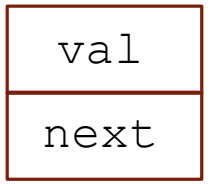
Lab 7

Demo and Helpful Tips

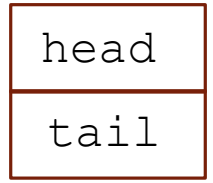
List.h -> 2 structures

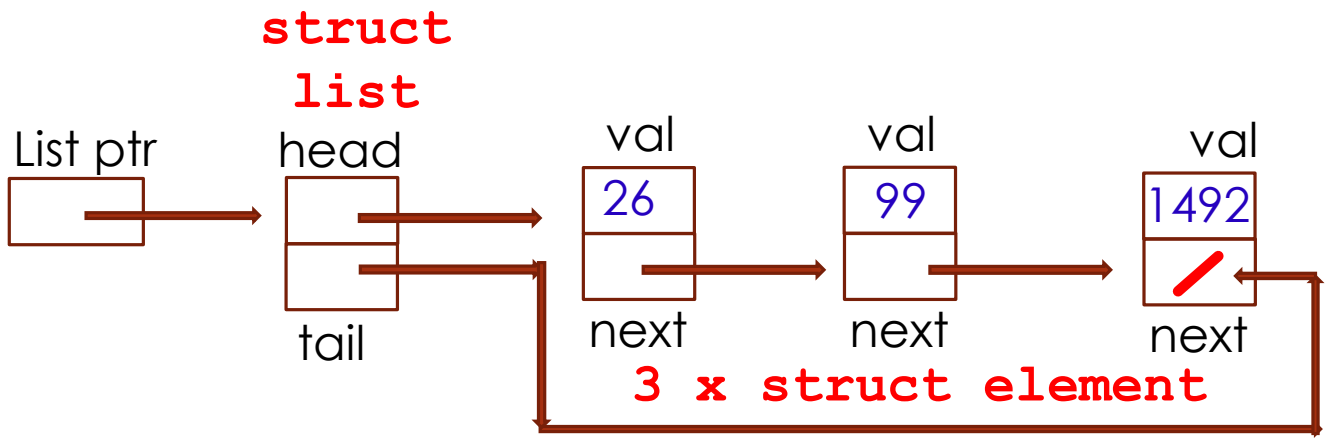
```
// List element: a list is a chain of these
typedef struct element
{
  int val;
  struct element* next;
} element_t;

// List header - keep track of the first and last list elements
typedef struct list
{
  element_t* head;
  element_t* tail;
} list_t;
```

element_t



list_t





List.h -> 7 functions

```
// Returns a pointer to a new header for an empty list, or NULL if
// memory allocation fails.
list_t* list_create( void );

// Frees all the memory used by the list
void list_destroy( list_t* list );

// Returns a pointer to a new list element containing integer i and
// next-pointer set to NULL, or NULL if memory allocation fails.
element_t* element_create( int i );

// Appends a new element containing integer i to the end of the
// list. Returns 0 on success, else 1.
int list_append( list_t* list, int i );

// Prepends a new element containing integer i to the head of the
// list. Returns 0 on success, else 1.
int list_prepend( list_t* list, int i );

// Returns a pointer to the ith list element, where the list head is
// 0, head->next is 1, etc., or NULL if i is out of range (i.e. larger
// than (number of list elements -1 ))
element_t* list_index( list_t* list, unsigned int i );

// Prints a list in human-readable form from the first to last
// elements, between curly braces.
void list_print( list_t* list );
```

The idea of Task 1 to Task 5 is …

- We are given 5 different buggy implementations of the functions described in `List.h`
- We are given a test driver `main.c`
- We are to discover these bugs by adding code to our test driver `main.c`
- Our test driver `main.c` has found a bug when it either
  - Returns 1

  OR

  - It 'crashes' with a segmentation fault

In this lab, getting a segmentation fault is a good and useful thing!

- In Task 1 to Task 5, we are not to fix these bugs (we are not to modify `t1.c`, `t2.c`, `t3.c`, `t4.c` and `t5.c`)!
  - We do this in Task 6!

Download `main.c` and ...

Let's have a look at `main.c`

```c
#include <stdio.h>
#include <stdlib.h>

#include "list.h"

int main( int argc, char* argv[] )
{
  // test the create function
  list_t* list = list_create();

  // check to see if the create function did everything it was supposed to
  if( list == NULL )
    {
      printf( "list_create(): create failed to malloc\n" );
      return 1;
    }

  if( list->head != NULL )
    {
      printf( "list_create(): head is not null!\n" );
      return 1;
    }

  if( list->tail != NULL )
    {
      printf( "list_create(): tail is not null!\n" );
      return 1;
    }

  // now test all the other functions (except list_print) to see if
  // they do what they are supposed to

  // you code goes here

  return 0; // tests pass
}
```

We are checking to see if any of the 5 implementations of `list_create()` contains a bug

We are expecting the function `list_create()` to

- Get memory for a `list`, and to verify that it was successful at getting this memory
- To set the `head` of the `list` to NULL
- To set the `tail` of the `list` to NULL

So, the code already in `main.c` is there
to check that `list_create()` did indeed do all that was expected. If not, then it's a bug and we report it by printing a useful message and returning 1.

Let's compile our `main.c`

Makefile

```
all: t1 t2 t3 t4 t5

t1: main.c t1.c
    gcc -Wall -std=c99 -o $@ main.c t1.c

t2: main.c t2.c
    gcc -Wall -std=c99 -o $@ main.c t2.c

t3: main.c t3.c
    gcc -Wall -std=c99 -o $@ main.c t3.c

t4: main.c t4.c
    gcc -Wall -std=c99 -o $@ main.c t4.c

t5: main.c t5.c
    gcc -Wall -std=c99 -o $@ main.c t5.c

clean:
    rm -f t1 t2 t3 t4 t5 *.o
```

At the command line:

```
$ make all
or
$ make
or
$ make t1
$ make t2
$ make t3
$ make t4
$ make t5
or
$ for i in {1..5}; do make t$i; done
or
$ for i in {1..5};
> do
> make t$i;
> done
```

Let's execute our `main`

- At the command line:

```
$ for i in {1..5}; do ./t$i; echo $?; done
```

or

```
$ for i in {1..5};
> do
> ./t$i; echo $?;
> done
```

- Are we getting the results we are expecting?

Result of executing `main`

```
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ make
gcc -Wall -std=c99 -o t1 main.c t1.c
gcc -Wall -std=c99 -o t2 main.c t2.c
gcc -Wall -std=c99 -o t3 main.c t3.c
gcc -Wall -std=c99 -o t4 main.c t4.c
gcc -Wall -std=c99 -o t5 main.c t5.c
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ for i in {1..5}; do ./t$i ; echo $? ; done
0   <- executing t1 so t1 return 0
0   <-------------------------------------executing t2 so t2 return 0
0   <- executing t3 so t3 return 0
0   <-------------------------------------executing t4 so t4 return 0
0   <- executing t5 so t5 return 0
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$
```

All 5 executables (`t1`, `t2`, `t3`, `t4` and `t5`) are returning 0.
This means that no bugs have been discovered in the 5 implementations of **`list_create()`**!!!
Great! Let's move on to the next function!

How to proceed!

- Do not look at `t1.c`, `t2.c`, `t3c`, `t4.c`, `t5.c` – searching for the bugs! Nope! That would be cheating!
- Instead, work only with `main.c`, extending it, i.e., adding code to it in order to verify that all 7 functions behave as you expect
- So, what is the expected behaviour of these 7 functions?

- Hint: no bugs in implementation of `list_create()`, `list_print()` and `list_destroy()`

Let's investigate `list_prepend( )` (1 of 3)

- What are we expecting from `list_prepend(…)`?
- To answer this question, let's read its description in `List.h`:

```
// Prepends a new element containing integer i to the head of the
// list. Returns 0 on success, else 1.
int list_prepend( list_t* list, int i );
```

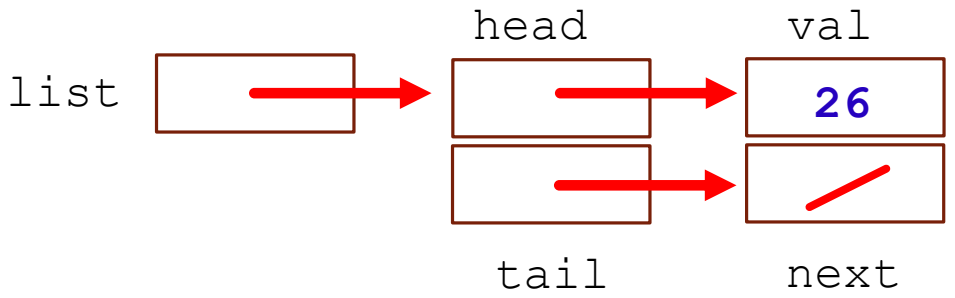
- In order to investigate whether there are bugs in any of the 5 implementations of `list_prepend(…)`, we consider various scenarios in which we could prepend a new element:
  - Prepend a new element in …
    - A list that has no elements -> an empty list
    - A list that has one element
    - A list that has two elements
    - A list that has several elements

Let's investigate `list_prepend( )` (2 of 3)

Scenario 1: Empty List

If we prepend an element to an empty list, what are we expecting the list to look like once we have called `list_prepend(list, 26)` ?

We are expecting the list to be as follows:



- So, let's add code to our `main.c` to confirm that the expected result depicted above is indeed what we obtained from `list_prepend(list, 26)`

We add the following code to `main.c`

```
// Testing list_prepend( )
int val = 26;
int ret = list_prepend( list, val );
// list_prepend(...) returns 0 on success, else 1.
if ( ret ) {
    puts( "list_prepend() failed." );
    return 1;
}
if( list->head == NULL ) {
    puts( "list_prepend(): list->head NULL." );
    return 1;
}
if( list->tail== NULL ) {
    puts( "list_prepend(): list->tail NULL." );
    return 1;
}
if( list->head != list->tail ) {
    puts( "list_prepend(): first prepend: head != tail." );
    return 1;
}
if( list->head->next != NULL ) {
    puts( "list_prepend(): list->head->next != NULL." );
    return 1;
}
if( list->head->val != val ){
    puts( "list_prepend(): list->head->val != val." );
    return 1;
}
```

Result of executing `main`

- Recompiling and executing the new executables, we get:

```
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ make
gcc -Wall -std=c99 -o t1 main.c t1.c
gcc -Wall -std=c99 -o t2 main.c t2.c
gcc -Wall -std=c99 -o t3 main.c t3.c
gcc -Wall -std=c99 -o t4 main.c t4.c
gcc -Wall -std=c99 -o t5 main.c t5.c
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ for i in {1..5}; do ./t$i ; echo $? ; done
0
0
0
list_prepend(): list->tail NULL.
1
0
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$
```

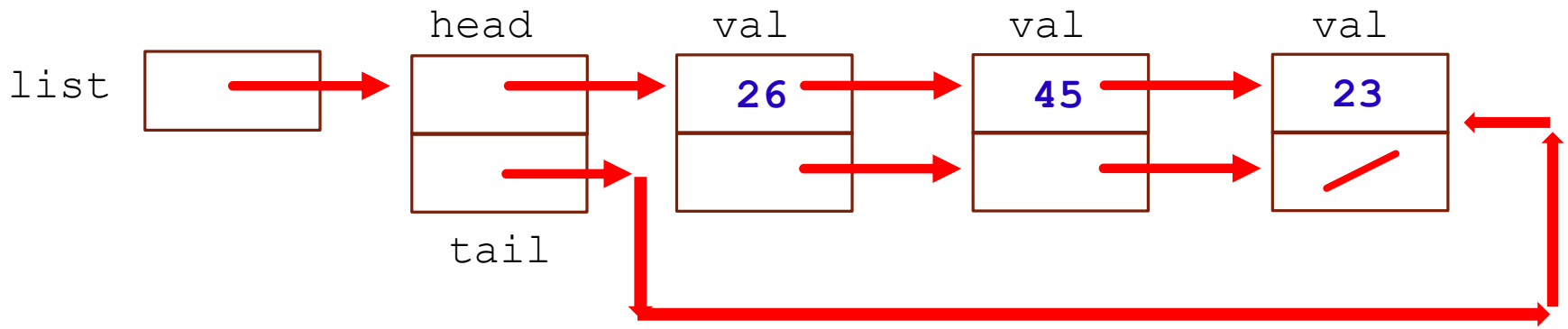
Bingo!!! We discovered a bug in `t4.c`
i.e., the implementation of `list_prepend()` in t4.c contains a bug!

Let's investigate `list_prepend( )` (3 of 3)

Scenario 2: Existing List

If we prepend an element to an already existing list which contains elements 45 and 23, what are we expecting the list to look like once we have called `list_prepend(list, 26)` ?

We are expecting the list to be as follows:



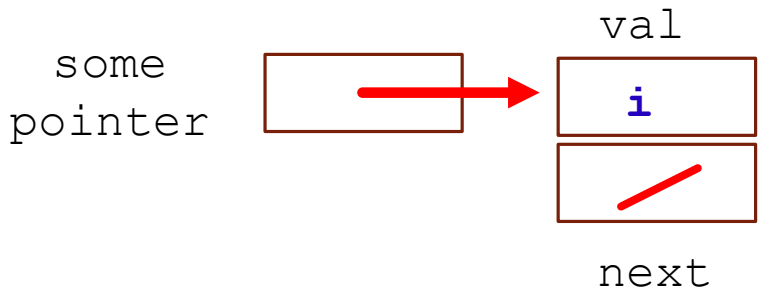
So, we would add code to our `main.c` to confirm that the expected result depicted above is indeed what we obtained

Moving on to another function: Let's investigate `element_create()` (1 of 4)

- What are we expecting from `element_create(...)`?
- To answer this question, let's read its description in `List.h`:

```
// Returns a pointer to a new list element containing integer i and
// next-pointer set to NULL, or NULL if memory allocation fails.
element_t* element_create( int i );
```

- So, I am expecting the following:



- So, let's add code to our `main.c` to confirm that the expected result depicted above is indeed what we obtained from `element_create(...)`

Let's investigate `element_create()` (2 of 4)

```
el = element_create( 1492 );
assert(el);

if( el->next )
{
   puts( "element_create(): el->next not NULL." );
   return 1;
}

if( el->val != 1492 )
{
   puts( "element_create(): el->val not correct." );
   return 1;
}
```

We add the following code to our `main.c` to confirm that `element_create(…)` performs as expected!

- However, when we recompile and execute the new executables, we don't discover any bugs ("0" is echoed on the computer monitor screen)
- Can we conclude that there are no buggy implementations of **`element_create()`**? Actually, no. We can't!
- There is something else we need to consider …

Let's investigate `element_create()` (3 of 4)

- We need to consider the following:
  - `element_create(...)` calls `malloc(...)` in order to get memory for the `element` structure
  - In doing so, it may be the case that the memory obtained is actually already set to a bunch of 0's
    - So, if `element_create(...)` does not explicitly set the field `next` to `NULL`, this will not be detected by our code in `main.c` because this memory labeled `next` already contains 0's and these 0's are interpreted as `NULL`:

```
if( el->next )  // i.e., if (el->next == 1)
{
   puts( "element_create(): el->next not NULL." );
   return 1;
}
```

Setting the field `next` to `NULL` is the same as setting the memory labelled `next` to a bunch of 0's

  - And this may be why the above code (in `main.c`) does not produce a return value of 1 (i.e., does not detect the buggy implementation of `element_create(...)`)

Let's investigate `element_create()` (4 of 4)

```
// Testing element_create( )
element_t* el = malloc( sizeof( element_t ) );
assert(el);
memset( el, 0xFF, sizeof( element_t ) );
free(el);

el = element_create( 1492 );
assert(el);

if( el->next )
{
   puts( "element_create(): el->next not NULL." );
   return 1;
}

if( el->val != 1492 )
{
   puts( "element_create(): el->val not correct." );
   return 1;
}
```

So, let's investigate to confirm whether `element_create(…)` does set `next` to `NULL` or not.

First, we shall assume that when we ask for memory twice in a row, we are given the same memory both times.

Based on this assumption, we ask for memory once, set this memory to the value 1 (11111111_2 -> FF_{16}) which cannot be mistaken for `NULL` (i.e., 0).

Then we free the memory and ask for it again via `element_create(…)`. If `element_create(…)` does not set `next` to `NULL` as expected, this will be detected because `next` will have the default value of 1 (because this memory has been set to a bunch of 1's) and 1 != `NULL`.

Result of our testing

- Recompiling and executing the new executables, we get:

```
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ make
gcc -Wall -std=c99 -o t1 main.c t1.c
gcc -Wall -std=c99 -o t2 main.c t2.c
gcc -Wall -std=c99 -o t3 main.c t3.c
gcc -Wall -std=c99 -o t4 main.c t4.c
gcc -Wall -std=c99 -o t5 main.c t5.c
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$ for i in {1..5}; do ./t$i ; echo $? ; done
0
element_create(): el->next not NULL.
1
0
list_prepend(): list->tail NULL.
1
0
alavergn@cs-moyie:~/sfuhome/cmpt-127/cmpt127-1194-alavergn/7$
```

Bingo!!! We discovered a bug in `t2.c`
i.e., the implementation of `element_create()` in `t2.c` contains a bug!

Continue modifying `main.c`

- … by adding code to `main.c` that verifies the expectations you have of the behaviour of each of the functions called from `main.c`
- Once you have detected the bug in each of the 5 implementations of the `List.h` functions (`t1.c`, `t2.c`, …, `t5.c`), commit your `main.c` to Gitlab and move on to Lab 7 Task 6 and Task 7

Task 6

- To compile:
  - at the command line:

```
$ gcc -o t6 list.c main.c
```

- To execute:
  - at the command line:

```
$ ./t6; echo $?
```

or

```
$ ./t6
$ echo $?
```

- Are we getting the results we are expecting?
  - This time, are we expecting 5 `0`'s to be printed on the screen?