Intermediate Programming

Day 11

Outline

- Exercise 10
- Dynamic memory allocation
- `Valgrind`
- Review questions

Exercise 10

Declare and define the **getDate** function

passing.c

```
#include <stdio.h>
int getDate( int *mon , int *day , int *yr );

int main()
{
	int mon=0 , day=0 , yr=0;
	…
	return 0;
}
int getDate( int *mon , int *day , int *yr )
{
	printf( "Please enter a date (MM/DD/YYYY): " );
	return fscanf( stdin , "%d/%d/%d" , mon , day , yr );
}
```

Exercise 10

Declare and init. an array of strings that are the names of the month.

passing.c

```
#include <stdio.h>
int getDate( int *mon , int *day , int *yr );

int main()
{
	int mon=0 , day=0 , yr=0;
	char months[][4] =
	{
		"Jan" , "Feb" , "Mar" , "Apr" ,
		"May" , "Jun" , "Jul" , "Aug" ,
		"Sep" , "Oct" , "Nov" , "Dec“
	};
	…
	return 0;
}
int getDate( int *mon , int *day , int *yr )
{
	printf( "Please enter a date (MM/DD/YYYY): " );
	return fscanf( stdin , "%d/%d/%d" , mon , day , yr );
}
```

Exercise 10

Call the getDate function

passing.c

```
#include <stdio.h>
int getDate( int *mon , int *day , int *yr );

int main()
{
	int mon=0 , day=0 , yr=0;
	char months[][4] =
	{
		"Jan" , "Feb" , "Mar" , "Apr" ,
		"May" , "Jun" , "Jul" , "Aug" ,
		"Sep" , "Oct" , "Nov" , "Dec"
	};
	while (  getDate( &mon , &day , &yr )==3 )
	{
		printf("%s %d, %d\n", months[mon-1], day, yr);
	}
	return 0;
}
int getDate( int *mon , int *day , int *yr )
{
	printf( "Please enter a date (MM/DD/YYYY): " );
	return fscanf( stdin , "%d/%d/%d" , mon , day , yr );
}
```

Outline

- Exercise 10
- Dynamic memory allocation
- `Valgrind`
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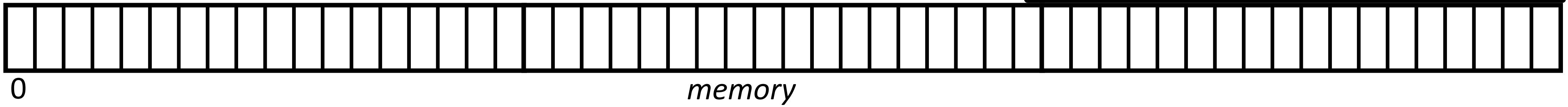
Returning an array in C

Q: Why doesn't this code work?

```c
#include <stdio.h>
int *getArray3( void )
{
        int a[3];
        for( int i=0 ; i<3 ; i++ ) a[i] = 1;
        return a;
}
int main( void )
{
        int *list = NULL;
        list = getArray3();
        for( int i=0 ; i<3 ; i++ )
                printf( "%d " , list[i] );
        printf( "\n" );
        return 0;
}
```

```
>> ./a.out
Segmentation fault (core dumped)
>>
```



Stack frame

- Each function call gets a new, fixed size, *stack frame* “pushed onto” the *call stack* in memory for storing
  - Local variables
  - Copies of function parameters
  - Information about the calling function
  - Other miscellany

- Once the current function call returns, the stack frame is “popped off” the stack, and execution returns to the calling function
  (so the current function’s frame is always on top)

Returning an array in C

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- **Frames get pushed on the stack when the function is called**
- And are popped off when it returns

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int *getArray3( void )
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                printf( "%d " , list[i] );
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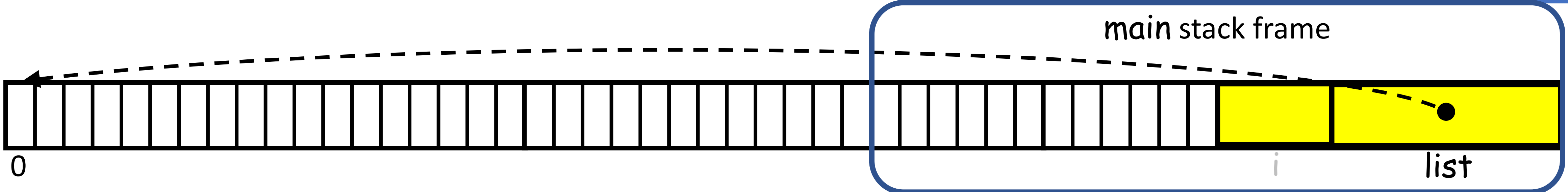
}
```



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        list = getArray3();
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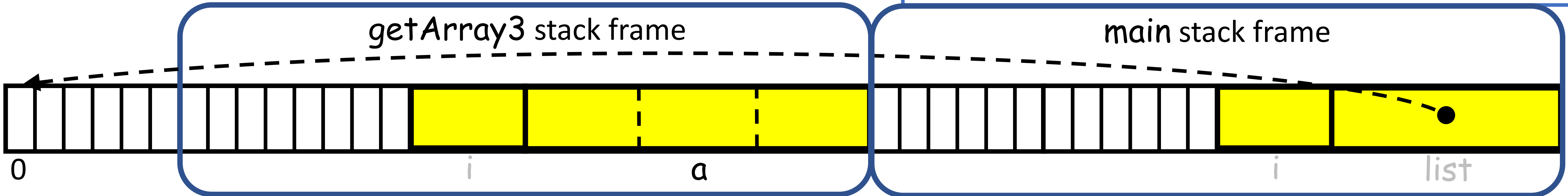

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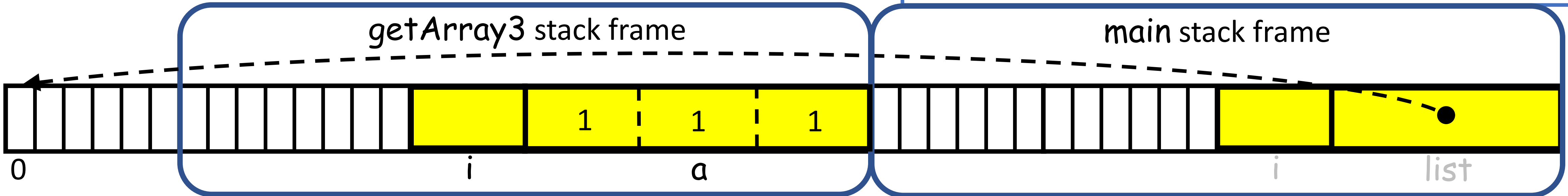

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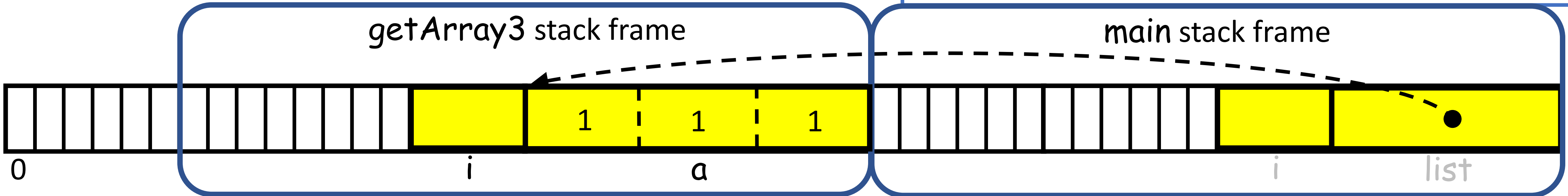


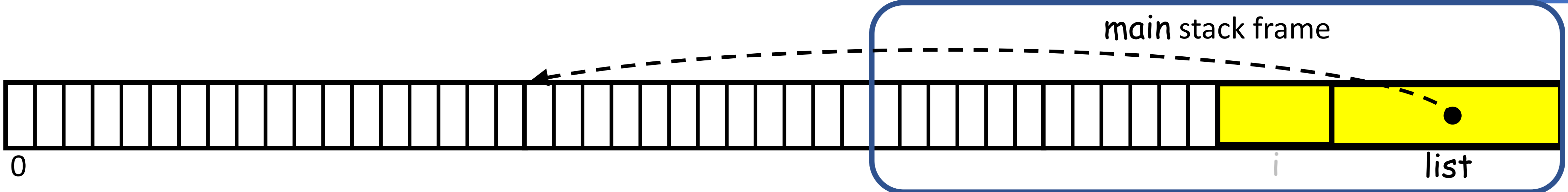
Returning an array in C

Q: Why doesn't this code work?

- Frames get pushed on the stack when the function is called
- **And are popped off when it returns**

A: By the time `list` is assigned the address `a`, the stack frame holding the array values is popped off and the address points to unassigned memory.

```
#include <stdio.h>
int *getArray3( void )
{
        int a[3];
        for( int i=0 ; i<3 ; i++ ) a[i] = 1;
        return a;
}
int main( void )
{
        int *list = NULL;
        list = getArray3();
        for( int i=0 ; i<3 ; i++ )
                printf( "%d " , list[i] );
        printf( "\n" );
        return 0;
}
```



Limitations of arrays allocated in a stack frame

- Arrays ("statically") allocated on the stack frame have limitations
  - Arrays created on a called function's frame are not accessible to the calling function once the function returns
    - Returning *a* is meaningless

```
#include <stdio.h>
int *getArray3( void )
{
        int a[3];
        for( int i=0 ; i<3 ; i++ ) a[i] = 1;
        return a;
}
int main( void )
{
        int *list = NULL;
        list = getArray3();
        for( int i=0 ; i<3 ; i++ )
                printf( "%d " , list[i] );
        printf( "\n" );
        return 0;
}
```

Limitations of arrays allocated in a stack frame

- Arrays ("statically") allocated on the stack frame have limitations
  - Arrays created on a called function's frame are not accessible to the calling function once the function returns
  - Stack frames have fixed (small) size
    - Cannot statically allocate more memory than the size of the stack frame

```
#include <stdio.h>
int main( void )
{
        int values[10000000];
        return 0;
}
```

```
>> ./a.out
Segmentation fault (core dumped)
>>
```

Note that 10,000,000 `int`s is roughly 40 megabytes, which is not an unreasonable amount of memory.

Dynamic Memory Allocation

- Dynamically-allocated memory:
  - Is located on the *heap* – a part of memory separate from the stack
  - Lives as long as we like (until the entire program ends)
    - We don't lose access to it when function call returns
      - ✓ We can return it to a calling function!
      - ✗ We are responsible for managing the memory (and cleaning it up when we're done)
  - Is not subject to stack frame's size limitations because it isn't part of the stack

Dynamic Memory Allocation

- ✘ We are responsible for managing the memory
  - Memory should be *deallocated* when it is no longer needed
  - Allocated memory is not available to other programs/users until we deallocate it
  - Failing to deallocate memory is the cause of “memory leaks”

Dynamic Memory Allocation (single)

- We allocate memory using the malloc command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

  - Input: how much memory (in bytes) to allocate
    - size_t is an unsigned integer type:*
      - 4 bytes on 32-bit machines
      - 8 bytes on 64-bit machines
  - Output: the location (on the heap) of the memory
    - malloc doesn't need to know what you're going to store just how much memory you need (so it returns a void *)

```
…
int *ip = malloc( sizeof( int ) );
```

*On a 32-bit machine you can't ask for more than 2^{32} bytes.

Dynamic Memory Allocation (single)

- We allocate memory using the malloc command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

- Check that allocation succeeded

```
…
int *ip = malloc( sizeof( int ) );
if( ip==NULL )
{
    fprintf( stderr , "…\n" );
    // do something
}
```

Dynamic Memory Allocation (single)

- We allocate memory using the `malloc` command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

- Check that allocation succeeded
- After allocation with `malloc`, memory <u>cannot</u> be assumed to be initialized

```
…
int *ip = malloc( sizeof( int ) );
if( !ip )
{
    fprintf( stderr , "…\n" );
    // do something
}
*ip = 0;
…
```

Dynamic Memory Allocation (single)

- We allocate memory using the malloc command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

- Check that allocation succeeded
- After allocation with malloc, memory <u>cannot</u> be assumed to be initialized
- When done using dynamically-allocated memory, deallocate using free

```
void free( void *ptr );
```

  - Input: address of the memory on the heap

```
…
int *ip = malloc( sizeof( int ) );
if( !ip )
{
    fprintf( stderr , "…\n" );
    // do something
}
*ip = 0;
…
free( ip );
```

Dynamic Memory Allocation (single)

- We allocate memory using the `malloc` command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

- Check that allocation succeeded
- After allocation with `malloc`, memory cannot be assumed to be initialized
- When done using dynamically-allocated memory, deallocate using `free`

```
void free( void *ptr );
```

- It's good practice to set the pointer to `NULL` to avoid accidental use

```
…
int *ip = malloc( sizeof( int ) );
if( !ip )
{
    fprintf( stderr , "…\n" );
    // do something
}
*ip = 0;
…
if( ip!=NULL ) free( ip );
ip = NULL;
…
```

Dynamic Memory Allocation (multiple)

- We allocate memory using the malloc command (declared in `stdlib.h`)

  `void *malloc( size_t );`

- Check that allocation succeeded
- After allocation with malloc, memory cannot be assumed to be initialized
- When done using dynamically-allocated memory, deallocate using free

  `void free( void *ptr );`

- It's good practice to set the pointer to NULL to avoid accidental use

```
…
int *ip = malloc( sizeof( int ) * sz );
if( !ip )
{
    fprintf( stderr , "…\n" );
    // do something
}
for( int i=0 ; i<sz ; i++ ) ip[i] = 0;
…
if( ip!=NULL ) free( ip );
ip = NULL;
…
```

Dynamic Memory Allocation (multiple)

- We allocate memory using the `malloc` command (declared in `stdlib.h`)

```
void *malloc( size_t );
```

- Check that allocation succeeded
- After allocation with `malloc`, memory cannot be assumed to be initialized
- When done using dynamically-allocated memory, deallocate using `free`

```
void free( void *ptr );
```

Note:
Call `free` once for every `malloc` called.

```
…
int *ip = malloc( sizeof( int ) * sz );
if( !ip )
{
    fprintf( stderr , "…\n" );
    // do something
}
for( int i=0 ; i<sz ; i++ ) ip[i] = 0;
…
if( ip!=NULL ) free( ip );
ip = NULL;
…
```

Deallocation

- Deallocation does not have to happen in the same function where allocation occurred. . .
  - But it does have to happen!
  - Otherwise you can get a *memory leak*

[BADNESS] Only the last allocation was deallocated!

```
#include <stdio.h>
#include <stdlib.h>
int *getArray( unsigned int sz )
{
    int *a = malloc( sizeof(int) * sz );
    for( int i=0 ; i<sz ; i++ ) a[i] = 1;
    return a;
}
int main( void )
{
    int *list;
    for( int i=0 ; i<100000 ; i++ )
    {
        list = getArray( 100000 );
        // do something with list
    }
    free( list );
    return 0;
}
```

Deallocation

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  - But it does have to happen!
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```
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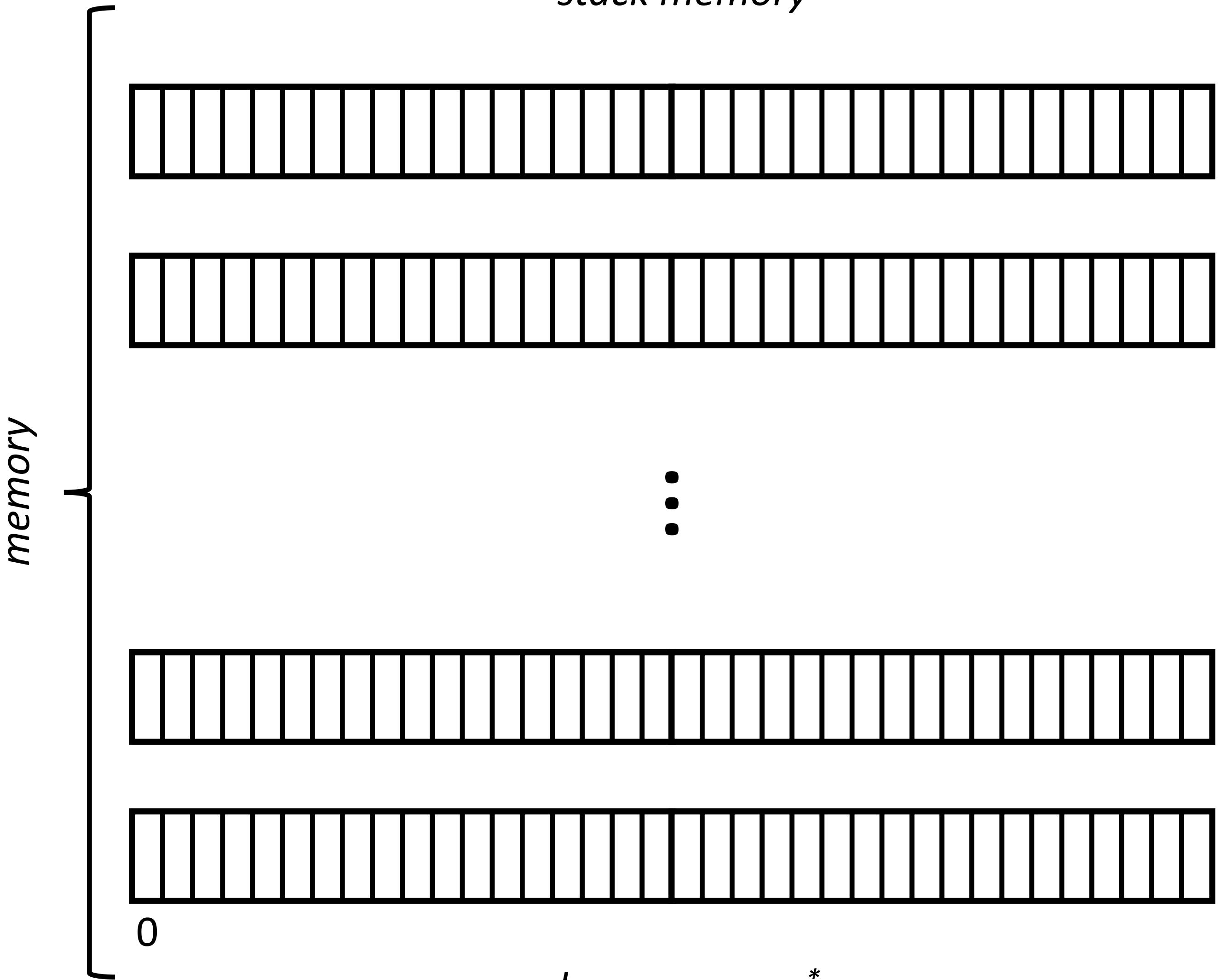
#include <stdlib.h>
int *getArray( unsigned int sz )
{
    int *a = malloc( sizeof(int) * sz );
    for( int i=0 ; i<sz ; i++ ) a[i] = 1;
    return a;
}
int main( void )
{
    int *list;
    for( int i=0 ; i<100000 ; i++ )
    {
        list = getArray( 100000 );
        // do something with list
        free( list );
    }
    return 0;
}
```

Dynamic Memory Allocation

stack memory

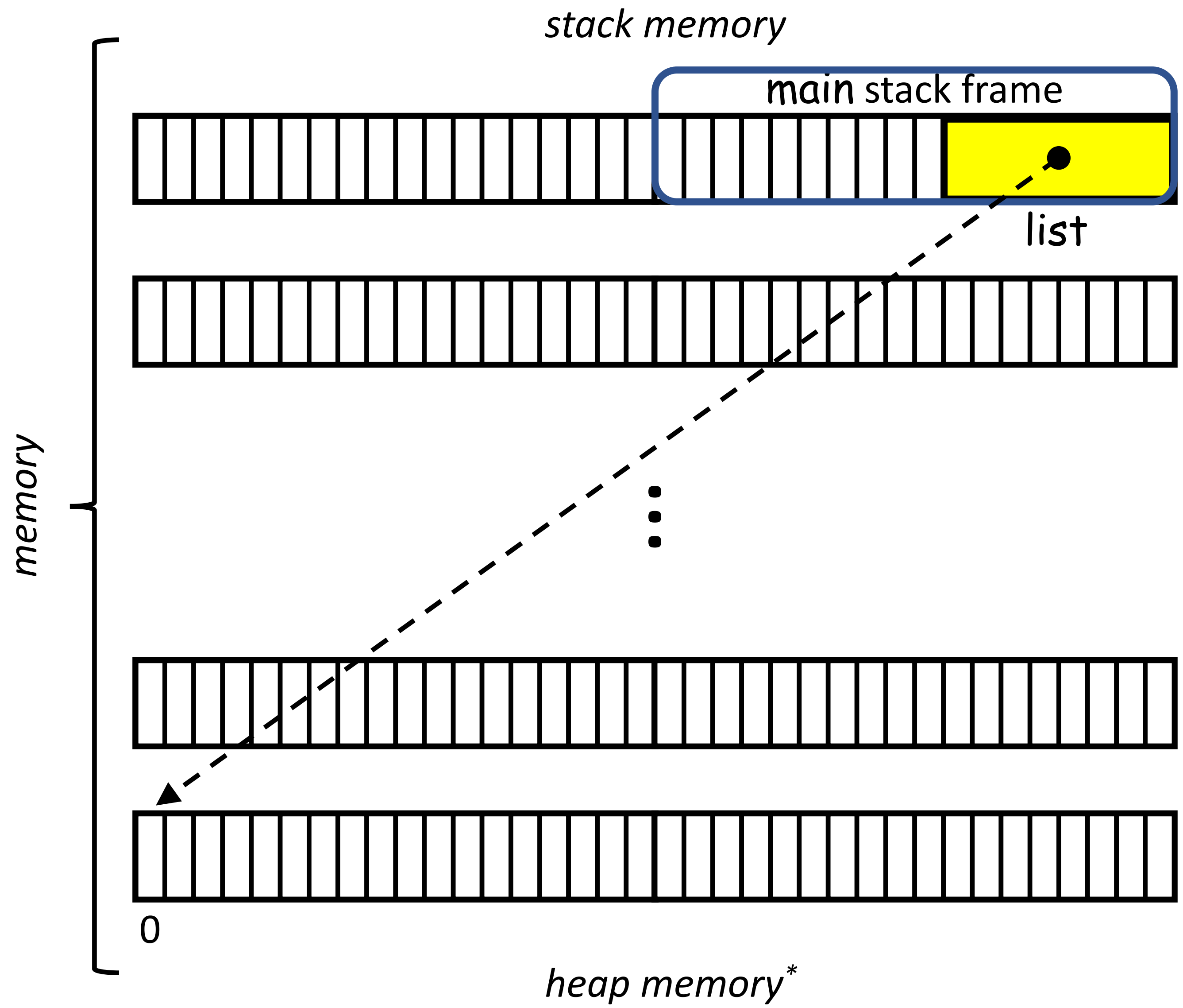


*heap memory**

```c
#include <stdio.h>
#include <stdlib.h>
int *getArray( unsigned int sz )
{
    int *a = NULL;
    a = malloc( sizeof(int) * sz );
    for( int i=0 ; i<sz ; i++ ) a[i] = 0;
    return a;
}
int main( void )
{
    int *list = NULL;
    list = getArray( 8 );
    // do something with list
    free( list );
    list = NULL;
    return 0;
}
```

* Visualization is not to scale:
There is much more room on the heap than on the stack.

Dynamic Memory Allocation

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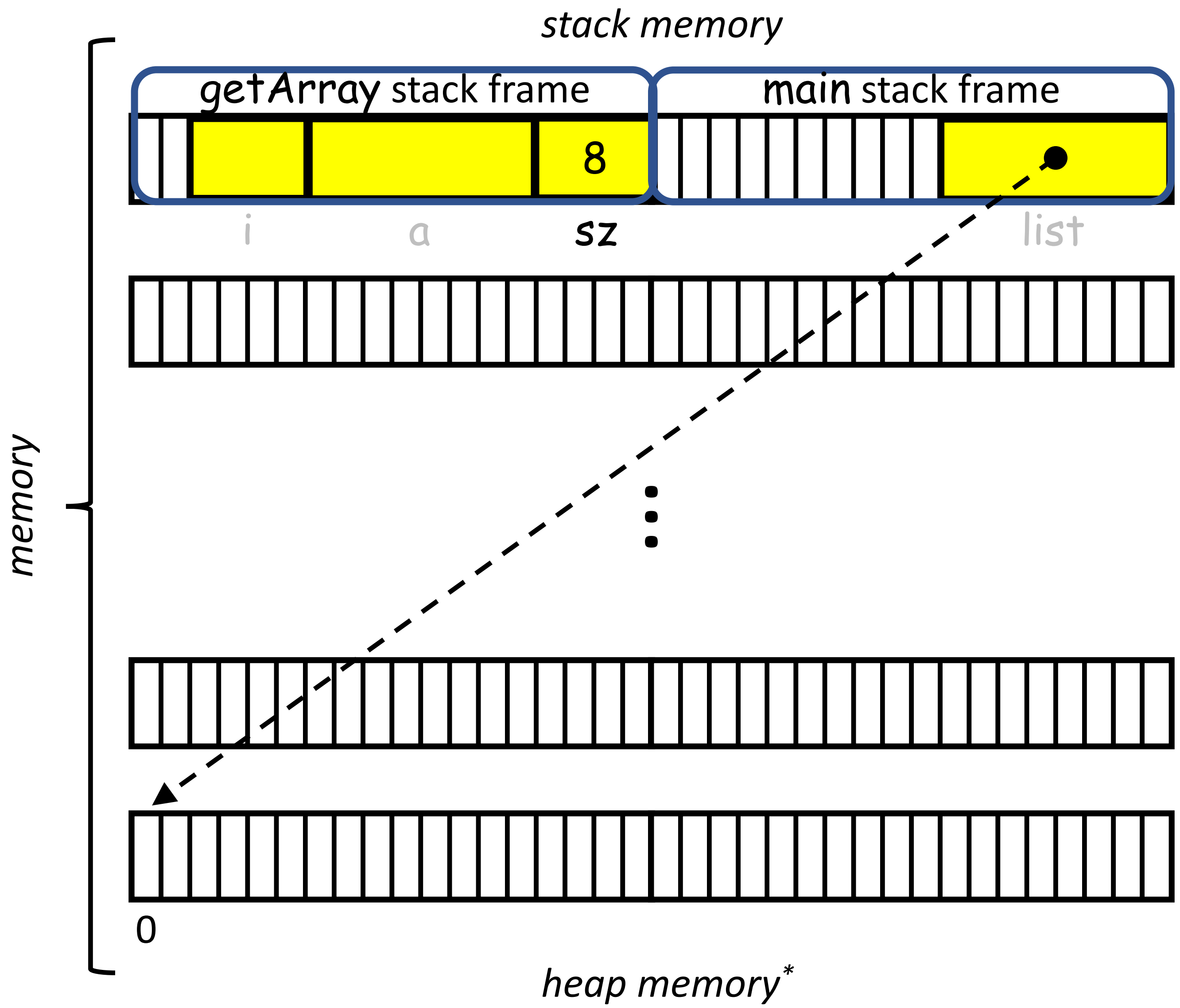


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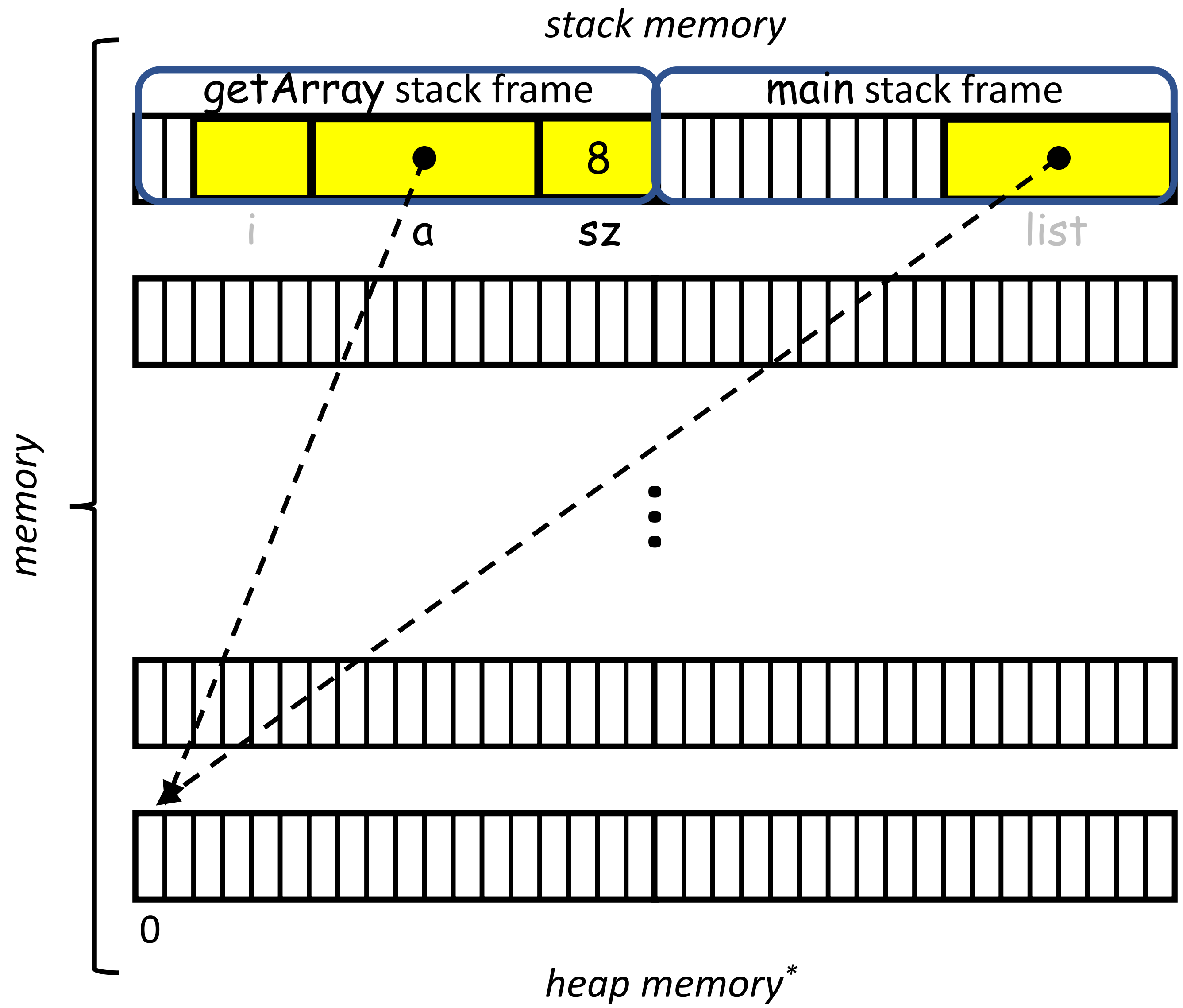


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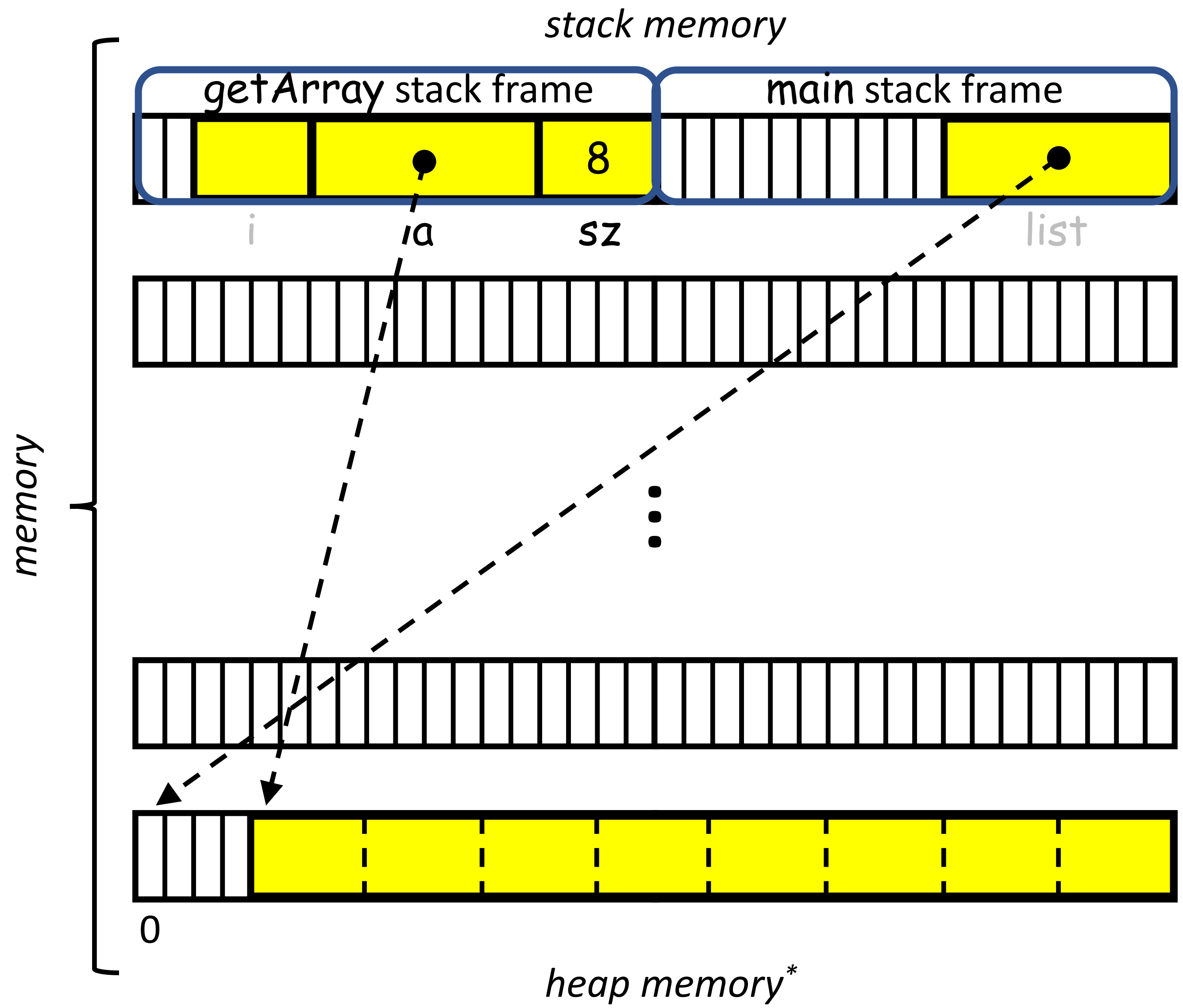


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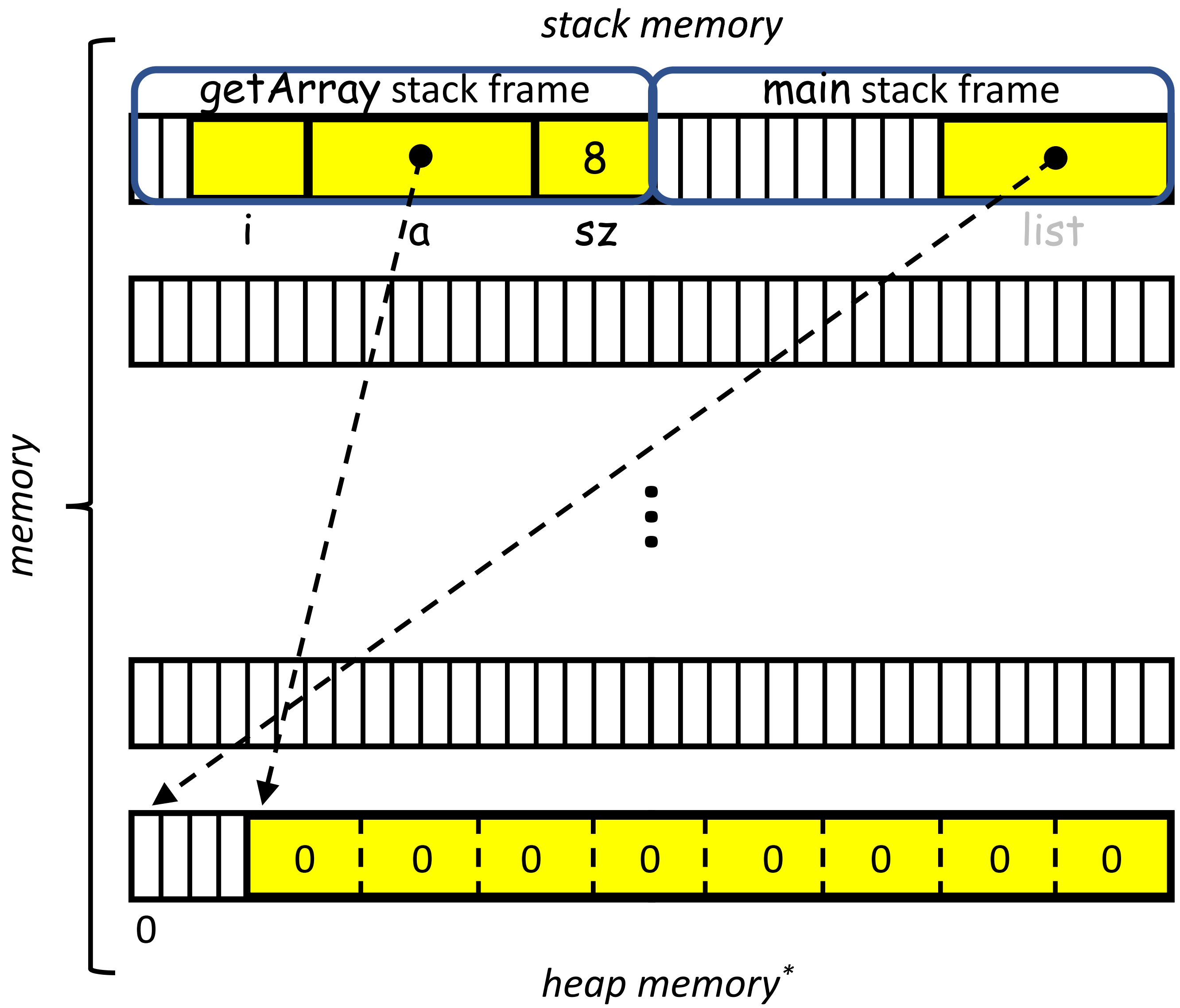


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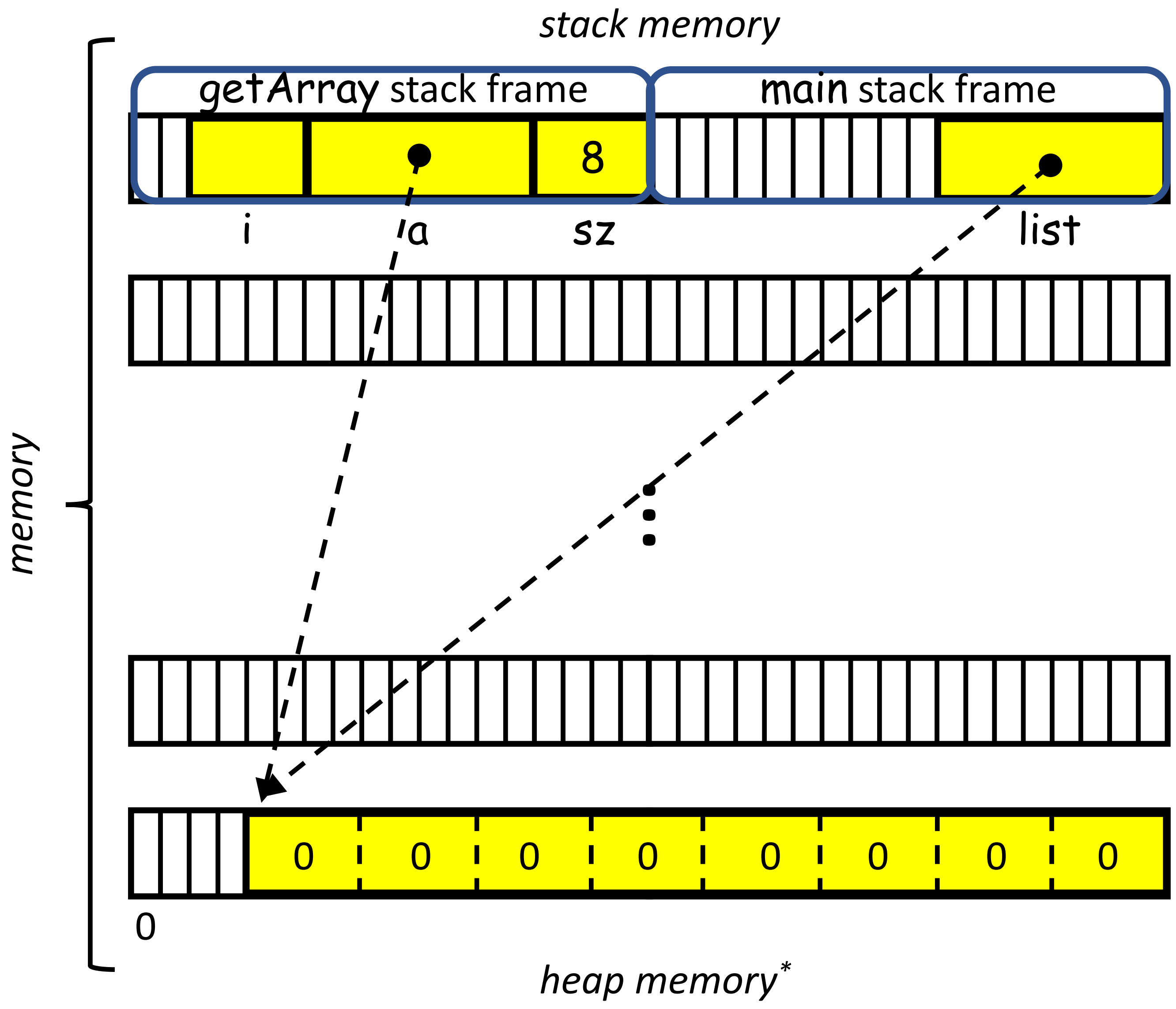


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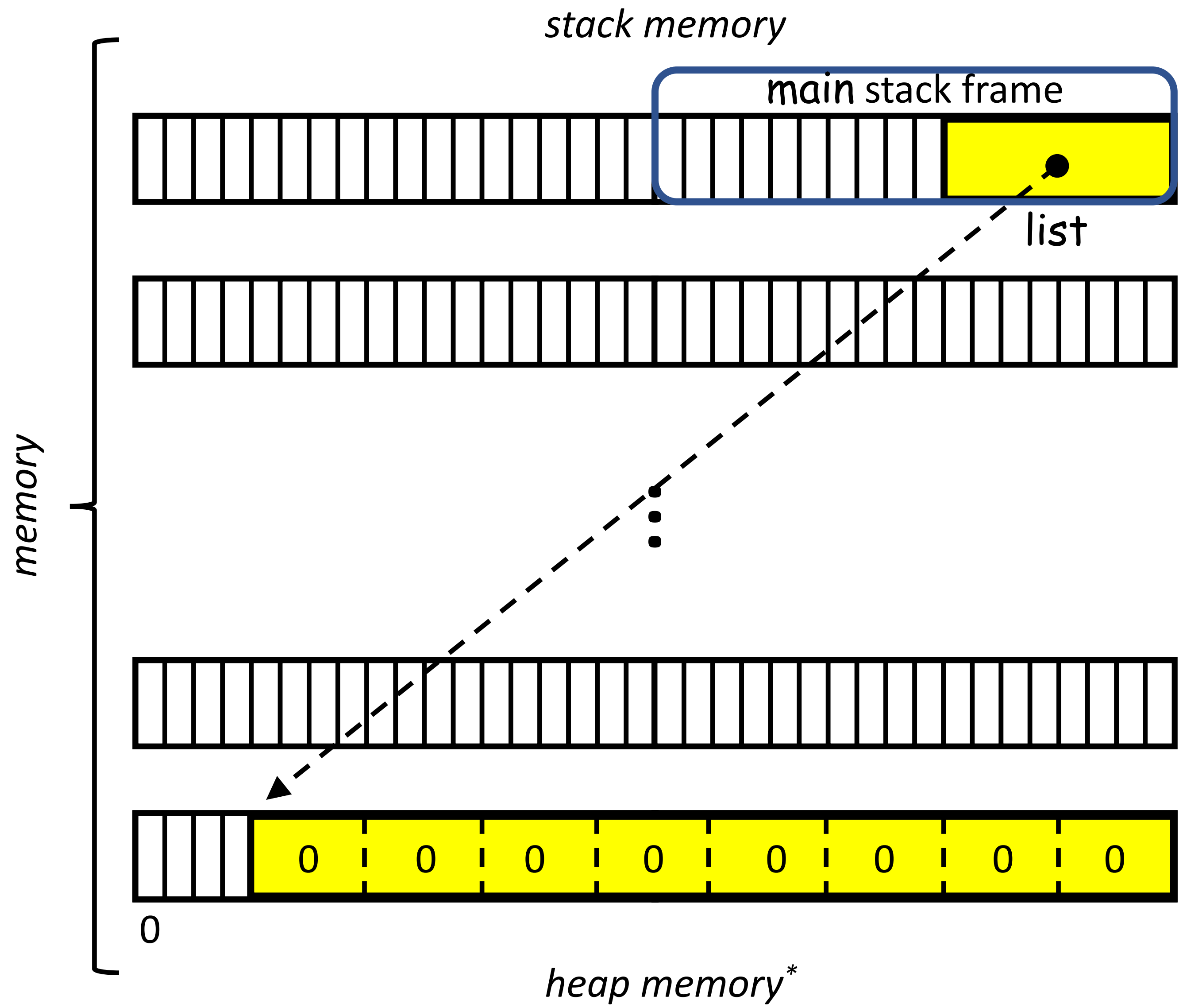


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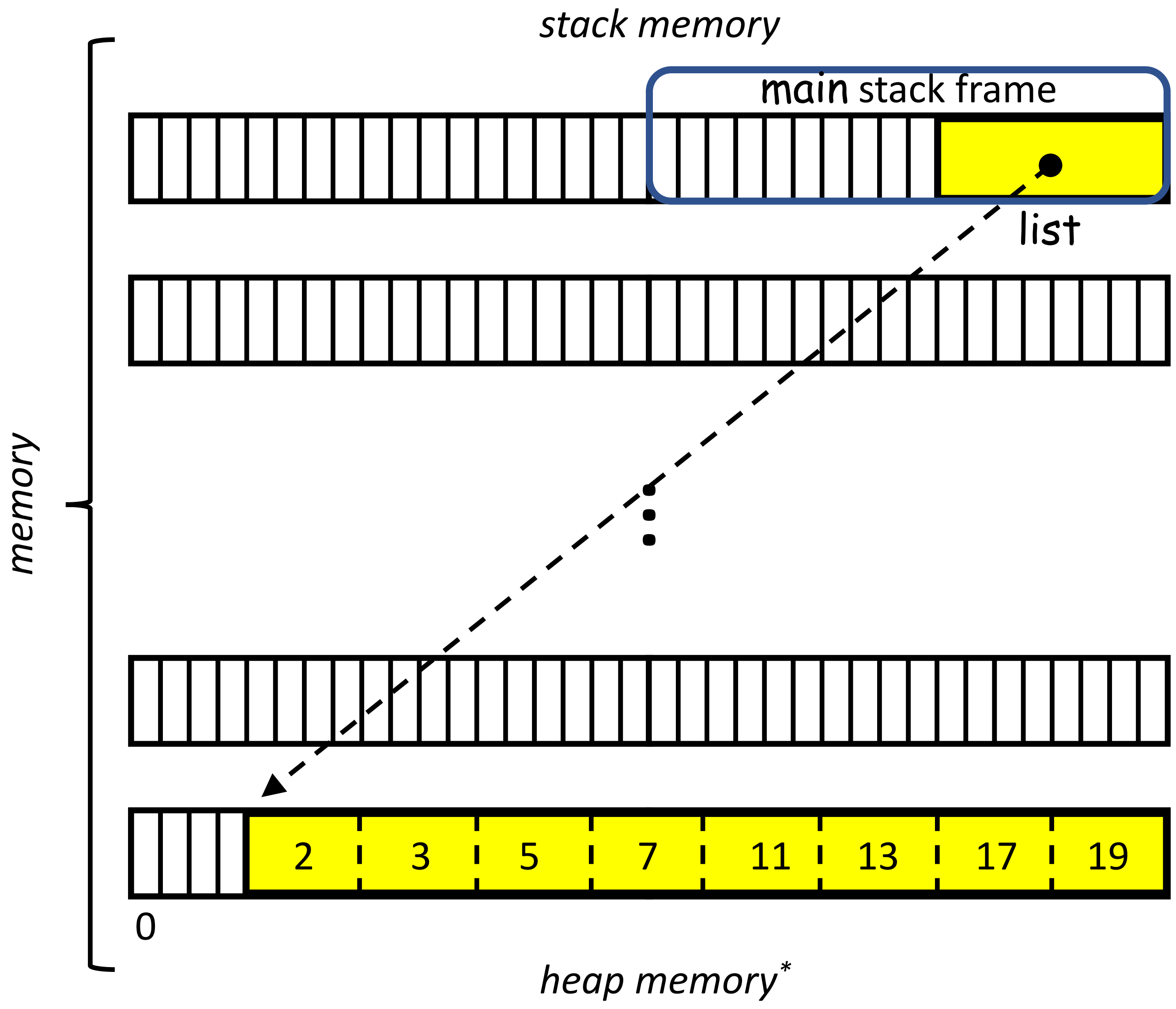


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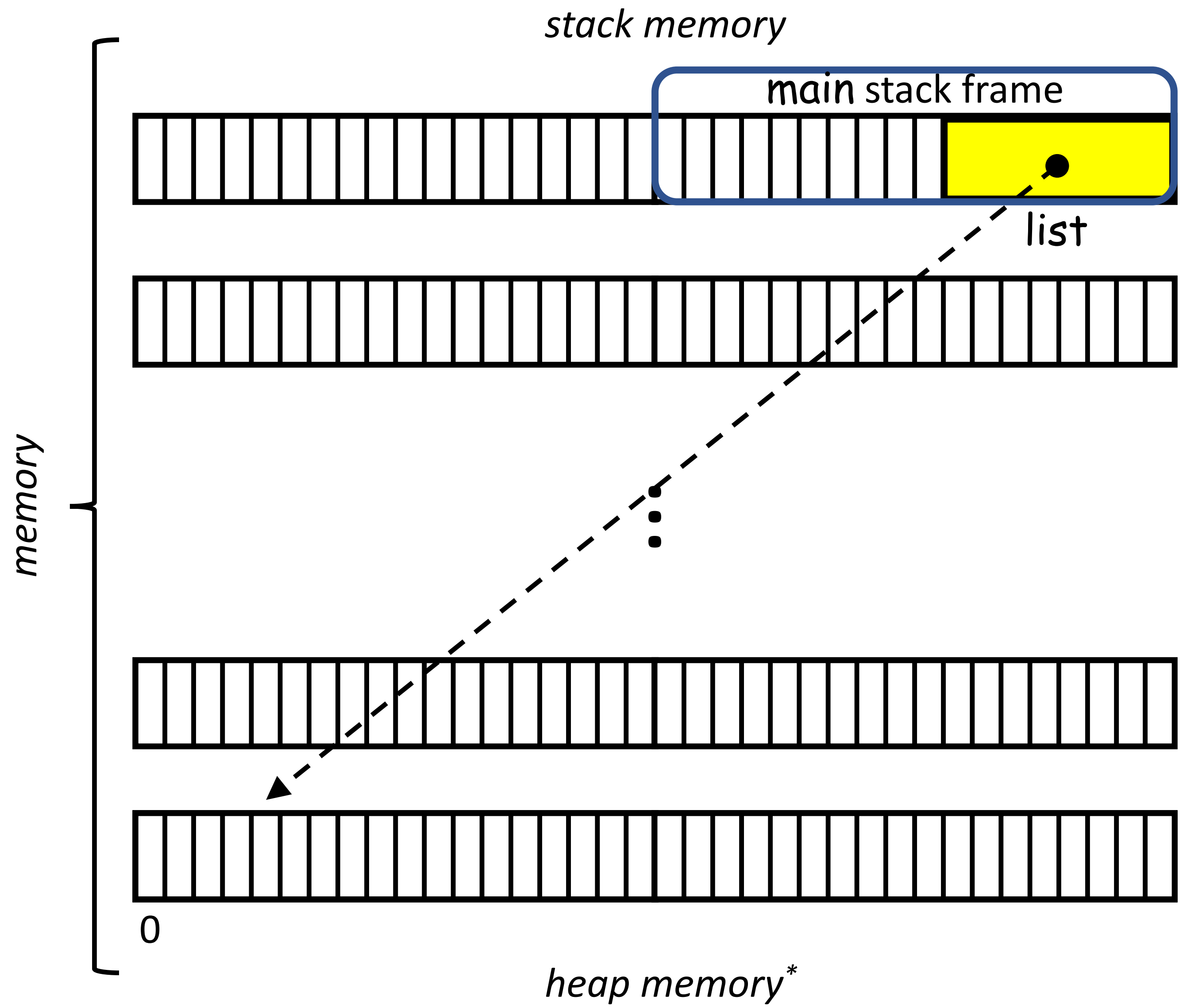


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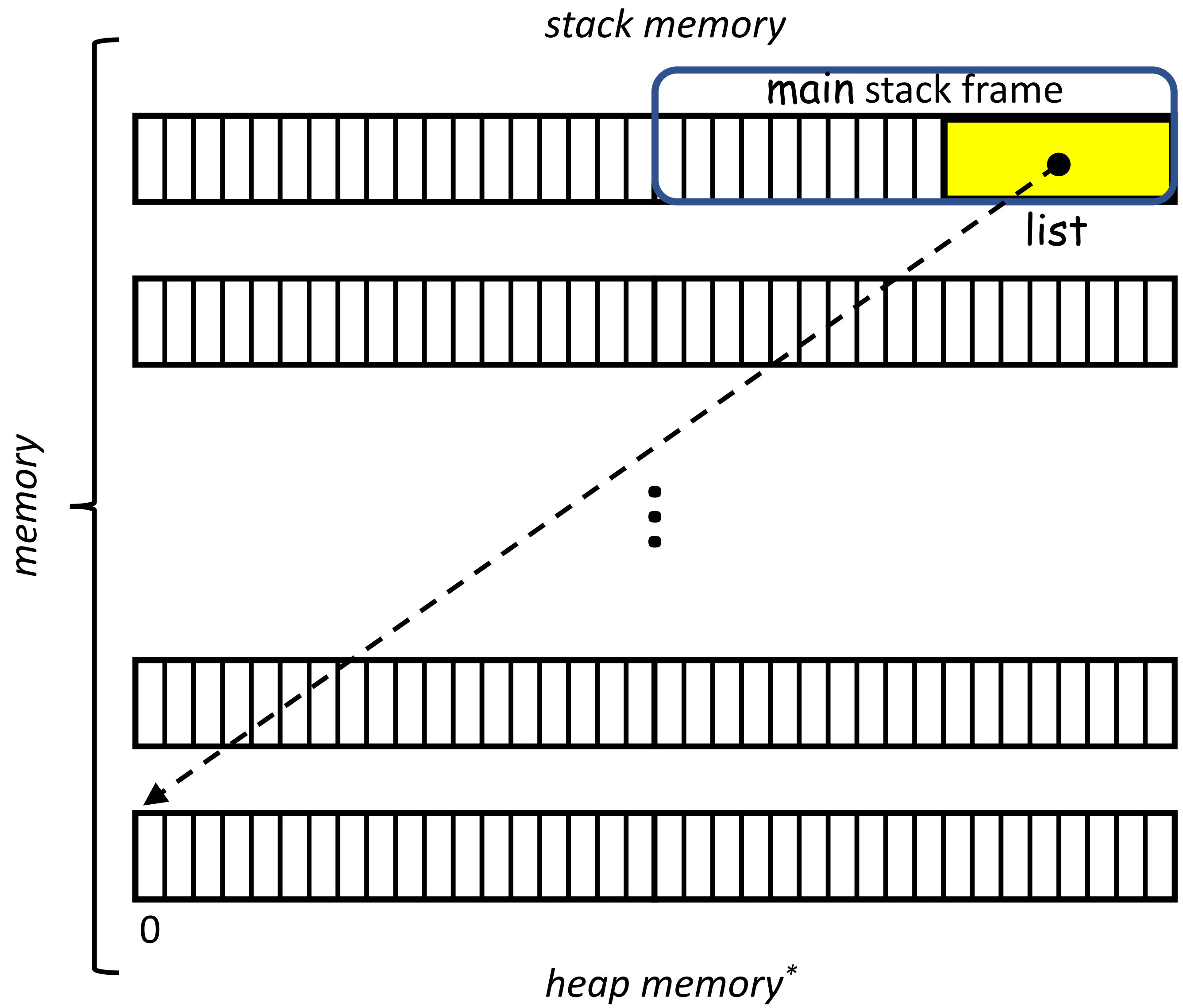


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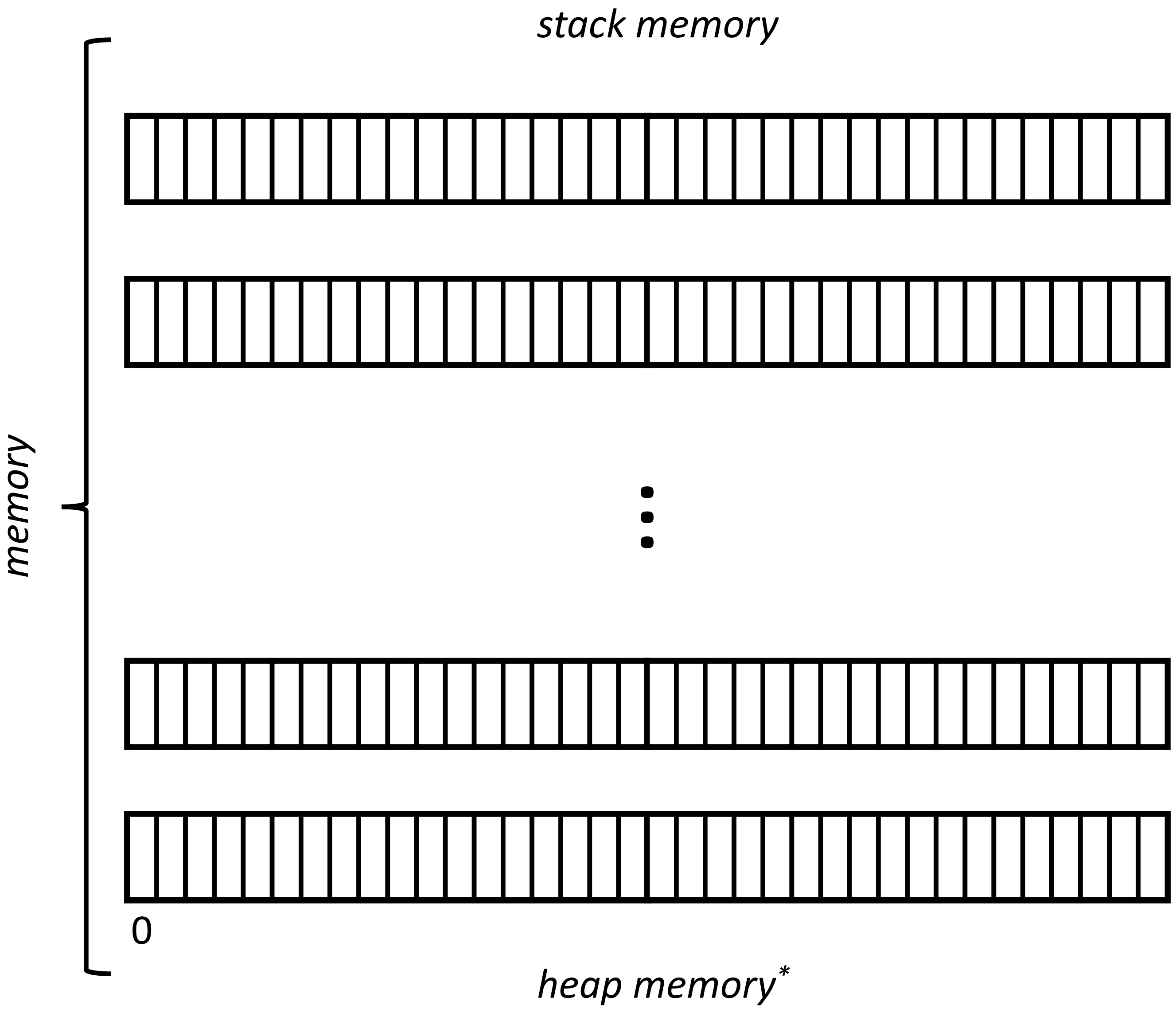
There is much more room on the heap than on the stack.

Dynamic Memory Allocation




```
#include <stdio.h>
#include <stdlib.h>
int *getArray( unsigned int sz )
{
    int *a = NULL;
    a = malloc( sizeof(int) * sz );
    for( int i=0 ; i<sz ; i++ ) a[i] = 0;
    return a;
}
int main( void )
{
    int *list = NULL;
    list = getArray( 8 );
    // do something with list
    free( list );
    list = NULL;
    return 0;
}
```

* Visualization is not to scale:
There is much more room on the heap than on the stack.

Working w/ Memory (declared in `stdlib.h`)

- Allocate and clear memory:

  `void *calloc( size_t num , size_t size );`

  Input:
  - `num`: the number of elements
  - `size`: the size of each element (undefined behavior if zero)

  Output:
  - On success: a pointer to the allocated and cleared memory
  - On failure: a null-pointer

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
	int *v = calloc( 4 , sizeof(int) );
	if( !v ) …
	for( int i=0 ; i<4 ; i++ ) printf( "%d] %d\n" , i , v[i] );
	free( v );
	return 0;
}
```

```
>> ./a.out
0] 0
1] 0
2] 0
3] 0
>>
```

Working w/ Memory (declared in `stdlib.h`)

- Change the size of memory pointed to by a pointer while preserving the data (up to the minimum of the old and new sizes):

  `void *realloc( void *ptr , size_t size );`

  Input:
  - `ptr`: pointer to memory on the heap (if `NULL`, `realloc` behaves like `malloc`)
  - `size`: new size for the memory block (if 0, `realloc` behaves like `free`)

  Output:
  - On failure or if `size`=0: a null-pointer
  - On success: a pointer to the new memory with old values preserved up to `size` bytes (may or may not be the address of the old memory)

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
	int *v = malloc( sizeof(int)*3 );
	for( int i=0 ; i<3 ; i++ ) v[i] = i;
	int *_v = realloc( v , sizeof(int)*4 );
	_v[3] = 3;
	for( int i=0 ; i<4 ; i++)
		printf( "%d] %d\n" , i , _v[i] );
	free( _v );
	return 0;
}
```

```
>> ./a.out
0] 0
1] 1
2] 2
3] 3
>>
```

Working w/ Memory (declared in `stdlib.h`)

- Change the size of memory pointed to by a pointer while preserving the data (up to the minimum of the old and new sizes):

```
void *realloc( void *ptr , size_t size );
```

WARNING:
`realloc` will try to extend/shrink the memory in place but is not guaranteed to (e.g. if there isn't sufficient space to grow).
⇒ Do not assume that the input and output pointers are equal

- In that case, `realloc` handles deallocation of the old memory (e.g. there is no call "`free(v);`")

  - On failure or if `size`=0: a null-pointer
  - On success: a pointer to the new memory with old values preserved up to `size` bytes (may or may not be the address of the old memory)

```
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
	int *v = malloc( sizeof(int)*3 );
	for( int i=0 ; i<3 ; i++ ) v[i] = i;
	int *_v = realloc( v , sizeof(int)*4 );
	_v[3] = 3;
	for( int i=0 ; i<4 ; i++)
		printf( "%d] %d\n" , i , _v[i] );
	free( _v );
	return 0;
}
```

```
>> ./a.out
0] 0
1] 1
2] 2
3] 3
>>
```

Working w/ Memory (declared in `stdlib.h`)

- Change the size of memory pointed to by a pointer while preserving the data (up to the minimum of the old and new sizes):

  `void *realloc( void *ptr , size_t size );`

WARNING:
realloc will try to extend/shrink the memory in place but is not guaranteed to (e.g. if there isn't sufficient space to grow).
⇒ Do not assume that the input and output pointers are equal
- In that case, realloc handles deallocation of the old memory (e.g. there is no call "free(v);")

⇒ Don't need to make a separate int *_v variable.

  - On success: a pointer to the new memory with old values preserved up to size bytes (may or may not be the address of the old memory)

```c
#include <stdio.h>
#include <stdlib.h>
int main( void )
{
	int *v = malloc( sizeof(int)*3 );
	for( int i=0 ; i<3 ; i++ ) v[i] = i;
	v = realloc( v , sizeof(int)*4 );
	v[3] = 3;
	for( int i=0 ; i<4 ; i++)
		printf( "%d] %d\n" , i , v[i] );
	free( v );
	return 0;
}
```

```
>> ./a.out
0] 0
1] 1
2] 2
3] 3
>>
```

Outline

- Exercise 10
- Dynamic memory allocation
- `Valgrind`
- Review questions

Valgrind

- Easy-to-use tool for finding memory leaks and other memory issues
- Compile with `-g` to get more helpful output from `valgrind`
- Then run using `valgrind`:

```
valgrind --leak-check=full ./myFile <arg1> <arg2> ...
```

```
#include <stdio.h>
int main( void )
{
    printf( "Hello world!\n" );
    return 0;
}
```

```
>>  gcc -std=c99 -Wall -Wextra -g foo.c
>> ./a.out
Hello world!
>>
```

See also http://valgrind.org/docs/manual/QuickStart.html

Valgrind

- Easy-to-use tool for finding memory leaks and other memory issues
- Compile with `-g` to get more helpful output from `valgrind`
- Then run using `valgrind`:

va

```
>> valgrind --leak-check=full ./a.out
                                   header
==12133== Command: ./a.out
==12133==
Hello World!
==12133==
==12133== HEAP SUMMARY:
==12133==     in use at exit: 0 bytes in 0 blocks
==12133==   total heap usage: 1 allocs, 1 frees, 1,024 bytes allocated
==12133==
==12133== All heap blocks were freed -- no leaks are possible
==12133==
==12133== For counts of detected and suppressed errors, rerun with: -v
==12133== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
>>
```

```
>
world!\n" );
```

```
Wextra -g foo.c
```

See also http://va

`Valgrind`

- The program output is interspersed with messages from `valgrind`
- Kinds of issues flagged by `valgrind`
  - Invalid reads or writes:
    Attempts to dereference pointers to memory that's not yours
  - Memory leaks:
    Failing to deallocate a block of memory you allocate previously
    - Info about leaks appears in HEAP SUMMARY section

Valgrind

```
1.  #include <stdio.h>
2.  #include <stdlib.h>
3.  #include <string.h>
4.  #include <assert.h>
5.  char *string_copy( const char *in )
6.  {
7.      char *out = malloc( strlen( in ) );
8.      assert( out!= NULL );
9.      return strcpy( out , in );
10. }
11. int main( void )
12. {
13.     char *str = string_copy( "hello" );
14.     assert( str!=NULL );
15.     printf( "%s\n" , str );
16.     return 0;
17. }
```

```
>> ./a.out
hello
>>
```

```
>> valgrind --leak-check=full ./a.out
```

header

```
==17647== Command: ./a.out
==17647==
==17647== Invalid write of size 1
==17647==    at 0x4C30CB7: strcpy (vg_replace_strmem.c:506)
==17647==    by 0x40067C: string_copy (foo.c:9)
==17647==    by 0x400690: main (foo.c:13)
==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
==17647== Invalid read of size 1
==17647==    at 0x4C30BC4: strlen (vg_replace_strmem.c:454)
==17647==    by 0x4EAAAA1: puts (in /usr/lib64/libc-2.24.so)
==17647==    by 0x4006C0: main (foo.c:15)
==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
hello
==17647==
```

first half of output

Valgrind

```
1.  #include <stdio.h>
2.  #include <stdlib.h>
3.  #include <string.h>
4.  #include <assert.h>
5.  char *string_copy( const char *in )
6.  {
7.      char *out = malloc( strlen( in ) );
8.      assert( out!= NULL );
9.      return strcpy( out , in );
10. }
11. int main( void )
12. {
13.     char *str = string_copy( "hello" );
14.     assert( str!=NULL );
15.     printf( "%s\n" , str );
16.     return 0;
17. }
```

```
>> ./a.out
hello
>>
```

second half of output

```
==17647== HEAP SUMMARY:
==17647==     in use at exit: 5 bytes in 1 blocks
==17647==   total heap usage: 2 allocs, 1 frees, 1,029 bytes allocated
==17647==
==17647== 5 bytes in 1 blocks are definitely lost in loss record 1 of 1
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
==17647== LEAK SUMMARY:
==17647==    definitely lost: 5 bytes in 1 blocks
==17647==    indirectly lost: 0 bytes in 0 blocks
==17647==      possibly lost: 0 bytes in 0 blocks
==17647==    still reachable: 0 bytes in 0 blocks
==17647==         suppressed: 0 bytes in 0 blocks
==17647==
==17647== For counts of detected and suppressed errors, rerun with: -v
==17647== ERROR SUMMARY: 3 errors from 3 contexts (suppressed: 0 from 0)
>>
```

Valgrind

```
1.  #include <stdio.h>
2.  #include <stdlib.h>
3.  #include <string.h>
4.  #include <assert.h>
5.  char *string_copy( const char *in )
6.  {
7.      char *out = malloc( strlen( in ) );
8.      assert( out!= NULL );
9.      return strcpy( out , in );
10. }
11. int main( void )
12. {
13.     char *str = string_copy( "hello" );
14.     assert( str!=NULL );
15.     printf( "%s\n" , str );
16.     return 0;
17. }
```

```
>> ./a.out
hello
>>
```

```
>> valgrind --leak-check=full ./a.out
```

header

```
==17647== Command: ./a.out
==17647==
==17647== Invalid write of size 1
==17647==    at 0x4C30CB7: strcpy (vg_replace_strmem.c:506)
==17647==    by 0x40067C: string_copy (foo.c:9)
==17647==    by 0x400690: main (foo.c:13)
==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
==17647== Invalid read of size 1
==17647==    at 0x4C30BC4: strlen (vg_replace_strmem.c:454)
==17647==    by 0x4EAAAA1: puts (in /usr/lib64/libc-2.24.so)
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==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
hello
==17647==
```

first half of output

Valgrind

```c
1.  #include <stdio.h>
2.  #include <stdlib.h>
3.  #include <string.h>
4.  #include <assert.h>
5.  char *string_copy( const char *in )
6.  {
7.      char *out = malloc( strlen( in ) );
8.      assert( out!= NULL );
9.      return strcpy( out , in );
10. }
11. int main( void )
12. {
13.     char *str = string_copy( "hello" );
14.     assert( str!=NULL );
15.     printf( "%s\n" , str );
16.     return 0;
17. }
```

```
>> ./a.out
hello
>>
```

```
>> valgrind --leak-check=full ./a.out
```

header

```
==17647== Command: ./a.out
==17647==
==17647== Invalid write of size 1
==17647==    at 0x4C30CB7: strcpy (vg_replace_strmem.c:506)
==17647==    by 0x40067C: string_copy (foo.c:9)
==17647==    by 0x400690: main (foo.c:13)
==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
==17647== Invalid read of size 1
==17647==    at 0x4C30BC4: strlen (vg_replace_strmem.c:454)
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==17647==  Address 0x5200045 is 0 bytes after a block of size 5 alloc'd
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
hello
==17647==
```

first half of output

Valgrind

```
1.  #include <stdio.h>
2.  #include <stdlib.h>
3.  #include <string.h>
4.  #include <assert.h>
5.  char *string_copy( const char *in )
6.  {
7.      char *out = malloc( strlen( in ) );
8.      assert( out!= NULL );
9.      return strcpy( out , in );
10. }
11. int main( void )
12. {
13.     char *str = string_copy( "hello" );
14.     assert( str!=NULL );
15.     printf( "%s\n" , str );
16.     return 0;
17. }
```

```
>> ./a.out
hello
>>
```

second half of output

```
==17647== HEAP SUMMARY:
==17647==     in use at exit: 5 bytes in 1 blocks
==17647==   total heap usage: 2 allocs, 1 frees, 1,029 bytes allocated
==17647==
==17647== 5 bytes in 1 blocks are definitely lost in loss record 1 of 1
==17647==    at 0x4C2DB9D: malloc (vg_replace_malloc.c:299)
==17647==    by 0x400645: string_copy (foo.c:7)
==17647==    by 0x400690: main (foo.c:13)
==17647==
==17647== LEAK SUMMARY:
==17647==    definitely lost: 5 bytes in 1 blocks
==17647==    indirectly lost: 0 bytes in 0 blocks
==17647==      possibly lost: 0 bytes in 0 blocks
==17647==    still reachable: 0 bytes in 0 blocks
==17647==         suppressed: 0 bytes in 0 blocks
==17647==
==17647== For counts of detected and suppressed errors, rerun with: -v
==17647== ERROR SUMMARY: 3 errors from 3 contexts (suppressed: 0 from 0)
>>
```

`Valgrind`

- So what was wrong?
  - An invalid write
  - An invalid read
  - A block of memory that wasn't `free`d
- On ugradx, this program didn't crash and seemed to work properly

⇒ Not every bad memory access leads to error (or bad output)

⇒ `valgrind` is a useful tool to help us find problematic code

Valgrind

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <assert.h>
char *string_copy( const char *in )
{
    char *out = malloc( strlen( in )+1 );
    assert( out!= NULL );
    return strcpy( out , in );
}
int main( void )
{
    char *str = string_copy( "hello" );
    assert( str!=NULL );
    printf( "%s\n" , str );
    free( str );
    return 0;
}
```

```
>> ./a.out
hello
>>
```

```
>> valgrind --leak-check=full ./a.out
```

header

```
==30398== Command: ./a.out
==30398==
hello
==30398==
==30398== HEAP SUMMARY:
==30398==     in use at exit: 0 bytes in 0 blocks
==30398==   total heap usage: 2 allocs, 2 frees, 1,030 bytes allocated
==30398==
==30398== All heap blocks were freed -- no leaks are possible
==30398==
==30398== For counts of detected and suppressed errors, rerun with: -v
==30398== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
>>
```

Outline

- Exercise 10
- Dynamic memory allocation
- `Valgrind`
- Review questions

Review questions

1. What is the difference between stack and heap memory?

Static memory resides on the call stack and is released once the function returns. It is statically allocated as an array.

Heap memory resides on the heap and persists until it is `free`d. It is dynamically allocated using `malloc`.

Review questions

2. What is dynamic memory allocation in C?

Reserving memory on the heap using `malloc`, `calloc`, or `realloc`.

Review questions

3. What is the memory leak problem?

When memory is dynamically allocated on the heap but not released before the program terminates.

Review questions

4. What is the difference between malloc, realloc, and calloc?

malloc: allocates memory on the heap

calloc: allocates and clears memory on the heap

realloc: grows/shrinks memory on the heap

Review questions

5. What do we use `valgrind` to check for?

Invalid memory access

Memory leaks

Review questions

6. Consider the exclaim function below. Do you see any problems with this function?

```
// Return a C character string containing n exclamation points.
// n must be less than 20.
char *exclaim( int n )
{
        char s[20];
        assert( n<20 );
        for( int i=0 ; i<n ; i++ ) s[i] = '!';
        s[n] = '\0';
        return s;
}
```

Returning memory that was statically allocated.

Exercise 11

- Website -> Course Materials -> Exercise 11