ECE 220 Computer Systems & Programming

Lecture 22 – C to LC-3 with Linked Data Structure

- Programming competition on April 29th

ECE ILLINOIS

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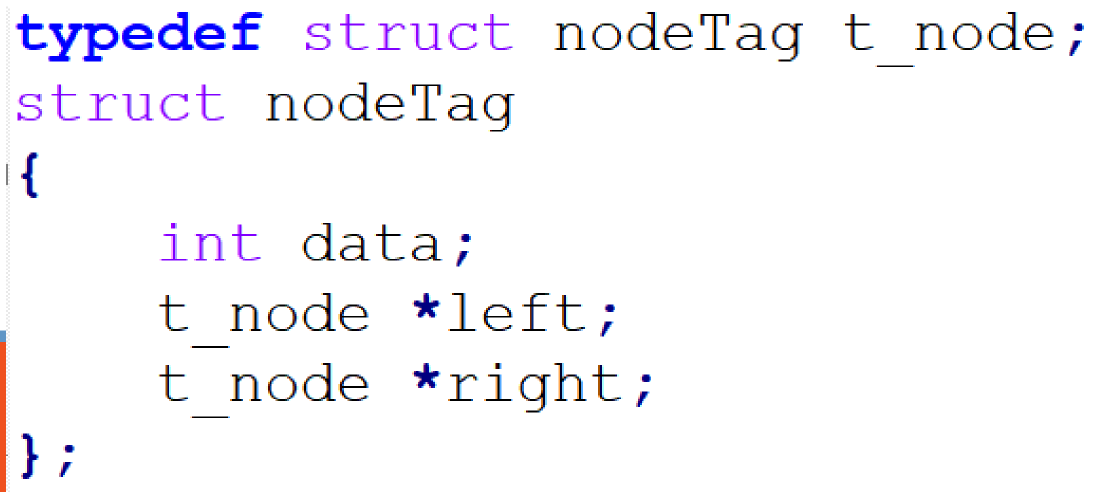
C to LC-3 – Assembly Translation with linked data structure

Recursive tree traversal

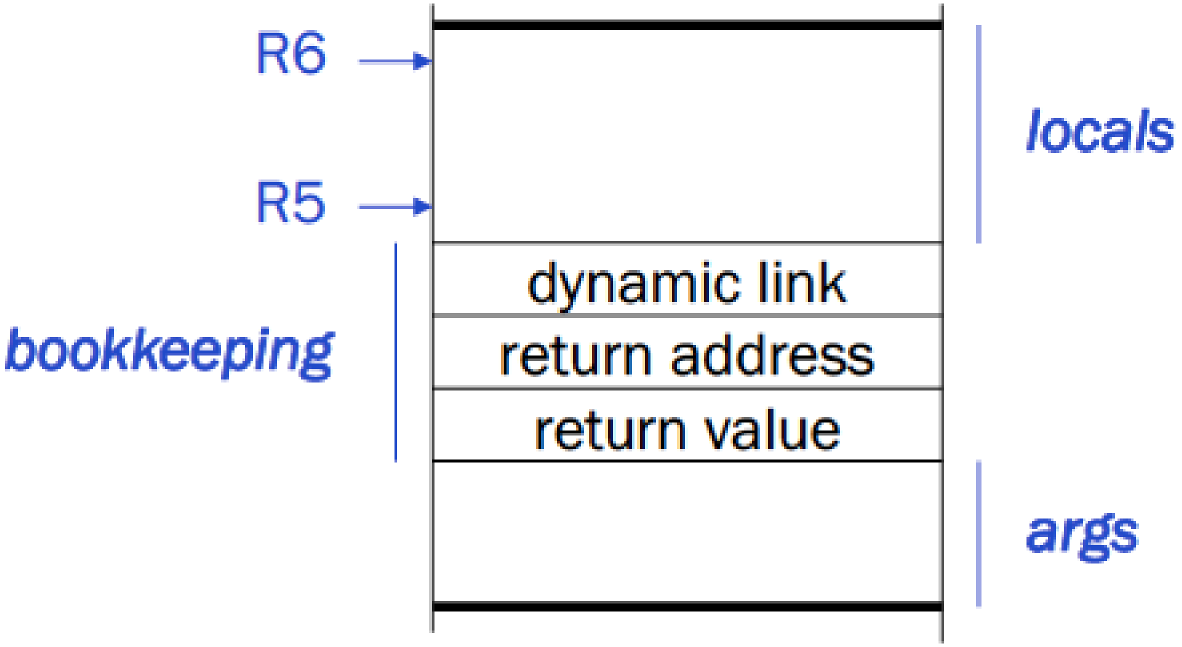
Problem statement: Convert the following function from C to LC-3. This function recursively traverses a binary tree.

```
    void TraverseTree(t_node *nd)
  {
      if (nd != NULL)
  {
     TraverseTree(nd->left);
     TraverseTree(nd->right);
  }
  }
```



```
typedef struct nodeTag t_node;
struct nodeTag
{
    int data;
    t_node *left;
    t_node *right;
};
```

Activation Record


R6

R5

locals

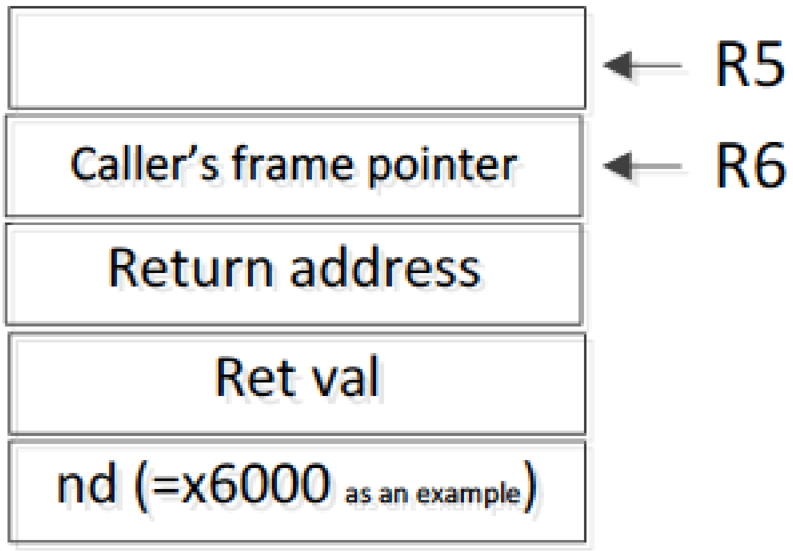
dynamic link

return address

return value

bookkeeping

args


R5

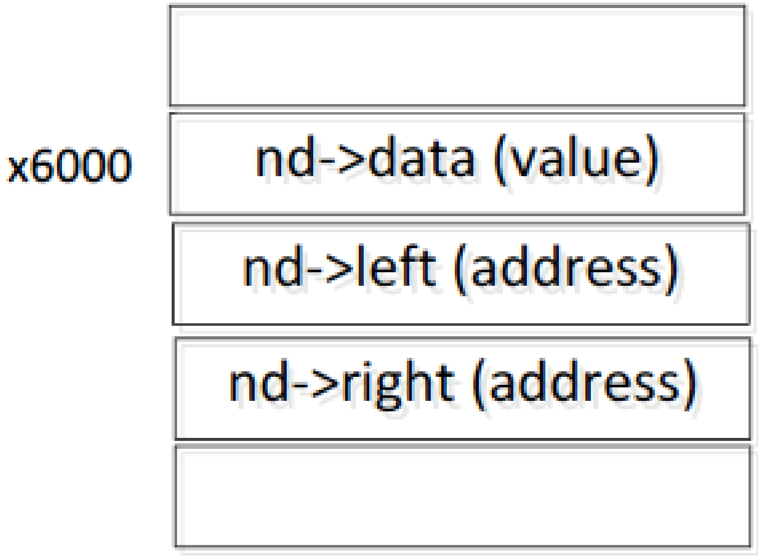
Caller's frame pointer

R6

Return address

Ret val

nd (=x6000 as an example)

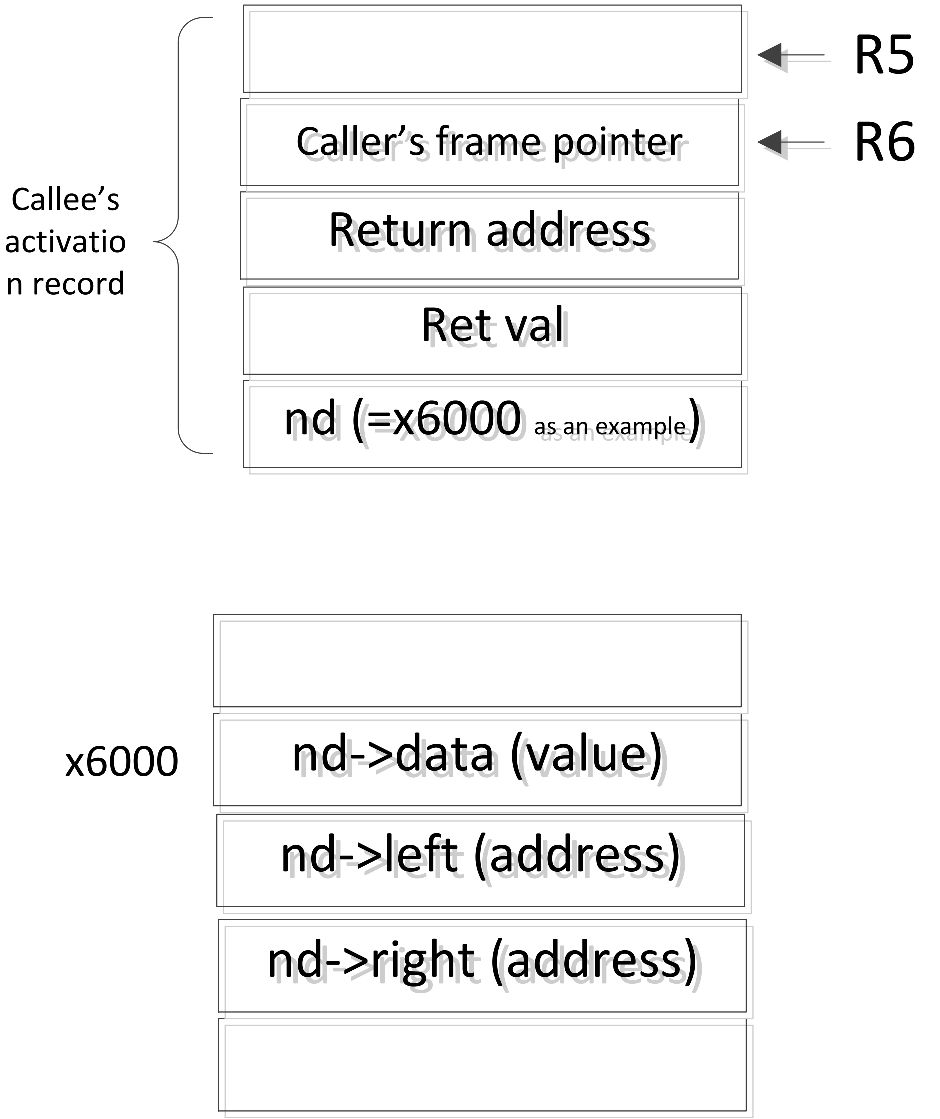

x6000

nd->data (value)

nd->left (address)

nd->right (address)

Step#1



R5

R6

Callee's activatio n record

Caller's frame pointer

Return address

Ret val

nd (=x6000 as an example)

x6000

nd->data (value)

nd->left (address)

nd->right (address)

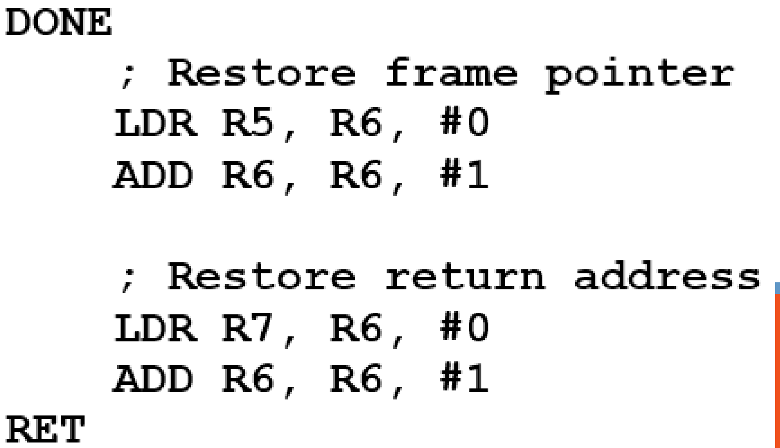
```
TRAVERSE_TREE
    ; Allocate space for return value
    ADD R6, R6, #-1

    ; Push return address to stack
    ADD R6, R6, #-1
    STR R7, R6, #0

    ; Store callee's frame pointer
    ADD R6, R6, #-1
    STR R5, R6, #0

    ; Set up new frame pointer
    ADD R5, R6, #-1
```

Step#2: Implement Logic Function

```
; if (nd == NULL), skip to the end
   LDR R0, R5, #4;
   BRz DONE

   ; TraverseTree(nd->left);
   LDR R1, R0, #1 ; load nd->left to R1

   ; push nd->left to stack
   ADD R6, R6, #-1
   STR R1, R6, #0

   ; call subroutine
   JSR TRAVERSE_TREE
```

```
; tear-down the rest of the stack
  ADD R6, R6, #2
   ; TraverseTree(nd->right);
  LDR R2, R0, #2    ; load nd->right to R2

  ; push nd->right to stack
  ADD R6, R6, #-1;
  STR R2, R6, #0;

  ; call subroutine
  JSR TRAVERSE_TREE

  ; tear-down the rest of the stack
  ADD R6, R6, #2
```

Teardown the activation record, return:



```
DONE
      ; Restore frame pointer
      LDR R5, R6, #0
      ADD R6, R6, #1

      ; Restore return address
      LDR R7, R6, #0
      ADD R6, R6, #1
RET
```

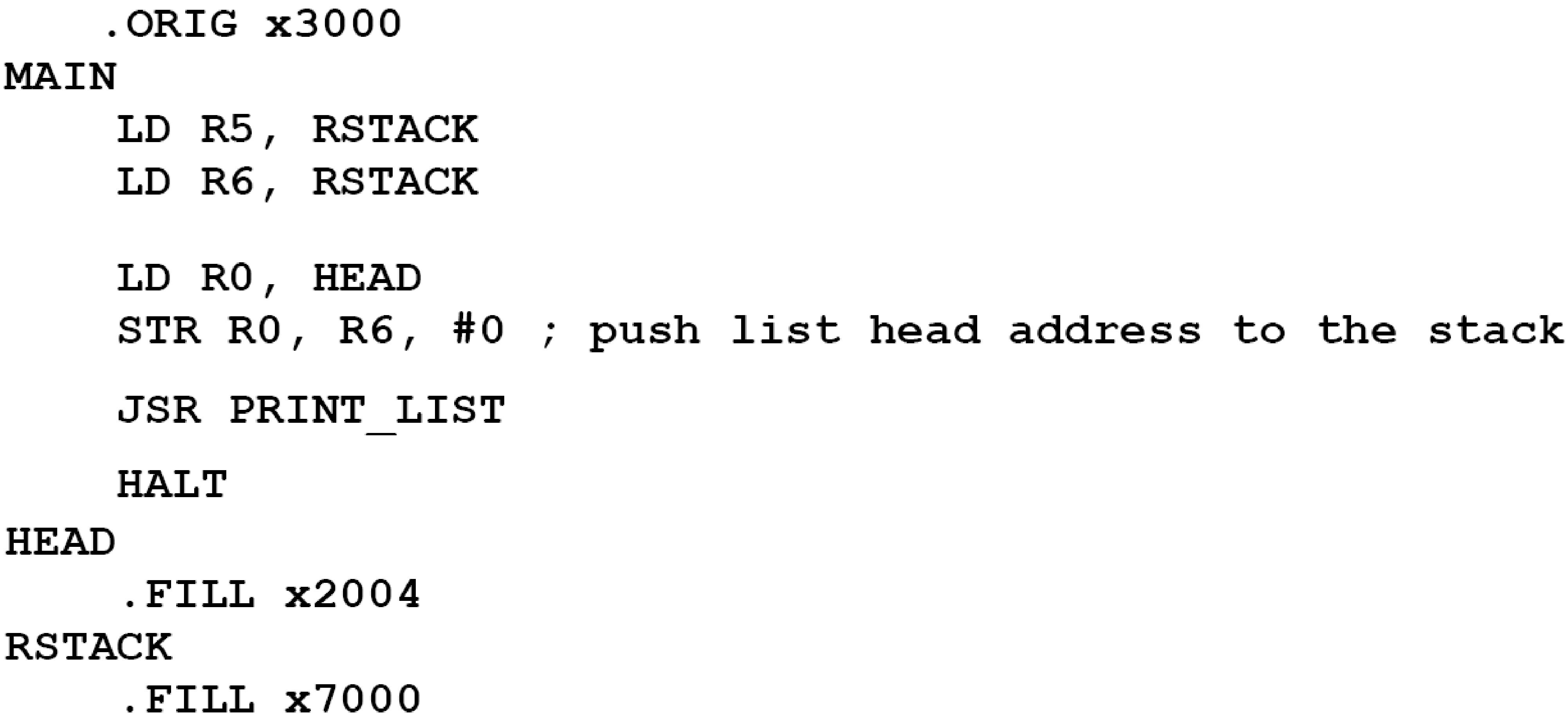
Recursive linked list traversal

Problem statement: Convert the following function from C to LC-3. This function recursively traverses a linked list and prints its content.

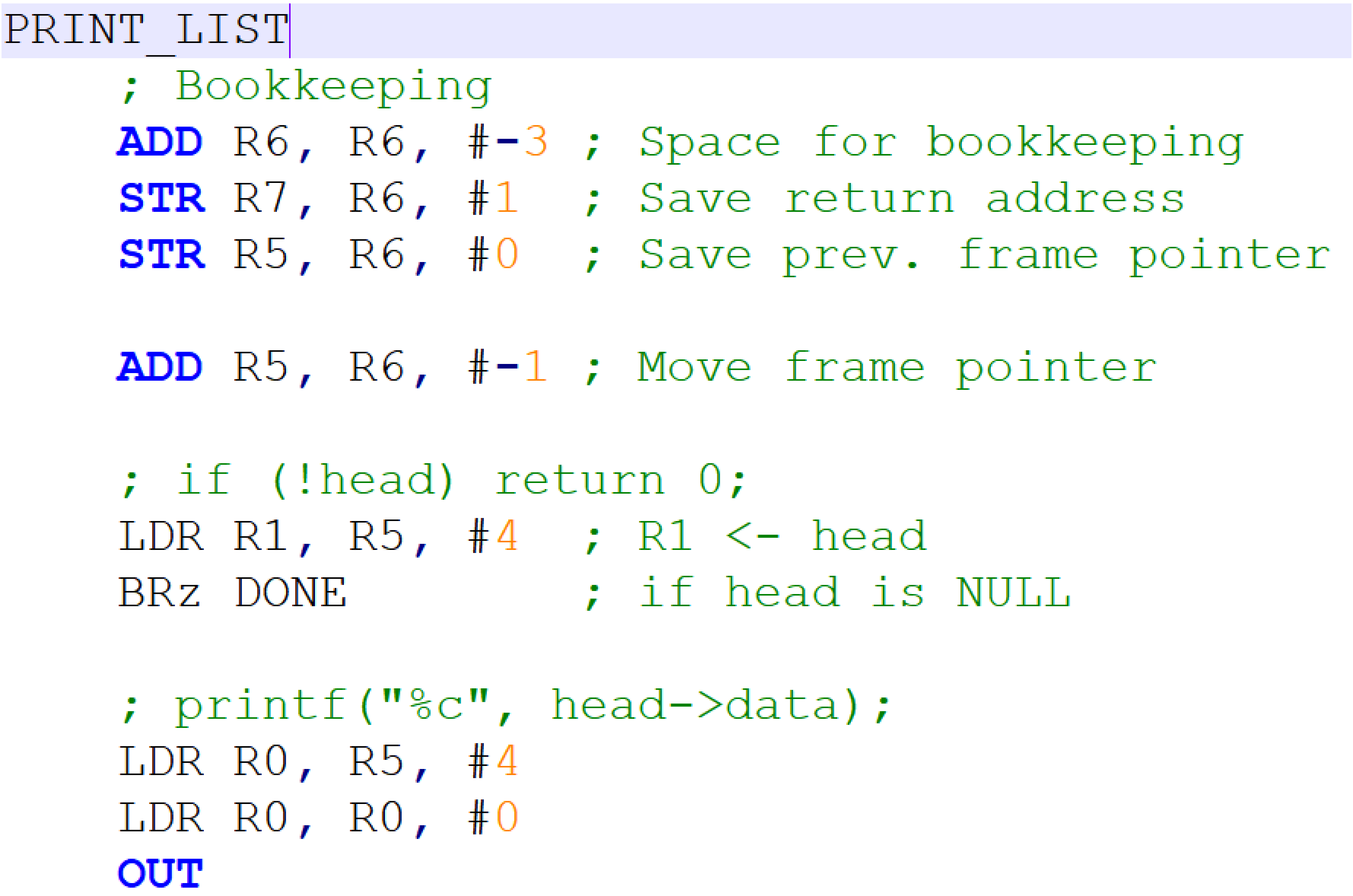
/* typedef struct tag {char data; struct tag *next;} node; */

```
int print_list(node *head)
{
  if (!head) return 0;
  printf("%c", head->data);
  return print_list(head->next);
}
```

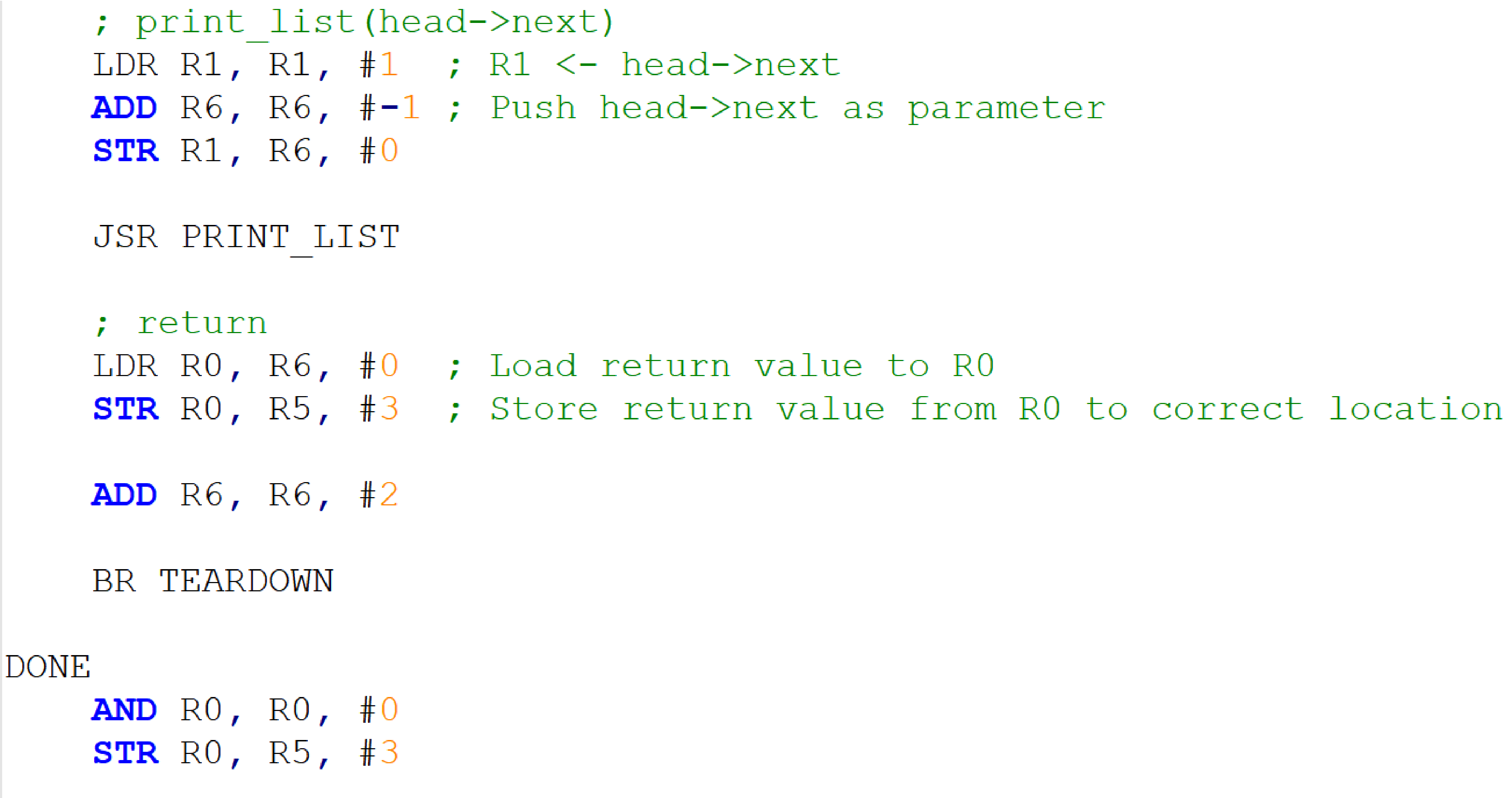
Main function: (print_list.asm)



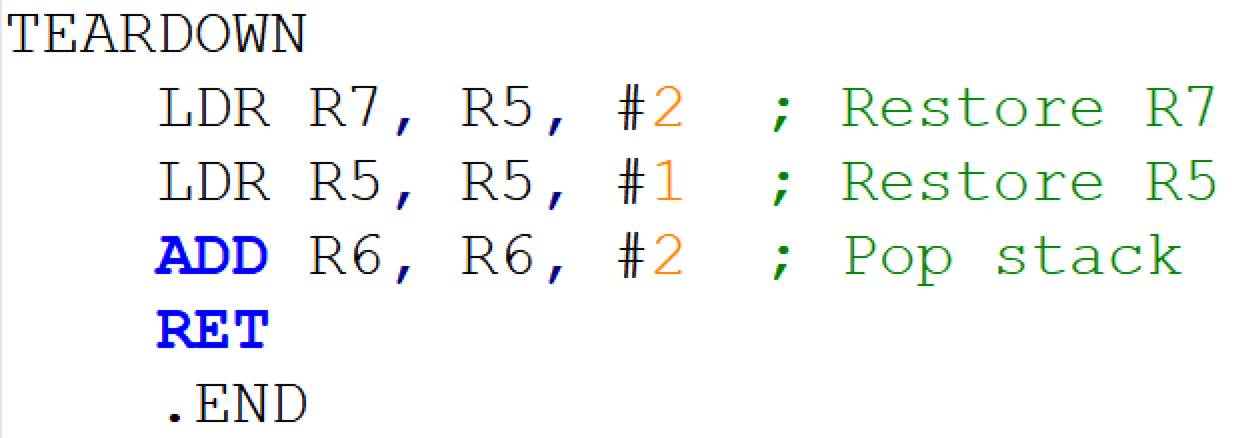
```
     .ORIG x3000
MAIN
      LD R5, RSTACK
      LD R6, RSTACK

      LD R0, HEAD
      STR R0, R6, #0 ; push list head address to the stack

      JSR PRINT_LIST

      HALT
HEAD
      .FILL x2004
RSTACK
      .FILL x7000
```



```
PRINT_LIST
    ; Bookkeeping
    ADD R6, R6, #-3 ; Space for bookkeeping
    STR R7, R6, #1  ; Save return address
    STR R5, R6, #0  ; Save prev. frame pointer

    ADD R5, R6, #-1 ; Move frame pointer

    ; if (!head) return 0;
    LDR R1, R5, #4  ; R1 <- head
    BRz DONE        ; if head is NULL

    ; printf("%c", head->data);
    LDR R0, R5, #4
    LDR R0, R0, #0
    OUT
```

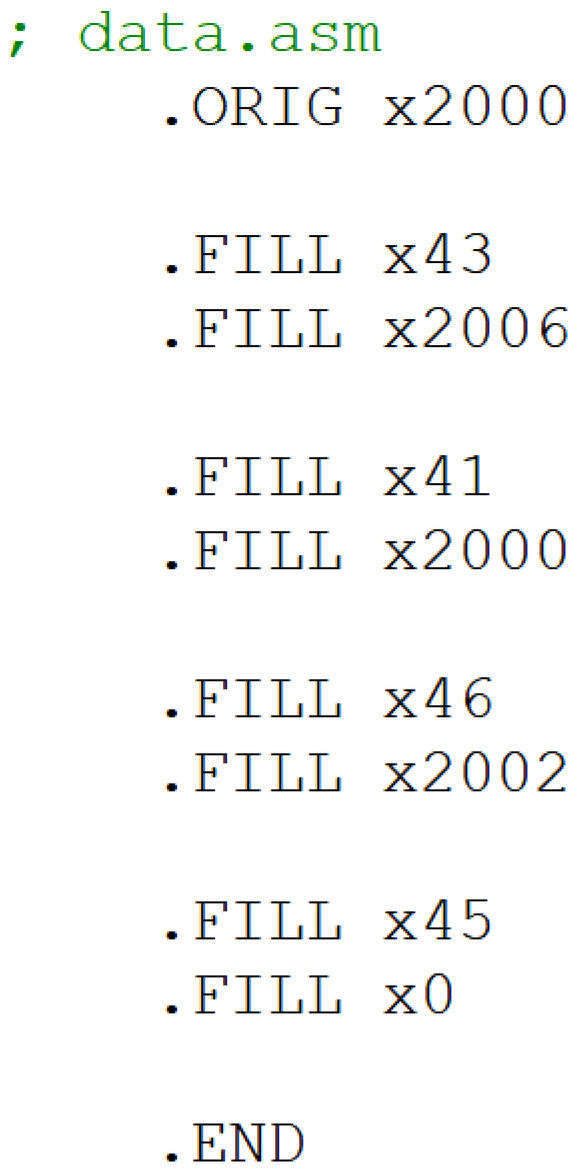


```
    ; print_list(head->next)
    LDR R1, R1, #1  ; R1 <- head->next
    ADD R6, R6, #-1 ; Push head->next as parameter
    STR R1, R6, #0

    JSR PRINT_LIST

    ; return
    LDR R0, R6, #0  ; Load return value to R0
    STR R0, R5, #3  ; Store return value from R0 to correct location

    ADD R6, R6, #2

    BR TEARDOWN

DONE
    AND R0, R0, #0
    STR R0, R5, #3
```



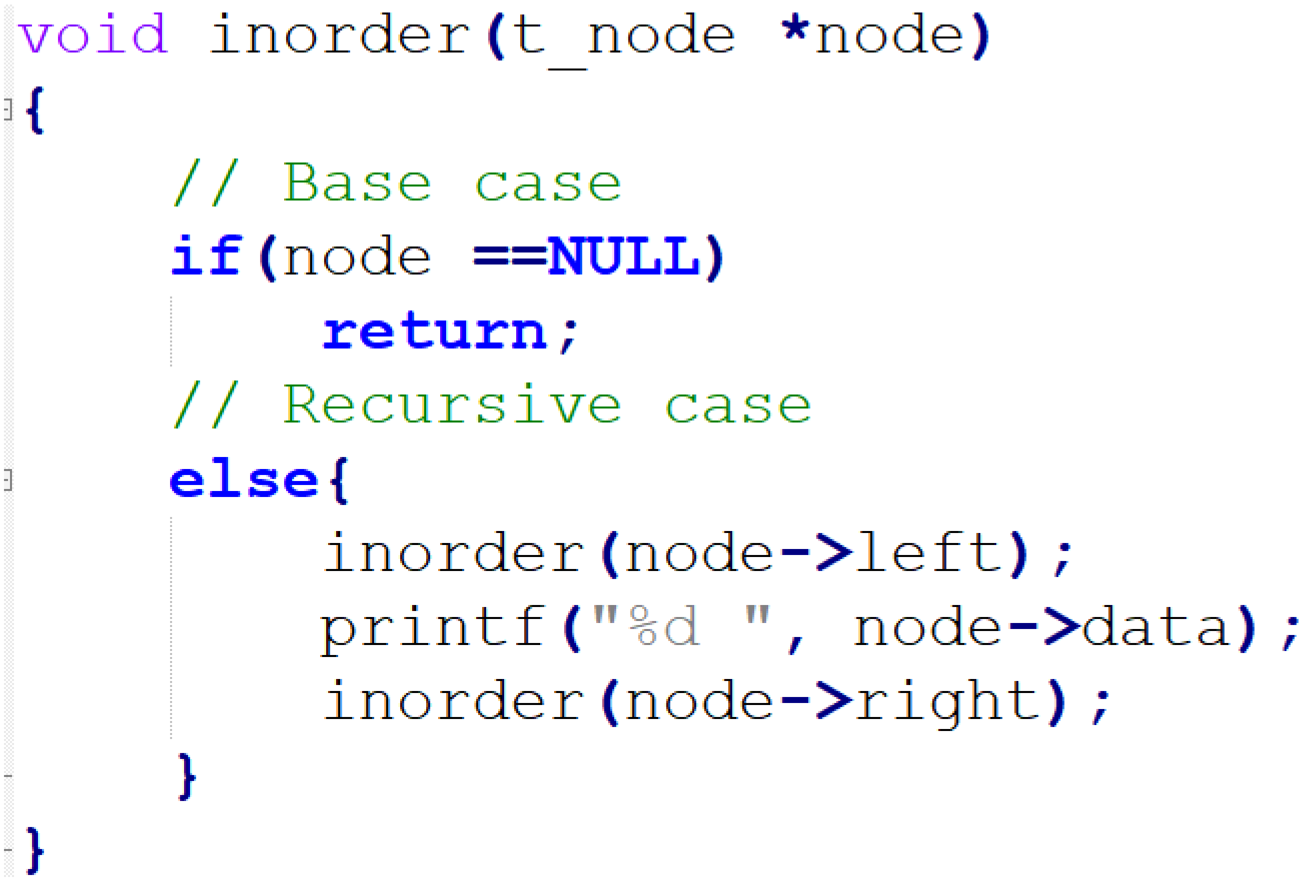
```
TEARDOWN
    LDR R7, R5, #2  ; Restore R7
    LDR R5, R5, #1  ; Restore R5
    ADD R6, R6, #2  ; Pop stack
    RET
    .END
```

Data file: data.asm

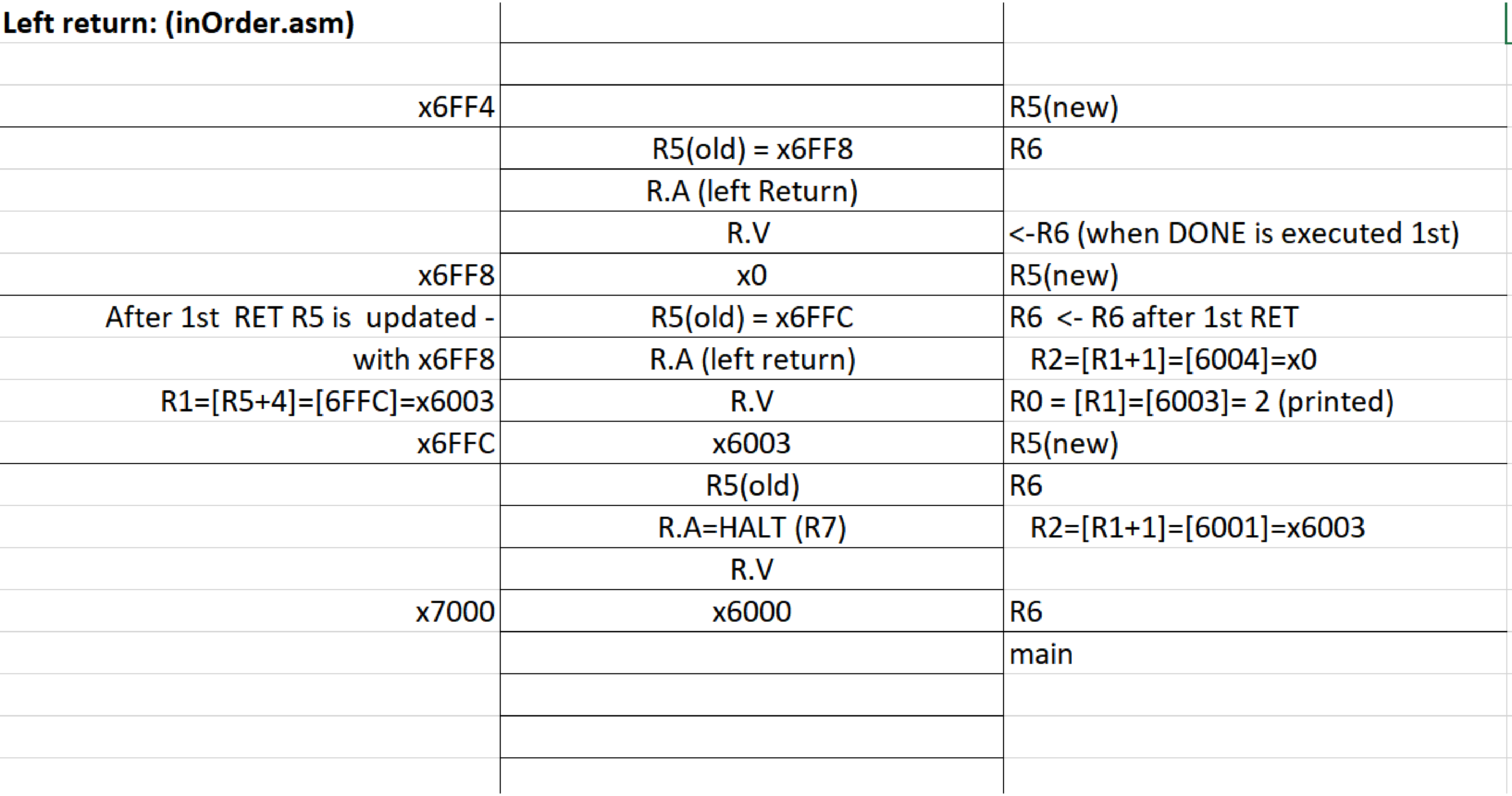


```
; data.asm
        .ORIG x2000

        .FILL x43
        .FILL x2006

        .FILL x41
        .FILL x2000

        .FILL x46
        .FILL x2002

        .FILL x45
        .FILL x0

        .END
```

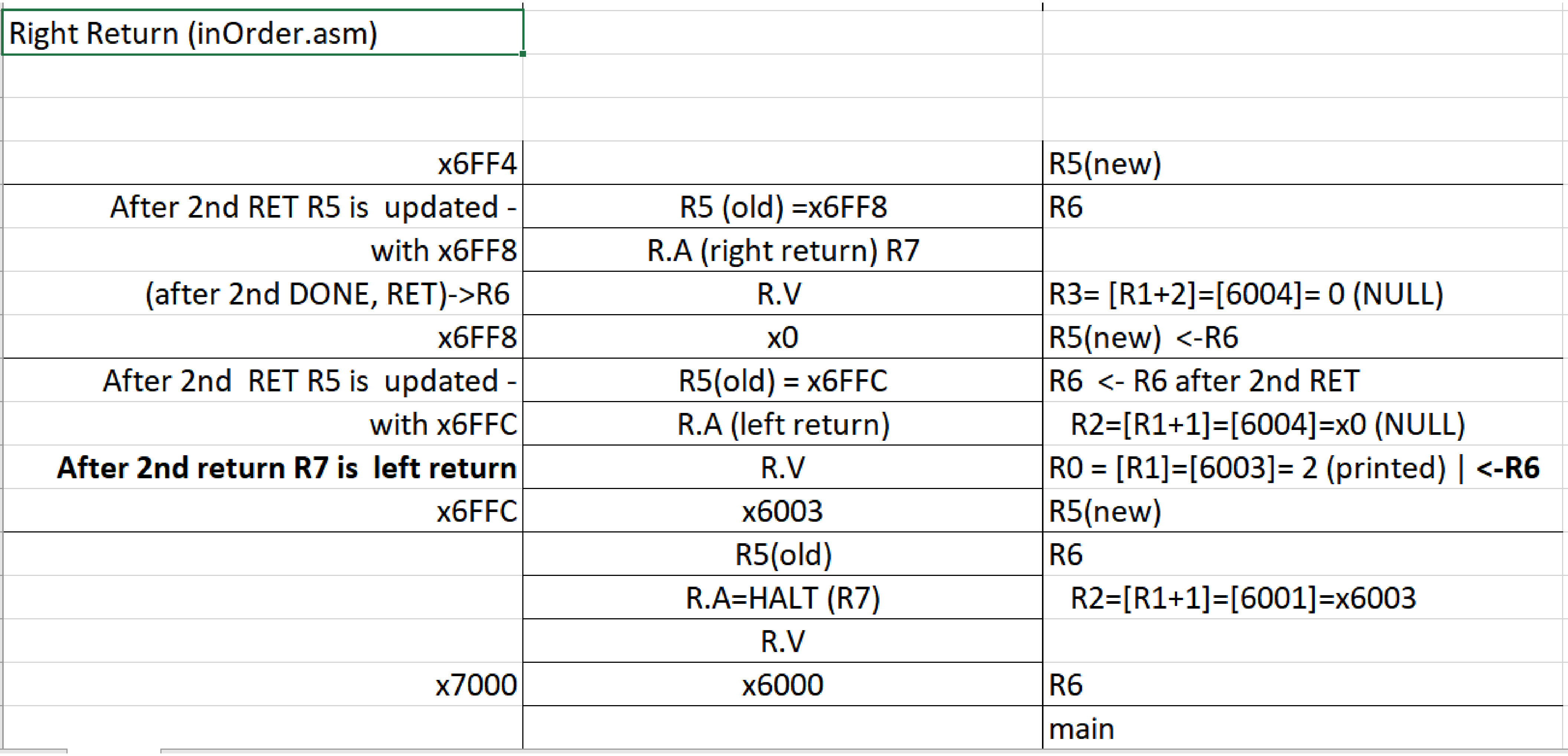
inOrder LC3 (please see, inOrder.asm in github)



```
void inorder(t_node *node)
{
    // Base case
    if(node ==NULL)
        return;
    // Recursive case
    else{
        inorder(node->left);
        printf("%d ", node->data);
        inorder(node->right);
    }
}
```



Left return: (inOrder.asm)		
x6FF4		R5(new)
	R5(old) = x6FF8	R6
	R.A (left Return)	
	R.V	<-R6 (when DONE is executed 1st)
x6FF8	x0	R5(new)
After 1st RET R5 is updated -	R5(old) = x6FFC	R6 <- R6 after 1st RET
with x6FF8	R.A (left return)	R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003	R.V	R0 = [R1]=[6003]= 2 (printed)
x6FFC	x6003	R5(new)
	R5(old)	R6
	R.A=HALT (R7)	R2=[R1+1]=[6001]=x6003
	R.V	
x7000	x6000	R6
		main



Right Return (inOrder.asm)		
x6FF4		R5(new)
After 2nd RET R5 is updated -	R5 (old) =x6FF8	R6
with x6FF8	R.A (right return) R7	
(after 2nd DONE, RET)->R6	R.V	R3= [R1+2]=[6004]= 0 (NULL)
x6FF8	x0	R5(new) <-R6
After 2nd RET R5 is updated -	R5(old) = x6FFC	R6 <- R6 after 2nd RET
with x6FFC	R.A (left return)	R2=[R1+1]=[6004]=x0 (NULL)
After 2nd return R7 is left return	R.V	R0 = [R1]=[6003]= 2 (printed) | **<-R6**
x6FFC	x6003	R5(new)
	R5(old)	R6
	R.A=HALT (R7)	R2=[R1+1]=[6001]=x6003
	R.V	
x7000	x6000	R6
		main