

# Lecture 9: Some practical aspects of compiling C

John Wickerson

Compilers

# Lecture outline

- Parsing C: the *dangling-else* problem.
- Parsing C: the *lexer hack*.
- Generating RISC-V assembly for function calls.

# The dangling-else problem

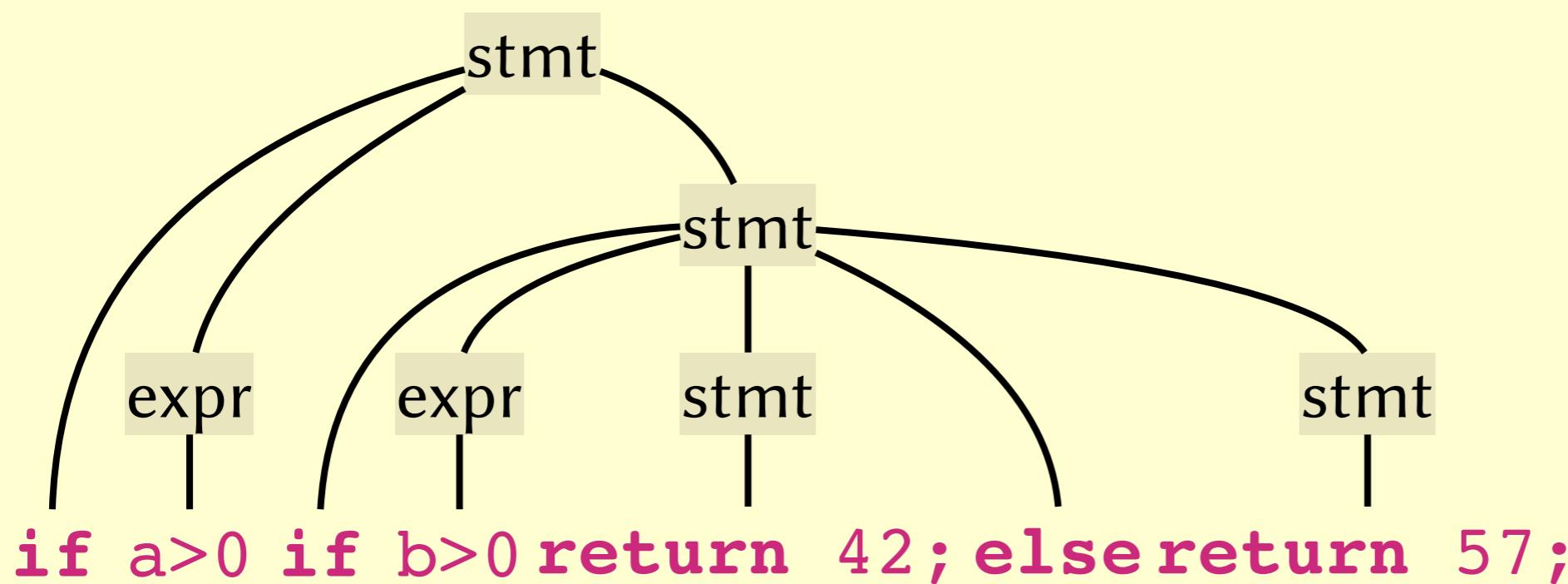
```
if (a > 0)
    if (b > 0)
        return 42;
    else
        return 57;
```

# The dangling-else problem

```
if (a > 0)
    if (b > 0)
        return 42;
else
    return 57;
```

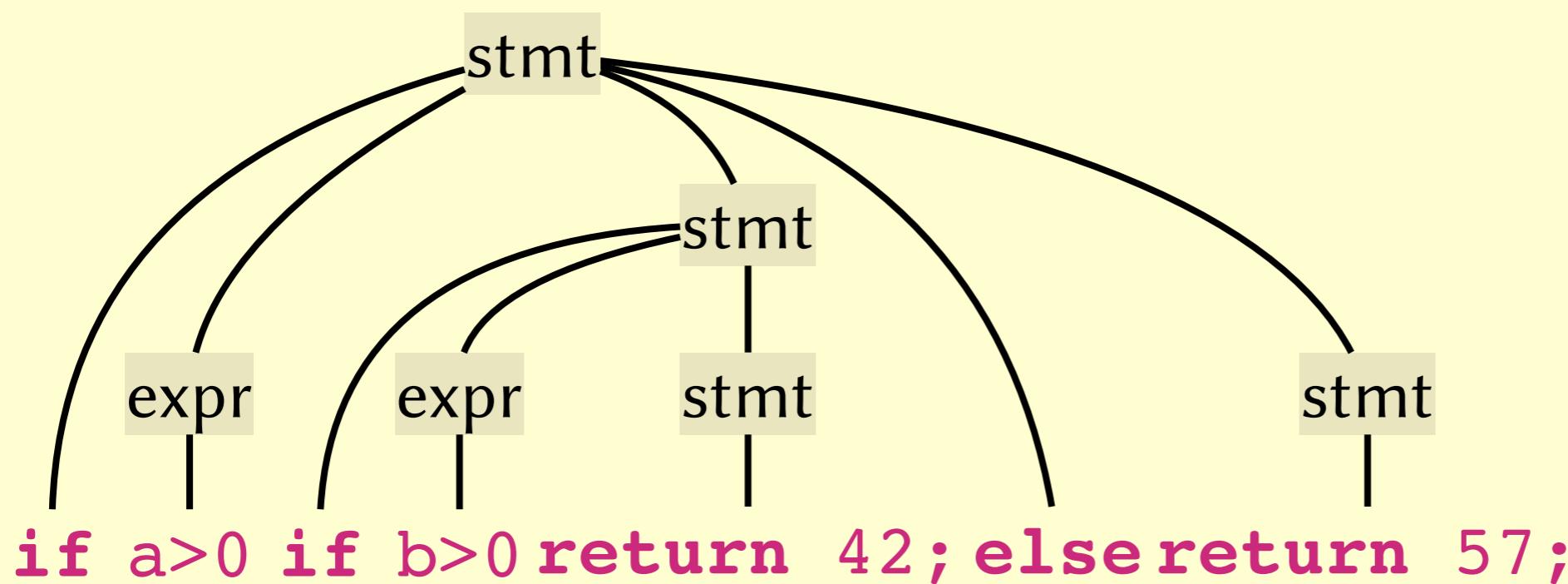
# The dangling-else problem

```
stmt ::= if ( expr ) stmt else stmt  
      | if ( expr ) stmt  
      | return expr ;
```



# The dangling-else problem

```
stmt ::= if ( expr ) stmt else stmt  
      | if ( expr ) stmt  
      | return expr ;
```



# The dangling-else problem

```
stmt ::= open_stmt
      | closed_stmt
open_stmt ::= if ( expr ) stmt
            | if ( expr ) closed_stmt else open_stmt
closed_stmt ::= if ( expr ) closed_stmt else closed_stmt
              | return expr ;
```

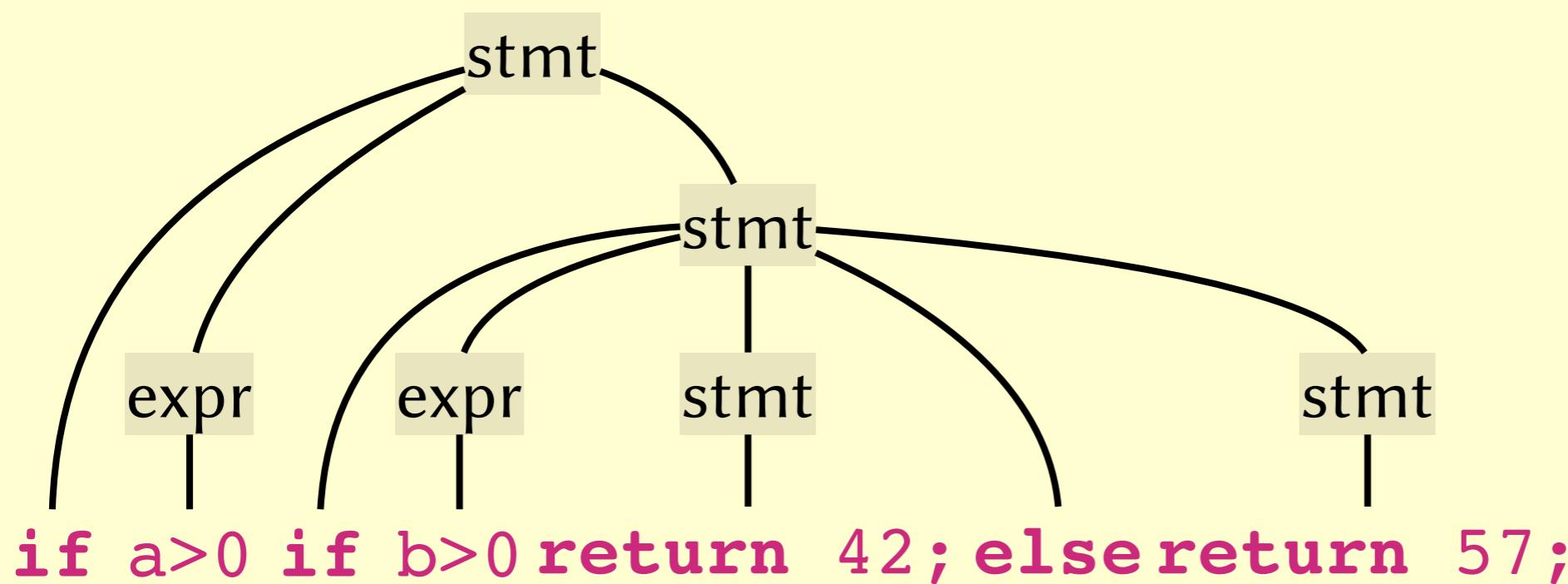
# The dangling-else problem

```
%nonassoc NOELSE
```

```
%nonassoc else
```

```
%%
```

```
stmt ::= if ( expr ) stmt else stmt  
      | if ( expr ) stmt %prec NOELSE  
      | return expr ;
```



# Lecture outline

✓ Parsing C: the *dangling-else* problem.

- Parsing C: the *lexer hack*.
- Generating RISC-V assembly for function calls.

# C is not context-free!

```
int a, b;
```

```
a * b;
```

# C is not context-free!

```
typedef int a;  
a * b;
```

# The lexer hack

- When the parser sees a `typedef` instruction, e.g.  
`typedef int a;`  
it adds `a` to a list of 'type variables'.
- When the lexer sees a token that looks like an identifier, it looks up the matched string in this list. If it is there, it returns a `TYPEID` token, and otherwise it returns an `ID` token.
- Thus the parser can distinguish between  
`TYPEID * ID; // declaring a pointer to a typedef'd type`  
and  
`ID * ID; // a multiplication expression`

# Lecture outline

- ✓ Parsing C: the *dangling-else* problem.
- ✓ Parsing C: the *lexer hack*.
- Generating RISC-V assembly for function calls.

# Function calls

```
int f (int a, int b,
       int c, int d) {
    int t=6;
    int u=7;
    return 42;
}

int main () {
    f(1,2,3,4);
}
```

f:

```
local t, 4;
local u, 4;
t = 6;
u = 7;
return 42;
```

main:

```
param 1;
param 2;
param 3;
param 4;
call f, 4;
```

# Function calls

f:

```
local t, 4;  
local u, 4;  
t = 6;  
u = 7;  
return 42;
```

ret val

42

stack  
frame  
for  
main

main:

```
param 1;  
param 2;  
param 3;  
param 4;  
call f, 4;
```

ret addr

t

6

u

7

stack  
frame  
for f

# ABI

- An **Application Binary Interface** defines:
  - how parameters are passed to functions,
  - which registers need to be preserved by a function call,
  - how the fields of a **struct** are laid out,
  - and so on.
- Here's an illustration of the ABI used by GCC when targeting RISC-V...



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C source #1 RISC-V (64-bits) gcc (trunk) (Editor #1)

A + C ▾

```
1 int f (int a, int b, int c, int d) {  
2     int t=6;  
3     int u=7;  
4     return 42;  
5 }  
6  
7 int main () {  
8     f(1,2,3,4);  
9 }  
10
```

RISC-V (64-bits) gcc (trunk) ▾ -std=c90 -O3 -march=rv32imfd -mabi=ilp32d

A Output... ▾ Filter... ▾ Libraries Overrides + Add new... ▾ Add tool... ▾

C source #1  

A ▾  + ▾  C ▾

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2     int t=6;  
3     int u=7;  
4     return 42;  
5 }  
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RISC-V (64-bits) gcc (trunk) ▾   -std=c90 -O3 -march=rv32imfd -mabi=ilp32d 

A ▾  Output... ▾  Filter... ▾  Libraries  Overrides  Add new... 

```
1 f:  
2     li      a0,42  
3     ret  
4 main:  
5     ret
```

C source #1

RISC-V (64-bits) gcc (trunk) (Editor #1)

A C RISC-V (64-bits) gcc (trunk) -std=c90 -O0 -march=rv32imfd -mabi=ilp32d

A Output... Filter... Libraries Overrides + Add new... Add tool...

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```



C source #1 ✓ ✗

RISC-V (64-bits) gcc (trunk) (Editor #1) ✓ ✗

RISC-V (64-bits) gcc (trunk) ✓ -std=c90 -O0 -march=rv32imfd -mabi=ilp32d

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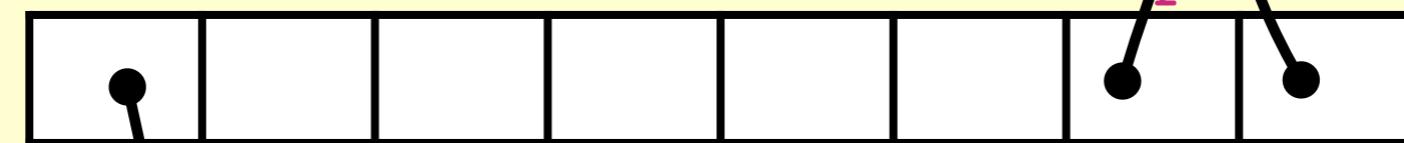
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2     int t=6;  
3     int u=7;  
4     return 42;  
5 }  
6  
7 int main () {  
8     f(1,2,3,4);  
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```

```
1 f:  
2     addi    sp,sp,-48  
3     sw      ra,44(sp)  
4     sw      s0,40(sp)  
5     addi    s0,sp,48  
6     sw      a0,-36(s0)  
7     sw      a1,-40(s0)  
8     sw      a2,-44(s0)  
9     sw      a3,-48(s0)  
10    li      a5,6  
11    sw      a5,-20(s0)  
12    li      a5,7  
13    sw      a5,-24(s0)  
14    li      a5,42  
15    mv      a0,a5  
16    lw      ra,44(sp)  
17    lw      s0,40(sp)  
18    addi   sp,sp,48  
19    jr      ra  
20 main:  
21    addi   sp,sp,-16  
22    sw      ra,12(sp)  
23    sw      s0,8(sp)  
24    addi   s0,sp,16  
25    li      a3,4  
26    li      a2,3  
27    li      a1,2  
28    li      a0,1  
29    call    f  
30    nop  
31    mv      a0,a5  
32    lw      ra,12(sp)  
33    lw      s0,8(sp)  
34    addi   sp,sp,16  
35    jr      ra
```

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addi sp,sp,-48
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mv a0,a5
lw ra,44(sp)
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addi sp,sp,48
jr ra
```

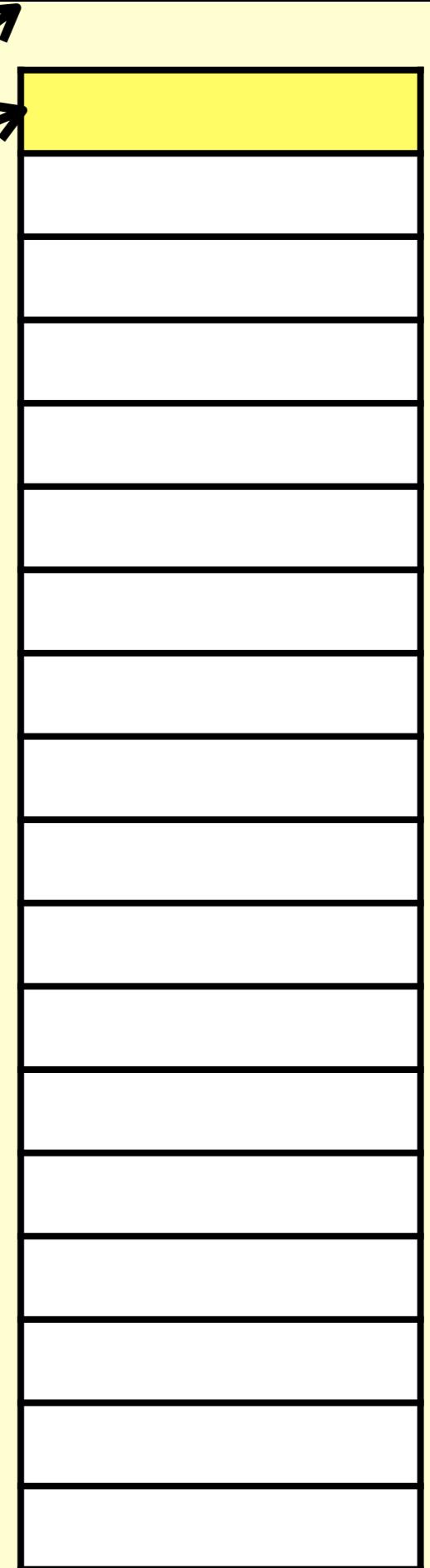
```
int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0



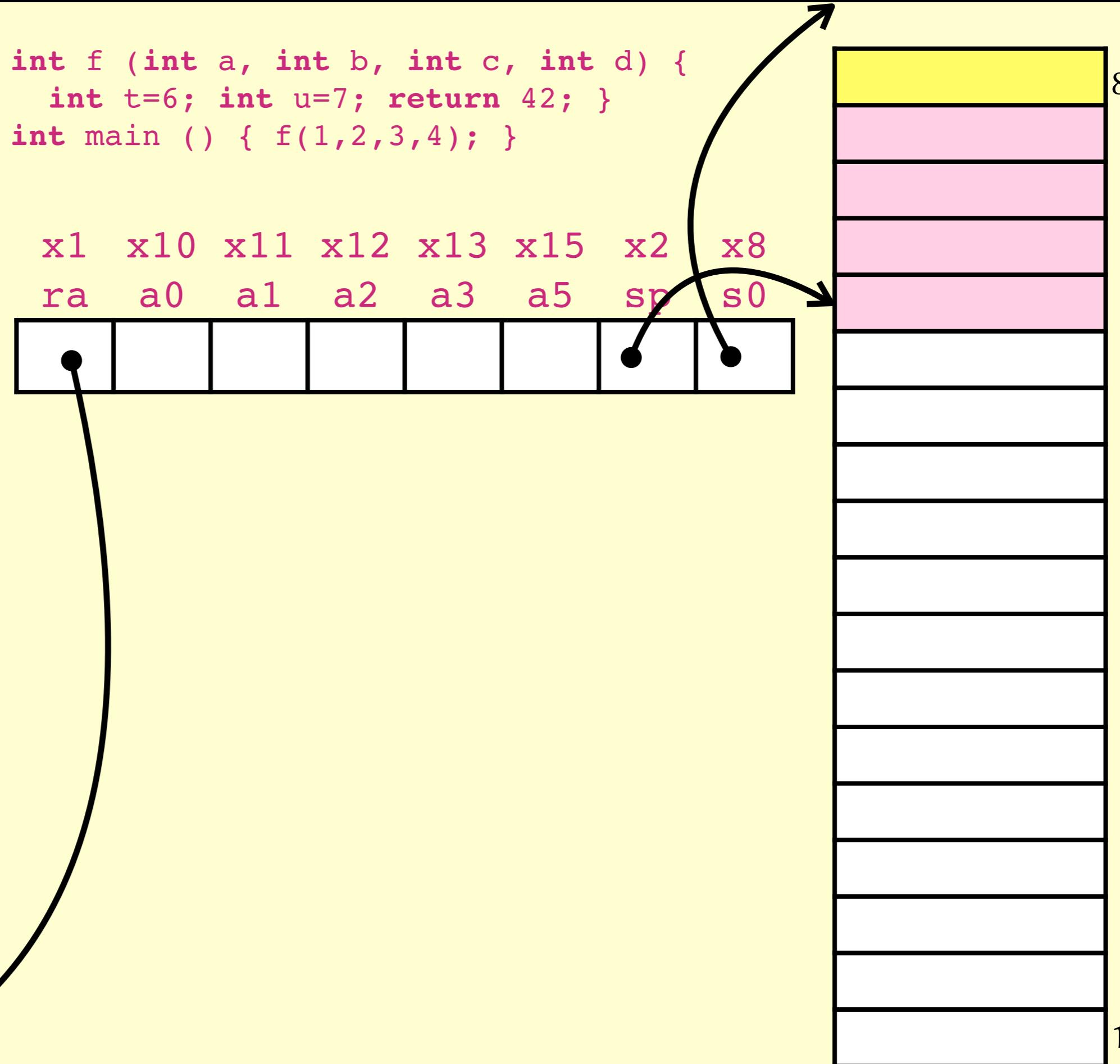
main:

```
addi sp,sp,-16
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```



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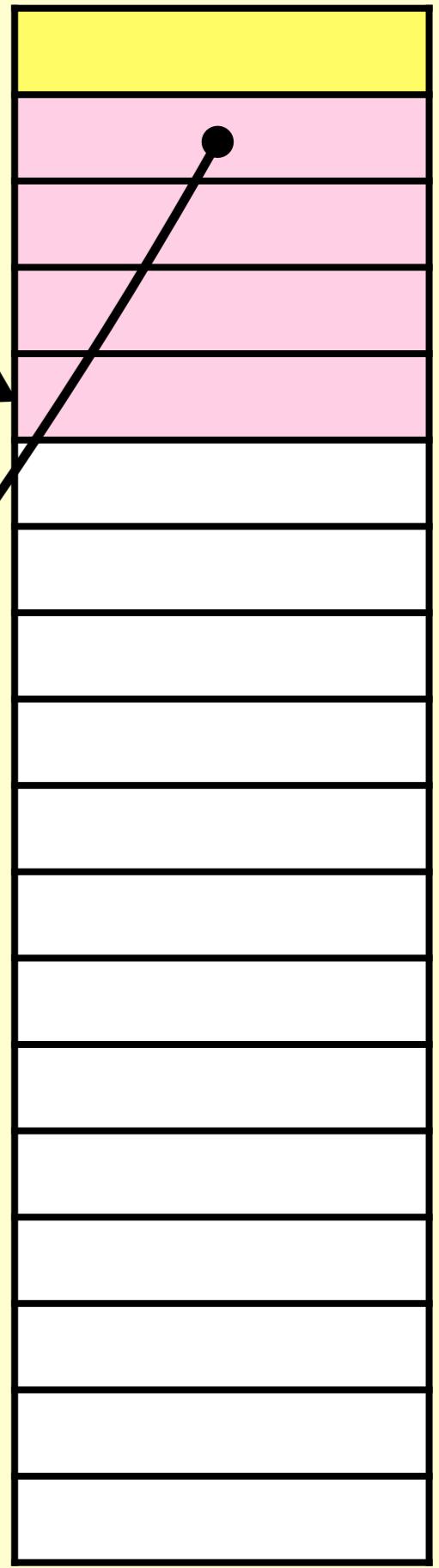
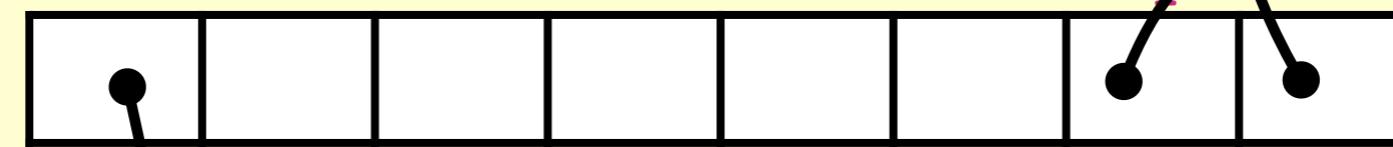
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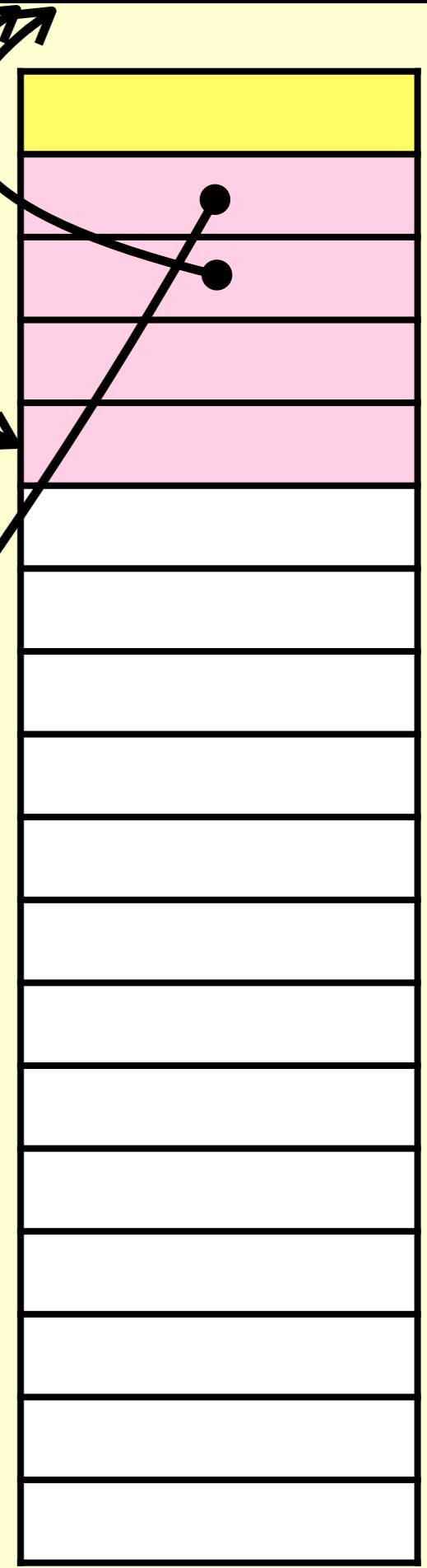
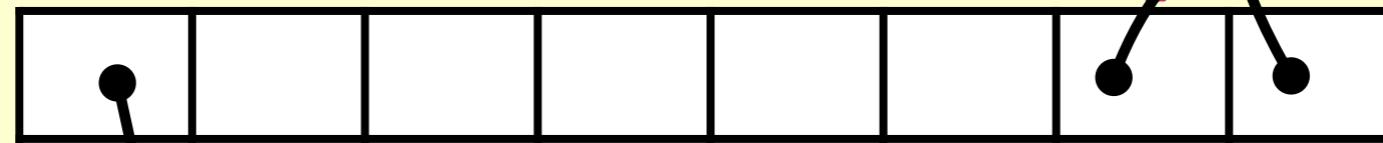


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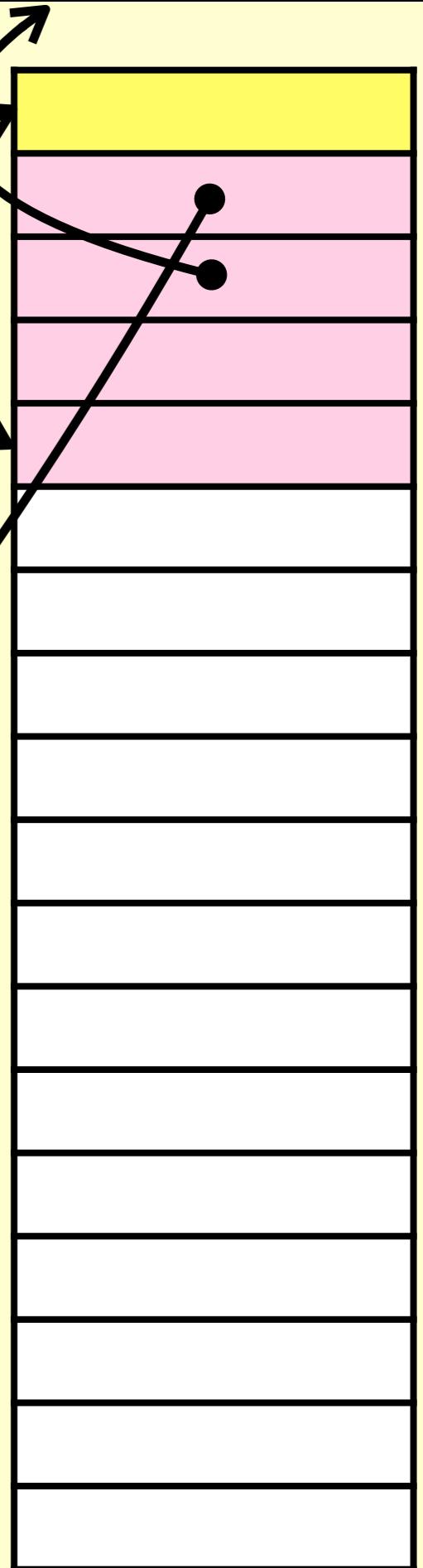
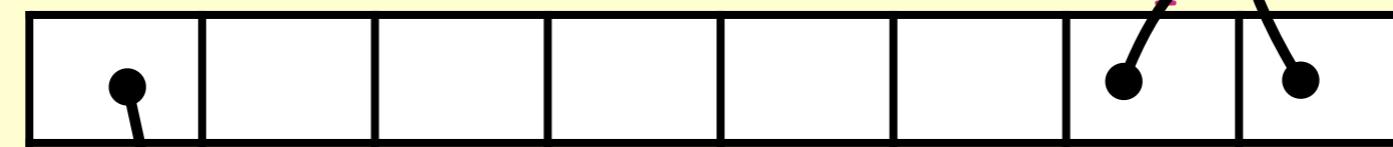


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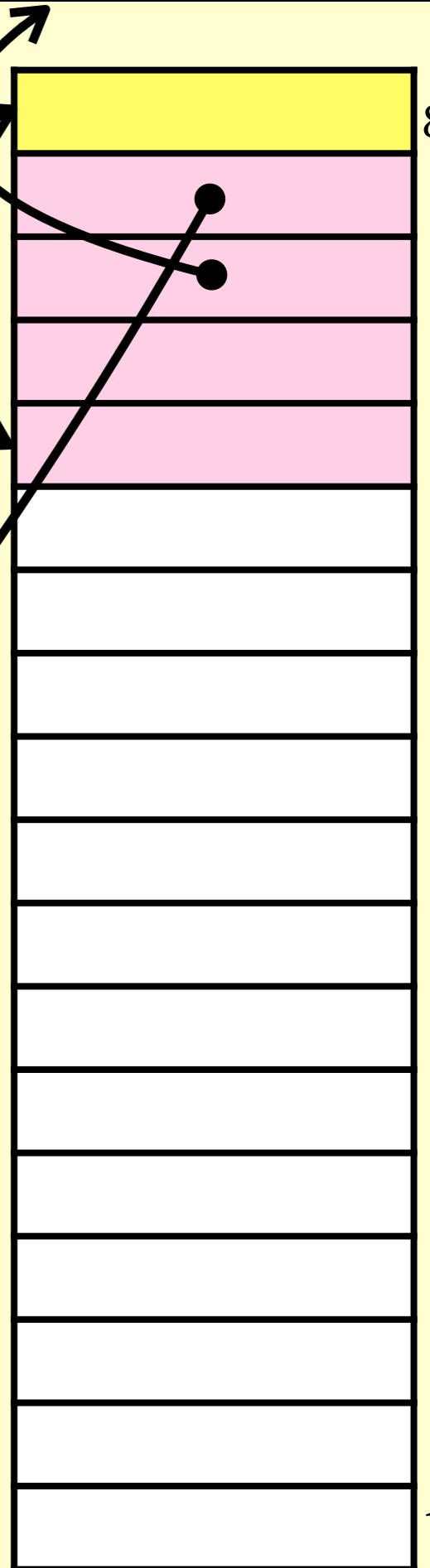
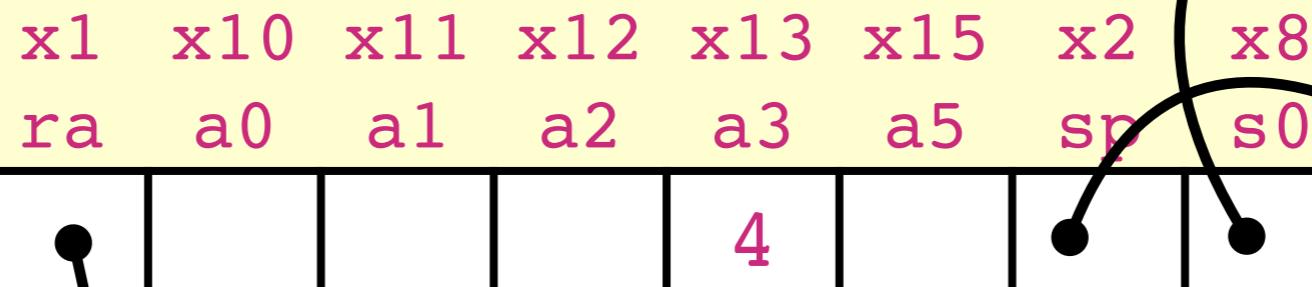
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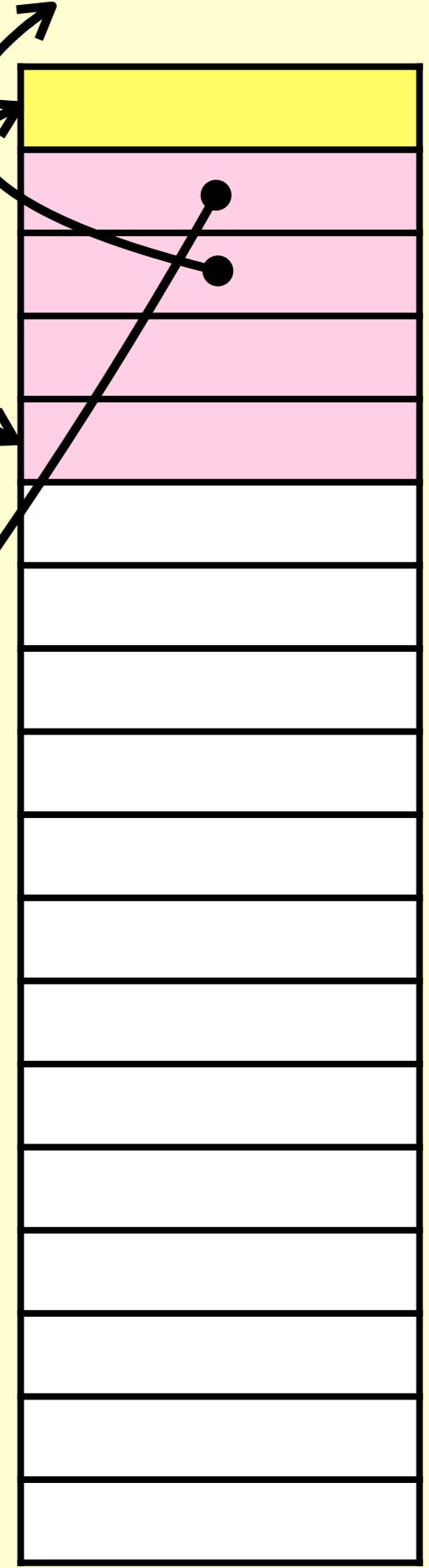
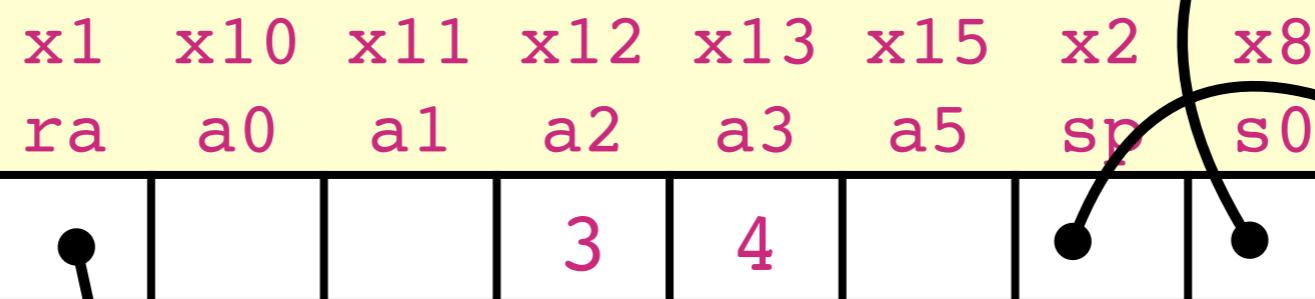
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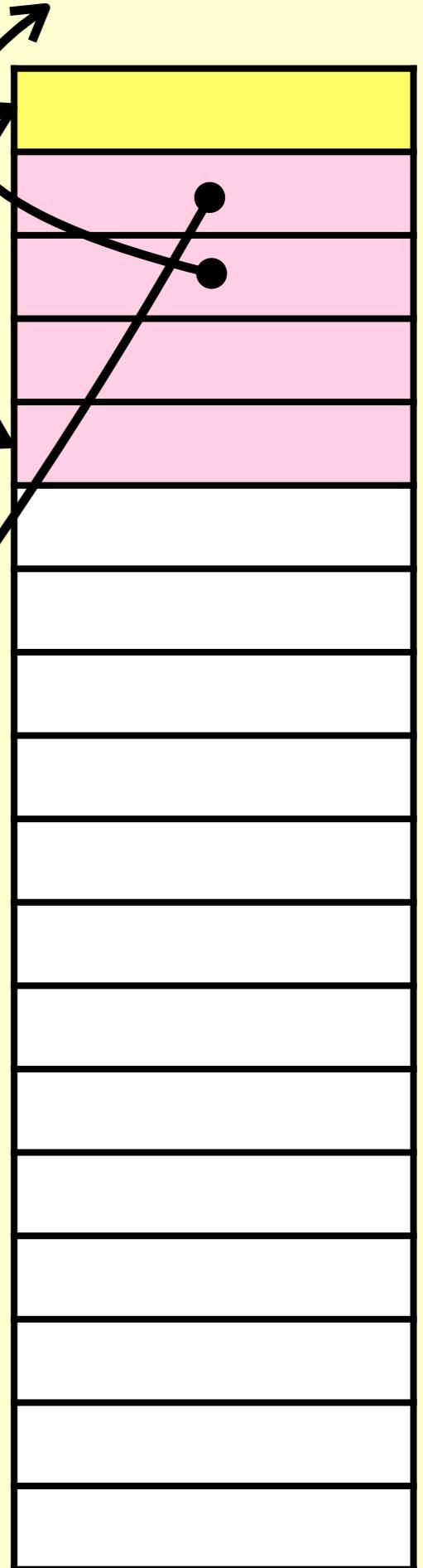
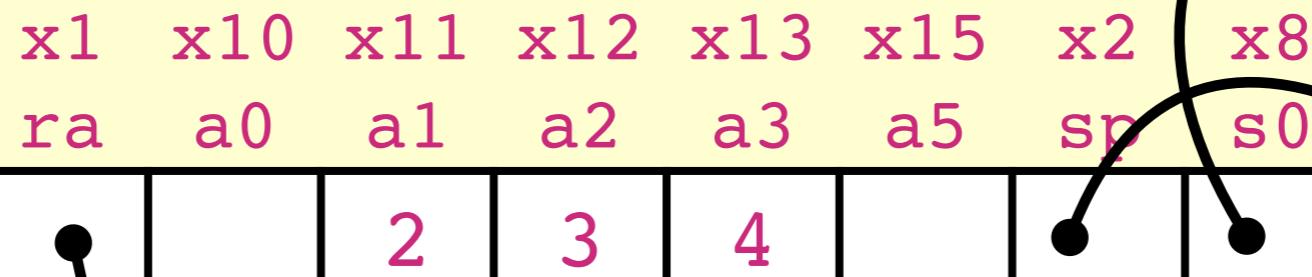
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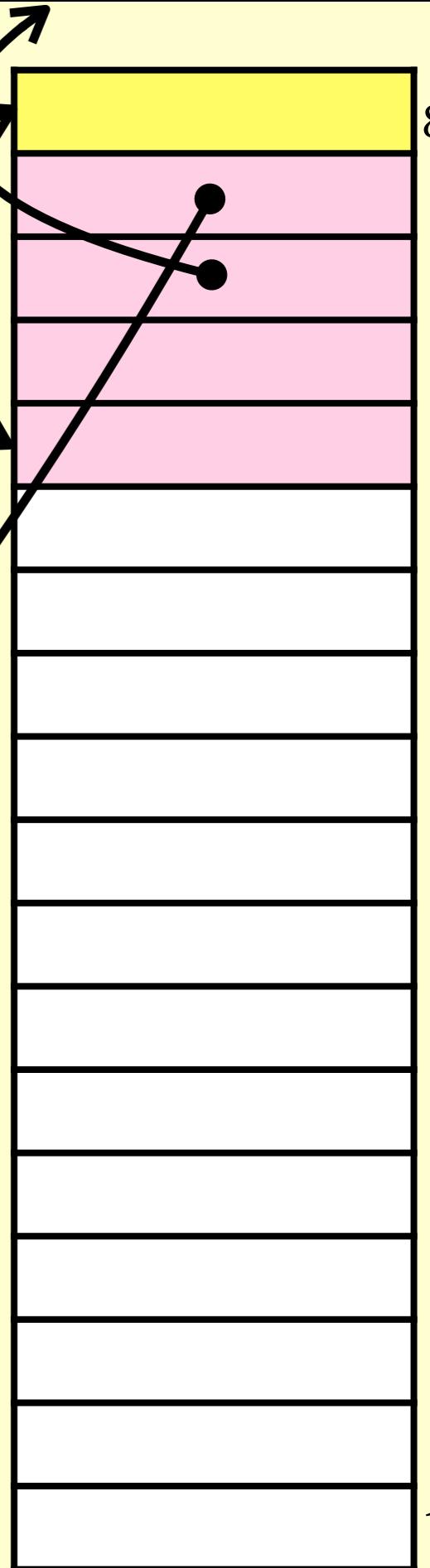


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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			



**f:**

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```

**main:**

```

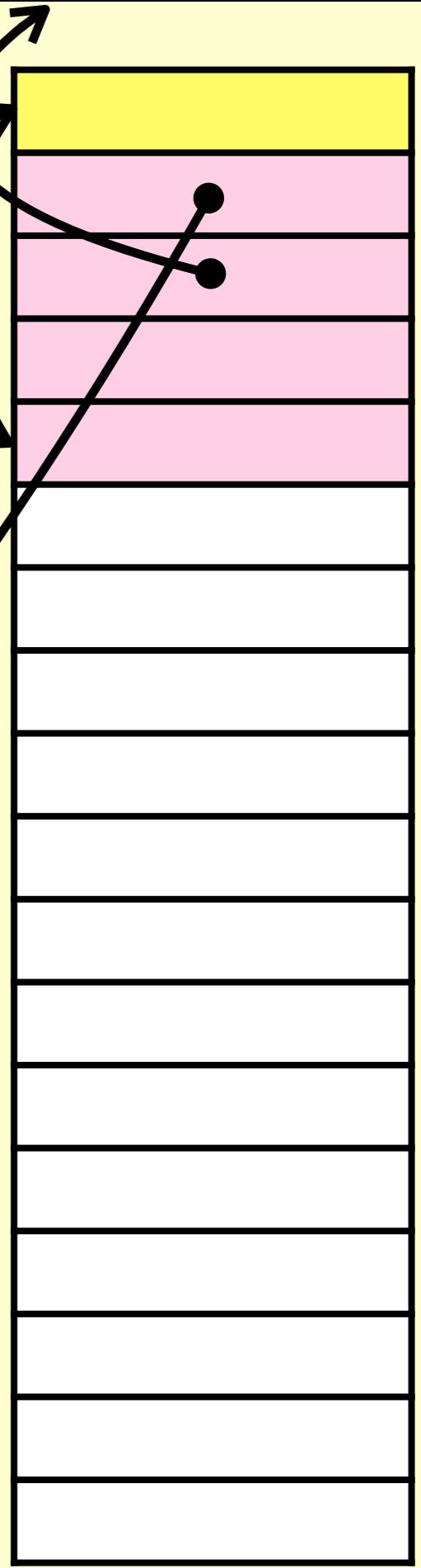
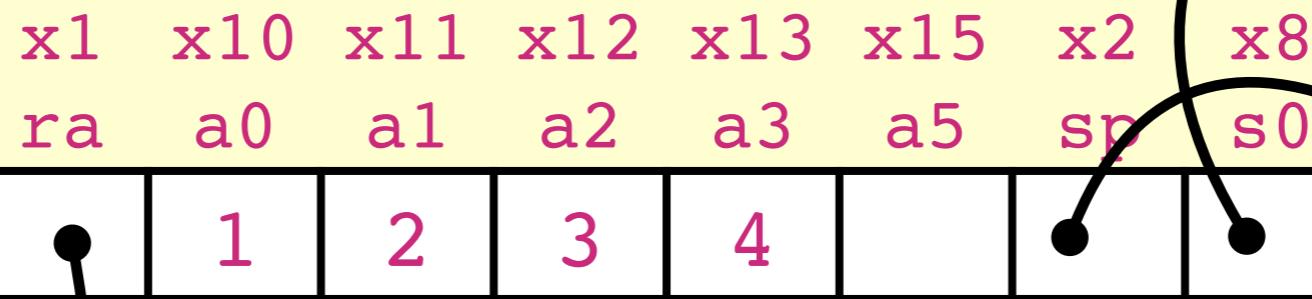
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lw s0,8(sp)
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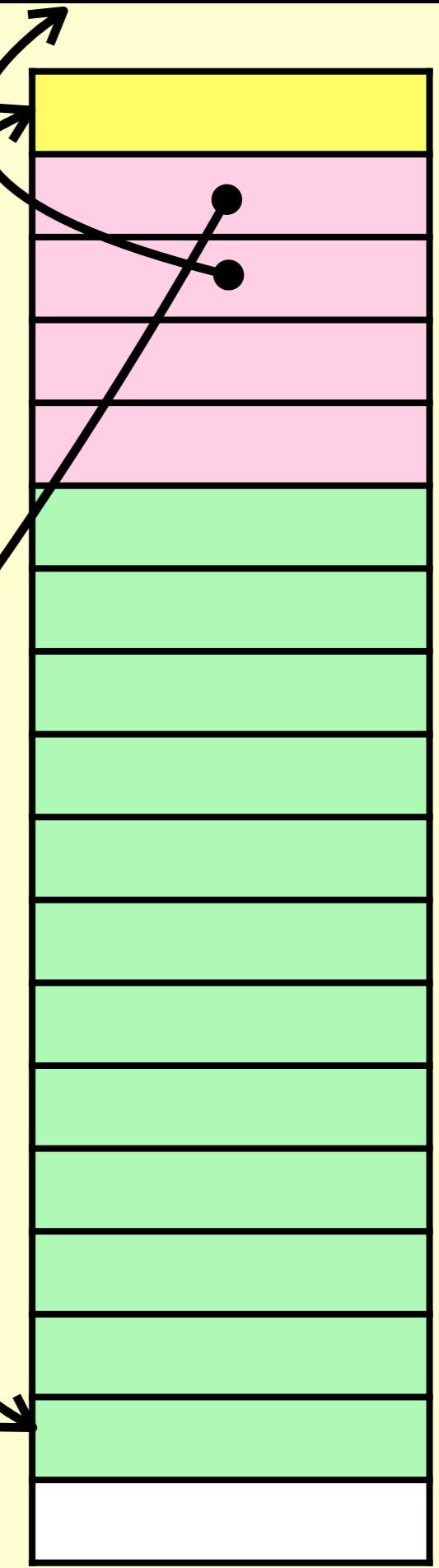


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mv a0,a5
lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra
```

```
main:
addi sp,sp,-16
sw ra,12(sp)
sw s0,8(sp)
addi s0,sp,16
li a3,4
li a2,3
li a1,2
li a0,1
call f
nop
mv a0,a5
lw ra,12(sp)
lw s0,8(sp)
addi sp,sp,16
jr ra
```

```
int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			

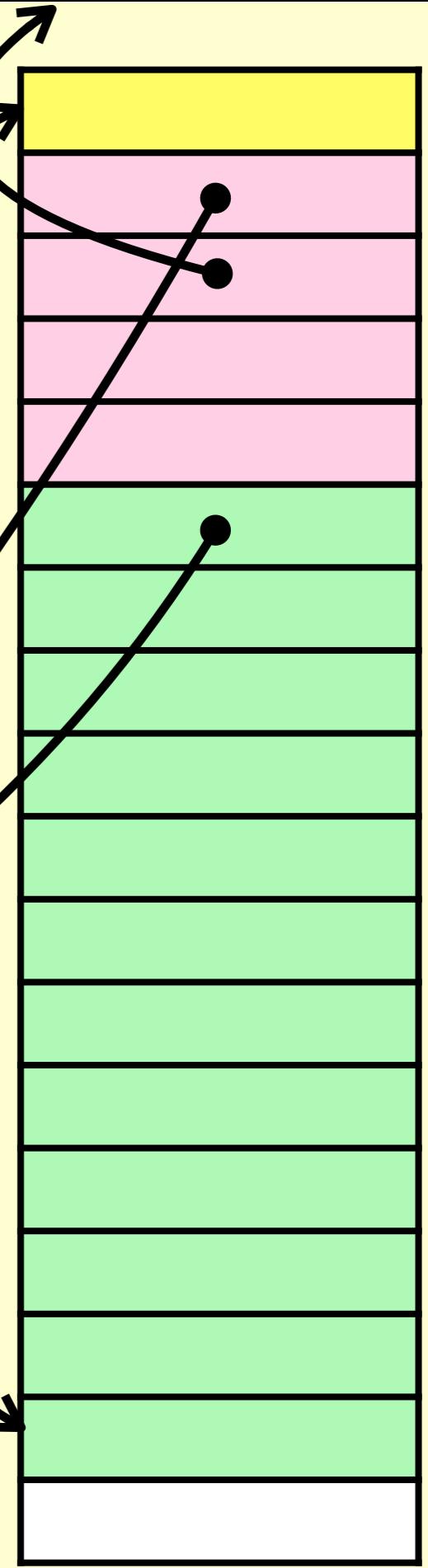


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
li a5,6
sw a5,-20(s0)
li a5,7
sw a5,-24(s0)
li a5,42
mv a0,a5
lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra
```

```
main:
addi sp,sp,-16
sw ra,12(sp)
sw s0,8(sp)
addi s0,sp,16
li a3,4
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call f
nop
mv a0,a5
lw ra,12(sp)
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addi sp,sp,16
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```

```
int f (int a, int b, int c, int d) {
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			

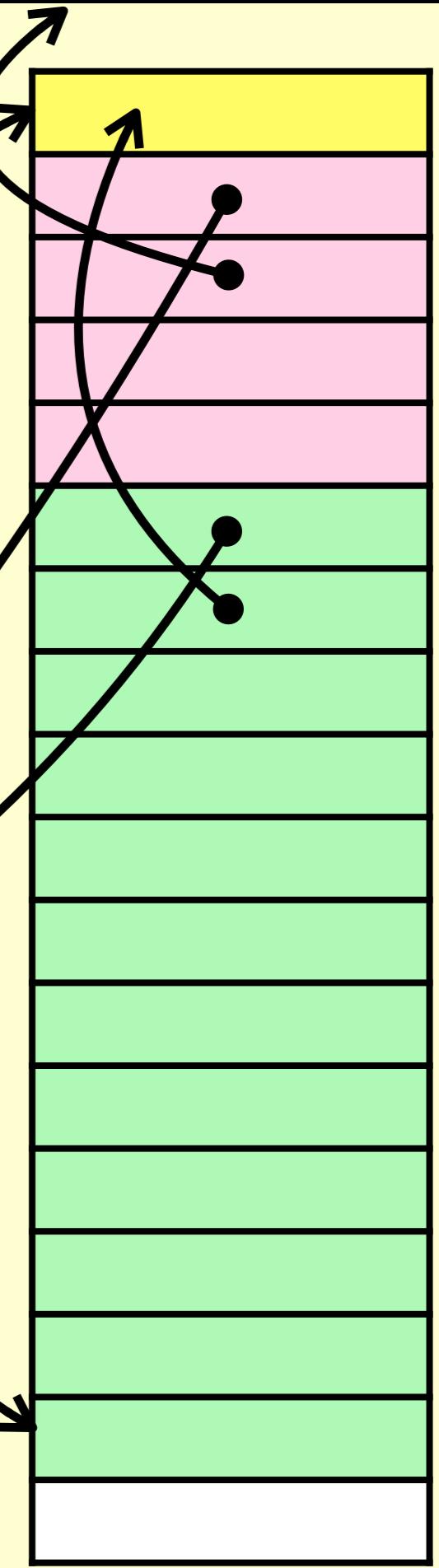
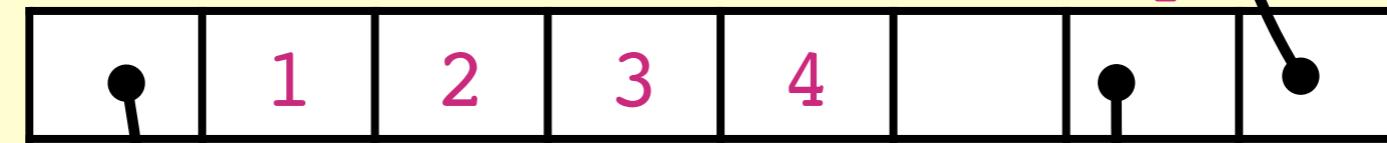


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
li a5,6
sw a5,-20(s0)
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lw s0,40(sp)
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main:
addi sp,sp,-16
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```
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			

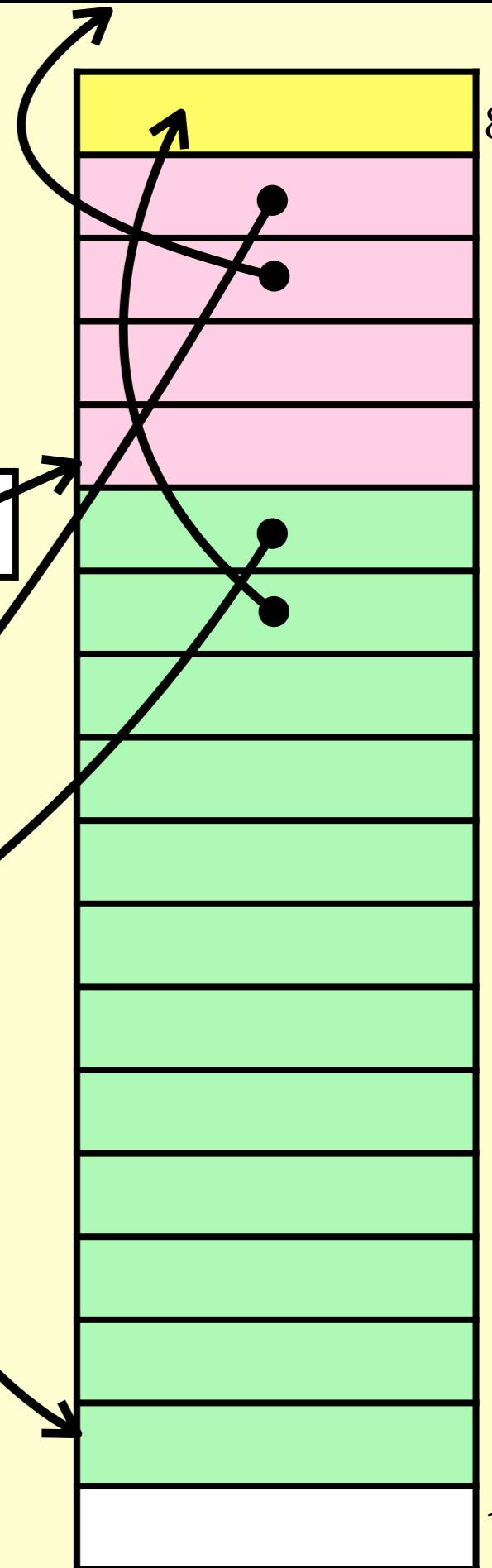
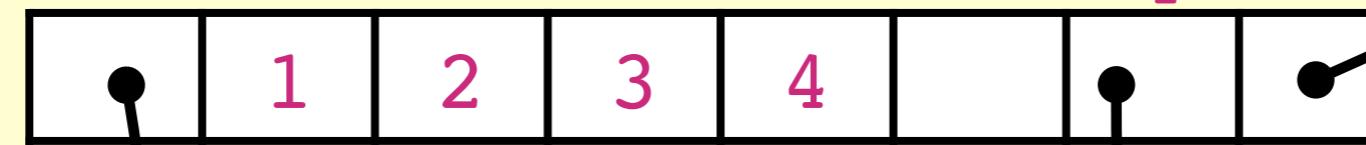


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
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li a5,6
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main:
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lw s0,8(sp)
addi sp,sp,16
jr ra
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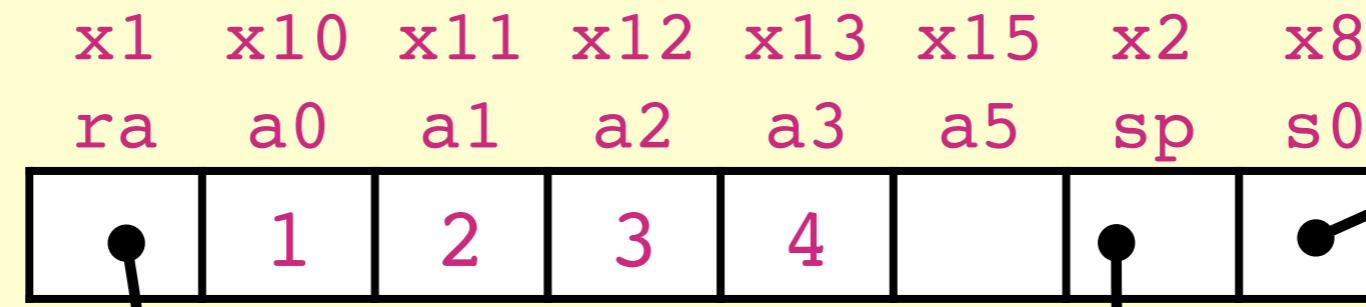
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int f (int a, int b, int c, int d) {
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int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			



f:  
**addi** sp,sp,-48  
**sw** ra,44(sp)  
**sw** s0,40(sp)  
**addi** s0,sp,48  
**sw** a0,-36(s0)  
**sw** a1,-40(s0)  
**sw** a2,-44(s0)  
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**li** a5,6  
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**li** a5,7  
**sw** a5,-24(s0)  
**li** a5,42  
**mv** a0,a5  
**lw** ra,44(sp)  
**lw** s0,40(sp)  
**addi** sp,sp,48  
**jr** ra

```
int f (int a, int b, int c, int d) {  
    int t=6; int u=7; return 42; }  
int main () { f(1,2,3,4); }
```



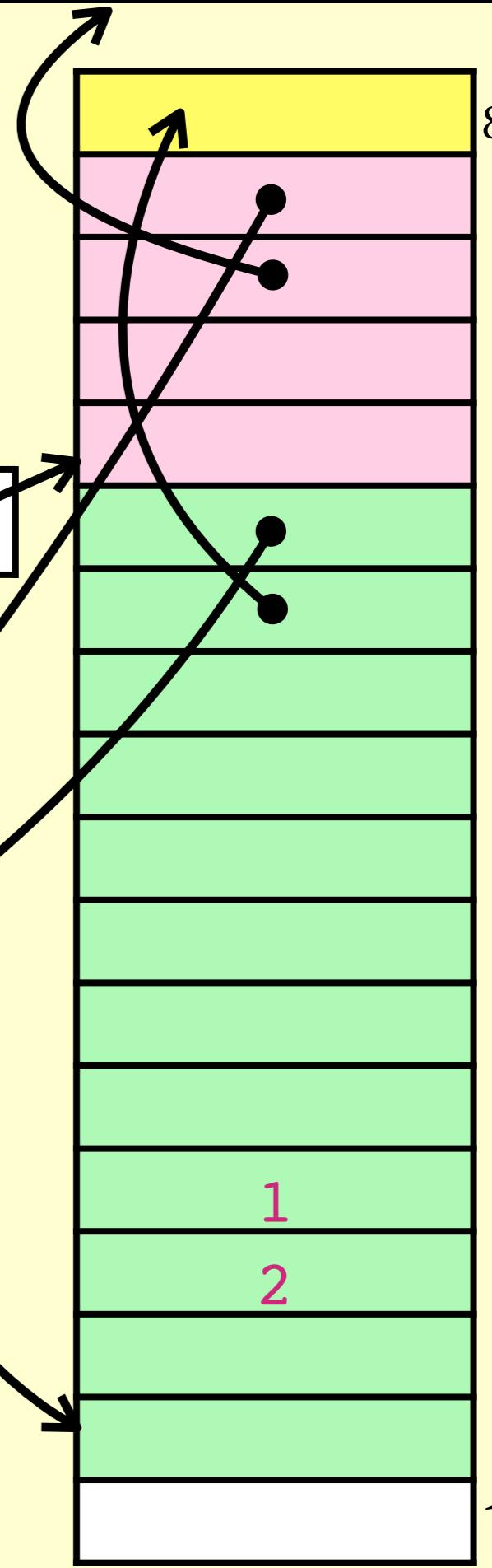
```
main:  
    addi    sp,sp,-16  
    sw      ra,12(sp)  
    sw      s0,8(sp)  
    addi    s0,sp,16  
    li      a3,4  
    li      a2,3  
    li      a1,2  
    li      a0,1  
    call    f  
    nop  
    mv      a0,a5  
    lw      ra,12(sp)  
    lw      s0,8(sp)  
    addi    sp,sp,16  
    jr      ra
```

```
f:
addi sp,sp,-48
sw ra,44(sp)
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sw a1,-40(s0)
sw a2,-44(s0)
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lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra
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main:
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mv a0,a5
lw ra,12(sp)
lw s0,8(sp)
addi sp,sp,16
jr ra
```

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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			

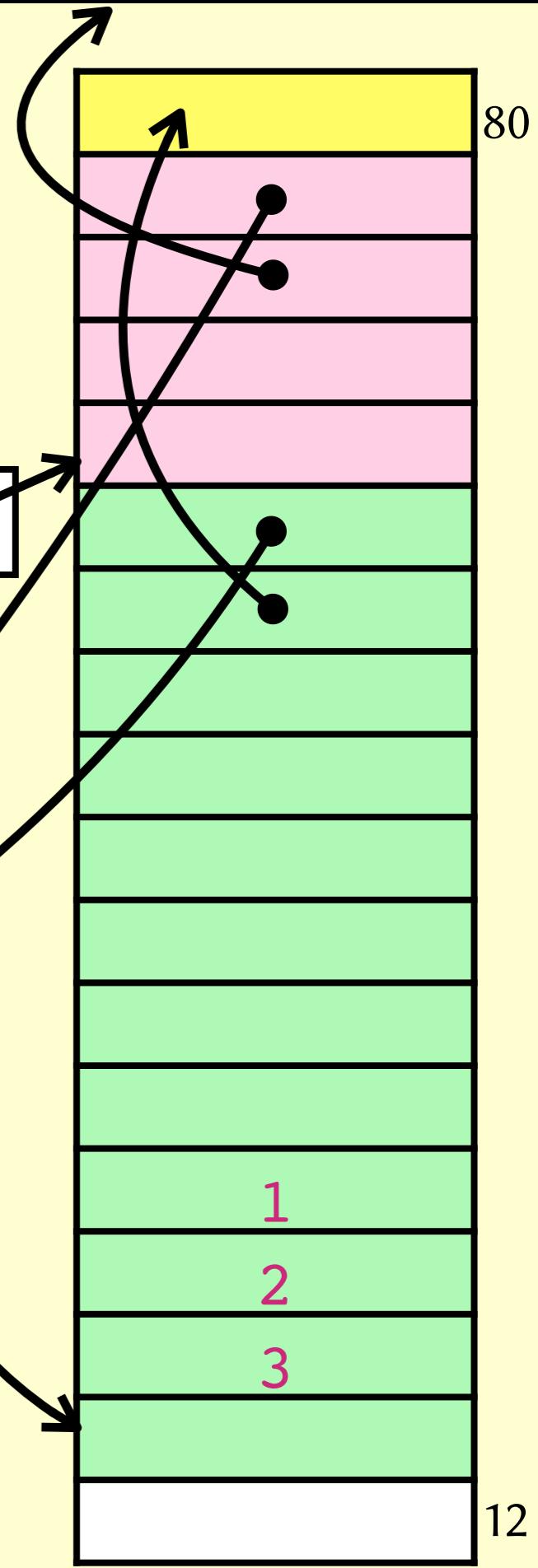


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
li a5,6
sw a5,-20(s0)
li a5,7
sw a5,-24(s0)
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main:
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```
int f (int a, int b, int c, int d) {
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			

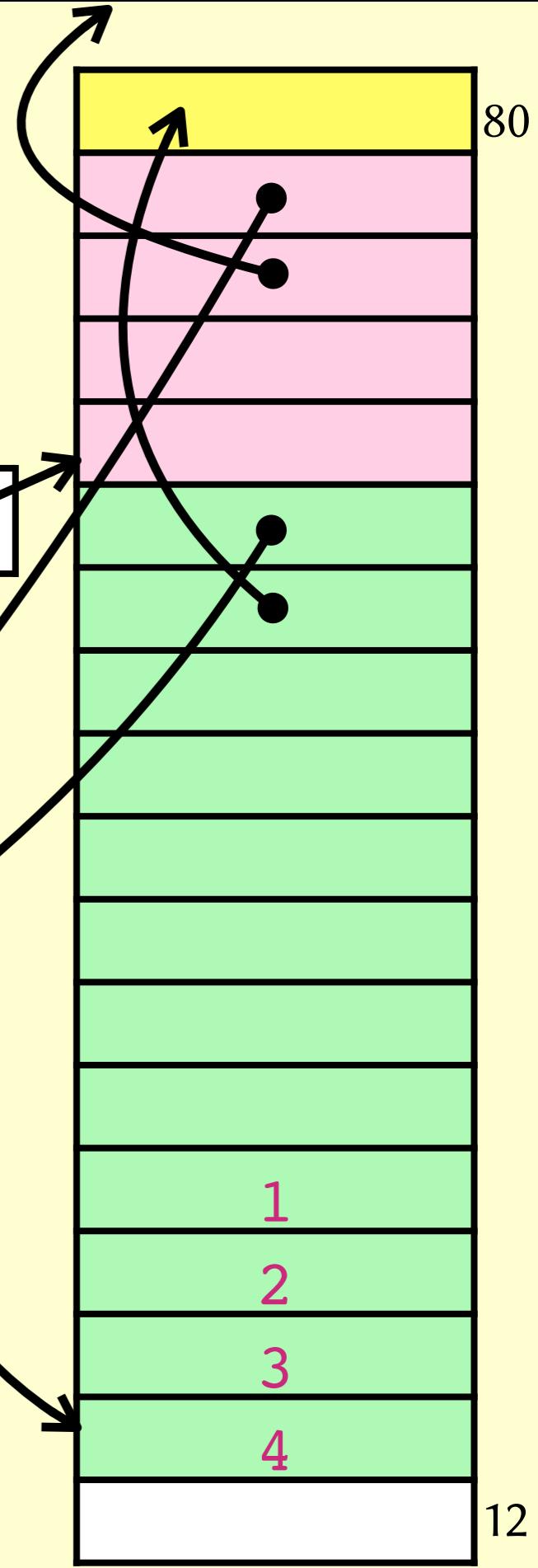
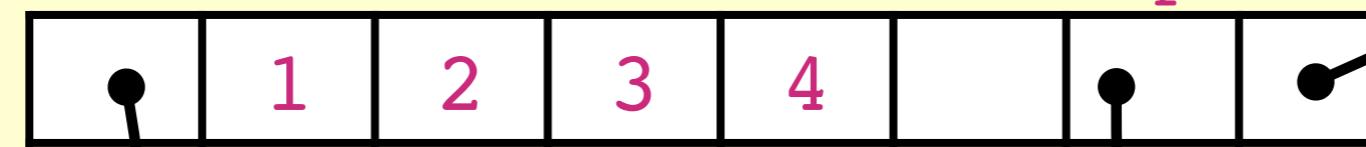


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
li a5,6
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li a5,7
sw a5,-24(s0)
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lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra
```

```
main:
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sw ra,12(sp)
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addi s0,sp,16
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call f
nop
mv a0,a5
lw ra,12(sp)
lw s0,8(sp)
addi sp,sp,16
jr ra
```

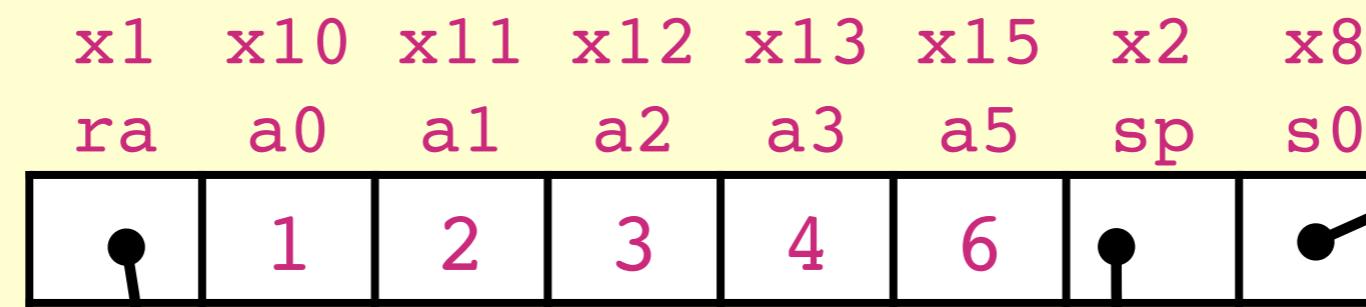
```
int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4			



f:  
**addi** sp,sp,-48  
**sw** ra,44(sp)  
**sw** s0,40(sp)  
**addi** s0,sp,48  
**sw** a0,-36(s0)  
**sw** a1,-40(s0)  
**sw** a2,-44(s0)  
**sw** a3,-48(s0)  
**li** a5,6  
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**li** a5,7  
**sw** a5,-24(s0)  
**li** a5,42  
**mv** a0,a5  
**lw** ra,44(sp)  
**lw** s0,40(sp)  
**addi** sp,sp,48  
**jr** ra

```
int f (int a, int b, int c, int d) {  
    int t=6; int u=7; return 42; }  
int main () { f(1,2,3,4); }
```



```
main:  
    addi    sp,sp,-16  
    sw      ra,12(sp)  
    sw      s0,8(sp)  
    addi    s0,sp,16  
    li      a3,4  
    li      a2,3  
    li      a1,2  
    li      a0,1  
    call    f  
    nop  
    mv      a0,a5  
    lw      ra,12(sp)  
    lw      s0,8(sp)  
    addi    sp,sp,16  
    jr      ra
```

f:

```

addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
li a5,6
sw a5,-20(s0)
li a5,7
sw a5,-24(s0)
li a5,42
mv a0,a5
lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra

```

main:

```

addi sp,sp,-16
sw ra,12(sp)
sw s0,8(sp)
addi s0,sp,16
li a3,4
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lw ra,12(sp)
lw s0,8(sp)
addi sp,sp,16
jr ra

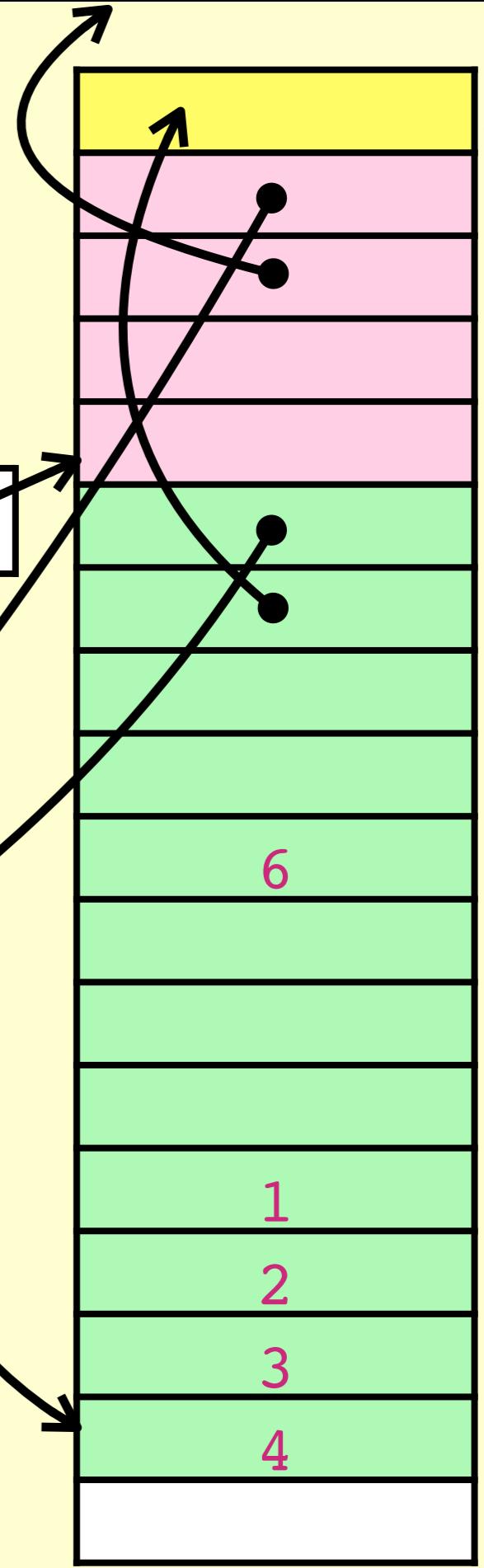
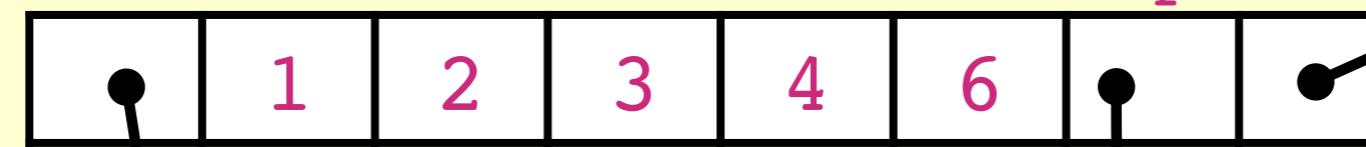
```

```

int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }

```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4	6		

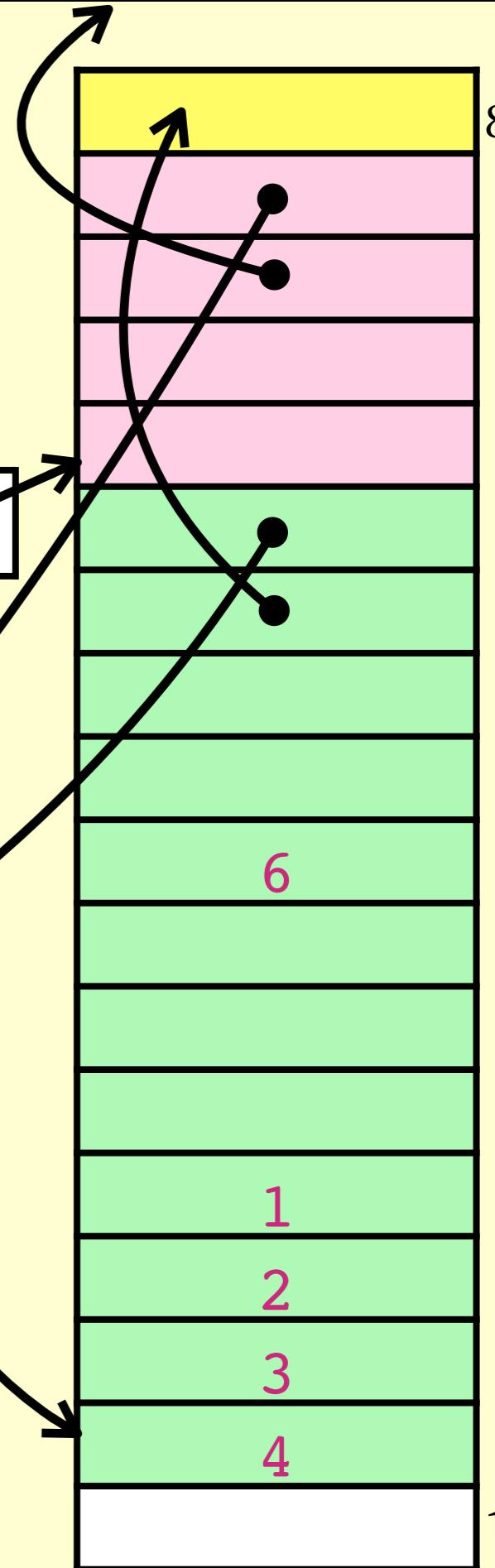
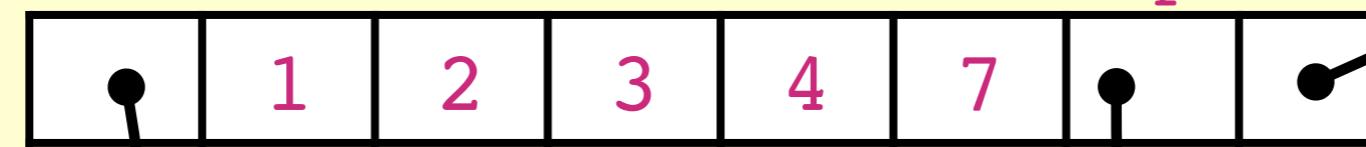


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
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main:
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int f (int a, int b, int c, int d) {
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4	7		

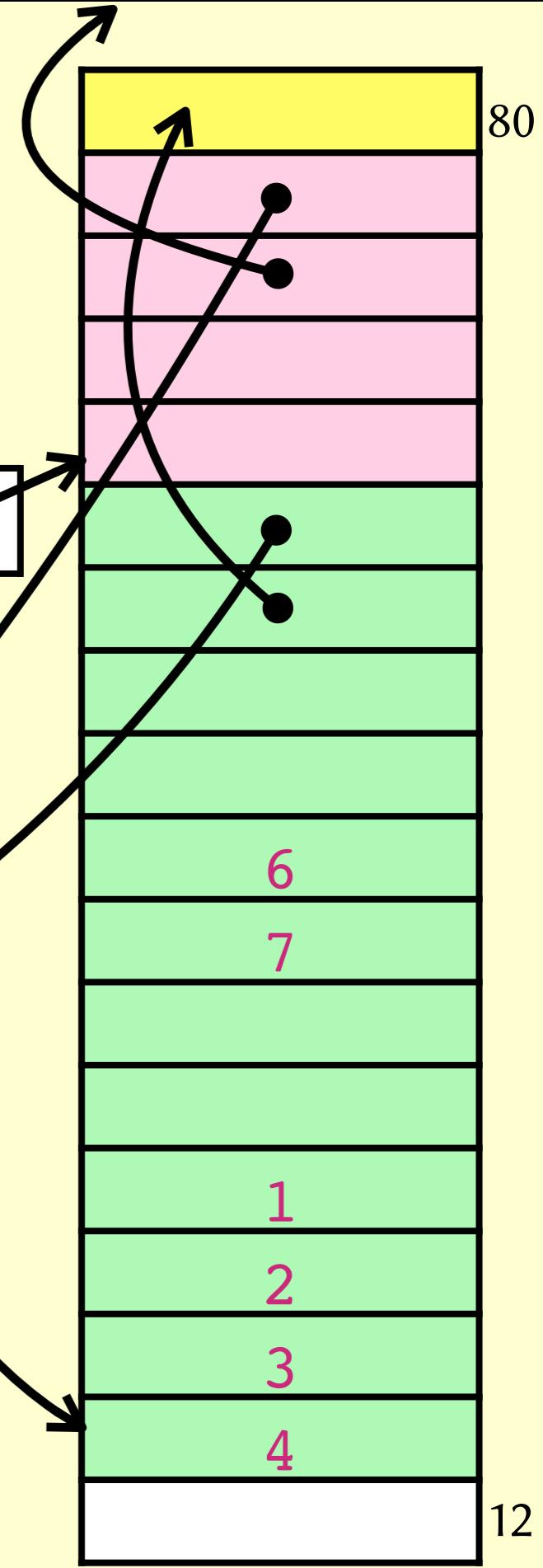


```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
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```
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4	7		

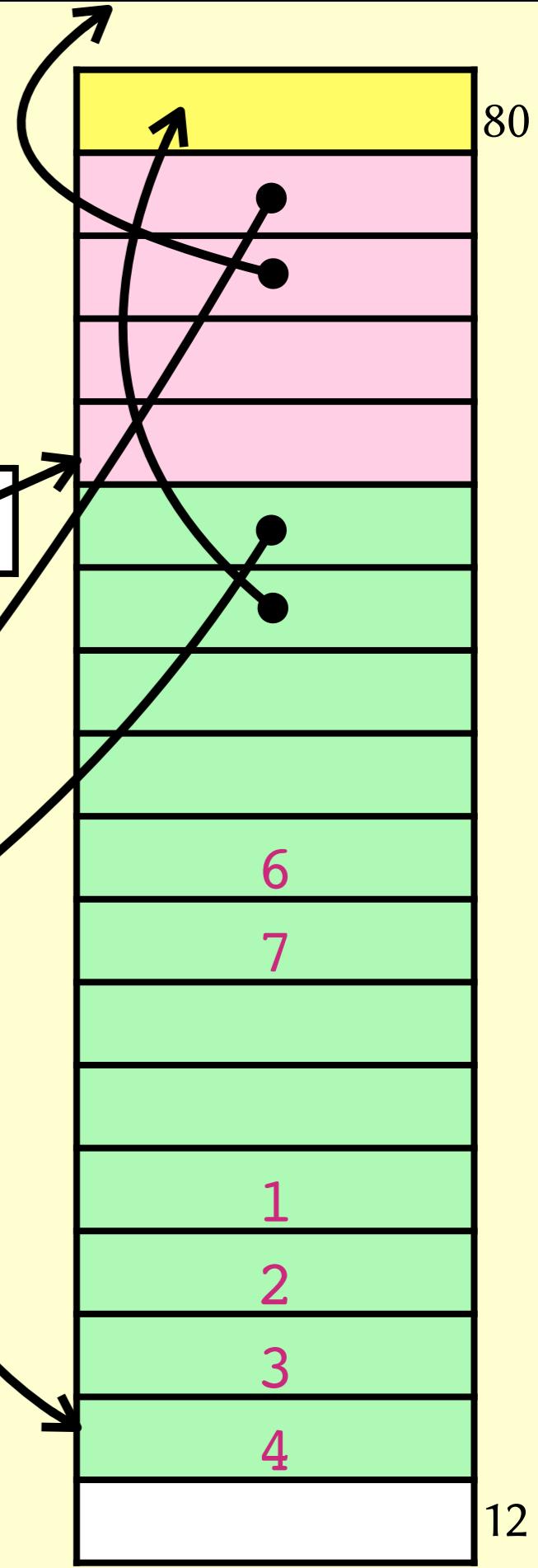


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f:
addi sp,sp,-48
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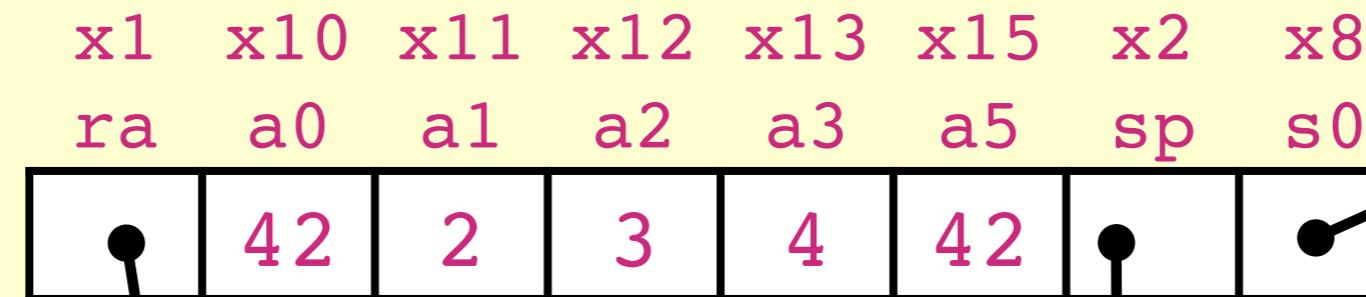
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```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	1	2	3	4	42		



f:  
**addi** sp,sp,-48  
**sw** ra,44(sp)  
**sw** s0,40(sp)  
**addi** s0,sp,48  
**sw** a0,-36(s0)  
**sw** a1,-40(s0)  
**sw** a2,-44(s0)  
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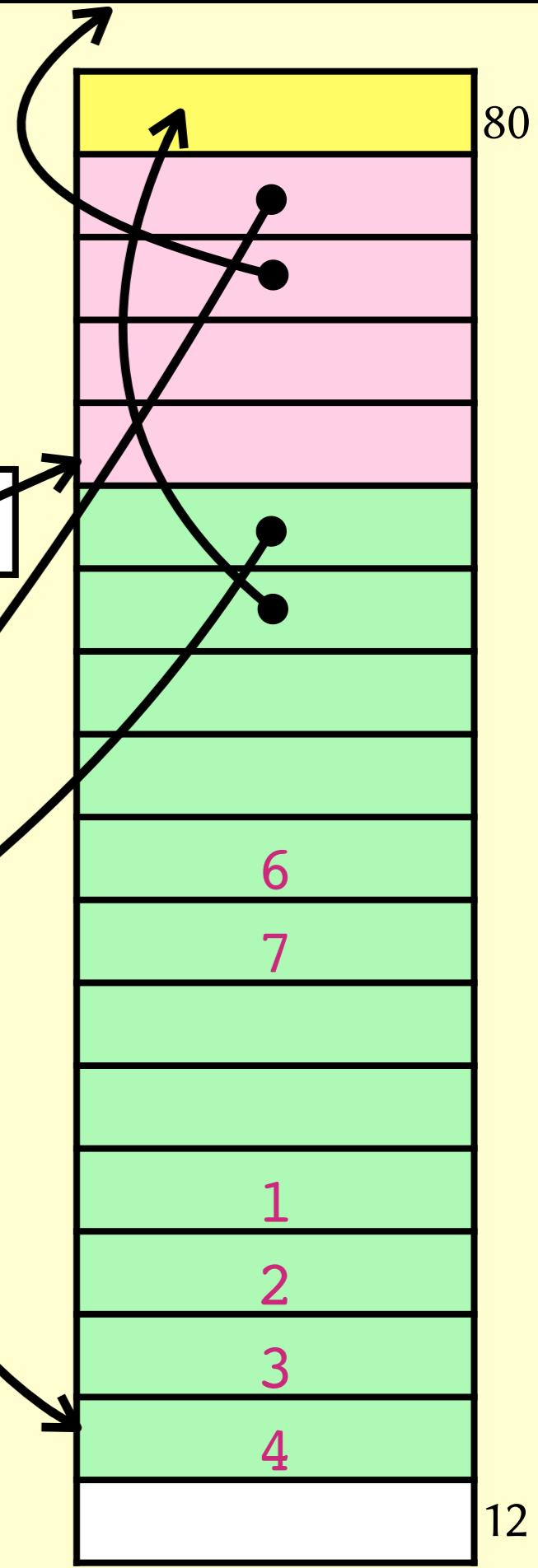
```
main:  
    addi    sp,sp,-16  
    sw      ra,12(sp)  
    sw      s0,8(sp)  
    addi    s0,sp,16  
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    li      a2,3  
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    mv      a0,a5  
    lw      ra,12(sp)  
    lw      s0,8(sp)  
    addi    sp,sp,16  
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```
int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	42	2	3	4	42		

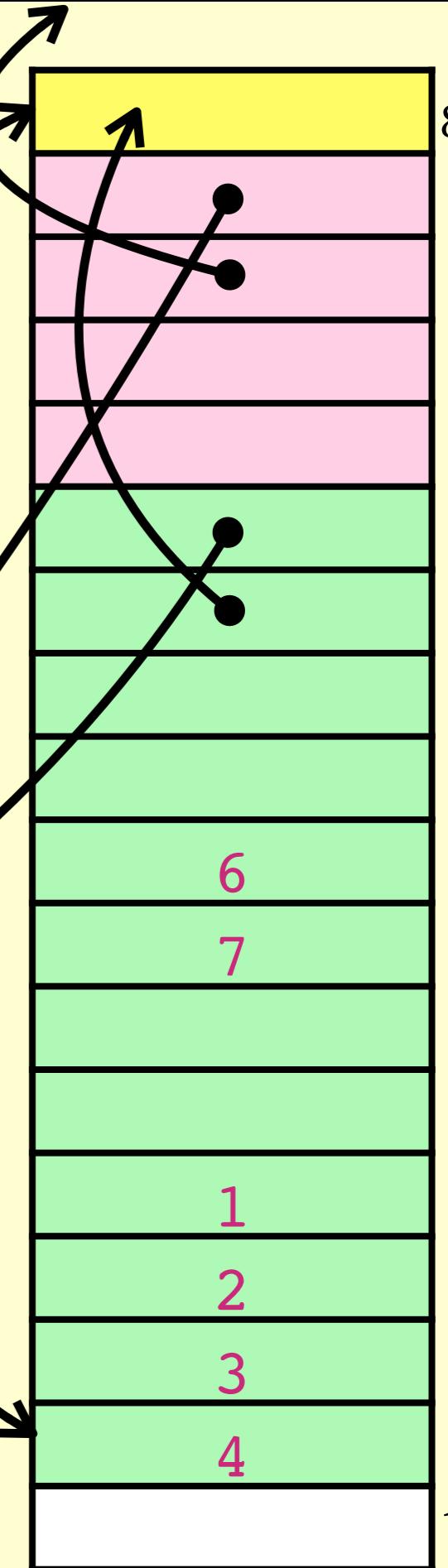
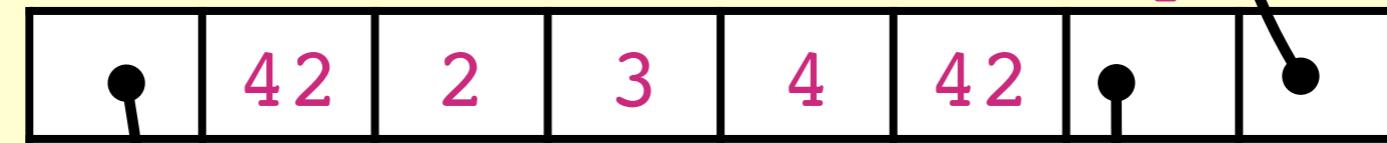


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addi sp,sp,-48
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sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
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sw a3,-48(s0)
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sw a5,-20(s0)
li a5,7
sw a5,-24(s0)
li a5,42
mv a0,a5
lw ra,44(sp)
lw s0,40(sp)
addi sp,sp,48
jr ra
```

```
main:
addi sp,sp,-16
sw ra,12(sp)
sw s0,8(sp)
addi s0,sp,16
li a3,4
li a2,3
li a1,2
li a0,1
call f
nop
mv a0,a5
lw ra,12(sp)
lw s0,8(sp)
addi sp,sp,16
jr ra
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```
int f (int a, int b, int c, int d) {
    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
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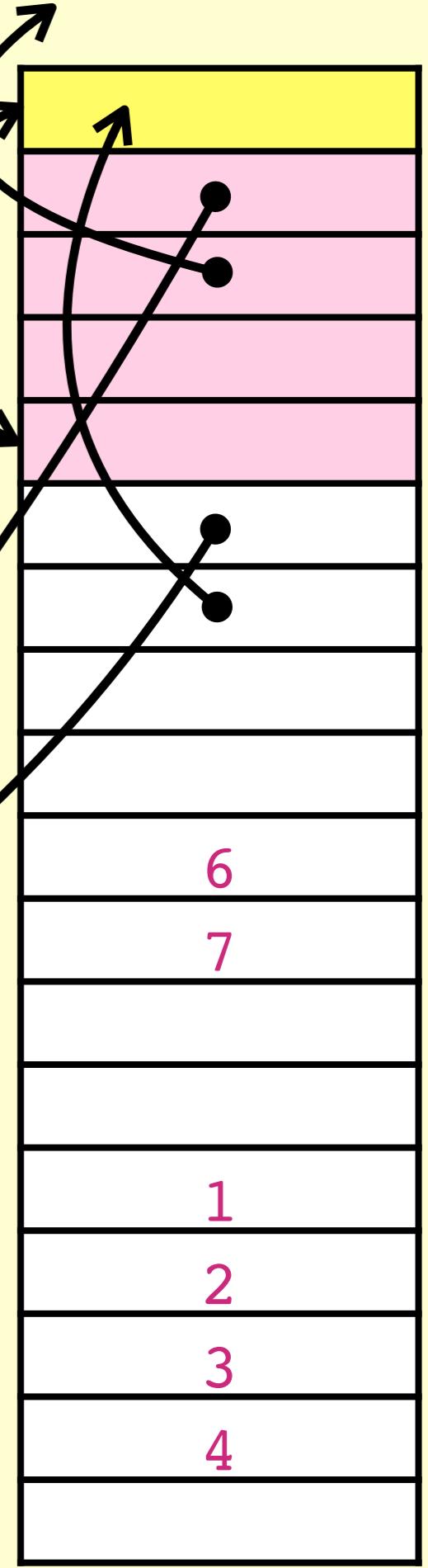
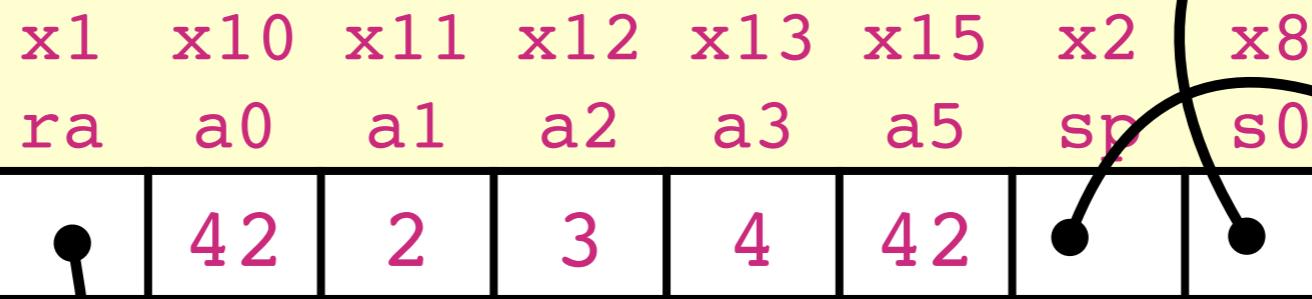
x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	42	2	3	4	42		



```
f:
addi sp,sp,-48
sw ra,44(sp)
sw s0,40(sp)
addi s0,sp,48
sw a0,-36(s0)
sw a1,-40(s0)
sw a2,-44(s0)
sw a3,-48(s0)
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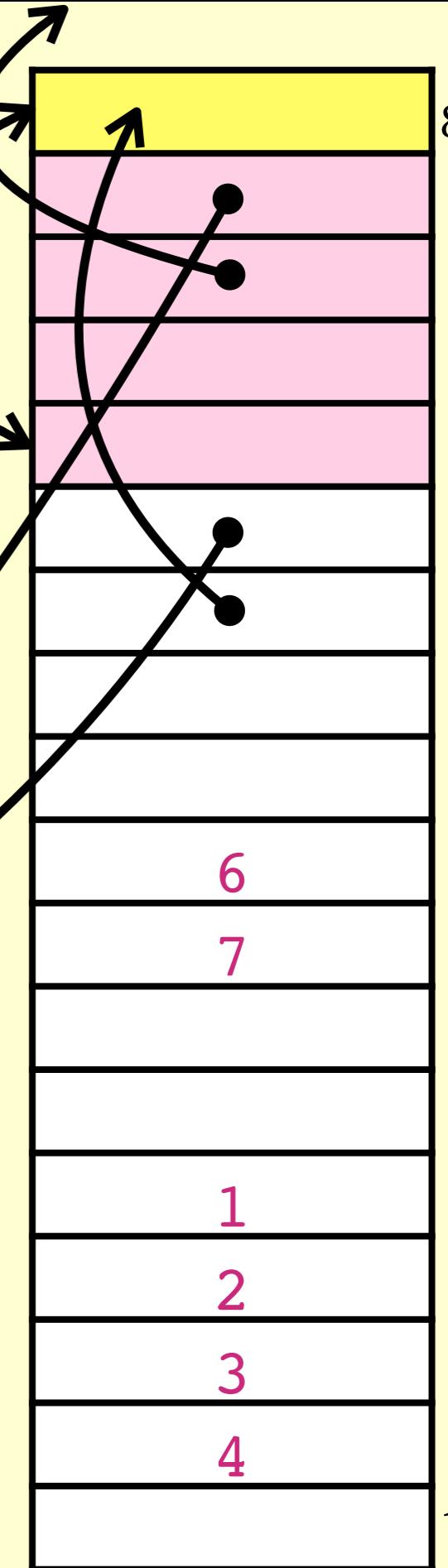
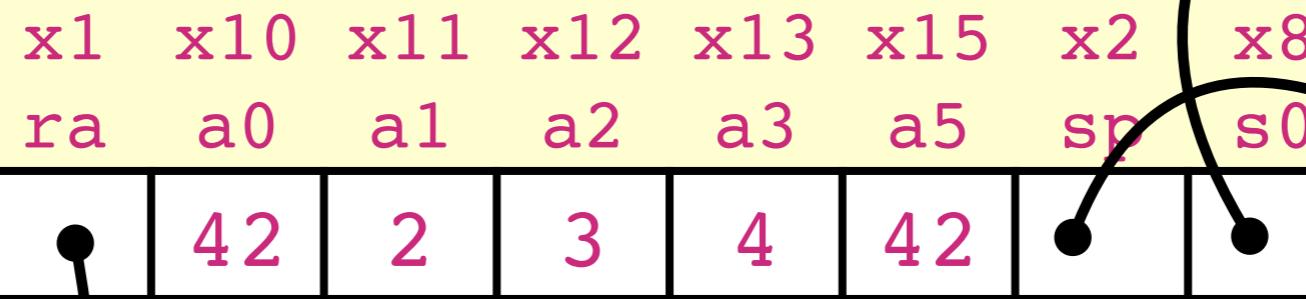
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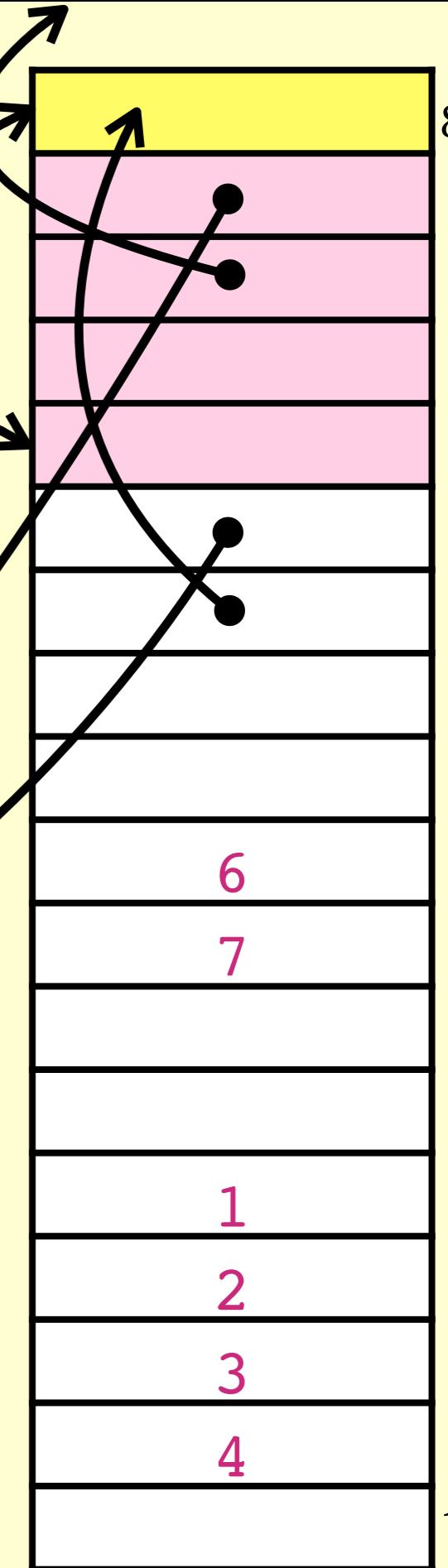
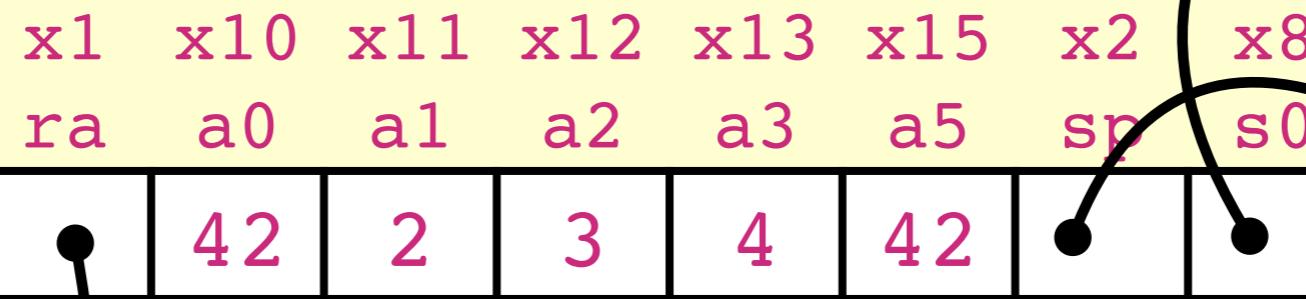
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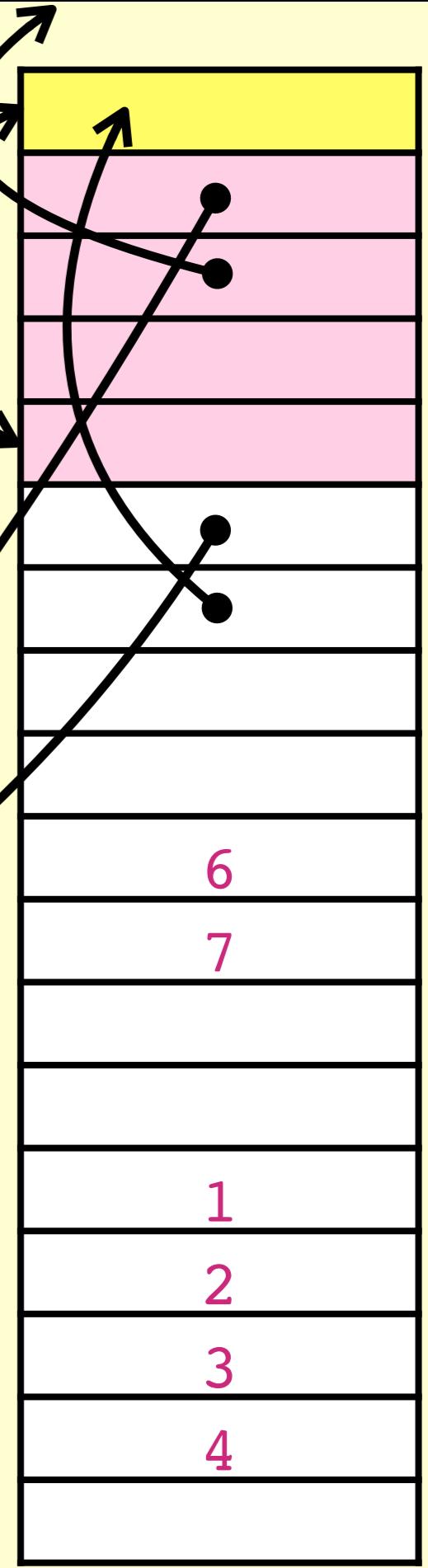
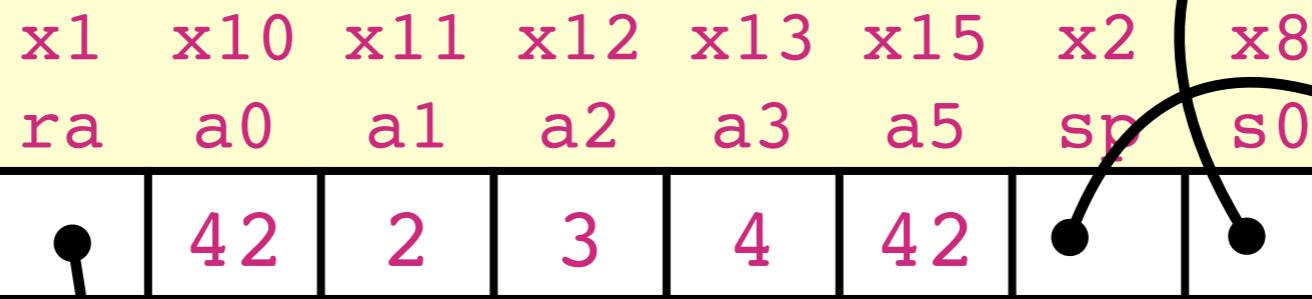
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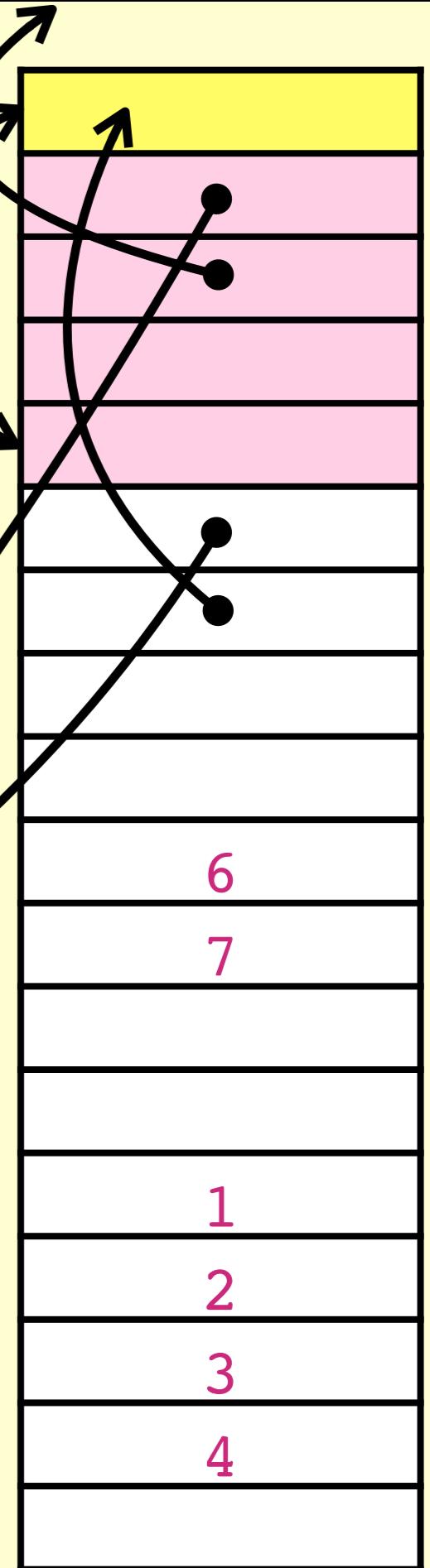
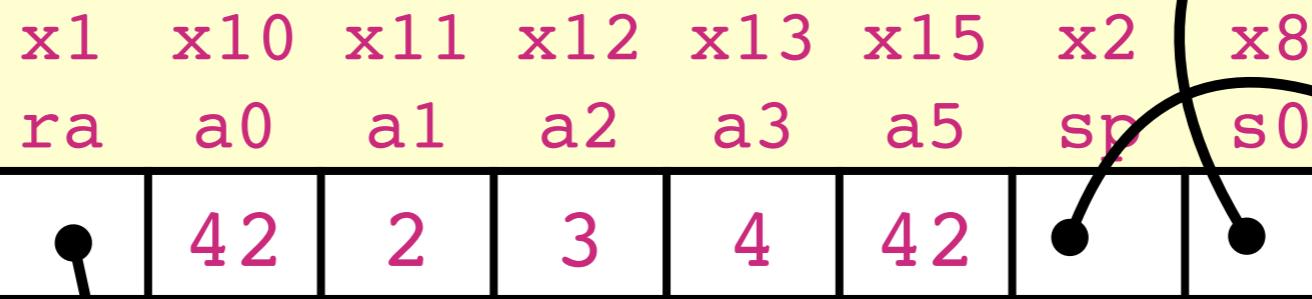
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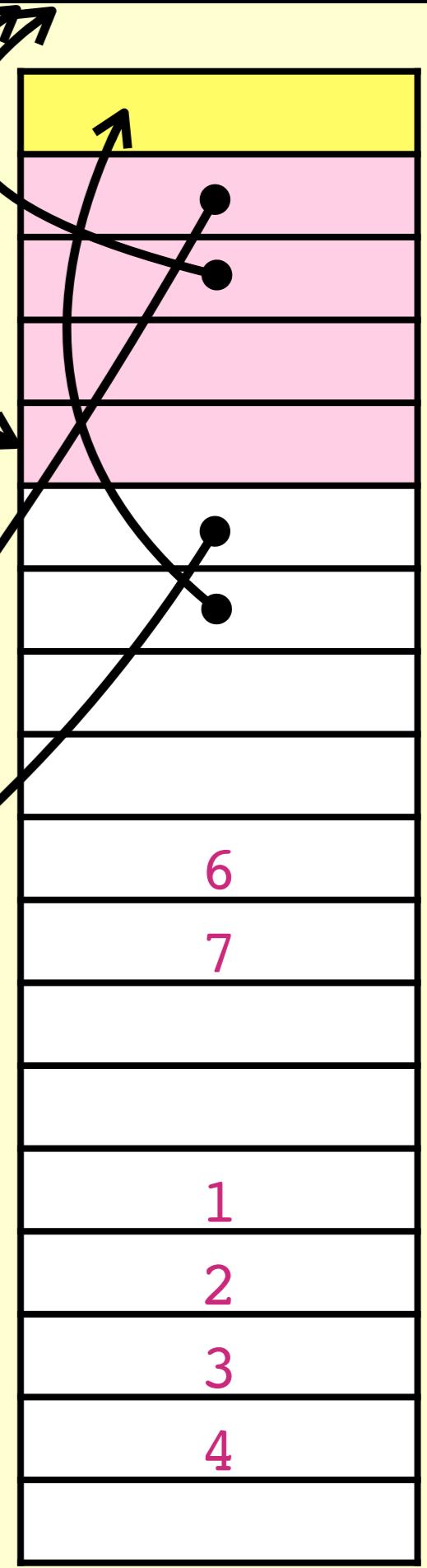
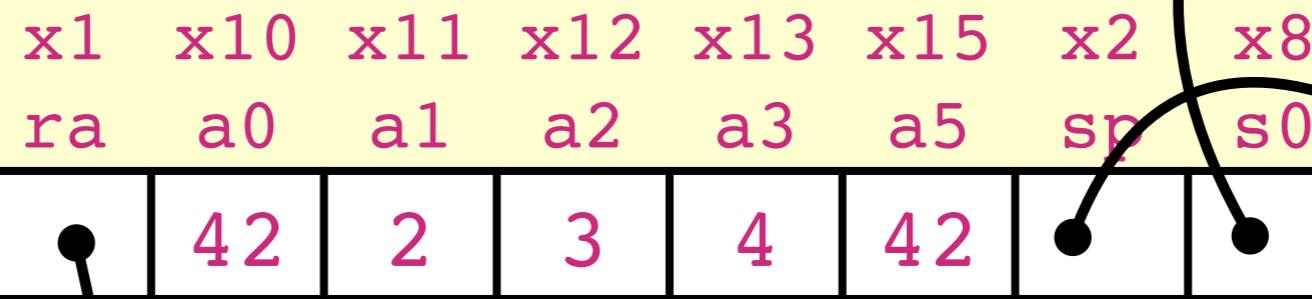
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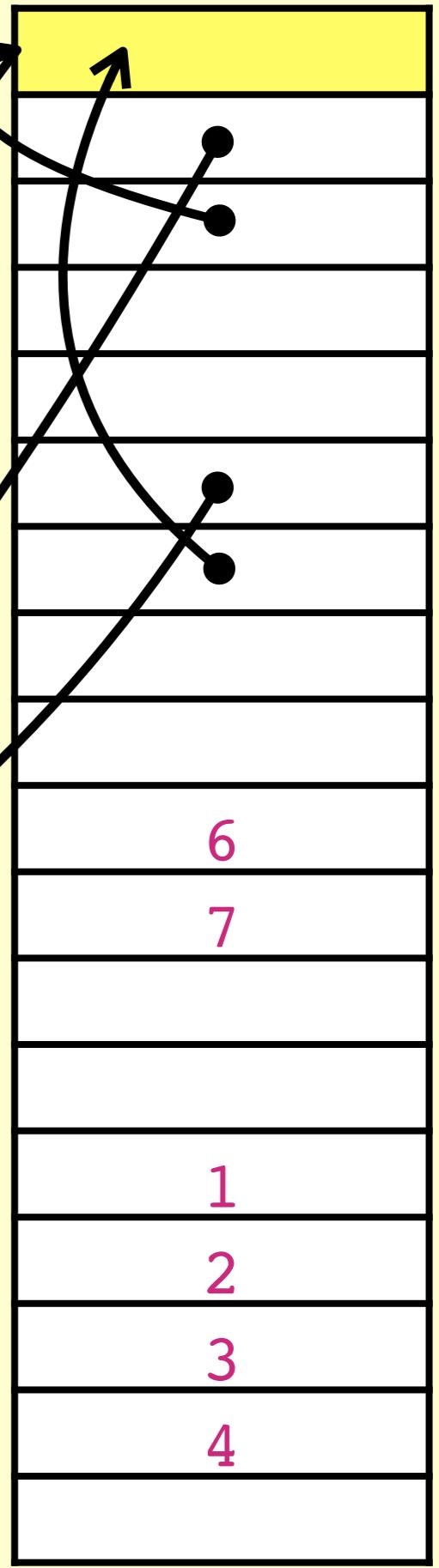


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x1	x10	x11	x12	x13	x15	x2	x8
ra	a0	a1	a2	a3	a5	sp	s0
	42	2	3	4	42		

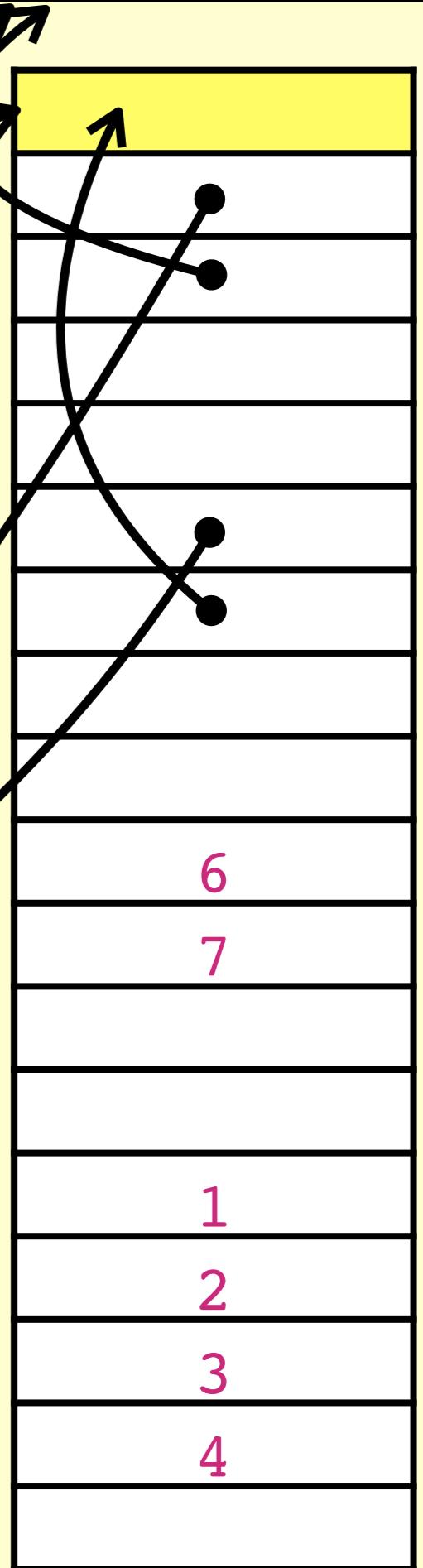


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lw s0,8(sp)
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    int t=6; int u=7; return 42; }
int main () { f(1,2,3,4); }
```

x1	x10	x11	x12	x13	x15	x2	x8
ra	42	2	3	4	42	sp	s0



# Lecture outline

- ✓ Parsing C: the *dangling-else* problem.
- ✓ Parsing C: the *lexer hack*.
- ✓ Generating RISC-V assembly for function calls.