

Intermediate Programming

Day 12

Outline

- Exercise 11
- Pointer operations
- Dynamic 2D arrays
- Pointers and **const**
- Review questions

Exercise 11

pairwise_sum.c:
valgrind to the rescue

```
>> valgrind ./a.out
...
==2131554== Command: ./a.out
==2131554==
==2131554== Invalid write of size 4
==2131554==    at 0x40120E: pairwise_sum (pairwise_sum.c:35)
==2131554==    by 0x4012B5: main (pairwise_sum.c:50)
==2131554== Address 0x4a8d050 is 0 bytes after a block of size 16 alloc'd
==2131554==    at 0x484186F: malloc (vg_replace_malloc.c:381)
==2131554==    by 0x4011A2: pairwise_sum (pairwise_sum.c:28)
==2131554==    by 0x4012B5: main (pairwise_sum.c:50)
==2131554==
...
```

Exercise 11

pairwise_sum.c:
valgrind to the rescue

pairwise_sum.c

```
...
23. int *pairwise_sum( int *array , int length ){
...
28.     int *fresh = malloc( sizeof(int) * ( length-1 ) );
...
32.     // do the pairwise sum into "fresh"
33.     for( int i=0 ; i<length ; i++ )
34.     {
35.         fresh[i] = array[i] + array[i+1];
36.     }
37.     return fresh;
38. }
...
```

```
>> valgrind ./a.out
...
==2131554== Command: ./a.out
==2131554==
==2131554== Invalid write of size 4
==2131554==    at 0x40120E: pairwise_sum (pairwise_sum.c:35)
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==2131554==
...
```

Exercise 11

pairwise_sum.c:
valgrind to the rescue

pairwise_sum.c

```
...
23. int *pairwise_sum( int *array , int length ){
...
28.     int *fresh = malloc( sizeof(int) * ( length-1 ) );
...
32.     // do the pairwise sum into "fresh"
33.     for( int i=0 ; i<length ; i++ )
34.     {
35.         fresh[i] = array[i] + array[i+1];
36.     }
37.     return fresh;
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...
```

```
>> valgrind ./a.out
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==2131554==
...
```

Exercise 11

pairwise_sum.c: valgrind to the rescue

pairwise_sum.c

```
...
23. int *pairwise_sum( int *array , int length ){
...
28.     int *fresh = malloc( sizeof(int) * ( length-1 ) );
...
32.     // do the pairwise sum into "fresh"
33.     for( int i=0 ; i<length-1 ; i++ )
34.     {
35.         fresh[i] = array[i] + array[i+1];
36.     }
37.     return fresh;
38. }
...
```

```
>> valgrind ./a.out
...
==2186254== HEAP SUMMARY:
==2186254==      in use at exit: 16 bytes in 1 blocks
==2186254==    total heap usage: 4 allocs, 3 frees, 1,068 bytes allocated
==2186254==
==2186254== LEAK SUMMARY:
==2186254==    definitely lost: 16 bytes in 1 blocks
==2186254==    indirectly lost: 0 bytes in 0 blocks
==2186254==    possibly lost: 0 bytes in 0 blocks
==2186254==    still reachable: 0 bytes in 0 blocks
==2186254==    suppressed: 0 bytes in 0 blocks
==2186254== Rerun with --leak-check=full to see details of leaked memory
==2186254==
...
```

Exercise 11

`pairwise_sum.c`:
valgrind to the rescue

```
>> valgrind ./a.out
...
==2186254== HEAP SUMMARY:
==2186254==      in use at exit: 16 bytes in 1 block
==2186254==    total heap usage: 4 allocs, 3 frees
==2186254==
==2186254== LEAK SUMMARY:
==2186254==    definitely lost: 16 bytes in 1 block
==2186254==    indirectly lost: 0 bytes in 0 blocks
==2186254==    possibly lost: 0 bytes in 0 blocks
==2186254==    still reachable: 0 bytes in 0 blocks
==2186254==          suppressed: 0 bytes in 0 blocks
==2186254== Rerun with --leak-check=full to see details of leaked memory
==2186254==
...
```

pairwise_sum.c

```
...
23. int *pairwise_sum( int *array , int length ){
...
28.     int *fresh = malloc( sizeof(int) * ( length-1 ) );
...
38. }
...
49. int main(){
...
52.     int *pairsum1 = pairwise_sum(array, 5);
...
57.     free(pairsum1);
58.
59.     int *pairsum2 = pairwise_sum(pairwise_sum(array, 5), 4);
...
63.     free(pairsum2);
64.
65.     return 0;
66. }
```

Exercise 11

`pairwise_sum.c`:
valgrind to the rescue

pairwise_sum.c

```
...
23. int *pairwise_sum( int *array , int length ){
...
28.     int *fresh = malloc( sizeof(int) * ( length-1 ) );
...
38. }
...
49. int main(){
...
52.     int *pairsum1 = pairwise_sum(array, 5);
...
57.
58.     int *pairsum2 = pairwise_sum(pairsum1, 4);
59.     free(pairsum1);
...
63.     free(pairsum2);
64.
65.     return 0;
66. }
```

```
>> valgrind ./a.out
...
==2192565== HEAP SUMMARY:
==2192565==      in use at exit: 0 bytes in 0 blocks
==2192565==    total heap usage: 3 allocs, 3 frees, 1,052 bytes allocated
==2192565==
==2192565== All heap blocks were freed -- no leaks are possible
...
```


Exercise 11

primes.c:

valgrind to the rescue

```
>> valgrind ./a.out
...
==2193150== Invalid read of size 4
==2193150==    at 0x4012DD: main (primes.c:64)
==2193150== Address 0x4b6e070 is 9,808 bytes inside a block of size 10,240 free'd
==2193150==    at 0x48466AF: realloc (vg_replace_malloc.c:1437)
==2193150==    by 0x40122A: set_primes (primes.c:44)
==2193150==    by 0x4012AC: main (primes.c:62)
==2193150== Block was alloc'd at
==2193150==    at 0x48466AF: realloc (vg_replace_malloc.c:1437)
==2193150==    by 0x40122A: set_primes (primes.c:44)
==2193150==    by 0x4012AC: main (primes.c:62)
...
```

Exercise 11

primes.c:

valgrind to the rescue

primes.c

```
...
32. int set_primes( int *list , int capacity ){
...
44.             list = realloc(list, capacity * sizeof(int));
...
49.             return idx;
50. }
...
53. int main() {
...
57.             int *list = malloc(capacity * sizeof(int));
...
62.             int prime_count = set_primes( list , capacity );
63.             printf( "Found %d primes in the range [2,%d)\n" , prime_count , MAX_CANDIDATE );
64.             printf( "First and last primes are %d and %d\n" , list[0] , list[ prime_count-1 ] );
...
67. }
```

```
>> valgrind ./a.out
```

```
...
```

```
==2193150== Invalid read of size 4
```

```
==2193150==    at 0x4012DD: main (primes.c:64)
```

```
==2193150== Address 0x4b6e070 is 9,808 bytes inside a block of size 10,240 free'd
```

```
==2193150==    at 0x48466AF: realloc (vg_replace_malloc.c:1437)
```

```
==2193150==    by 0x40122A: set_primes (primes.c:44)
```

```
==2193150==    by 0x4012AC: main (primes.c:62)
```

```
==2193150== Block was alloc'd at
```

```
==2193150==    at 0x48466AF: realloc (vg_replace_malloc.c:1437)
```

```
==2193150==    by 0x40122A: set_primes (primes.c:44)
```

```
==2193150==    by 0x4012AC: main (primes.c:62)
```

```
...
```

Exercise 11

primes.c:

valgrind to the rescue

primes.c

```
...
32. int set_primes( int *list , int capacity ){
...
44.         list = realloc(list, capacity * sizeof(int));
...
49.         return idx;
50.     }
...
53. int main() {
...
57.         int *list = malloc(capacity * sizeof(int));
...
62.         int prime_count = set_primes( list , capacity );
63.         printf( "Found %d primes in the range [2,%d)\n" , prime_count , MAX_CANDIDATE );
64.         printf( "First and last primes are %d and %d\n" , list[0] , list[ prime_count-1 ] );
...
67. }
```

```
>> valgrind ./a.out
```

```
...
```

```
==2193150== Invalid read of size 4
```

```
==2193150==      at 0x4012DD: main (primes.c:64)
```

```
==2193150== Address 0x4b6e070 is 9,808 bytes inside a block of size 10,240 free'd
```

```
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```

```
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```

```
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```

```
==2193150== Block was alloc'd at
```

```
==2193150==      at 0x48466AF: realloc (vg_replace_malloc.c:1437)
```

```
==2193150==      by 0x40122A:
```

```
==2193150==      by 0x40122A:
```

```
...
```

The problem is that in line 44, the value of `list` can change (if `realloc` cannot extend the memory). But the `main` function doesn't know this. (It's copy of `list` does not change).

Exercise 11

primes.c:

valgrind to the rescue

primes.c

```
...
32. int *set_primes( int *list , int capacity , int *prime_count ){
...
44.             list = realloc(list, capacity * sizeof(int));
...
49.     *prime_count = idx;
50.     return list;
51. }
...
54. int main() {
...
58.     int *list = malloc(capacity * sizeof(int));
...
63.     int prime_count;
64.     list = set_primes( list , capacity , &prime_count );
65.     printf( "Found %d primes in the range [2,%d)\n" , prime_count , MAX_CANDIDATE );
66.     printf( "First and last primes are %d and %d\n" , list[0] , list[ prime_count-1 ] );
...
69. }
```

```
>> valgrind ./a.out
```

```
...
```

```
==2203638== HEAP SUMMARY:
```

```
==2203638==      in use at exit: 0 bytes in 0 blocks
```

```
==2203638==    total heap usage: 12 allocs, 12 frees, 82,904 bytes allocated
```

```
==2203638==
```

```
==2203638== All heap blocks were freed -- no leaks are possible
```

```
...
```

Outline

- Exercise 11
- **Pointer operations**
- Dynamic 2D arrays
- Pointers and `const`
- Review questions

Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.*
 - We can add /subtract integers from a pointer (to get a new pointer):
 `b = a+2;`
 `b -= 3;`
 `b++;`
 etc.
 - We can compute the difference between two pointers (to get a signed integer)**:
 `ptrdiff_t d = b-a;`
 - We can print out the value of a pointer:
 `printf("Address: %p\n" , (void*)a);`

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int *b = a+2;

    return 0;
}
```

* The size of a pointer depends on the architecture.
On 64-bit architectures, it is eight bytes long

** `ptrdiff_t` is a predefined type in `stddef.h`
designed to store the difference between pointers

Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.
 - We can add /subtract integers from a pointer

Q: What is the value of b?

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int *b = a+2;

    return 0;
}
```

Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.

- We can add /subtract integers from a pointer

Q: What is the value of b?

A: b is the address of the integer two in from the start of the array

Note:

- The `int` two elements in from the start of the array is 8 bytes away in memory
 - Because the type of the pointer is known, the compiler automatically deduces that two `int` lengths correspond to 8 bytes

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int *b = a+2;
    printf( "%d %d\n" , *a , *b );
    return 0;
}
```

```
>> ./a.out
2 6
>>
```


Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.

- We can add /subtract integers from a pointer

Q: What is the value of b?

A: b is the address of the integer two in from the start of the array

Note:

- The `int` two elements in from the start of the array is 8 bytes away in memory
 - Because the type of the pointer is known, the compiler automatically deduces that two `int` lengths correspond to 8 bytes
 - Similarly, the difference between pointers is measured in units of elements

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int *b = a+2;
    printf( "%d %d\n" , a-b );
    return 0;
}
```

```
>> ./a.out
-2
>>
```

Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.

- We can add /subtract integers from a pointer

Q: What is the value of b?

A: b is the address of the integer two in from the start of the array

Note:

- The `int` two elements in from the start of the array is 8 bytes away in memory
 - Because the type of the pointer is known, the compiler automatically deduces that two `int` lengths correspond to 8 bytes
 - A pointer of type `void*` is treated as a raw memory address (w/o size information)

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int *b = a+2;
    void *_a = a , *_b = b;
    printf( "%d\n" , b-a );
    printf( "%d\n" , _b-_a );
    return 0;
}
```

```
>> ./a.out
2
8
>>
```

Pointer arithmetic

- If `ip` points to `int x`. Then `*ip` can be used anywhere that `x` makes sense:

`printf("%d\n" , *ip)` \Leftrightarrow `printf("%d\n" , x)`

- Unary ops `&` and `*` bind more tightly than binary arithmetic ops

`*ip += 1` \Leftrightarrow `x += 1`
`y = *ip + 1` \Leftrightarrow `y = x+1`

- [WARNING] unary operators associate from right to left
 - `++*ip` is the same as `++x`
 - `*ip++` means something else

Pointer arithmetic

- A pointer is an unsigned integer value indicating a location in memory.

- We can add /subtract integers from a pointer

Q: So what does `*b++ = 0` do?

A: It's a combination of four instructions:

1. Increment the pointer `b`,
2. Return the old pointer's value,*
3. Dereference that
4. Set it to zero

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int* b = a+2;
    *b++ = 0;
    printf( "%d %d %d %d : %d\n" ,
           a[0] , a[1] , a[2] , a[3] , *b );
    return 0;
}
```

```
>> ./a.out
2 4 0 8 : 8
>>
```

*Recall that post-increment/decrement returns the old value

Pointer arithmetic

- We can access a pointer by dereferencing
`printf("%d\n" , *b);`
- We can access array elements with []
`printf("%d\n" , b[0]);`
- Since pointers and arrays are essentially the same, these are the same operations!

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int* b = a+2;
    printf( "%d\n" , *b );
    printf( "%d\n" , b[0] );
    return 0;
}
```

```
>> ./a.out
6
6
>>
```

- More generally `*(b+k)` is the same as `b[k]` for any integer `k`

Pointer arithmetic

Though similar, arrays and pointers differ in a couple of ways:

1. The use of `sizeof`

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int* b = a;
    printf( "%d\n" , sizeof(a) );
    printf( "%d\n" , sizeof(b) );
    return 0;
}
```

```
>> ./a.out
16
8
>>
```

Pointer arithmetic

Though similar, arrays and pointers differ in a couple of ways:

1. The use of **sizeof**
2. Arrays are immutable

```
#include <stdio.h>
int main( void )
{
    int a[] = { 2 , 4 , 6 , 8 };
    int b = 10;
    a = &b;
    return 0;
}
```

```
>> gcc ...
foo.c: In function 'main':
foo.c:6:4: error: assignment to expression with array type
    6 |   a = &b;
      |     ^
>>
```

Outline

- Exercise 11
- Pointer operations
- **Dynamic 2D arrays**
- Pointers and `const`
- Review questions

Dynamic 2D arrays

Q: How do we dynamically declare a 2x3 grid of `int` values?

A1: Declare an array of 6 `int` values

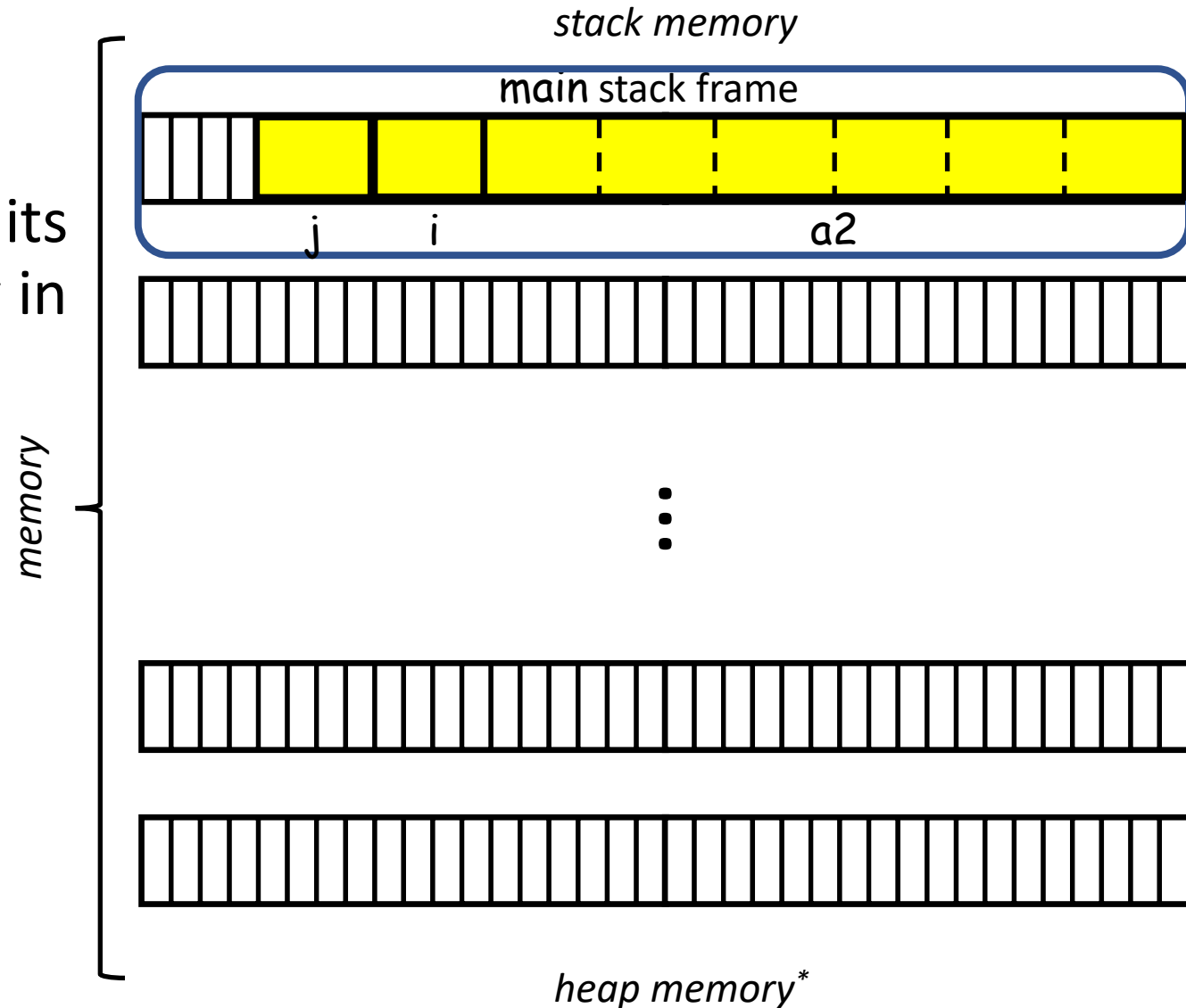
A2: Declare an array (of size 2) containing `int` arrays (of size 3).

Dynamic 2D arrays

Recall:

If we statically declare a 2D array its contents are laid out sequentially in (stack) memory.

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int a2[2][3];
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[i][j] = 3*i+j;
    return 0;
}
```

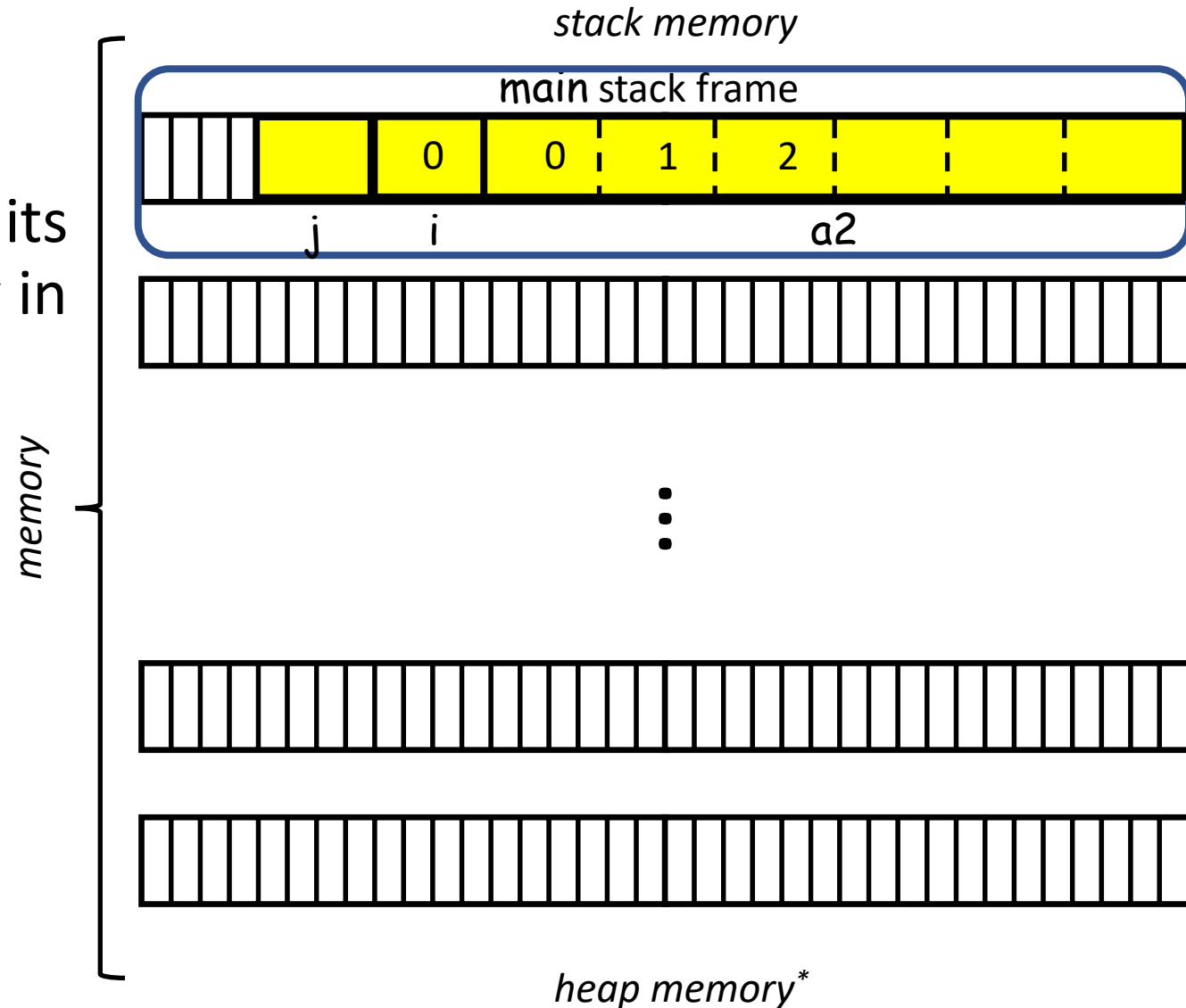


Dynamic 2D arrays

Recall:

If we statically declare a 2D array its contents are laid out sequentially in (stack) memory.

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int a2[2][3];
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[i][j] = 3*i+j;
    return 0;
}
```

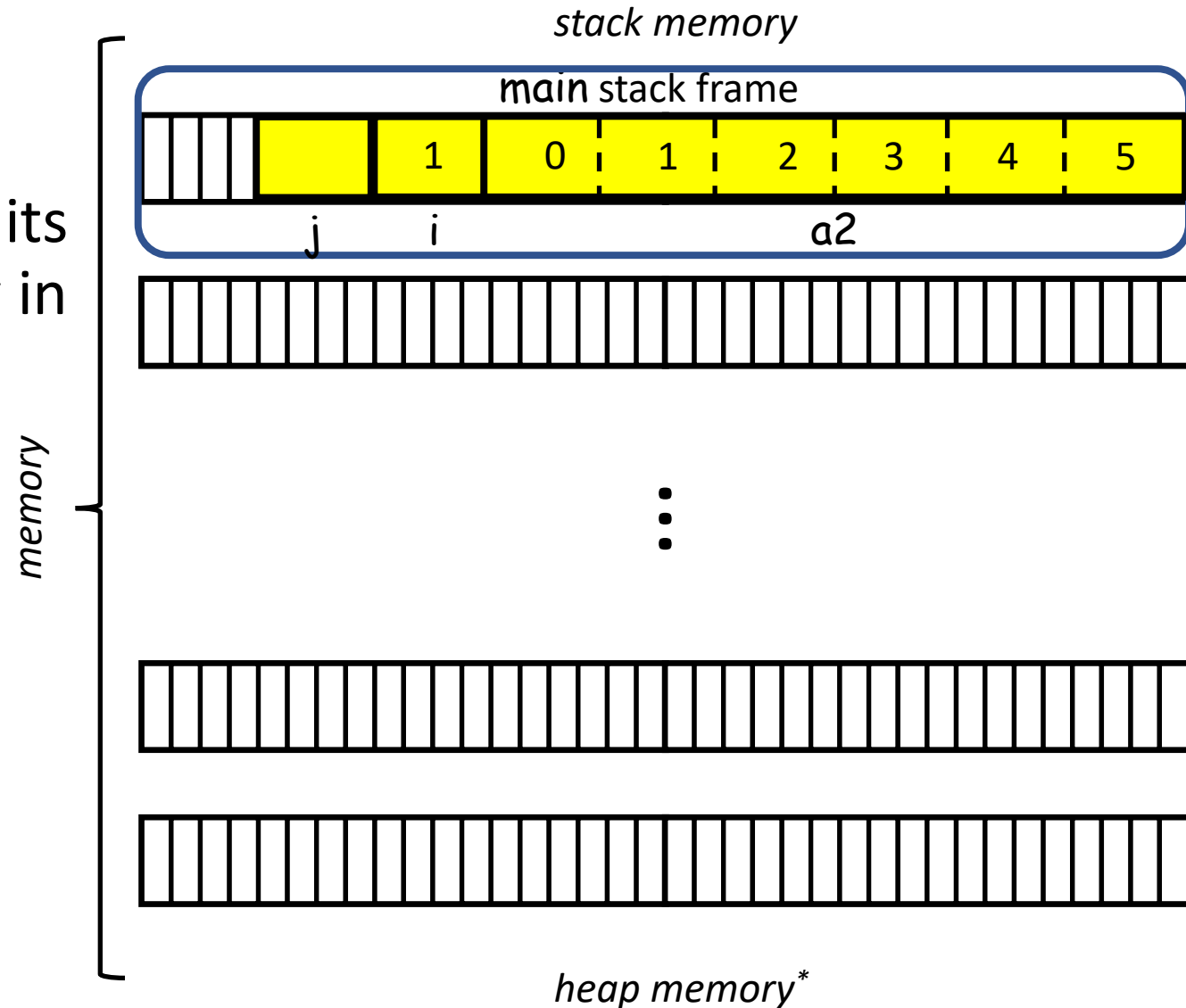


Dynamic 2D arrays

Recall:

If we statically declare a 2D array its contents are laid out sequentially in (stack) memory.

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int a2[2][3];
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[i][j] = 3*i+j;
    return 0;
}
```

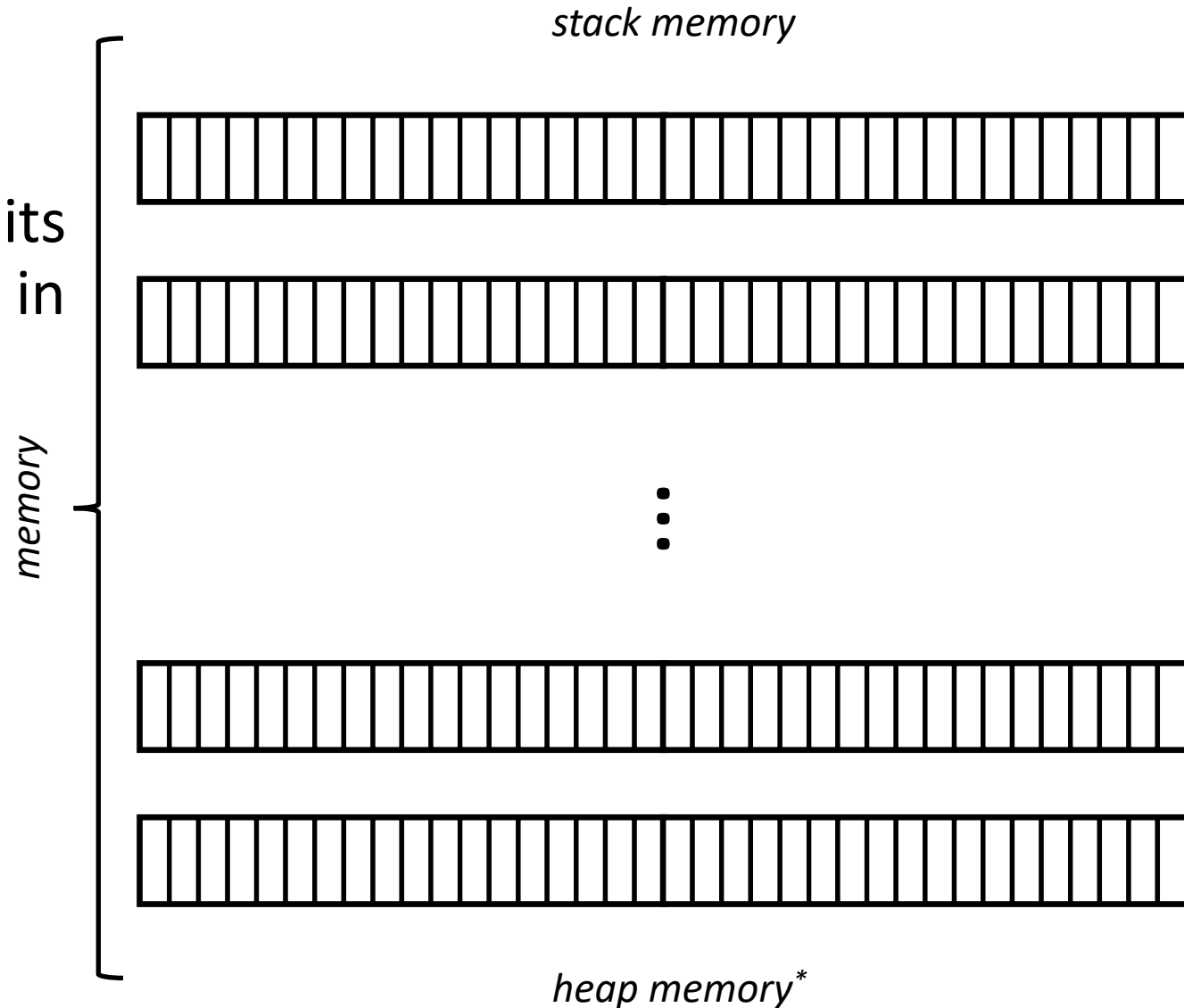


Dynamic 2D arrays

Recall:

If we statically declare a 2D array its contents are laid out sequentially in (stack) memory.

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int a2[2][3];
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[i][j] = 3*i+j;
    return 0;
}
```



Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
 - Need to allocate/deallocate the `int` array

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

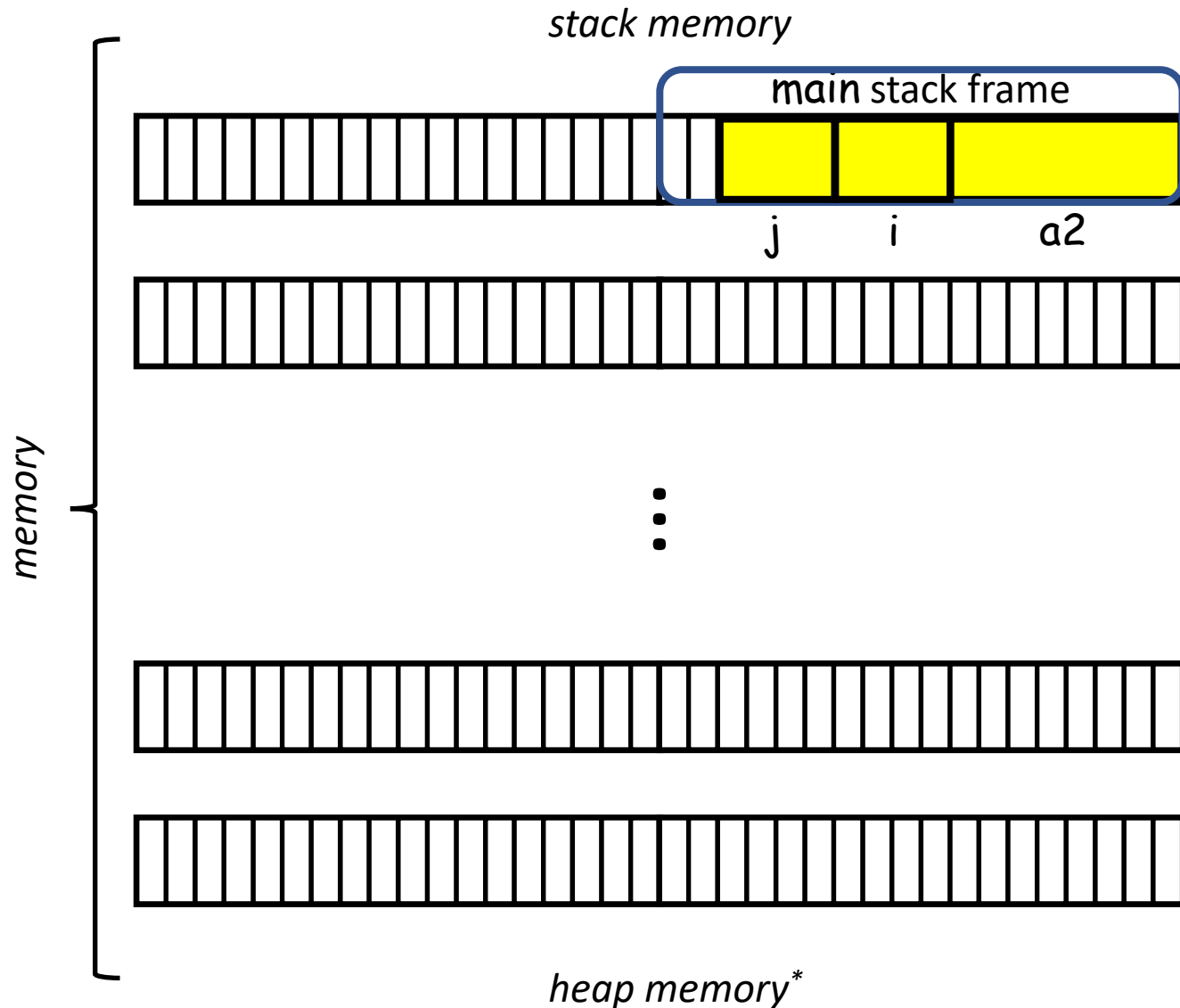
Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`

- Need to allocate/deallocate the `int` array
- ✗ Indexing is ugly

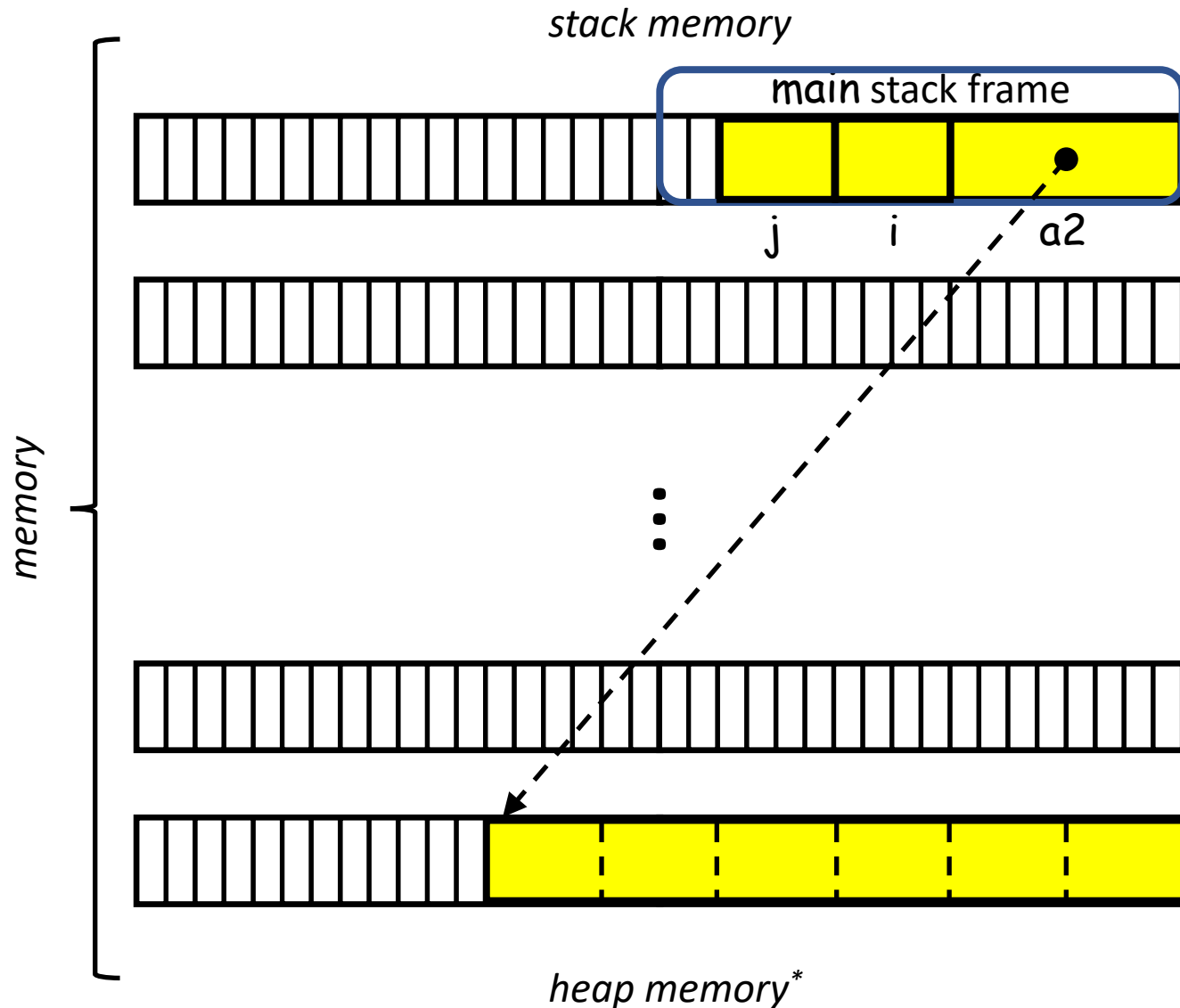
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```


Dynamic 2D arrays



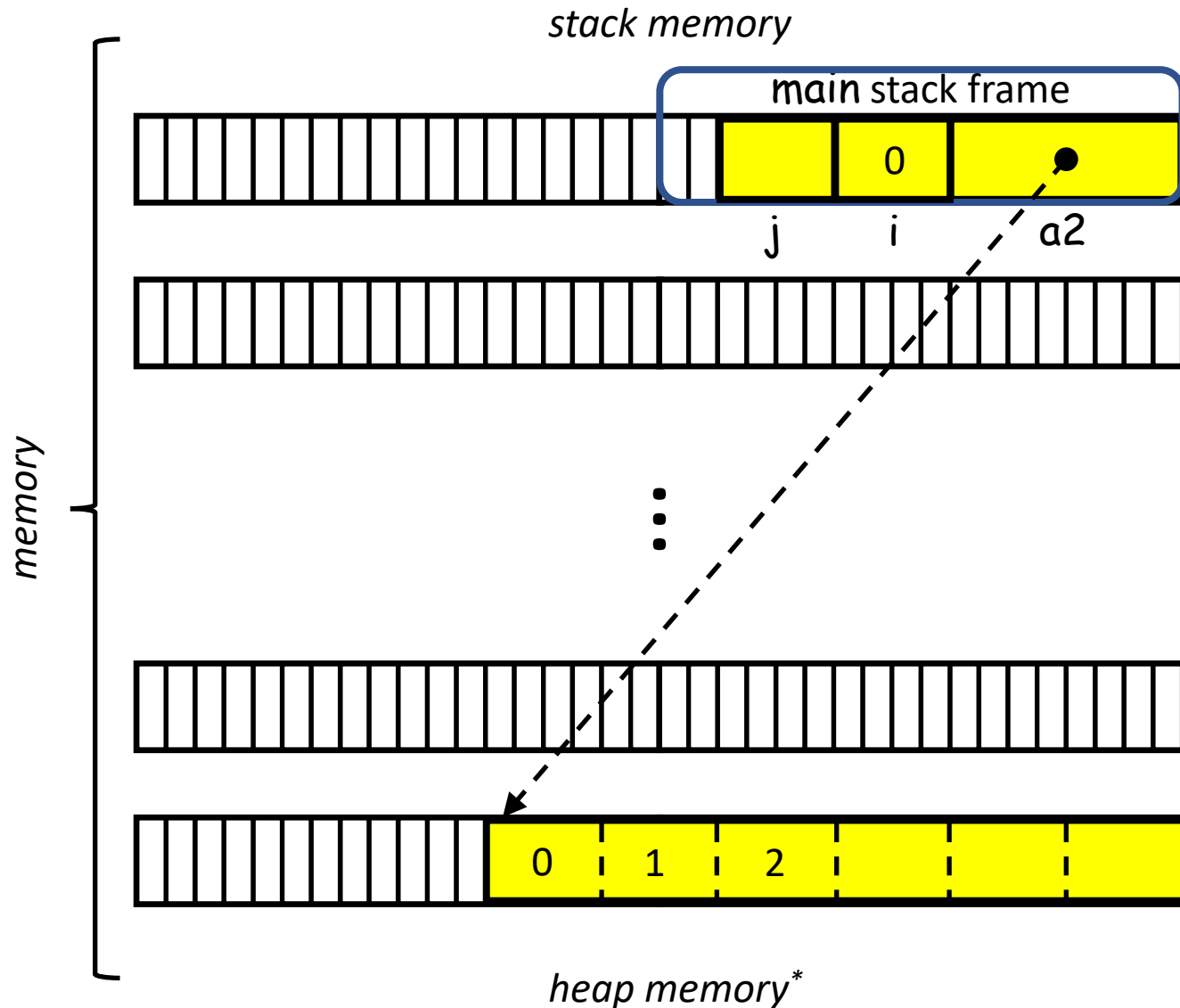
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



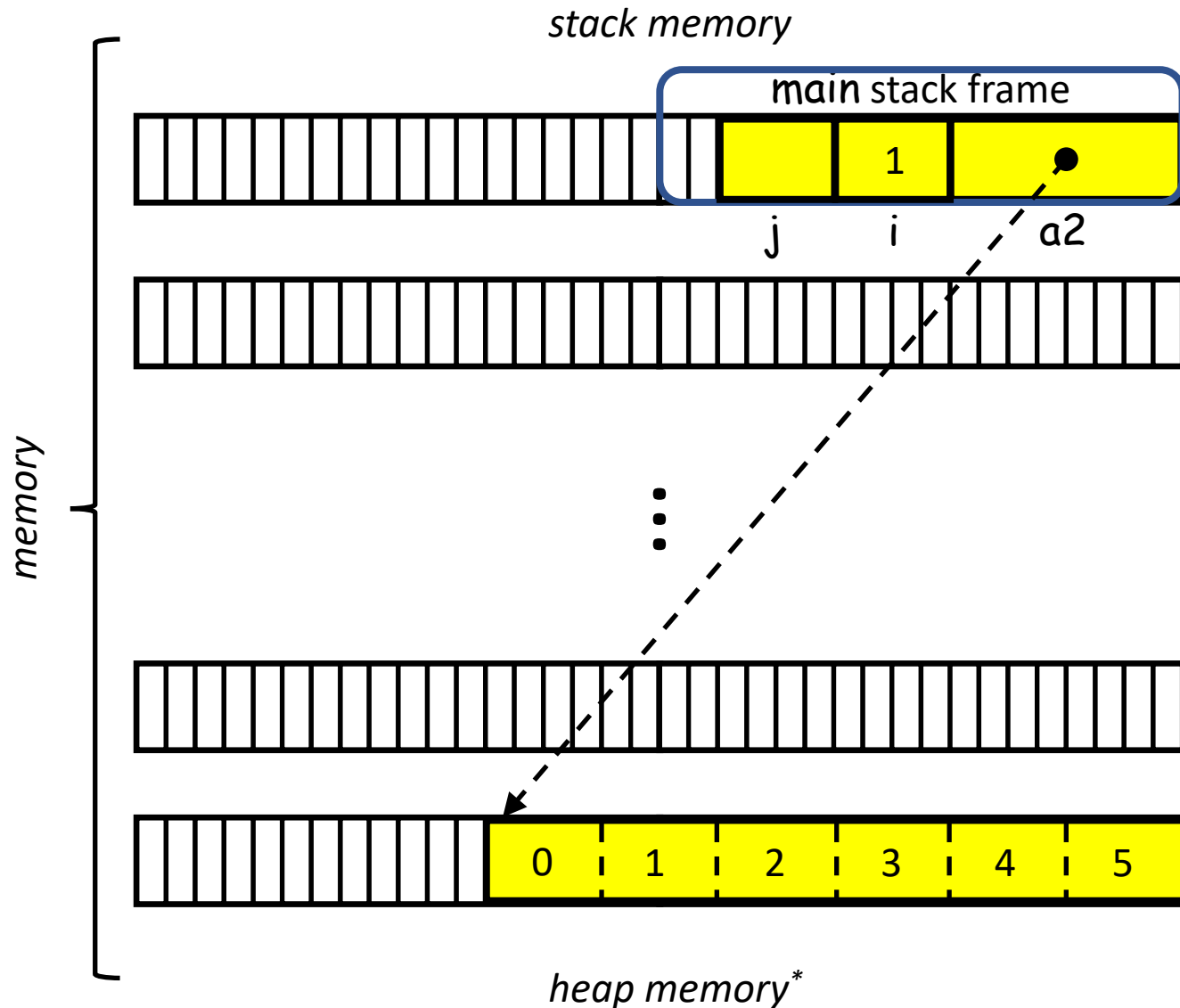
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



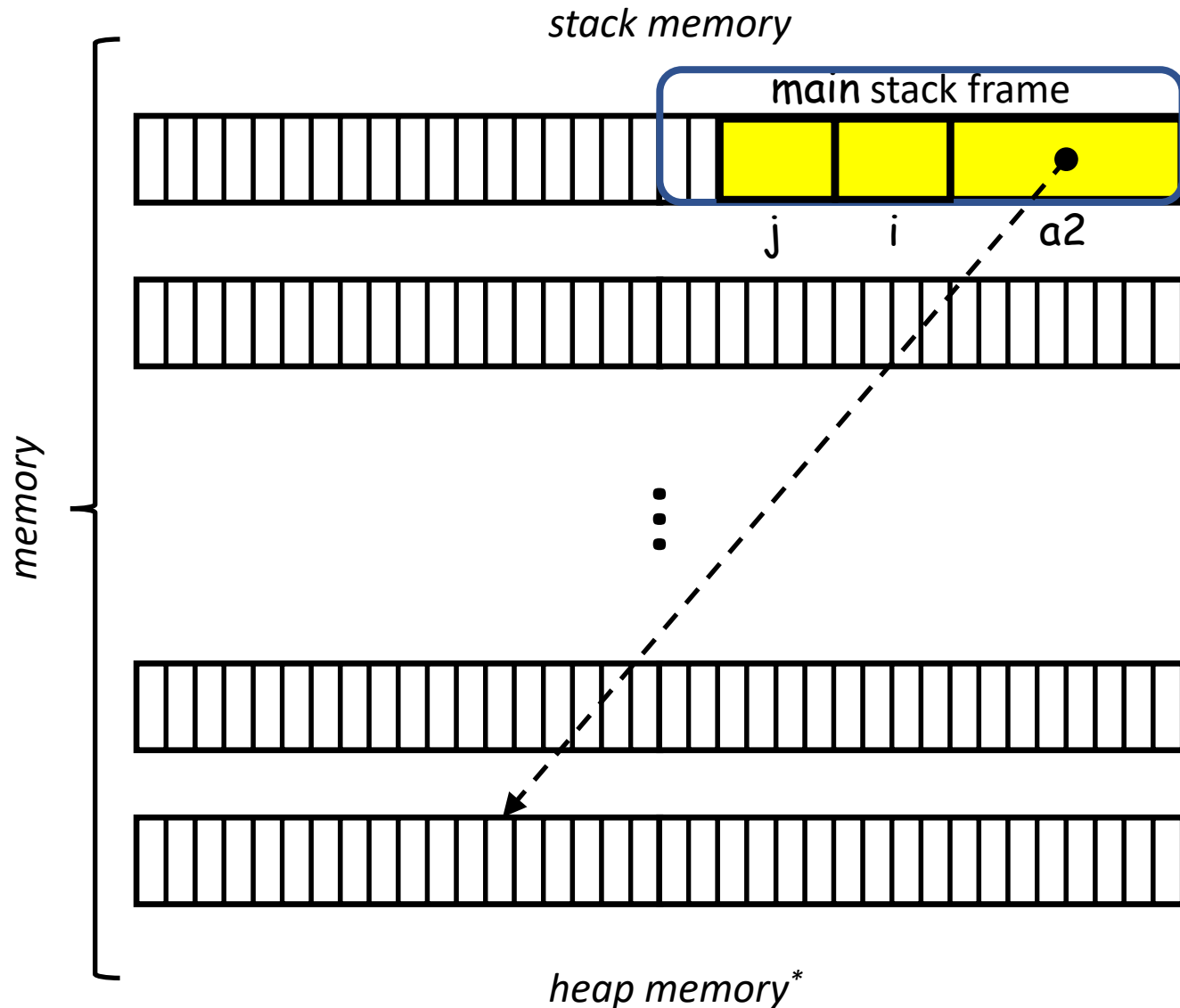
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



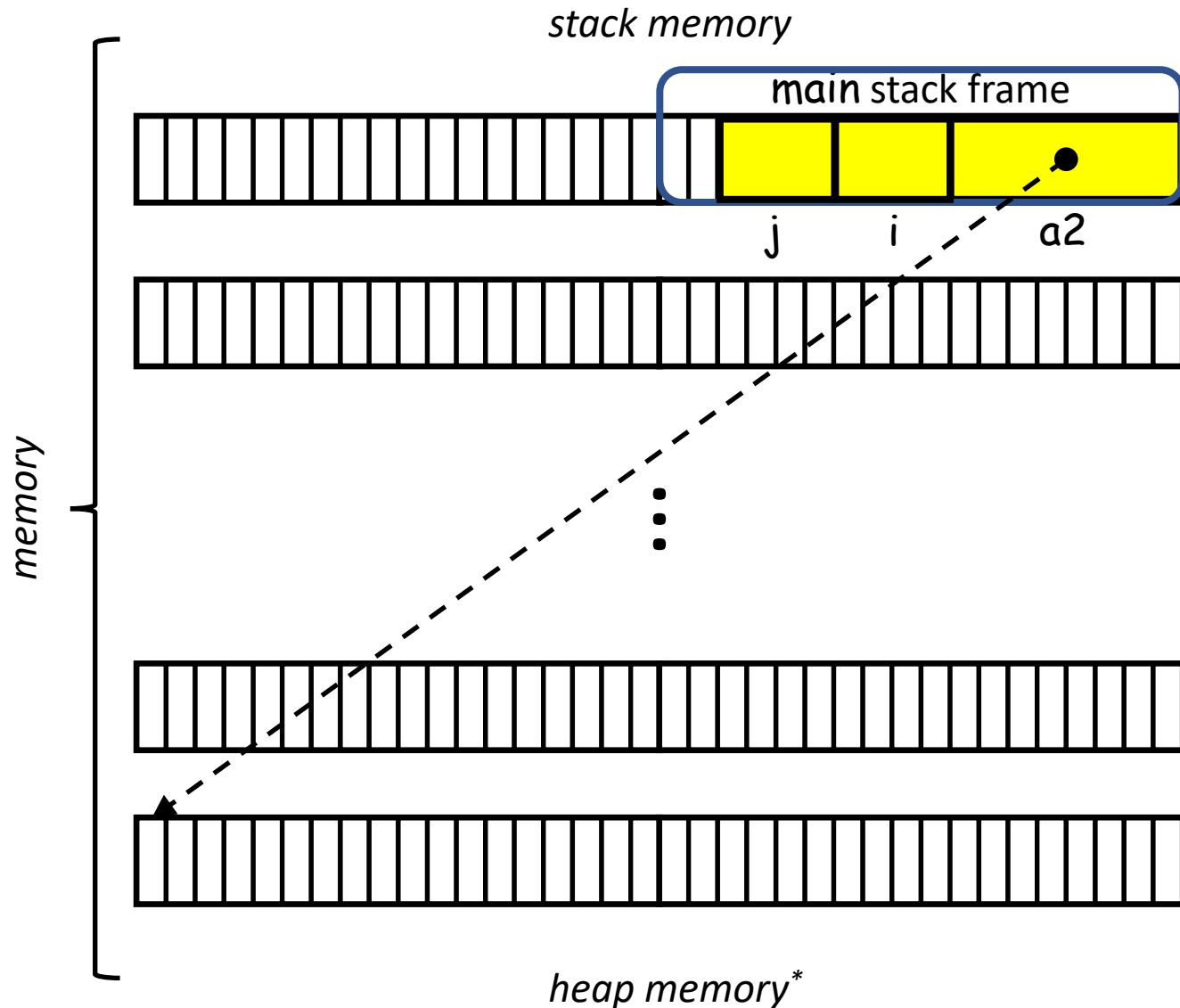
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



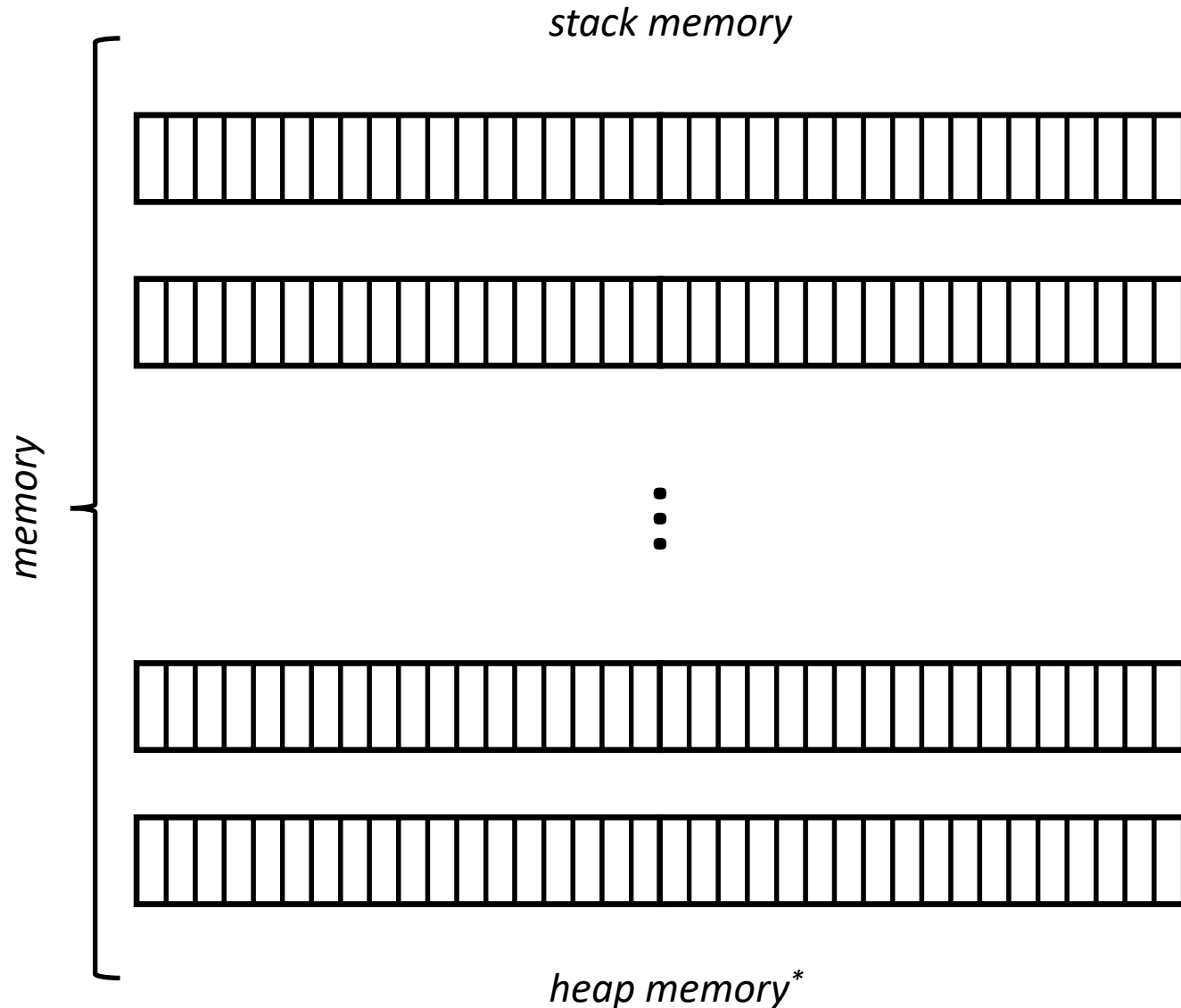
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
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        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



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#include <stdlib.h>
int main( void )
{
    int *a2 = malloc( sizeof(int) * 2 * 3 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
        for( int j=0 ; j<3 ; j++ )
            a2[3*i+j] = 3*i+j;
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
2. Declare an array of `int` arrays

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```


Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
2. Declare an array of `int` arrays
 - Need to allocate/deallocate the array of `int` arrays

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
2. Declare an array of `int` arrays
 - Need to allocate/deallocate the array of `int` arrays
 - Need to allocate/deallocate each `int` array

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
2. Declare an array of `int` arrays

- Need to allocate/deallocate the array of `int` arrays
- Need to allocate/deallocate each `int` array

✓ Indexing is clean

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays

Declaring a 2x3 grid of `int` values:

1. Declare a single array of `ints`
2. Declare an array of `int` arrays

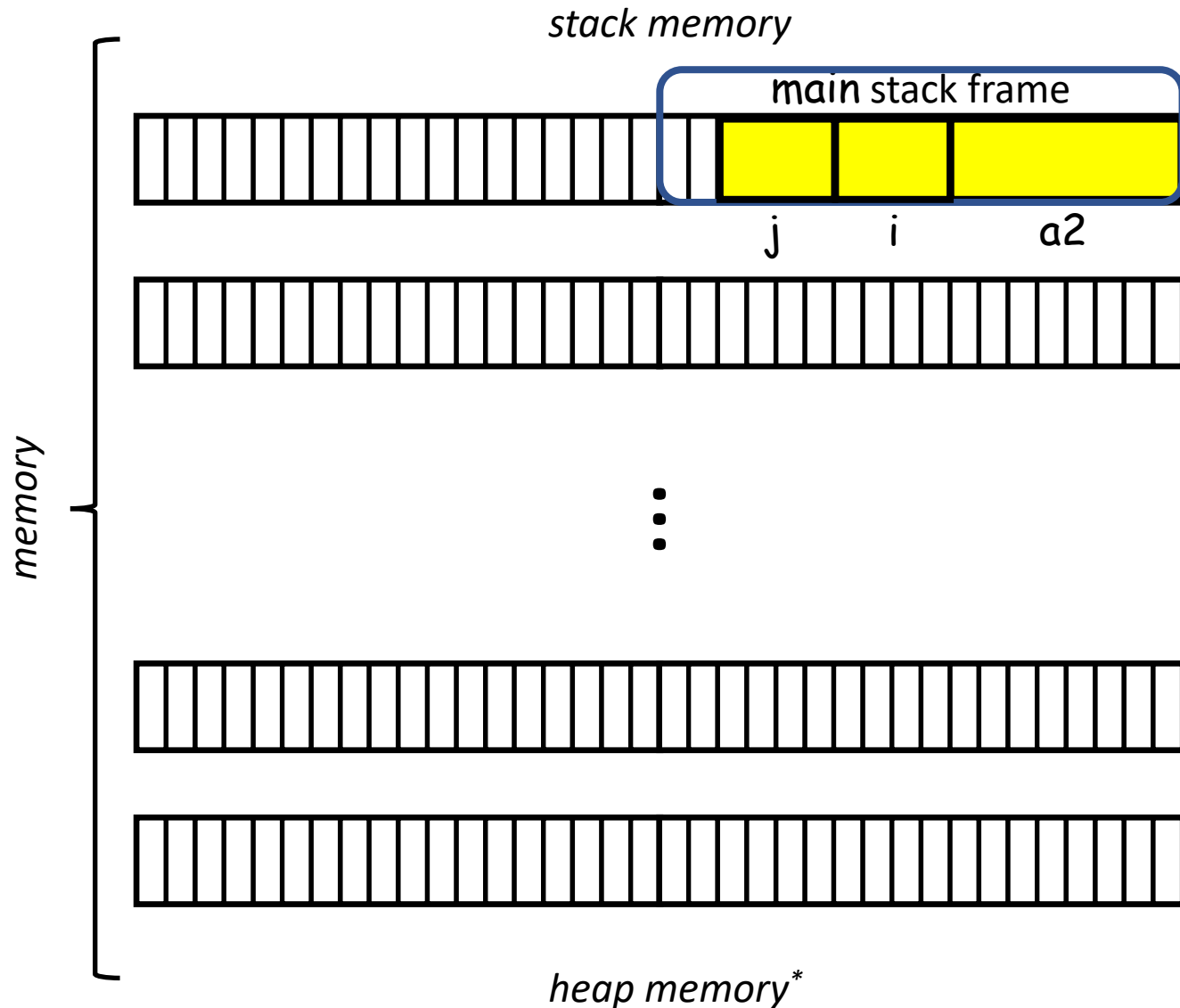
- Need to allocate/deallocate the array of `int` arrays
- Need to allocate/deallocate each `int` array

✓ Indexing is clean

⇒ With dynamic allocation we can have (jagged/non-uniform) 2D arrays with different rows having different sizes.

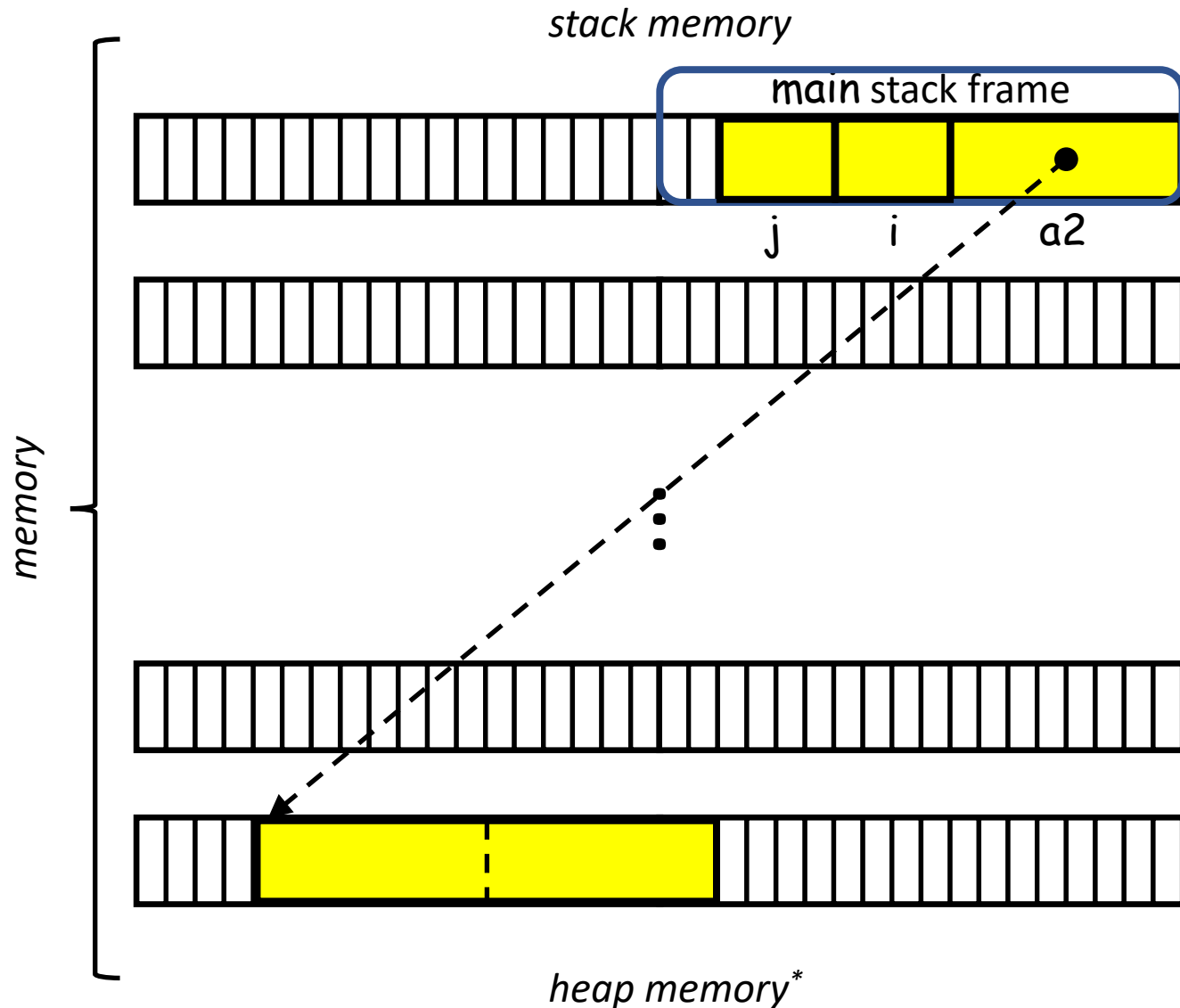
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



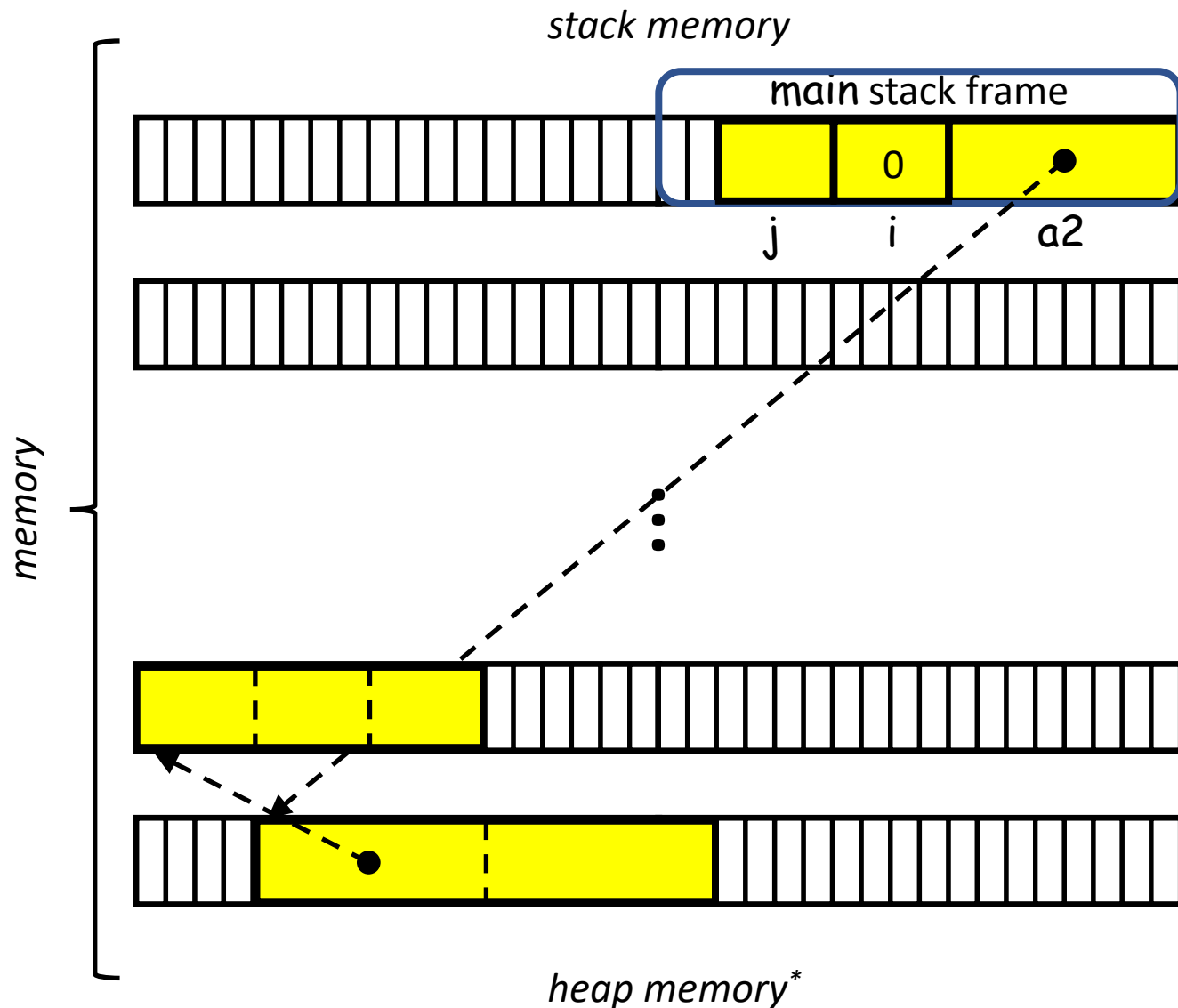
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



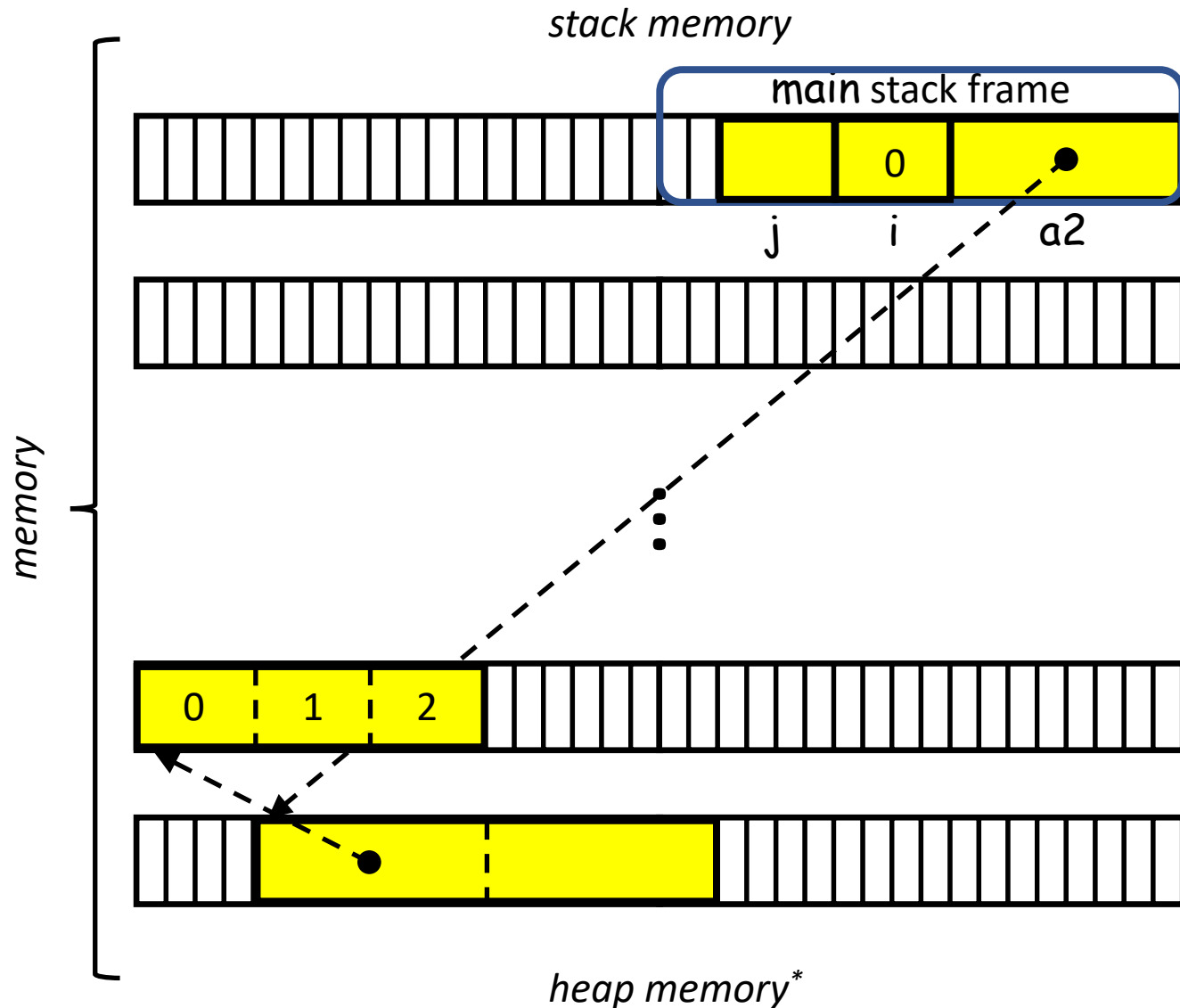
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



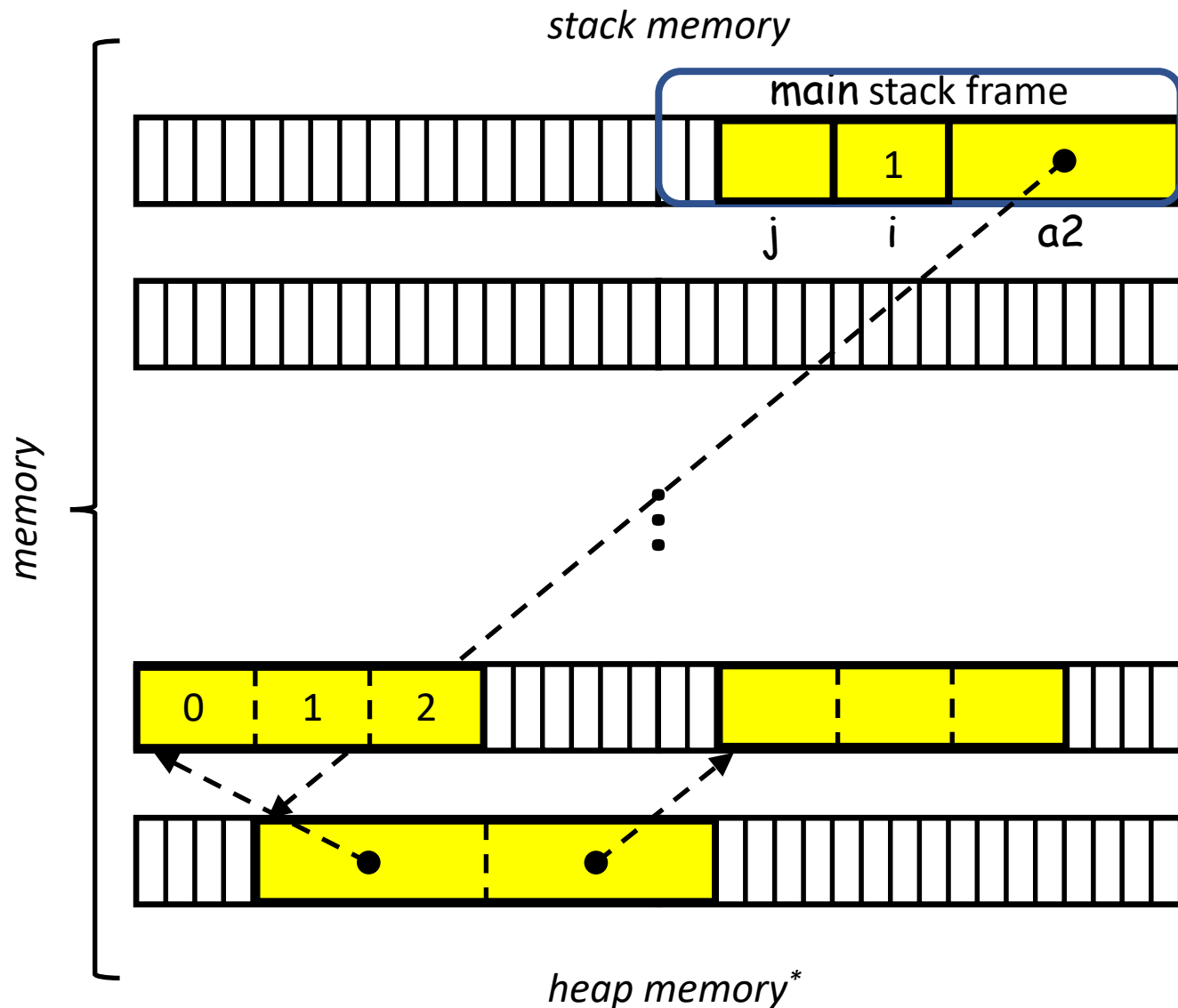
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



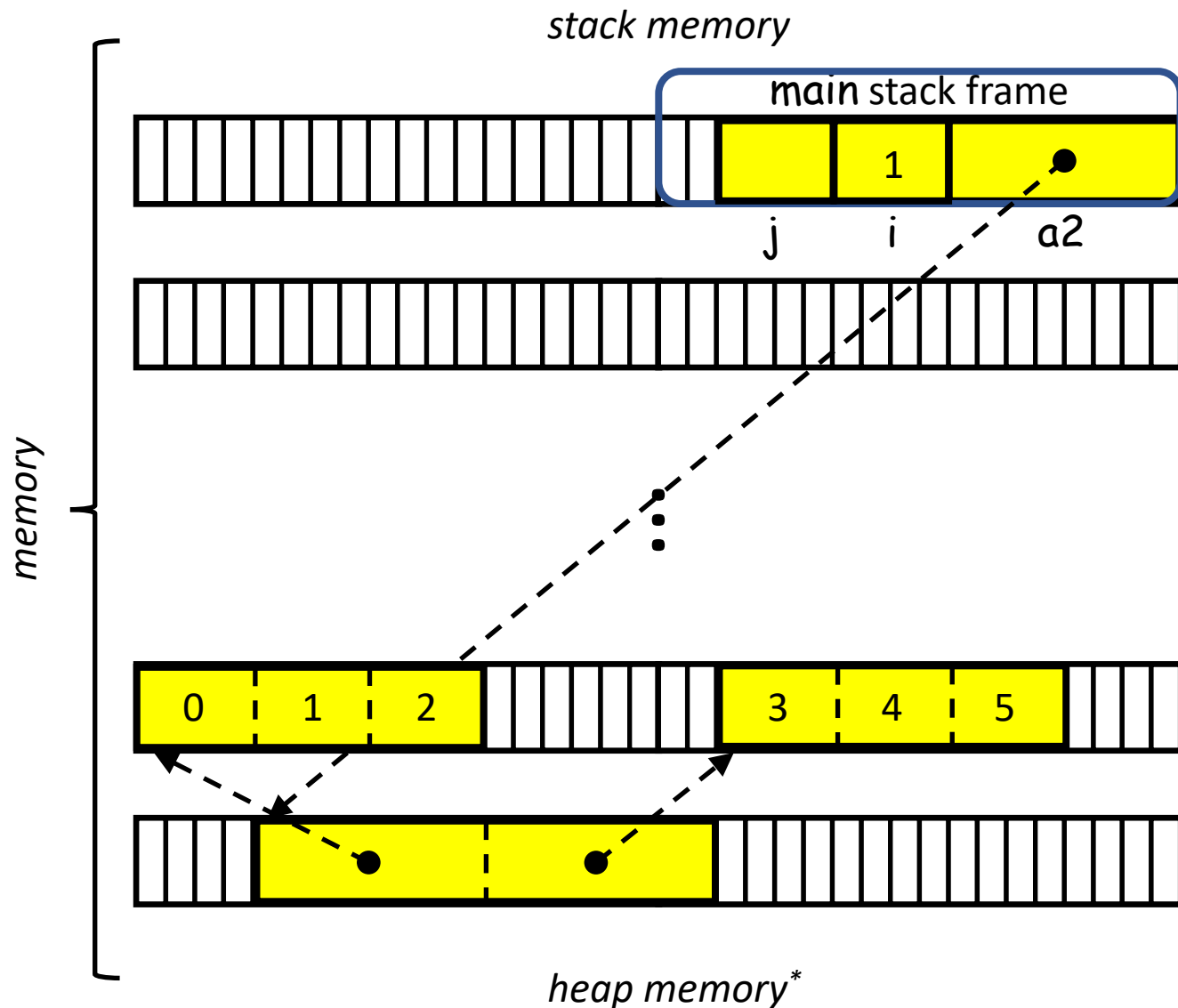
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```


Dynamic 2D arrays



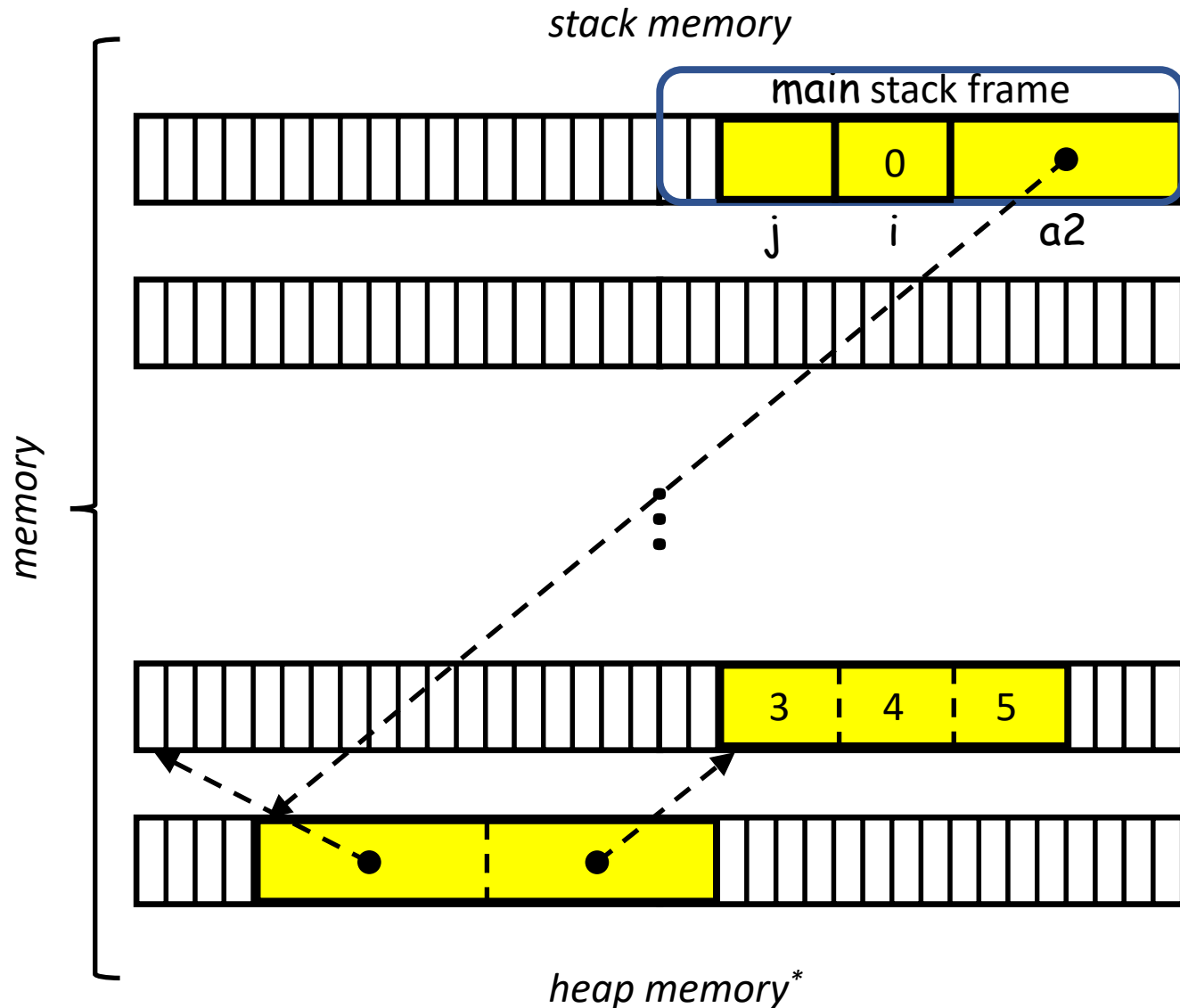
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



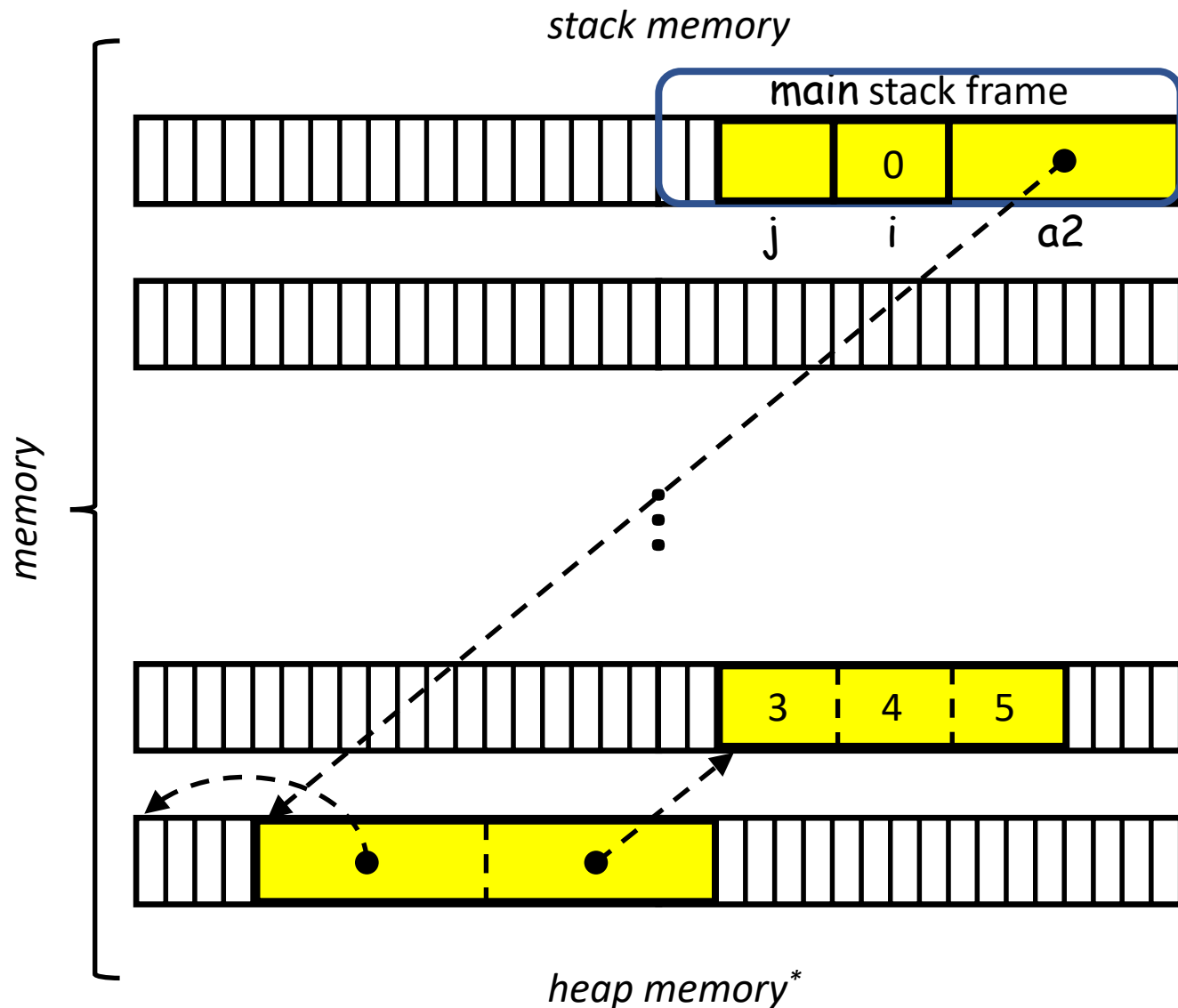
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



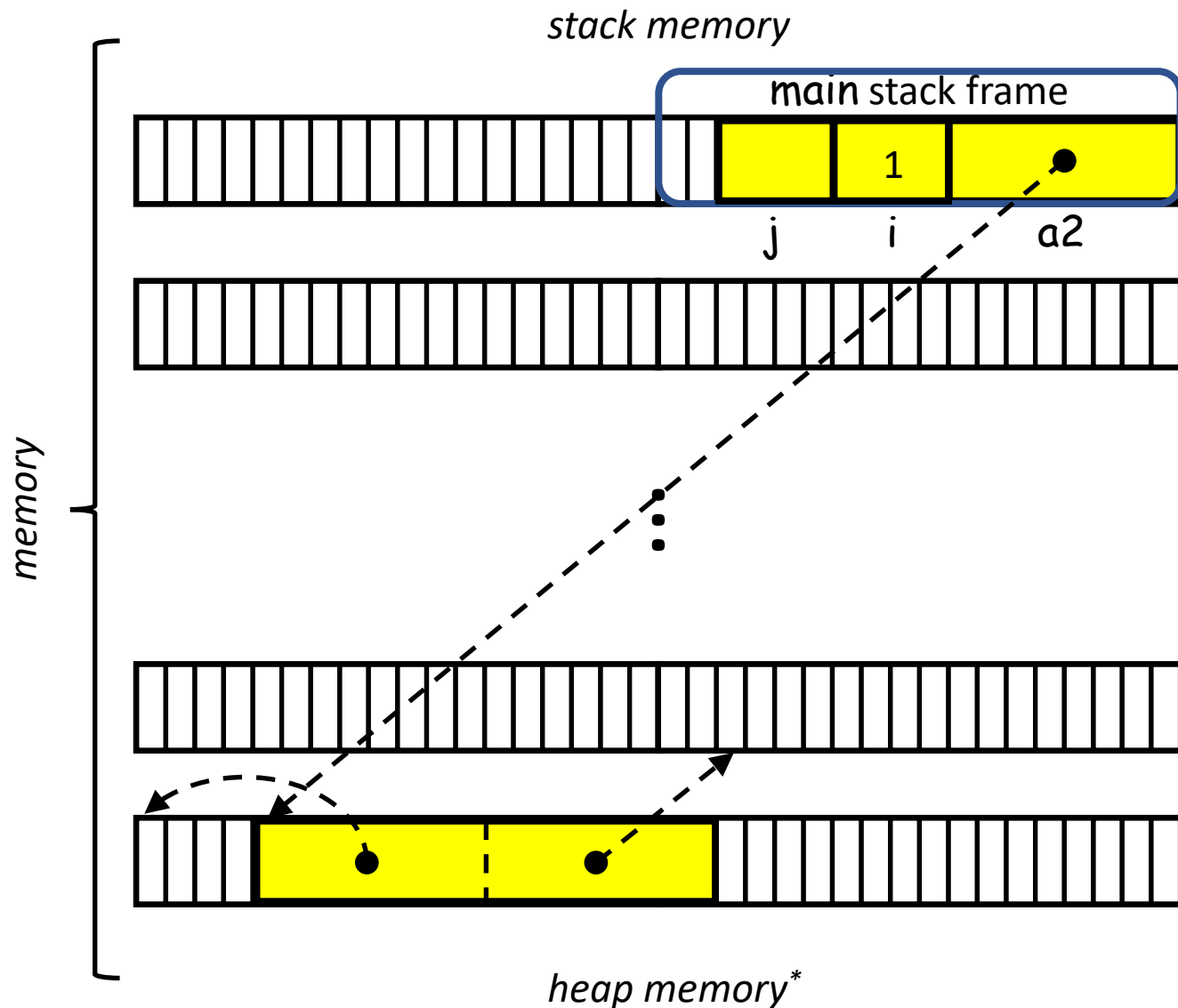
```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
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    {
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    }
    free( a2 );
    a2 = NULL;
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}
```

Dynamic 2D arrays



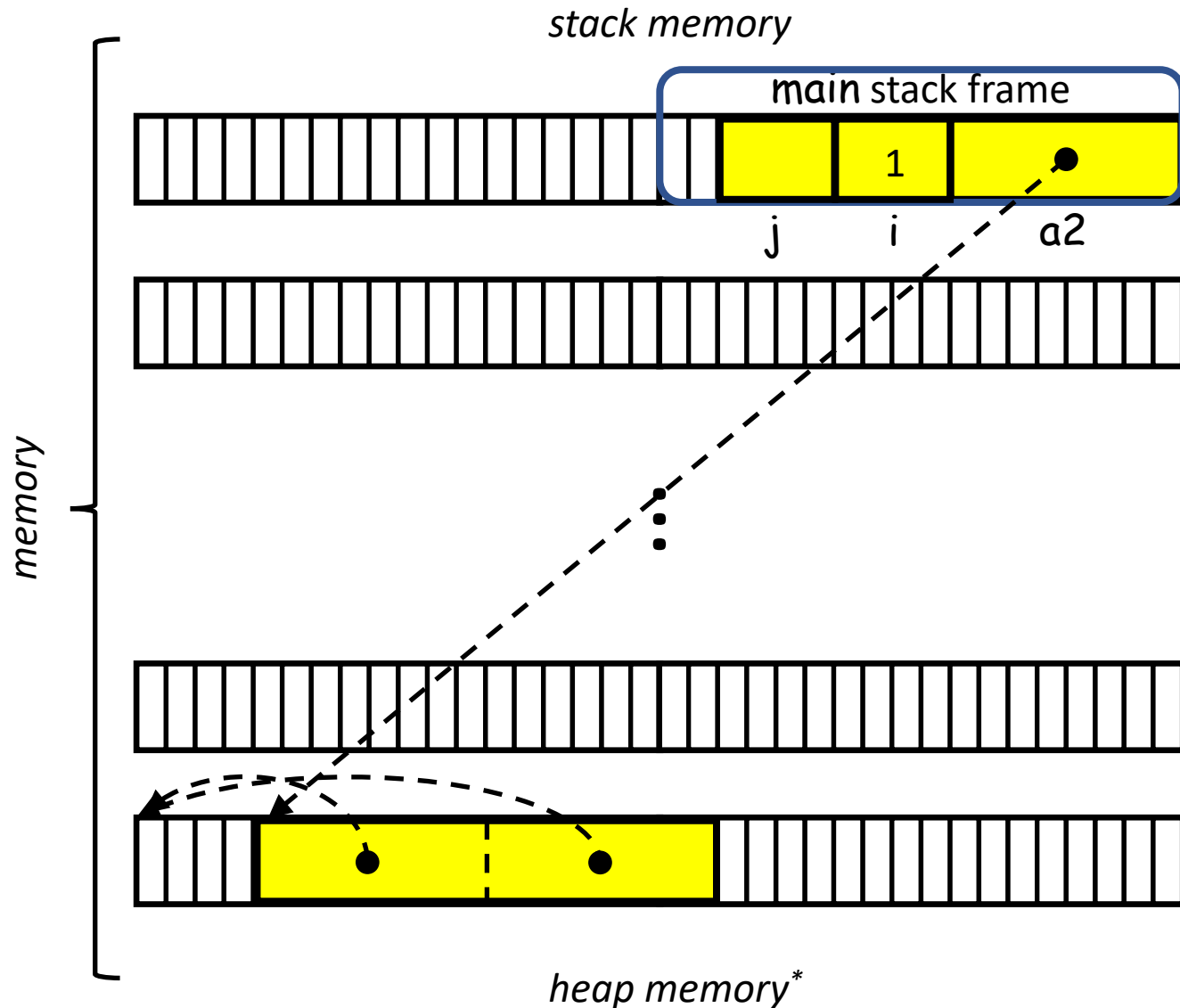
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        if( !a2[i] ) return 1;
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    {
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    }
    free( a2 );
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```

Dynamic 2D arrays



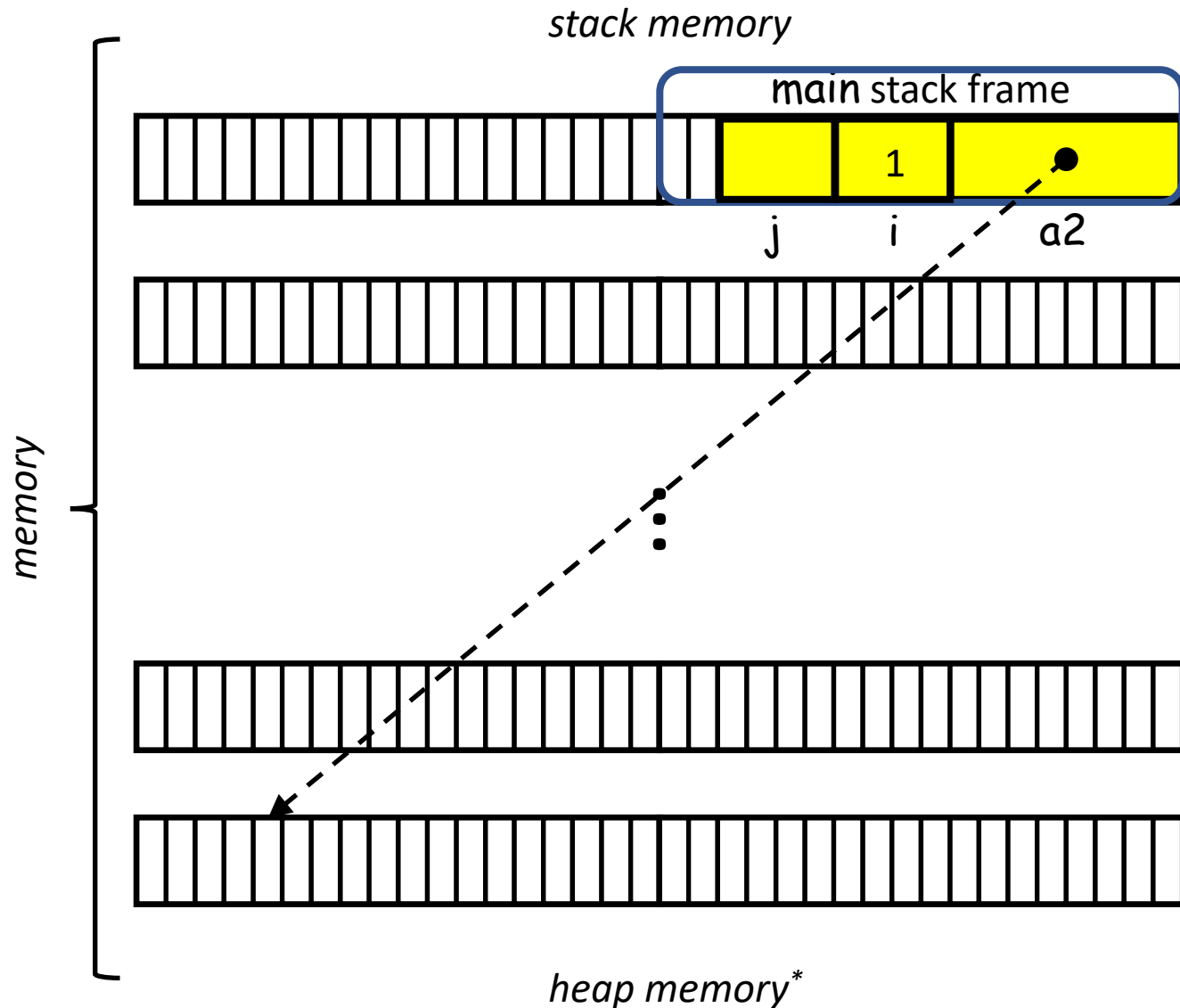
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#include <stdio.h>
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int main( void )
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    int **a2 = malloc( sizeof(int*) * 2 );
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    }
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```

Dynamic 2D arrays



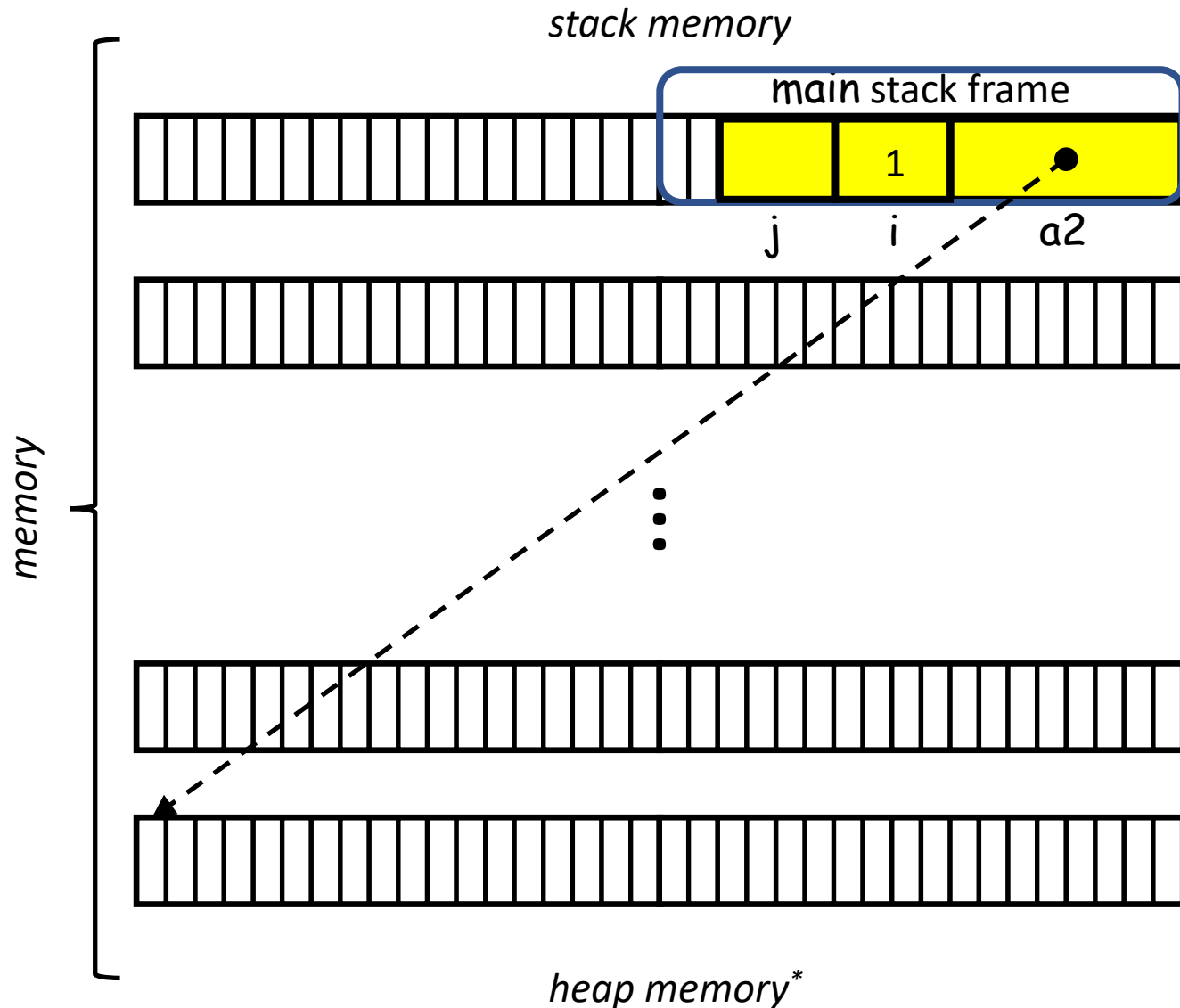
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        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



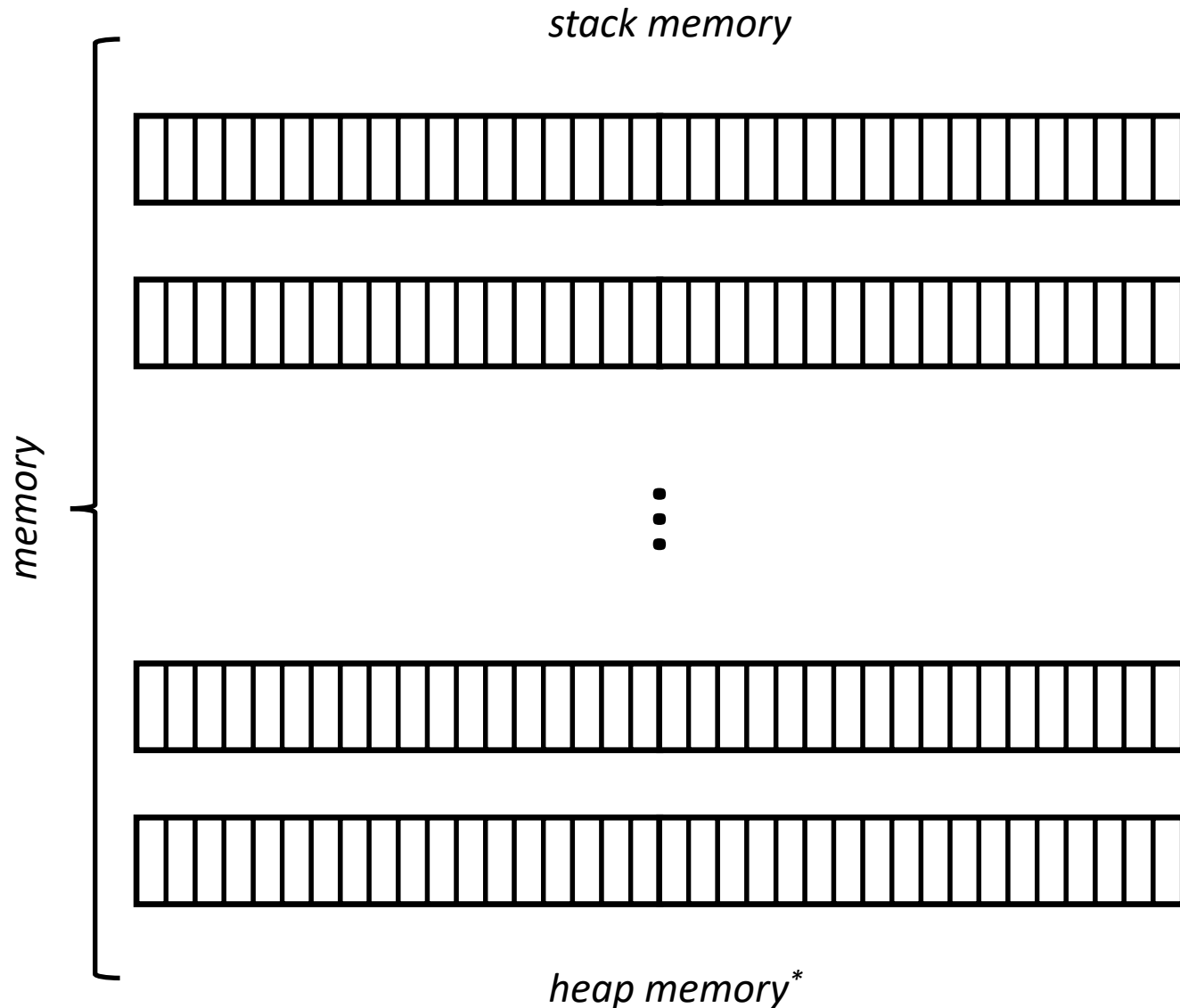
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#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
    {
        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Dynamic 2D arrays



```
#include <stdio.h>
#include <stdlib.h>
int main( void )
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    for( int i=0 ; i<2 ; i++ )
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        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```


Dynamic 2D arrays



```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
    int **a2 = malloc( sizeof(int*) * 2 );
    if( !a2 ) return 1;
    for( int i=0 ; i<2 ; i++ )
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        a2[i] = malloc( sizeof(int) * 3 );
        if( !a2[i] ) return 1;
        for( int j=0 ; j<3 ; j++ ) a2[i][j] = 3*i+j;
    }
    for( int i=0 ; i<2 ; i++ )
    {
        free( a2[i] );
        a2[i] = NULL;
    }
    free( a2 );
    a2 = NULL;
    return 0;
}
```

Outline

- Exercise 11
- Pointer operations
- Dynamic 2D arrays
- Pointers and **const**
- Review questions

Pointers and **const**

Recall:

When we use the **const** keyword, we are declaring a variable immutable.

```
#include <stdio.h>
int main( void )
{
    const int a = 5;
    a = 0;
    return 0;
}
```

```
>> gcc ...
foo.c:5:4: error: assignment of read-only variable 'a'
    5 |   a = 0;
      |   ^
>>
```

Pointers and **const**

Q: When we use the **const** keyword with a pointer, who is immutable, the pointer or the pointee?

Pointers and **const**

A: It depends

- If the keyword **const** precedes the type, then the pointee is immutable.

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int *c = a;
    c[0] = b;
    return 0;
}
```

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int *c = a;
    c = &b;
    return 0;
}
```

Pointers and `const`

A: It depends

- If the keyword `const` precedes the type, then the pointee is immutable.

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int *c = a;
    c[0] = b;
    return 0;
}
```

```
>> gcc ...
foo.c: In function 'main':
foo.c:8:8: error: assignment of read-only location '*c'
      8 |     c[0] = b;
        |         ^
>>
```

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int *c = a;
    c = &b;
    return 0;
}
```

```
>> gcc ...
>>
```

Pointers and **const**

A: It depends

- If the keyword **const** follows the type, then the pointer is immutable.

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    int * const c = a;
    c[0] = b;
    return 0;
}
```

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    int * const c = a;
    c = &b;
    return 0;
}
```

Pointers and `const`

A: It depends

- If the keyword `const` follows the type, then the pointer is immutable.

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    int * const c = a;
    c[0] = b;
    return 0;
}
```

```
>> gcc ...
>>
```

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    int * const c = a;
    c = &b;
    return 0;
}
```

```
>> gcc ...
foo.c: In function 'main':
foo.c:8:5: error: assignment of read-only variable 'c'
      8 |     c = &b;
        |         ^
>>
```


Pointers and `const`

A: It depends

- If the keyword `const` precedes and follows the type, both are immutable.

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int * const c = a;
    c[0] = b;
    return 0;
}
```

```
>> gcc ...
foo.c: In function 'main':
foo.c:8:8: error: assignment of read-only location '*c'
      8 |     c[0] = b;
        |         ^
>>
```

```
#include <stdio.h>
int main( void )
{
    int a[] = { 1 , 2 , 3 };
    int b = 0;
    const int * const c = a;
    c = &b;
    return 0;
}
```

```
>> gcc ...
foo.c: In function 'main':
foo.c:8:5: error: assignment of read-only variable 'c'
      8 |     c = &b;
        |         ^
>>
```

Outline

- Exercise 11
- Pointer operations
- Dynamic 2D arrays
- Pointers and `const`
- Review questions

Review questions

1. What output is printed by the code below?

```
int arr[] = { 94, 69, 35, 72, 9 };
int *p = arr;
int *q = p + 3;
int *r = q - 1;
printf( "%d %d %d\n" , *p , *q , *r );
ptrdiff_t x = q - p;
ptrdiff_t y = r - p;
ptrdiff_t z = q - r;
printf( "%d %d %d\n" , (int)x , (int)y , (int)z );
ptrdiff_t m = p - q;
printf( "%d\n" , (int)m );
int c = ( p < q );
int d = ( q < p );
printf( "%d %d\n" , c , d );
```

p points to arr[0]=94
q points to arr[3]=72
r points to arr[2]=35

```
>> ./a.out
94 72 35
3 2 1
-3
1 0
```

Review questions

2. Assume that `arr` is an array of 4 `int` elements. Is the code
- ```
int *p = arr + 5;
```
- legal?

Yes. (It's the accessing that's the problem)

# Review questions

3. Assume that `arr` is an array of 4 `int` elements. Is the code

```
int *p = arr + 5;
printf("%d\n" , *p);
```

legal?

No. (It's the accessing that's the problem)

# Review questions

4. What output is printed by the code below?

```
#include <stdio.h>
int sum(int a[] , int n)
{
 int x = 0;
 for (int i=0 ; i<n ; i++) x += a[i];
 return x;
}
int main(void)
{
 int data[] = { 23 , 59 , 82 , 42 , 67 , 89 , 76 , 44 , 85 , 81 };
 int result = sum(data + 3 , 4);
 printf("result=%d\n" , result);
 return 0;
}
```

Passing in the sub-array a[] = {42,67,89,76}

```
>> ./a.out
result = 274
```

# Exercise 12

- Website -> Course Materials -> Exercise 12