Languages for Informatics

6 – User defined datatype and data structure

Department of Computer Science
University of Pisa
Largo B. Pontecorvo 3
56127 Pisa

Topics

- Linux programming environment (2h)
- Introduction to C programming (12h)
  1. Getting started with C Progamming
  2. Variables, Data-types, Operators and Control Flow
  3. Functions and Libraries
  4. Arrays and Pointers
  5. User defined datatype and data structure
  6. Input and Output
- Basic system programming in Linux (10h)

Overview

Definition of a `struct`

- Array: *N* items all having the **same type**.
- `struct`: a collection of possibly **different types** grouped together under a single name.
  - made out of primitive data type variables
  - can contain arrays
  - can contain other structs

General syntax for a `struct` declaration:

```
struct <StructName> {
    <type name1>;
    <type name2>;
     ...
};
```

Basics

Example

```
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
    double food[7];   // food during last week (kg)
}; /* notice the ';' at the end */
```

Features and Usage

- **`struct`** defines a **new datatype**
- The variables declared within a structure are called its **members**
- An optional `TagLabel` may be assigned:
  `struct {...} TagLabel;`
- Variables can be declared like any other built in data-type
  `struct <StructName> <MyfavoriteName>;`
- To (read/write) access a member of **`struct`**, use the following syntax `<MyfavoriteName>.<MemberName>`

Parametric Init

Example

```
#include <stdio.h>
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
    double food[7];   // food during last week (kg)
};

int main(){
        struct cat felix;          /* Declaration */
        struct cat luna;

        felix.age = 14;            /* Assignment */
        felix.weight = 4.5;
        luna.age = felix.age - 5;
        luna.food[0] = 0.5;
        luna.weight = 5.3;

        if (luna.weight > 5)
                printf("Luna eats too much!\n");

        return 0;
}
```

Direct Init

Example

To initialize a **`struct`**, values can be assigned to its members in the same order they appear in the declaration of the `struct`:

```
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
    double food[7];   // food during last week (kg)
};

int main(){
        struct cat felix = {14, 4.5, {0.2, 0.1, 0.3, 0.3, 0.2, 0.5, 0.3}};

        /* do something */

        return 0;
}
```

Passing structs to functions

Here's how you can pass structs as argument to a function

```
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
    double food[7];   // food during last week
      (kg)
};
void display(struct cat mycat);

int main(){
        struct cat felix;    /* Declaration */
        felix.age = 14;      /* Assignment */
        felix.weight = 4.5;

        display(felix);    /* call function */
        return 0;
}

void display(struct cat mycat) {    /* STRUCT
      as argument */
   printf("\nDisplaying info\n");
   printf("Age: %d\n", mycat.age);
   printf("Weight: %.2lf", mycat.weight);
}
```

Output

```
Displaying info
Age:  14
Weight:  4.50
```

Returning structs from a function

Here's how you can return a structure from a function

```
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
};
struct cat setInformation();

int main(){
        struct cat felix; /* Declaration */

        felix = setInformation();
        printf("\nDisplaying info\n");
        printf("Age: %d\n", felix.age);
        printf("Weight: %.2lf", felix.weight);
        return 0;
}
struct cat setInformation() { /* returning a
      STRUCT */
   struct cat mycat;
   printf("Age: "); scanf("%d", &mycat.age);
   printf("Weight: "); scanf("%lf", &mycat.
      weight);
   return mycat;
}
```

Output

```
Age:   14
Weight:   4.5
Displaying info
Age:  14
Weight:  4.50
```

Passing a struct as a parameter

Let us assume to have a **`struct`** `cat` named `felix`:

```
struct cat felix;
```

Passing a **`struct`** as a parameter works like passing a variable:

- If you want to pass a **copy** of variable in **`felix`** to the frame of the function, pass the value of **`struct`**:
  `check_weight(felix);`
- If you want to pass a **reference** to the variables in **`felix`** (changes visible also when function returns), pass the memory's address of **`struct`**:
  `update_weight(&felix, new_weight);`

Access to `struct`

Summary:

- To access variables in a **`struct`** *s*, when we have the *value* of the struct

```
struct name_struct s
s.name_var
```

- To access variables in a **`struct`** *s*, when we have the *address* of the struct

```
struct name_struct* s
s->name_var
```

Passing structs by reference

Example

```c
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
};
void update_weight(struct cat *felix, double new_weight);

int main(){
   struct cat felix;          /* Declaration */
   felix.weight = 4.5;        /* Assignment */

   printf("Current Weight: %.2lf \n", felix.weight);
   update_weight(&felix, 5.2);  //pass a reference
   printf("Updated Weight: %.2lf", felix.weight);
   return 0;
}
void update_weight(struct cat *felix, double new_weight) {
   felix->weight = new_weight;   /* modifies the struct */
}
```

Output

```
Current
Weight:   4.50
Updated
Weight:   5.20
```

`struct` and arrays

A `struct` can contain an array, accessible like a primitive data.

`struct` and arrays

Example

```
struct cat {
    int age;          // cat's age
    double weight;    // weight (kg)
    double food[7];   // food during the last week (kg)
};
int main(){
        struct cat felix;
        int i;
        double sum_food = 0;

        felix.age = 14;
        felix.food[0] = 0.50;
        felix.food[1] = 0.22;
        felix.food[2] = 0.56;

        for (i=0; i<3; i++)
                sum_food += felix.food[i];
        printf("In three days, Felix ate %.2lf kg.", sum_food);
        return 0;
}
```

Output

```
In three days, Felix ate 1.28 kg.
```

Arrays of Structures (1)

- Consider writing a program that counts the number of each cat.
- We need an array of char strings to hold the names, and array of integer for the counts.
- One possibility is to use two parallel arrays

```
char *name[NumCats];
int count[NumCats];
```

- But the very fact that the arrays are parallel suggests a different organization, an array of structures. Each keyword is a pair:

```
char *name;
int count;
```

Arrays of Structures (2)

- The structure declaration

```
struct cat {
    char *name;
    int count:
} cats[NumCats];
```

- declares a structure type `cat`, and there is an array of pairs.

Arrays of Structures (3)

- This could also be written as

```
struct cat {
    char *name;
    int count:
};

struct cat cats[NumCats];
```

Arrays of Structures

Example

```
#include <stdio.h>
#define NumCats 2
struct cat {
    char *name;
    int count;
} cats[NumCats];


int main() {
   cats[0].name = "Felix"; //declare & init
   cats[0].count = 31;
   cats[1].name = "Luna";
   cats[1].count = 12;

   for (int i=0;i<NumCats;i++)
     printf("%d %s \n",cats[i].count,cats[i].name);

   return 0;
}
```

Output

```
31 Felix
12 Luna
```

Pointers to Structure

- Above array structure uses fixed amount memory.
- Can we allocate memory dynamically to `struct` types?
- We have already learned that a pointer is a variable which points to the address of another variable of any data type.
- Similarly, we can have **a pointer to structures**, where a pointer variable can point to the address of a structure variable.
- To get started, let us **use pointers to (array of) struct having fixed size**.

Pointers to Structure

Let us revisit above cat counting program, this time using **pointers instead of array indices.**

```
#include <stdio.h>
#include <string.h>
struct cat {
    char *name;
    int count;
};
int main() {
   struct cat mycat, *catPtr;    //a struct and a pointer
   catPtr = &mycat;              //Ptr points to struct

   catPtr->name = "Felix";       //assign values
   catPtr->count = 31;
   printf("%d %s \n",catPtr->count,catPtr->name);
   return 0;
}
```

Pointers to Structure

Note

- `catPtr->name` is equivalent to `(*catPtr).name`
- `catPtr->count` is equivalent to `(*catPtr).count`

Pointers to Structure

For a fixed number of cats,

```
#include <stdio.h>
#include <string.h>
#define NumCats 2
struct cat {
    char *name;
    int count;
};
int main() {
   struct cat mycat[NumCats], *catPtr; //array of struct + Ptr
   catPtr = mycat;                     // Ptr points to first element

   catPtr[0].name = "Felix";
   catPtr[0].count = 31;
   printf("catPtr[0] %d %s \n",catPtr[0].count,catPtr[0].name);
   return 0;
}
```

Nested `struct` (1)

- A **`struct`** can contain another **`struct`**, but there are rules.
- The size of the **`struct`** has to be finite, constant, and calculable at compilation time, therefore they cannot be recursive!
- A struct S_2 can contain a **`struct`** S_1 only if S_1 is defined before in the program.
- In this way, the nesting of **`struct`** forms a **tree**.

Nested `struct` (2)

```
struct city {
        int n_citizens;
};
struct nation {
        struct city capital;
        double surface;
        int time_zone;
};
```

The **`struct nation`** has a variable of type **`struct city`**.
The **`struct city`** **cannot have** a variable **`struct nation`**, otherwise it would not be possible to determine the space occupied by the **`struct`**.

Nested `struct` (3)

```
struct city {
        int citizens;
        struct nation n;
};
struct nation {
        struct city capital;
        double surface;
        int time_zone;
};
```

```
sizeof(struct city) = 4 + sizeof(struct nation)
sizeof(struct nation) = 4 + 8 + sizeof(struct city)
```

Note

This `struct` would form a loop rather than a tree. Hence, the compiler gives an **error**.

Self-referential `struct`

However, there are cases when structs have to logically recursively call themselves (recursive nesting). **Example**: we want to represent a family tree:

```
struct person {
        struct person mother;
        struct person father;
        int birth_year;
};
```

Memory size would tend to infinity. What to do?
Pointers to `struct` have always the same size (e.g., 8 bytes in 64 bit). Solution:

```
struct person {
        struct person* mother; //pointer to struct
        struct person* father;
        int birth_year;
};
```

Example

```c
int main() {

struct person me;                    //init
me.mother = NULL;
me.father = NULL;
me.birth_year = 2000;

struct person dad;
dad.mother = NULL;
dad.father = NULL;
dad.birth_year = 1971;

struct person mum;
mum.mother = NULL;
mum.father = NULL;
mum.birth_year = 1976;

me.father = &dad;                  //tree linking
me.mother = &mum;

//Print data
printf("me: %d\n", me.birth_year);
printf("dad: %d\n", me.father->birth_year);
printf("mum: %d", me.mother->birth_year);
return 0;
}
```

Terminal

```
me:  2000
dad:  1971
mum:  1976
```

Size of a `struct`

- The size of a **`struct`** is greater than or equal to the sum of the sizes of its members.
- Byte alignment

```
struct cat {
    int age;
    /* padding for alignment requirements */
    double weight;
    double food[7];
};
```

- Size of a **`struct`** is the sum of the sizes of its primitive data `PLUS possibly padding` to align with the ”natural” address boundaries.

Padding

- Why doing that? Unaligned memory access is slower on architectures that allow it (like x86 and amd64), and is explicitly prohibited on strict alignment architectures like SPARC.
- The structure **padding is automatically done by the compiler** to make sure all its members are byte aligned.
- A `char` of 1 byte can be allocated anywhere in memory.
- An `int` of 4 bytes must start at a 4-byte boundary.
- In our case,
  `sizeof(struct cat) == sizeof(int)` [4 Bytes] + PADDING [4 Bytes] + `sizeof(double)` [8 Bytes] + `7*sizeof(double)` [7*8 Bytes] = 72 Bytes.

Packing

- Packing, on the other hand prevents compiler from doing padding
- Alignment can be explicitly requested by the compiler extension **`__attribute__((__packed__))`**

```
struct __attribute__((__packed__)) cat {
    int age;                // 4 Bytes
    double weight;          // 8 Bytes
    double food[7];         // 7*8 = 56 Bytes
};
```

- Now, the `struct` **`cat`** occupies only 68 Bytes of memory.

typedef

The keyword **typedef** can be used to define an *alias* for types i.e., an alternative names for an existing data type.
Example:

```
typedef int age_t;
```

defines a new type `age_t`, equivalent to type `int`. Now, we can:

```
age_t age_mario = 67;
```

Equivalent to

```
int age_mario = 67;
```

typedef and struct

use **typedef** with structure to define a new data type and then use that data type to define structure variables directly (analogous for **enum** as we will see shortly).

Example:

```
struct student_struct{
        int StudentID;
        int birth_year;
};
typedef struct student_struct student;

int main(){
        student giorgio;     /* we save the long
    declaration */
        giorgio.StudentID = 666;
}
```

`typedef` and `struct`

It is also possible to define a struct directly with a **`typedef`**.

```
typedef struct {
        int StudentID;
        int birth_year;
} student;
```

This is the best way.

enum

- Enumeration is a **user defined datatype** in C language.
- It is used to **assign names to enumeration constants** (type **`int`**) making a program easy to read and maintain.
- keyword **`enum`** is used to declare an enumeration.
- Syntax

```
enum <EnumName> {const1, const2, ........ };
```

- The value of the first enumerator is zero by default.

enum

Example

Definition:

```
enum color_cat {
        red,
        black,
        white
};
```

Function `main`:

```
enum color_cat color;
color = red;
switch (color) {
  case red:
    /* do sth. */
    break;
  case black:
    /* do sth. else*/
    break;
  case white:
    /* do sth. else*/
    break;
}
```

enum

Example (cont'd)

Like in **struct**, it is possible to define **enum** and its **typedef** in one statement as follows:

Definition:

```
typedef enum {
        red,
        black,
        white
} color_cat;
```

Function `main`:

```
color_cat color;
color = red;
/* print enum values */
printf("color = %d\t%d\t%d\t
    \n",red,black,white);
```

Terminal

```
color = 0   1   2
```

enum

Example (cont'd)

To assign **other enumeration constants**,

Definition:

```
typedef enum {
        red=10,
        black,
        white=4
} color_cat;
```

Function `main`:

```
color_cat color;
printf("color = %d\t%d\t%d\t
    \n",red,black,white);
```

Terminal

```
color = 10    11    4
```

enum within struct

To access the enum types without a scope, declare them so:

```
typedef enum {
    red,
    black,
    white
} color_cat;

typedef struct {
    color_cat color;    /* enum call */
    int age;
    double weight;
} cat;

void main(){
    cat felix;
    felix.color = red;
    if (felix.color != black)
      printf("We wanted a black cat!");
}
```

Output

```
We wanted a
black cat!
```

union

A **union** is **one variable** that may hold objects of **different types** (and hence, sizes) in the **same memory location**.

- Any built-in or user defined data types can be used inside a union
- Useful when you want to store a data that could have several data types.

```
union <Tag> {
  <type1> <variable1>;
  <type2> <variable2>;
  ...
  <typeN> <variableN>;
} <UnionTag>;
```

- The UnionTag is optional.

`union` (cont'd)

- The size of the union variable is equal to the **size of its largest element plus padding**.

```
union foo {
  int i;          // 4 Bytes, 4-Byte alignment
  float f;        // 8 Bytes, 4-Byte alignment
  char str[10];   // 10*1 Byte, no alignment
};
int main() {
  union foo data;
  printf( "Memory size: %zu\n", sizeof(data));
  return 0;
}
```

Output

Memory size: 12

union

Example

```
int main() {
  union foo data;
  data.i = 10;
  data.f = 3.141529;
  strcpy(data.str,"Teams");
  printf( "data.i : %d\n", data.i);
  printf( "data.f : %.3f\n", data.f);
  printf( "data.str : %s\n", data.str);
  return 0;
}
```

What result do you expect?

union

Example (cont'd)

Output

data.i : 1835099476
data.f : 435978908727301740000000000.00000
data.str : Teams

Note

the `int` and `float` values of the union **became corrupted** because the final `str` value assigned to the variable has occupied the memory location.

Bit-fields

- A **bit-field** is a set of adjacent bits within a single `WORD`.
- One common use is a **set of single-bit flags** in applications like compiler symbol tables.
- Syntax

```
struct {
    type <StructName> : <Width> ;
};
```

- The `<type>` determines how a bit-field's value is interpreted. The type may be `int`, `signed int`, or `unsigned int`.
- The `<Width>` determines the number of **bits** in the bit-field. Its max. width is given by `type`.

Size of Bit-fields

- The **memory size** of a bit-field is determined by the sum of the bits for each variable **plus padding** to be aligned with a 4-Byte boundary of `int`.
- The idea is to use memory efficiently when we know that the value of a field or group of fields will never exceed a limit.
- ```
  struct flag {
      unsigned int error_code: 8;   // 8 bits
      unsigned int sector: 5;       // 5 bits
      unsigned int command: 5;      // 5 bits
  };
  ```
- The memory size is 4 Bytes (= 32 bits) according to `unsigned int`.
  ```

Bit-fields

Notes

- Some bit field members are stored left to right others are stored right to left in memory.
- If bit fields too large, next bit field may be stored consecutively in memory
- If portability of code is a premium you can use bit shifting and masking to achieve the same results
- Array of bit-fields is not allowed.

Dynamical allocation of a `struct`

- So far, we have assigned a fixed amount of memory to the array of **`struct`** e.g., `NumCats=2` elements.
- What to do when the `exact number of cats is unknown or the number becomes larger than two`???
- Alternative approach: Allocate **memory dynamically** to Pointers of struct

Dynamical memory allocation

Syntax

New memory allocation

```
<MyfavoriteName> = malloc(<Size> * sizeof(struct <
    StructName>));
```

New memory allocation + init to `NULL`

```
<MyfavoriteName> = calloc(<Size>,sizeof(struct <
    StructName>));
```

Memory reallocation (Elements are not deleted)

```
<MyfavoriteName> = realloc(<MyfavoriteName>,<NewSize>*sizeof(
    struct <StructName>));
```

Remedy against memory leaks

```
free(<MyfavoriteName>)
```

Dynamical memory allocation

Example

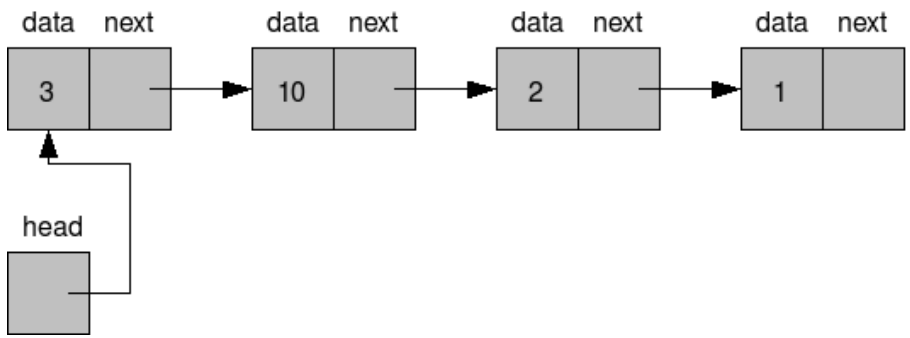
```
struct student {
        int birth_year;
        int StudID;
};
int main() {
  struct student* giovanni;  /* one struct */
  giovanni = malloc(sizeof(struct student));
  giovanni->birth_year = 1960;

  struct student* student_inf;   /* array of structs */
  student_inf = calloc(10, sizeof(struct student));
  student_inf[0].StudID = 431950;
  student_inf[0].birth_year= 1991;
  /* your favorite program */

free(giovanni);
free(student_inf);
```

Concatenated List

Let us see now a powerful data structure, the **Concatenated List**.

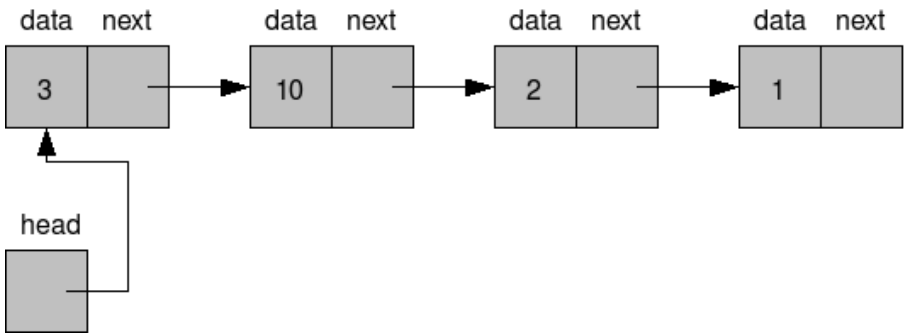


A list is made out of nodes:

1. Data;
2. Reference to the next node.

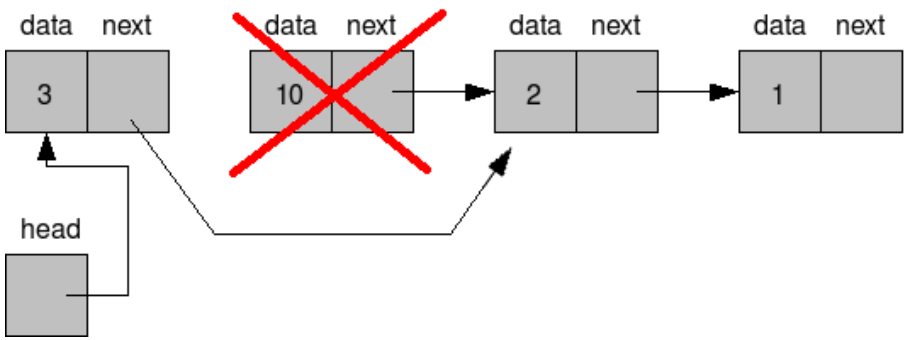
Rule: last node has, as reference to next, `NULL`.

Concatenated lists - properties



The list, like an array, keeps the data sorted, but:

3. The deletion of an element does not require the rebuilding of the whole array.



Concatenated list - code

Definition of `node` incorporated as `head`:

```
struct node
{
    int data;
    struct node *next;
};

struct node* head; // starting node of list
```

Concatenated list - append a node

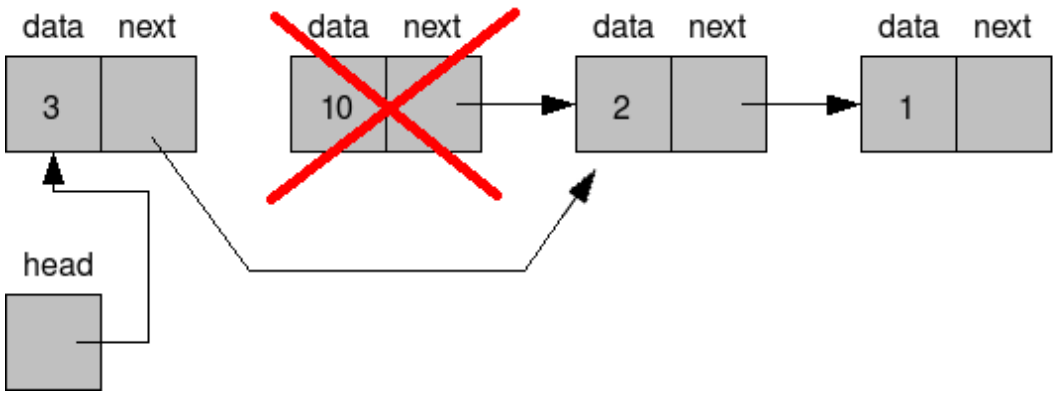
```
void append(int num)  //add to end of list
{
    struct node *temp,*last;
    // create a new temp node
    temp= (struct node *)malloc(sizeof(struct node)); //create temp node
    temp->data=num;  //set temp value
    temp->next=NULL; // set as end of list

    last = head;
    if (last==NULL)  // no head node exists yet
      head=temp;
    else   // find end of current list and add node
    {
      while(last->next != NULL)
        last=last->next;  // goto next node

        last->next =temp;  // set temp as new last node
     }

}
```

Concatenated list - delete a node



Which operations are necessary to delete the next of node `p`?

- Get the address s of next of p.
- Get the address s' of next of s.
- Assign s' to the value of the next of p.
- Free memory pointed by s.

Concatenated list - delete a node

```
int delete(int num)
{
    struct node *temp, *next;

    temp=head;    // start at first node

    if (num == 0) {  //head to be deleted
        head=temp->next;
        return 0;
    }

    for (int i = 0; temp!=NULL && i<num-1; i++)  //loop until previous node
      temp = temp->next;

    /* Node temp->next is the node to be deleted,
    Store pointer to the next of node to be deleted  */
    next = temp->next->next;

    free(temp->next);     //delete current node

    temp->next = next; //unlink the deleted node
}
```

Quiz

Consider the following declaration

```
struct addr {
     char village[10];
     char street[30];
     int ID ;
};

struct {
char name[30];
int gender;
struct addr locate;
} student , *sptr = &student ;
```

Then `*(sptr -> name +2)` can be used instead of

1. `student.name +2`
2. `sptr -> (name +2 )`
3. `*((*sptr).name + 2 )`