Computer Programming

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Session: Flow of Control in Function Call

Quick Recap of Relevant Topics

- Use of simple functions in programs
    - Encapsulating computational sub-tasks as functions
    - Invoking functions from other functions
    - Functions returning values of specified types
    - Modular development of programs
- Contract-centric view of programming with functions

Overview of This Lecture

- Flow of control in a function call and return
- Activation records and call stack

Recall: Encoding Example

- We want to store quiz 1 and quiz 2 marks of CS101 students in an encoded form

  So that others cannot figure out the actual marks

- Encoding strategy:

  The ordered pair of marks (m, n) is encoded as 2^m x 3^n

- Assume all marks are integers in {1, 2, … 10}

Recall: C++ Program Structure

```
#include <iostream>
using namespace std;
int myEncode
int power(int
int main() { …
  for ( … ) { …
   cip                                   ks);
   .
…
}
```

1 <= q1Marks <= 10
1 <= q2Marks <= 10

$2^{q1Marks} \times 3^{q2Marks}$
can be represented
as int (4 bytes)

```
// PRECONDITION:  …
int myEncode(int q1Marks,
                int q2Marks)
{ …
 twoRaisedQ1 = power(2, q1Marks);
 threeRaisedQ2 = power(3, q2Marks);
 … }
// POSTCONDITION:  …
```

```
// PRECONDITION:  …
int power(int base, int exponent)
{ … }
// POSTCONDITION:  …
```

Recall: C++ Program Structure

```
#include <iostream>
using namespace std;
in                              arks);
in
in
 for ( … ) { …
  cipher = myEncode(q1Marks, q2Marks);
 …}
…
}
```

return value =

$2^{q1Marks} \times 3^{q2Marks}$

```
// PRECONDITION:  …
int myEncode(int q1Marks,
                  int q2Marks)
{ …
 twoRaisedQ1 = power(2, q1Marks);
 threeRaisedQ2 = power(3, q2Marks);
 … }
// POSTCONDITION:  …
```

```
// PRECONDITION:  …
int power(int base, int exponent)
{ … }
// POSTCONDITION:  …
```

Recall: C++ Program Structure

```
#include <iostream>
using
in
in
int ma
  for ( … ) {  …
   cipher = myEncode(q1Ma ks, q2Marks);
}
```

base ^{exponent} can be represented as int (4 bytes)

base > 0, exponent >= 0, 1 <= base ^{exponent} <= $2^{31} - 1$

```
// PRECONDITION:  …
int myEncode(int q1Marks,
                 int q2Marks)
{ …
 twoRaisedQ1 = power(2, q1Marks);
 threeRaisedQ2 = power(3, q2Marks);
 … }
// POSTCONDITION:  …
```

```
// PRECONDITION:  …
int power(int base, int exponent)
{ … }
// POSTCONDITION:  …
```

Recall: C++ Program Structure

```
#include <iostream>
using namespace std;
int myEncode(int q1Marks,int q2Marks);
int power(int base, int exponent);
int main() { …
  for ( … ) {  …
   cipher = myEncode(q1Marks, q2Marks);
   }
..
}
```

```
// PRECONDITION:  …
int myEncode(int q1Marks,
                   int q2Marks)
{ …
 twoRaisedQ1 = power(2, q1Marks);
 threeRaisedQ2 = power(3, q2Marks);
 … }
// POSTCONDITION:  …
```

```
// PRECONDITION:  …
int power(int base, int exponent)
{ … }
// POSTCONDITION:  …
```

return value = base $^{\text{exponent}}$

Flow of Control: An Animation

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```
#include <iostream>
using namespace std;
int myEncode(int q1Marks,int q2Marks);
int power(int base, int exponent);
int main() { …
  for ( ) {  …
   ipher = myEncode(q1Marks, q2Mar s);
  …}
 …
return 0; }
```

```
int myEncode(int q1Marks,
                int q2Marks)
{ …
   RaisedQ1 = power(2, q1Marks);
   eeRaisedQ2 = power(3, q2Marks);
 …
 return cipher;
}
```

```
int power(int base, int exponent)
{ …
  return result;
}
```

Flow of Control: A Closer Look

Operating System (OS) calls **main**

main calls **myEncode(q1Marks, q2Marks)**

  myEncode calls **power(2, q1Marks)**

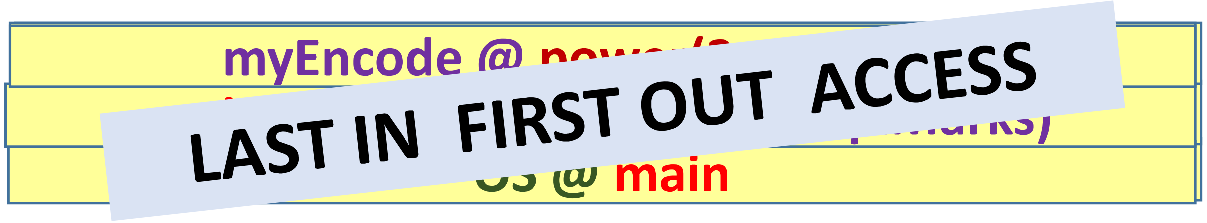
    power returns to **myEncode**, where **power(2, q1Marks)** called

  myEncode calls **power(3, q2Marks)**

    power returns to **myEncode**, where **power(3, q2Marks)** called

  myEncode returns to **main**, where **myEncode(q1Marks, q2Marks)** called

main returns to **OS**



Call Stack

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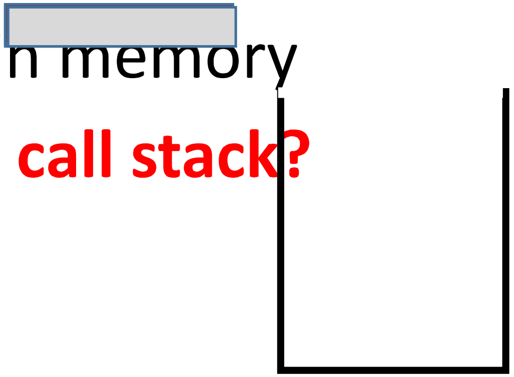
- We need to store “information” about function calls in a way that allows last-in-first-out (LIFO) access

  A stack (think, stack of papers) does exactly that

- **Call stack** used to store “information” about function calls

  Resides in a special, reserved part of main memory

- **What “information” must be stored in the call stack?**



Recall Flow of Control

```
#
u
i
i
i
  for ( … ) {  …
  ipher = myEncode(q1Marks, q2Marks);
  …}
…
return 0; }
```

```
yEncode(int q1Marks,
              int q2Marks)

aisedQ1 = power(2, q1Marks);
RaisedQ2 = power(3, q2Marks);

 return cipher;
}
```

```
int power(int base, int exponent)
{ …
  return result;
}
```

Must remember:

- **Where to return in calling function**
- **Values of local variables in calling function at time of function call**

Memory For An Executing Program (Process)

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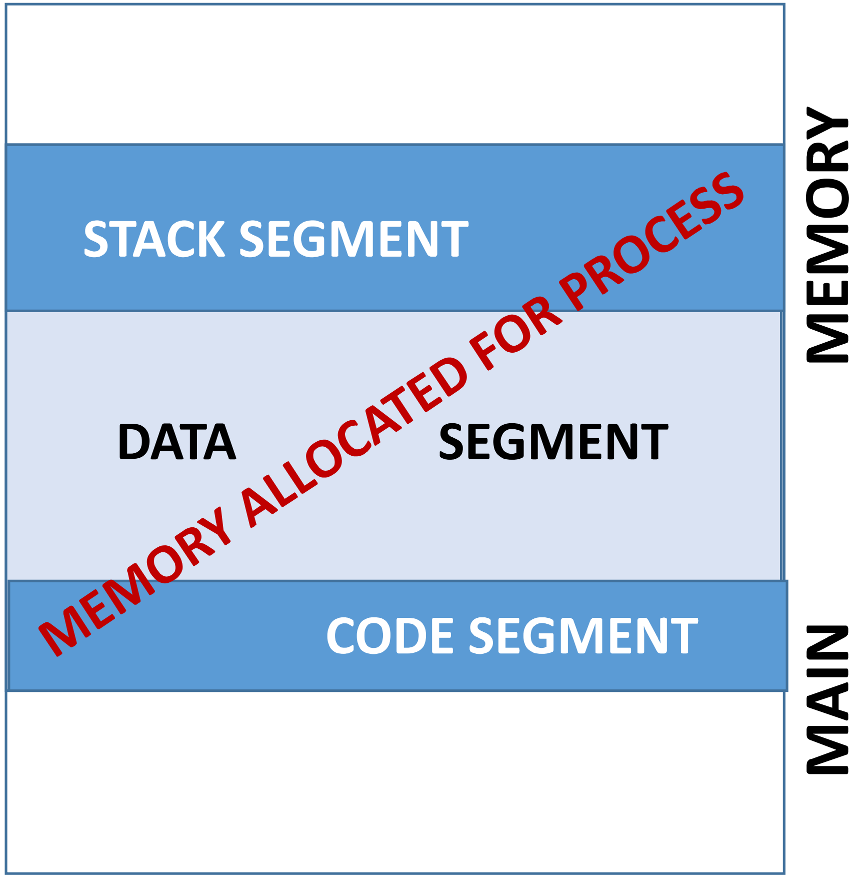
- Operating system allocates a part of main memory for use by a process
- Divided into:

  Code segment: Stores executable instructions in program

  Data segment: For dynamically allocated data (later lecture)

  Stack segment: Call stack



Where To Return From Called Function?

- Program stored in code segment of main memory
- Every (machine language) instruction has a memory address
- Program counter (PC)

  Special CPU register that holds memory address of current instruction being executed
- When **myEncode** is called from **main**, value of PC must be saved.

  On returning from **myEncode**, execution should resume from instruction at this address.

Activation Frame/Record

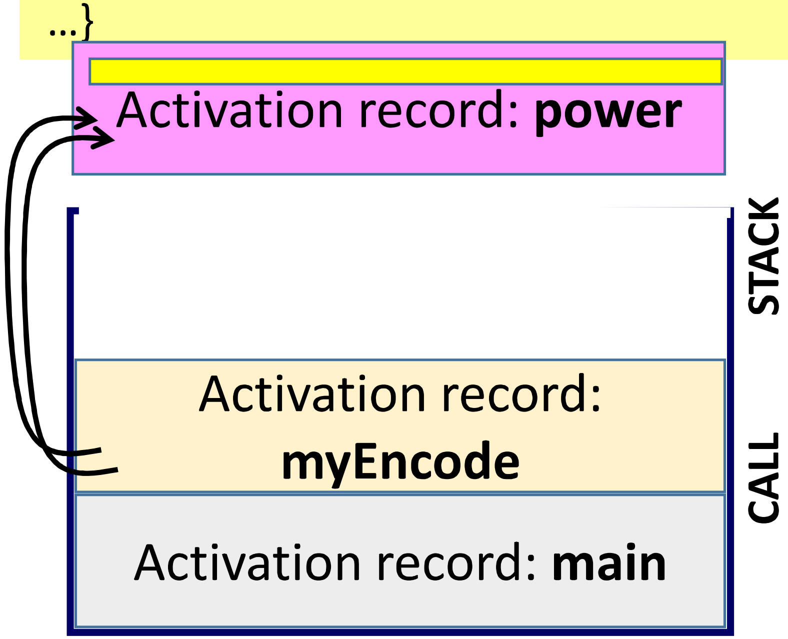
- Entry in call stack for each function called
  - E.g., **main (caller)** calling **myEncode (callee)**
- Activation record contains
  - Memory for all local variables of callee (**myEncode**)
  - PC value in caller when callee was called (address of instruction in **main** that calls **myEncode**)
  - Space for return value of callee
  - Additional book-keeping information (let’s not worry …)

Activation Records in Call Stack

When a function (caller) calls a function (callee)

- a **fresh** activation record for callee created
- Values of function parameters from caller copied to space allocated for formal parameters of callee
- PC of caller saved
- Other book-keeping information updated
- Activation record for callee pushed on call stack

```
int
myEncode(int q1Marks, int q2Marks)
{ ….
  twoRaisedQ1 = power(2, q1Marks);
 …}
```

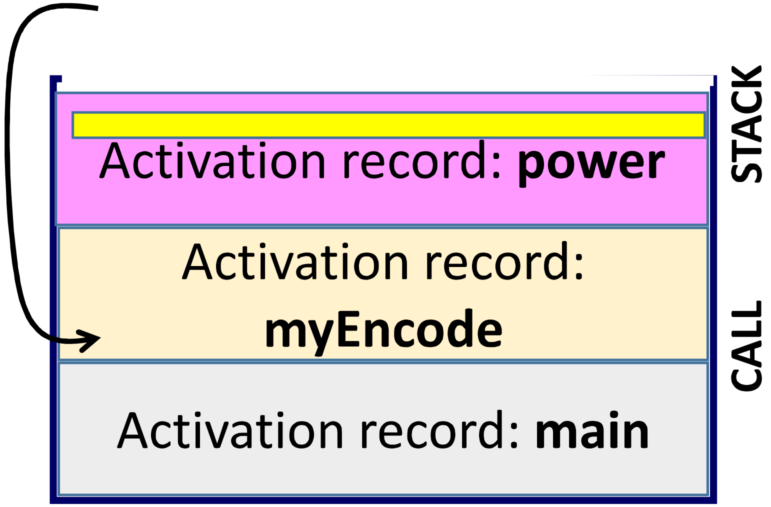

Activation record: **power**
Activation record: **myEncode**
Activation record: **main**
CALL STACK

Activation Records in Call Stack

When a function (callee) returns

- Callee’s activation record popped from call stack
- Return value from popped activation record copied to activation record of caller (now on top of stack)
- Value of PC saved in popped activation record loaded in PC of CPU
- Free activation record of callee
- Resume execution of instruction at location given by updated PC

```
int power(int base, int exponent)
{ ….
  return result;
 …}
```


Activation record: **power**
Activation record: **myEncode**
Activation record: **main**
CALL STACK

Summary

- Flow of control in function call and return
- Memory layout of a process
- Call stack and activation records