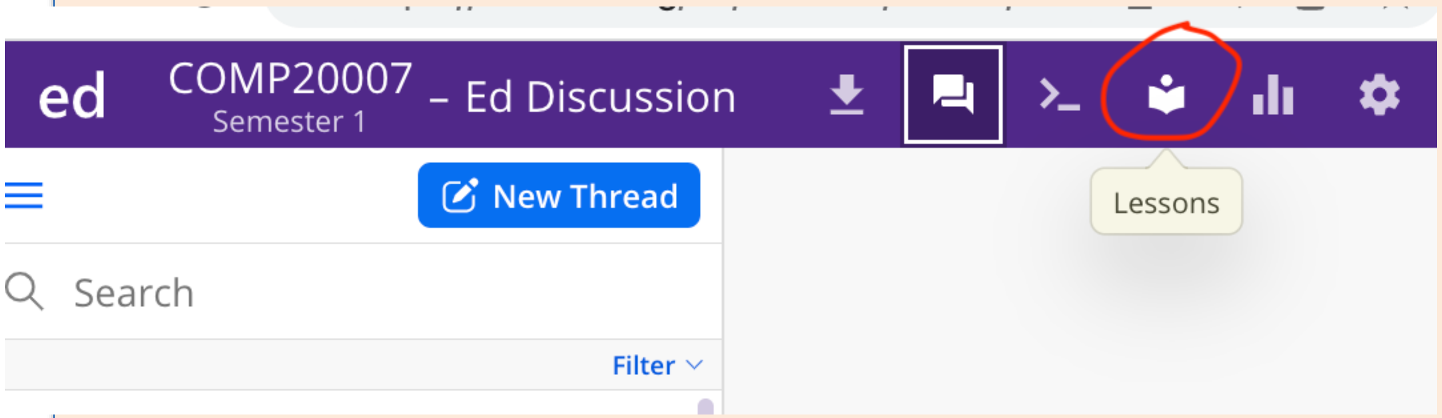
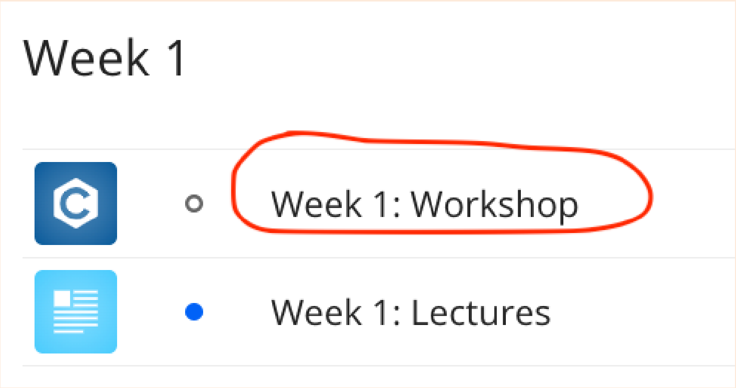
COMP20007 Workshop Week 1
about Us and ... C

While waiting:

- Talk to classmates, make friends
- Open LMS and click on "Ed Discussion" to open ED, on ED:

  ➢ click on Lessons → Week 1 Workshop





  ➢ Inspect the first 2 slides: "Tutorial" and "Tutorial: Pre-Workshop"

A Bit on C: Memory Management

C Memory Management: What?

- Memory management is the process of allocating, using, and freeing memory in a program
- Unlike Python or Java, some parts of C memory need to be managed **manually**

Visualisation: Memory Lane

	8 blocks		1 block		8 blocks		4 blocks	...
	1 Foo St		13 Foo St		21 Foo St		42 Foo St	...
type	double	...	char	...	long	...	int	...
size	8 Bytes		1 Byte		8 Bytes		4 Bytes	...
sample address	0x075f5f		0x603e7a		0xbcde77		0xbd370a	...

Static vs Dynamic Memory Allocation

- **Static Allocation**:
  - Memory *automatically* allocated and deallocated by compilers.
  - Example:

```
int x = 10;
int *p = &x;
```

- **Dynamic Allocation**:
  - Memory allocated *by programmers* at runtime using `malloc`, `calloc`, `realloc`.
  - Memory deallocated *by programmers* at runtime using `free`()
  - Example:

```
int *p = malloc(100 * sizeof(int));
```

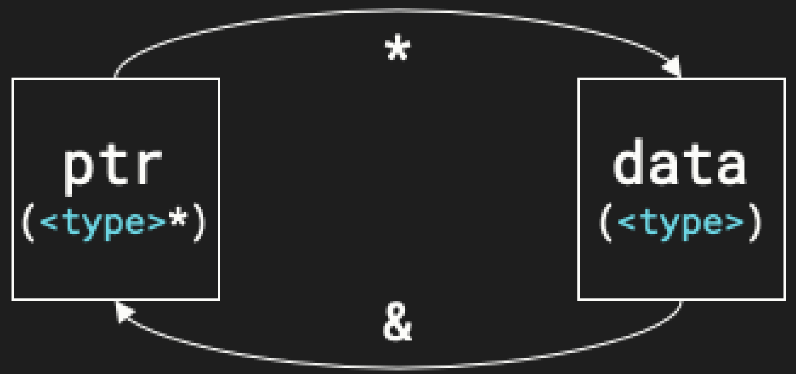
Pointers

Pointers are variables that store memory addresses.

Variables are actually aliases for pointers at known locations.

There are two basic **pointer operators**:

- **dereference operator** (*): “value pointed by”
- **reference operator** (&): “address of”



Pointers: Example of Declarations and Pointer-Array Relationship

```c
/* Variable vs. pointer declarations */
int number = 5;   // run-of-the-mill variable
int *example;     // pointer to an int
char *example2;   // pointer to a char
int **example3;   // pointer to a [pointer to an int]

/* An Array Name is a Pointer Constant */
int arr[9]= {1, 2, 3, 4, 5};    // arr is an array, is a pointer constant
example= arr;                   // now example is equivalent to arr
                                // but example is a variable
arr[5] == *(arr + 5);           // these are functionally equivalent
```

Pointers: sizes

```c
/* Expected values in bytes
 * (within most systems, anyways)
 */
sizeof(char) == 1;
sizeof(float) == 4;
sizeof(int) == 4;
sizeof(double) == 8;
sizeof(long) == 8;
```

```c
/* All pointers have the same size
 * since addresses have equal sizes
 */
sizeof(int*) == 8;
sizeof(int**) == 8;
sizeof(char*) == 8;
```

Pointers: Basic Memory Allocation & Deallocation

```c
/* Return a pointer to memory space for an int */
void *ptr = malloc(sizeof(int));
/* Ensure that memory allocation succeeded */
assert(ptr);
/* Frees memory that was allocated with malloc() */
free(ptr);
```

Dynamic Memory

Operation	How?
Pointer declaration for <type>	<type> *ptr;
Allocation, method 1	ptr= (<type>*) malloc(n * sizeof(<type>)); assert(ptr);
Allocation, method 2 (using automatic casting)	ptr= malloc(n * sizeof(*ptr)); assert(ptr);
Allocation, zero-initialised	ptr= calloc(n, sizeof(*ptr)); assert(ptr);

Re-allocation (resizing) a previously allocated memory	ptr= malloc(n * sizeof(*ptr));
	assert(ptr);
	...
	ptr= realloc(ptr, (n * 2) * sizeof(*ptr));
	assert(ptr);

Deallocation	free(ptr);

Common Memory Issues

- **Not checking return value of malloc/calloc/realloc**
- **Memory Leaks**: Forgetting to free memory.
- **Dangling Pointers**: Using a pointer after freeing memory.

```
int *p = malloc( sizeof(*p) );
free(p);
*p = 10;  // undefined behaviour
```

- **Segmentation Faults**: Accessing invalid memory.

```
int *p;  // p is a pointer with undefined value
*p = 10; // Trying to write to an undefined cell (invalid write)
printf("Value: %d\n",  *p);  // this line won't be reached
```

Example Program

- write a code segment that reads at most 100 of integers and store them for further processing
- then, change so that it can reads and stores any number of integers

Remember

Key Takeaways:

- Dynamic Memory Management in C is manual.
- Use `malloc`, `calloc`, `realloc`, and `free` for dynamic memory.
- Avoid memory leaks, dangling pointers, and segmentation faults.

Best Practices for Memory Management:

- Always check if `malloc`, `calloc`, or `realloc` returns NULL (using `assert`).
- Always free allocated memory: one `malloc`/`calloc` – one `free`.
- Avoid dangling pointers and segmentation faults.
- Use tools like `valgrind` to detect memory problems.

Class Activity: Example of Automatic Variables in Memory

```c
int main(void){

    int *example;
    int number = 5;
    int **example2;
    char *example3;
    example2 = &example;
    *example2 = &number;
    *example = 10;
    example3 = (char *) example;
    example3[0] = 'a'; // a is 0x61 or 97
    example3[1] = 'b'; // b is 0x62 or 98
}
```

Name	Address	Value	Memory (Bytes)							
example	0x7fffffffe0b0									
number	0x7fffffffe0ac		5	0	0	0				
example2	0x7fffffffe0b8									
example3	0x7fffffffe0c0									

Peer Activity: String Duplication with Dynamically-Allocated Memory

Supposing that MAX_LEN and INITIAL are large enough.

Will this code snippet work as intended? Why or why not?

A. Yes, it will.

B. No, it will not.

```
...
char buf[MAX_LEN];  // string buffer
char **dups =       // array of strings
    (char**)malloc(INITIAL*sizeof(char*));
int num_strings = 0;
/* Read strings from stdin */
while (fgets(buf, MAX_LEN, stdin) != NULL) {
    /* NULL-terminate the string */
    if (buf[strlen(buf) - 1] == '\n')
        buf[strlen(buf) - 1] = '\0';
    /* Store it into the array */
    dups[num_strings] = buf;
    num_strings++;
}
```

C Program Development on ED

ED supplies

- file systems (aka. *workspaces*),
- a Text Editor for Creating/Editing programs and text files,
- a Shell (aka. *command-line interpreter*), which could be used for
  - compiling, such as

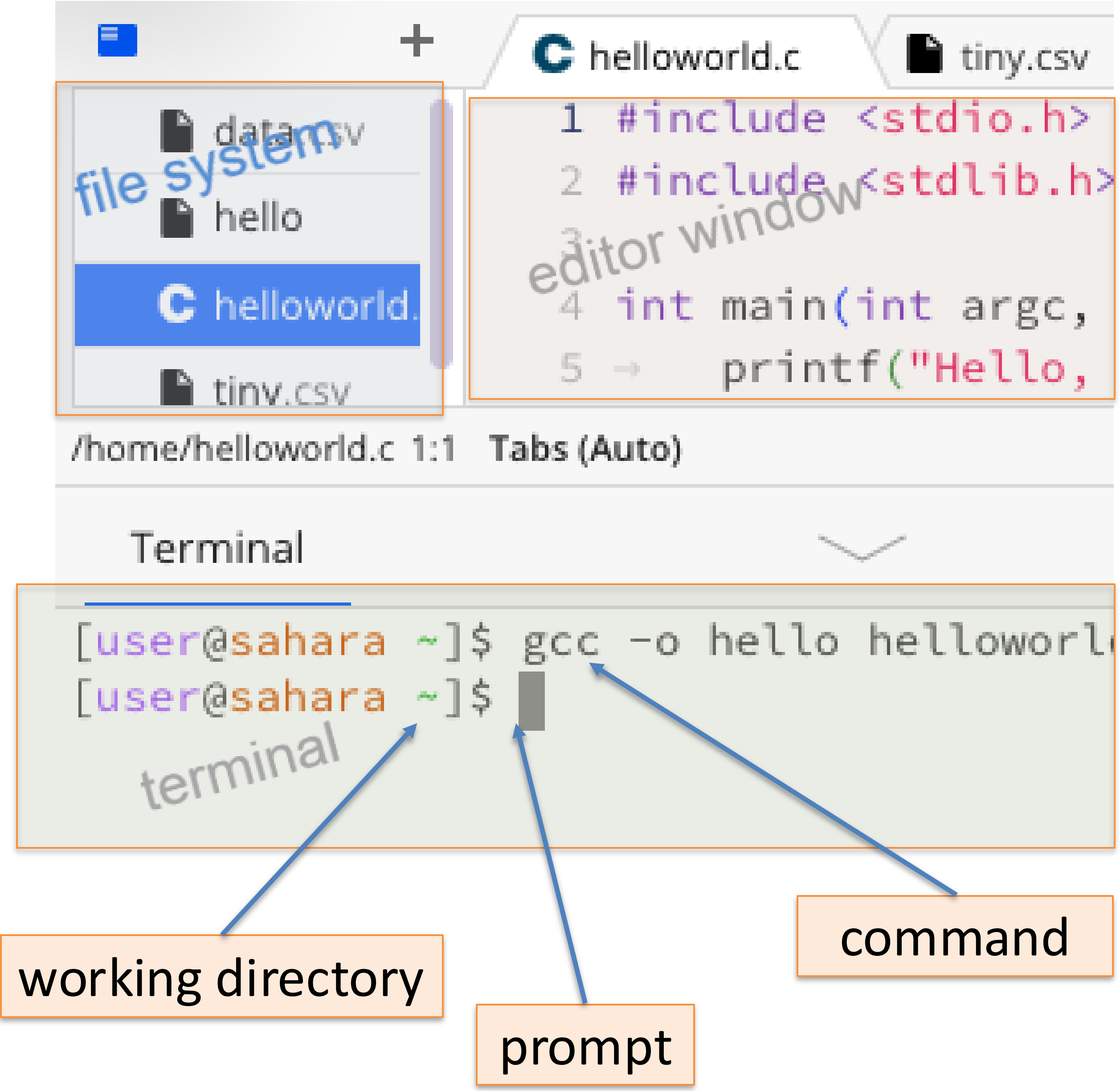
```
gcc -Wall -g -o program program.c
gcc -Wall -g -o qStud driver.c data.c array.c
make
```

  - debugging with some tools, for example:

```
valgrind --leak-check=full --track-origins=yes ./program
gdb ./program
```

  - and many other useful jobs such as seeing manual pages (man) of functions/tools, copying or displaying files...

Lab Time: Using ED Workspace for Program Projects



A *workspace* is used for a programming project:

- It has a *file system*, starting with a *home directory* (~). Recursively, a directory can host files and its own sub-directories.
- The terminal allows us to interact with a Unix-style shell (namely bash).

Together with the Tutor, do:

- Problem 1: essential shell commands
- Problem 6
- Problem 2: using valgrind for debugging
- Problem 3: Makefile, gdb

Appendices

Class Activity: Example of Automatic Variables in Memory

```c
int main(void){

    int *example;
    int number = 5;
    int **example2;
    char *example3;
    example2 = &example;
    *example2 = &number;
    *example = 10;
    example3 = (char *) example;
    example3[0] = 'a'; // a is 0x61 or 97
    example3[1] = 'b'; // b is 0x62 or 98
}
```

Name	Address	Value	Memory (Bytes)							
example	0x7ffffffe0b0									
number	0x7ffffffe0ac	5	5	0	0	0				
example2	0x7ffffffe0b8									
example3	0x7ffffffe0c0									

Automatic allocation/deallocation of Local Variables

For the function main(), all its local variables (a, b and sum):

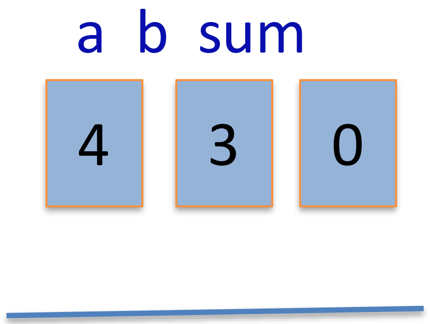
- are automatically allocated memory on the stack frame (SF) when the program starts,
- are automatically deallocated when the function exits.

main.c

```
f1    int foo(int m, int n) {
f2      int tmp;
f3      if (m > n) {
f4        tmp= m;
f5        m= n;
f6        n= tmp;
f7      }
        return m+n;
      }
```

```
m1    int main() {
m2      int a= 4, b= 3, sum=0;
m3      sum= foo(a, b);
m4      printf(“%d %d %d\n”,
               a, b, sum);
```

SF at line m2



Automatic allocation/deallocation of Local Variables - 2

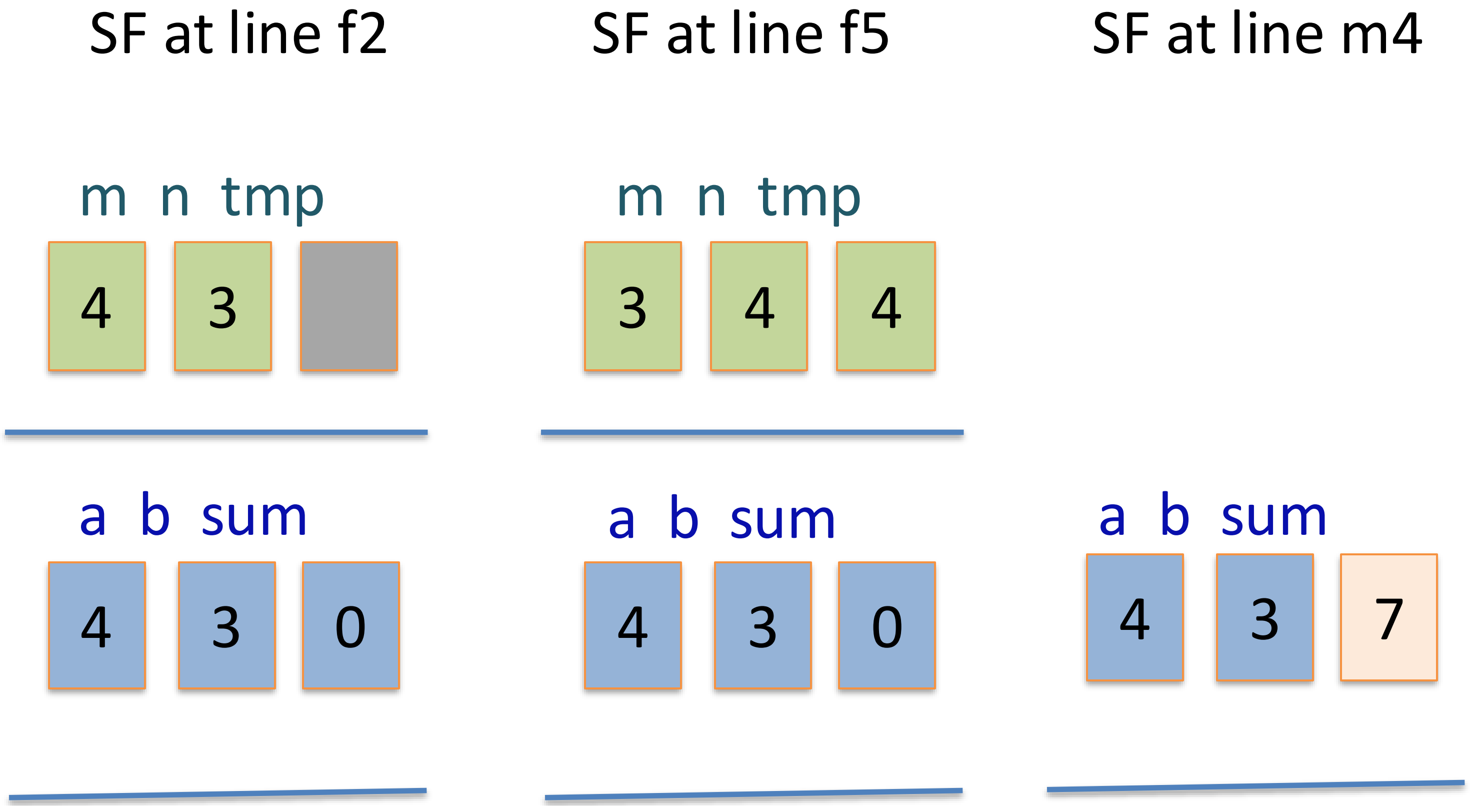
For a function (foo), all its local variables (m and n):

- are automatically allocated memory on the stack frame (SF) when the function is called,
- are automatically deallocated when the function exits.

main.c

```
f1  int foo(int m, int n) {
f2    int tmp;
f3    if (m > n) {
f4      tmp= m;
f5      m= n;
f6      n= tmp;
f7    }
      return m+n;
    }
```

```
m1  int main() {
m2    int a= 4, b= 3, sum=0;
m3    sum= foo(a, b);
m4    printf("%d %d %d\n",
            a, b, sum);
```

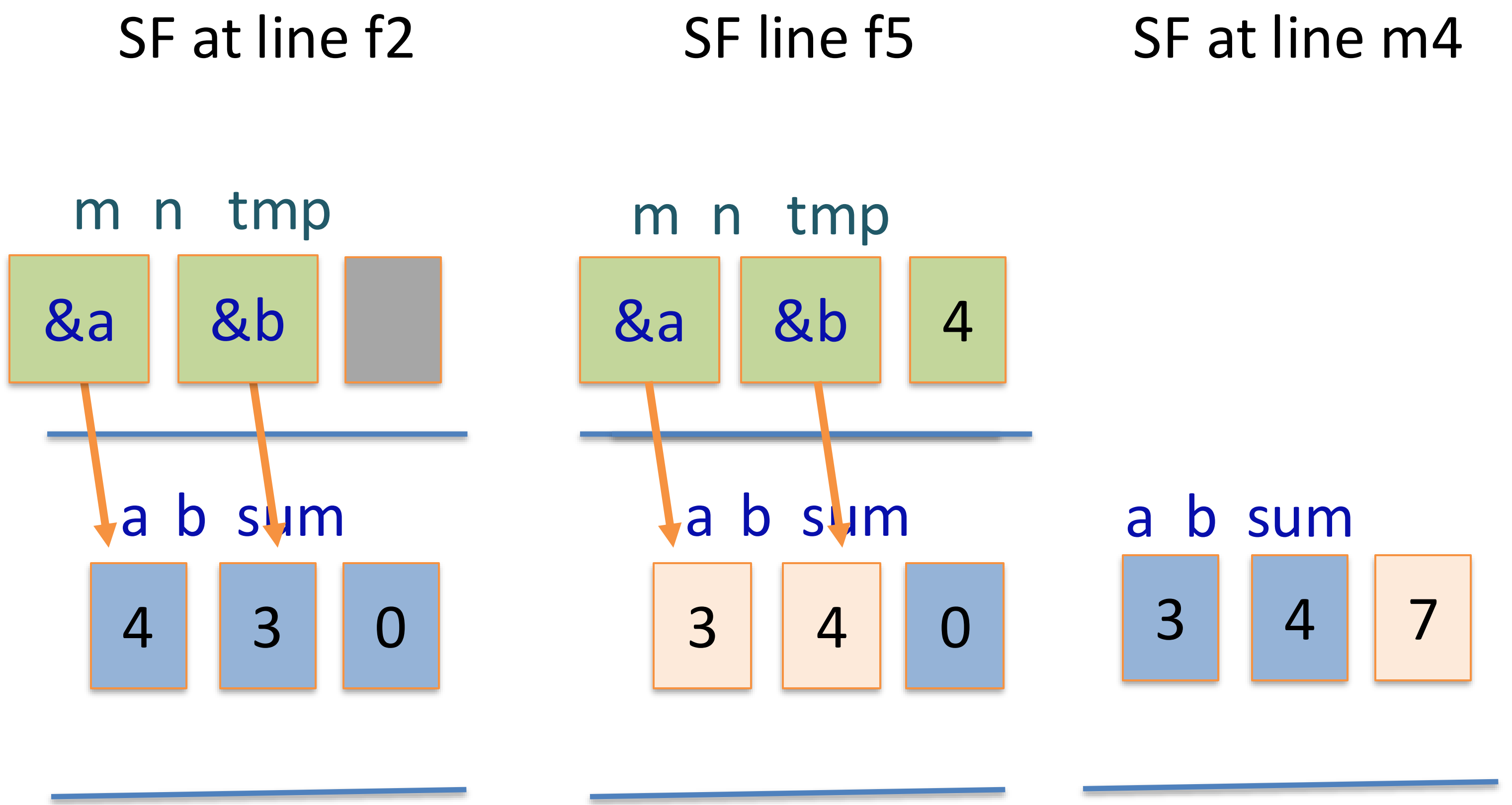


Automatic allocation/deallocation of Local Variables – 3 (with pointers)

If function fool also wants to change a and b it needs to receive the *address* of a and b. The address &a and &b are called *pointers*. The type of &a and &b is int *

Here m and n are *pointer variables*, &a and &b are *pointer constants*.

int foo(int m, int n)	
f1	int fool(int *m, int *n) {
f2	int tmp;
f3	if (*m > *n) {
f4	tmp= *m;
f5	*m= *n;
f6	*n= tmp;
f7	}
	return *m + *n;
	}
m1	int main() {
m2	int a= 4, b= 3, sum=0;
m3	sum= foo(&a, &b);
m4	printf("%d %d %d\n", a, b, sum);



Testing: Simplest Failing Test Case

Test code with the **simplest test case** that:

- you know should work, but
- does not work :')

For example,

Debugging principles

- get no warnings/errors from gcc –Wall
- get a clean valgrind report
- when having problem, first debug with small and simple input
- having problems with larger inputs: focus on the first troublesome input part
- remember: all debug tools have limitations...

Memory Profiling: Valgrind

Valgrind is a suite of dynamic analysis tools.

Memcheck is the default, memory-analysing tool and allows us to:

- see a program's cumulative memory utilisation
- decode arcane segmentation faults
- find **memory leaks:** manually-allocated memory that was never freed

Memory Profiling: Valgrind: Cheat Sheet

Synopsis:

```
valgrind [valgrind-options] your-program [your-program-options]
```

Essential options:

```
--leak-check=full     # shows details of each individual memory leaks
--track-origins=yes   # tracks the origins of uninitialised values
```

Note: This is an excerpt of [Valgrind's man page].

Memory Profiling: Valgrind: Common Errors

Error message	Possible cause(s)
`Conditional jump or move depends on uninitialised value(s)`	Uninitialised values were used in the guard of `for`/`if`/`switch`/`while` statements
`Invalid free() / delete / delete[]`	Non-`*alloc()`'d memory was `free()`'d Some `*alloc()`'d memory was `free()`'d multiple times
`Invalid read/write of size X`	Accessing/modifying restricted memory
`Use of uninitialised value of size X`	Accessing/modifying uninitialised values

Common sizes: 1 (`char`), 2 (`short`), 4 (`float`, `int`), 8 (`double`, `long`, `<type>*`)

Daily Tool: Command-Line Interface

```
cat file_name     # prints file_name's contents to stdout
cd dir_path       # changes the current directory to dir_path
clear             # wipes the terminal clean
ls dir_path       # lists the contents of dir_path
mkdir dir_name    # creates a new directory dir_name
rm file_name      # removes file_name
rm -r dir_name    # removes dir_name and everything inside it
```

Daily Tool: command **man** for manual pages

Man(ual) pages are a form of software documentation.

They usually **document**:

- formal standards and conventions (e.g. TCP/IP)
- libraries (e.g. `stdio.h`)
- system calls (e.g. `fork()`)

They can be **accessed** via the man command.

Examples:

- How to use malloc?
- How to use fgets or getline?