Informatica e Sistemi in tempo reale

Dynamic memory

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October 5, 2011

Outline

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Global, stack, heap

- All memory in a C/C++ program can be divided into 3 types:
  - **Global static memory**: this memory contains all code and all global variables. It is created by the system when the program starts executing, and it is destroyed when the program terminates. Therefore, it is *static*, i.e. it never change its size

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  - **Stack memory**: this memory contains all local variables of any function. The memory for a local variable is *dynamically* created when the function is called, and it is destroyed (i.e. it is not available anymore) when the function returns.
  - **Heap memory**: this memory is created by the programmer by calling an appropriate function (`malloc()`), and it is released by calling another function (`free()`). It is the user that manages this memory, so he must be careful in not making errors.

Examples

distance.c

```
struct point2D {
  double x, y;
  int z;
};
int a;
char name[10];
double vect[5];
struct point2D x1, x2;

double distance(struct point2D *p1, struct point2D *p2)
{
    return sqrt(pow((p1->x - p2->x),2) + pow((p1->y - p2->y),2));
}

int main()
{
  x1.x = 0; x1.y = 0;
  x2.x = 2; x2.y = 2;
  printf("distance: %lf\n", distance(&x1, &x2));
  return 0;
}
```

Pointers and dynamic memory

- We must be careful when using pointers with dynamically allocated memory
- A pointer is just variable that stores an address, i.e. a number. However, there is no assumption on what the address contains.
- In particular, nobody guarantees that the pointer always points to a **valid** location throught the life of the program.
- This can be the source of many subtle errors.

Example

- Where is the mistake in the following code?

stackerror.c

```
char *get_substring(char *str)
{
    char sub[100];
    int i = 0;

    while (str[i] != ' ' && str[i] != 0)
        sub[i] = str[i++];
    sub[i] = 0;
    return sub;
}

int main()
{
    char name[100] = "Giuseppe Lipari";
    char *p = get_substring(name);

    printf("substring: %s\n", p);
    return 0;
}
```

What happened?

- In the previous example, `sub` is a local variable
  - therefore, the memory for the array is stack memory; it is created (*allocated*) when the function is called, and it is destroyed (*deallocated*) when the function finished
- Function `get_substring()` returns the address of a local variable
  - This address is not valid when the function terminates
  - Therefore, p contains an *invalid address*
  - The address is likely to be reused by the program at the next function call (the following cout to pring on the terminal), and the memory is overwritten by other local variables.
  - Recent compilers raise a warning to the programmer: this is surely an error!

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  - How many times we will call the function?
  - How long can a substring be?
- The C/C++ standard library (`stdlib.h`) provides functions to precisely allocate/deallocate memory

Malloc

- In C, the standard library provides functions `malloc()` and `free()`

```
#include <stdlib.h>

void *malloc(size_t s);
void free(void *p);
```

- The `malloc()` takes an integer parameters to specify the amount of bytes to allocate, and returns the address of the allocated memory block. From now on, the memory block is available for use until the corresponding `free()` is called
- The `free()` takes a pointer to a previously allocated memory block and releases it. After the call, the address is not valid anymore.

malloc

- Notice that the `malloc()` returns a pointer to void. This is because the programmer that wrote this function and included it in the library did not know what the caller will want to do with the memory
- Thus, the programmer must *cast* the result of the malloc to the correct pointer type.

Solution to the previous example

stackcorrect.c

```
char *get_substring(char *str)
{
    char *sub;
    int i = 0;

    while (str[i] != ' ' && str[i] != 0) i++;
    sub = (char *)malloc((i+1)*sizeof(char)); // allocate mem
    strncpy(sub, str, i);   // copies i chars from str to sub
    return sub;
}

int main()
{
    char name[100] = "Giuseppe Lipari";
    char *p = get_substring(name);

    printf("substring: %s\n", p);
    free(p);
}
```

Comments

- The programmer can allocate exactly the right amount of memory:
  - In the previous example, the programmer allocated exactly `i+1` bytes for the string
- However, the programmer must deal with this memory in the program
  - The stack memory is managed by the run-time system of the computer; it is automatically allocated when the function is called, and automatically deallocated when the function finishes
  - for this reason, local variables are also called *automatic variables*
  - heap memory, instead, must be managed by the programmer
  - heap memory management and pointers are the source of more than 90% of program bugs.

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Memory leak

- One important thing to remember is to store the address of the allocated memory, so that we can later free it

leak.c

```
// function to swap the contents of two strings
void str_swap(char *p, char *q)
{
    char *tmp_p = (char *)malloc(strlen(p)+1);
    strcpy(tmp_p, p);
    strcpy(p, q);
    strcpy(q, tmp_p);
    return;
}

int main()
{
    char name[10] = "Giuseppe";
    char surn[10] = "Lipari";

    str_swap(name, surn);
    printf("%s %s\n", name, surn);
    str_swap(name, surn);
    printf("%s %s\n", name, surn);
}
```

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- Every time we call the `str_swap()` function, the total amount of allocate memory increases
- If the program is expected to run forever (for example a web server), at some point the computer memory will be over!
- What happens is that you will see the program slow down a lot, until it crashes with an *out of memory* message
- This bug is called **memory leak**

Another example

- In the following example, we lose the reference to a memory block

```
int *p = (int *)malloc(10);
p[0] = 0;
for (i=1; i<10; i++) p[i] = p[i-1] + i;
...
p = (int *)malloc(20);
// we have lost reference to the previous memory block!
```

- The Java language has a feature called *garbage collector* that looks around for memory blocks that are not referenced by any pointer, and delete them.
- Garbage collection is an heavy task, so many languages like C/C++ do not have such a feature