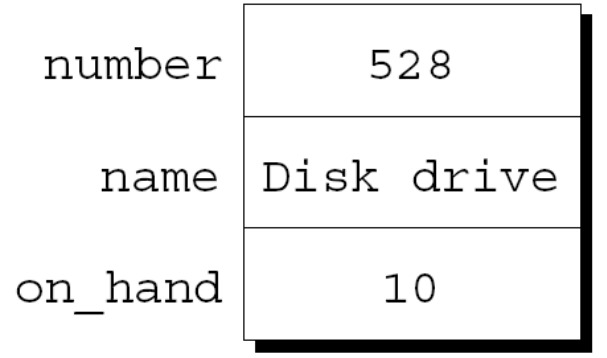
```
struct {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} part1, part2;

struct {
  char name[NAME_LEN+1];
  int number;
  char sex;
} employee1, employee2;
```

Initializing Structure Variables

- A structure declaration may include an initializer:

```
struct {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} part1 = {528, "Disk drive", 10},
  part2 = {914, "Printer cable", 5};
```

- Appearance of `part1` after initialization:



Initializing Structure Variables (cont.)

- Structure initializers follow rules similar to those for array initializers.
- Expressions used in a structure initializer must be constant. (This restriction is relaxed in C99.)
- An initializer can have fewer members than the structure it's initializing.
- Any "leftover" members are given 0 as their initial value.

Designated Initializers (C99)

- The initializer for `part1` shown in the previous example:

```
{528, "Disk drive", 10}
```

- In a designated initializer, each value would be labeled by the name of the member that it initializes:

```
{.number = 528, .name = "Disk drive", .on_hand = 10}
```

- The combination of the period and the member name is called a ***designator.***

Designated Initializers (C99) (cont.)

- Designated initializers are easier to read and check for correctness.
- Also, values in a designated initializer don't have to be placed in the same order that the members are listed in the structure.
  - The programmer doesn't have to remember the order in which the members were originally declared.
  - The order of the members can be changed in the future without affecting designated initializers.

Designated Initializers (C99) (cont.)

- Not all values listed in a designated initializer need be prefixed by a designator.
- Example:

```
{.number = 528, "Disk drive", .on_hand = 10}
```

  The compiler assumes that `"Disk drive"` initializes the member that follows `number` in the structure.

- Any members that the initializer fails to account for are set to zero.

Operations on Structures

- To access a member within a structure, we write the name of the structure first, then a period, then the name of the member.
- Statements that display the values of `part1`'s members:

```
printf("Part number: %d\n", part1.number);
printf("Part name: %s\n", part1.name);
printf("Quantity on hand: %d\n", part1.on_hand);
```

Operations on Structures (cont.)

- The members of a structure are lvalues.
- They can appear on the left side of an assignment or as the operand in an increment or decrement expression:

```
part1.number = 258;
  /* changes part1's part number */
part1.on_hand++;
  /* increments part1's quantity on hand */
```

Operations on Structures (cont.)

- The period used to access a structure member is actually a C operator.
- It takes precedence over nearly all other operators.
- Example:

```
scanf("%d", &part1.on_hand);
```

The . operator takes precedence over the `&` operator, so `&` computes the address of `part1.on_hand`.

Operations on Structures (cont.)

- The other major structure operation is assignment:

```
part2 = part1;
```

- The effect of this statement is to copy `part1.number` into `part2.number`, `part1.name` into `part2.name`, and so on.

Operations on Structures (cont.)

- Arrays can't be copied using the = operator, but an array embedded within a structure is copied when the enclosing structure is copied.
- Some programmers exploit this property by creating "dummy" structures to enclose arrays that will be copied later:

```
struct { int a[10]; } a1, a2;
a1 = a2;
  /* legal, since a1 and a2 are structures */
```

Structure Types

- Suppose that a program needs to declare several structure variables with identical members.
- We need a name that represents a type of structure, not a particular structure variable.
- Ways to name a structure:
  - Declare a "structure tag"
  - Use typedef to define a type name

Declaring a Structure Tag

- A ***structure tag*** is a name used to identify a particular kind of structure.
- The declaration of a structure tag named `part`:

```
struct part {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
};
```

- Note that a semicolon must follow the right brace.

Declaring a Structure Tag (cont.)

- The `part` tag can be used to declare variables:

```
struct part part1, part2;
```

- We can't drop the word `struct`:

```
part part1, part2;   /*** WRONG ***/
```

`part` isn't a type name; without the word `struct`, it is meaningless.

- Since structure tags aren't recognized unless preceded by the word `struct`, they don't conflict with other names used in a program.

Declaring a Structure Tag (cont.)

- The declaration of a structure *tag* can be combined with the declaration of structure *variables:*

```
struct part {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} part1, part2;
```

Declaring a Structure Tag (cont.)

- All structures declared to have type `struct part` are compatible with one another:

```
struct part part1 = {528, "Disk drive", 10};
struct part part2;

part2 = part1;
  /* legal; both parts have the same type */
```

Defining a Structure Type

- As an alternative to declaring a structure tag, we can use `typedef` to define a genuine type name.
- A definition of a type named `Part`:

```
typedef struct {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} Part;
```

- `Part` can be used in the same way as the built-in types:

```
Part part1, part2;
```

Structures as Arguments and Return Values

- Functions may have structures as arguments and return values.
- A function with a structure argument:

```
void print_part(struct part p)
{
  printf("Part number: %d\n", p.number);
  printf("Part name: %s\n", p.name);
  printf("Quantity on hand: %d\n", p.on_hand);
}
```

- A call of `print_part`:

```
print_part(part1);
```

Structures as Arguments and Return Values (cont.)

- A function that returns a `part` structure:

```
struct part build_part(int number, const char *name,
                       int on_hand)
{
  struct part p;

  p.number = number;
  strcpy(p.name, name);
  p.on_hand = on_hand;
  return p;
}
```

- A call of `build_part`:

```
part1 = build_part(528, "Disk drive", 10);
```

Structures as Arguments and Return Values (cont.)

- Passing a structure to a function and returning a structure from a function both require making a copy of all members in the structure.
- To avoid this overhead, it's sometimes advisable to pass a pointer to a structure or return a pointer to a structure.
- Lecture 17 gives examples of functions that have a pointer to a structure as an argument and/or return a pointer to a structure.

Structures as Arguments and Return Values (cont.)

- There are other reasons to avoid copying structures.
- For example, the `<stdio.h>` header defines a type named `FILE`, which is typically a structure.
- Each `FILE` structure stores information about the state of an open file and therefore must be unique in a program.
- Every function in `<stdio.h>` that opens a file returns a pointer to a `FILE` structure.
- Every function that performs an operation on an open file requires a `FILE` pointer as an argument.

Structures as Arguments and Return Values (cont.)

- Within a function, the initializer for a structure variable can be another structure:

```
void f(struct part part1)
{
  struct part part2 = part1;
  …
}
```

- The structure being initialized must have automatic storage duration.

Compound Literals (C99)

- Lecture 9 introduced the C99 feature known as the ***compound literal*.**
- A compound literal can be used to create a structure "on the fly," without first storing it in a variable.
- The resulting structure can be passed as a parameter, returned by a function, or assigned to a variable.

Compound Literals (C99)

- A compound literal can be used to create a structure that will be passed to a function:

```
print_part((struct part) {528, "Disk drive", 10});
```

  The compound literal is shown in **bold**.

- A compound literal can also be assigned to a variable:

```
part1 = (struct part) {528, "Disk drive", 10};
```

- A compound literal consists of a type name within parentheses, followed by a set of values in braces.
- When a compound literal represents a structure, the type name can be a structure tag preceded by the word `struct` or a `typedef` name.

Compound Literals (C99) (cont.)

- A compound literal may contain designators, just like a designated initializer:

```
print_part((struct part) {.on_hand = 10,
                          .name = "Disk drive",
                          .number = 528});
```

- A compound literal may fail to provide full initialization, in which case any uninitialized members default to zero.

Nested Arrays and Structures

- Structures and arrays can be combined without restriction.
- Arrays may have structures as their elements, and structures may contain arrays and structures as members.

Nested Structures

- Nesting one structure inside another is often useful.
- Suppose that `person_name` is the following structure:

```
struct person_name {
  char first[FIRST_NAME_LEN+1];
  char middle_initial;
  char last[LAST_NAME_LEN+1];
};
```

Nested Structures (cont.)

- We can use `person_name` as part of a larger structure:

```
struct student {
  struct person_name name;
  int id, age;
  char sex;
} student1, student2;
```

- Accessing `student1`'s first name, middle initial, or last name requires two applications of the . operator:

```
strcpy(student1.name.first, "Fred");
```

Nested Structures (cont.)

- Having `name` be a structure makes it easier to treat names as units of data.
- A function that displays a name could be passed one `person_name` argument instead of three arguments:

```
display_name(student1.name);
```

- Copying the information from a `person_name` structure to the `name` member of a student structure would take one assignment instead of three:

```
struct person_name new_name;
…
student1.name = new_name;
```

Arrays of Structures

- One of the most common combinations of arrays and structures is an array whose elements are structures.
- This kind of array can serve as a simple database.
- An array of `part` structures capable of storing information about 100 parts:

```
struct part inventory[100];
```

Arrays of Structures (cont.)

- Accessing a part in the array is done by using subscripting:

```
print_part(inventory[i]);
```

- Accessing a member within a `part` structure requires a combination of subscripting and member selection:

```
inventory[i].number = 883;
```

- Accessing a single character in a part name requires subscripting, followed by selection, followed by subscripting:

```
inventory[i].name[0] = '\0';
```

Initializing an Array of Structures

- Initializing an array of structures is done in much the same way as initializing a multidimensional array.
- Each structure has its own brace-enclosed initializer; the array initializer wraps another set of braces around the structure initializers.

Initializing an Array of Structures (cont.)

- One reason for initializing an array of structures is that it contains information that won't change during program execution.
- Example: an array that contains country codes used when making international telephone calls.
- The elements of the array will be structures that store the name of a country along with its code:

```
struct dialing_code {
  char *country;
  int code;
};
```

Initializing an Array of Structures (cont.)

```
const struct dialing_code country_codes[] =
  {{"Argentina",             54}, {"Bangladesh",       880},
   {"Brazil",                55}, {"Burma (Myanmar)",   95},
   {"China",                 86}, {"Colombia",          57},
   {"Congo, Dem. Rep. of", 243}, {"Egypt",             20},
   {"Ethiopia",            251}, {"France",            33},
   {"Germany",              49}, {"India",             91},
   {"Indonesia",            62}, {"Iran",              98},
   {"Italy",                39}, {"Japan",             81},
   {"Mexico",               52}, {"Nigeria",          234},
   {"Pakistan",             92}, {"Philippines",       63},
   {"Poland",               48}, {"Russia",             7},
   {"South Africa",         27}, {"South Korea",       82},
   {"Spain",                34}, {"Sudan",            249},
   {"Thailand",             66}, {"Turkey",            90},
   {"Ukraine",             380}, {"United Kingdom",    44},
   {"United States",         1}, {"Vietnam",           84}};
```

- The inner braces around each structure value are optional.

Initializing an Array of Structures (cont.)

- C99's designated initializers allow an item to have more than one designator.
- A declaration of the `inventory` array that uses a designated initializer to create a single part:

```
struct part inventory[100] =
  {[0].number = 528, [0].on_hand = 10,
   [0].name[0] = '\0'};
```

The first two items in the initializer use two designators; the last item uses three.

Program: Maintaining a Parts Database

- The `inventory.c` program illustrates how nested arrays and structures are used in practice.
- The program tracks parts stored in a warehouse.
- Information about the parts is stored in an array of structures.
- Contents of each structure:
  - Part number
  - Name
  - Quantity

Program: Maintaining a Parts Database (cont.)

- Operations supported by the program:
  - Add a new part number, part name, and initial quantity on hand
  - Given a part number, print the name of the part and the current quantity on hand
  - Given a part number, change the quantity on hand
  - Print a table showing all information in the database
  - Terminate program execution

Program: Maintaining a Parts Database (cont.)

- The codes `i` (insert), `s` (search), `u` (update), `p` (print), and `q` (quit) will be used to represent these operations.
- A session with the program:

```
Enter operation code: i
Enter part number: 528
Enter part name: Disk drive
Enter quantity on hand: 10

Enter operation code: s
Enter part number: 528
Part name: Disk drive
Quantity on hand: 10
```

Program: Maintaining a Parts Database (cont.)

```
Enter operation code: s
Enter part number: 914
Part not found.

Enter operation code: i
Enter part number: 914
Enter part name: Printer cable
Enter quantity on hand: 5

Enter operation code: u
Enter part number: 528
Enter change in quantity on hand: -2
```

Program: Maintaining a Parts Database (cont.)

```
Enter operation code: s
Enter part number: 528
Part name: Disk drive
Quantity on hand: 8

Enter operation code: p
Part Number   Part Name                 Quantity on Hand
    528       Disk drive                       8
    914       Printer cable                    5

Enter operation code: q
```

Program: Maintaining a Parts Database (cont.)

- The program will store information about each part in a structure.
- The structures will be stored in an array named `inventory`.
- A variable named `num_parts` will keep track of the number of parts currently stored in the array.

Program: Maintaining a Parts Database (cont.)

- An outline of the program's main loop:

```
for (;;) {
    prompt user to enter operation code;
    read code;
    switch (code) {
      case 'i': perform insert operation; break;
      case 's': perform search operation; break;
      case 'u': perform update operation; break;
      case 'p': perform print operation; break;
      case 'q': terminate program;
      default:  print error message;
    }
}
```

Program: Maintaining a Parts Database (cont.)

- Separate functions will perform the insert, search, update, and print operations.
- Since the functions will all need access to `inventory` and `num_parts`, these variables will be external.
- The program is split into three files:
  - `inventory.c` (the bulk of the program)
  - `readline.h` (contains the prototype for the `read_line` function)
  - `readline.c` (contains the definition of `read_line`)

Program: Maintaining a Parts Database (cont.)

inventory.c

```
#include <stdio.h>
#include "readline.h"

#define NAME_LEN 25
#define MAX_PARTS 100

struct part {
  int number;
  char name[NAME_LEN+1];
  int on_hand;
} inventory[MAX_PARTS];

int num_parts = 0;   /* number of parts currently stored */

int find_part(int number);
void insert(void);
void search(void);
void update(void);
void print(void);
```

Program: Maintaining a Parts Database (cont.)

```
int main(void)
{
  char code;
  for (;;) {
    printf("Enter operation code: ");
    scanf(" %c", &code);
    while (getchar() != '\n')   /* skips to end of line */
      ;
    switch (code) {
      case 'i': insert();
                break;
      case 's': search();
                break;
      case 'u': update();
                break;
      case 'p': print();
                break;
      case 'q': return 0;
      default:  printf("Illegal code\n");
    }
    printf("\n");
  }
}
```

Program: Maintaining a Parts Database (cont.)

```
int find_part(int number)
{
  int i;

  for (i = 0; i < num_parts; i++)
    if (inventory[i].number == number)
      return i;
  return -1;
}

void insert(void)
{
  int part_number;

  if (num_parts == MAX_PARTS) {
    printf("Database is full; can't add more parts.\n");
    return;
  }
```

Program: Maintaining a Parts Database (cont.)

```
  printf("Enter part number: ");
  scanf("%d", &part_number);
  if (find_part(part_number) >= 0) {
    printf("Part already exists.\n");
    return;
  }
  // insert at the end
  inventory[num_parts].number = part_number;
  printf("Enter part name: ");
  read_line(inventory[num_parts].name, NAME_LEN);
  printf("Enter quantity on hand: ");
  scanf("%d", &inventory[num_parts].on_hand);
  num_parts++;
}
```

Program: Maintaining a Parts Database (cont.)

```
void search(void)
{
  int i, number;

  printf("Enter part number: ");
  scanf("%d", &number);
  i = find_part(number);
  if (i >= 0) {
    printf("Part name: %s\n", inventory[i].name);
    printf("Quantity on hand: %d\n", inventory[i].on_hand);
  } else
    printf("Part not found.\n");
}
```

Program: Maintaining a Parts Database (cont.)

```
void update(void)
{
  int i, number, change;

  printf("Enter part number: ");
  scanf("%d", &number);
  i = find_part(number);
  if (i >= 0) {
    printf("Enter change in quantity on hand: ");
    scanf("%d", &change);
    inventory[i].on_hand += change;
  } else
    printf("Part not found.\n");
}
```

Program: Maintaining a Parts Database (cont.)

```
void print(void)
{
  int i;

  printf("Part Number   Part Name                    "
         "Quantity on Hand\n");
  for (i = 0; i < num_parts; i++)
    printf("%7d       %-25s%11d\n", inventory[i].number,
           inventory[i].name, inventory[i].on_hand);
}
```

```
Enter operation code: p
Part Number   Part Name                  Quantity on Hand
      528     Disk drive                               8
      914     Printer cable                            5
```

Program: Maintaining a Parts Database (cont.)

- The version of `read_line` in Lecture 13 won't work properly in the current program.
- Consider what happens when the user inserts a part:

```
Enter part number: 528
Enter part name: Disk drive
```

- The user presses the Enter key after entering the part number, leaving an invisible new-line character that the program must read.
- When `scanf` reads the part number, it consumes the 5, 2, and 8, but leaves the new-line character unread.

Program: Maintaining a Parts Database

- If we try to read the part name using the original `read_line` function, it will encounter the new-line character immediately and stop reading.
- This problem is common when numerical input is followed by character input.
- One solution is to write a version of `read_line` that skips white-space characters before it begins storing characters.
- This solves the new-line problem and also allows us to avoid storing blanks that precede the part name.

Program: Maintaining a Parts Database (cont.)

readline.h

```
#ifndef READLINE_H
#define READLINE_H

/**********************************************************
 * read_line: Skips leading white-space characters, then  *
 *            reads the remainder of the input line and   *
 *            stores it in str. Truncates the line if its *
 *            length exceeds n. Returns the number of     *
 *            characters stored.                          *
 **********************************************************/
int read_line(char str[], int n);

#endif
```

Program: Maintaining a Parts Database (cont.)

readline.c

```
#include <ctype.h>
#include <stdio.h>
#include "readline.h"

int read_line(char str[], int n)
{
  int ch, i = 0;

  while (isspace(ch = getchar()))
    ;
  while (ch != '\n' && ch != EOF) {
    if (i < n)
      str[i++] = ch;
    ch = getchar();
  }
  str[i] = '\0';
  return i;
}
```