

P6 – Scientific Programming

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Part #13

Functions in C (cont.)

function objects, function types, function pointers, stack frame



Intro: Gauss3 (1/4)

The following Gaussian integration formula is exact for polynomials of degree up to 5 on [-1,1]:

$$\sum_{k=1}^{3} \omega_k f(x_k) \ , \quad x_k \in \left(-\frac{\sqrt{15}}{5}, 0, \frac{\sqrt{15}}{5}\right) \ , \quad \omega_k \in \left(\frac{5}{9}, \frac{8}{9}, \frac{5}{9}\right)$$

For general intervals [a, b] we need to adapt weights and points to

$$\hat{x}_k = \frac{b+a}{2} + \frac{b-a}{2} x_k \ , \quad \hat{\omega}_k = \frac{b+a}{2} \omega_k$$



Intro: Gauss3 (2/4)

```
double gauss3( double a, double b ) {
 double weight[] = { 5.0/9.0, 8.0/9.0, 5.0/9.0 };
 double pos[] = { - 0.2 * sqrt( 15.0 ), 0.0, 0.2 * sqrt( 15.0 ) };
 double fac1 = (b+a)*0.5:
 double fac2 = (b-a)*0.5;
 double integral = 0.0;
 for ( int k = 0; k < 3; k++ ) {
    integral += fac2 * weight[k] * func( fac1 + fac2 * pos[k] );
 return integral;
```

In order to test our algorithm/implementation we need to implement a function double func(double); for the integrand.



Intro: Gauss3 (3/4)

Testing with a degree 3 polynomial:

```
double func( double x ) {
  return x*x*x + 2.0*x*x - 3.0*x + 4.0;
}
int main( void ) {
  double integ = gauss3( 1.0, 2.0 );
  double exact = 95.0 / 12.0;

  printf( "Gauss3: Value of integral = %f\n", integ );
  printf( "Exact: Value of integral = %f\n", exact );
  printf( "Error: %e\n", exact - integ );
}
```

Gauss3: Value of integral = 7.916667 Exact: Value of integral = 7.916667 Error: 8.881784e-16



Intro: Gauss3 (4/4)

- Now let us test with a polynomial of degree 5
 → need to change implementation of func()
- What if we want to run a series of tests in one program?
- We would need a way to pass the integrand function func() to the function gauss3()



Intro: Gauss3 (4/4)

- Now let us test with a polynomial of degree 5
 → need to change implementation of func()
- What if we want to run a series of tests in one program?
- We would need a way to pass the integrand function func() to the function gauss3()
- We can add a formal parameter that is of the function type of the function we want to use.



Variant #1

```
double gauss3( double a, double b, double func( double ) ) {
  double weight[] = { 5.0/9.0, 8.0/9.0, 5.0/9.0 };
  double pos[] = { - 0.2 * sqrt( 15.0 ), 0.0, 0.2 * sqrt( 15.0 ) };
  double fac1 = (b+a)*0.5:
  double fac2 = (b-a)*0.5;
  double integral = 0.0;
  for ( int k = 0; k < 3; k++ ) {
    integral += fac2 * weight[k] * func( fac1 + fac2 * pos[k] );
  return integral;
}
```

```
double poly3( double x ) {
 return x*x*x + 2.0*x*x - 3.0*x + 4.0;
}
double poly5( double x ) {
 return 0.1 * x*x*x*x + 2.0*x*x - 3.0*x + 4.0:
}
int main ( void ) {
 double integ = 0.0;
 double exact = 0.0;
 // test with 3rd order polynomial
 integ = gauss3(1.0, 2.0, poly3);
 exact = 95.0 / 12.0;
 printf( "Gauss3: Value of integral = %f\n", integ );
 printf( "Exact: Value of integral = %f\n", exact );
 printf( "Error: %e\n", exact - integ );
 // test with 5th order polynomial
 integ = gauss3(1.0, 2.0, poly5);
 exact = 313.0 / 60.0;
 printf( "Gauss3: Value of integral = %f\n", integ );
 printf( "Exact: Value of integral = %f\n", exact );
 printf( "Error: %e\n", exact - integ );
```



Function Addresses

- One of the design principles of the von Neumann architecture was the stored program approach.
- The machine code of a function is stored in the memory of our computer and, thus, has an address.

```
void f( int a ) {
  printf( "a = %d\n", a );
}

int main( void ) {
  int a = 42;
  printf( "address of a = %p\n", &a );
  printf( "address of f = %p\n", &f );
  printf( "address of f = %p\n", f );
```

When executed the code might print:

```
address of a = 0x7ffea69bac4c
address of f = 0x4004f0
address of f = 0x4004f0
```

Note that f and &f result in the same.



Function Pointers

- We can also define function pointers, i.e. variables that hold the address of a function of an associated function type.
- Actually in variant #1 that was what our parameter 'decayed' into.

```
void f( int a ) {
  printf( "a = "d\n", a );
}

int main( void ) {
  int a = 42;
  printf( "address of a = %p\n", &a );
  printf( "address of f = %p\n", &f );
  printf( "address of f = %p\n", f );

// define a function pointer
  void (*fPtr) ( int ) = NULL;
  printf( "fPtr = %p\n", fPtr );

fPtr = f;
  printf( "address of f = %p\n", fPtr );
```

When executed the code might print:

```
address of a = 0x7fff534937bc
address of f = 0x5623cbf776aa
address of f = 0x5623cbf776aa
fPtr = (nil)
address of f = 0x5623cbf776aa
```



Typedefs

- Using function types or function pointers in interfaces quickly becomes hard to read.
- typedef can help here:

```
// declare a function pointer datatype for our integrand
typedef double (*integ_t) (double);

// alternatively we can use a two-step approach:
// step 1: generate an alias for the function type
typedef double (integrand) (double);
// step 2: now an alias for the function pointer type
typedef integrand* integ_t;
```

With this we can write the interface as

```
double gauss3( double a, double b, integ_t func );
```

```
double poly3( double x ) {
 return x*x*x + 2.0*x*x - 3.0*x + 4.0;
}
double poly5( double x ) {
 return 0.1 * x*x*x*x + 2.0*x*x - 3.0*x + 4.0:
}
double poly6( double x ) {
 return 2 * x*x*x*x*x - 32.0:
}
int main ( void ) {
 integ_t testFuncs[] = { poly3, poly5, poly6 };
 double testValues[] = { 95.0/12.0.313.0/60.0.30.0/7.0 }:
 double integ = 0.0:
 double exact = 0.0:
 for ( int k = 0: k < 3: k++ ) {
    integ = gauss3( 1.0, 2.0, testFuncs[k] );
    exact = testValues[k];
    printf( "Gauss3: Value of integral = %f\n", integ ):
    printf( "Exact: Value of integral = %f\n", exact ):
    printf( "Error: %e\n", exact - integ );
}
```

Test Results for gauss3

```
// degree 3
Gauss3: Value of integral = 7.916667
Exact: Value of integral = 7.916667
Error: 8.881784e-16
// degree 5
Gauss3: Value of integral = 5.216667
Exact: Value of integral = 5.216667
Error: 0.000000e+00
// degree 6
Gauss3: Value of integral = 4.285000
Exact: Value of integral = 4.285714
Error: 7.142857e-04
```



Function Calls and the Stack

- We are going to take a (generalised) look at what happens when our program calls a function. [details depend on OS & HW]
- The computer keeps track of the currently active functions inside our running program with a (call/execution/program) stack.
- When we compile our program the compiler generates a stack frame for each of our functions.
- When the function is called a stack frame instance is placed on top of the call stack.



- The stack frame is a template for the memory requirements of the function (parameters, local variables, return value, . . .)
- Let us take a look at how this works for the following function

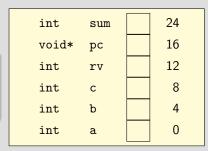
```
int sum3( int a, int b, int c ) {
  int sum = 0;
  sum = a + b + c;
  return sum;
}
```

and its driver

```
int main( void ) {
  int x = 1;
  x = sum3( x, x, x );
  return 0;
}
```



```
int sum3( int a, int b, int c ) {
  int sum = 0;
  sum = a + b + c;
  return sum;
}
```



- Note that the stack frame is only a template; that's why addresses start at 0.
- We need memory for the three parameters a, b, c and the local variable sum.
- rv is space for storing the return value.
- pc (program counter) is the address at which to continue execution once sum3() has finished.



```
1 int main( void ) {
2   int x = 1;
3   x = sum3( x, x, x );
4   return 0;
5 }
```

```
        int
        x
        1
        1000

        void*
        pc
        "system"
        992

        int
        rv
        ⊗
        988
```

- Main itself is also a function, with its own stack frame.
- When we execute it an instance of the frame is placed on the call stack (addresses in example are chosen arbitrarily).
- Starting to execute line #3 stack will have shown values.
- rv is still undefined; "system" represents code inserted by the compiler to interface our program with the OS.



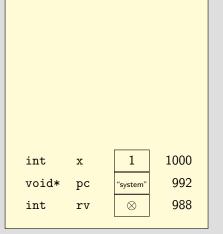
```
1 int main( void ) {
2   int x = 1;
3   x = sum3( x, x, x );
4   return 0;
5 }
```

```
 \begin{array}{c|cccc} \text{int} & x & 1 & 1000 \\ \text{void*} & \text{pc} & \text{"system"} & 992 \\ \text{int} & \text{rv} & \otimes & 988 \\ \end{array}
```

- Main itself is also a function, with its own stack frame.
- When we execute it an instance of the frame is placed on the call stack (addresses in example are chosen arbitrarily).
- Starting to execute line #3 stack will have shown values.
- rv is still undefined; "system" represents code inserted by the compiler to interface our program with the OS.
- now in line #3 we call sum3()

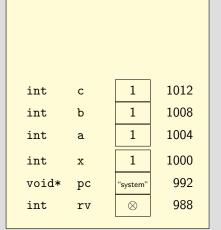


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- Happens on top of the frame for main using the next addresses.





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- Happens on top of the frame for main using the next addresses.
- First the three parameters are filled with their arguments.
- Space for return value and pc is allocated; the latter is set.

int*	рс	"line 3+"	1020
int	rv	\otimes	1016
int	С	1	1012
int	b	1	1008
int	a	1	1004
int	x	1	1000
void*	рс	"system"	992
int	rv	\otimes	988



- Call to sum3() triggers that an instance of its stack frame is placed on the call stack.
- Happens on top of the frame for main using the next addresses.
- First the three parameters are filled with their arguments.
- Space for return value and pc is allocated; the latter is set.
- Finally space for sum is allocated; the code of sum3 initialises it to 0.

int	sum	0	1028
int*	pc	"line 3+"	1020
int	rv	\otimes	1016
int	С	1	1012
int	b	1	1008
int	a	1	1004
int	x	1	1000
void*	pc	"system"	992
int	rv	\otimes	988



Next we execute sum = a + b + c;
 changing the value of local variable sum.

int	sum	3	1028
int*	pc	"line 3+"	1020
int	rv	\otimes	1016
int	С	1	1012
int	b	1	1008
int	a	1	1004
int	x	1	1000
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- Next we execute sum = a + b + c;
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- Then we execute return sum; which sets the return value rv.

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- Next we execute sum = a + b + c;
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- Now sum3 is done and we can start to deconstruct the stack frame instance again.

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int*	pc	"line 3+"	1020
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- Next we execute sum = a + b + c;
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- This starts with deallocating (popping) the local variables.

рс	"line 3+"	1020
rv	3	1016
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rv	\otimes	988
	rv c b a x	rv 3 c 1 b 1 a 1 x 1 pc "system"



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 changing the value of local variable sum.
- Then we execute return sum; which sets the return value rv.
- Now sum3 is done and we can start to deconstruct the stack frame instance again.
- This starts with deallocating (popping) the local variables.
- Program counter is restored from pc and then pc is popped.

rv	3	1016
С	1	1012
b	1	1008
a	1	1004
x	1	1000
рс	"system"	992
rv	\otimes	988
	c b a x pc	c 1 b 1 a 1 x 1 pc "system"



 Control is now back at line #3 of main which reads x = sum3(x,x,x);

int	rv	3	1016
int	С	1	1012
int	b	1	1008
int	a	1	1004
int	x	1	1000
void*	pc	"system"	992
int	rv	\otimes	988



- Control is now back at line #3 of main which reads x = sum3(x,x,x);
- The variable x (local to main) is updated using rv and then rv is popped.

int	rv	3	1016
int	С	1	1012
int	b	1	1008
int	a	1	1004
int	x	1	1000
void*	рс	"system"	992
int	rv	\otimes	988



- Control is now back at line #3 of main which reads x = sum3(x,x,x);
- The variable x (local to main) is updated using rv and then rv is popped.
- Finally the arguments are popped.

С	1	1012
b	1	1008
a	1	1004
x	3	1000
pc	"system"	992
rv	\otimes	988
	b a x pc	b 1 a 1 x 3 pc "system"



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- Finally the arguments are popped.

