

## Example of Subprogram Execution

In order to get a better understanding of the roles of the internal registers and runtime stack when executing subprograms, let's examine in detail the call of and return from a simple function. Consider the following CPRL program.

```
declare

  var x : Integer;

  function abs(n : Integer) return Integer is
  begin
    if n >= 0 then
      return n;
    else
      return -n;
    end if;
  end abs;

begin
  x := -5;
  writeln abs(x);
end.
```

Compiling this program yields the following assembly code:

PROGRAM 4	LOADW
BR L5	NEG
L0:	STOREW
PROC 0	RET 4
LDLADDR -4	L4:
LOADW	L5:
LDCINT 0	LDGADDR 0
CMP	LDCINT 5
BL L3	NEG
LDLADDR -8	STOREW
LDLADDR -4	ALLOC 4
LOADW	LDGADDR 0
STOREW	LOADW
RET 4	CALL L0
BR L4	PUTINT
L3:	PUTEOL
LDLADDR -8	HALT
LDLADDR -4	

After optimization and assembly, a disassembled version of the code would look as follows:

0:	PROGRAM 4	59:	LDLADDR -4
5:	BR 67	64:	LOADW
10:	PROC 0	65:	NEG
15:	LDLADDR -4	66:	STOREW
20:	LOADW	67:	RET 4
21:	LDCINT 0	72:	LDGADDR 0
26:	CMP	77:	LDCINT -5
27:	BL 27	82:	STOREW
32:	LDLADDR -8	83:	ALLOC 4
37:	LDLADDR -4	88:	LDGADDR 0
42:	LOADW	93:	LOADW
43:	STOREW	94:	CALL -84
44:	RET 4	99:	PUTINT
49:	BR 23	100:	PUTEOL
54:	LDLADDR -8	101:	HALT

Note that before execution of the first instruction, PC has the value 0, BP has the value 102, SB also has the value 102, and SP has the value 101. We visualize this state as follows:

PC ->	0:	PROGRAM 4	64:	LOADW
	5:	BR 67	65:	NEG
	10:	PROC 0	66:	STOREW
	15:	LDLADDR -4	67:	RET 4
	20:	LOADW	72:	LDGADDR 0
	21:	LDCINT 0	77:	LDCINT -5
	26:	CMP	82:	STOREW
	27:	BL 27	83:	ALLOC 4
	32:	LDLADDR -8	88:	LDGADDR 0
	37:	LDLADDR -4	93:	LOADW
	42:	LOADW	94:	CALL -84
	43:	STOREW	99:	PUTINT
	44:	RET 4	100:	PUTEOL
	49:	BR 23	SP -> 101:	HALT
	54:	LDLADDR -8	SB -> 102:	? <- BP
	59:	LDLADDR -4		

The first instruction, PROGRAM 4, allocates four bytes on the runtime stack, which now gives us the following:

0:	PROGRAM 4	65:	NEG
PC -> 5:	BR 67	66:	STOREW
10:	PROC 0	67:	RET 4
15:	LDLADDR -4	72:	LDGADDR 0
20:	LOADW	77:	LDCINT -5
21:	LDCINT 0	82:	STOREW
26:	CMP	83:	ALLOC 4
27:	BL 27	88:	LDGADDR 0
32:	LDLADDR -8	93:	LOADW
37:	LDLADDR -4	94:	CALL -84
42:	LOADW	99:	PUTINT
43:	STOREW	100:	PUTEOL
44:	RET 4	101:	HALT
49:	BR 23	SB -> 102:	0 <- BP
54:	LDLADDR -8	103:	0
59:	LDLADDR -4	104:	0
64:	LOADW	SP -> 105:	0

Below is a complete step-by-step execution trace of this code that shows memory contents, memory locations referenced by the registers, the runtime stack, etc.

0:	PROGRAM 4	65:	NEG
5:	BR 67	66:	STOREW
10:	PROC 0	67:	RET 4
15:	LDLADDR -4	PC -> 72:	LDGADDR 0
20:	LOADW	77:	LDCINT -5
21:	LDCINT 0	82:	STOREW
26:	CMP	83:	ALLOC 4
27:	BL 27	88:	LDGADDR 0
32:	LDLADDR -8	93:	LOADW
37:	LDLADDR -4	94:	CALL -84
42:	LOADW	99:	PUTINT
43:	STOREW	100:	PUTEOL
44:	RET 4	101:	HALT
49:	BR 23	SB -> 102:	0 <- BP
54:	LDLADDR -8	103:	0
59:	LDLADDR -4	104:	0
64:	LOADW	SP -> 105:	0

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW

```

```

67: RET 4
72: LDGADDR 0
PC -> 77: LDCINT -5
82: STOREW
83: ALLOC 4
88: LDGADDR 0
93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: 0          <- BP
103: 0
104: 0
105: 0
106: 0
107: 0
108: 0
SP -> 109: 102

```

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW
67: RET 4
72: LDGADDR 0

```

```

77: LDCINT -5
PC -> 82: STOREW
83: ALLOC 4
88: LDGADDR 0
93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: 0          <- BP
103: 0
104: 0
105: 0
106: 0
107: 0
108: 0
109: 102
110: -1
111: -1
112: -1
SP -> 113: -5

```

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW

```

```

65: NEG
66: STOREW
67: RET 4
72: LDGADDR 0
77: LDCINT -5
82: STOREW
PC -> 83: ALLOC 4
88: LDGADDR 0
93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1      <- BP
103: -1
104: -1
SP -> 105: -5

```

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW

```

```

67: RET 4
72: LDGADDR 0
77: LDCINT -5
82: STOREW
83: ALLOC 4
PC -> 88: LDGADDR 0
93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1      <- BP
103: -1
104: -1
105: -5
106: 0
107: 0
108: 0
SP -> 109: 102

```

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW
67: RET 4
72: LDGADDR 0

```

```

77: LDCINT -5
82: STOREW
83: ALLOC 4
88: LDGADDR 0
PC -> 93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1          <- BP
103: -1
104: -1
105: -5
106: 0
107: 0
108: 0
109: 102
110: 0
111: 0
112: 0
SP -> 113: 102

```

```

0:  PROGRAM 4
5:  BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW
67: RET 4
72: LDGADDR 0
77: LDCINT -5

```

```

82: STOREW
83: ALLOC 4
88: LDGADDR 0
93: LOADW
PC -> 94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1          <- BP
103: -1
104: -1
105: -5
106: 0
107: 0
108: 0
109: 102
110: -1
111: -1
112: -1
SP -> 113: -5

```

	0:	PROGRAM 4		93:	LOADW
	5:	BR 67		94:	CALL -84
PC ->	10:	PROC 0		99:	PUTINT
	15:	LDLADDR -4		100:	PUTEOL
	20:	LOADW		101:	HALT
	21:	LDCINT 0	SB ->	102:	-1
	26:	CMP		103:	-1
	27:	BL 27		104:	-1
	32:	LDLADDR -8		105:	-5
	37:	LDLADDR -4		106:	0
	42:	LOADW		107:	0
	43:	STOREW		108:	0
	44:	RET 4		109:	102
	49:	BR 23		110:	-1
	54:	LDLADDR -8		111:	-1
	59:	LDLADDR -4		112:	-1
	64:	LOADW		113:	-5
	65:	NEG	BP ->	114:	0
	66:	STOREW		115:	0
	67:	RET 4		116:	0
	72:	LDGADDR 0		117:	102
	77:	LDCINT -5		118:	0
	82:	STOREW		119:	0
	83:	ALLOC 4		120:	0
	88:	LDGADDR 0	SP ->	121:	99

0: PROGRAM 4  
5: BR 67  
10: PROC 0  
PC -> 15: LDLADDR -4  
20: LOADW  
21: LDCINT 0  
26: CMP  
27: BL 27  
32: LDLADDR -8  
37: LDLADDR -4  
42: LOADW  
43: STOREW  
44: RET 4  
49: BR 23  
54: LDLADDR -8  
59: LDLADDR -4  
64: LOADW  
65: NEG  
66: STOREW  
67: RET 4  
72: LDGADDR 0  
77: LDCINT -5  
82: STOREW  
83: ALLOC 4  
88: LDGADDR 0

93: LOADW  
94: CALL -84  
99: PUTINT  
100: PUTEOL  
101: HALT  
SB -> 102: -1  
103: -1  
104: -1  
105: -5  
106: 0  
107: 0  
108: 0  
109: 102  
110: -1  
111: -1  
112: -1  
113: -5  
BP -> 114: 0  
115: 0  
116: 0  
117: 102  
118: 0  
119: 0  
120: 0  
SP -> 121: 99



	0:	PROGRAM 4		99:	PUTINT
	5:	BR 67		100:	PUTEOL
	10:	PROC 0		101:	HALT
	15:	LDLADDR -4	SB ->	102:	-1
PC ->	20:	LOADW		103:	-1
	21:	LDCINT 0		104:	-1
	26:	CMP		105:	-5
	27:	BL 27		106:	0
	32:	LDLADDR -8		107:	0
	37:	LDLADDR -4		108:	0
	42:	LOADW		109:	102
	43:	STOREW		110:	-1
	44:	RET 4		111:	-1
	49:	BR 23		112:	-1
	54:	LDLADDR -8		113:	-5
	59:	LDLADDR -4	BP ->	114:	0
	64:	LOADW		115:	0
	65:	NEG		116:	0
	66:	STOREW		117:	102
	67:	RET 4		118:	0
	72:	LDGADDR 0		119:	0
	77:	LDCINT -5		120:	0
	82:	STOREW		121:	99
	83:	ALLOC 4		122:	0
	88:	LDGADDR 0		123:	0
	93:	LOADW		124:	0
	94:	CALL -84	SP ->	125:	110

	0:	PROGRAM 4		99:	PUTINT
	5:	BR 67		100:	PUTEOL
	10:	PROC 0		101:	HALT
	15:	LDLADDR -4	SB ->	102:	-1
	20:	LOADW		103:	-1
PC ->	21:	LDCINT 0		104:	-1
	26:	CMP		105:	-5
	27:	BL 27		106:	0
	32:	LDLADDR -8		107:	0
	37:	LDLADDR -4		108:	0
	42:	LOADW		109:	102
	43:	STOREW		110:	-1
	44:	RET 4		111:	-1
	49:	BR 23		112:	-1
	54:	LDLADDR -8		113:	-5
	59:	LDLADDR -4	BP ->	114:	0
	64:	LOADW		115:	0
	65:	NEG		116:	0
	66:	STOREW		117:	102
	67:	RET 4		118:	0
	72:	LDGADDR 0		119:	0
	77:	LDCINT -5		120:	0
	82:	STOREW		121:	99
	83:	ALLOC 4		122:	-1
	88:	LDGADDR 0		123:	-1
	93:	LOADW		124:	-1
	94:	CALL -84	SP ->	125:	-5

	0:	PROGRAM 4		101:	HALT
	5:	BR 67	SB ->	102:	-1
	10:	PROC 0		103:	-1
	15:	LDLADDR -4		104:	-1
	20:	LOADW		105:	-5
	21:	LDCINT 0		106:	0
PC ->	26:	CMP		107:	0
	27:	BL 27		108:	0
	32:	LDLADDR -8		109:	102
	37:	LDLADDR -4		110:	-1
	42:	LOADW		111:	-1
	43:	STOREW		112:	-1
	44:	RET 4		113:	-5
	49:	BR 23	BP ->	114:	0
	54:	LDLADDR -8		115:	0
	59:	LDLADDR -4		116:	0
	64:	LOADW		117:	102
	65:	NEG		118:	0
	66:	STOREW		119:	0
	67:	RET 4		120:	0
	72:	LDGADDR 0		121:	99
	77:	LDCINT -5		122:	-1
	82:	STOREW		123:	-1
	83:	ALLOC 4		124:	-1
	88:	LDGADDR 0		125:	-5
	93:	LOADW		126:	0
	94:	CALL -84		127:	0
	99:	PUTINT		128:	0
	100:	PUTEOL	SP ->	129:	0

	0:	PROGRAM 4		94:	CALL -84
	5:	BR 67		99:	PUTINT
	10:	PROC 0		100:	PUTEOL
	15:	LDLADDR -4		101:	HALT
	20:	LOADW	SB ->	102:	-1
	21:	LDCINT 0		103:	-1
	26:	CMP		104:	-1
PC ->	27:	BL 27		105:	-5
	32:	LDLADDR -8		106:	0
	37:	LDLADDR -4		107:	0
	42:	LOADW		108:	0
	43:	STOREW		109:	102
	44:	RET 4		110:	-1
	49:	BR 23		111:	-1
	54:	LDLADDR -8		112:	-1
	59:	LDLADDR -4		113:	-5
	64:	LOADW	BP ->	114:	0
	65:	NEG		115:	0
	66:	STOREW		116:	0
	67:	RET 4		117:	102
	72:	LDGADDR 0		118:	0
	77:	LDCINT -5		119:	0
	82:	STOREW		120:	0
	83:	ALLOC 4		121:	99
	88:	LDGADDR 0	SP ->	122:	-1
	93:	LOADW			

	0:	PROGRAM 4		93:	LOADW
	5:	BR 67		94:	CALL -84
	10:	PROC 0		99:	PUTINT
	15:	LDLADDR -4		100:	PUTEOL
	20:	LOADW		101:	HALT
	21:	LDCINT 0	SB ->	102:	-1
	26:	CMP		103:	-1
	27:	BL 27		104:	-1
	32:	LDLADDR -8		105:	-5
	37:	LDLADDR -4		106:	0
	42:	LOADW		107:	0
	43:	STOREW		108:	0
	44:	RET 4		109:	102
	49:	BR 23		110:	-1
PC ->	54:	LDLADDR -8		111:	-1
	59:	LDLADDR -4		112:	-1
	64:	LOADW		113:	-5
	65:	NEG	BP ->	114:	0
	66:	STOREW		115:	0
	67:	RET 4		116:	0
	72:	LDGADDR 0		117:	102
	77:	LDCINT -5		118:	0
	82:	STOREW		119:	0
	83:	ALLOC 4		120:	0
	88:	LDGADDR 0	SP ->	121:	99

0:	PROGRAM 4	99:	PUTINT
5:	BR 67	100:	PUTEOL
10:	PROC 0	101:	HALT
15:	LDLADDR -4	SB -> 102:	-1
20:	LOADW	103:	-1
21:	LDCINT 0	104:	-1
26:	CMP	105:	-5
27:	BL 27	106:	0
32:	LDLADDR -8	107:	0
37:	LDLADDR -4	108:	0
42:	LOADW	109:	102
43:	STOREW	110:	-1
44:	RET 4	111:	-1
49:	BR 23	112:	-1
54:	LDLADDR -8	113:	-5
PC -> 59:	LDLADDR -4	BP -> 114:	0
64:	LOADW	115:	0
65:	NEG	116:	0
66:	STOREW	117:	102
67:	RET 4	118:	0
72:	LDGADDR 0	119:	0
77:	LDCINT -5	120:	0
82:	STOREW	121:	99
83:	ALLOC 4	122:	0
88:	LDGADDR 0	123:	0
93:	LOADW	124:	0
94:	CALL -84	SP -> 125:	106

0:	PROGRAM 4	101:	HALT
5:	BR 67	SB -> 102:	-1
10:	PROC 0	103:	-1
15:	LDLADDR -4	104:	-1
20:	LOADW	105:	-5
21:	LDCINT 0	106:	0
26:	CMP	107:	0
27:	BL 27	108:	0
32:	LDLADDR -8	109:	102
37:	LDLADDR -4	110:	-1
42:	LOADW	111:	-1
43:	STOREW	112:	-1
44:	RET 4	113:	-5
49:	BR 23	BP -> 114:	0
54:	LDLADDR -8	115:	0
59:	LDLADDR -4	116:	0
PC -> 64:	LOADW	117:	102
65:	NEG	118:	0
66:	STOREW	119:	0
67:	RET 4	120:	0
72:	LDGADDR 0	121:	99
77:	LDCINT -5	122:	0
82:	STOREW	123:	0
83:	ALLOC 4	124:	0
88:	LDGADDR 0	125:	106
93:	LOADW	126:	0
94:	CALL -84	127:	0
99:	PUTINT	128:	0
100:	PUTEOL	SP -> 129:	110

0:	PROGRAM 4	101:	HALT
5:	BR 67	SB -> 102:	-1
10:	PROC 0	103:	-1
15:	LDLADDR -4	104:	-1
20:	LOADW	105:	-5
21:	LDCINT 0	106:	0
26:	CMP	107:	0
27:	BL 27	108:	0
32:	LDLADDR -8	109:	102
37:	LDLADDR -4	110:	-1
42:	LOADW	111:	-1
43:	STOREW	112:	-1
44:	RET 4	113:	-5
49:	BR 23	BP -> 114:	0
54:	LDLADDR -8	115:	0
59:	LDLADDR -4	116:	0
64:	LOADW	117:	102
PC -> 65:	NEG	118:	0
66:	STOREW	119:	0
67:	RET 4	120:	0
72:	LDGADDR 0	121:	99
77:	LDCINT -5	122:	0
82:	STOREW	123:	0
83:	ALLOC 4	124:	0
88:	LDGADDR 0	125:	106
93:	LOADW	126:	-1
94:	CALL -84	127:	-1
99:	PUTINT	128:	-1
100:	PUTEOL	SP -> 129:	-5

0:	PROGRAM 4	101:	HALT
5:	BR 67	SB -> 102:	-1
10:	PROC 0	103:	-1
15:	LDLADDR -4	104:	-1
20:	LOADW	105:	-5
21:	LDCINT 0	106:	0
26:	CMP	107:	0
27:	BL 27	108:	0
32:	LDLADDR -8	109:	102
37:	LDLADDR -4	110:	-1
42:	LOADW	111:	-1
43:	STOREW	112:	-1
44:	RET 4	113:	-5
49:	BR 23	BP -> 114:	0
54:	LDLADDR -8	115:	0
59:	LDLADDR -4	116:	0
64:	LOADW	117:	102
65:	NEG	118:	0
PC -> 66:	STOREW	119:	0
67:	RET 4	120:	0
72:	LDGADDR 0	121:	99
77:	LDCINT -5	122:	0
82:	STOREW	123:	0
83:	ALLOC 4	124:	0
88:	LDGADDR 0	125:	106
93:	LOADW	126:	0
94:	CALL -84	127:	0
99:	PUTINT	128:	0
100:	PUTEOL	SP -> 129:	5



```

0: PROGRAM 4
5: BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW
PC -> 67: RET 4
72: LDGADDR 0
77: LDCINT -5
82: STOREW
83: ALLOC 4
88: LDGADDR 0

```

```

93: LOADW
94: CALL -84
99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1
103: -1
104: -1
105: -5
106: 0
107: 0
108: 0
109: 5
110: -1
111: -1
112: -1
113: -5
BP -> 114: 0
115: 0
116: 0
117: 102
118: 0
119: 0
120: 0
SP -> 121: 99

```

```

0: PROGRAM 4
5: BR 67
10: PROC 0
15: LDLADDR -4
20: LOADW
21: LDCINT 0
26: CMP
27: BL 27
32: LDLADDR -8
37: LDLADDR -4
42: LOADW
43: STOREW
44: RET 4
49: BR 23
54: LDLADDR -8
59: LDLADDR -4
64: LOADW
65: NEG
66: STOREW

```

```

67: RET 4
72: LDGADDR 0
77: LDCINT -5
82: STOREW
83: ALLOC 4
88: LDGADDR 0
93: LOADW
94: CALL -84
PC -> 99: PUTINT
100: PUTEOL
101: HALT
SB -> 102: -1      <- BP
103: -1
104: -1
105: -5
106: 0
107: 0
108: 0
SP -> 109: 5

```

0: PROGRAM 4  
5: BR 67  
10: PROC 0  
15: LDLADDR -4  
20: LOADW  
21: LDCINT 0  
26: CMP  
27: BL 27  
32: LDLADDR -8  
37: LDLADDR -4  
42: LOADW  
43: STOREW  
44: RET 4  
49: BR 23  
54: LDLADDR -8  
59: LDLADDR -4  
64: LOADW

65: NEG  
66: STOREW  
67: RET 4  
72: LDGADDR 0  
77: LDCINT -5  
82: STOREW  
83: ALLOC 4  
88: LDGADDR 0  
93: LOADW  
94: CALL -84  
99: PUTINT  
PC -> 100: PUTEOL  
101: HALT  
SB -> 102: -1 <- BP  
103: -1  
104: -1  
SP -> 105: -5

0: PROGRAM 4  
5: BR 67  
10: PROC 0  
15: LDLADDR -4  
20: LOADW  
21: LDCINT 0  
26: CMP  
27: BL 27  
32: LDLADDR -8  
37: LDLADDR -4  
42: LOADW  
43: STOREW  
44: RET 4  
49: BR 23  
54: LDLADDR -8  
59: LDLADDR -4  
64: LOADW

65: NEG  
66: STOREW  
67: RET 4  
72: LDGADDR 0  
77: LDCINT -5  
82: STOREW  
83: ALLOC 4  
88: LDGADDR 0  
93: LOADW  
94: CALL -84  
99: PUTINT  
100: PUTEOL  
PC -> 101: HALT  
SB -> 102: -1 <- BP  
103: -1  
104: -1  
SP -> 105: -5