Pointers, Memory, and the Free Store

EECS 230

Winter 2017

00	10	20	30	40
01	11	21	31	41
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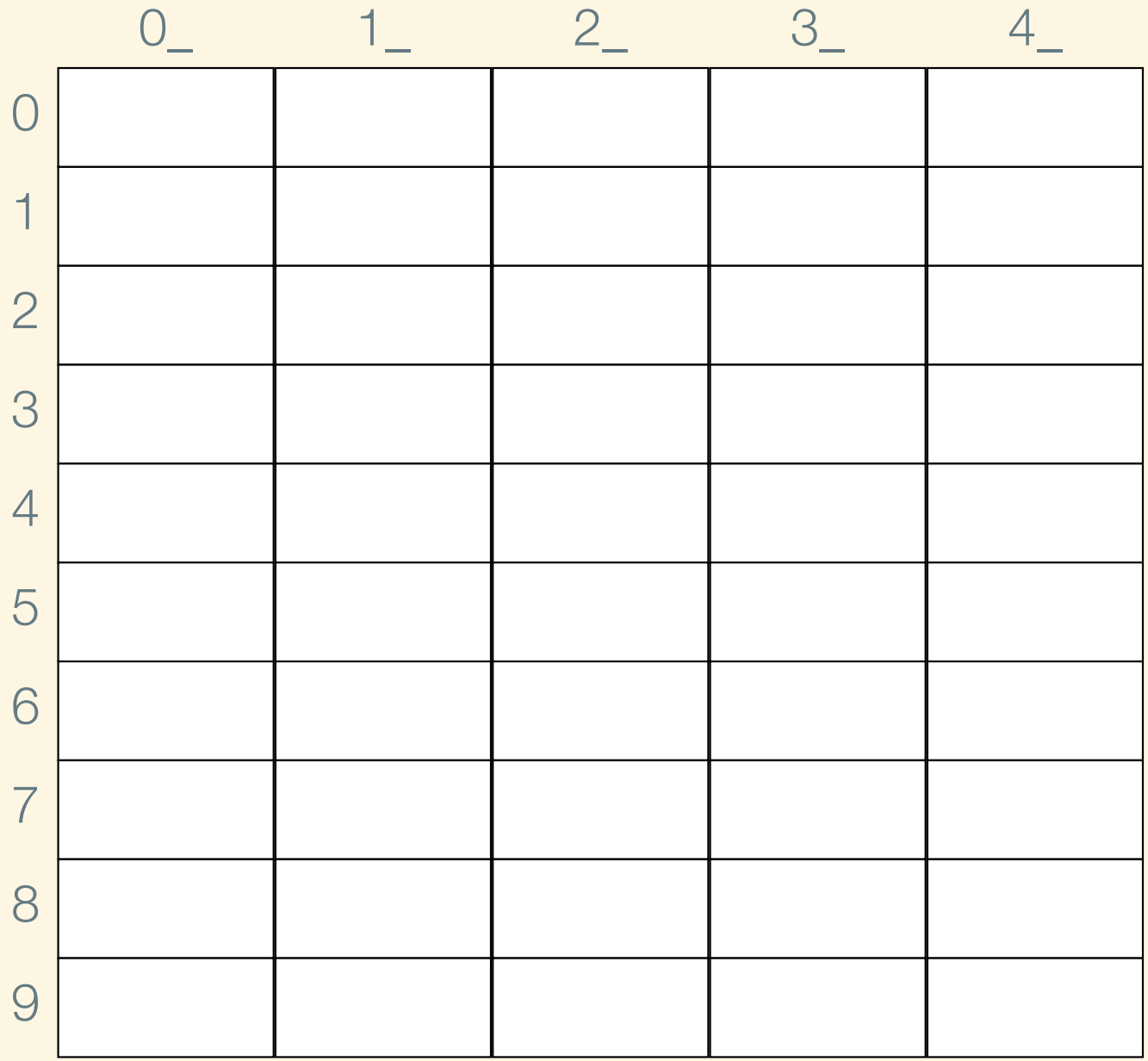
04	14	24	34	44
05	15	25	35	45
06	16	26	36	46
07	17	27	37	47
08	18	28	38	48
09	19	29	39	49

	0_	1_	2_	3_	4_
0	00	10	20	30	40
1	01	11	21	31	41
2	02	12	22	32	42
3	03	13	23	33	43
4	04	14	24	34	44
5	05	15	25	35	45
6	06	16	26	36	46
7	07	17	27	37	47
8	08	18	28	38	48
9	09	19	29	39	49


0_
1_
2_
3_
4_
0
1
2
3
4
5
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7
8
9

Understanding memory

	0_	1_	2_
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As operators, & and * are inverses!

Pointer example

```
int x = 4;
int y = 6;
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```
int x = 4;
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int* p = &x;
CHECK_EQUAL(4, *p);
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x = 5;
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Pointer example

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int* p = &x;
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x = 5;
CHECK_EQUAL(5, *p);

p = &y;
CHECK_EQUAL(6, *p);

*p = 7;
CHECK_EQUAL(7, y);
```

& versus *

	*	&
as type (postfix)	`int*` means pointer to `int`	`int&` means reference to `int`
as expression (prefix)	`*p` dereferences pointer `p` to get value	`&x` takes address of variable `x` to get pointer

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Unlike vectors, raw arrays don't know their size (so they can't bounds check):

```
arr.size();       // error!
```

Pointer arithmetic

Raw arrays are raw pointers in disguise:

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int arr[] = { 2, 3, 4 };
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Variable arr stores the address of the first element, 2.

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Pointers are just addresses—numbers—so we can do arithmetic on them:

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Pointers are just addresses—numbers—so we can do arithmetic on them:

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CHECK_EQUAL(&arr[1], p + 1);
CHECK_EQUAL(&arr[2], p + 2);
CHECK_EQUAL(arr[1], *(p + 1));
CHECK_EQUAL(arr[2], *(p + 2));
```

Array indexing *is* pointer arithmetic

That is,

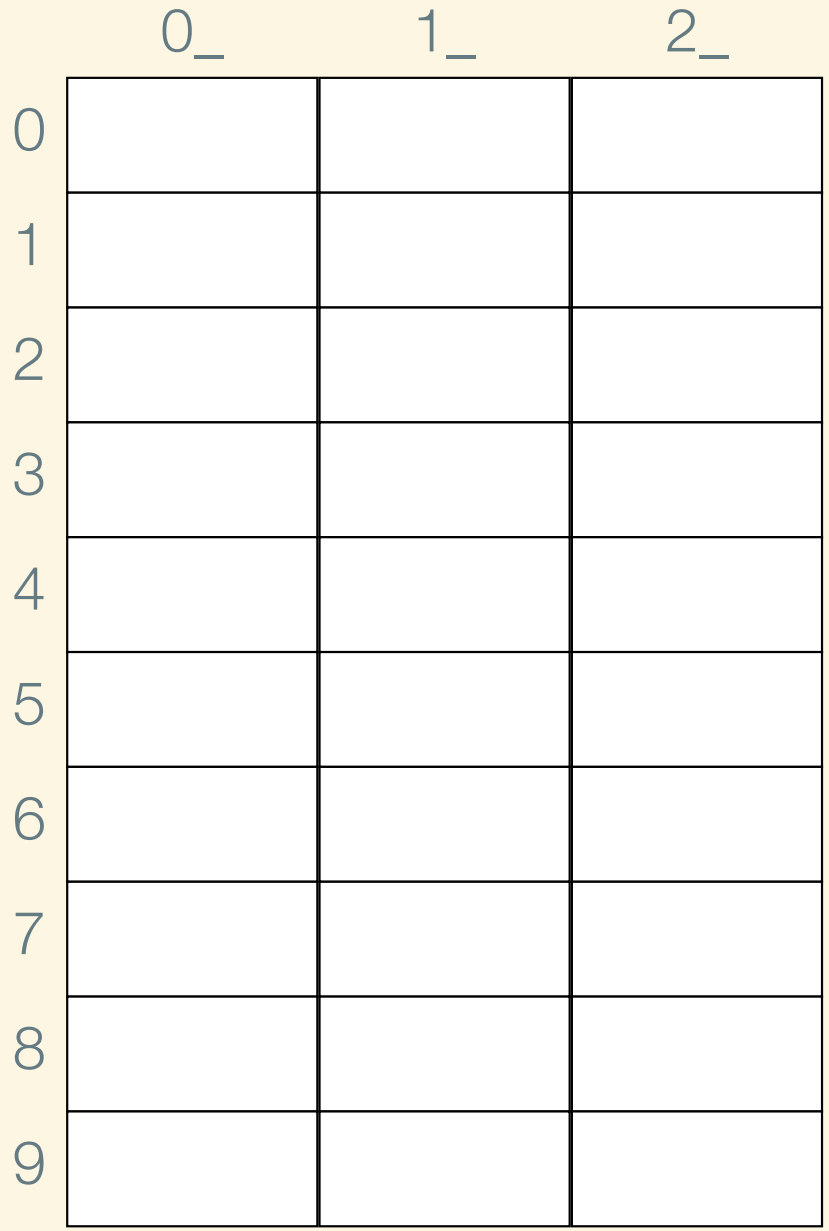
$\mathsf{arr}[\mathsf{i}]$ means the same thing as $*(\mathsf{arr} + \mathsf{i})$

Execution on the stack

```
int g(int x)
{
        return x + 2;
}

int f(int a, int b)
{
        return a * b;
}

int main()
{
        cout << f(g(3), g(8));
}
```



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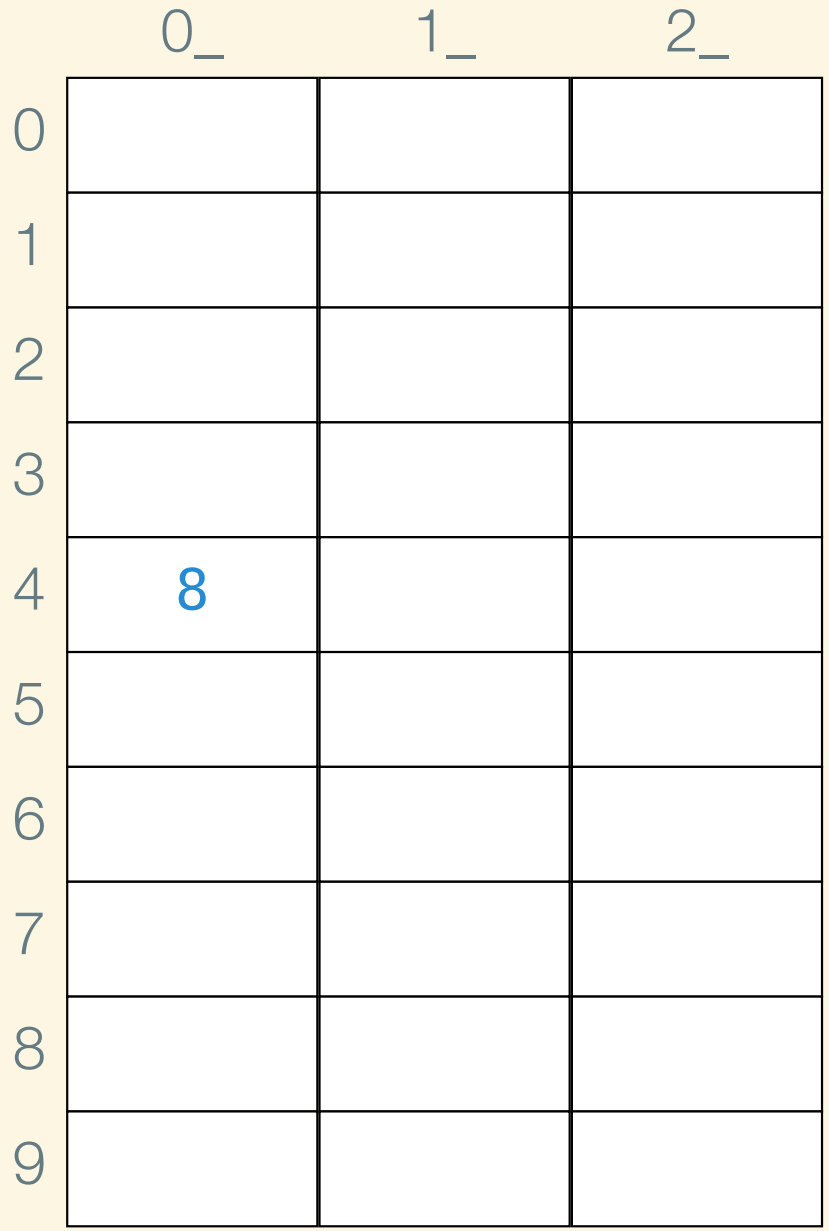

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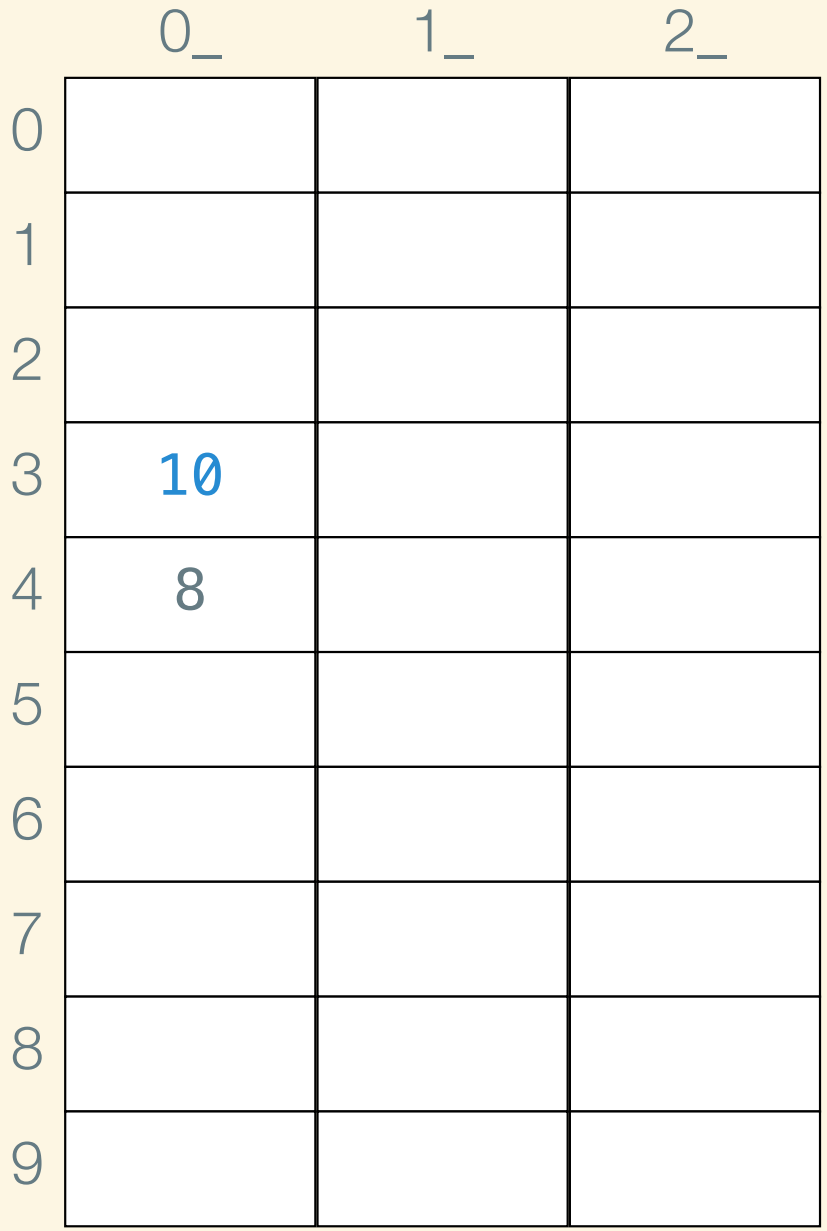

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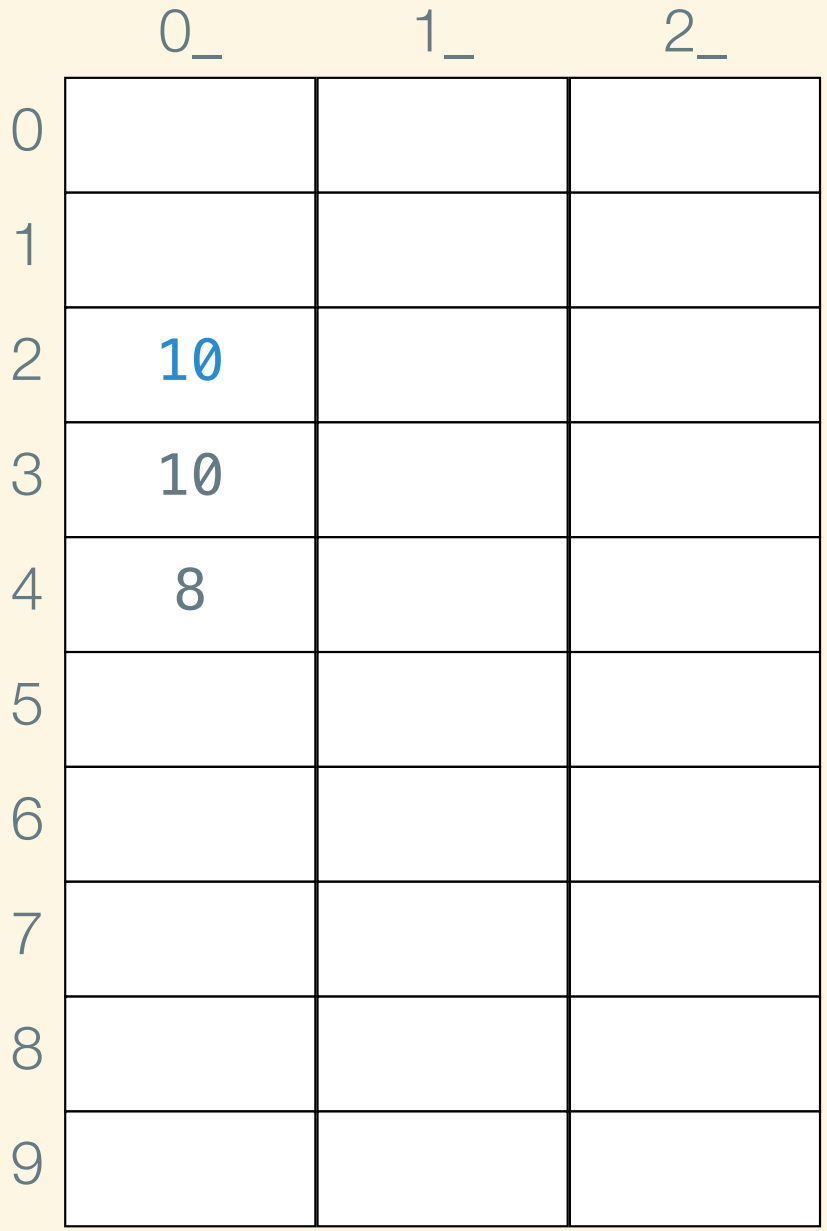

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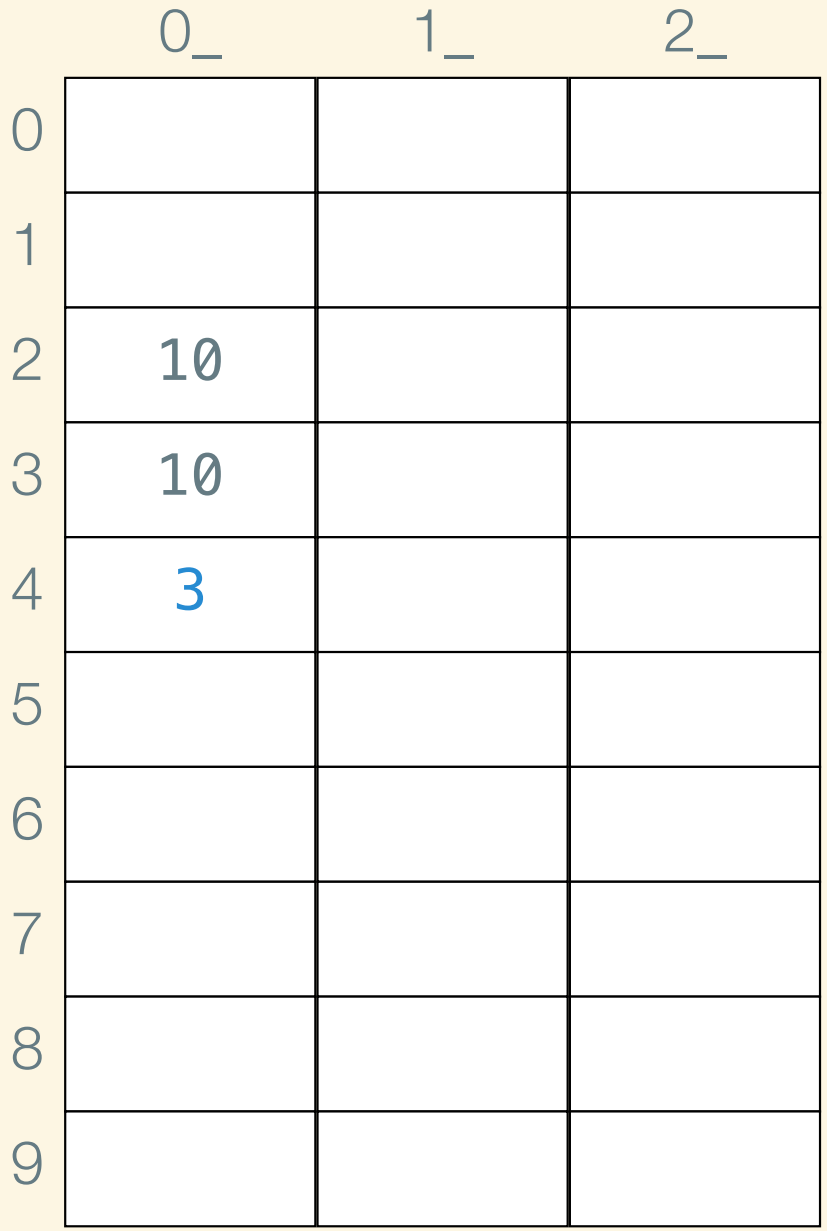

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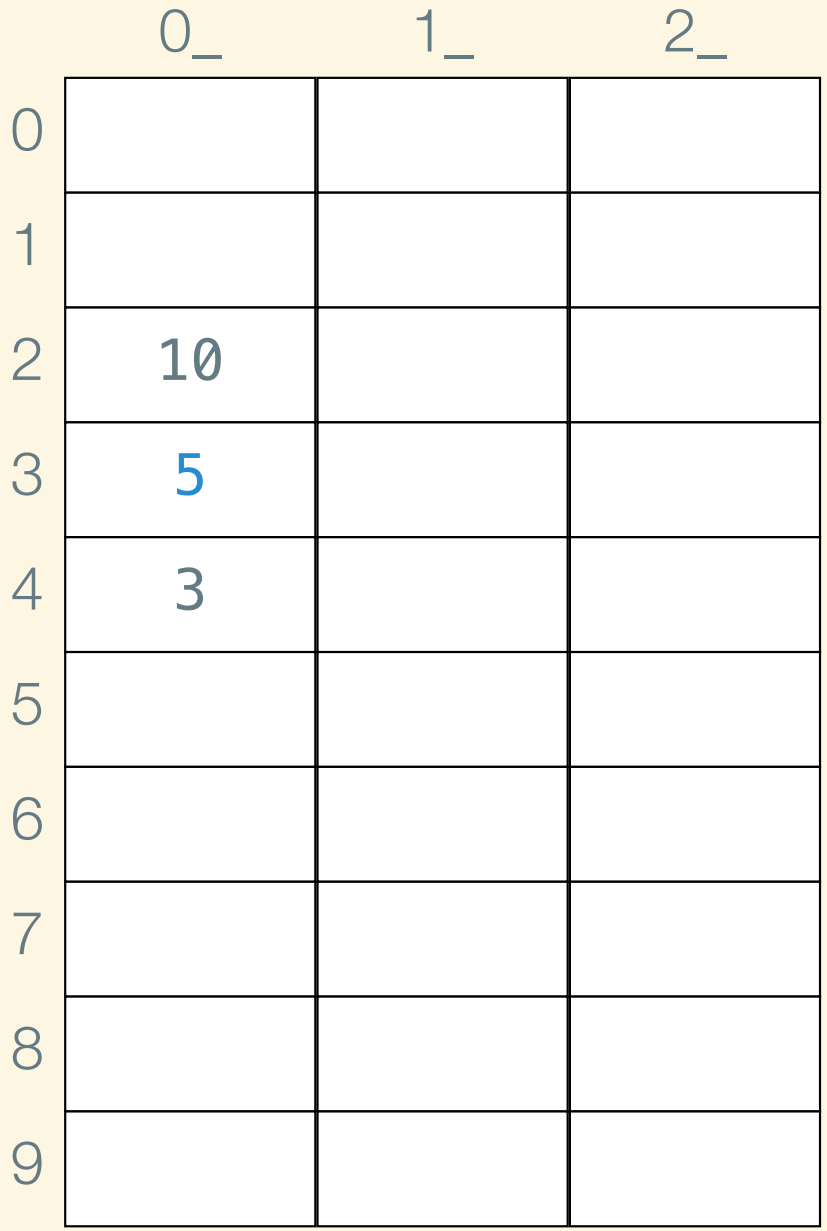

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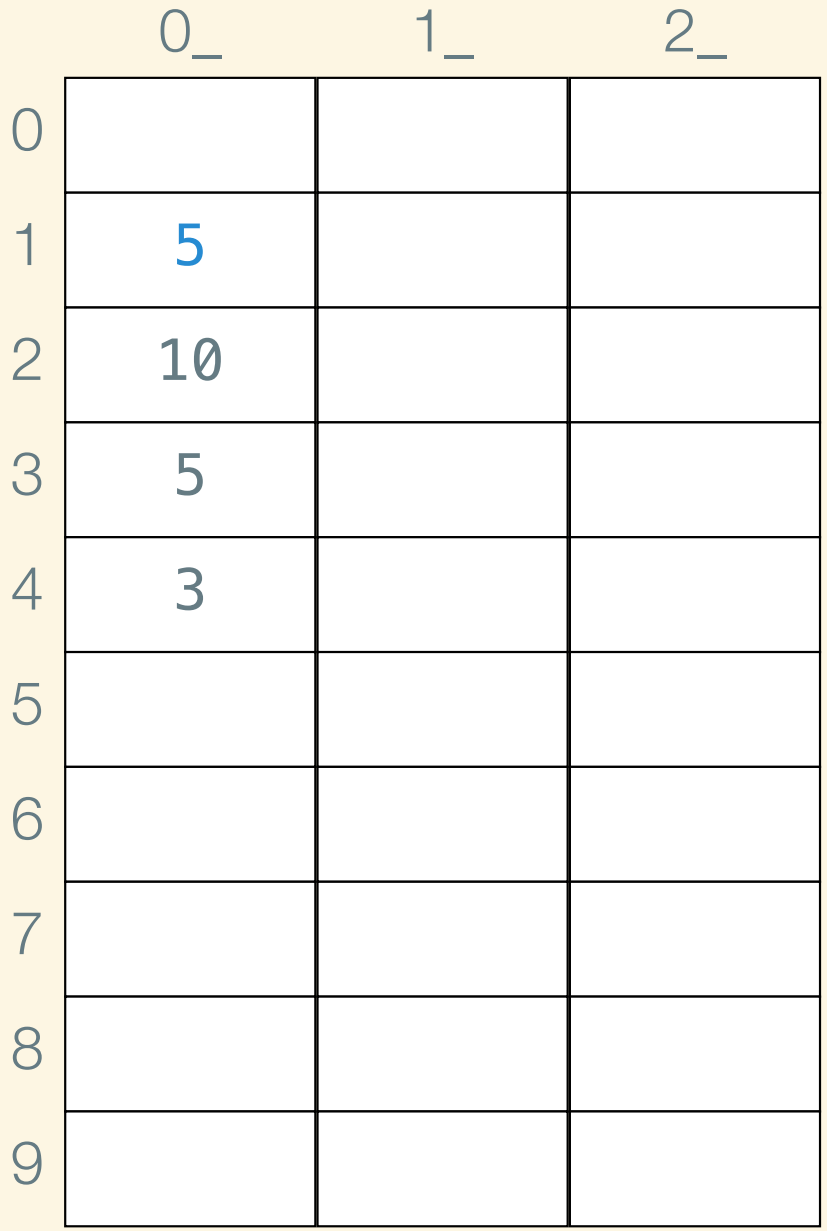

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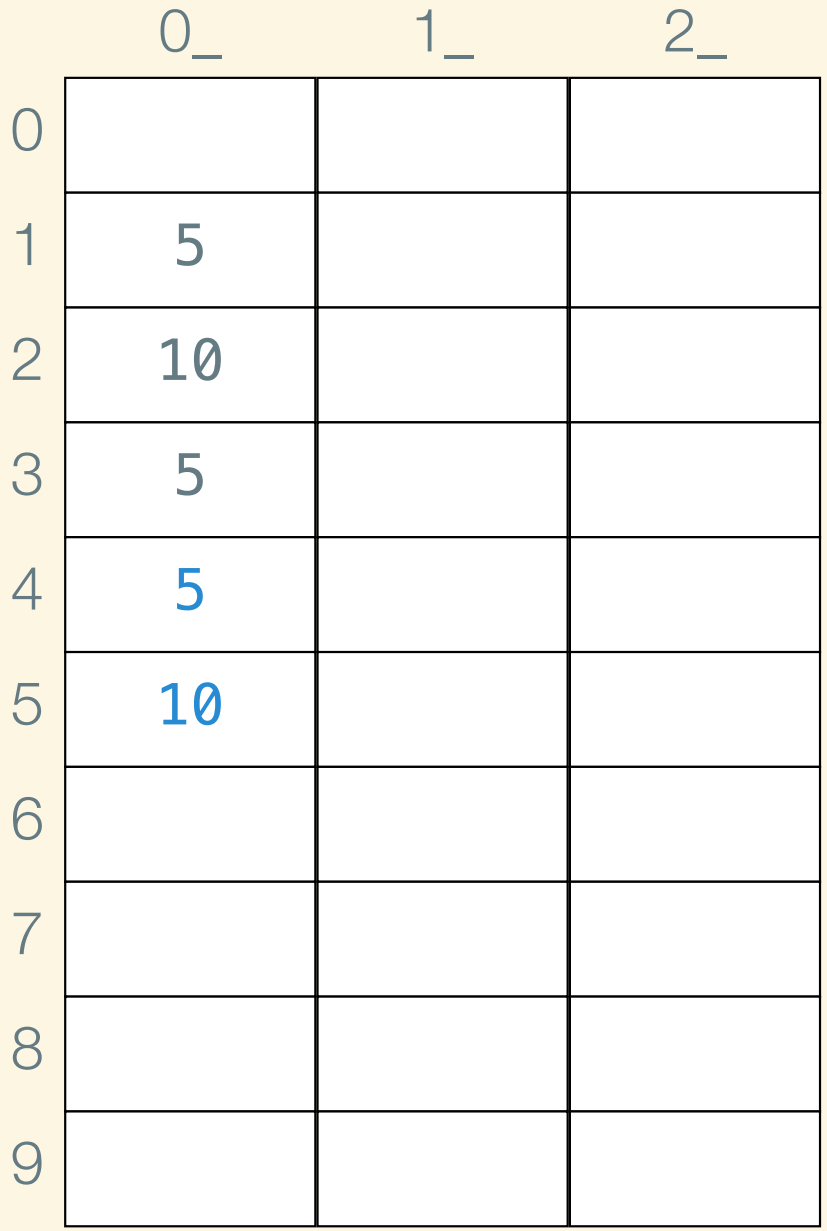

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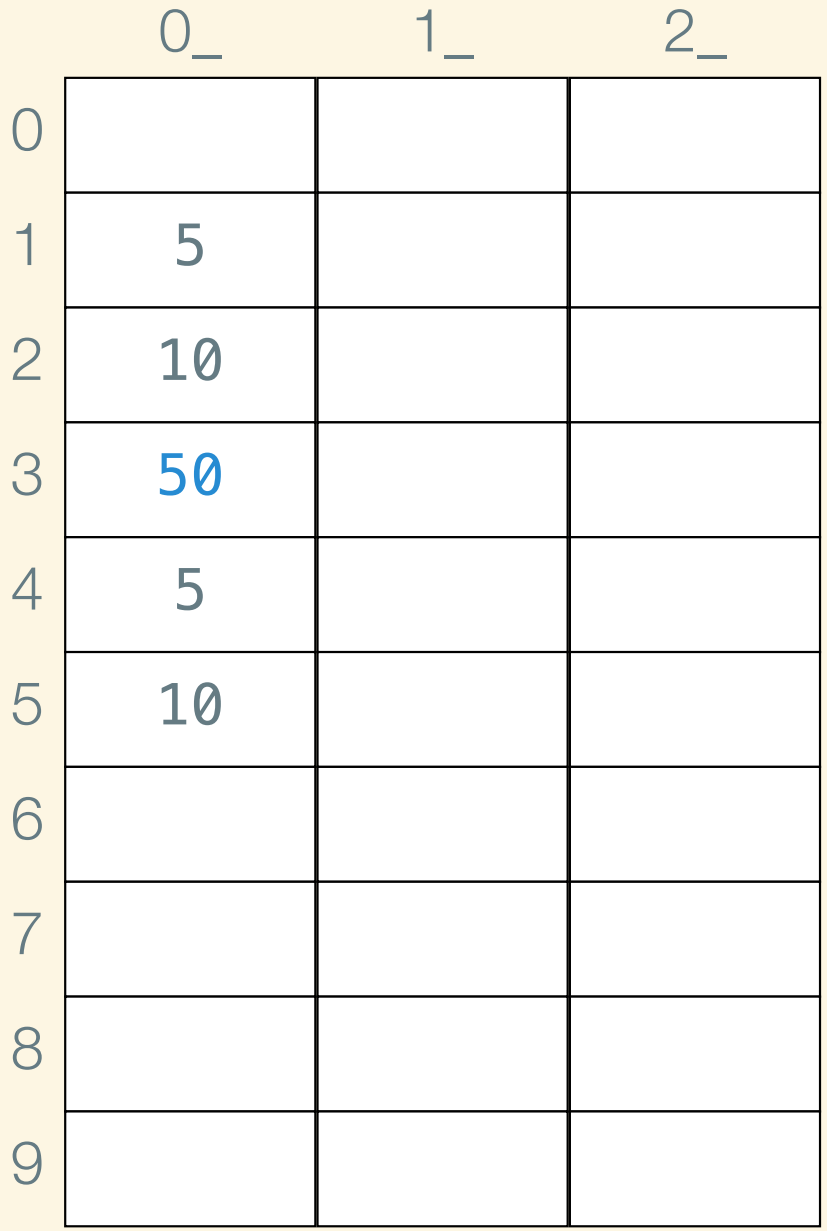

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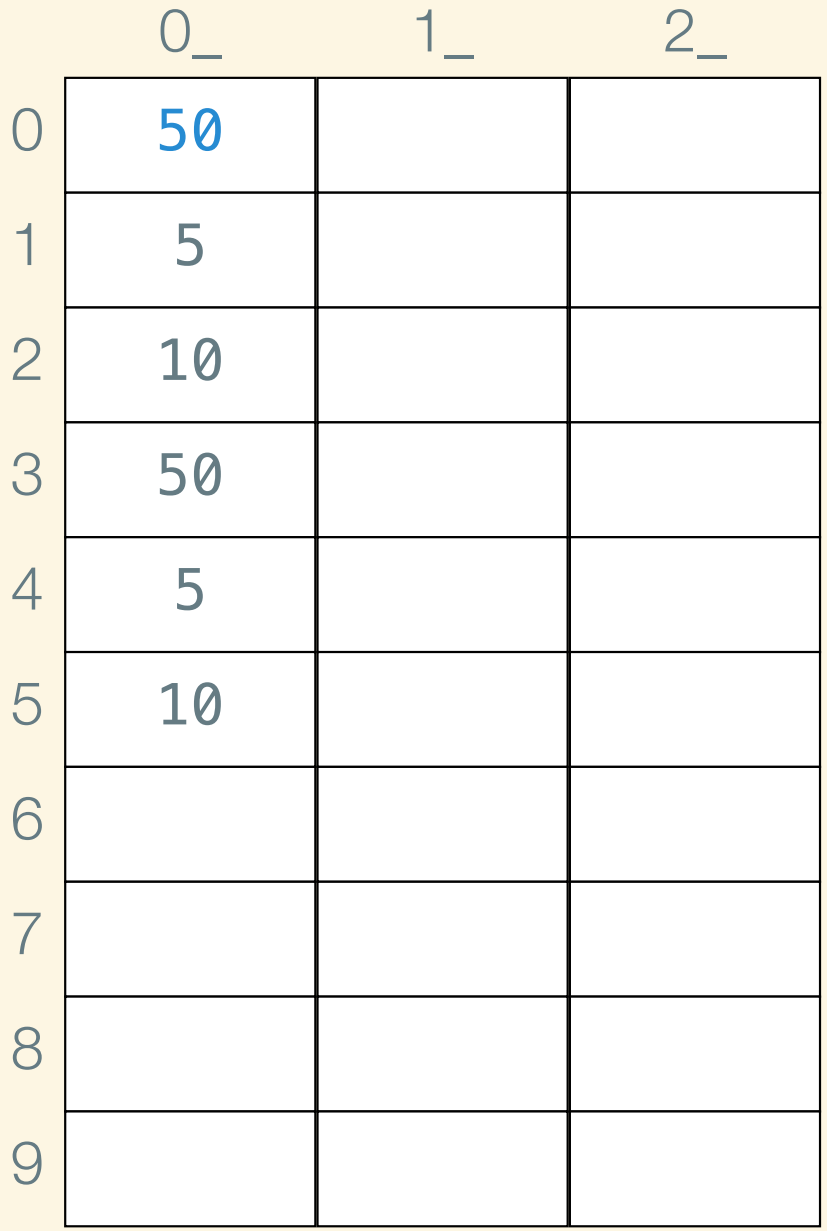

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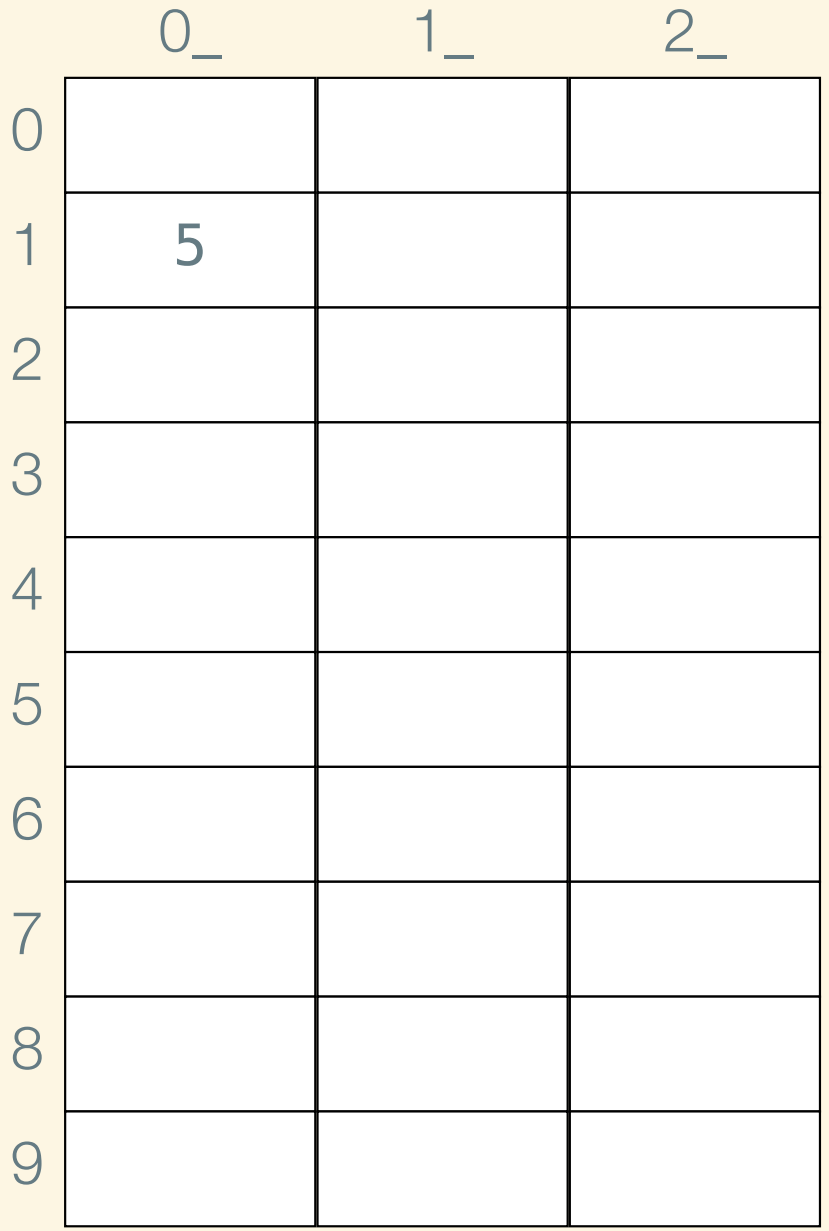
Execution on the stack (more realistic)

```
int g(int x)
{           @ 4
    return x + 2;
}     @ 3

int f(int a, int b)
{           @ 4   @ 5
    return a * b;
}     @ 3

int main()
{                     @ 1   @ 2
    cout << f(g(3), g(8));
}                   @ 0
```

	0_	1_	2_
0	50	798	13
1	5	-4	0
2	10	50	-1
3	50	12	-1
4	5	2	-1
5	10	4	-1
6	99	6	87
7	20	8	4
8	66	10	16
9	0	-9	255

Recursion on the stack

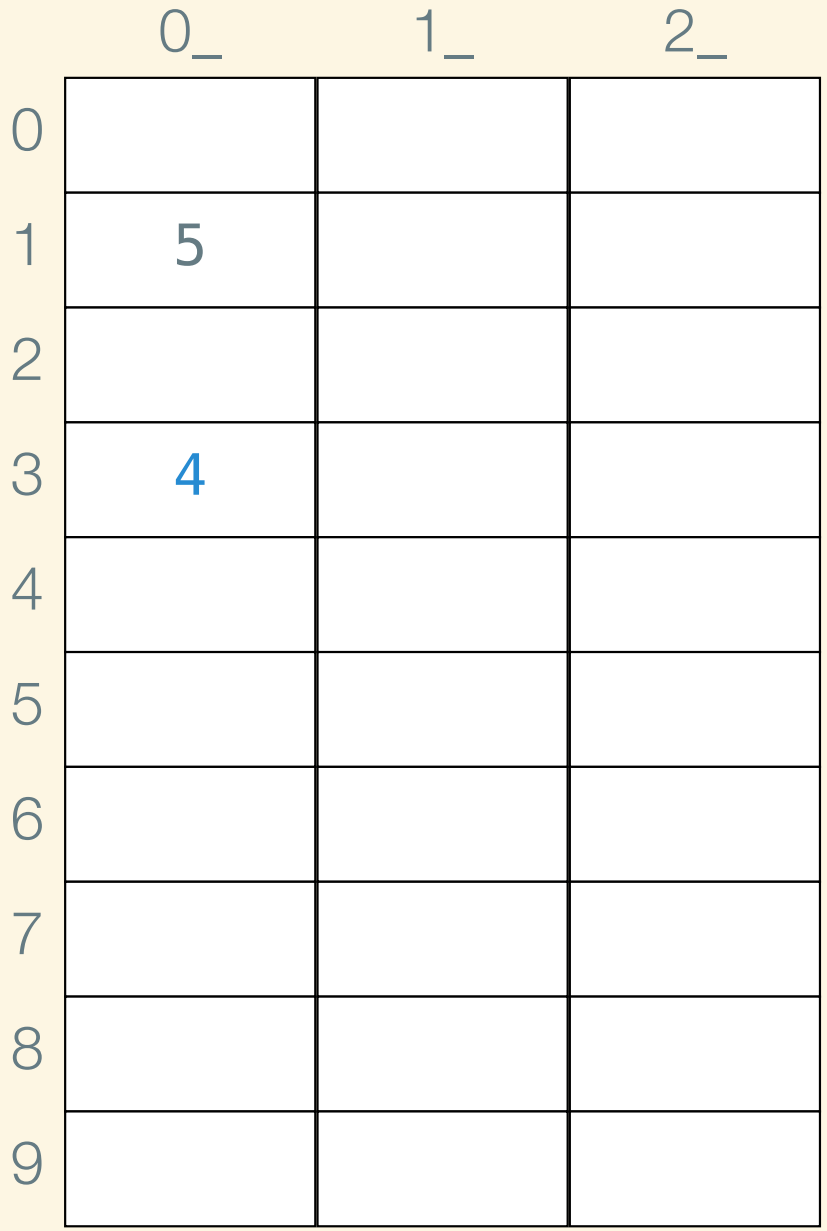
fact(n)	n @	result @
fact(5)	1	0




```
int fact(int n)
{
    if (n == 0)
        return 1;
    else
        return n * fact(n - 1)
}

        fact(5);
```

Recursion on the stack

fact(n)	n @	result @
fact(5)	1	0
fact(4)	3	2




```
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{
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}

        fact(5);
```
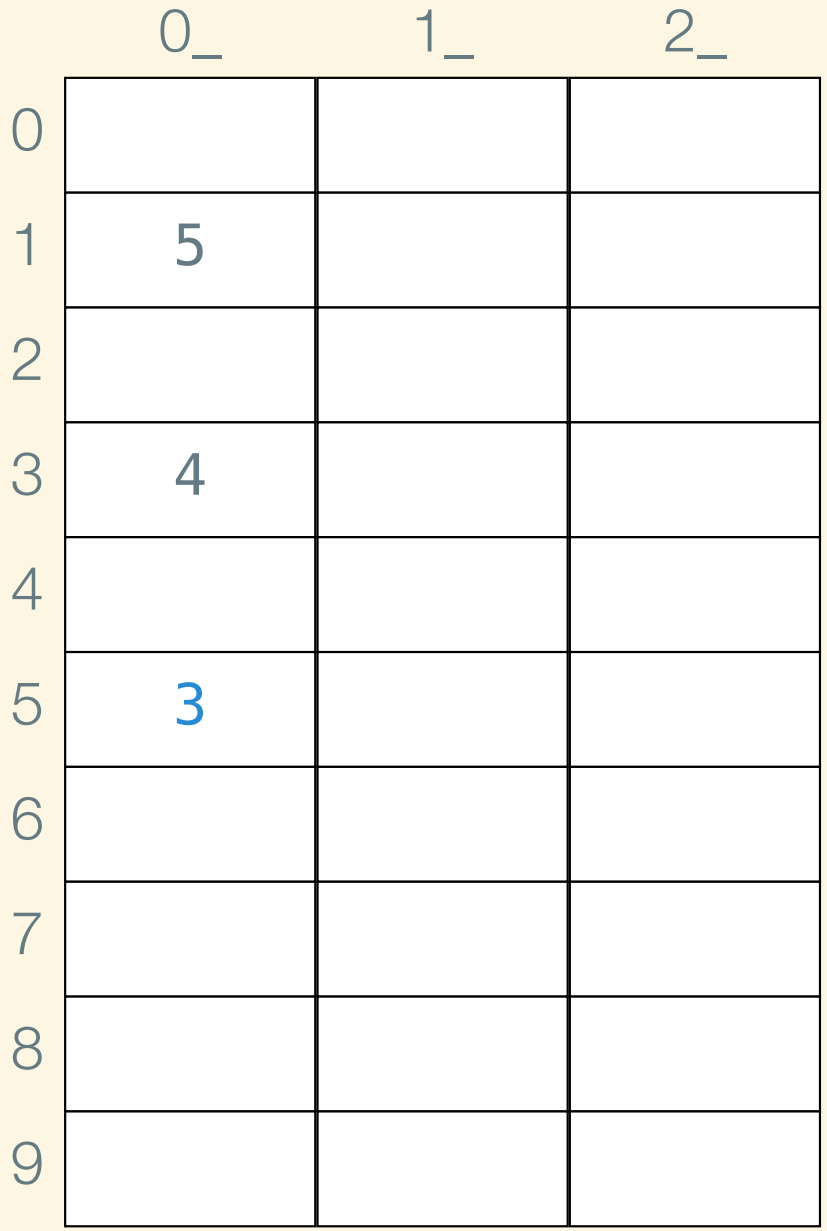

Recursion on the stack

fact(n)	n @	result @
fact(5)	1	0
fact(4)	3	2
fact(3)	5	4




```
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{
    if (n == 0)
        return 1;
    else
        return n * fact(n - 1)
}

        fact(5);
```
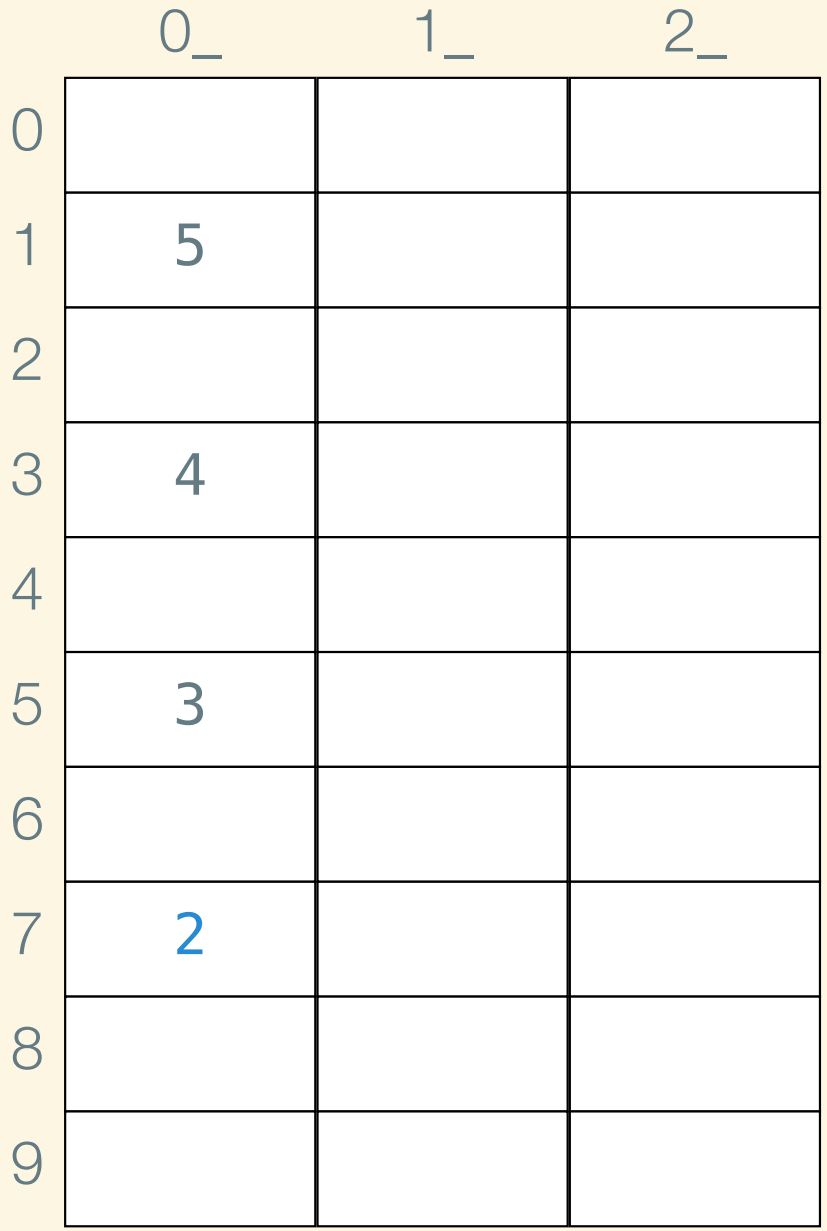

Recursion on the stack

fact(n)	n @	result @
fact(5)	1	0
fact(4)	3	2
fact(3)	5	4
fact(2)	7	6

```
int fact(int n)
{
    if (n == 0)
        return 1;
    else
        return n * fact(n - 1)
}

        fact(5);
```



Recursion on the stack

fact(n)	n @	result @
fact(5)	1	0
fact(4)	3	2
fact(3)	5	4
fact(2)	7	6
fact(1)	9	8

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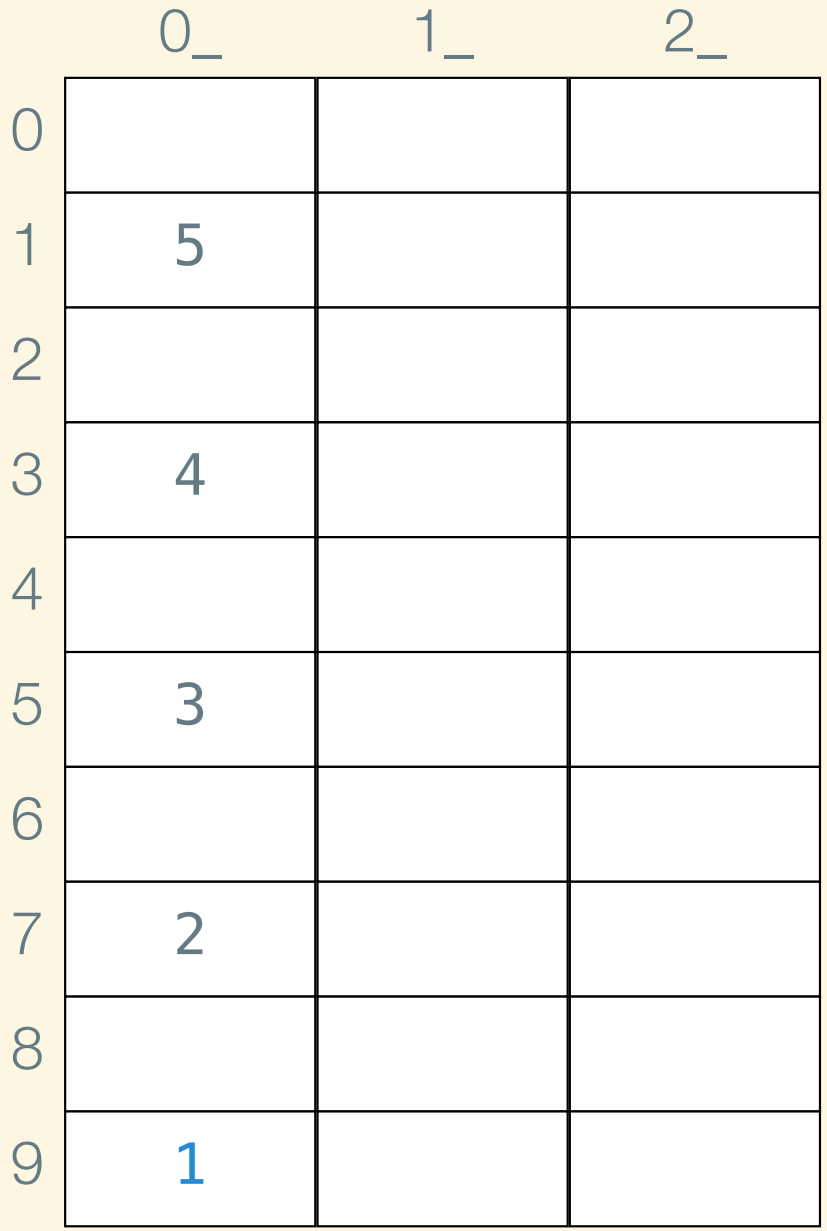

Recursion on the stack

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fact(5)	1	0
fact(4)	3	2
fact(3)	5	4
fact(2)	7	6
fact(1)	9	8
fact(0)	11	10

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{
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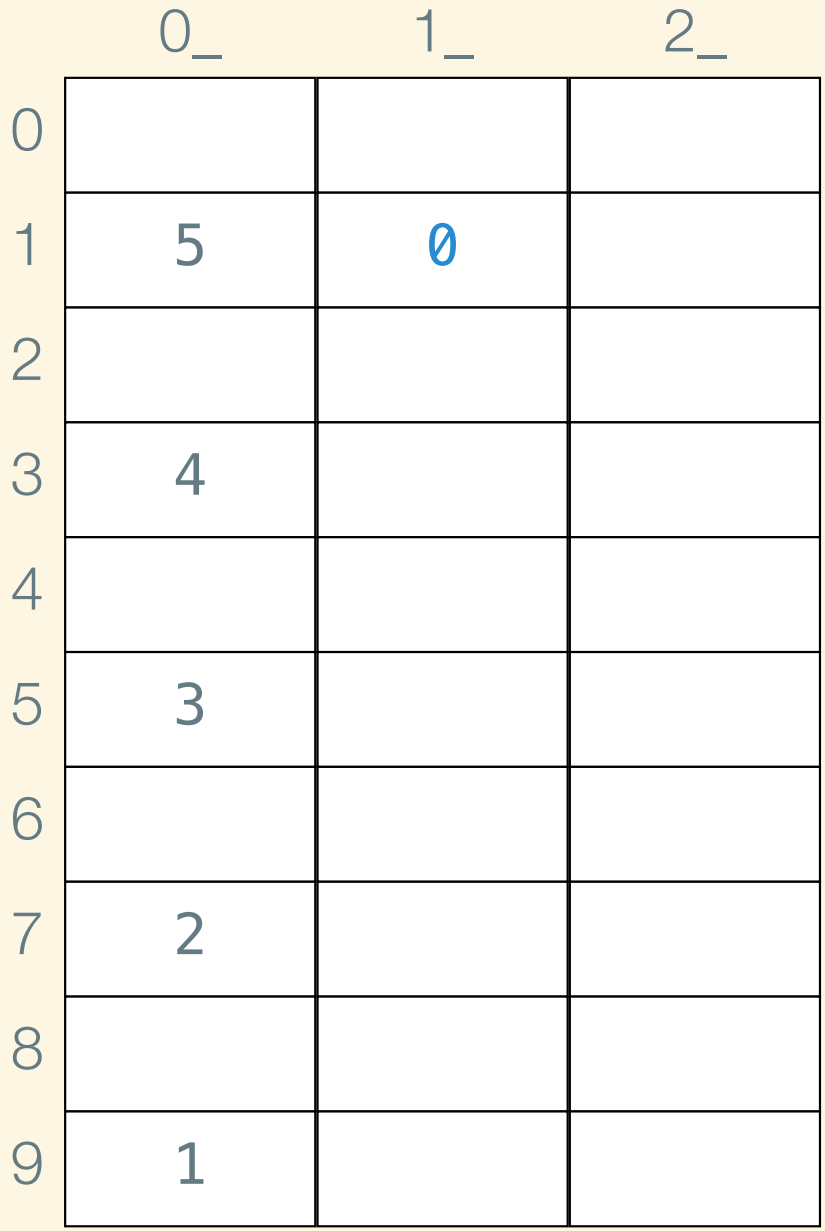
```



Recursion on the stack

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fact(4)	3	2
fact(3)	5	4
fact(2)	7	6
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```

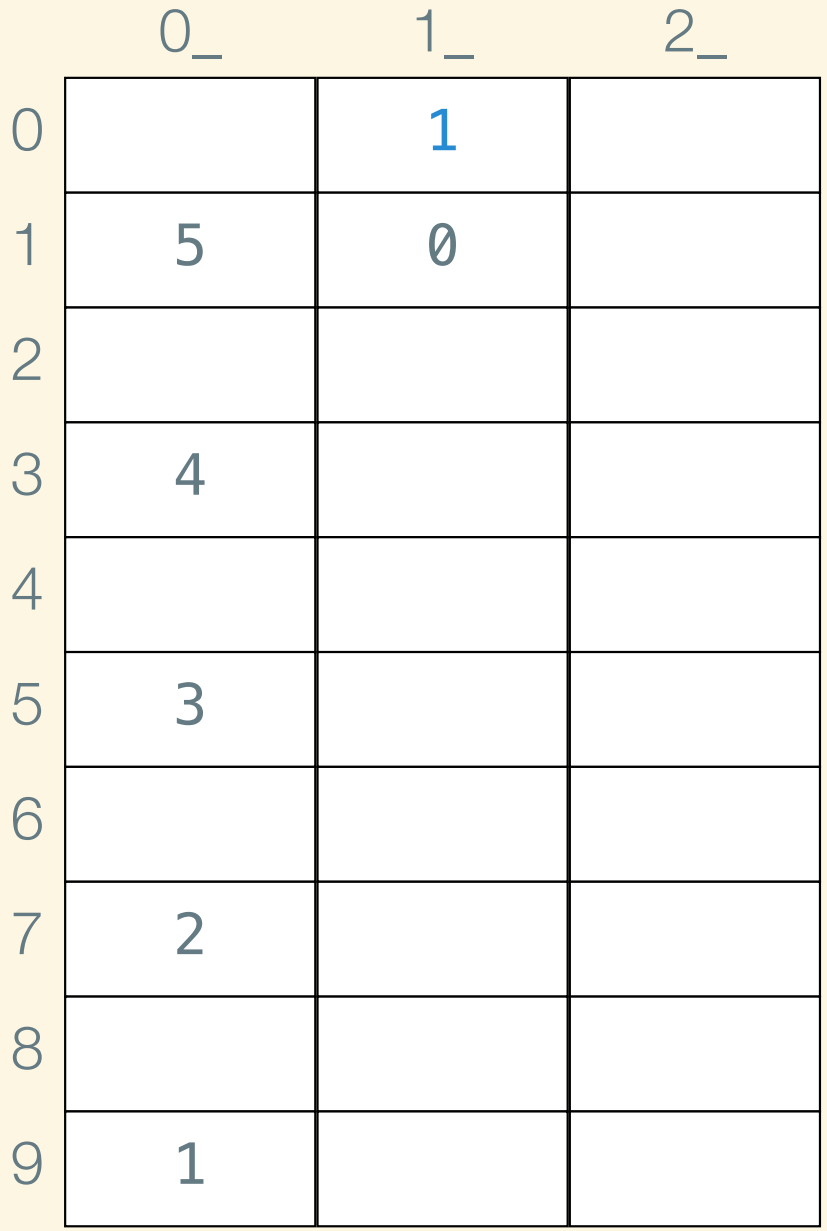

Recursion on the stack

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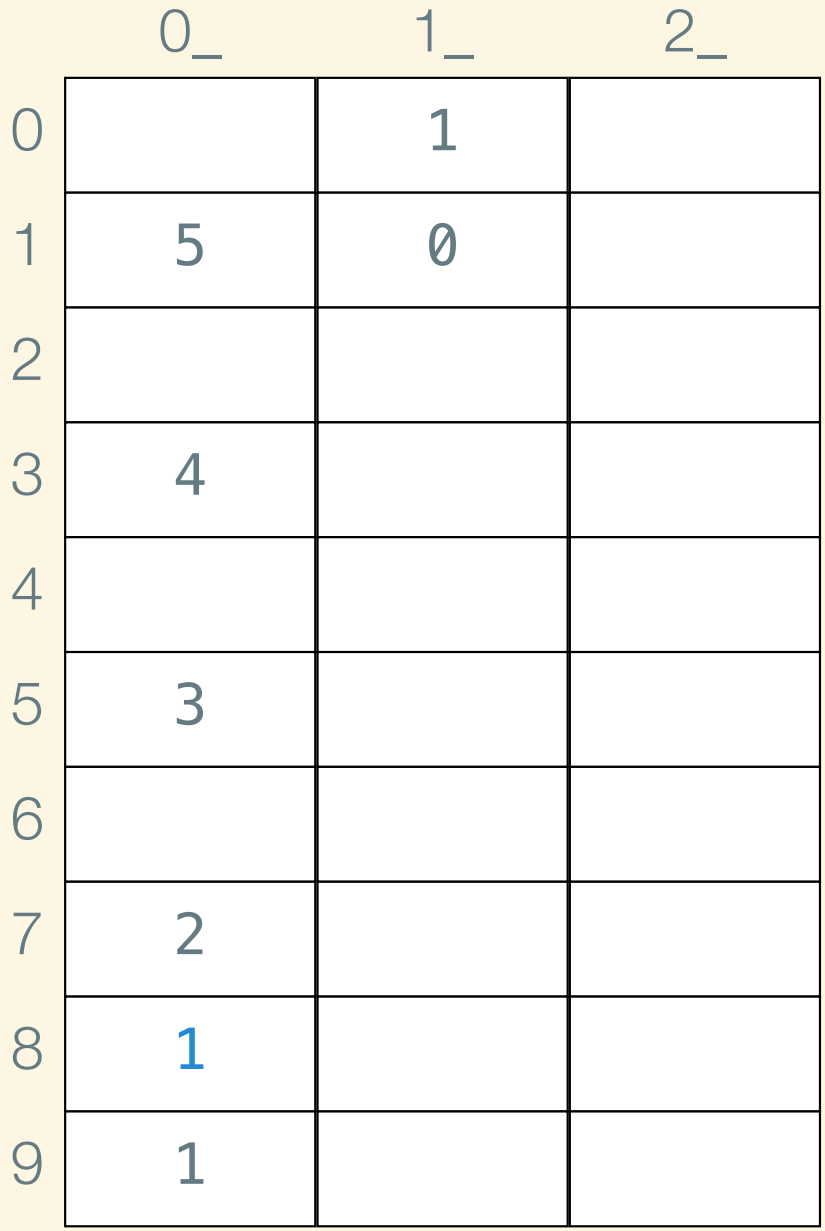

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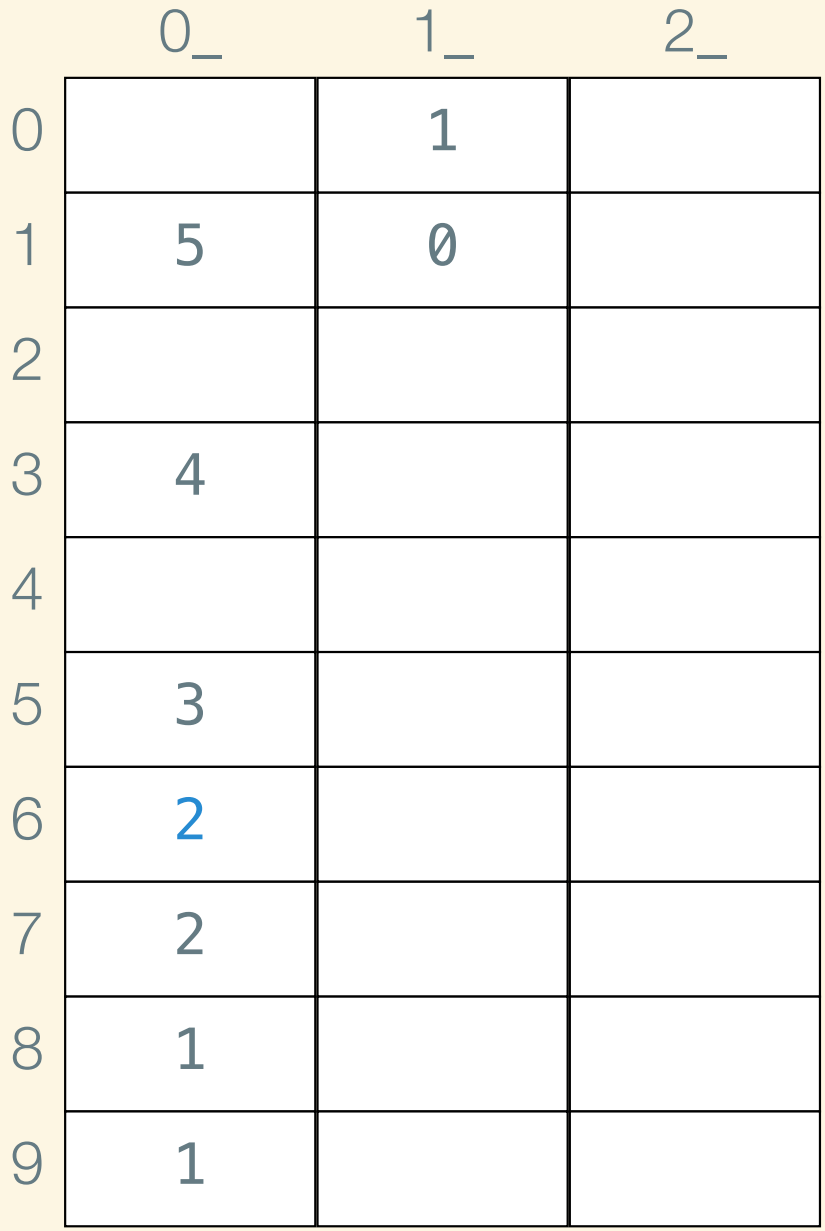
```



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{
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}

        fact(5);
```

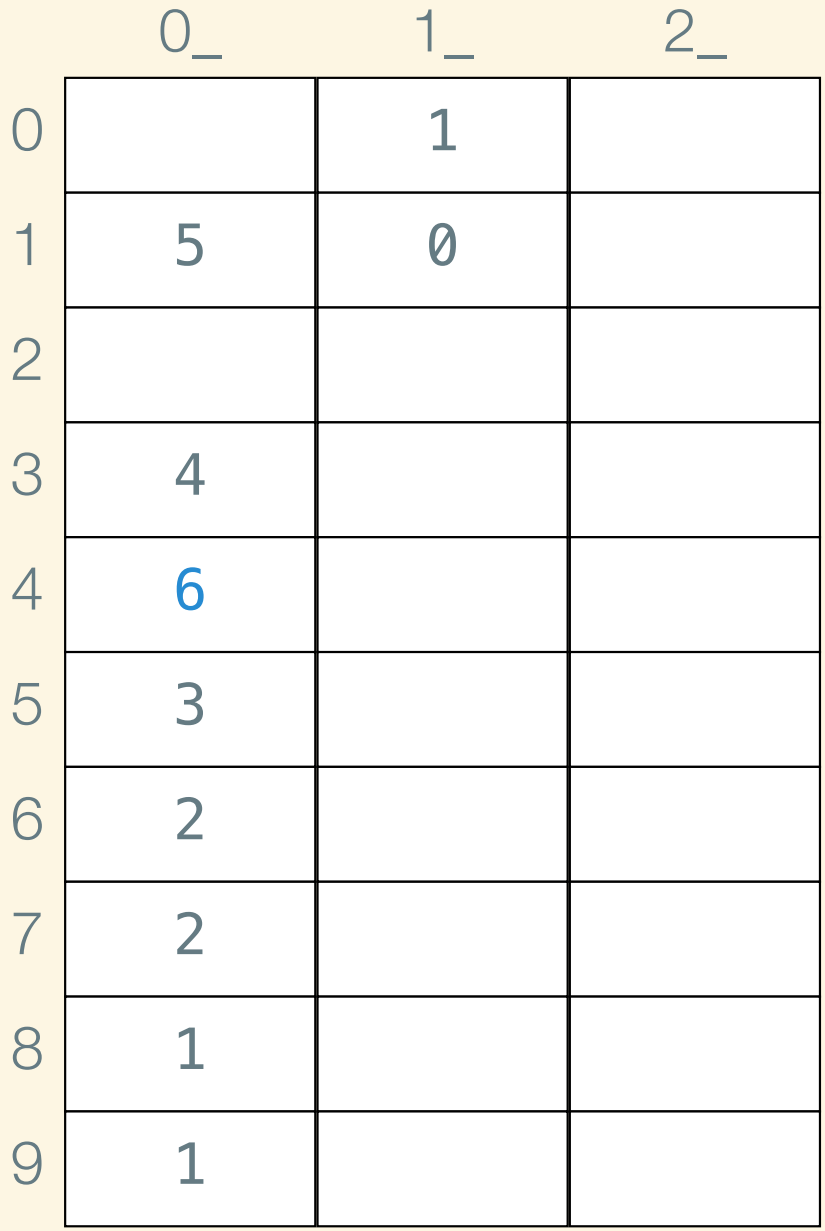

Recursion on the stack

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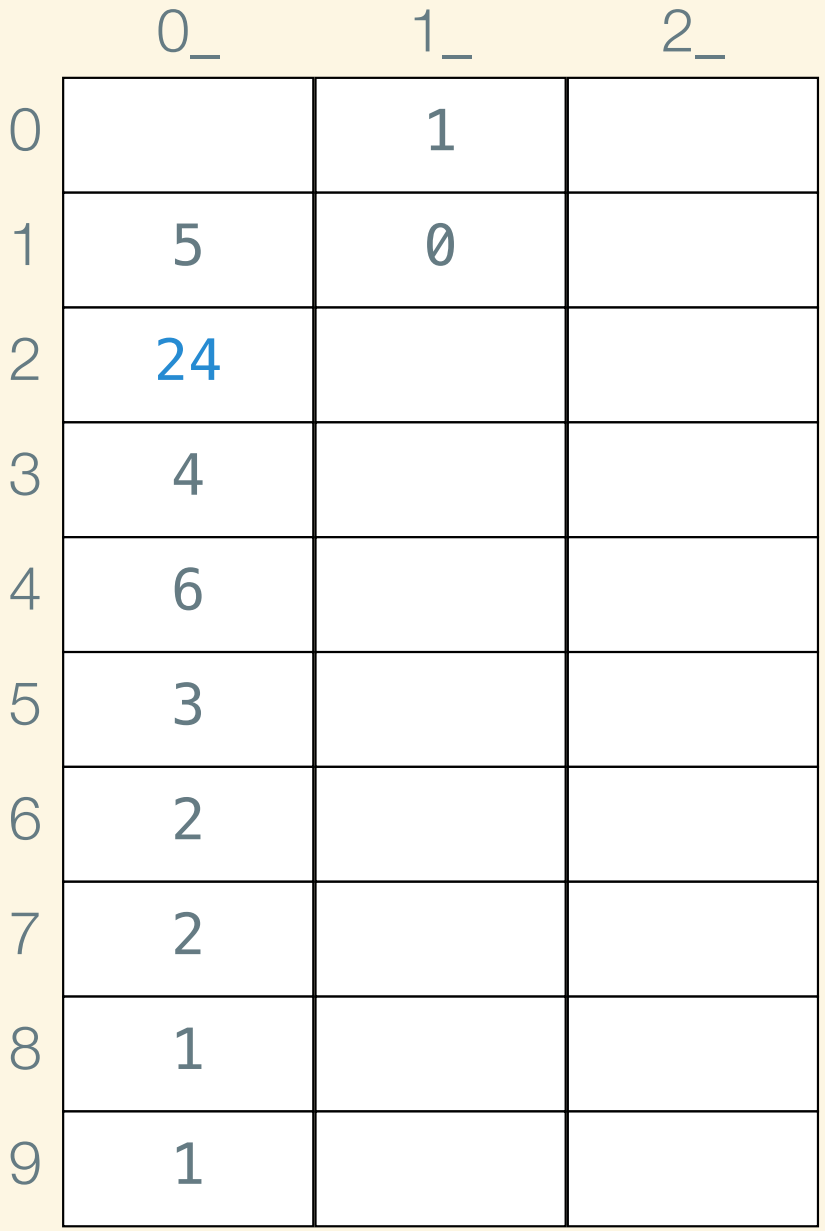

Recursion on the stack

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fact(5)	1	0
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fact(3)	5	4
fact(2)	7	6
fact(1)	9	8
fact(0)	11	10

```
int fact(int n)
{
    if (n == 0)
        return 1;
    else
        return n * fact(n - 1)
}

        fact(5);
```

	0_	1_	2_
0	120	1	
1	5	0	
2	24		
3	4		
4	6		
5	3		
6	2		
7	2		
8	1		
9	1		

Can’t return pointers to stack variables

This is fundamentally broken:

```
int* ptr_to_3()
{
        int x = 3;
        return &x;
}
```

Can’t return pointers to stack variables

This is fundamentally broken:

```
int* ptr_to_3()
{
        int x = 3;
        return &x;
}
```

So is this:

```
int* ptr_to_array()
{
        int x[] = { 3, 4, 5 };
        return x;
}
```

The free store

```
int* p = new int(3);
```

The free store

```
int* p = new int(3);

int* q = new int[]{ 3, 4, 5 };
```

The free store

```
int* p = new int(3);

int* q = new int[]{ 3, 4, 5 };

int* r = new int[32];
```

The free store

```
int* p = new int(3);

int* q = new int[]{ 3, 4, 5 };

int* r = new int[32];

int* s = new int[w * h];
```

The free store

```
int* p = new int(3);                    delete p;

int* q = new int[]{ 3, 4, 5 };

int* r = new int[32];

int* s = new int[w * h];
```

The free store

```
int* p = new int(3);                delete p;

int* q = new int[]{ 3, 4, 5 };      delete [] q;

int* r = new int[32];               delete [] r;

int* s = new int[w * h];            delete [] s;
```

A rudimentary vector

```
struct Int_vector
{
        size_t size;
        size_t capacity;
        int* data;
};
```