

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING
Department of Electrical & Computer Engineering

ECE 150 *Fundamentals of Programming*

The call stack

ECE150

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The call stack 2

Outline



- In this lesson, we will:
 - Describe instructions and constants
 - Give an overview of main memory
 - Look at how a program is loaded into main memory
 - Observe where instructions, constants and local variables are stored
 - Learn about the *call stack* to store local variables

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The call stack 3

Main memory

- Up to now, we have authored, compiled and executed programs
 - Question: How does this work?
- 
- 

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The call stack 4

Example

- What happens to a program when it is compiled?

```
#include <iostream>

int main();

int main() {
  double x{};
  std::cout << "Enter a value 'x': ";
  std::cin >> x;



  double pi{3.1415926535897932};

  double result{x - pi};

  if ( result < 0 ) {
    result = -result;
  }

  std::cout << "|x - pi| = " << result << std::endl;

  return 0;
}
```



Example

- A program is converted into a sequence of instructions that the computer can execute
 - These instructions are stored in persistent memory
 - A hard-disk drive
 - A solid-state drive
 - Some form of optical memory
 - It may also be stored as firmware in flash ROM
 - Each instruction has its own *address* in that memory



Instructions

| Address | Instruction (rendered into English) |
|---------|---|
| 1954 | Assign 'x' the value 0.0 |
| 1955 | Call routine to print a string at Address 14 |
| 1956 | Call routine to input a double, saving the value to 'x' |
| 1957 | Assign 'pi' the value at Address 15 |
| 1958 | Subtract 'pi' from 'x' |
| 1959 | Assign 'result' the previous calculation |
| 1960 | If 'result' is not negative, jump to Address 9 |
| 1961 | Negate 'result' |
| 1962 | Assign 'result' the previous calculation |
| 1963 | Call routine to print a string at Address 16 |
| 1964 | Call routine to print a double 'x' |
| 1965 | Call routine to print an end-of-line character |
| 1966 | Set return value to 0 |
| 1967 | Return |
| 1968 | "Enter a value 'x': " |
| 1969 | 3.1415926535897932 |
| 1970 | " x - pi = " |



Example

- When you run a program,
 - the instructions and constants are loaded into main memory
 - Main memory is volatile
 - It usually disappears when the computer is turned off
 - It is much faster to access values stored in main memory than it is access anything in persistent memory
 - The processor then starts executing one instruction at a time



Example

- In main memory,
 - we now have
 - Instructions
 - Constants (literals)
 - Question:
 - Where are the local variables stored?

| | |
|----|---|
| 0 | Assign 'x' the value 0.0 |
| 1 | Call routine to print a string at Address 14 |
| 2 | Call routine to input a double, saving the value to 'x' |
| 3 | Assign 'pi' the value at Address 15 |
| 4 | Subtract 'pi' from 'x' |
| 5 | Assign 'result' the previous calculation |
| 6 | If 'result' is not negative, jump to Address 9 |
| 7 | Negate 'result' |
| 8 | Assign 'result' the previous calculation |
| 9 | Call routine to print a string at Address 16 |
| 10 | Call routine to print a double 'x' |
| 11 | Call routine to print an end-of-line character |
| 12 | Set return value to 0 |
| 13 | Exit |
| 14 | "Enter a value 'x': " |
| 15 | 3.1415926535897932 |
| 16 | " x - pi = " |





Example

- One idea is to include the memory for the local variables together with the instructions and constants
 - Problem:
 - We would have to reserve memory for all local variables even if it is unlikely that they will ever be used
 - We will not be able to perform recursive algorithms
- The most common strategy is to place local variables elsewhere in memory
 - The most preferred place is at the *end* of main memory



Example

- Thus, our main memory is broken into three sections
 - Instructions
 - Constants
 - Local variables (the *call stack*)
- All the memory in between will be used for:
 - Function calls
 - Requests for additional memory

| |
|------------------|
| : |
| 60 |
| 61 <i>result</i> |
| 62 <i>pi</i> |
| 63 <i>x</i> |

```

1: int main() {
2:     int i;
3:     int j;
4:     int k;
5:     int l;
6:     int m;
7:     int n;
8:     int o;
9:     int p;
10:    int q;
11:    int r;
12:    int s;
13:    int t;
14:    int u;
15:    int v;
16:    int w;
17:    int x;
18:    int y;
19:    int z;
20:    int a;
21:    int b;
22:    int c;
23:    int d;
24:    int e;
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838:   int m;
839:   int n;
840:   int o;
841:   int p;
842:   int q;
843:   int r;
844:   int s;
845:   int t;
846:   int u;
847:   int v;
848:   int w;
849:   int x;
850:   int y;
851:   int z;
852:   int a;
853:   int b;
854:   int c;
855:   int d;
856:   int e;
857:   int f;
858:   int g;
859:   int h;
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861:   int j;
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996:   int o;
997:   int p;
998:   int q;
999:   int r;
1000:  int s;

```



Summary

- Following this lesson, you now:
 - Know programs are a sequences of instructions built by the compiler
 - Understand they must be loaded into main memory to run them
 - Know that instructions and constants are stored in separate blocks
 - Know that local variables are stored at the other end of memory
 - They are stored in what is called the *call stack*
 - Are aware that the remaining memory can also be used by the running program



References

- [1] No references?





Acknowledgments

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Colophon

These slides were prepared using the Georgia typeface. Mathematical equations use Times New Roman, and source code is presented using Consolas.

The photographs of lilacs in bloom appearing on the title slide and accenting the top of each other slide were taken at the Royal Botanical Gardens on May 27, 2018 by Douglas Wilhelm Harder. Please see

<https://www.rbg.ca/>

for more information.



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