Corso di Laurea in Ingegneria Informatica, Elettronica e delle Telecomunicazioni
Università degli Studi di Parma

Exercise 2: Programming Tools in Linux/UNIX

Sistemi Operativi ed in Tempo Reale
AA 2023/2024

Outline

- Random number generation
- Strings in C
- Pointers
- Structure
- Socket
- Linked List

Pseudo-Random Numers

- **rand()**: function for generating random number with uniform distribution on interval [0, RAND_MAX]
- **srand()** to set the seed of a sequence
  - sequences with the same seed are equal
  - usually initialized with time from libs *time.h* and *stdlib.h*

```
#include <stdlib.h>
#include <time.h>
…
int i;
…
srand(time(NULL));
i = rand() % 100 + 1; // genera un numero compreso tra 1 e
100
```

Strings

- No predefined string type in C language
- String is an array of characters terminated by `'\0'` (ASCII code equal to 0)
- A string of N chars is represented by

```
char str[N+1]
```

- N is the maximum length of the string not to exceed the array limit
  - a string with L<N chars is s.t. `str[L]='\0'`
  - chars after L position have undefined values

Strings

- Examples of string initialization

```
char S[6] = {'p','r','o','v','a','\0'};  // as an array of char
char S[6] = "prova";        // as a string: implicit '\0'
```

- Example of computation of string length

```
char S[6] = "prova";
int len=0;
while(S[len] != '\0')
   len++;
printf("String %s is long %d", S, len);
```

Strings

- Reading string with **scanf()**
- scanf() requires pointers, but string have pointer form
  - first argument is a format string: string are identified by “%s”
  - second argument is a pointer

```
scanf("%s",S);
```

- Unfortunately, with scanf() strings are terminated at first occurrence of blank char “ “
- Issues with strings longer than the string limit: they may not be terminated by a ‘\0’

Strings

char *gets(char *S)

- Puts int the string pointed by S the chars read from STDIN until a char '\n'
- String is terminated by '\0'
- Returns either the pointer to the first char in the string or NULL when reading fails

Example:

```
char string [256];
printf ("Insert your full address: ");
gets (string);
printf ("Your address is: %s\n", string);
```

Strings

Standard functions

```
#include <string.h>
int strcmp(char *string1, char *string2)    // Compare two stings string1 e string2
char *strcpy(char *string1, char *string2)  // Copy string2 in string1
int strlen(char *string)                    // Computes the length of a string
char *strncat(char *string1, char *string2, size_t n)
                            // Add n chars of string2 to string1
int strncmp(char *string1, char *string2, size_t n)
                            // Compare only the first "n" chars of two strings
char *strncpy(char *string1, char *string2, size_t n)
                            // Copy only the first "n" chars of string2 in string1
```

Example

```
char str[MAX_SIZE];
strcpy(str,"esempio di stringa");
```

Strings

- No assigning of strings, only intializations
- **Invalid** instructions: strin must be copied

```
char greeting[10];
greeting = "Hello";
```

- **Valid** instruction initialization

```
char greeting[10] = "Hello";
```

See example: `stringhe_esempi_c.c`

Pointers and Dynamic Memory Allocation

- **Pointers**: variable storing the memory address of another variable
- Pointers can access the value of the pointed variable
- **Pointer declaration**: pointer type is the type of pointed variable

```
int* pi;     /* pointer to an integer variable */
```

- Deferencing: accessing the variable value

```
*pi = 10;     /* set the value of variable pointed by pi */
```

  - pointer must be set to a correct address!

Pointer: Getting the address

- Address of a variable obtained by operator '**&**'

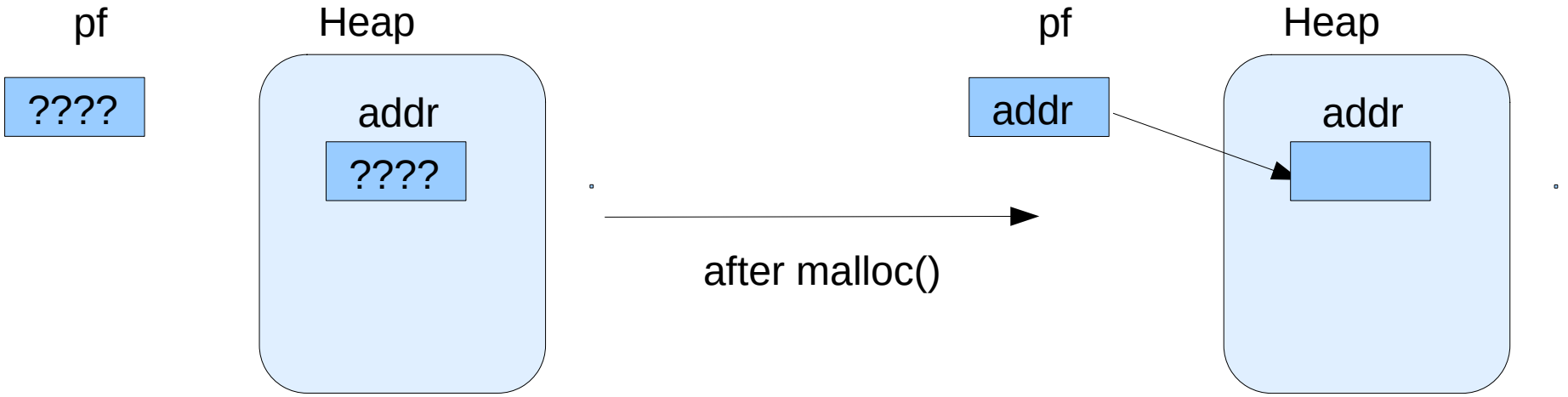
```
int i, *pi;
i = 42;            /* value assignment */
pi = &i;           /* pi points to address of i */
```


```
*pi = 3;           /* changed the value of i */
```

Memory Allocation/Deallocation

- Pointers support dynamic memory allocation
- **malloc()** function for allocation
  - reserve space for allocating the desired type, e.g. float
  - returns the address of the allocated memory

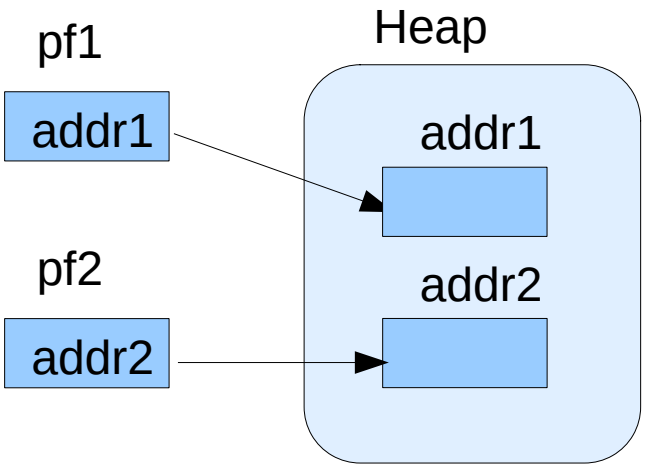
```
float* pf;      /* uninitialized pointer to float */
pf = (float*)malloc(sizeof(float));
```



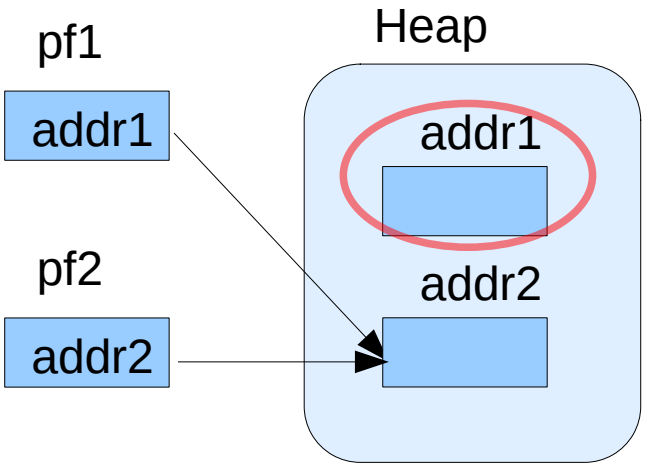
Memory Leak

- Allocated area that are not pointed and cannot be used anymore
- Example:

```
pf1 = (float*)malloc(sizeof(float));
pf2 = (float*)malloc(sizeof(float));
pf1 = pf2;
```



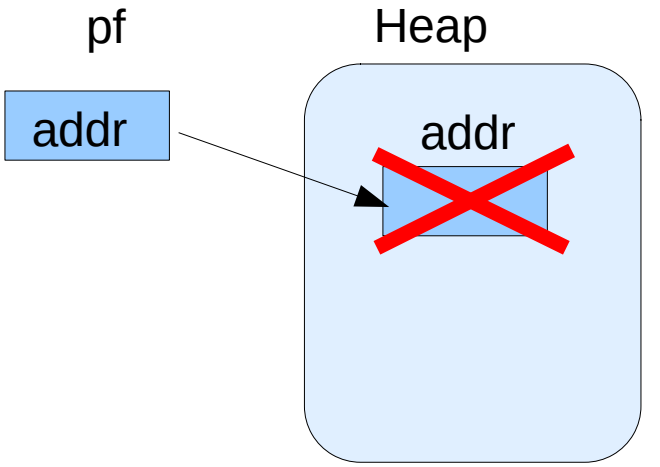
- No reference to the area originally pointed by pf1!
  - no access to the area
- The unreferenced memory area is “garbage”



Dangling Pointer

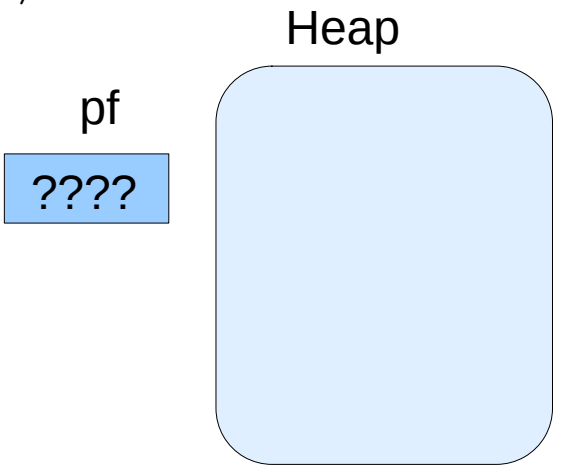
- Pointers pointing to an invalid memory area
  - Memoy area deallocated

```
free(puntfloat);
*punfloat = 1.0f;    /*error!*/
```



  - Memory area not yet allocated

```
float* puntfloat1;  /* undefined address */
*punfloat = 1.0f;
```



Typedef

- Redefined label of an existing type
  - Hide the real type and add abstraction to the code
  - Avoid repetition of keyword *struct* (only for C)

- Syntax: **`typedef`** *`ExistingType NewType;`*

```
typedef int MyLabel;
typedef struct Node* LIST;     /* pointer to first list item
                                  seen as a whole list*/
```

- Note: still used in C++, but now keyword ***using*** is recommended

```
using NewType = ExistingType;
```

Structured Types

- Composite data types consisting of eterogenous variables
  - **field**: each variable of the structure
  - keyword **struct**

- Example:

```
struct Person {
    int year;
    double height;
   char name[10];
};
struct Person p1;
p1.height = 178.2;
```

- **Anonymous struct + typedef**

```
typedef struct {
    int year;
    double height;
   char name[10];
} Person;
Person p1;
```

Structured Types

- Pointers to structred data and access to fields

```
typedef Person* PersonPtr;
 Person alice;
 PersonPtr p;
  …..
 p = &alice;
 (*p).age=5;
 p->height=180.0;
```

Socket

- Software interface for comunicating among processed
- It associate a channel to an integer **file descriptor**
- We focus on socket type STREAM for TCP
- **Client-Server**
  - Server is active and waiting for request from clients
  - Client connects to server
  - Client and server can exchange data on established connections
- Server supports *many* simultaneous connections

Socket

- API in C sockets (inherited from BSD UNIX sockets 1983)
  - **socket:** create a socket on a given domain, type and protocol
  - **bind:** assign a name/address to the socket
  - **listen**: set maximum numer of accepted simultaneous connections
  - **accept**: server socker accept incoming connection from client (blocking API!)
  - **connect**: client socket request to connect to server
  - **getsockname**: read local address of a socket
  - **close**: close a file descriptor associated to a socket (used also for files, other primitives, etc.)
  - **send**: to send data; it is an alias of *write()*
  - **recv**: to receive data (blocking API!); it is an alias of *read()*

Socket: Client

- **Client**: setting a connection

```
#include <unistd.h>
#include <netdb.h>

struct sockaddr_in serv_addr;
struct hostent* server;
char* host_name = "127.0.0.1"; /* address of the server as string*/
int port = 8000;
if ((server = gethostbyname(host_name)) == 0 ) {  /* address */
   perror("Error resolving local host\n"); exit(1);
}
bzero(&serv_addr, sizeof(serv_addr));
serv_addr.sin_family = AF_INET;
serv_addr.sin_addr.s_addr = ((struct in_addr *)(server→h_addr))->s_addr;
serv_addr.sin_port = htons(port);  /* htons() handle little and
                                      big endians*/
```

Socket: Client

- **Client**: setting a connection

```
int sockfd = socket(PF_INET, SOCK_STREAM, 0);  /* file descriptor sockfd */
if ( sockfd == -1 ) {
  … /* error */
}
if (connect(sockfd, (void*)&serv_addr, sizeof(serv_addr) ) == -1) {
   … /* error */
}
```

- Hence after connect is established: communication with **send()** and **recv()** until the *sockfd* is closed

Socket: Server

- Server: opening and waiting for client connections
- This part is standard for all servers

```
#include <unistd.h>
 #include <netdb.h>

 struct sockaddr_in serv_addr;
 struct sockaddr_in cli_addr;
 int sockfd = socket(PF_INET, SOCK_STREAM, 0);
 if ( sockfd == -1 ) {  … }
 bzero(&serv_addr, sizeof(serv_addr));
 serv_addr.sin_family = AF_INET;
  serv_addr.sin_addr.s_addr = INADDR_ANY;  /* the local address */
 serv_addr.sin_port = htons(port);  /* htons() little and big endians*/

 /* bind() associates the address to the socket */
 if (bind(sockfd, (struct sockaddr *)&serv_addr, sizeof(serv_addr)) == -1){
   …
 }
```

Socket: Server

```
   /* maximum number of connection kept in the socket queue*/
   if (listen( sockfd, 20 ) == -1) { … }
   socklen_t address_size = sizeof( cli_addr );
```

- Main server **loop** (infinite in this case)

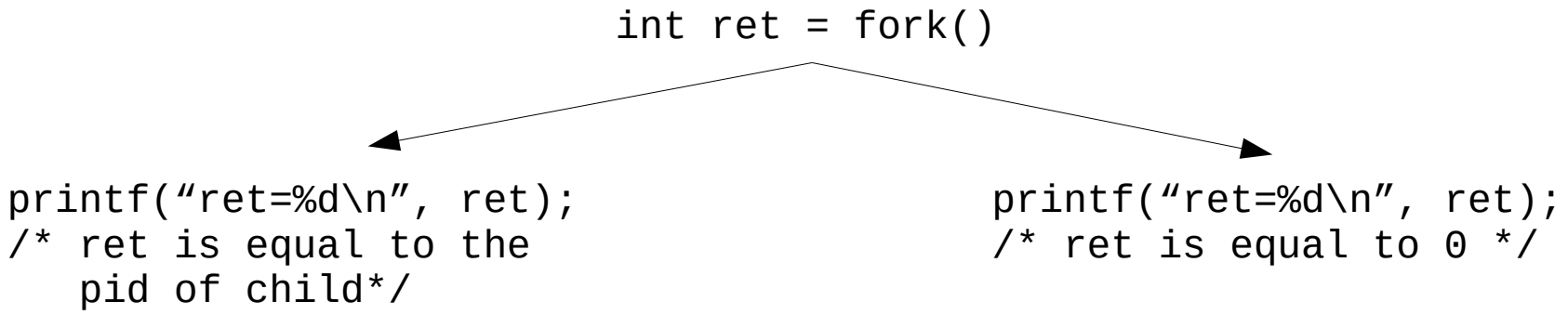
```
  while(1) {
    /* new connection acceptance with a novel socket/file descriptor */
    int newsockfd = accept( sockfd, (struct sockaddr *)&cli_addr, &address_size
);
    if (newsockfd == -1) { … }
    /* send/recv until close;
       newsockfd must be stored to communicate on connection */
  }
```

Fork

- UNIX/Linux API for starting a new process

```
#include <unistd.h>
int fork(void);
```

- An identical (child) process is created: same code and memory content of parent process
- Only difference: the **return value** of fork() is **0** for child and **PID** value of the child for the parent



Fork

- The return value can be used to differentiate the code executed by father and child processes

```
int ret = fork();
if (ret == 0) {
   /* code executed by child */
}
else {
   /* code executed by father */
}
```

- After the fork() the two processes are independent, i.e. do not share memory

Socket

- **Concurrent** server:
  - not blocked by servicing a client
  - creates a child process to every request
  - no shared state: need for IPC primitive (e.g. *pipe*)

```
int main(int argc, char *argv[]) {
        …
  /* Initialize socket */
  while (1) {
    …
    if ( (conn_fd = accept(list_fd, (struct sockaddr *)&client, &len))  <0 ) {
       perror("accept error");
       exit(-1);
    }
    /* Fork to handle connection */
  if ( (pid = fork()) < 0 ){
       perror("fork error");
       exit(-1);
  }
  if (pid == 0) { /* child servicing the request from conn_fd */ }
  else { /* father code */ }
}
```

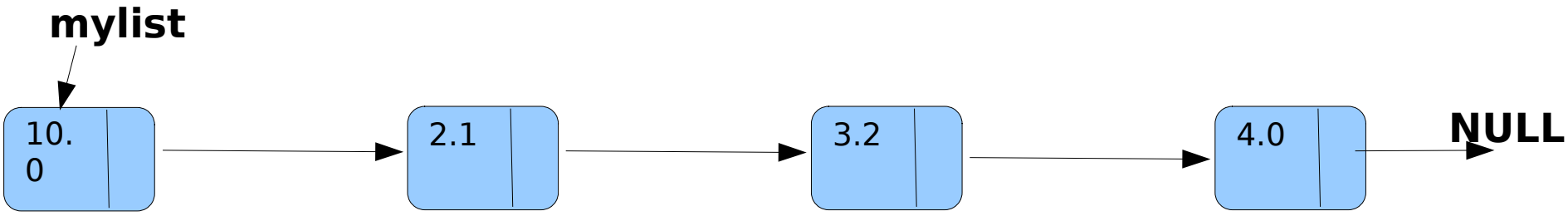
Linked List

- SORT exercises require a “container” storing items
  - arbitrary and dynamic size of container
- Linked list: simplest dynamic data structure in C language
- **Node** divided in two parts
  - data storage
  - reference to next item

```
 /* Data contained in item ***/
typedef struct  {
 double value;  /*** esempio ***/
}  itemType;

/* Node of the list */
struct LINKED_LIST_NODE  {
  itemType item;
  struct LINKED_LIST_NODE *next;
};

/* Alias for the node */
typedef struct LINKED_LIST_NODE NODE;

/* Pointer to first item of the list represents the whole list! */
typedef struct NODE * LIST;
```

Linked List

- Example:



- List is represented by a pointer to the first node

- field ***next*** of last node point to NULL

Linked List

/* Contructors */

LIST NewList(); /* *Intialization* */

/* Selector */
itemType getHead(LIST l); /* *Returns first item l*/*
itemType getTail(LIST l); /* *Returns last item* */

/* Predicates */
#define BOOL int
BOOL isEmpty(LIST l); /* *TRUE if list is empty* */

int getLength(LIST l); /* *computes the length of list* */
itemType * Find(LIST l, itemType item); /* *Finds an element if it exists; otherwise returns NULL* */

*** *Insertion and* removal of items */**
LIST EnqueueFirst(LIST l, itemType item); /* *Inserts item in first position* */
LIST EnqueueLast(LIST l, itemType item); /* *Inserts item in last position* */
LIST EnqueueOrdered(LIST l, itemType item); /* *inserts element in order* */
LIST DequeueLast(LIST l); /* *Removes the last item* */
LIST DequeueFirst(LIST l); /* *Removes the first item* */
LIST Dequeue(LIST l, itemType item); /* *Removes a given item if it is in the list* */

/* Destructors */
LIST DeleteList(LIST l);

/* Other */
void PrintList(LIST l); /* *Prints list* */
void PrintItem(ItemType item);

Linked List

```
/* Costructor */
LIST NewList()
{
  return NULL;
}
```

```
NODE * createNode( itemType item )
{
  NODE * p =
    (NODE*)malloc(sizeof(NODE));
  assert( p != NULL );
  p->item = item;
  p->next = NULL;
  return p;
}
```

```
/* alternative implementation */
   NODE *createElement(itemType item) {
      NODE *p;
      p = (NODE *)malloc(sizeof(NODE));
  if (isEmpty(p)) {
       printf("create element failed.\n");
       exit(0);
      }
  p->item = item;
  p->next = NULL;
  return p;
}
```

Assert

- Macro **assert()** evaluates an expression and terminates if not true
- Used to check *invariants*, i.e. properties that must hold during execution
  - if an expression it fails unexpectly there is a potential bug in our code or a function is wrongly used

```
#include <assert.h>
…
assert(x > 0);
```

- Possible implementation:

```
#define MY_ASSERT(X) \
     if (!(X)) { printf("failed %s\n",#X); exit(-1); }
```

Linked List

```
/* Selectors */


itemType getHead(LIST l) /* Returns item to first item in list l */
{
 assert( !isEmpty(l) );
 return l->item;
}


itemType getTail(LIST l) /* Returns item to last item in list l */
{
 NODE * tmp = l;
 assert( !isEmpty(l) );

 while( !isEmpty(tmp->next) )
       tmp = tmp->next;

 return tmp->item;
}
```

Linked List

```
/* Predicates */
BOOL isEmpty( LIST l ) /* check if list is exmpty */
 {
    return (l == NULL);
 }

int getLength(LIST l) /* computes the length of list */
 {
   int size = 0;
   LIST tmp = l;
   while ( ! isEmpty(tmp) )
       {
         ++size;
         tmp = tmp -> next;
       }
   return size;
}
```

Linked List

/* Insertion */

```
/* Inserts item to last position in the list */
LIST EnqueueLast (LIST l, itemType item)
 {
   NODE * new_node = createNode(item);
   if ( isEmpty( l ) )
     {     /* empty list: item in head position */
          l = new_node;
     }
   else
    {
      LIST tmp = l;
      while ( !isEmpty( tmp -> next ) )
          tmp = tmp -> next;
      tmp -> next = new_node;
    }
  return l;
}
```

Linked List

/* Removal */

```
/* Removes the given item from list if it is in the list */
LIST Dequeue( LIST l, itemType item )  {
 if (!isEmpty( l ))    {
  if ( itemCompare( l -> item, item ) == 0 ) {   /* remove item from head */
      NODE * todel = l;
      l = l -> next;
      deleteNode( todel );
   } else {
     LIST tmp = l;
     while ( !isEmpty(tmp ->next) &&
               itemCompare(tmp->next->item, item ) != 0 )
          tmp = tmp -> next;
     if ( ! isEmpty( tmp -> next ) )         {
         /* if item is found, then it is removed */
         NODE * todel = tmp -> next;
         tmp -> next = tmp -> next -> next;
         deleteNode( todel );
     }
   }
  }
  return l;
}
```

Linked List

```
/* General comparison function inspired by strcmp():
    - return value >0 if item1 > item2;
    - return value <0 if item1 < item2;
    - return value ==0 if item1 == item2.
  Note: used to sort, search or manage order
    It must be adapted to the exercise
*/

  int itemCompare( itemType item1, itemType item2 )
    {
     if ( item1.value > item2.value )  /* example with float field */
       return 1;
     else if ( item1.value < item2.value )
      return -1;
     else
   return 0;
 }
```

Linked List

```
/* Destructor */
/* frees node p */
void deleteNode( NODE * p )
 {
  free(p);
 }


LIST DeleteList( LIST l )
   {
    LIST tmp = l;  /* deallocate all the nodes */
    while ( !isEmpty(tmp) )    {
         NODE * todel = tmp;
         tmp = tmp -> next;
         deleteNode( todel );
     }  /* all node visited and freed */
   return NewList();
   }
```

Linked List

```
/* Print list */
void PrintList( LIST l )
 {
  LIST tmp = l;
  while (!isEmpty(tmp)) {
     PrintItem( tmp->item );
     tmp = tmp->next;
     if ( ! isEmpty(tmp) )
     printf("\n");
  }
}
```

- Custom *PrintItem()*: it depends on the item used in your problem

Linked List

- Exercise: implements the following functions

```
LIST EnqueueFirst(LIST l, itemType item );
/* Inserts item in first position of list */

LIST DequeueLast( LIST l );
/* Removes the last item from list, if list is not empty */


LIST EnqueueOrdered(LIST l, itemType item );
/* Inserts the item in the list according to an order */

itemType * Find( LIST l, itemType item );
/*  Finds the given item in the list and returns a pointer to the item
     (note: pointer to the item, not to the node type!!!)
*/
```

Problem Solving: Suggestions

- Decompose your exercise into functions
- Possible criteria:
  - Decompose your problem into smaller problem
  - A function must solve a single (sub)problem independent from the other parts
  - It must be clear what a function does
  - Keep the function as short as possible

Problem Solving: Suggestions

- Minimum numbers of function parameters required to solve the problem
- No constraints on parameters
- If number of parameters is high, possible warning
  - use a structure to store parameters?
- If you are doing cut & paste of parts of your code, then you may need a function doing it instead
- Avoid non-local access to variables:
  - access to data external to function only through parameters (with few exceptions)
  - violation of black box principle (only in very specific cases)