ECE 220 Computer Systems & Programming

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

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);
}
}
```

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

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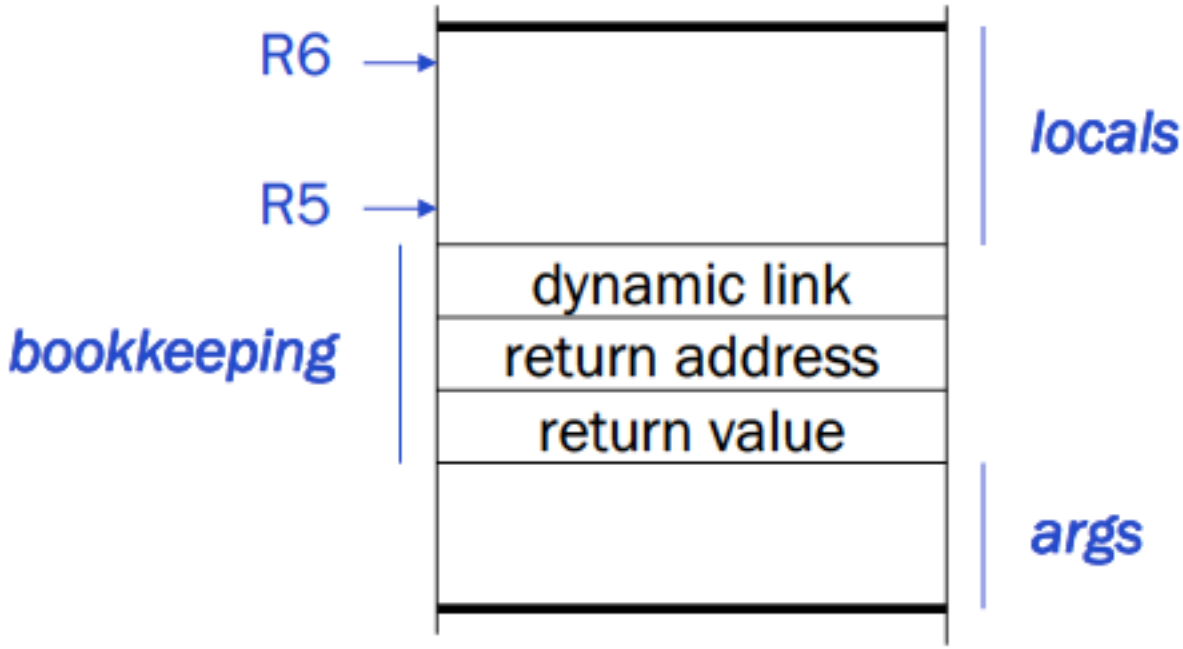
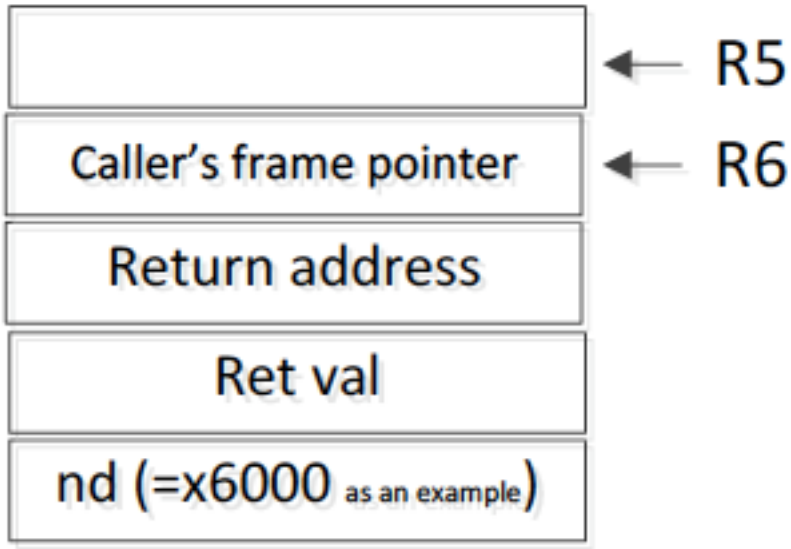
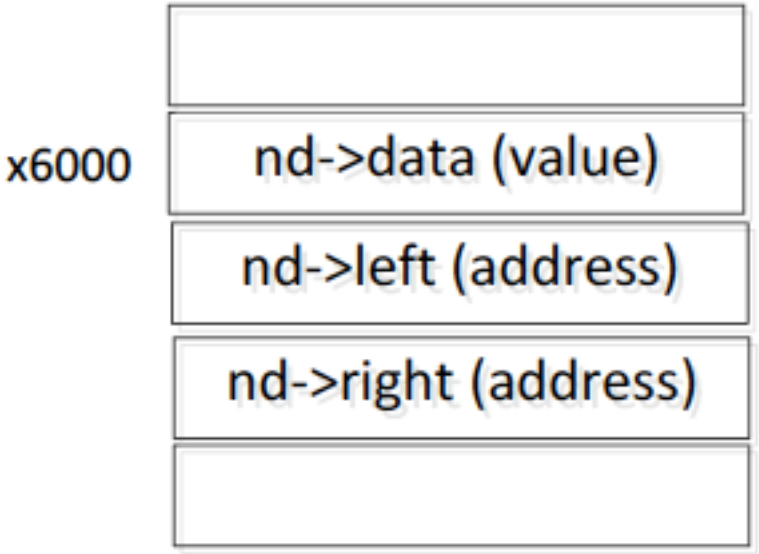
{
   if (nd != NULL)
{
   TraverseTree(nd->left);
   TraverseTree(nd->right);
}
}
```

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

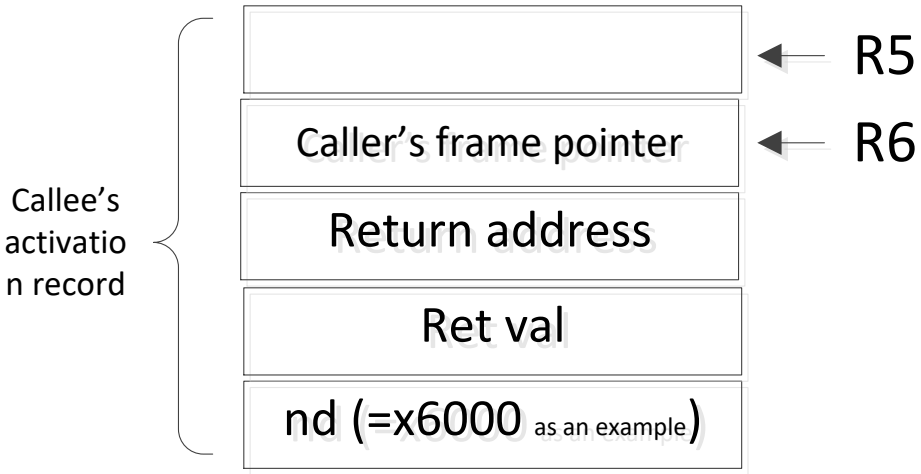
Activation Record

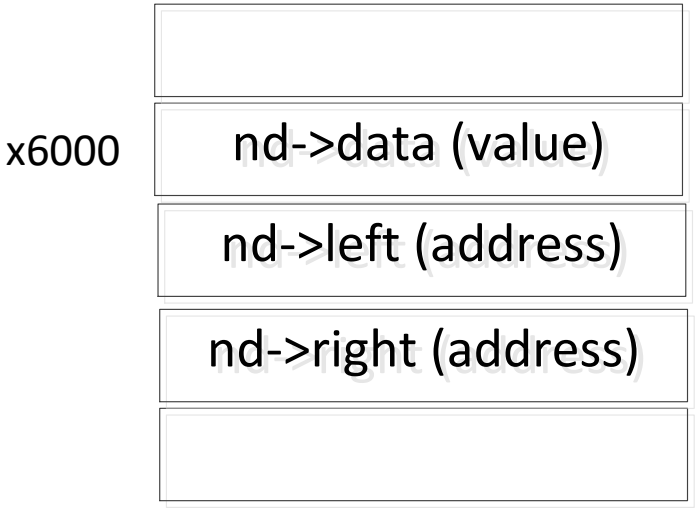






Step#1






```
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
```

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

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

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 R0, R5,#4
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:

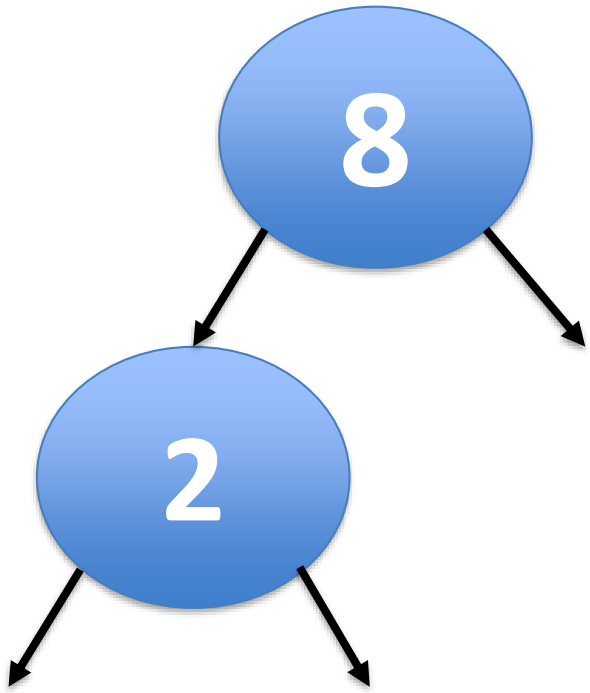
```
DONE
        ; Restore frame pointer
        LDR R5, R6, #0
        ADD R6, R6, #1

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

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);
    }
}
```

Data_inOrder.asm




```
.ORIG x6000

.FILL x38 ; ascii 8
.FILL x6003
.FILL x0    ;NULL

.FILL x32 ; ascii 2
.FILL x0
.FILL x0   ;NULL

.END
```

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

inOrder.asm

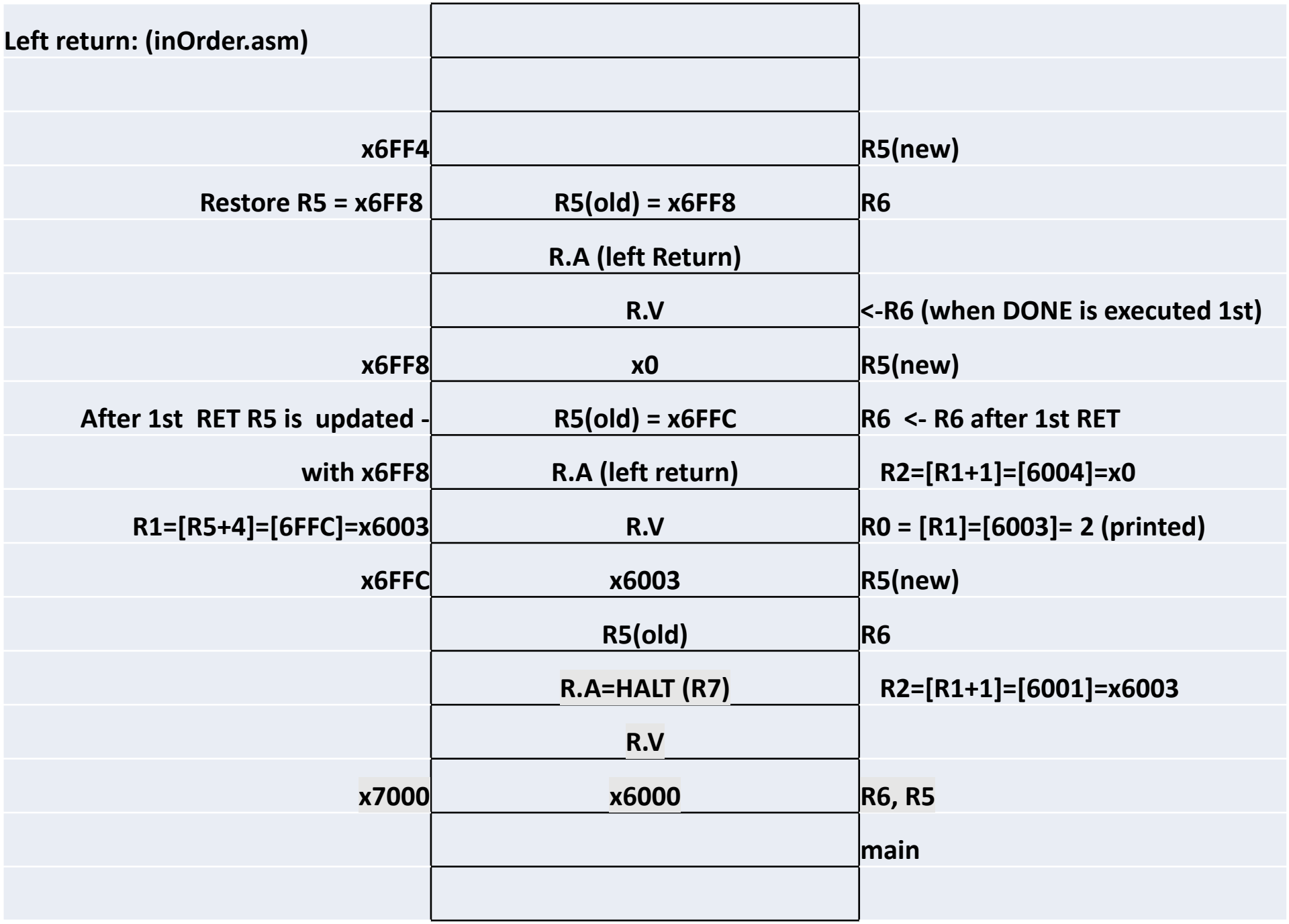
```
1  .ORIG x3000
2
3  ;;R5 - frame pointer
4  ;;R6 - stack pointer
5  ;;MAIN
6  LD R6, STACK
7  LD R5, STACK
8  LD R1, ND_VAL
9  STR R1, R5, #0     ; push nd (x6000) to stack
10 JSR INORDER
11 HALT
12
13 ;;INORDER TRAVERSAL
14 INORDER
15 ;;Part 1 - push book keeping info
16 ;allocate space for return value
17 ADD R6, R6, #-1
18 ;Push return address to stack
19 ADD R6, R6, #-1
20 STR R7, R6, #0
21 ;Store old frame pointer
22 ADD R6, R6, #-1
23 STR R5, R6, #0
24 ;Set up new frame pointer
25 ADD R5, R6, #-1
26
27 ;;Part 2 - implement function logic
28 ;if (nd == NULL) skip to the end (Done)
29 LDR R1, R5, #4
30 BRz DONE
31 ;else
32 ;inorder(nd->left);
```

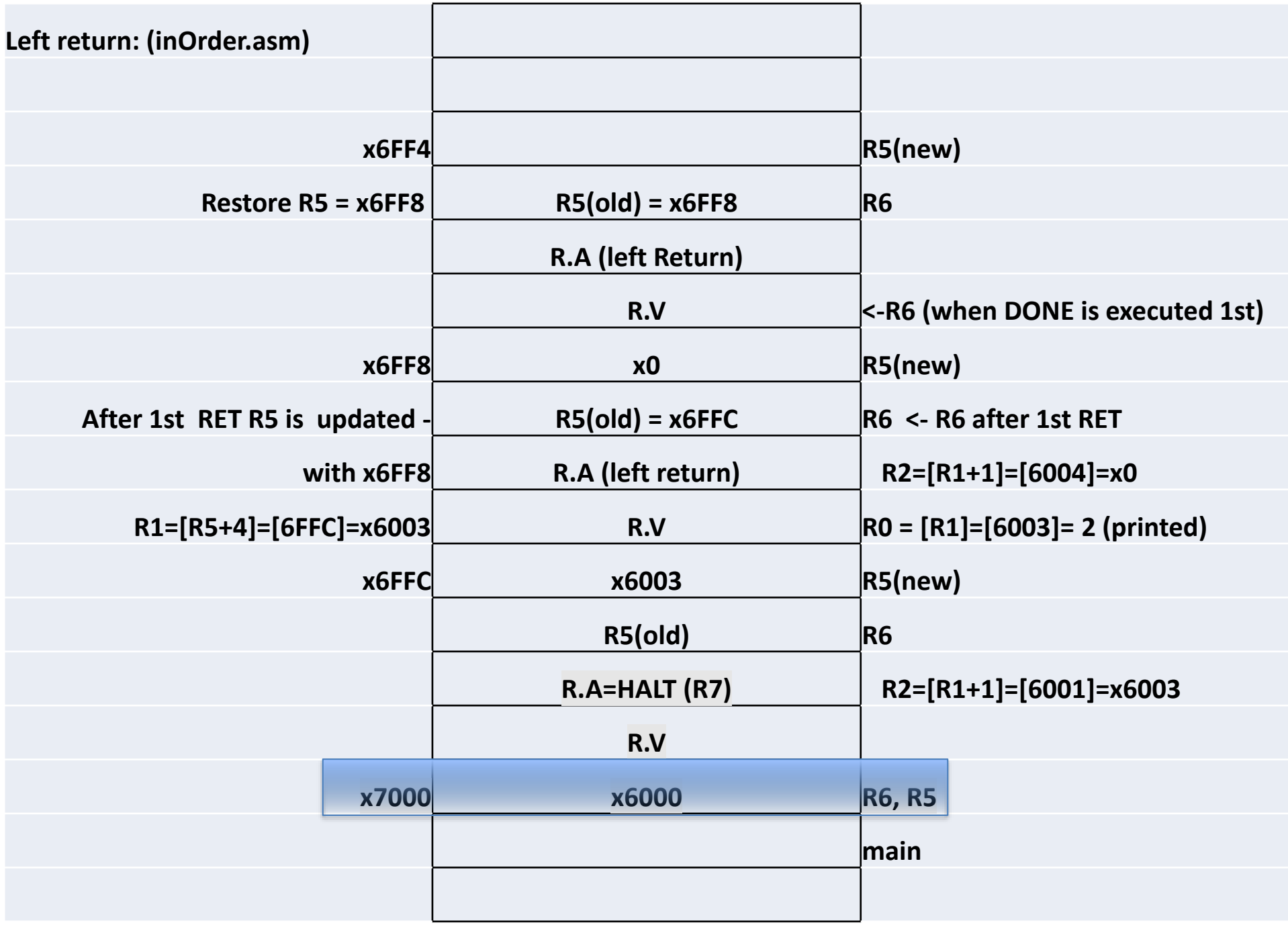
inOrder.asm(cont)

```
32 ;inorder(nd->left);
33 LDR R2, R1, #1          ;load nd->left to R2
34 ADD R6, R6, #-1
35 STR R2, R6, #0          ;push nd->left to stack
36 JSR INORDER            ;;;;;;;;;;;;;;;;;;;;;;;;;
37 ADD R6, R6, #2  ;(left return);stack tear down
38 ;printf("%c", nd->data);
39 LDR R1, R5, #4
40 LDR R0, R1, #0
41 OUT
42 ;inorder(nd->right);
43 ;LDR R1, R5, #4          ;reload nd first
44 LDR R3, R1, #2          ;load nd->right to R3
45 ADD R6, R6, #-1
46 STR R3, R6, #0          ;push nd->right to stack
47 JSR INORDER             ;;;;;;;;;;;;;;;;;;;;;;;;;;;;
48 ADD R6, R6, #2 ;(right return);stack tear down
49
50 ;;Part 3 - tear down part of activation record
51 ;;(prepare to return)
52 DONE
53 LDR R5, R6, #0          ;restore old frame pointer
54 ADD R6, R6, #1
55
56 LDR R7, R6, #0          ;restore return address
57 ADD R6, R6, #1
58
59 RET
60
61 STACK .FILL x7000
62 ND_VAL .FILL x6000
63
64 .END
```

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


Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
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, R5
main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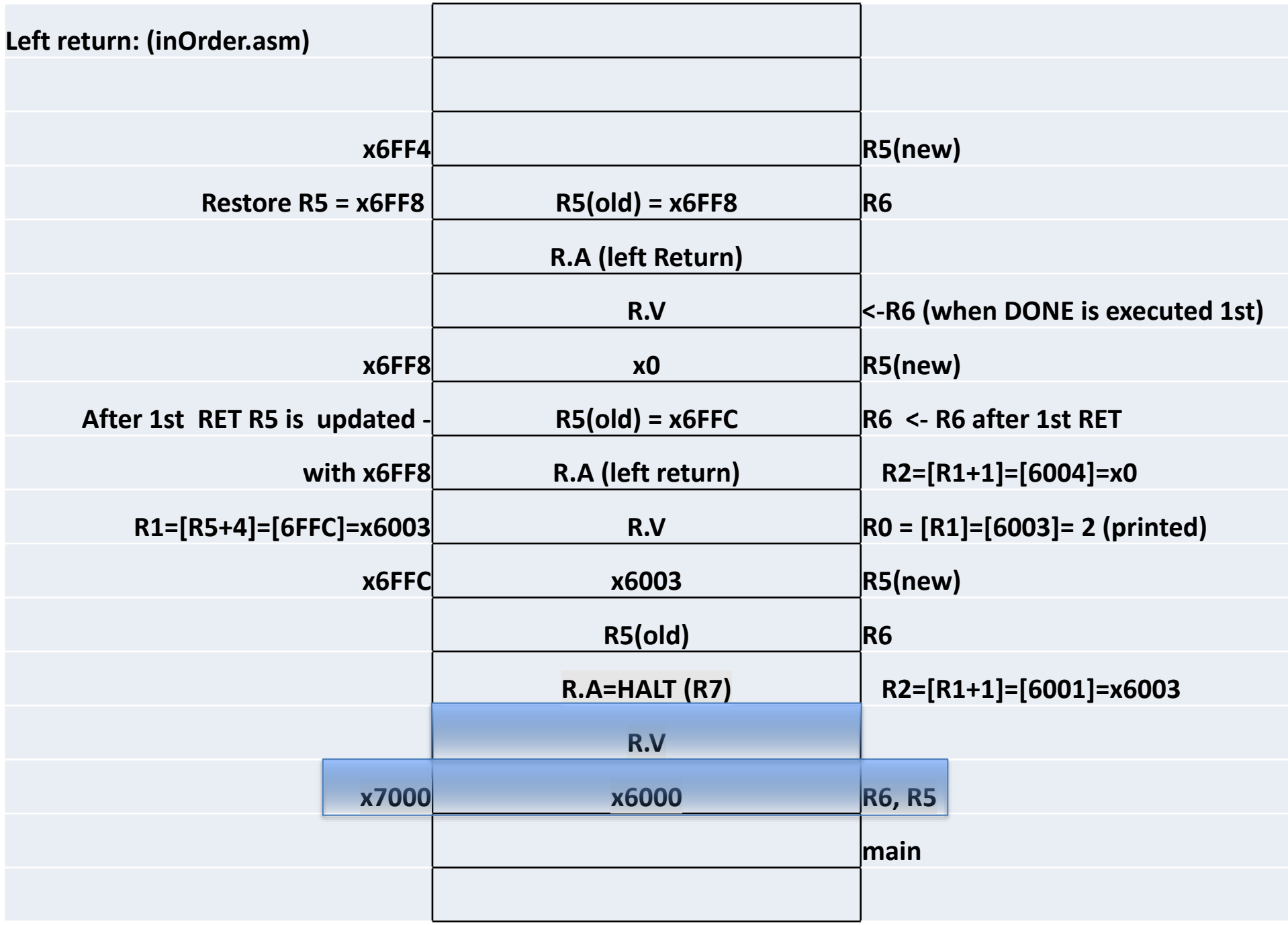
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x7000
x6000
R6, R5
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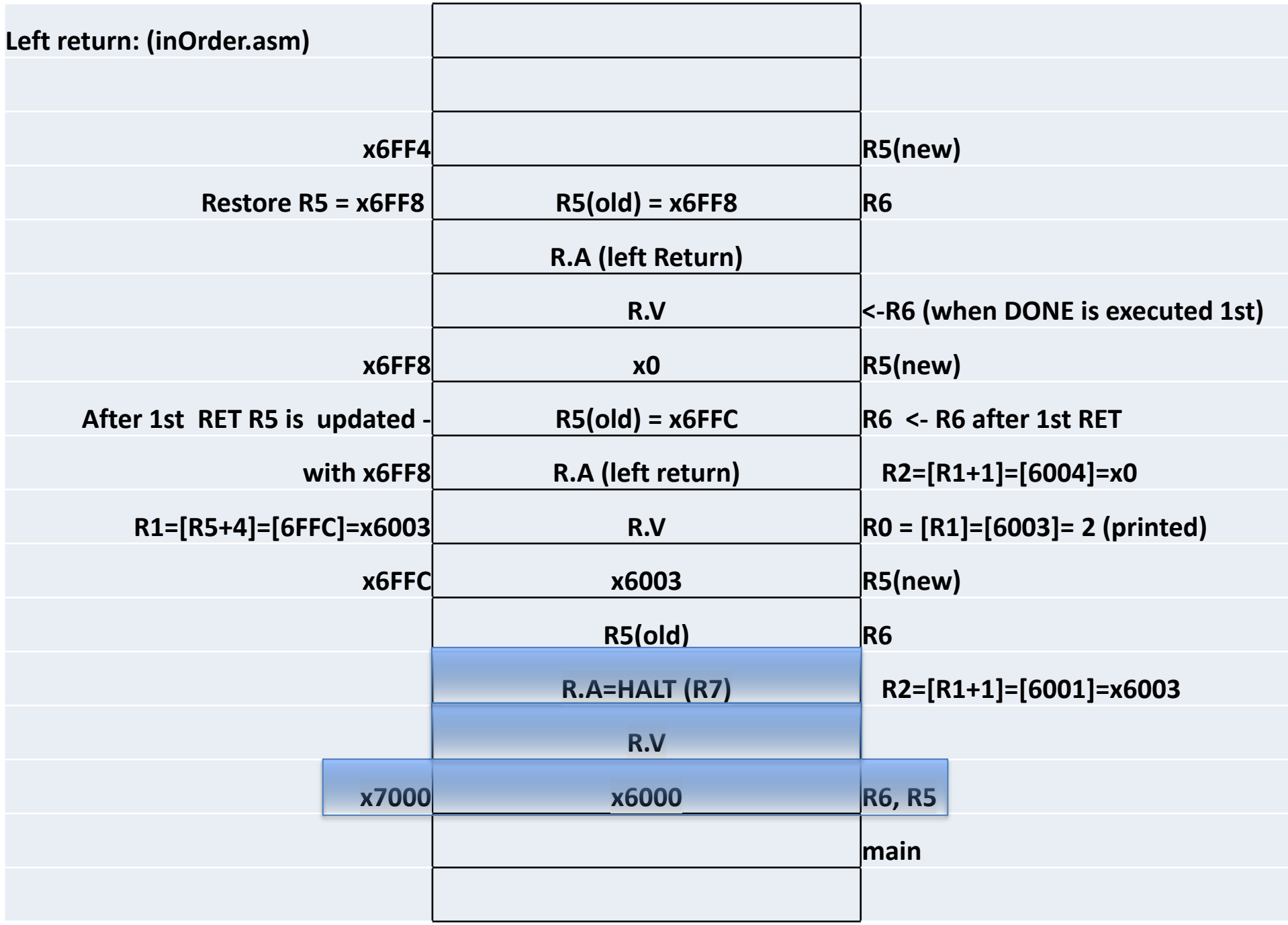
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x7000
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R6, R5
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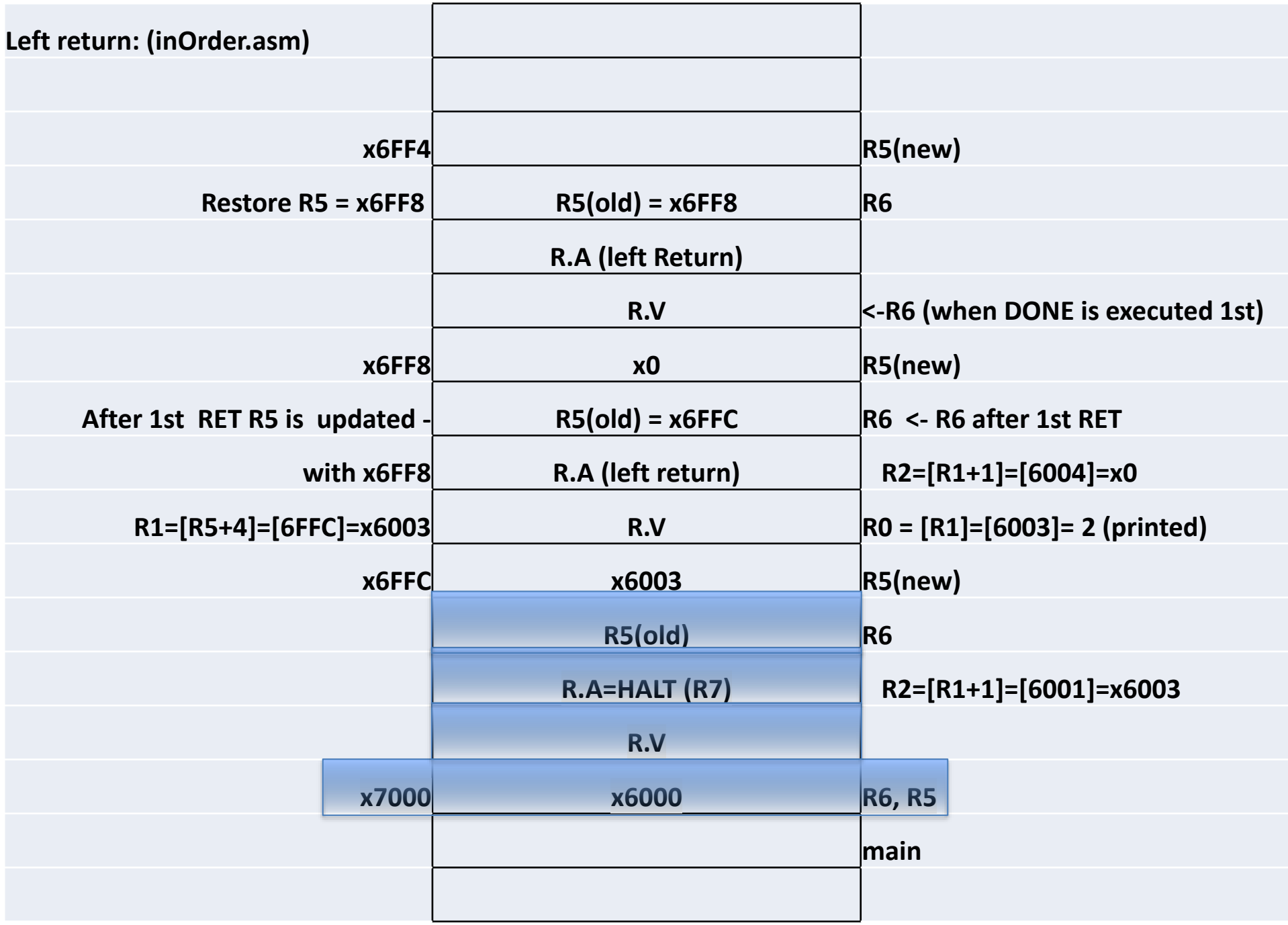
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R6
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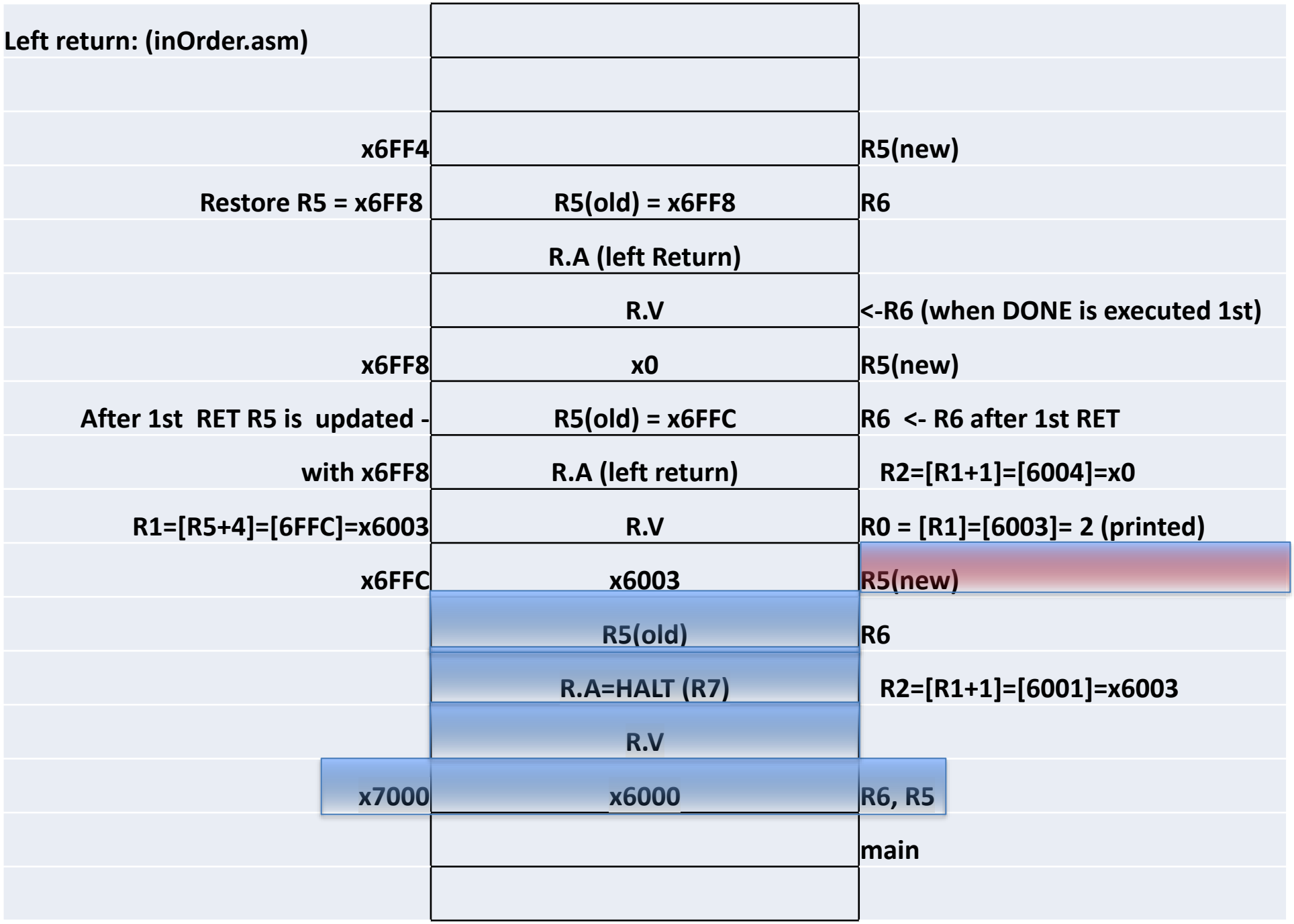
R.V
x7000
x6000
R6, R5
main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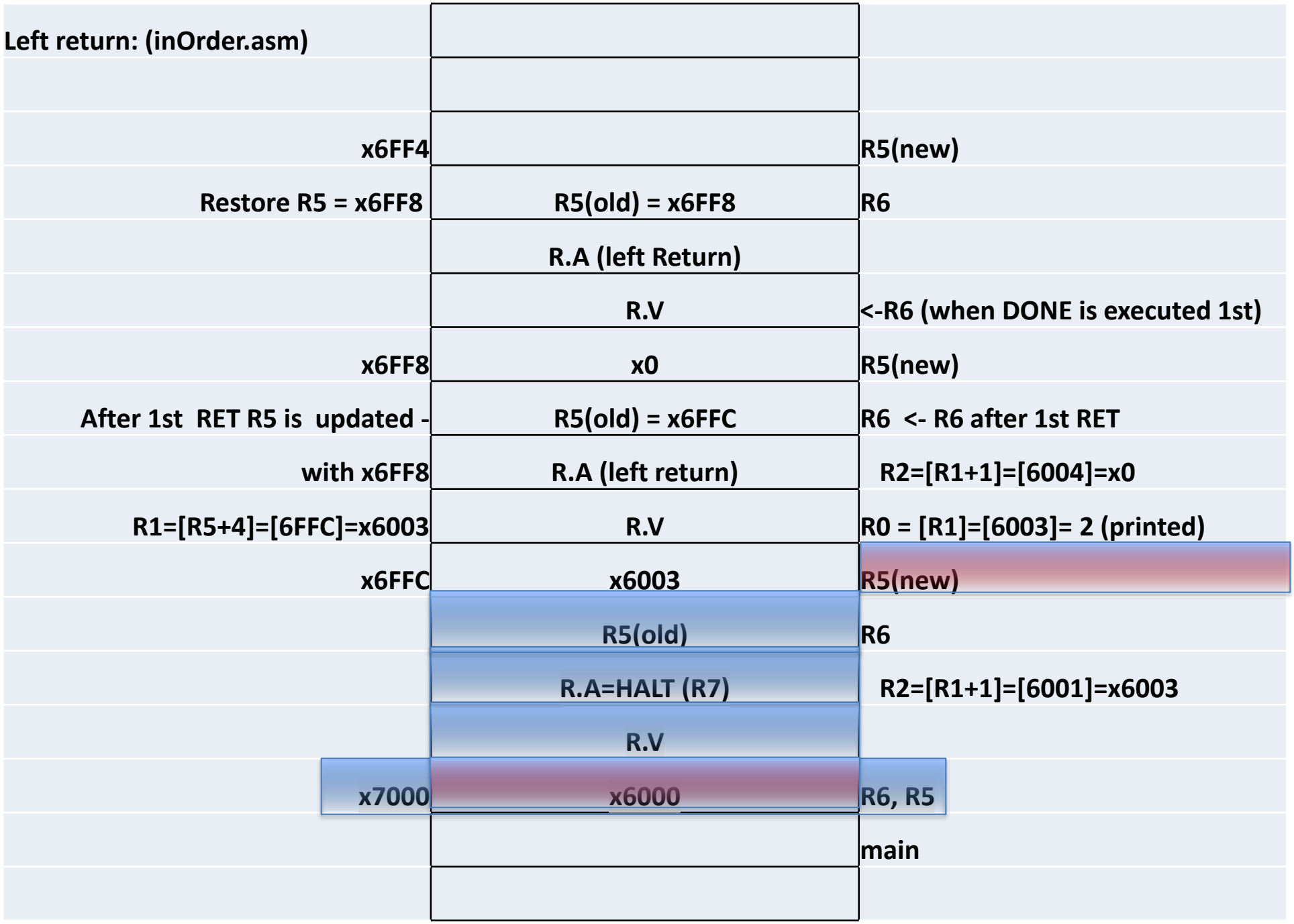
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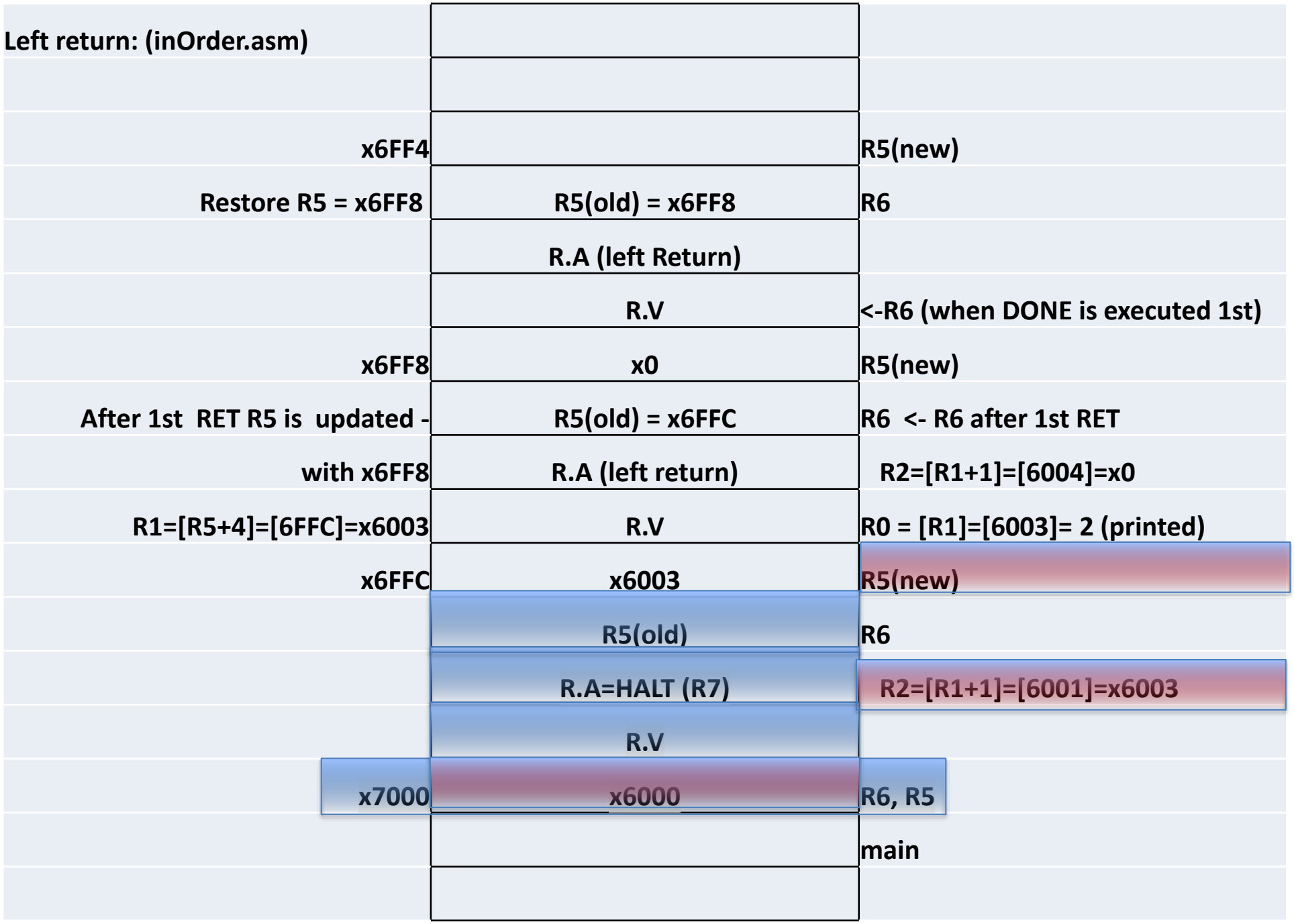
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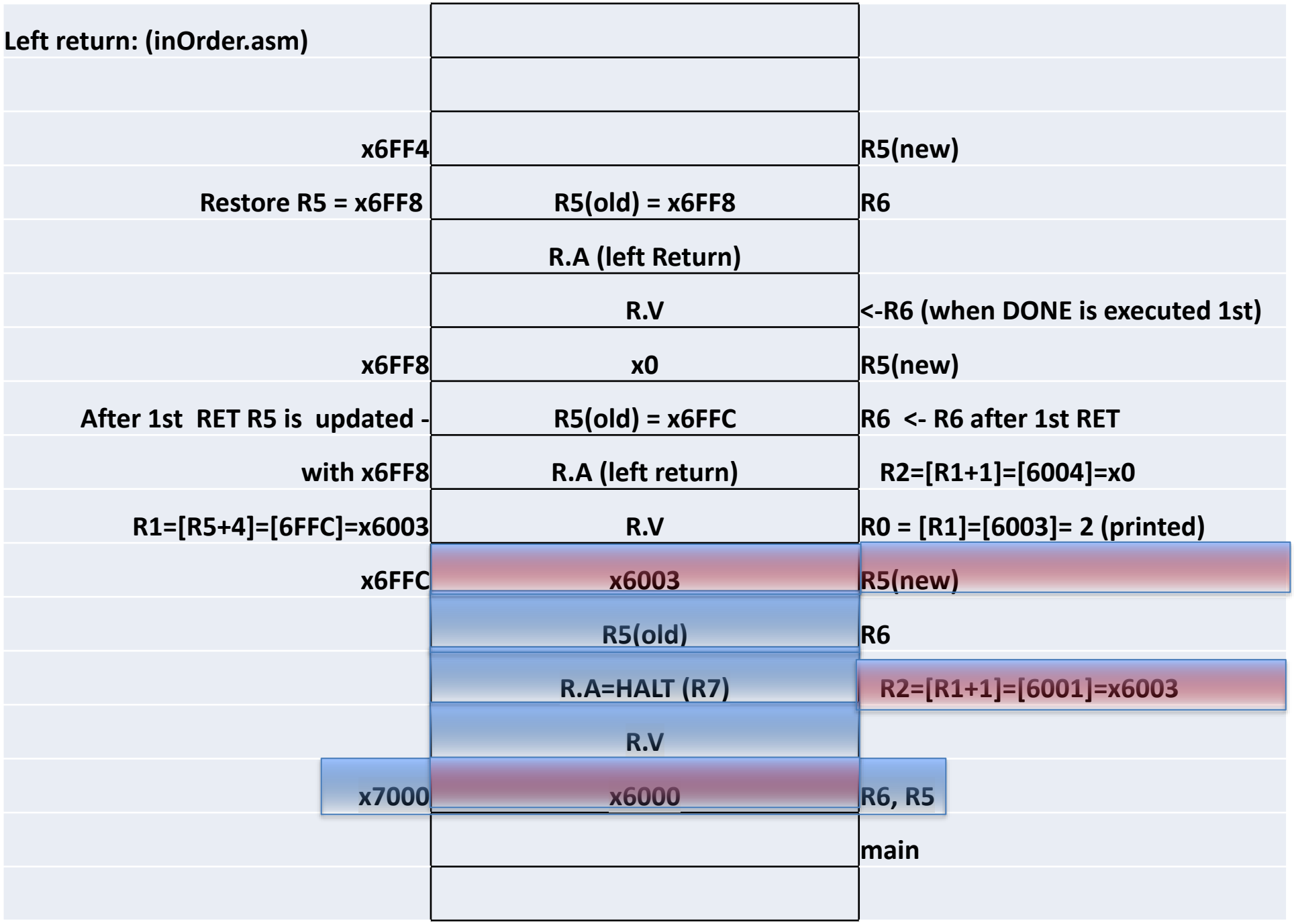
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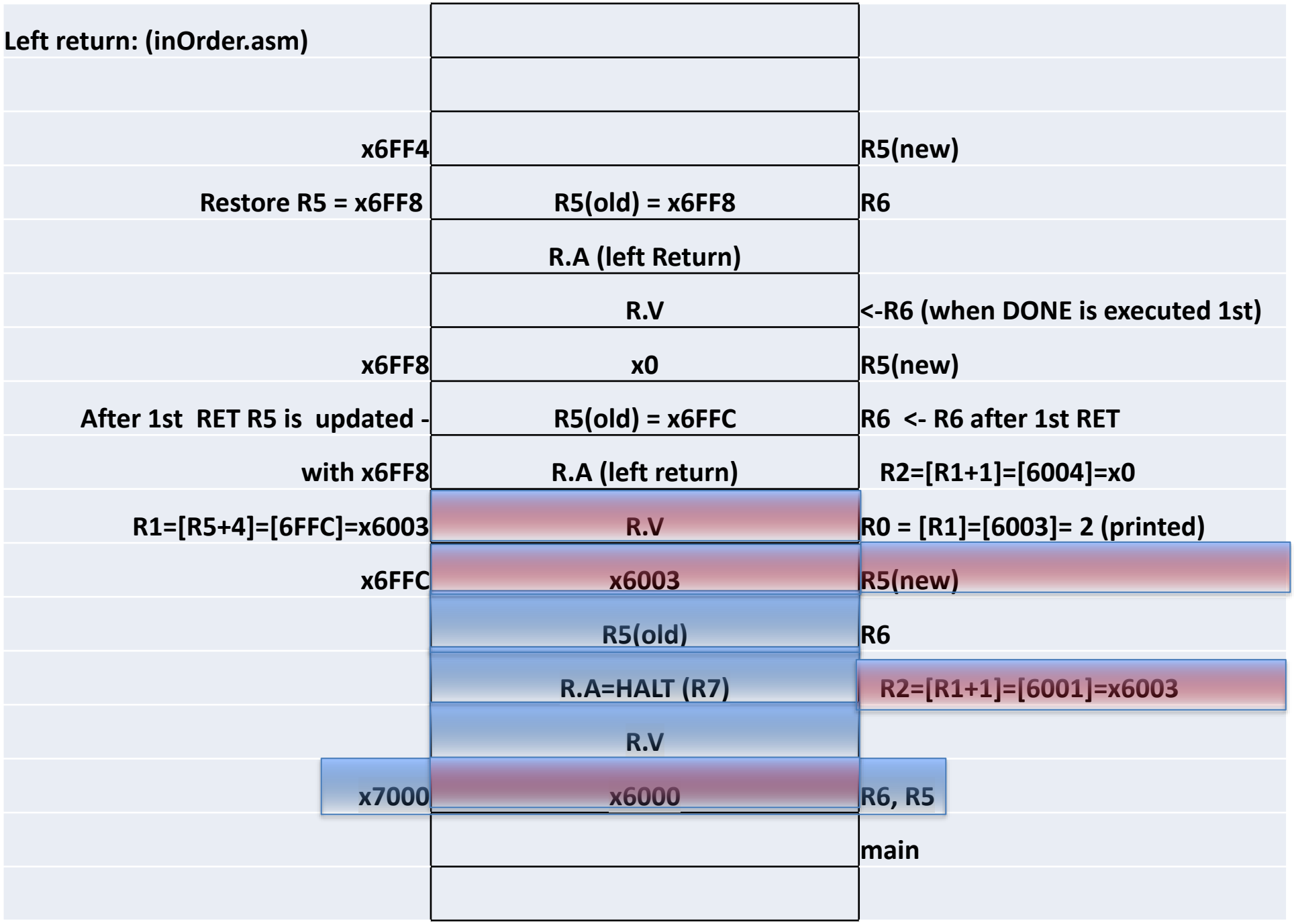
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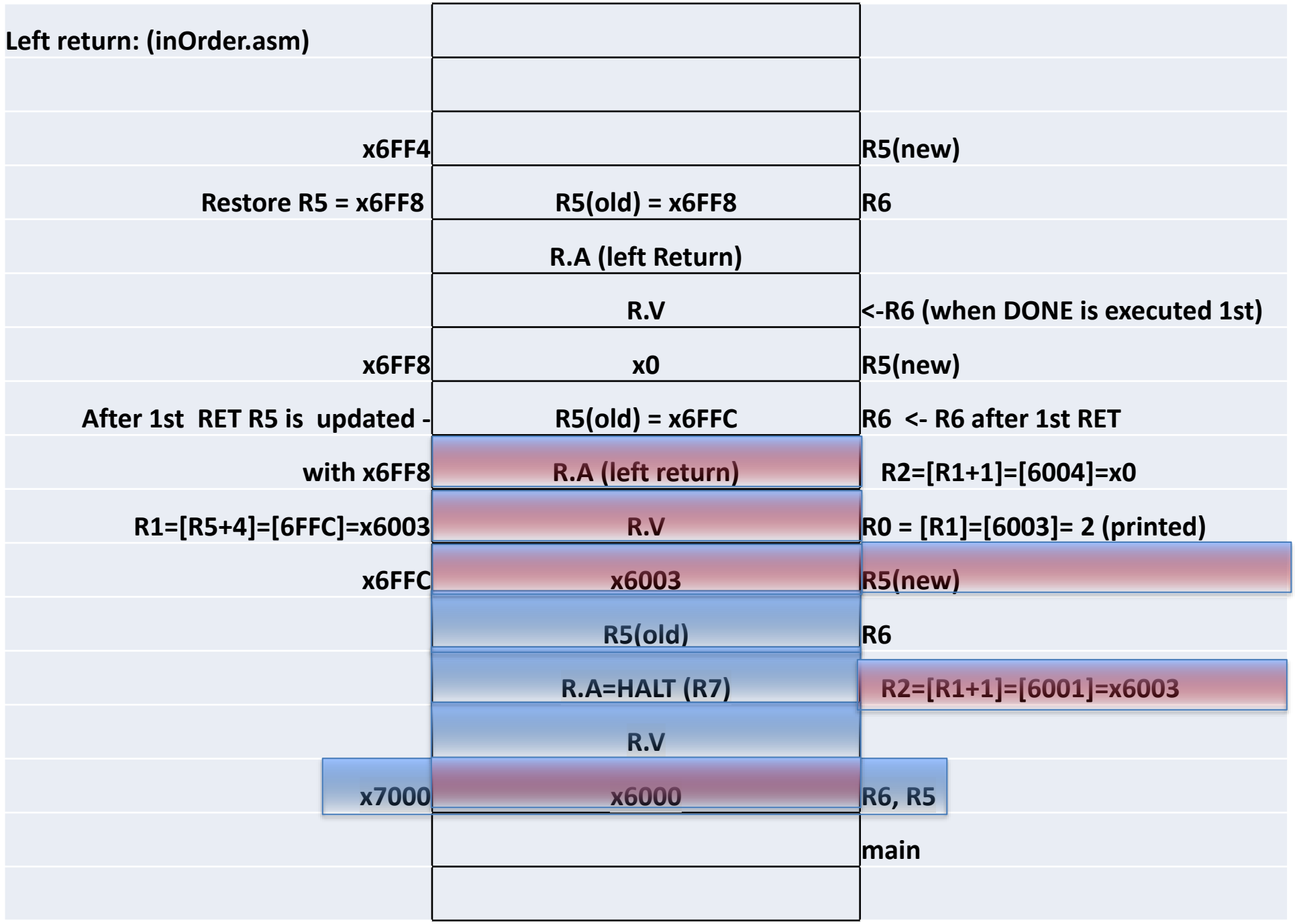
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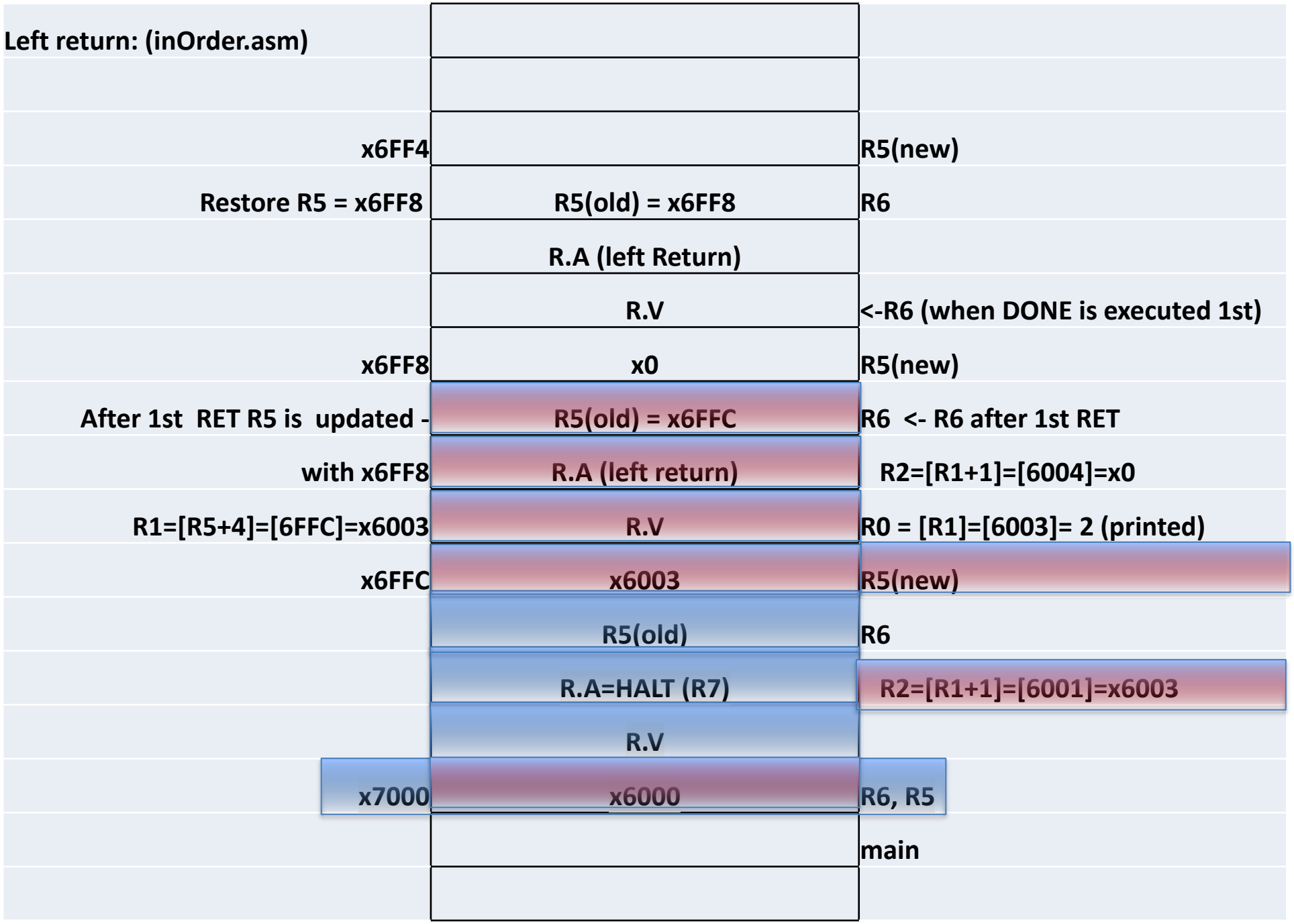
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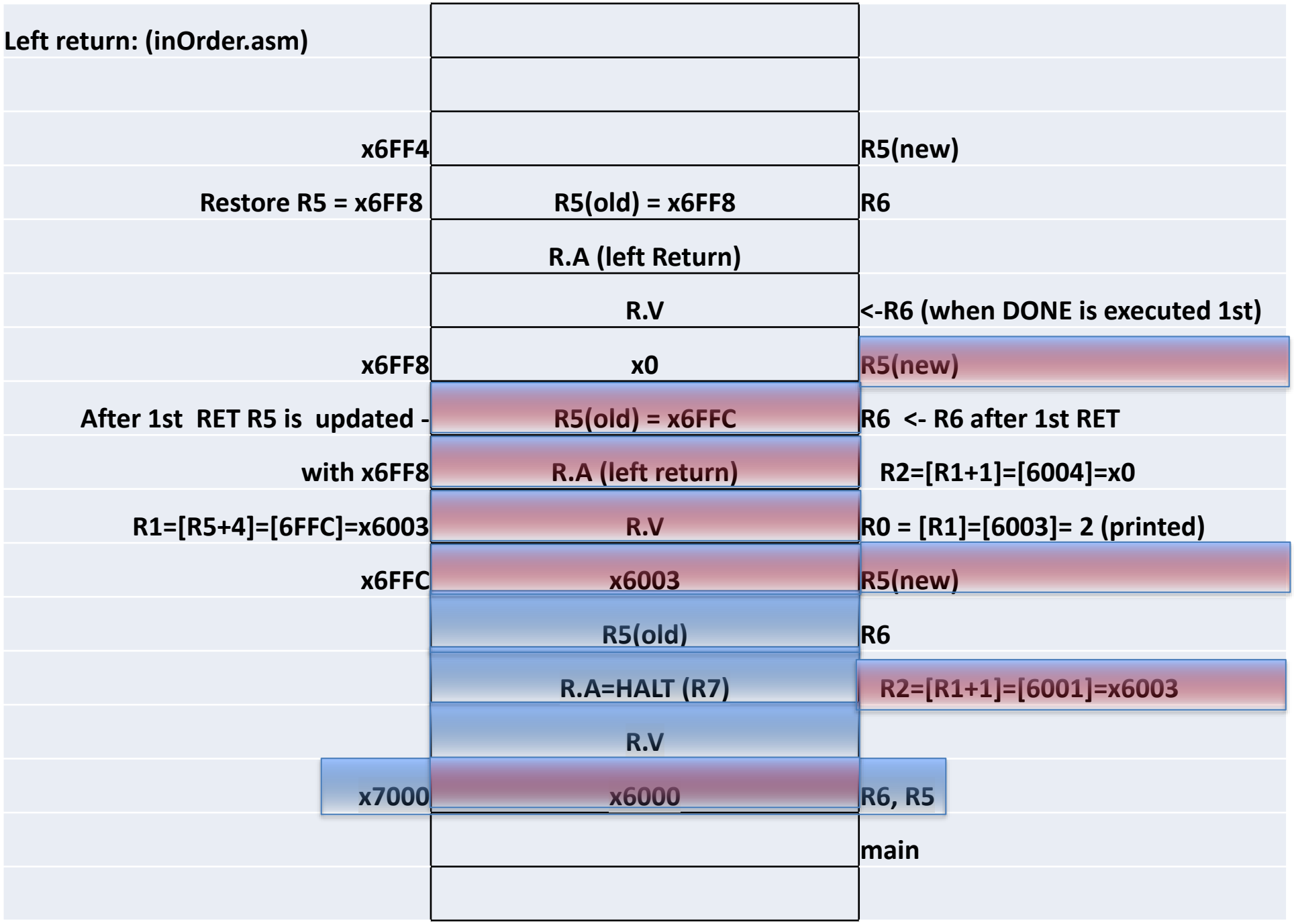
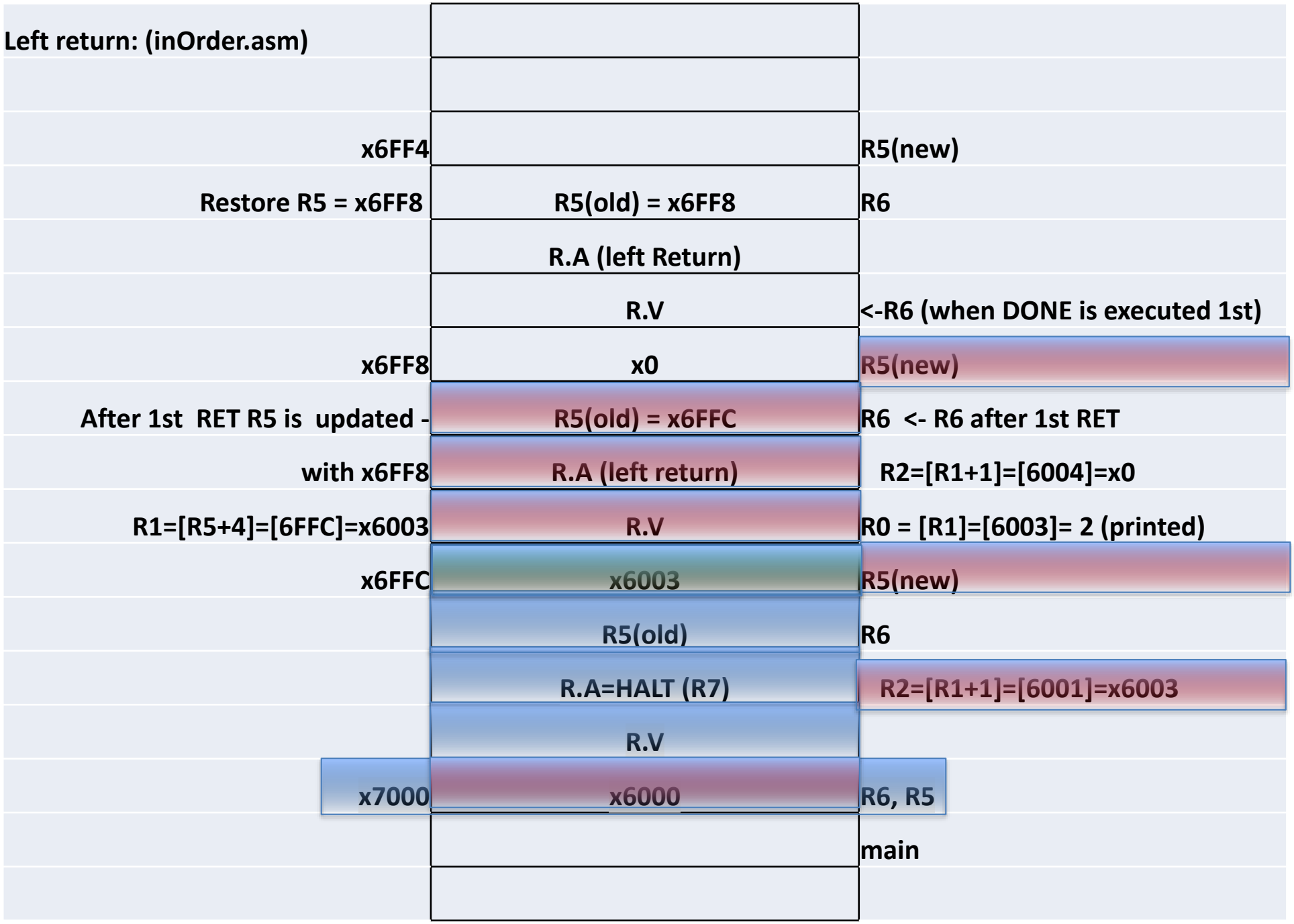
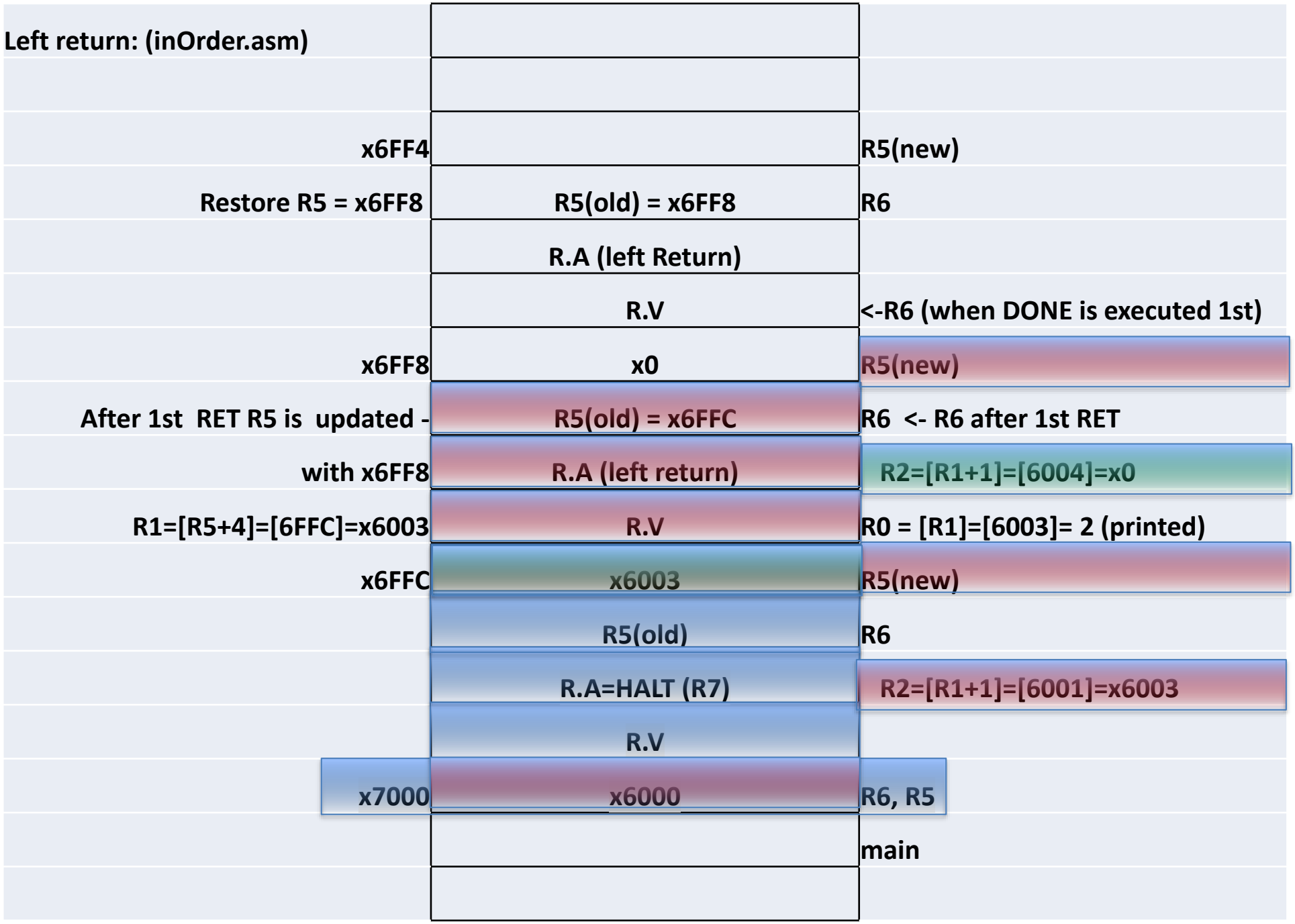
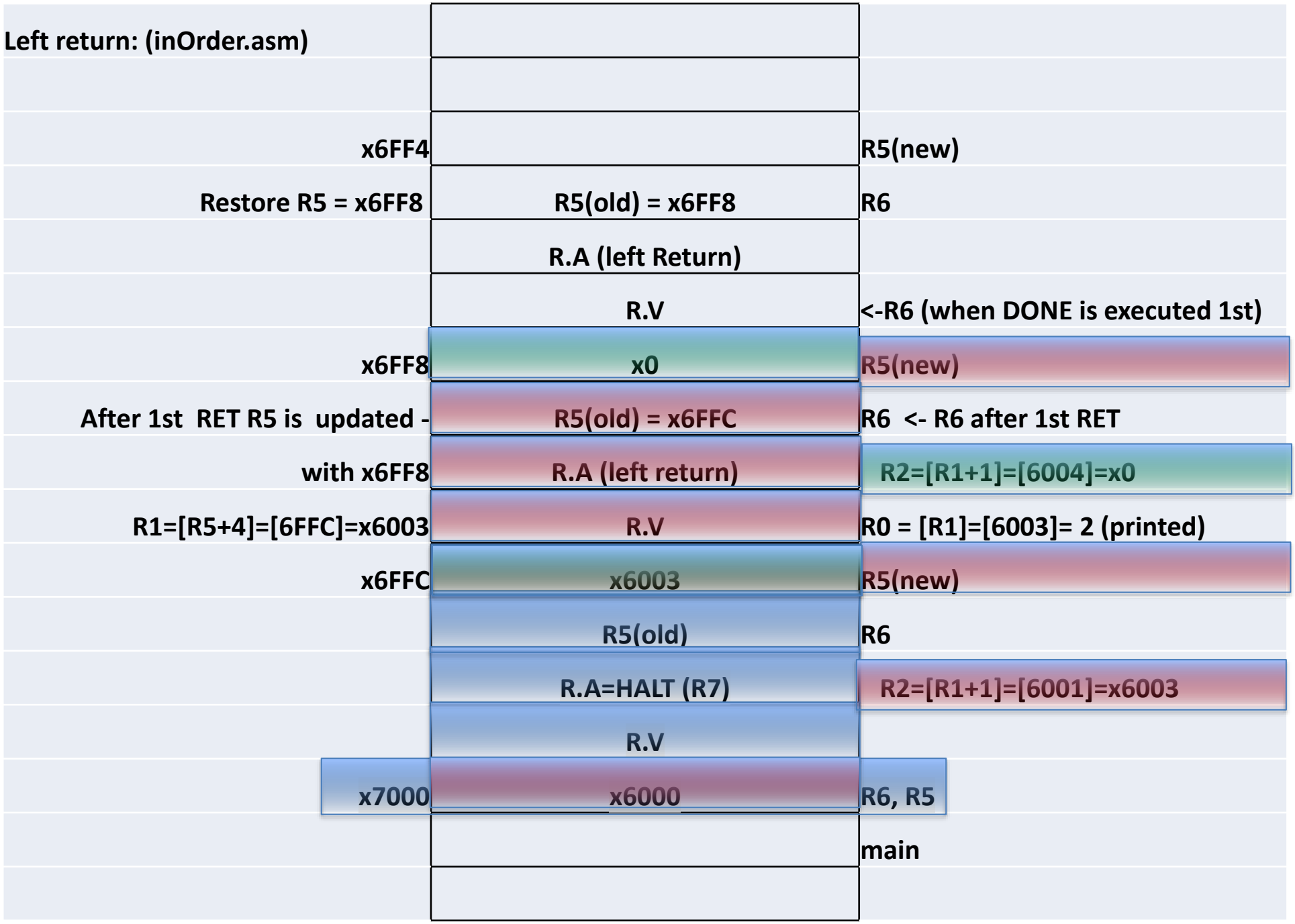
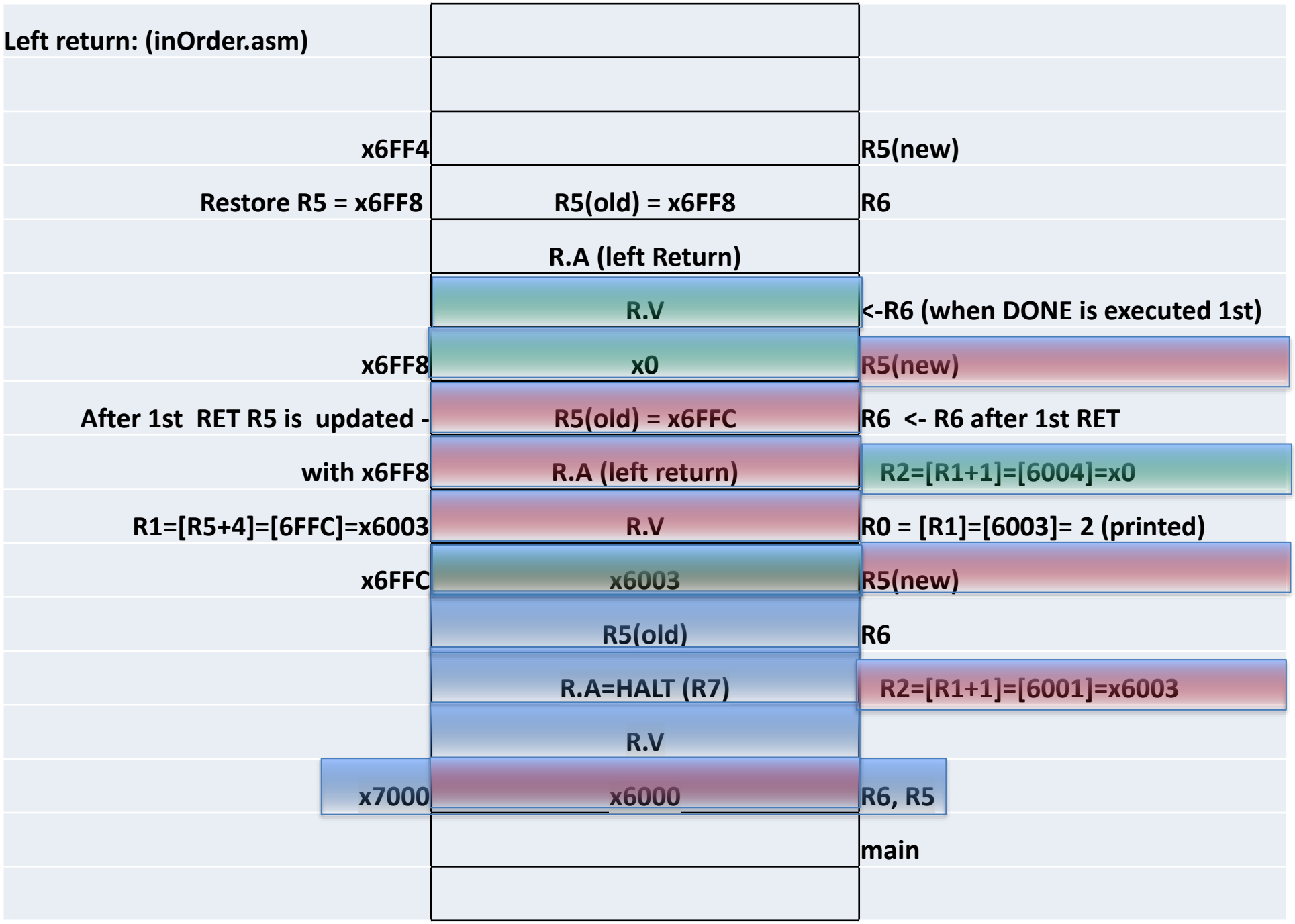
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 = [R1]=[6003]= 2 (printed)
x6FFC
x6003
R5(new)
R5(old)
R6
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6, R5
main

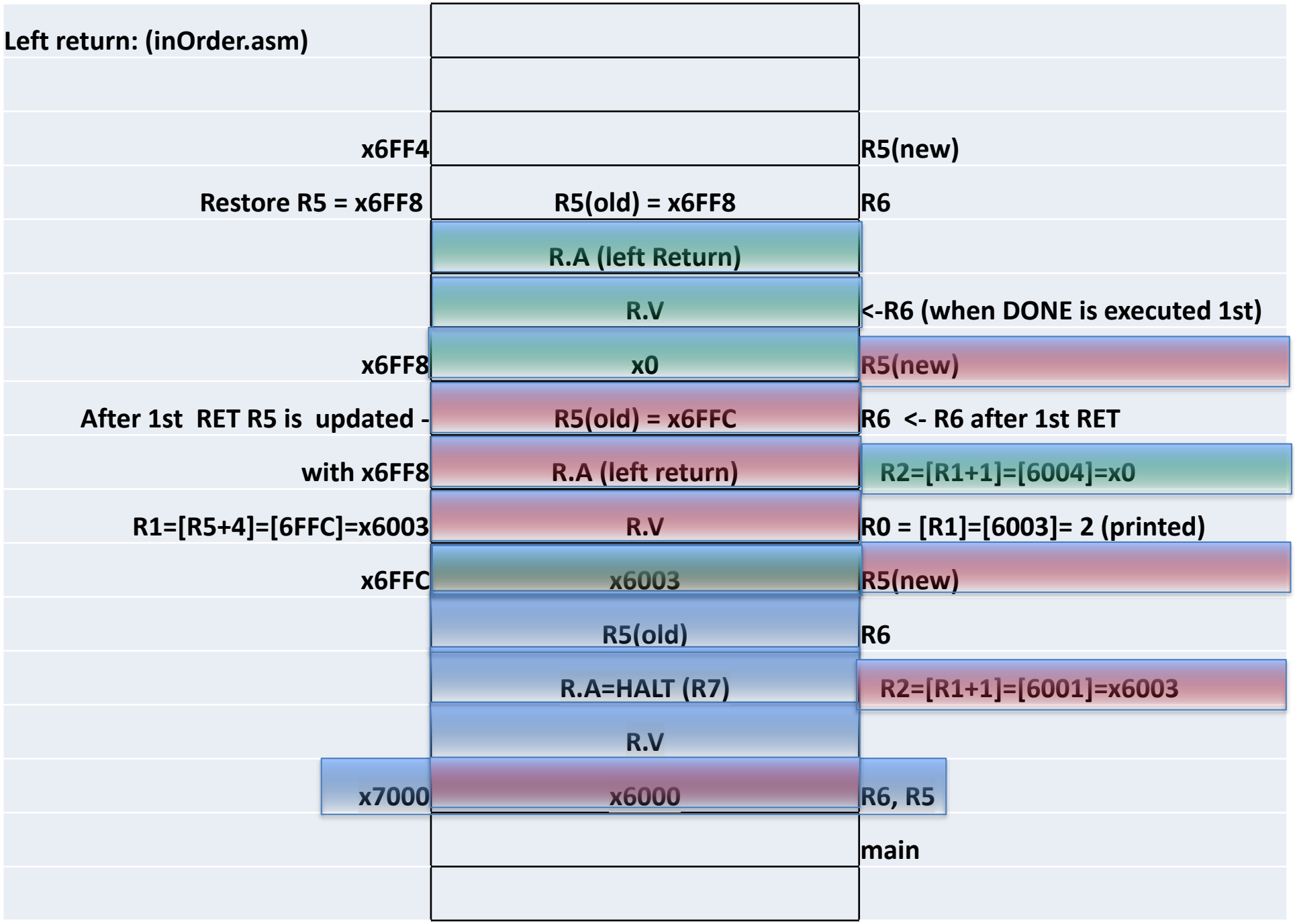

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

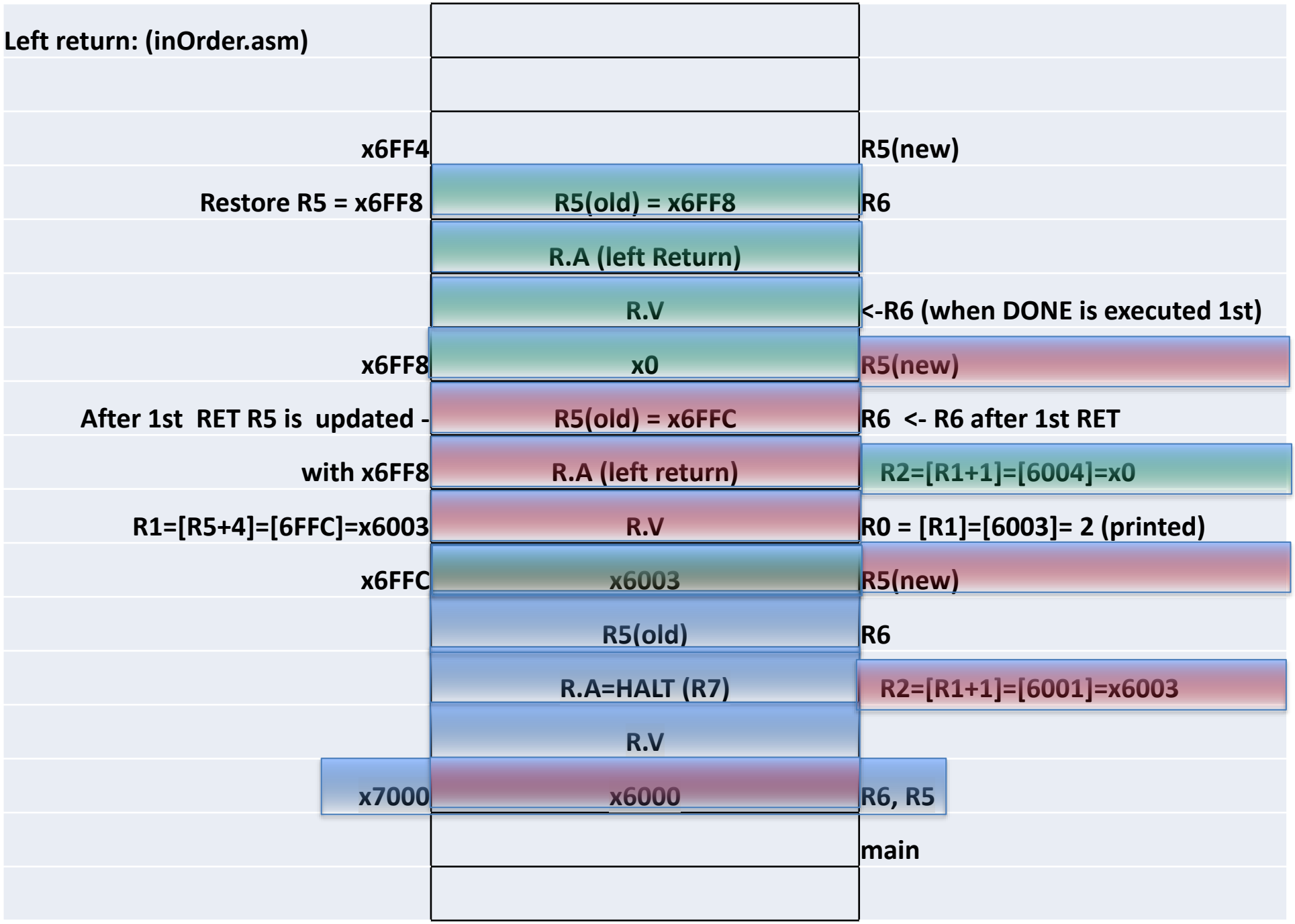

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

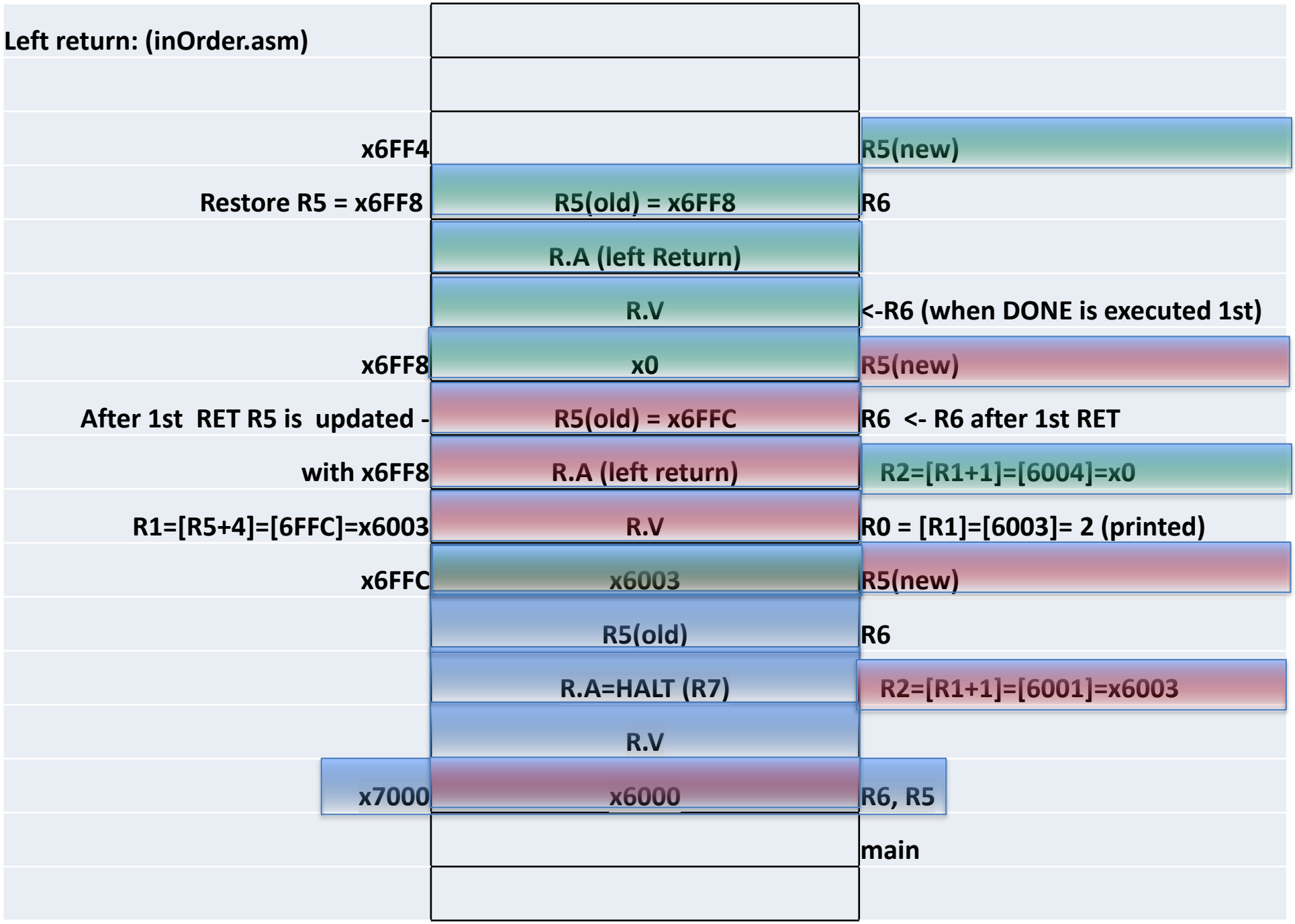

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

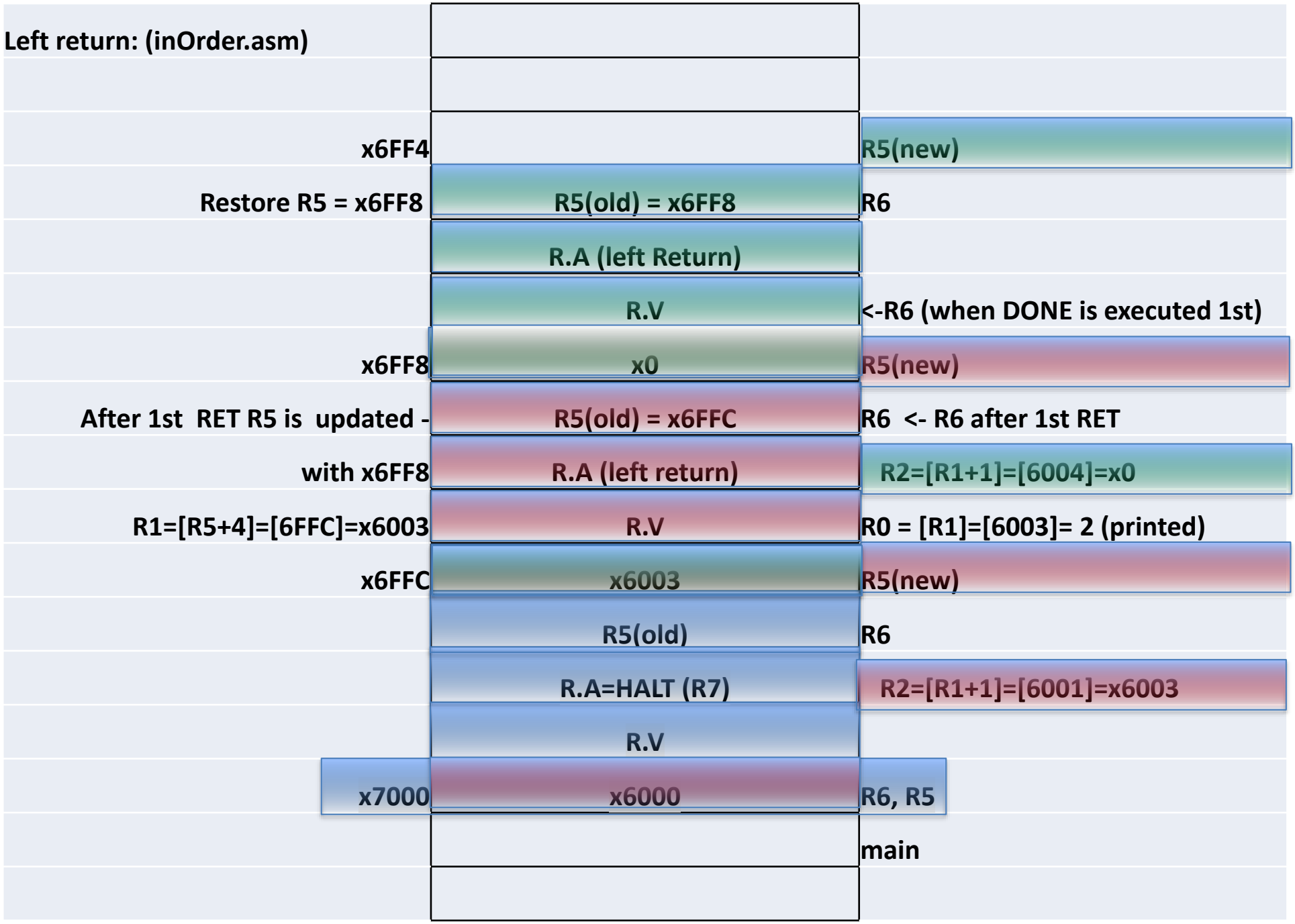

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

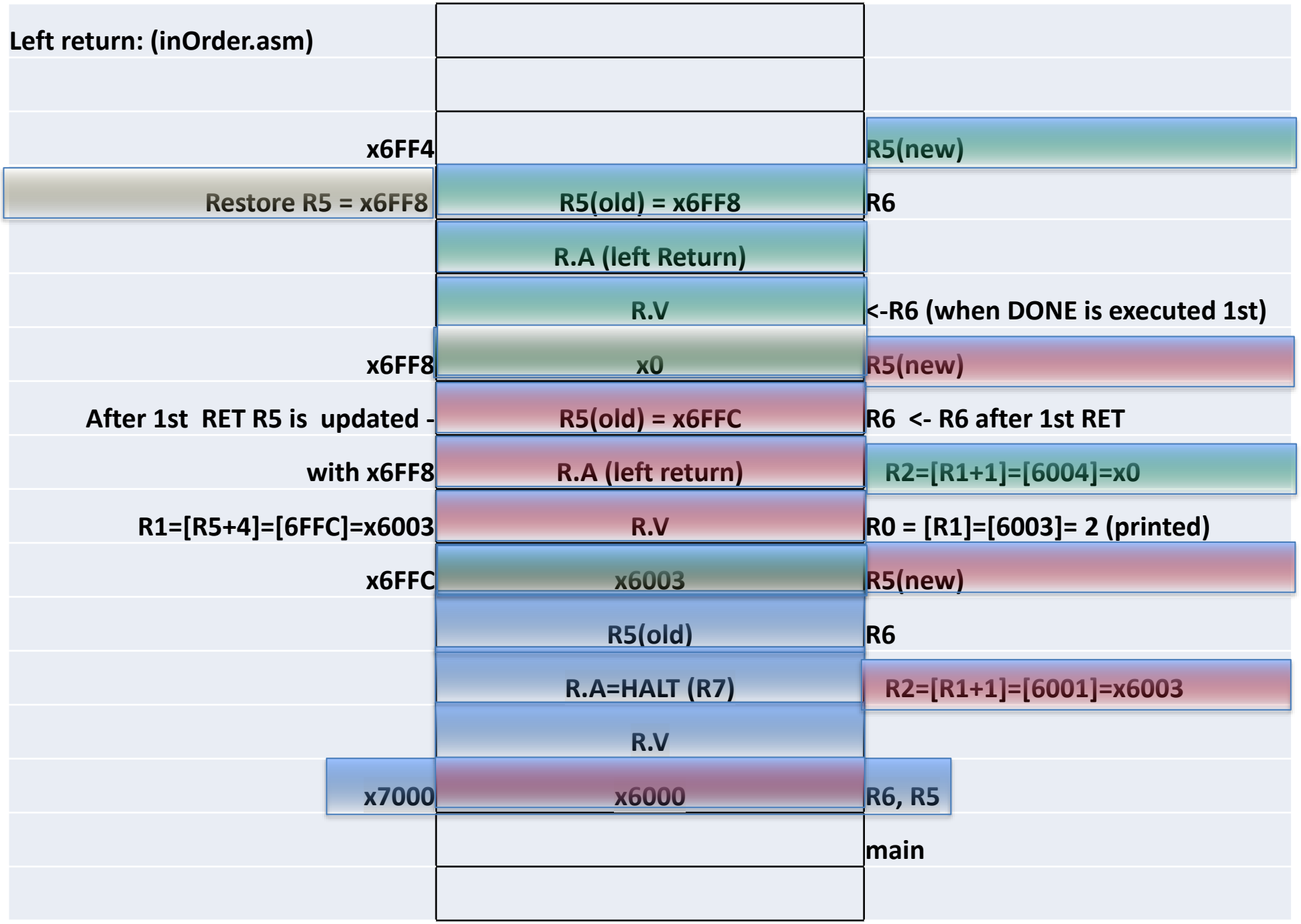

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

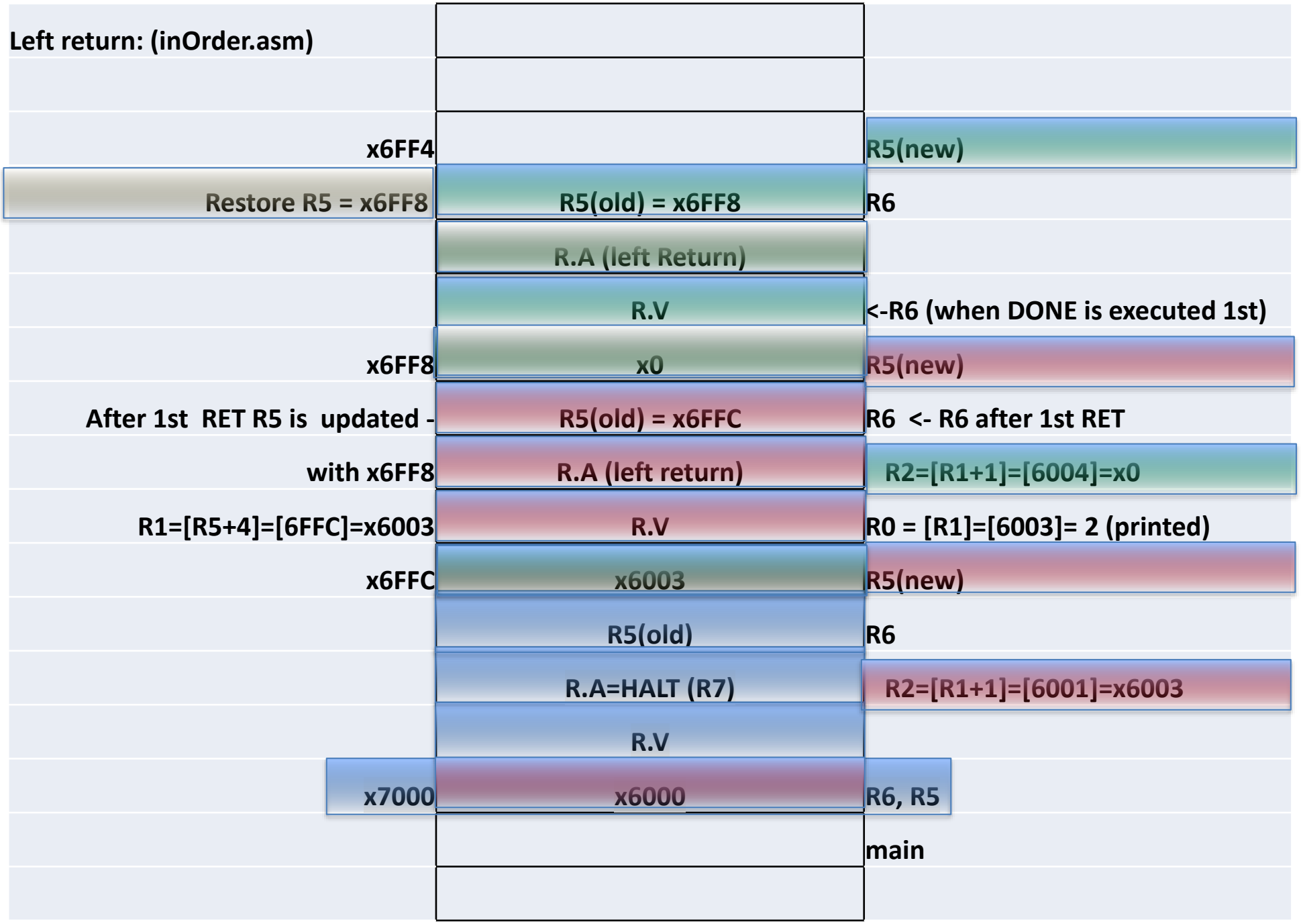

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

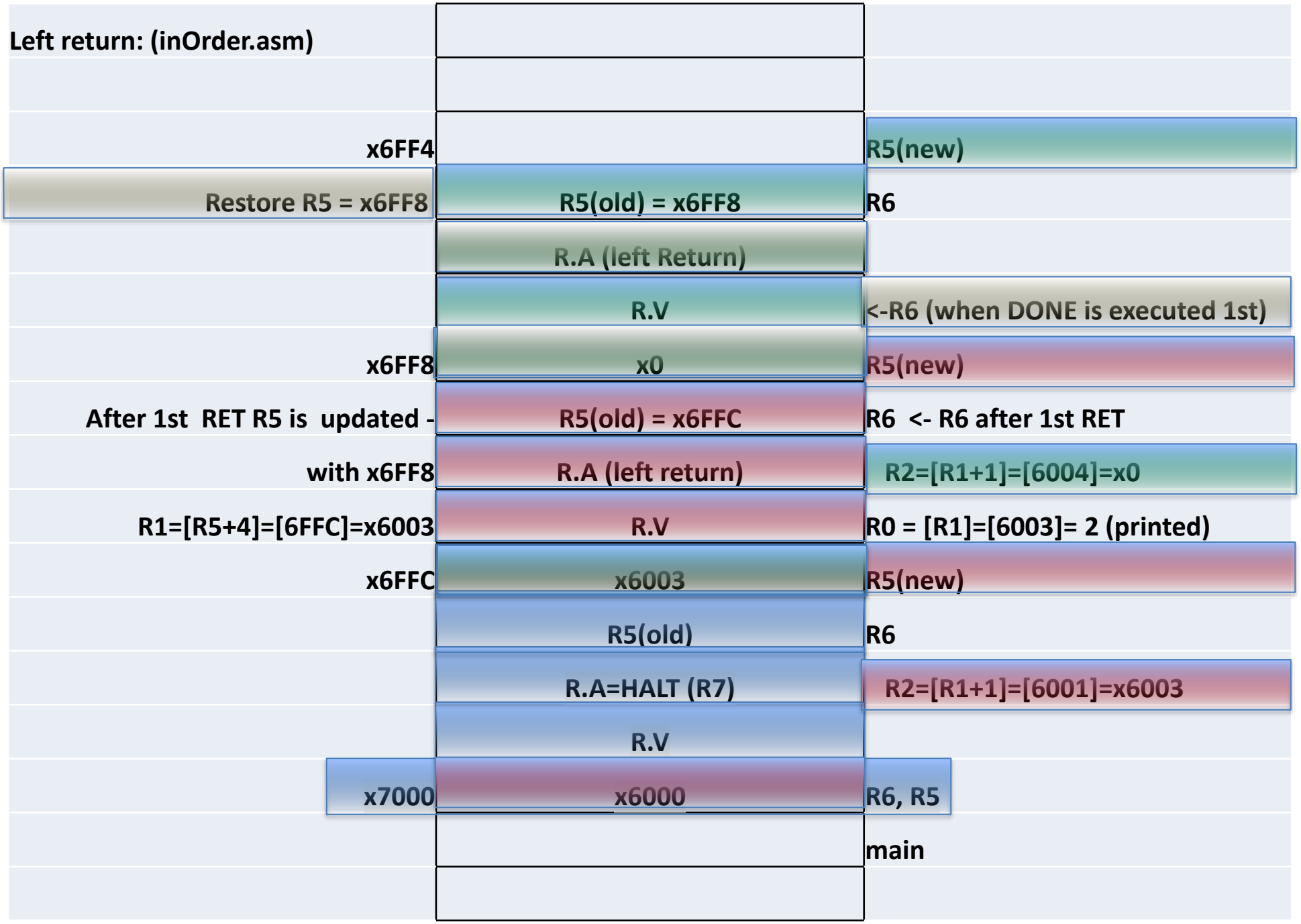

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

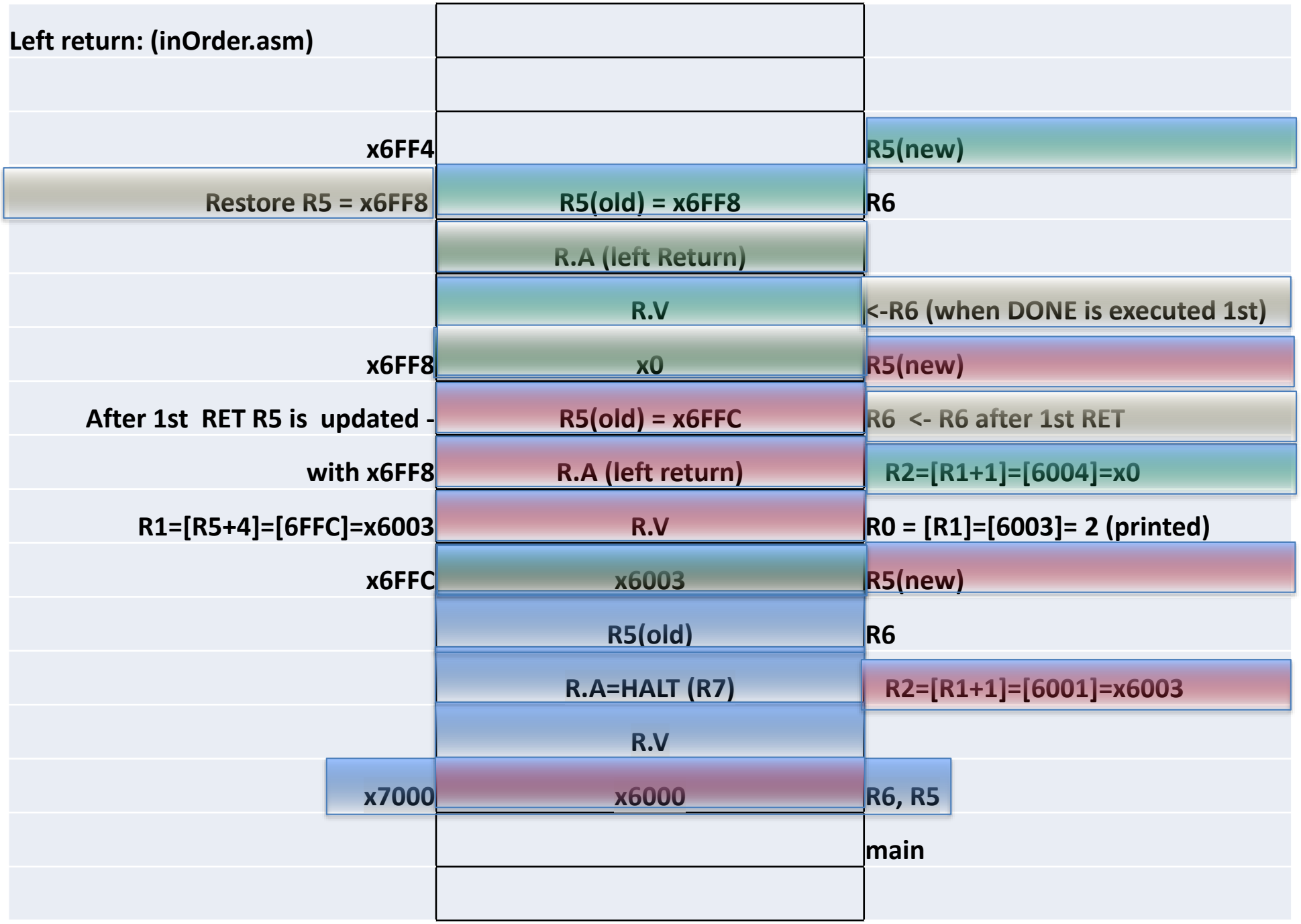

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

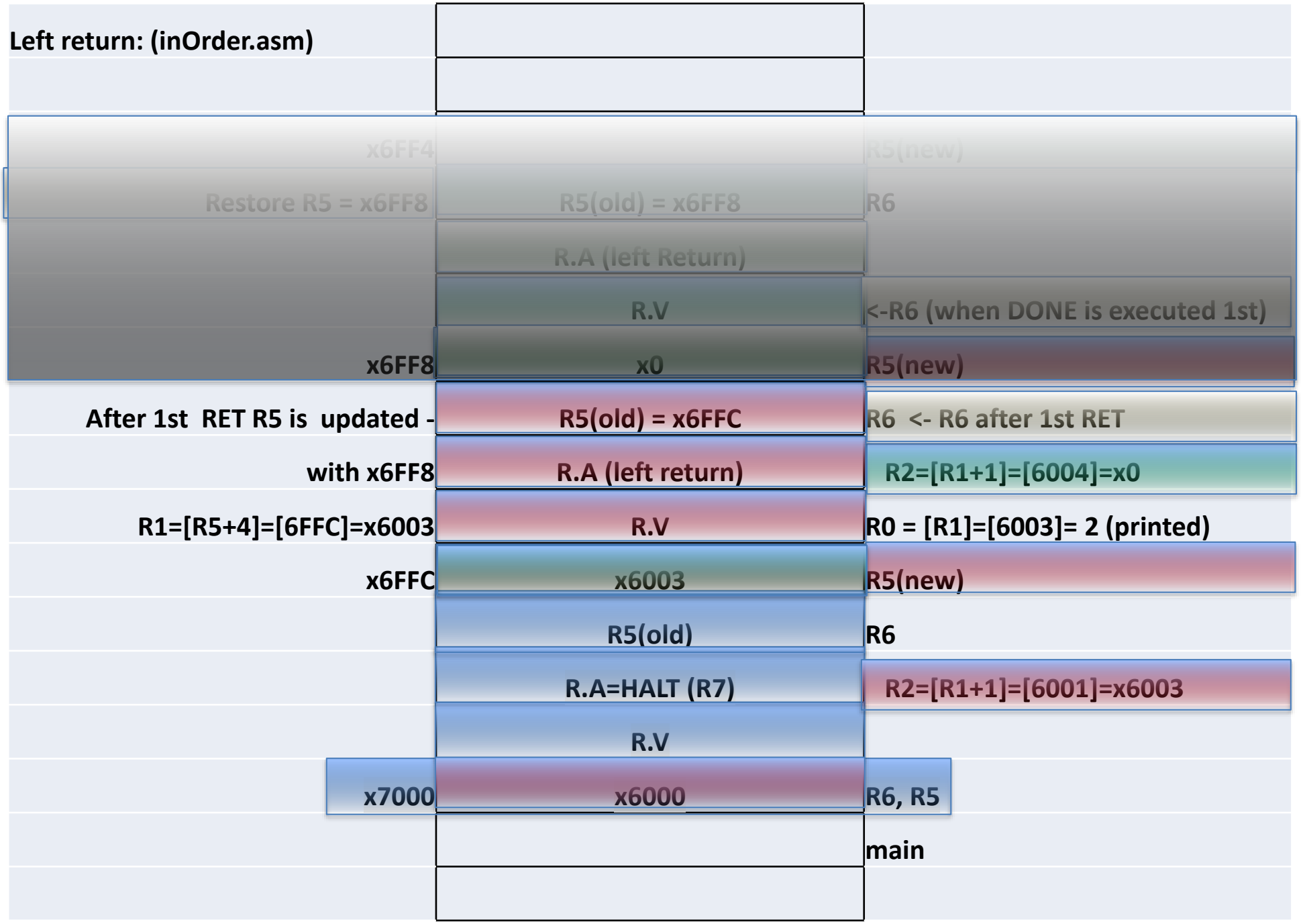

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

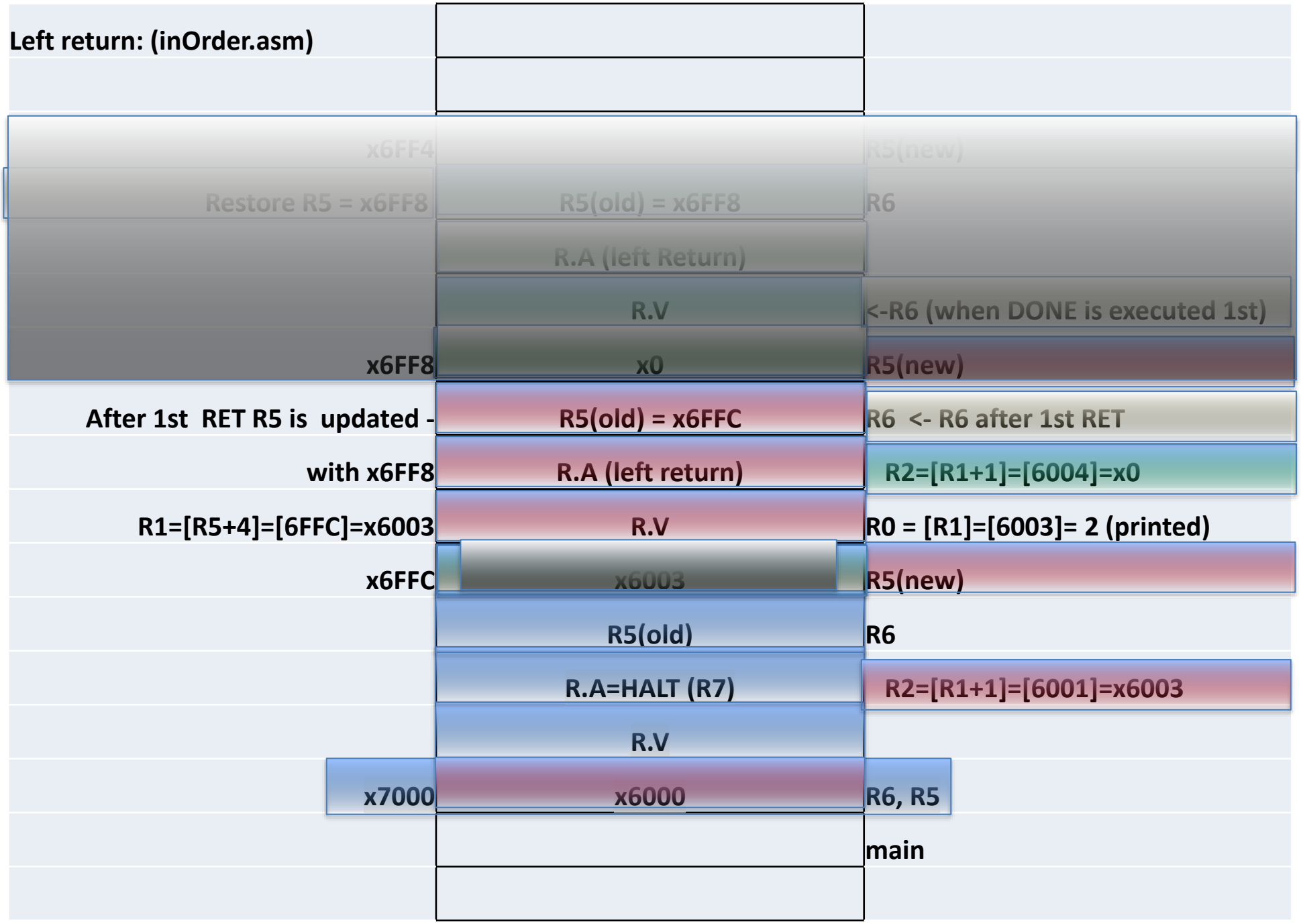

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

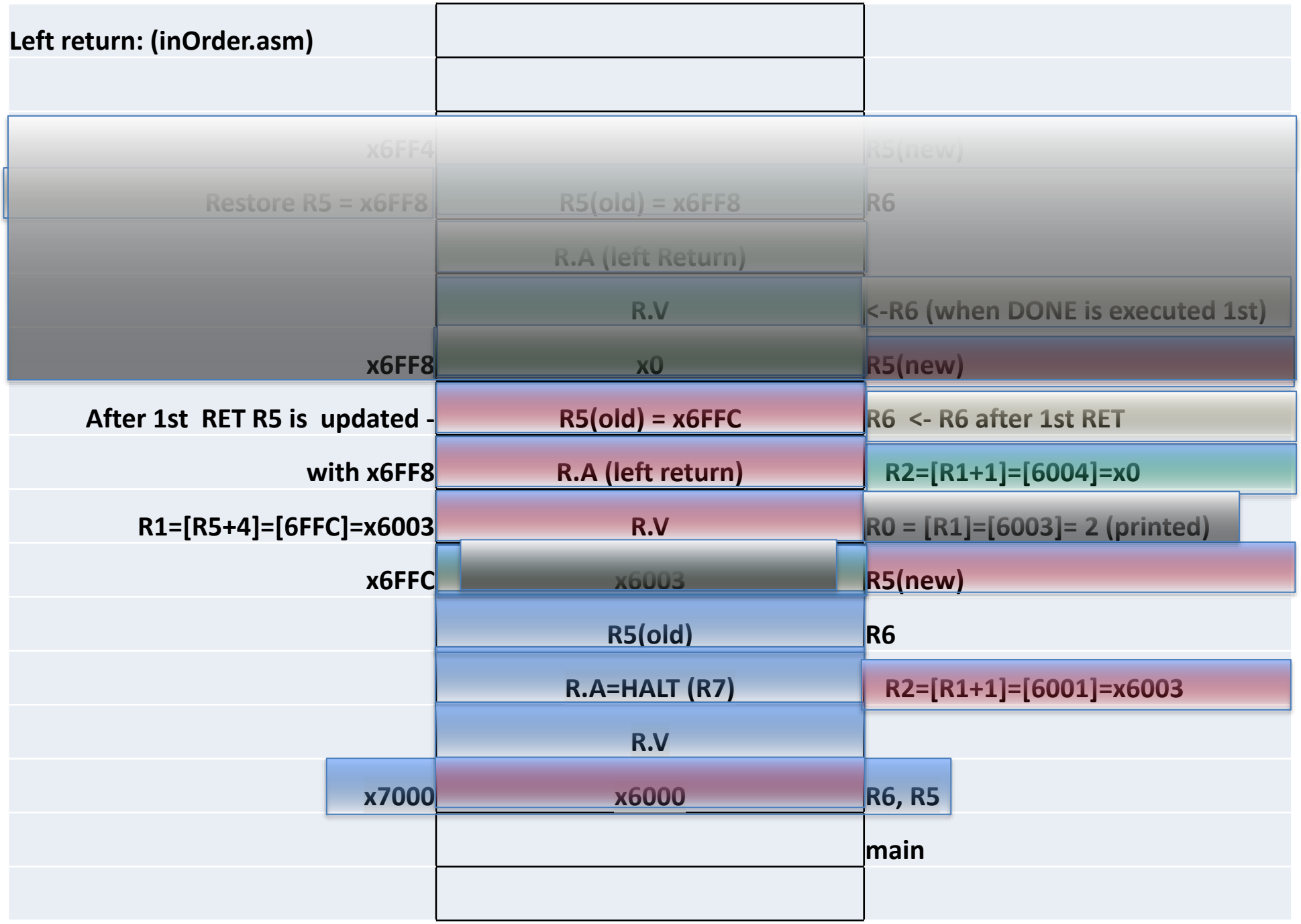

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

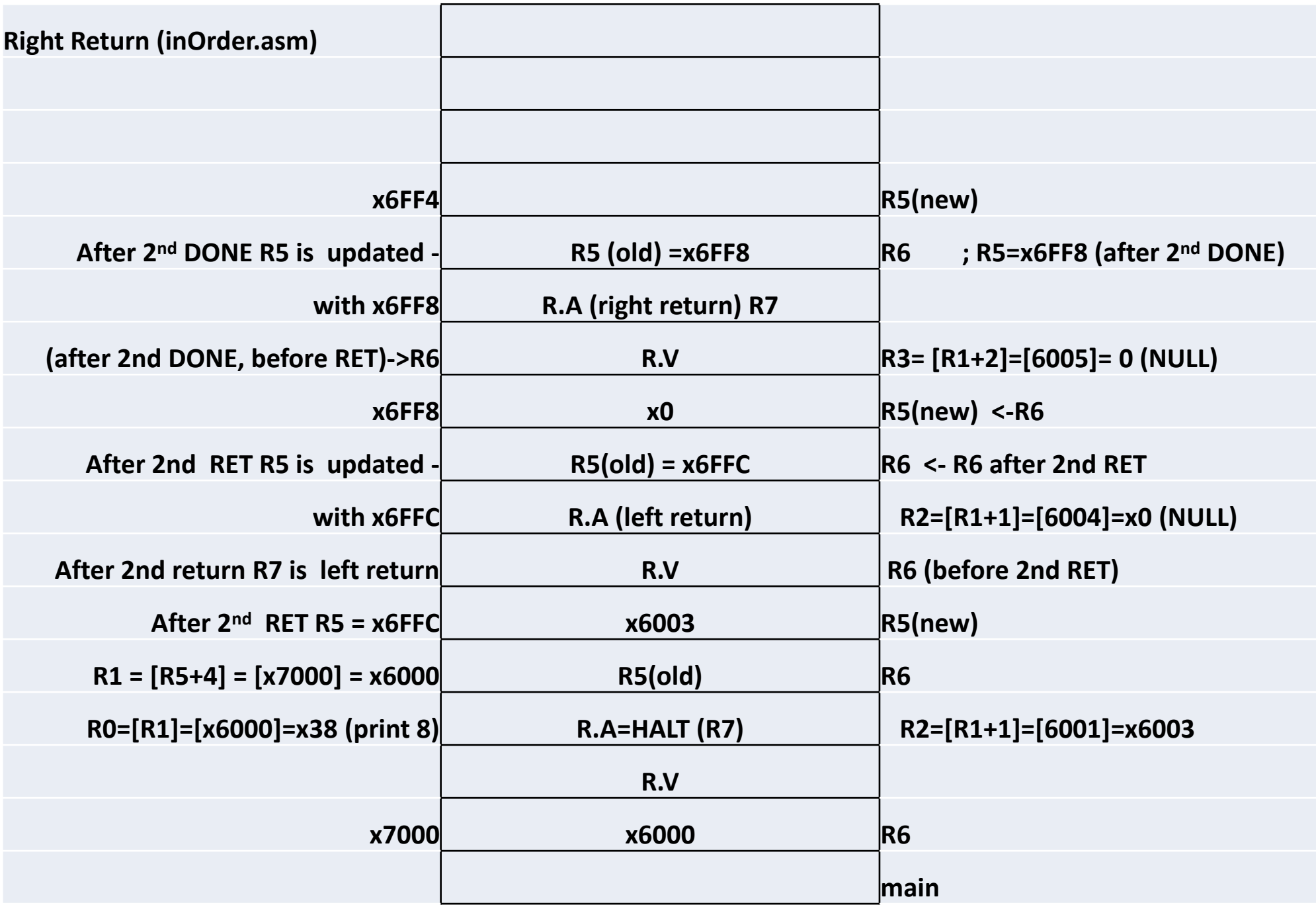

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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


Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
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, R5
main


Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
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, R5
main

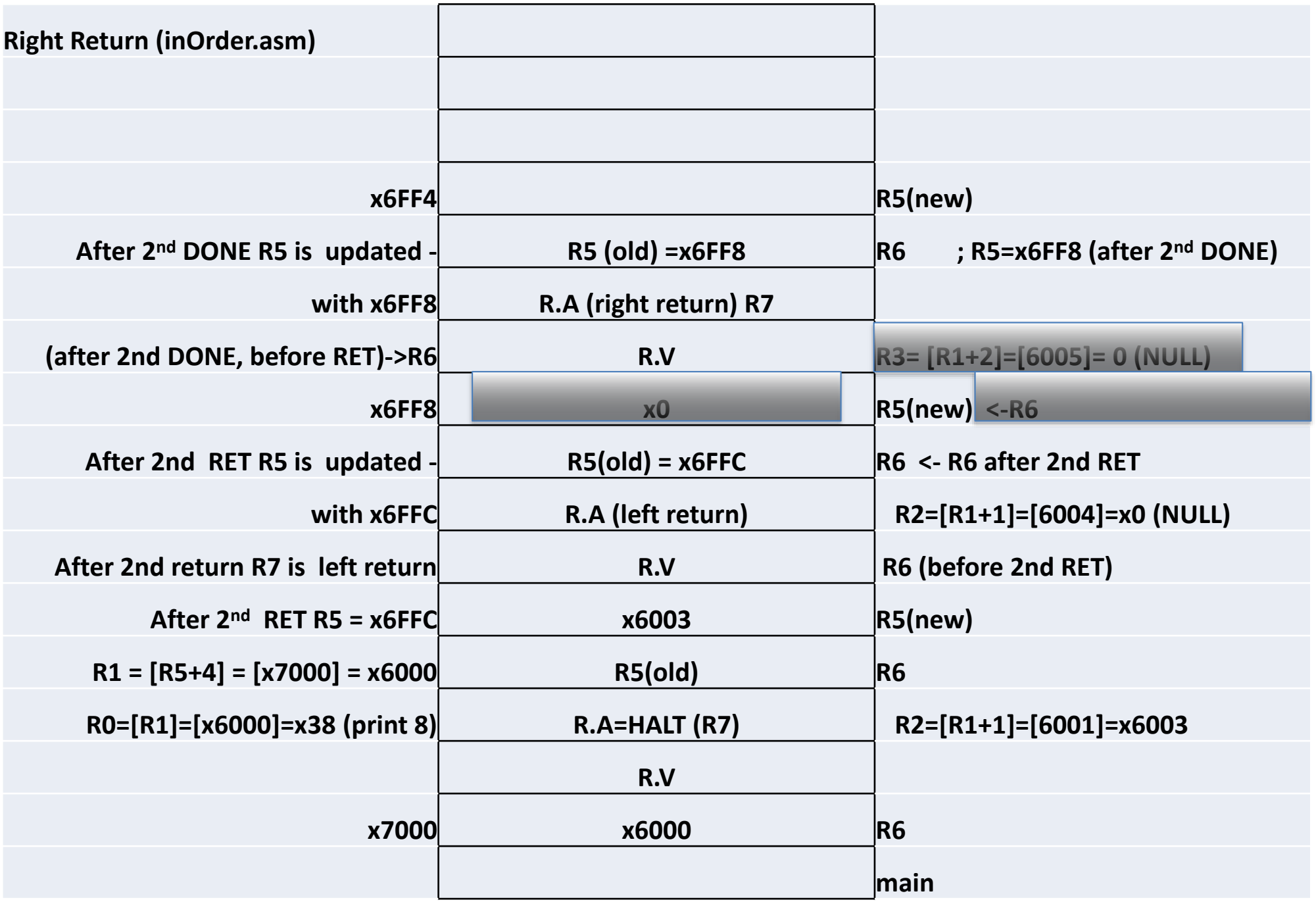

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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

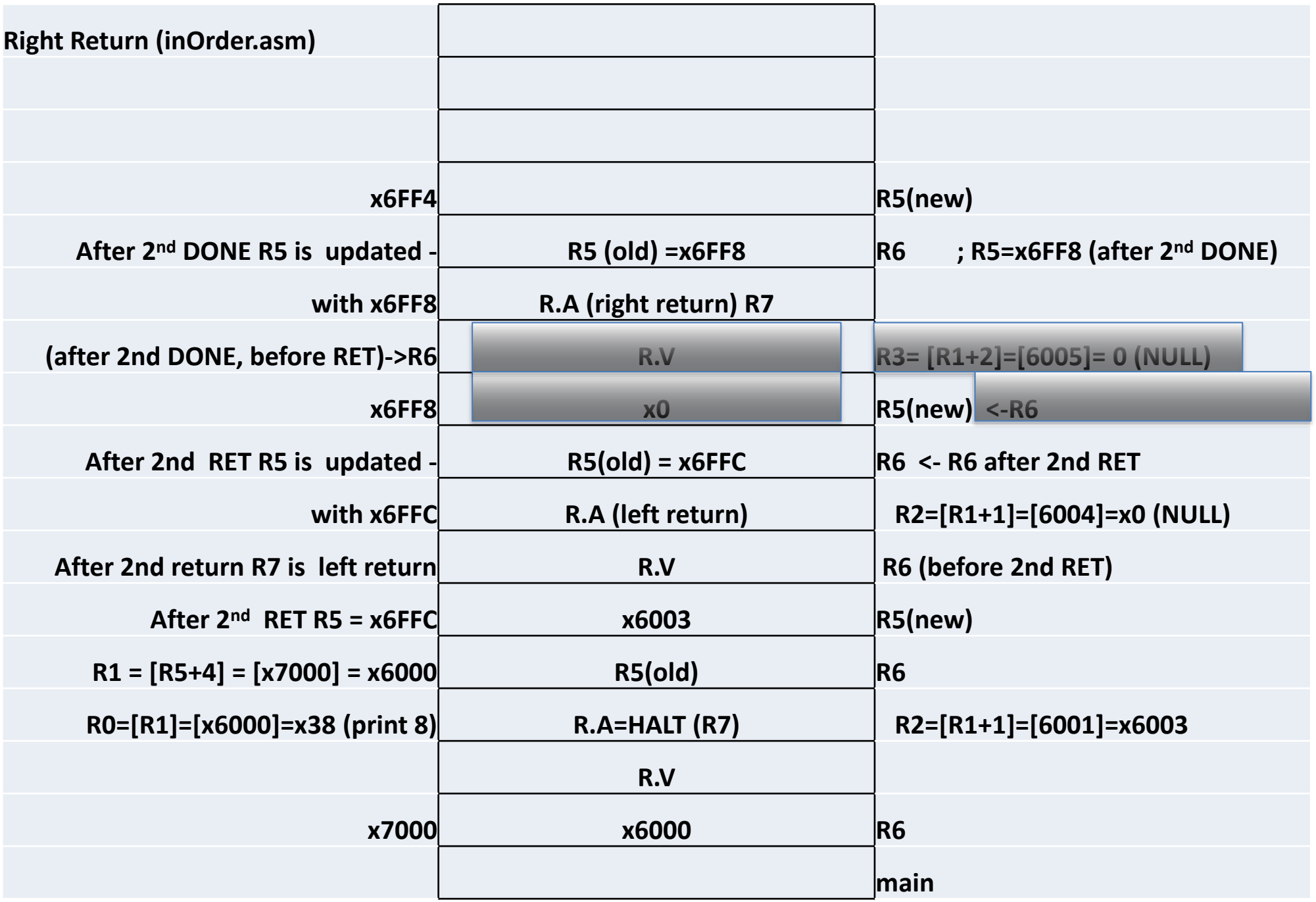

Left return: (inOrder.asm)
x6FF4
R5(new)
Restore R5 = x6FF8
R5(old) = x6FF8
R6
R.A (left Return)
R.V
<-R6 (when DONE is executed 1st)
x6FF8
x0
R5(new)
After 1st RET R5 is updated -
R5(old) = x6FFC
R6 <- R6 after 1st RET
with x6FF8
R.A (left return)
R2=[R1+1]=[6004]=x0
R1=[R5+4]=[6FFC]=x6003
R.V
R0 =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


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8
R.A (right return) R7
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 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
R6 (before 2nd RET)
After 2nd RET R5 = x6FFC
x6003
R5(new)
R1 = [R5+4] = [x7000] = x6000
R5(old)
R6
R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main

Right Return (inOrder.asm)		
x6FF4		R5(new)
After 2nd DONE R5 is updated -	R5 (old) =x6FF8	R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8	R.A (right return) R7	
(after 2nd DONE, before RET)->R6	R.V	R3= [R1+2]=[6005]= 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	R6 (before 2nd RET)
After 2nd RET R5 = x6FFC	x6003	R5(new)
R1 = [R5+4] = [x7000] = x6000	R5(old)	R6
R0=[R1]=[x6000]=x38 (print 8)	R.A=HALT (R7)	R2=[R1+1]=[6001]=x6003
	R.V	
x7000	x6000	R6
		main

Right Return (inOrder.asm)		
x6FF4		R5(new)
After 2nd DONE R5 is updated -	R5 (old) =x6FF8	R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8	R.A (right return) R7	
(after 2nd DONE, before RET)->R6	R.V	R3= [R1+2]=[6005]= 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	R6 (before 2nd RET)
After 2nd RET R5 = x6FFC	x6003	R5(new)
R1 = [R5+4] = [x7000] = x6000	R5(old)	R6
R0=[R1]=[x6000]=x38 (print 8)	R.A=HALT (R7)	R2=[R1+1]=[6001]=x6003
	R.V	
x7000	x6000	R6
		main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8
R.A (right return) R7
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 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
R6 (before 2nd RET)
After 2nd RET R5 = x6FFC
x6003
R5(new)
R1 = [R5+4] = [x7000] = x6000
R5(old)
R6
R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8
R.A (right return) R7
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 0 (NULL)
x6FF8
x0
R5(new)
<-R6
After 2nd RET R5 is updated -
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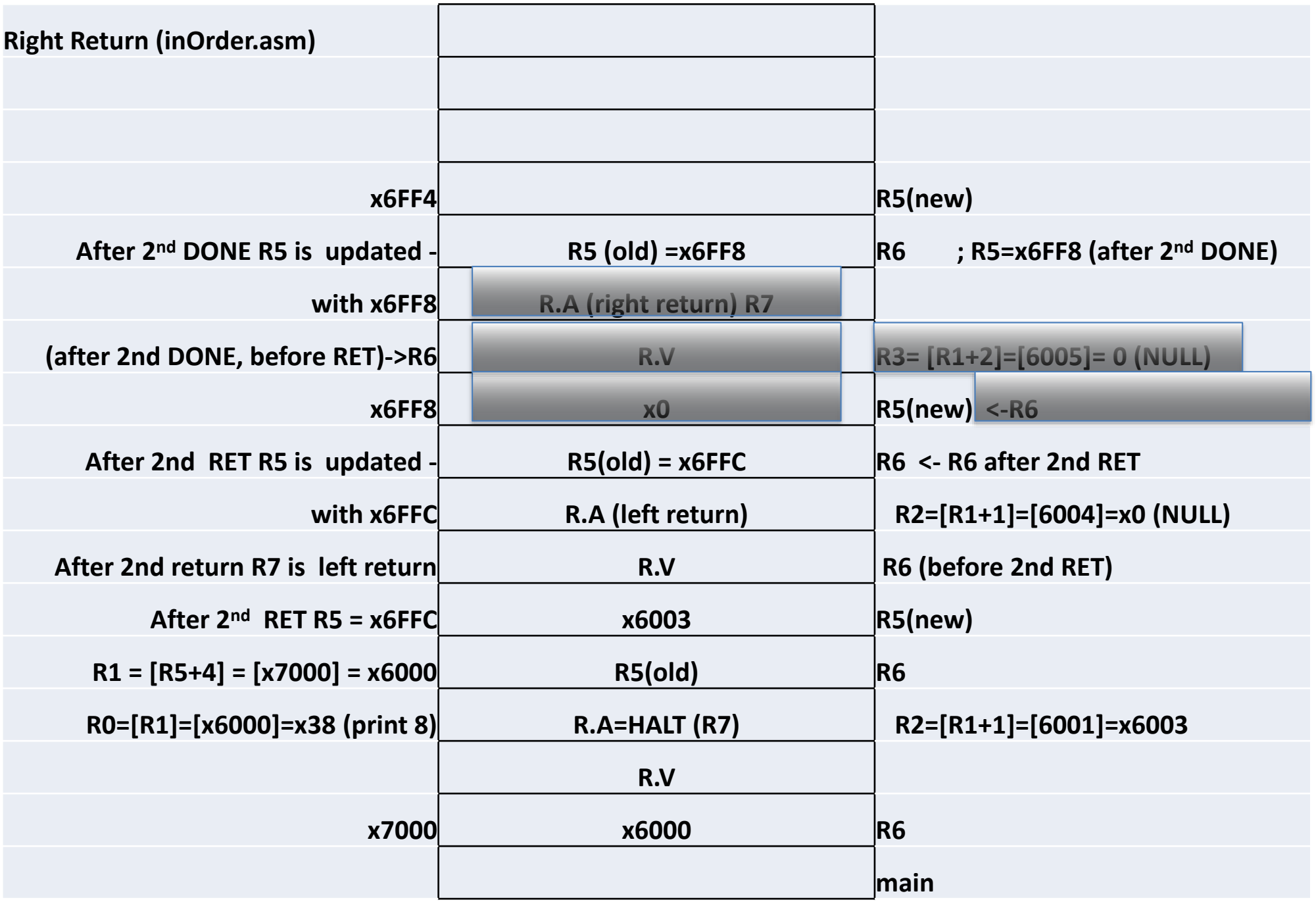
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8
R.A (right return) R7
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 0 (NULL)
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R5(new)
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After 2nd RET R5 is updated -
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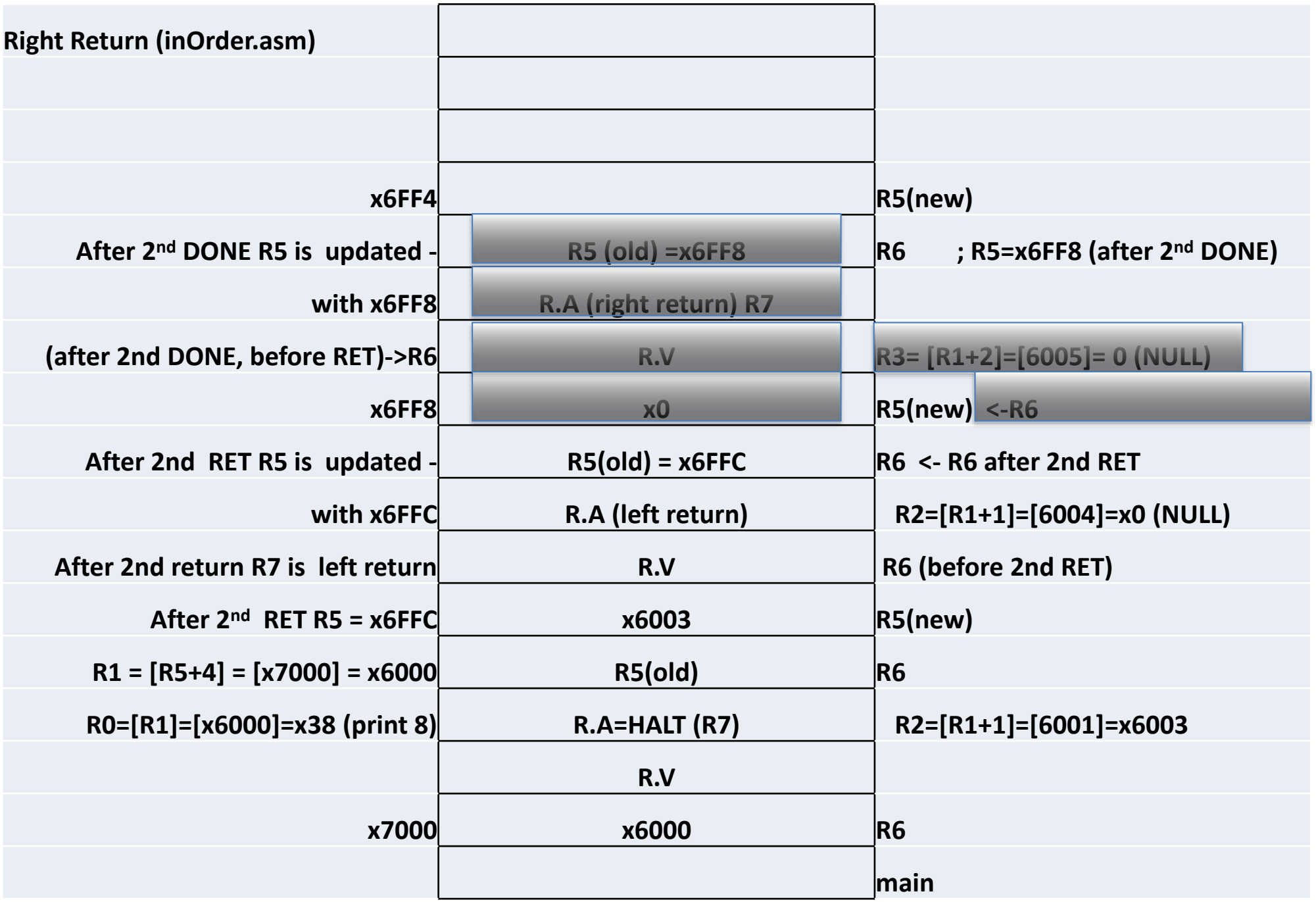
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6 ; R5=x6FF8 (after 2nd DONE)
with x6FF8
R.A (right return) R7
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 0 (NULL)
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R5(new) <-R6
After 2nd RET R5 is updated -
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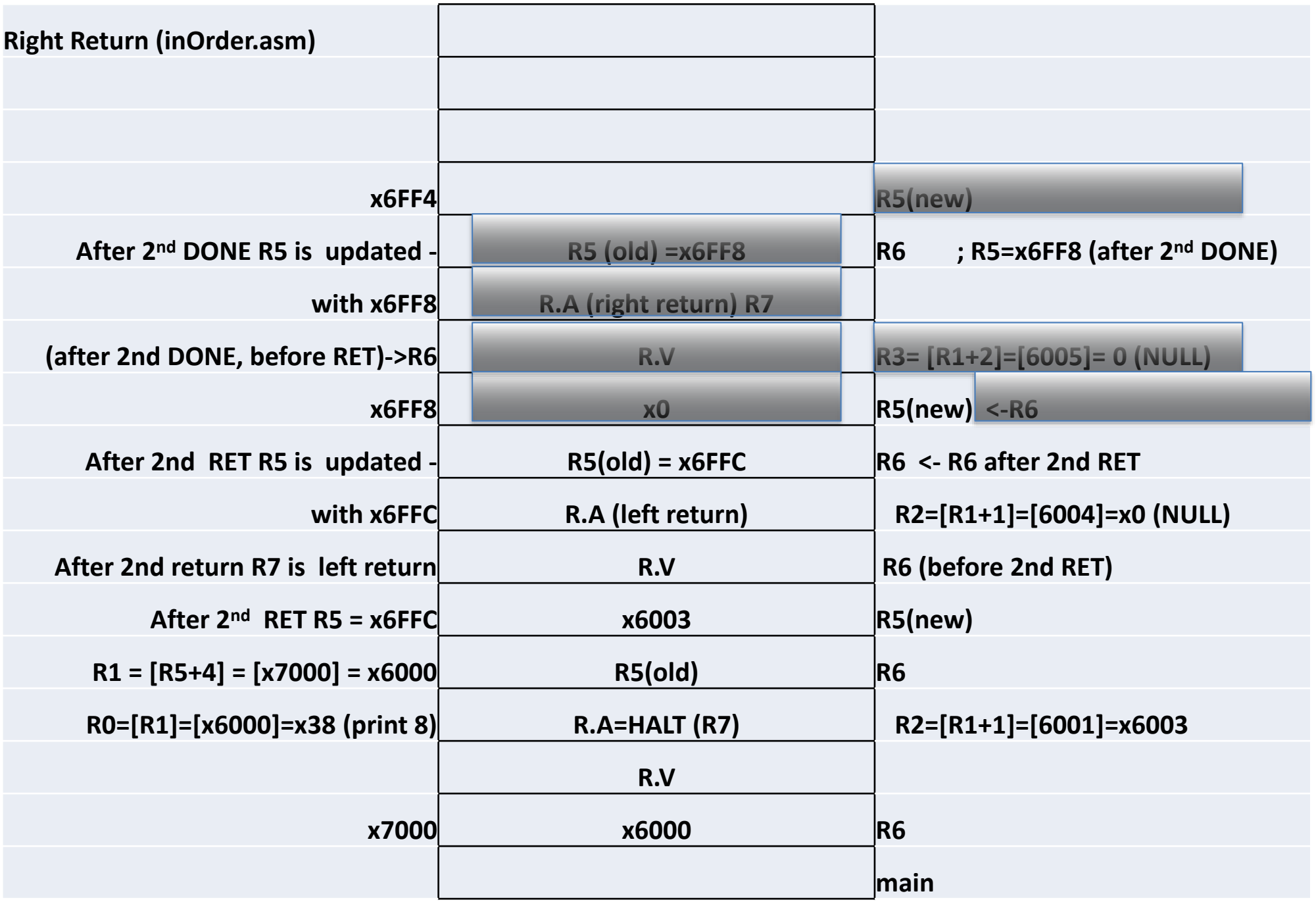
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
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R5 (old) =x6FF8
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R5(new) <-R6
After 2nd RET R5 is updated -
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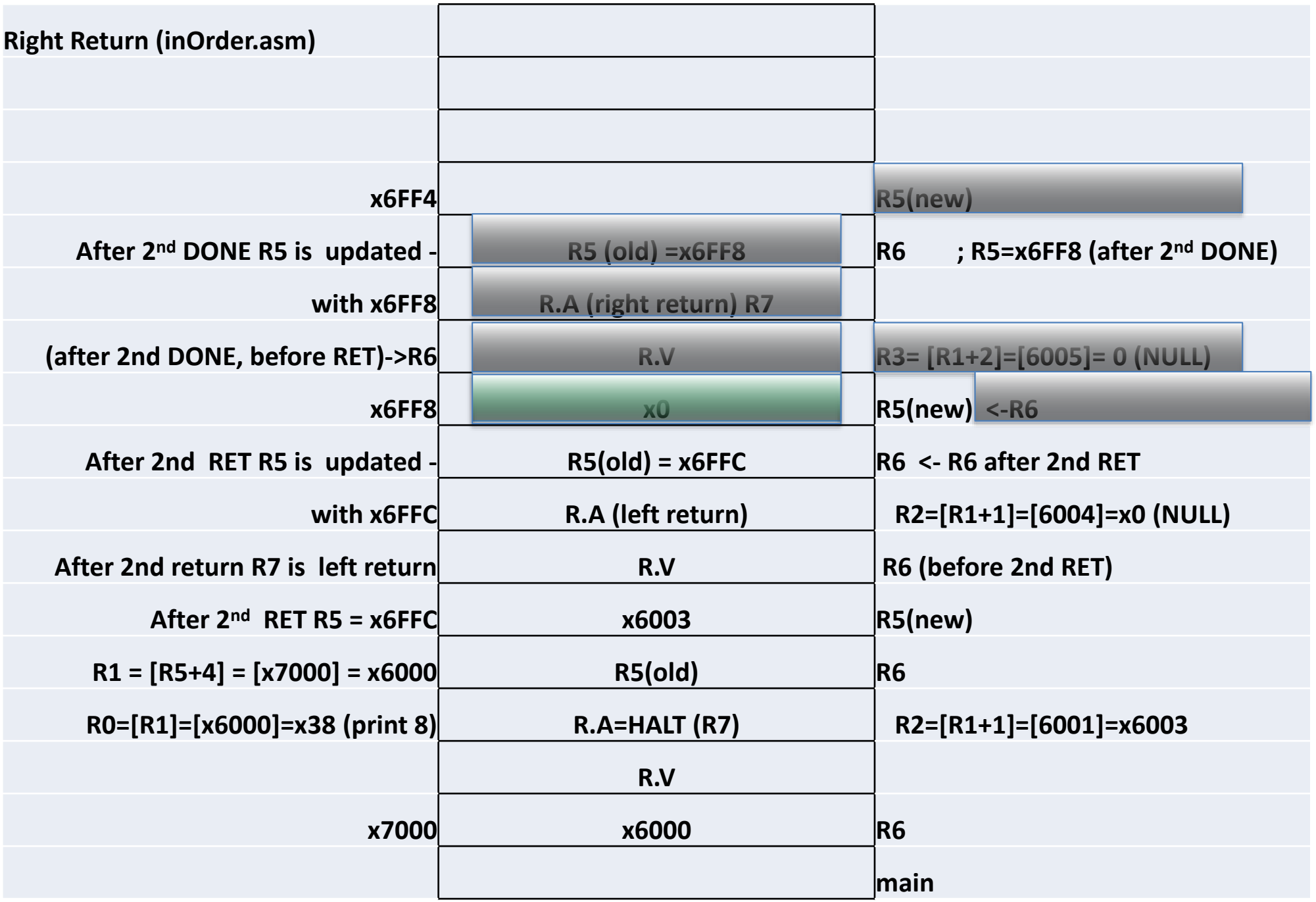
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
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R.V
R3= [R1+2]=[6005]= 0 (NULL)
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R5(new) <-R6
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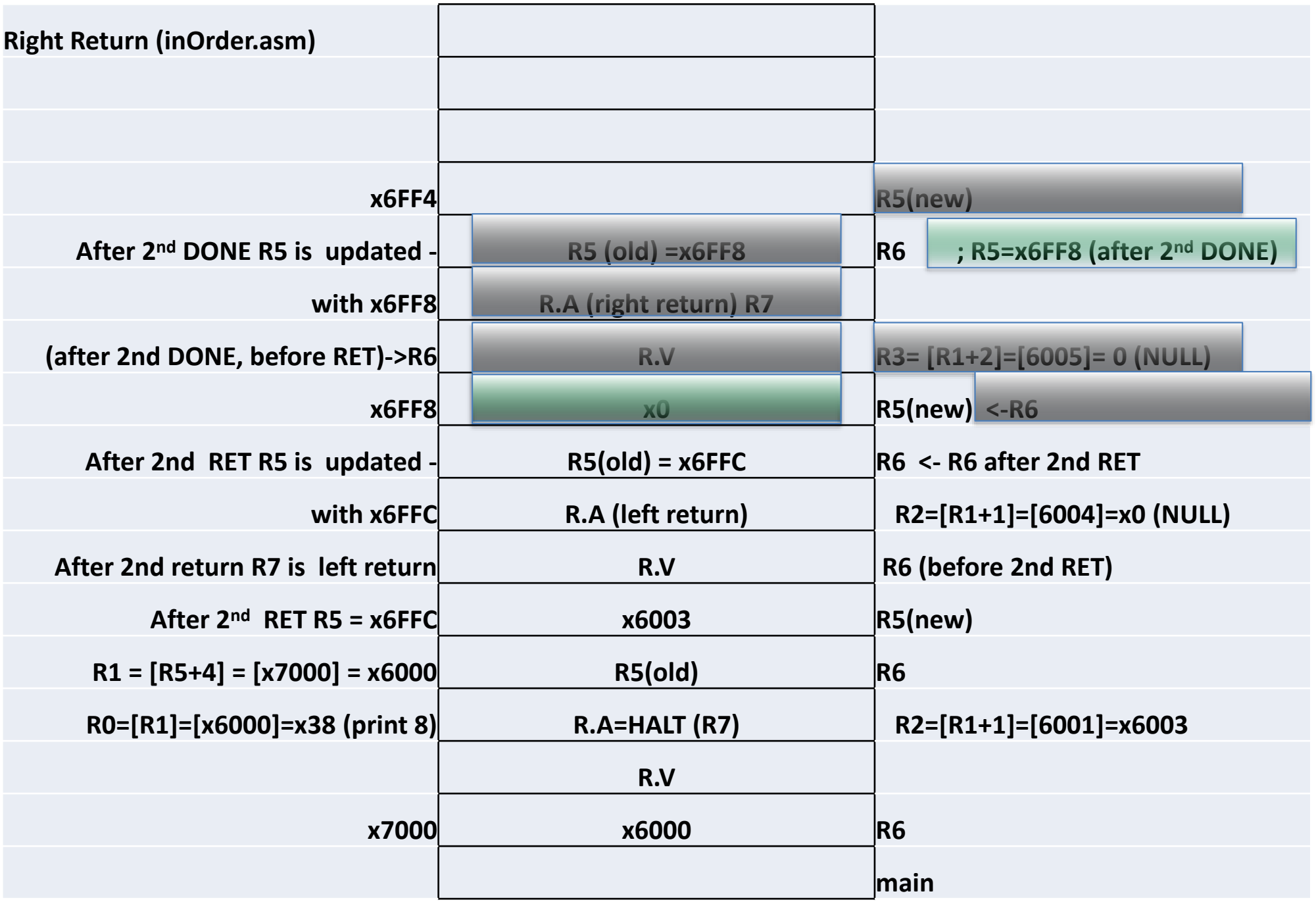
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
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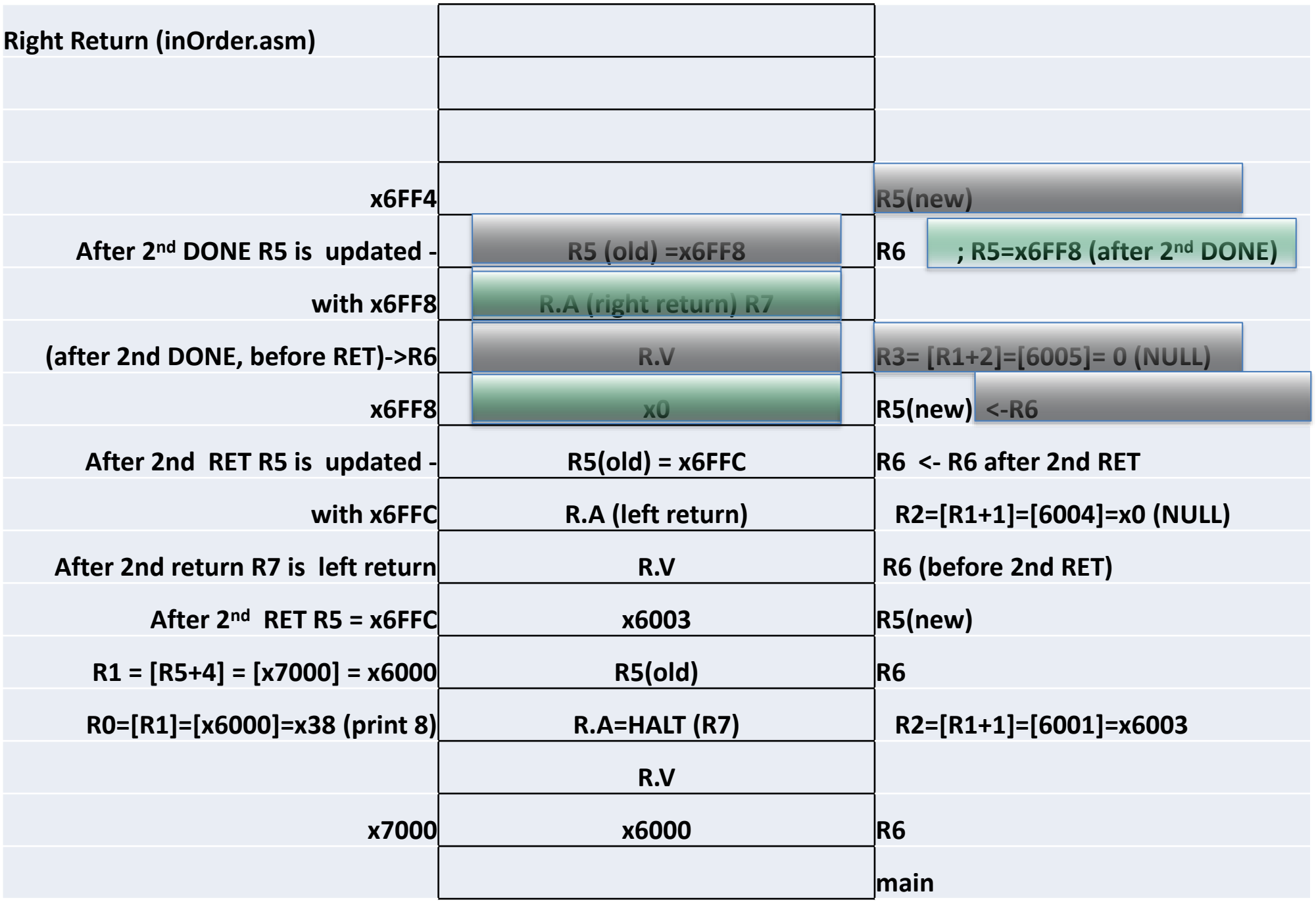
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
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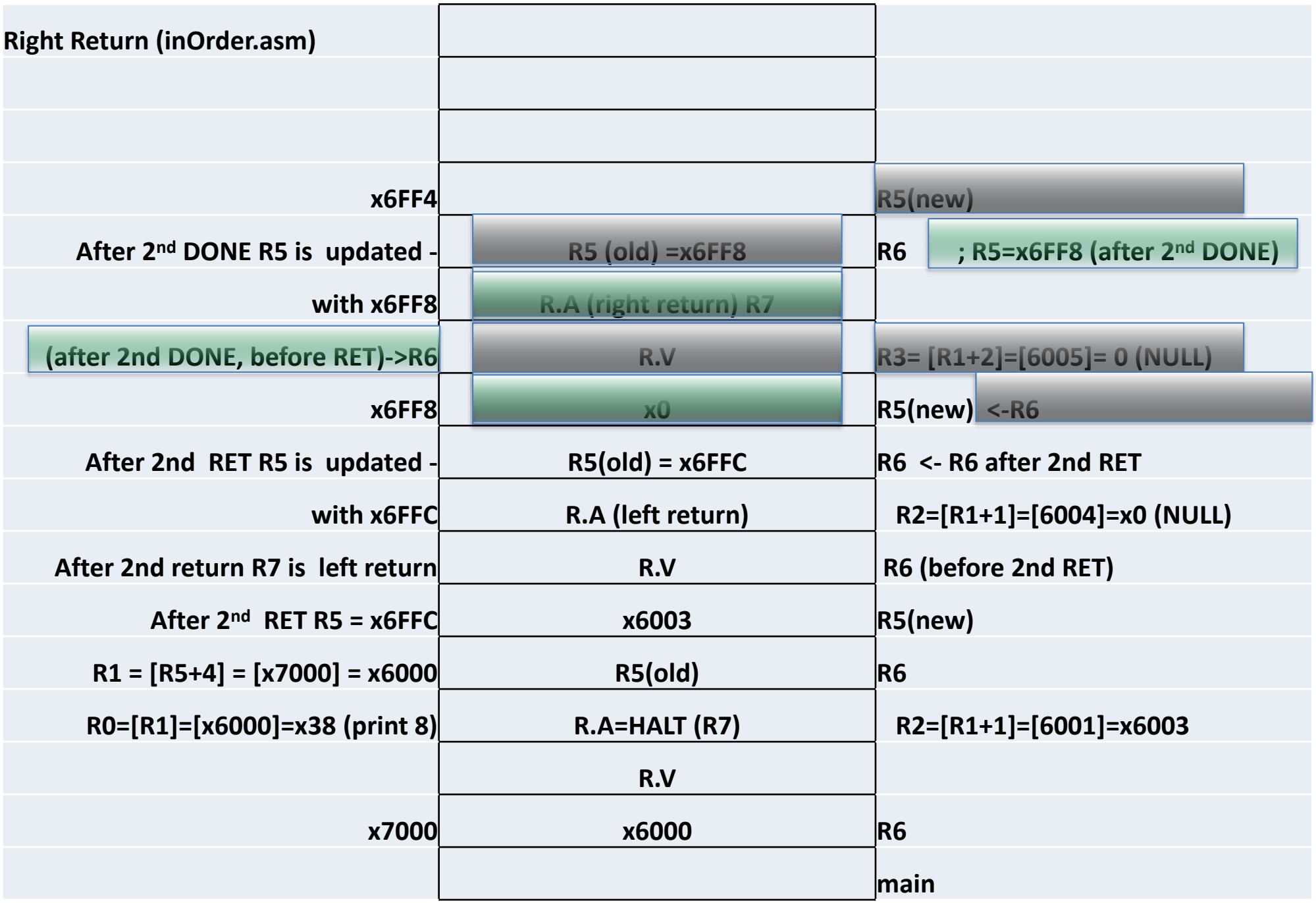
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
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R3= [R1+2]=[6005]= 0 (NULL)
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R5(new)
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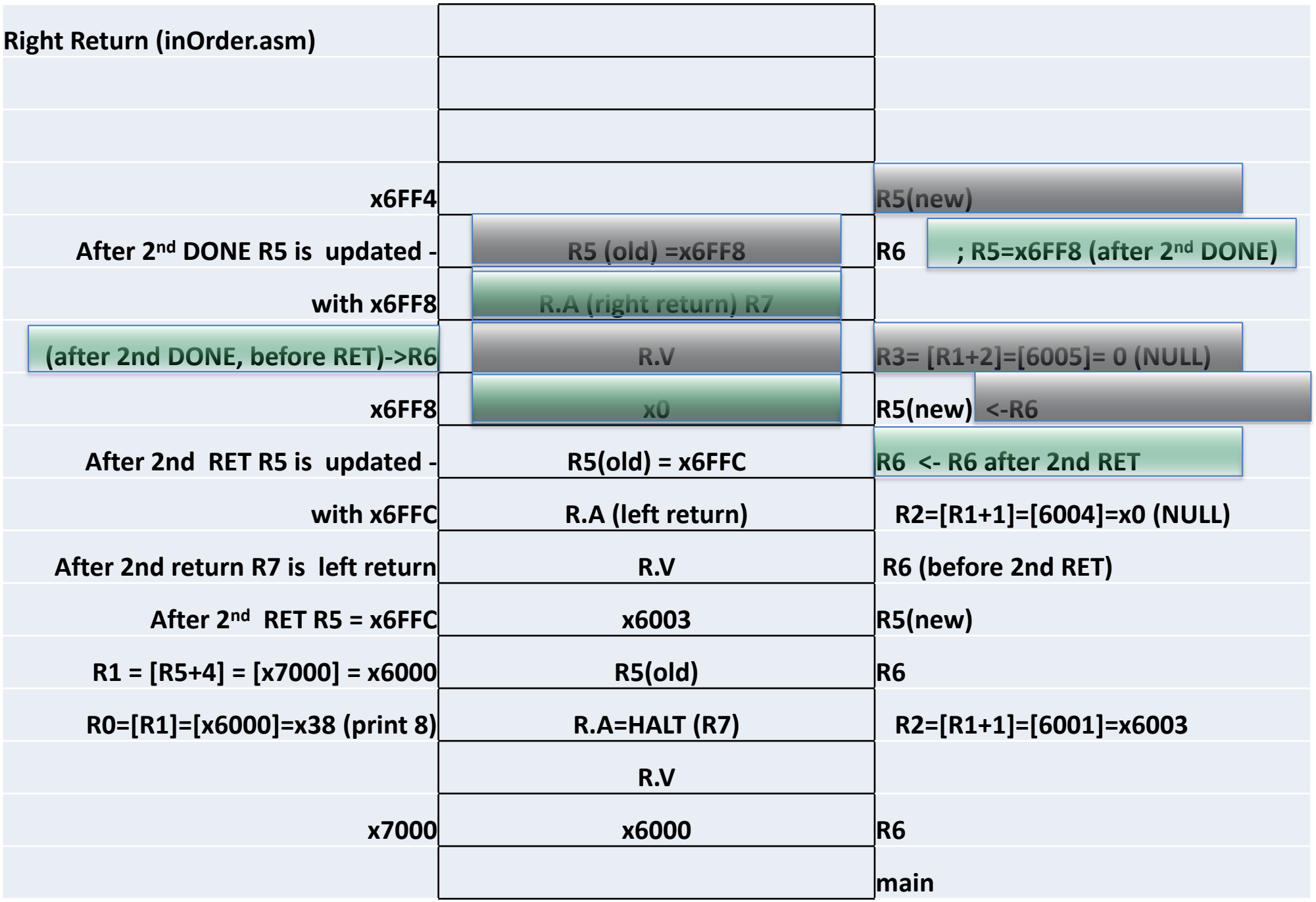
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
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R.A (right return) R7
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R.V
R3= [R1+2]=[6005]= 0 (NULL)
x6FF8
x0
R5(new)
<-R6
After 2nd RET R5 is updated -
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R6 <- R6 after 2nd RET
with x6FFC
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R2=[R1+1]=[6004]=x0 (NULL)
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R1 = [R5+4] = [x7000] = x6000
R5(old)
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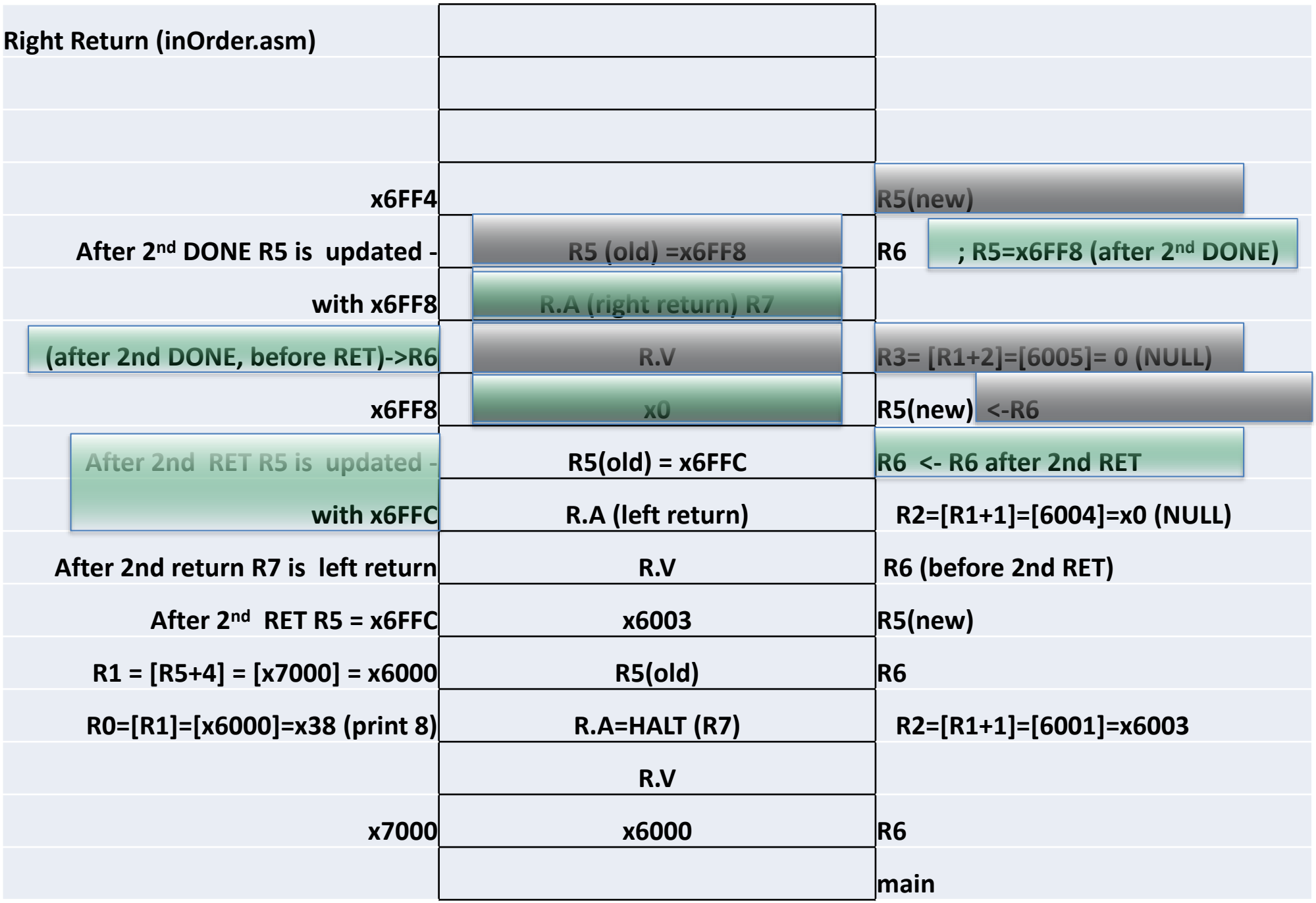
R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
R6
; R5=x6FF8 (after 2nd DONE)
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R.A (right return) R7
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R3= [R1+2]=[6005]= 0 (NULL)
x6FF8
x0
R5(new)
<-R6
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R5(old) = x6FFC
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R6 (before 2nd RET)
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R5(new)
R1 = [R5+4] = [x7000] = x6000
R5(old)
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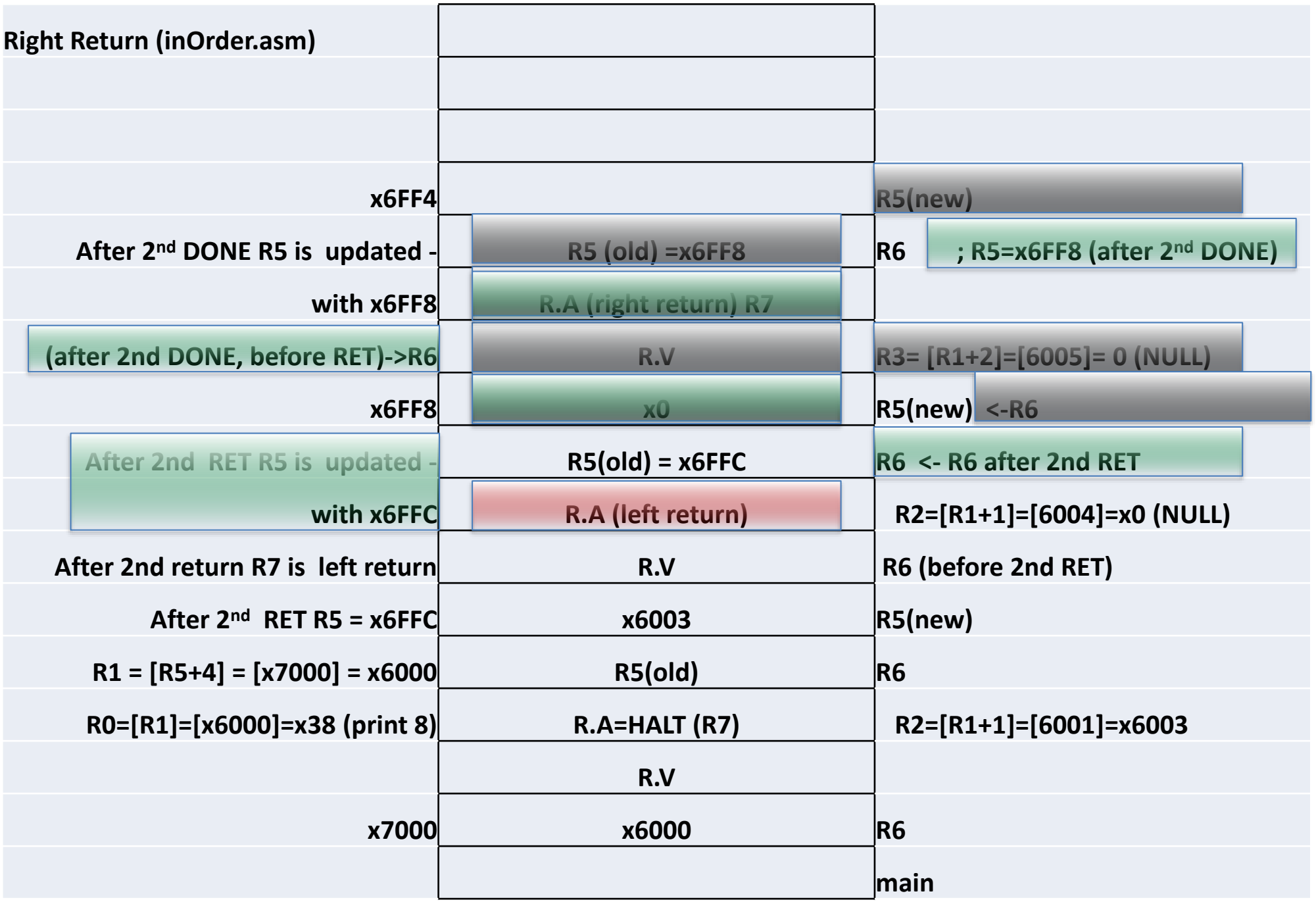
R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
R5 (old) =x6FF8
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R5(new)
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R.A=HALT (R7)
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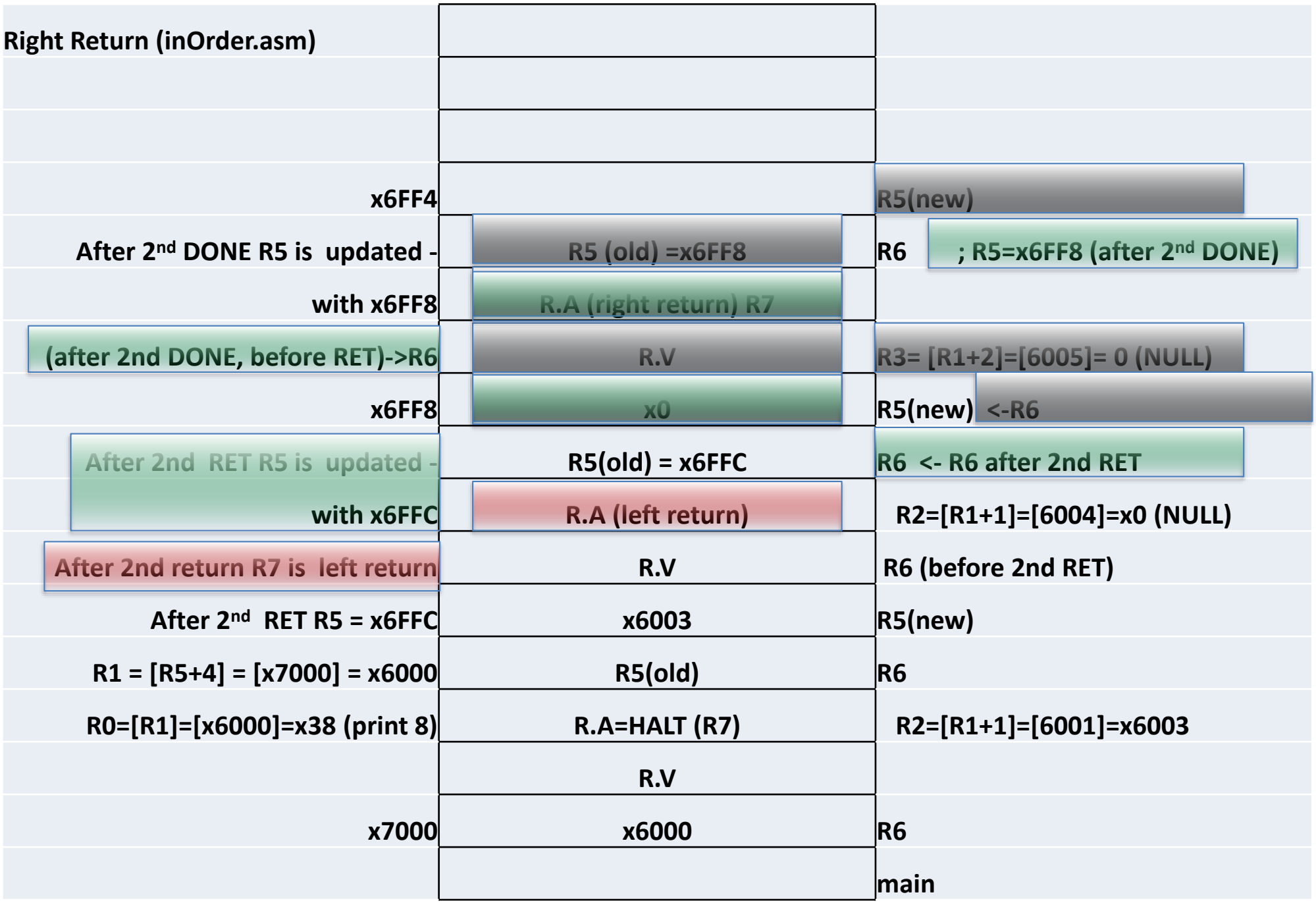
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
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with x6FF8
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R6
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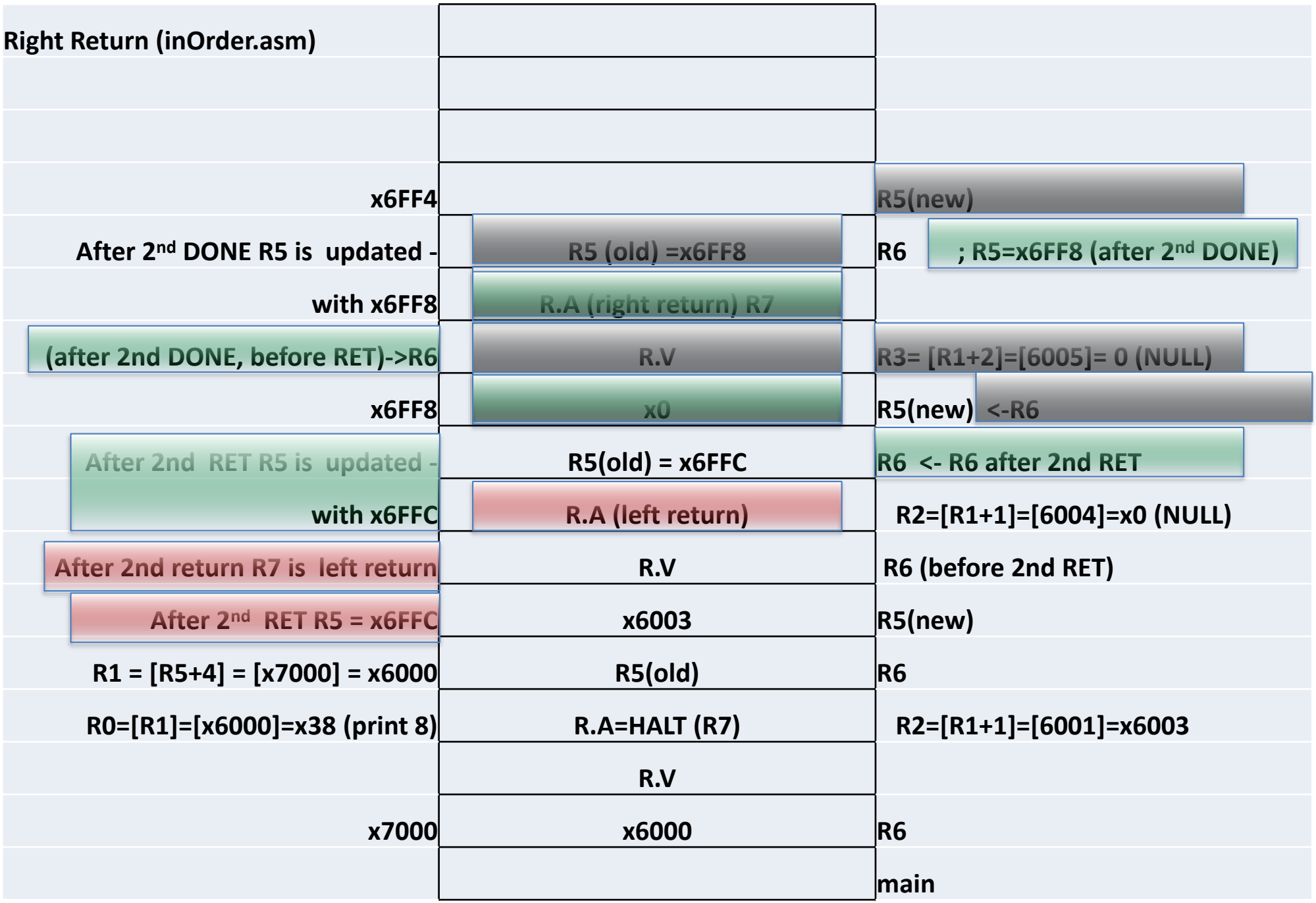
Right Return (inOrder.asm)
x6FF4
R5(new)
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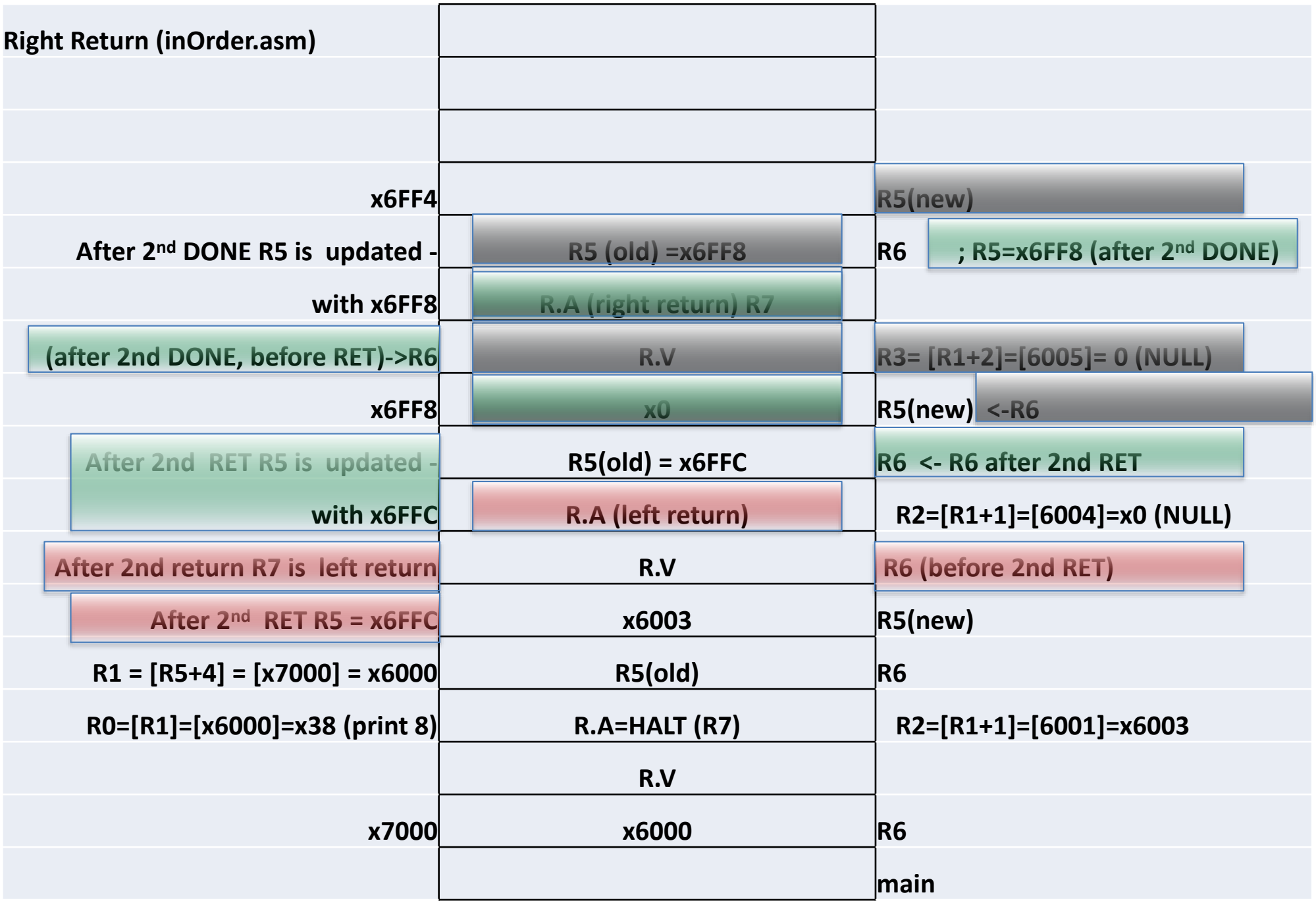
R.V
x7000
x6000
R6
main


Right Return (inOrder.asm)
x6FF4
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R6
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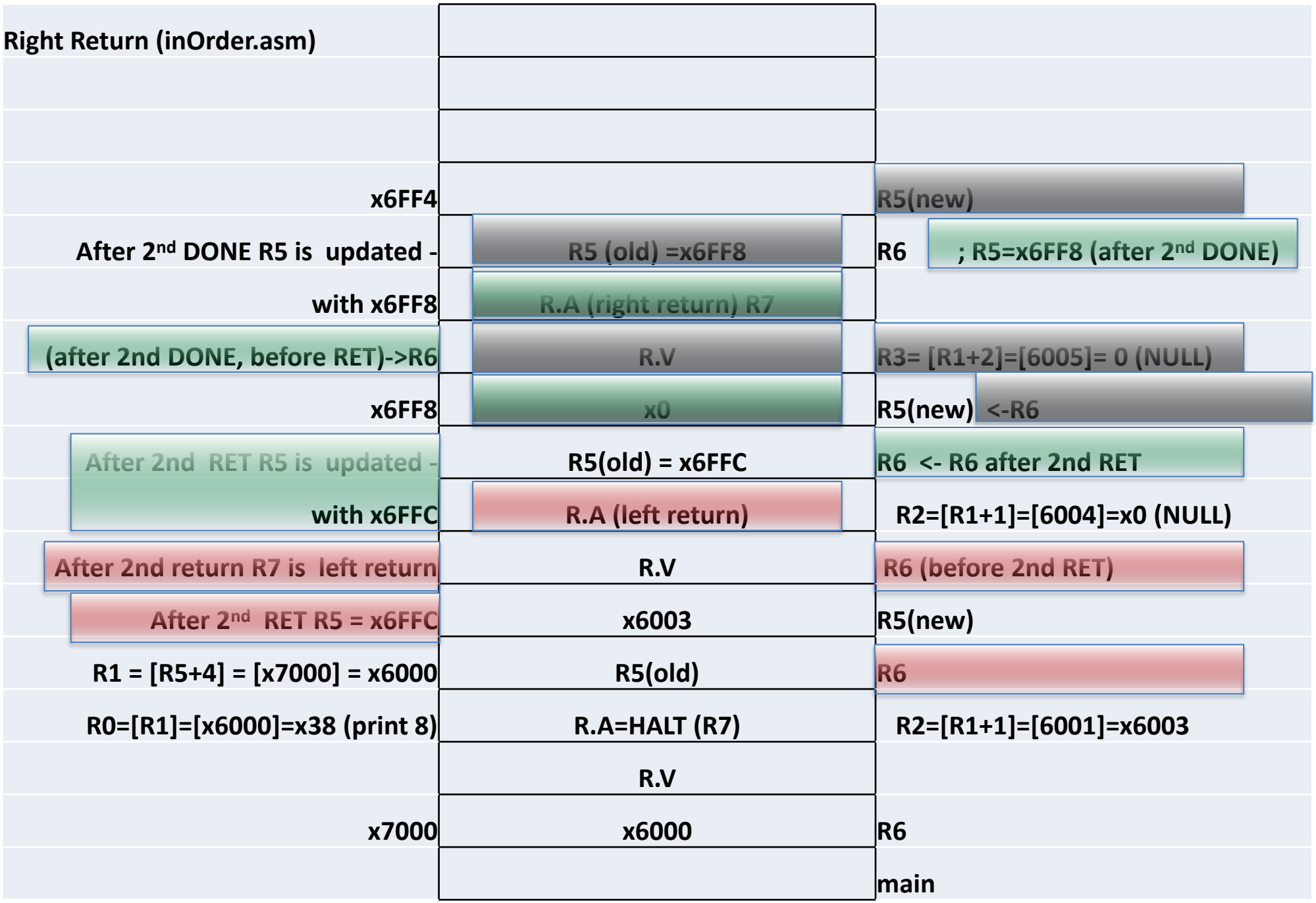
Right Return (inOrder.asm)
x6FF4
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x7000
x6000
R6
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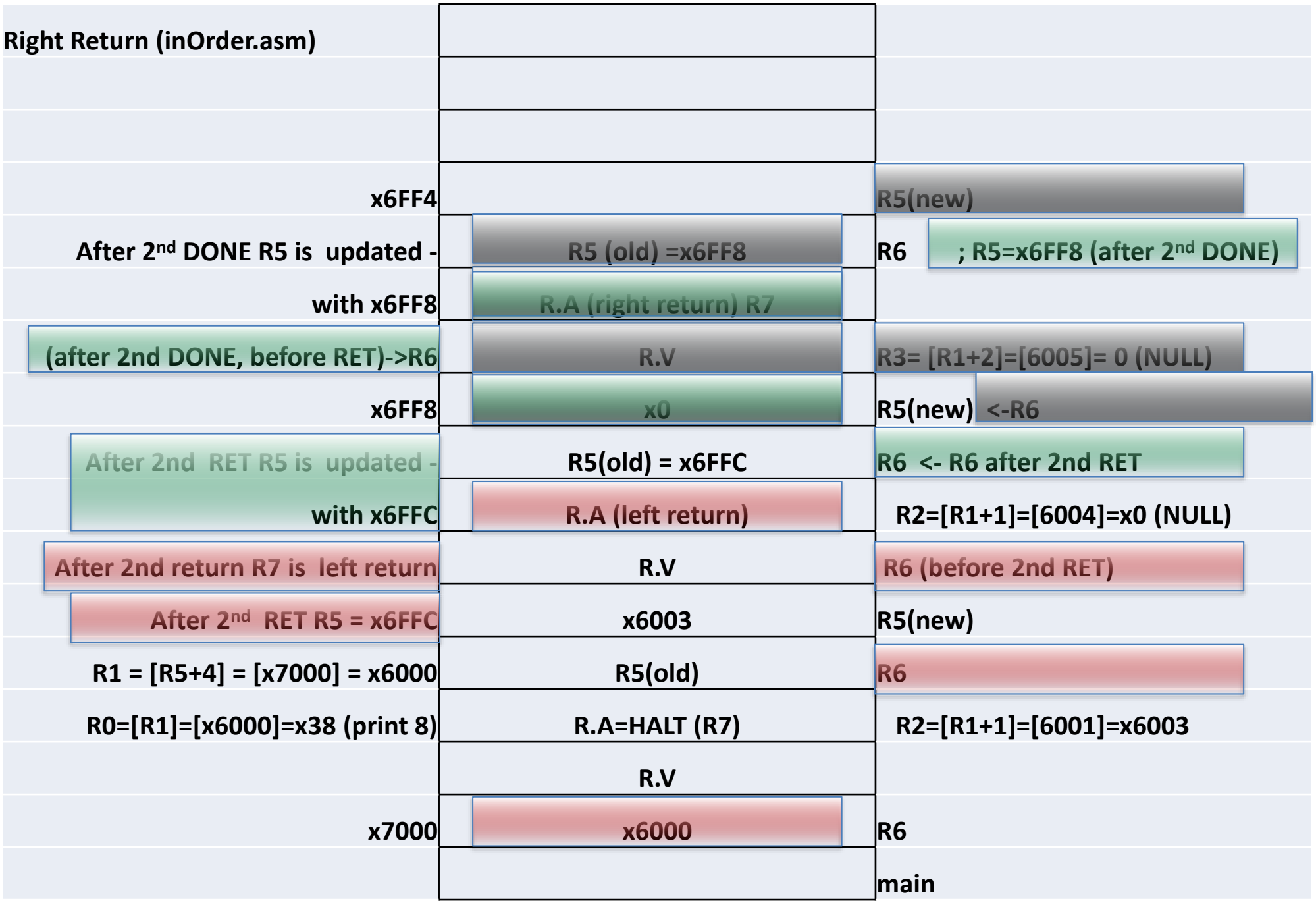
Right Return (inOrder.asm)
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R5(new)
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R5(new)
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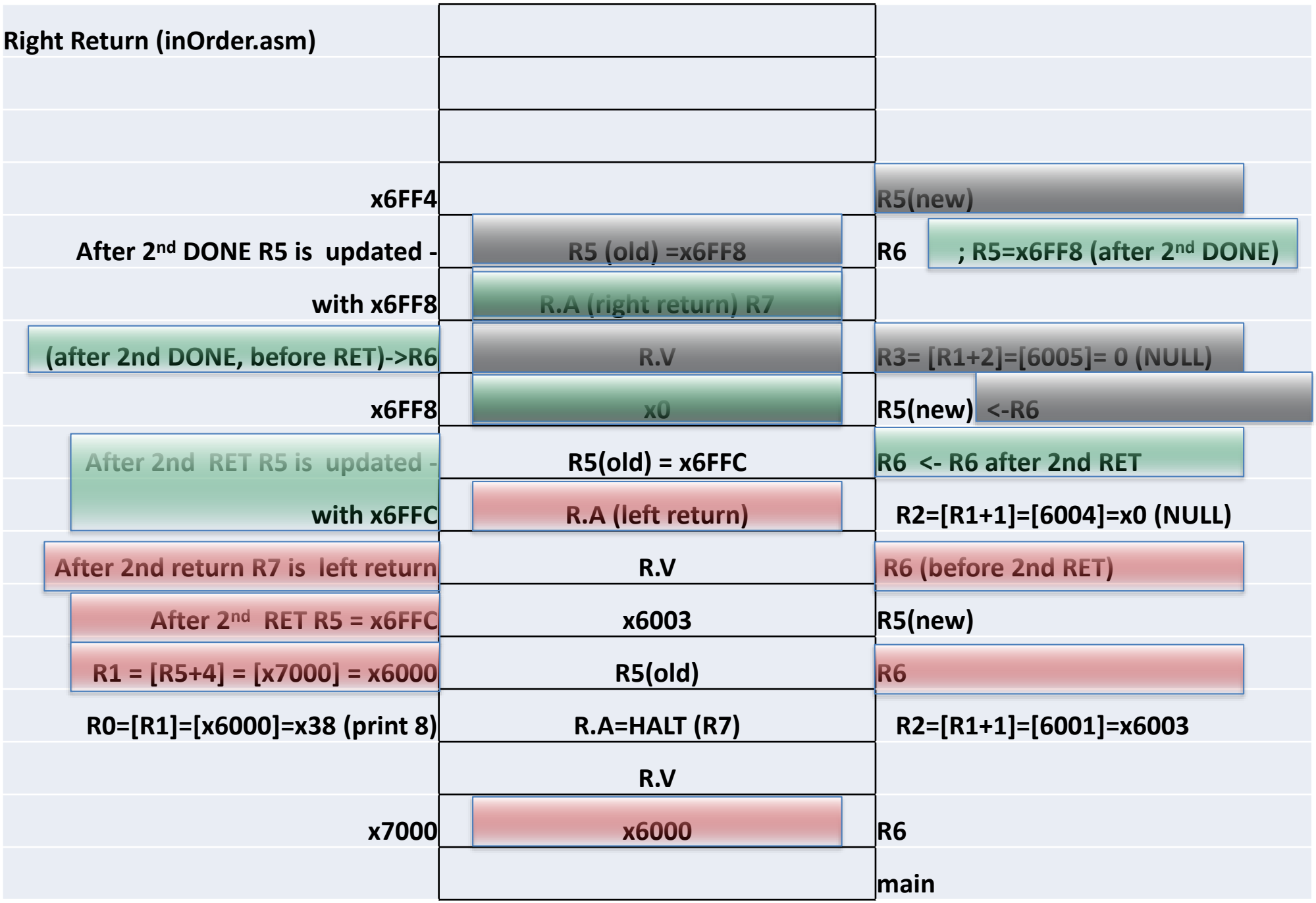
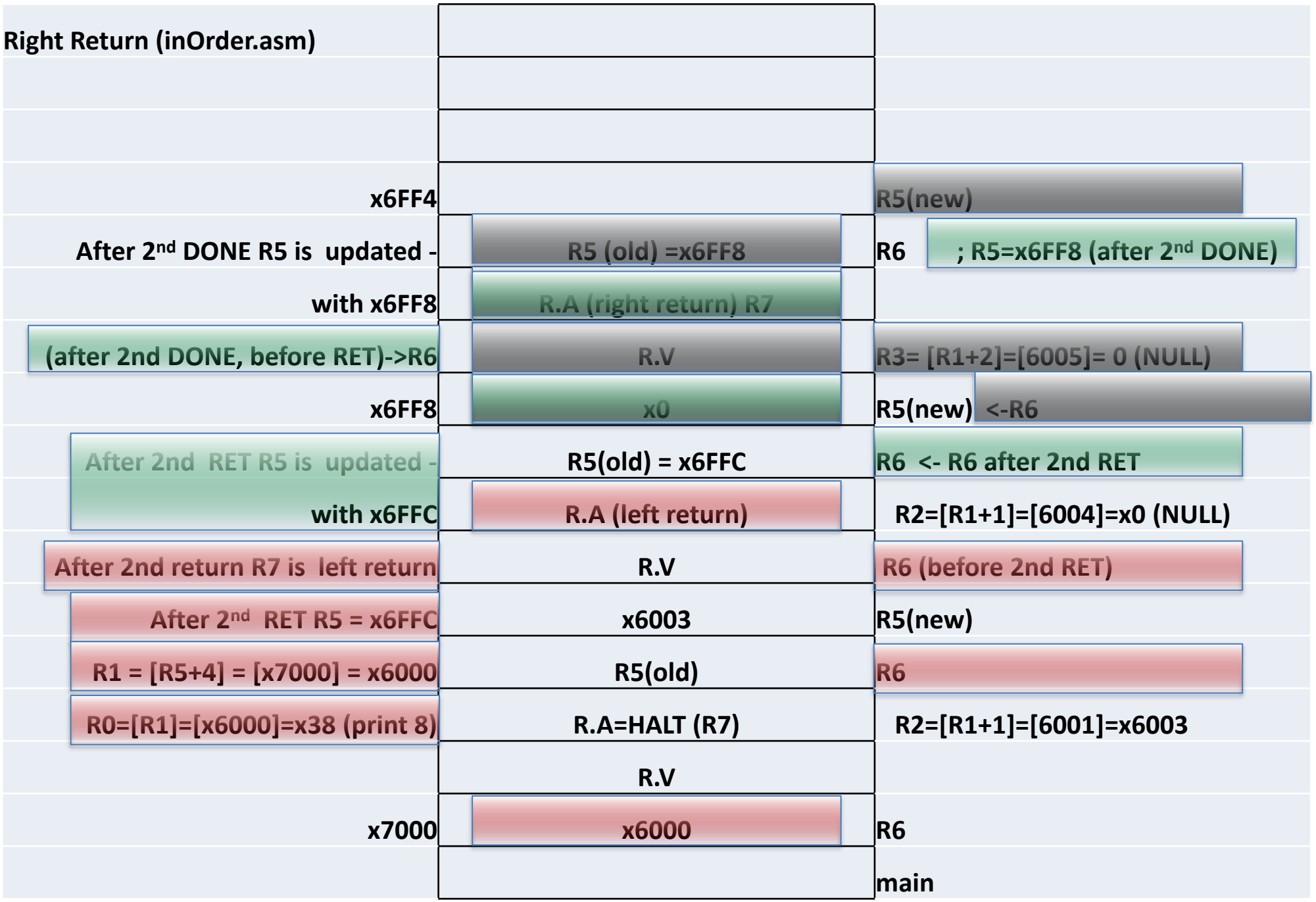
R6
main


Right Return (inOrder.asm)
x6FF4
R5(new)
After 2nd DONE R5 is updated -
with x6FF8
R5 (old) =x6FF8
R.A (right return) R7
R6
; R5=x6FF8 (after 2nd DONE)
(after 2nd DONE, before RET)->R6
R.V
R3= [R1+2]=[6005]= 0 (NULL)
x6FF8
x0
R5(new)
<-R6
After 2nd RET R5 is updated -
with x6FFC
R5(old) = x6FFC
R.A (left return)
R6 <- R6 after 2nd RET
R2=[R1+1]=[6004]=x0 (NULL)
After 2nd return R7 is left return
R.V
R6 (before 2nd RET)
After 2nd RET R5 = x6FFC
x6003
R5(new)
R1 = [R5+4] = [x7000] = x6000
R5(old)
R6
R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main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R5(new)
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R0=[R1]=[x6000]=x38 (print 8)
R.A=HALT (R7)
R2=[R1+1]=[6001]=x6003
R.V
x7000
x6000
R6
main

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
```