Functions (10A)

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Based on

ARM System-on-Chip Architecture, 2nd ed, Steve Furber

Introduction to ARM Cortex-M Microcontrollers
– Embedded Systems, Jonathan W. Valvano

Digital Design and Computer Architecture,
D. M. Harris and S. L. Harris

https://thinkingeek.com/arm-assembler-raspberry-pi/

Supporting Procedures

1. put parameters in a place where the procedure can access them
2. transfer control to the procedure
3. acquire the storage resources needed fr the procedure
4. perform the desired task
5. put the result value in a place where the calling program can access it
6. return control to the points of origin, since a procedure can be called
   from several points in a program

Computer Organization and Design ARM Edition: The Hardware Software Interface by D. A. Patterson and J. L. Hennessy

Registers

R0, R1, R2, R3 : four argument registers to pass parameters

LR : one link register containing the return address register
to the point of origin

Computer Organization and Design ARM Edition: The Hardware Software Interface by D. A. Patterson and J. L. Hennessy

Registers

```
BL ProcedureAddress
```

```
MOV     PC, LR
```

Computer Organization and Design ARM Edition: The Hardware Software Interface by D. A. Patterson and J. L. Hennessy

A procedure that does not call another procedures

```
int leaf_example (int g, int h, int I, int j)
{
    int f;
    f = (g + h) - (i+j);
    return f;
}
```

```
SUB     SP, SP, #12      ; adjust stack to make room for 3 items
STR     R6, [SP, #8]     ; save register R6 for a later use
STR     R6, [SP, #4]     ; save register R5 for a later use
STR     R6, [SP, #0]     ; save register R4 for a later use
```

Computer Organization and Design ARM Edition: The Hardware Software Interface by D. A. Patterson and J. L. Hennessy

A procedure that does not call another procedures

```
int leaf_example (int g, int h, int I, int j)
{
        int f;
        f = (g + h) - (i+j);
        return f;
}
```

```
ADD     R5, R0, R1        ; R5 = g + h
ADD     R6, R2, R3        ; R6 = I + j
SUB     R4, R5, R6        ; R4 = R5 - R6

MOV     R0, R4            ; returns f (R0 = R4)
```

Computer Organization and Design ARM Edition: The Hardware Software Interface by D. A. Patterson and J. L. Hennessy

A procedure that does not call another procedures

```
int leaf_example (int g, int h, int I, int j)
{
        int f;
        f = (g + h) - (i+j);
        return f;
}
```

```
LDR     R4, [SP, #0]        ; restore R4 for the caller
LDR     R5, [SP, #4]        ; restore R5 for the caller
LDR     R6, [SP, #8]        ; restore R6 for the caller
ADD     SP, SP, #12         ; adjust stack t delete 3 items

MOV     PC, LR              ; jump back to calling procedure
```

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Instructions for procedures

BL ProcedureAddress

jumps to an address and simultaneously saves
the address of the following instruction in register LR

MOV PC, LR

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Recursive procedure

```
Int fact (int n)
{
    if (n < 1) return (1);
    else return (n * fact(n-1));
}
```

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Recursive procedure

```
Fact:
        SUB     SP, SP, #8          ; adjust stack for 2 items
        STR     LR, [SP, #8]        ; save the return address
        STR     R0, [SP, #0]        ; save the argument n

        CMP     R0, #1              ; compare n to 1
        BGE     L1                  ; if n >= 1, go to L1

        MOV     R0, #1              ; return 1
        ADD     SP, SP, #8          ; pop 2 items off stack
        MOV     PC, LR              ; return to the caller
```

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Recursive procedure

```
L1:
        SUB     R0, R0, #1          ; n >= 1 argument gets (n-1)
        BL      fact                ; call fact with (n-1)

        MOV     R12, R0             ; save the return value
        LDR     R0, [SP, #0]        ; return from BL ; restore argument n
        LDR     LR, [SP, #0]        ; restore the return address
        ADD     SP, SP, #8          ; adjust stack pointer to pop 2 items

        MUL     R0, R0, R12         ; return n * fact (n-1)
        MOV     PC, LR              ; return to the caller
```

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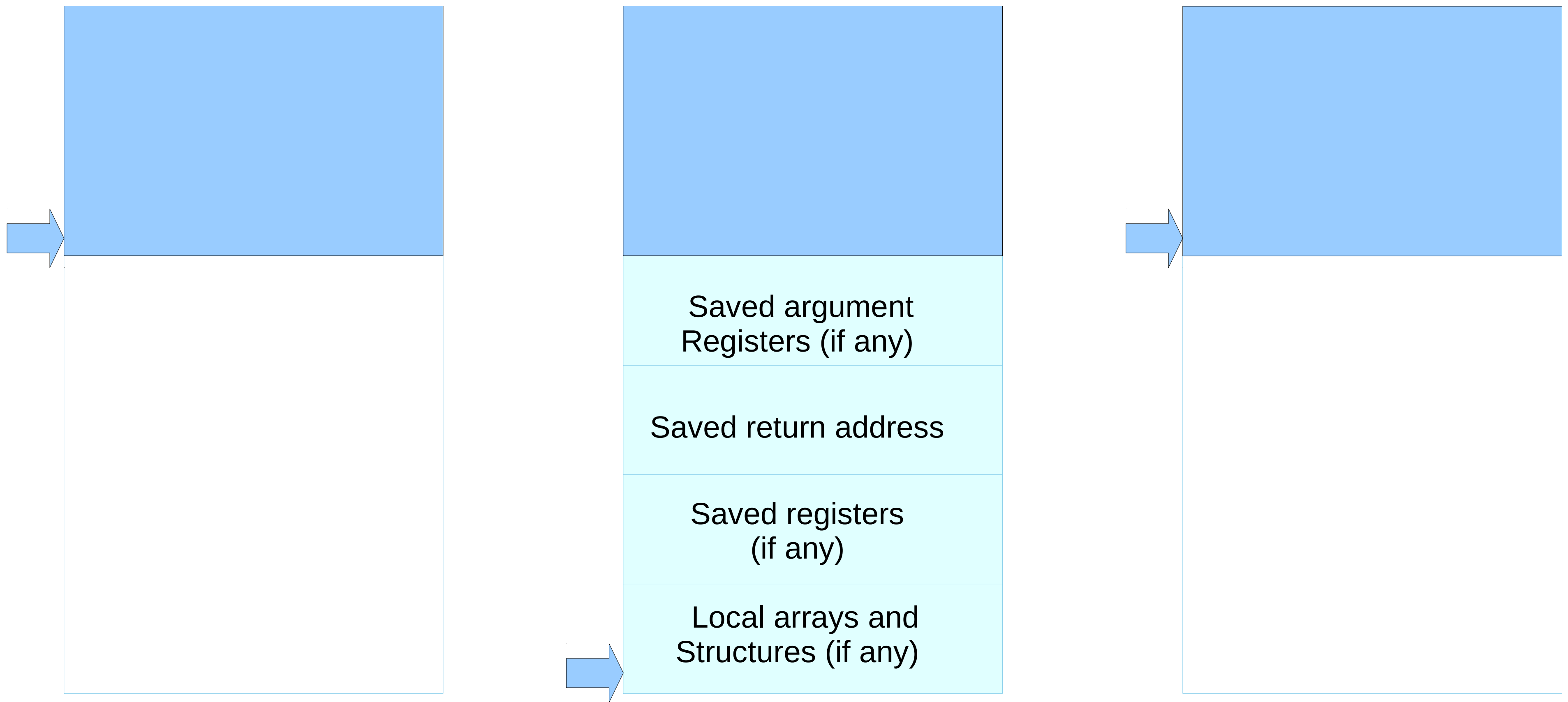
Stack allocation



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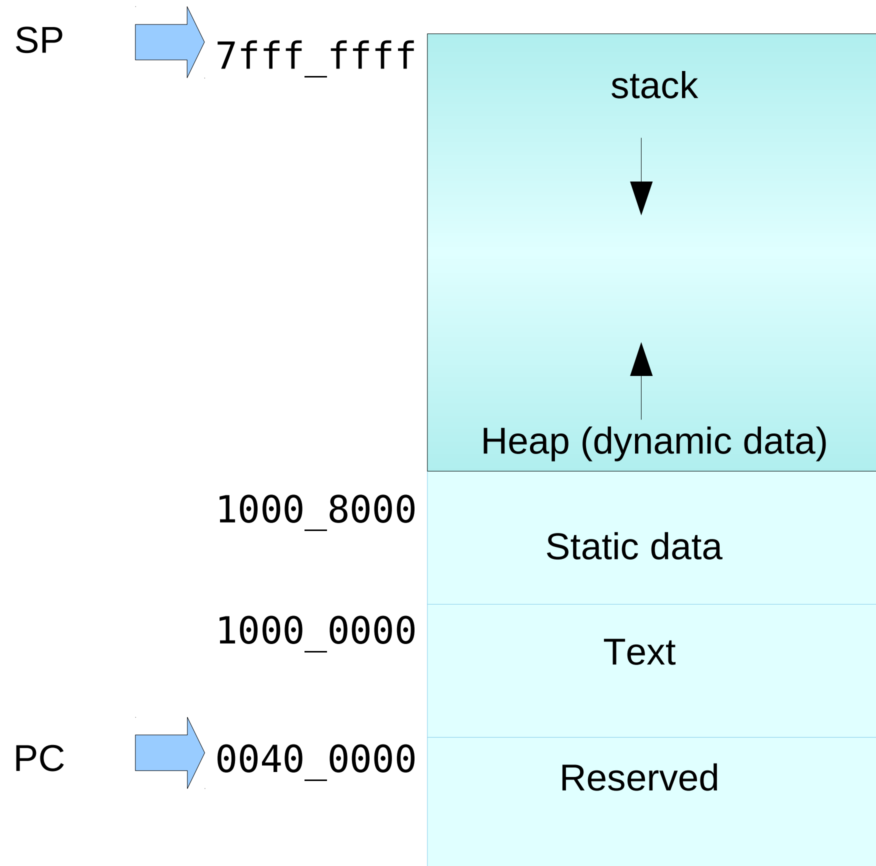
Memory map



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RM Register Conventions

Names	Reg No	Usage	preserved
a1-a2	0-1	Argument / return result/ scratch register	no
a3-a4	2-3	Argument / scratch register	no
v1-v8	4-11	Variables for local routine	yes
ip	12	Intra procedure call scratch register	no
sp	13	Stack pointer	yes
lr	14	Link register (Return address)	yes
pc	15	Program counter	n.a.

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Recursive Procedure and Iterative Implementation

```
int sum (int n, int acc) {
        if (n > 0)
                return sum(n-1, acc+n);
        else
                return acc;
}

Sum:    CMP     R0, #0          ; test if n <= 0
        BLE sum_exit            ; go to sum_exit if n <= 0;
        ADD     R1, R1, R0      ; add n to acc
        SUB     R0, R0, #1      ; subtract 1 from n
        B   sum                 ; go to sum
sum_exit:
        MOV     R0, R1          ; return value acc
        MOV     PC, LR          ; return to caller
```

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String Copy Procedure

```
void strcpy (char x[], char y[])
{
        int i;

        i = 0;
        while ((x[i] = y[i]) != '\0')            // copy & test byte
                i += 1;
}
```

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String Copy Procedure

```
Strcpy:  SUB    SP, SP, #4       ; adjust stack for 1 more item
         STR    R4, [SP, #0]     ; save R4
         MOV    R4, #0           ; I = 0 + 0
L1:      ADD    R2, R4, R1       ; address of y[i] in R2
         LDRBS  R3, [R2, #0]     ; R3 = y[i] and set condition flag
         ADD    R12, R4, R0      ; addressof x[i] in r12
         STRB   R3, [R12, #0]    ; x[i] = y[i]
         BEQ    L2               ; if y[i] == 0, go to L2
         ADD    R4, R4, #1       ; I = i+1
         B      L1               ; go to L1
L2       LDR    R4, [SP, #0]     ; y[i] == 0 : end of string, restore old R4
         ADD    SP, SP, #4       ; pop 1 word off stack
         MOV    PC, LR           ; return
```

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Swap (1)

```
void swap(int v[], int k)
{
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

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Swap (2)

```
v       RN  0    ;  1st argument address of v
k       RN  1    ; 2nd argument index k
temp    RN  2    ; local variable
temp2   RN  3    ; temporary for v[k+1]
vkAddr  RN  12   ; to hold address of v[k]
```

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Swap (3)

```
swap:   ADD   vkAddr, v, k, LSL #2      ; reg vkAddr = v + (k * 4)
                                        ; reg vkAddr has the address of v[k]
        LDR   temp, [vkAddr, #0]        ; temp = v[k]
        LDR   temp2, [vkAddr, #4]       ; temp2 = v[k+1]
                                        ; refers to next element of v
        STR   temp2, [vkAddr, #0]       ; v[k] = temp2
        STR   temp, [vkAddr, #4]        ; v[k+1] = temp

        MOV   PC, LR                    ; return to calling routine
```

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Sort (1)

```
void sort(int v[], int n)
{
    int i, j;
    for (i=0, i<n,  ++i) {
        for (j=1; j >= 0 && v[j] > v[j+1]) ; --j) {
            swap(v, j);
        }
    }
}
```

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Sort (2)

```
v       RN  0   ; 1st argument address of v
n       RN  1   ; 2nd argument index n
i       RN  2   ; local variable i
j       RN  3   ; local variable j
vkAddr  RN  12  ; to hold address of v[j]
vj      RN  4   ; to hold a copy of v[j]
vj1     RN  5   ; to hold a copy of v[j+1]
vcopy   RN  6   ; to hold a copy of v
ncopy   RN  7   ; to hold a copy of n
```

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Sort (3) outer loop

for (i=0, i<n, ++i)

```
         MOV   i, #0          ; i =0
for1tst: CMP   i, n           ; if i > n
         BGE   exit1          ; go to exit1 if i >= n
         * * *
         body of 1st for loop
         * * *
         ADD   i, i, #1       ; i += 1
         B for1tst            ; branch to test of outer loop
exit1:
```

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Sort (3) inner loop

for (j=1; j >= 0 && v[j] > v[j+1]) ; --j)

```
         SUB   j, i, #1               ; j = i -1
for2tst: CMP   j, #0                  ; if j < 0
         BLT   exit2                  ; go to exit2 if j < 0
         ADD   vjAddr, v, j, LSL #2   ; reg vjAdr = v + (j * 4)
         LDR   vj, [vjAddr, #0]       ; reg vj = v[j]
         LDR   vj1, [vjAddr, #4]      ; reg vj = v[j+1]
         CMP   vj, vj1                ; if vj < vj1
         BLE   exit2                  ; go to  exit2 if vj < vj1
         * * *
         body of 2nd for loop
         * * *
         SUB   j, j, #1               ; j -= 1
         B for2tst                    ; branch to test of outer loop
exit2:
```

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Sort (4) Saving registers

```
sort:   SUB   SP, SP, #20          ; make room on stack for 5 registers
        STR   LR, [SP, #16]        ; save LR on stack
        STR   ncopy, [SP, #12]     ; save ncopy on stack
        STR   vcopy, [SP, #8]      ; save vcopy on stack
        STR   j, [SP, #4]          ; save j on stack
        STR   I, [SP, #0]          ; save i on stack
```

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Sort (5) Restoring registers

```
exit1:  LDR   i, [SP, #0]         ; restore I from stack
        LDR   j, [SP, #4]         ; restore j from stack
        LDR   vcopy, [SP, #8]     ; restore vcopy from stack
        LDR   ncopy, [SP, #12]    ; restore ncopy from stack
        LDR   LR, [SP, #16]       ; restore LR from stack
        ADD   SP, SP, #20         ; restore stack pointer
```

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Sort (6) Calling swap

swap(v, j);

```
MOV     vcopy, v          ; copy parameter v into vcopy  (save R0)
MOV     ncopy, n          ; copy parameter n into ncopy  (save R1)

BL      swap

MOV     R0, vcopy         ; first swap parameter is v
MOV     R1, j             ; second swap parameter is j
```

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Sort (1) full listing

Saving Registers

```
sort:        SUB   SP, SP, #20          ; make room on stack for 5 registers
             STR   LR, [SP, #16]        ; save LR on stack
             STR   ncopy, [SP, #12]     ; save ncopy on stack
             STR   vcopy, [SP, #8]      ; save vcopy on stack
             STR   j, [SP, #4]          ; save j on stack
             STR   I, [SP, #0]          ; save i on stack
```

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Sort (1) full listing

Procedure Body

```
            MOV  vcopy, v              ; copy parameter v into vcopy  (save R0)
            MOV  ncopy, n              ; copy parameter n into ncopy  (save R1)
            MOV  i, #0                 ; i = 0
for1tst:    CMP  i, n                  ; if i > n
            BGE  exit1                 ; go to exit1 if i >= n
            SUB  j, i, #1              ; j = i -1
for2tst:    CMP  j, #0                 ; if j < 0
            BLT  exit2                 ; go to exit2 if j < 0
            ADD  vjAddr, v, j, LSL #2  ; reg vjAdr = v + (j * 4)
            LDR  vj, [vjAddr, #0]      ; reg vj = v[j]
            LDR  vj1, [vjAddr, #4]     ; reg vj = v[j+1]
            CMP  vj, vj1               ; if vj < vj1
            BLE  exit2                 ; go to  exit2 if vj < vj1
            MOV  R0, vcopy             ; first swap parameter is v
            MOV  R1, j                 ; second swap parameter is j
            BL   swap
            SUB  j, j, #1              ; j -= 1
            B    for2tst               ; branch to test of outer loop
exit2:      ADD  i, i, #1              ; i += 1
            B    for1tst               ; branch to test of outer loop
```

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Sort (2) full listing

Restoring Registers

```
exit1:    LDR   i, [SP, #0]        ; restore I from stack
          LDR   j, [SP, #4]        ; restore j from stack
          LDR   vcopy, [SP, #8]    ; restore vcopy from stack
          LDR   ncopy, [SP, #12]   ; restore ncopy from stack
          LDR   LR, [SP, #16]      ; restore LR from stack
          ADD   SP, SP, #20        ; restore stack pointer
```

Procedure Return

```
          MOV   PC, LR             ; return to calling routine
```

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Instructions for procedures

B{cond}	**label**	; branch to label
BX{cond}	**Rm**	; branch indirect to location specified by **Rm**
BL{cond}	**label**	; branch to *subroutine* at label
BLX{cond}	**Rm**	; branch to *subroutine* indirect specified by **Rm**

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Instructions for procedures

```
uint32_t Num;

void Change(void) {
    Num = Num + 25;
}

void main(void) {
    Num = 0;
    while (1) {
        Change();
    }
}
```

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Instructions for procedures

```
Change  LDR    R1, =Num       ; 5) R1 = &Num
        LDR    R0, [R1]       ; 6) R0 = Num
        ADD    R0, R0, #25    ; 7) R0 = Num + 25
        STR    R0, [R1]       ; 8) Num = Num + 25
        BX     LR             ; 9) return

Main    LDR    R1, =Num       ; 1) R1 = &Num
        MOV    R0, #0         ; 2) R0 = 0
        STR    R0, [R1]       ; 3) Num = 0
Loop    BL     Change         ; 4) call to Change
        B      Loop           ; 10) repeat
```

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Instructions for procedures

```
uint32_t Num;

void Change(void) {
        if (Num <25600) {
                Num = Num + 25;
        }
}

void main(void) {
        Num = 0;
        while (1) {
                Change();
        }
}
```

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Instructions for procedures

```
Change  LDR    R1, =Num        ; R1 = &Num
        LDR    R0, [R1]        ; R0 = Num
        CMP    R0, #25600      ;
        BHS    skip
        ADD    R0, R0, #25     ; R0 = Num + 25
        STR    R0, [R1]        ; Num = Num + 25
Skip    BX     LR              ; return

Main    LDR    R1, =Num        ; R1 = &Num
        MOV    R0, #0          ; R0 = 0
        STR    R0, [R1]        ; Num = 0
Loop    BL     Change          ; call to Change
        B      Loop            ; repeat
```

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Instructions for procedures

```
uint32_t Num;

void Change(void) {
    if (Num <100) {
        Num = Num + 1;
    } else {
        Num = -100;
    }
}

void main(void) {
    Num = 0;
    while (1) {
        Change();
    }
}
```

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Instructions for procedures

```
Change  LDR   R1, =Num      ; R1 = &Num
        LDR   R0, [R1]      ; R0 = Num
        CMP   R0, #100      ;
        BGE   else
        ADD   R0, R0, #1    ; R0 = Num + 1
        B     skip
Else    MOV   R0, #-100     ; R0 = -100
skip    STR   R0, [R1]      ; Num = Num + 1 or -100
        BX    LR            ; return

Main    LDR   R1, =Num      ; R1 = &Num
        MOV   R0, #0        ; R0 = 0
        STR   R0, [R1]      ; Num = 0
Loop    BL    Change        ; call to Change
        B     Loop          ; repeat
```

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Pointer access to an array

References

[1] ftp://ftp.geoinfo.tuwien.ac.at/navratil/HaskellTutorial.pdf
[2] https://www.umiacs.umd.edu/~hal/docs/daume02yaht.pdf