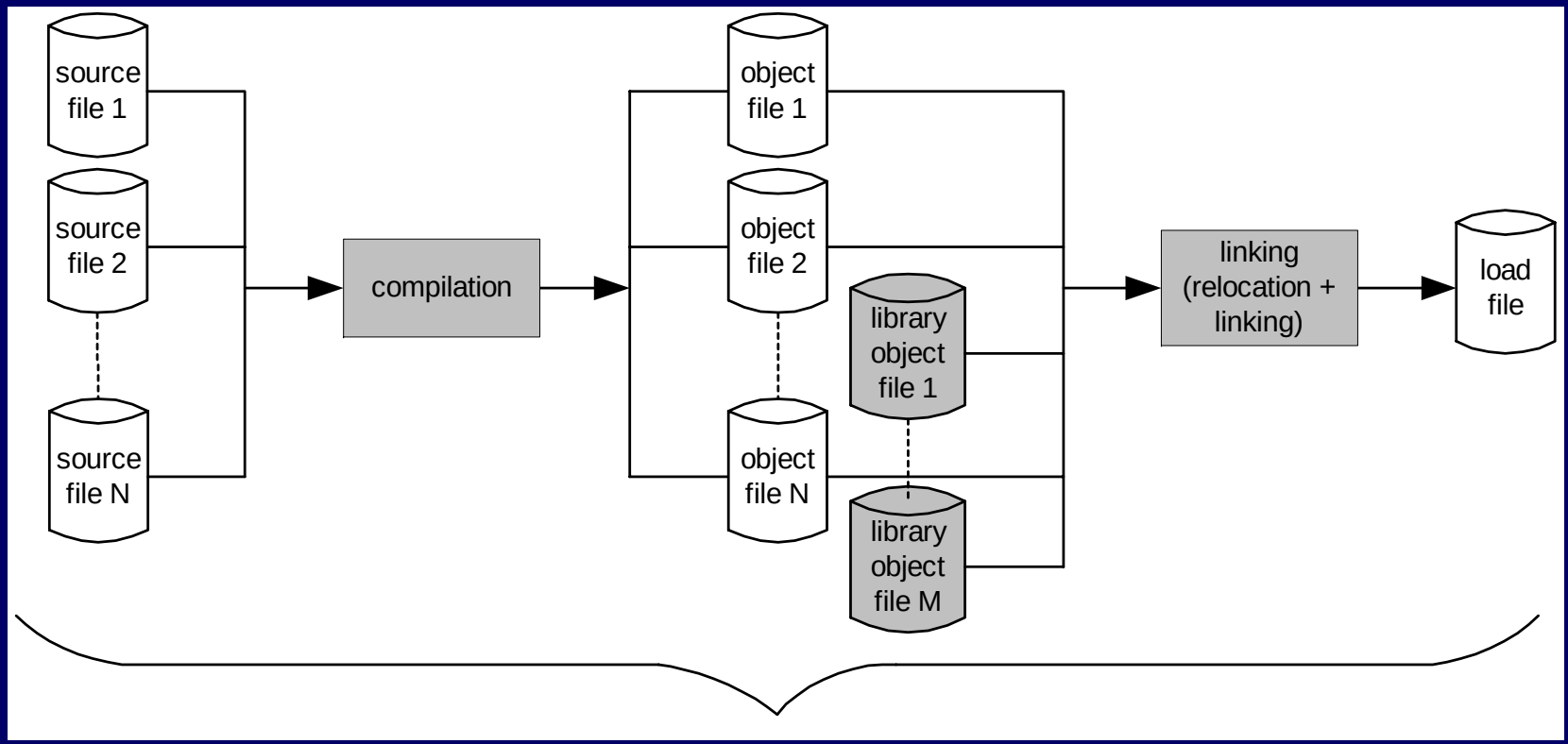
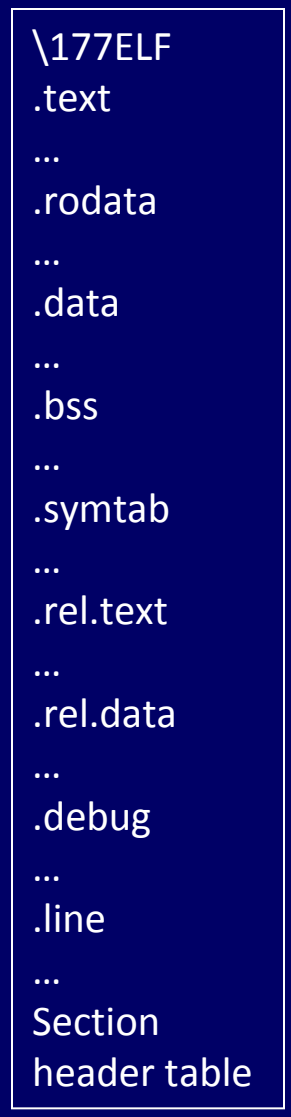
Reminder: compiling & linking



Usually performed by gcc/g++ in one uninterrupted sequence

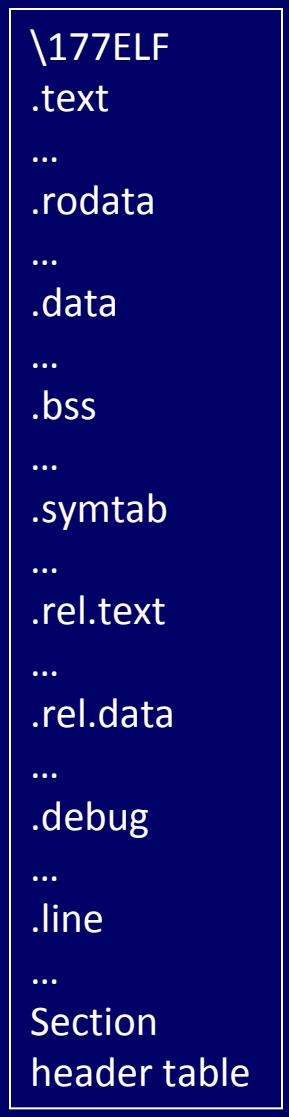
Linux object file format

- "ELF" – stands for Executable and Linking Format
  - A 4-byte magic number followed by a series of named sections
- Addresses assume the object file is placed at memory address 0
  - When multiple object files are linked together, we must update the offsets (relocation)
- Tools to read contents: `objdump` and `readelf` – not available on all systems



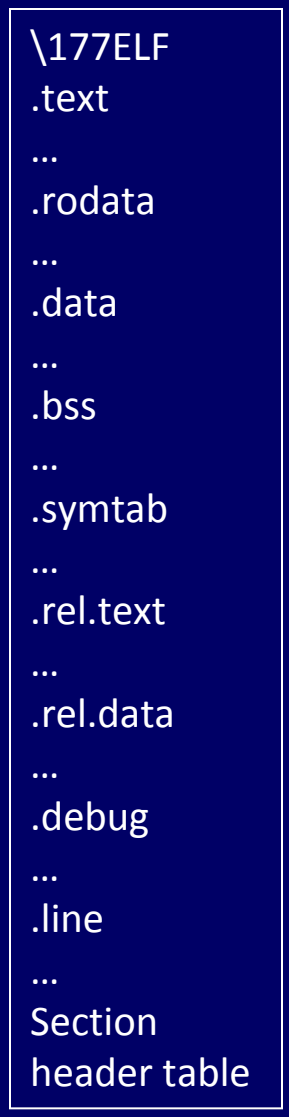
ELF sections

- .text = machine code (compiled program instructions)
- .rodata = read-only data
- .data = initialized global variables
- .bss = “block storage start” for uninitialized global variables – actually just a placeholder that occupies no space in the object file
- .symtab = symbol table with information about functions and global variables defined and referenced in the program

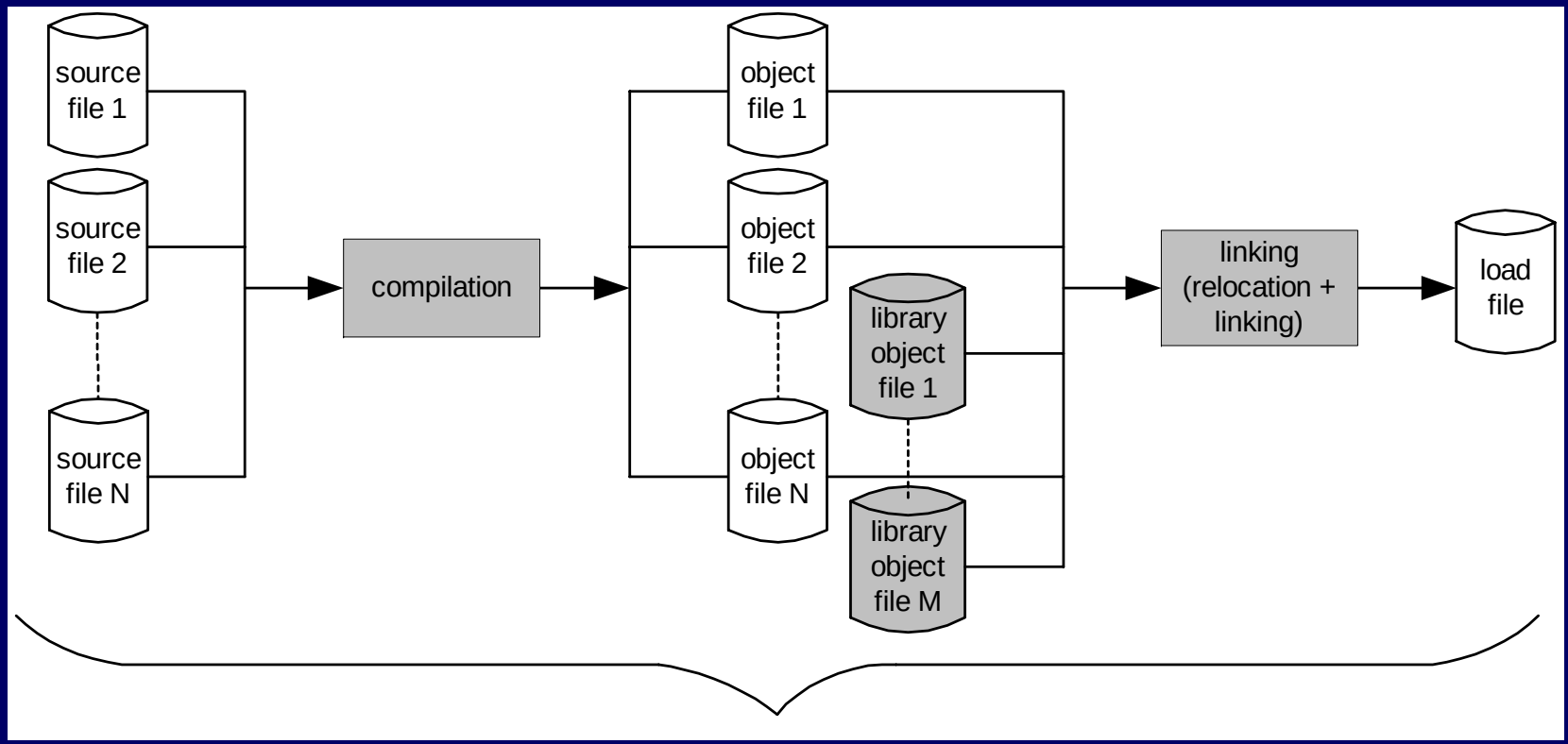


ELF Sections (cont.)

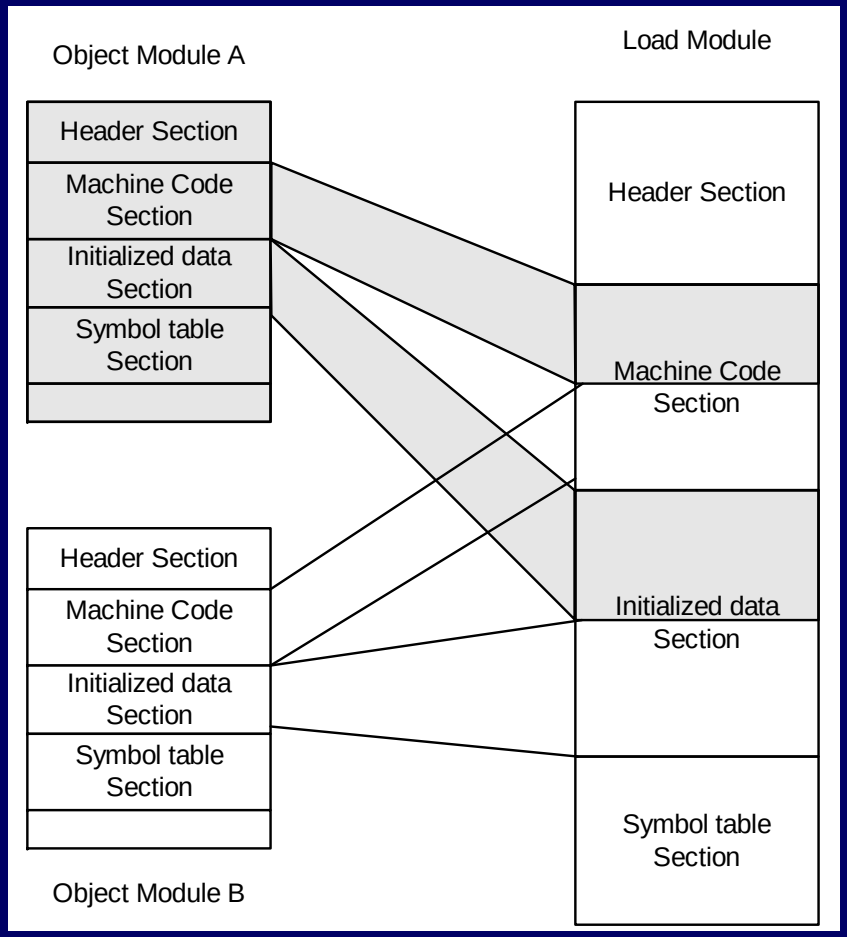
- .rel.text = list of locations in .text section that need to be modified when linked with other object files
- .rel.data = relocation information for global variables referenced but not defined
- .debug = debugging symbol table; only created if compiled with -g option
- .line = mapping between line numbers in source and machine code in .text; used by debugger programs



Reminder again: … linking

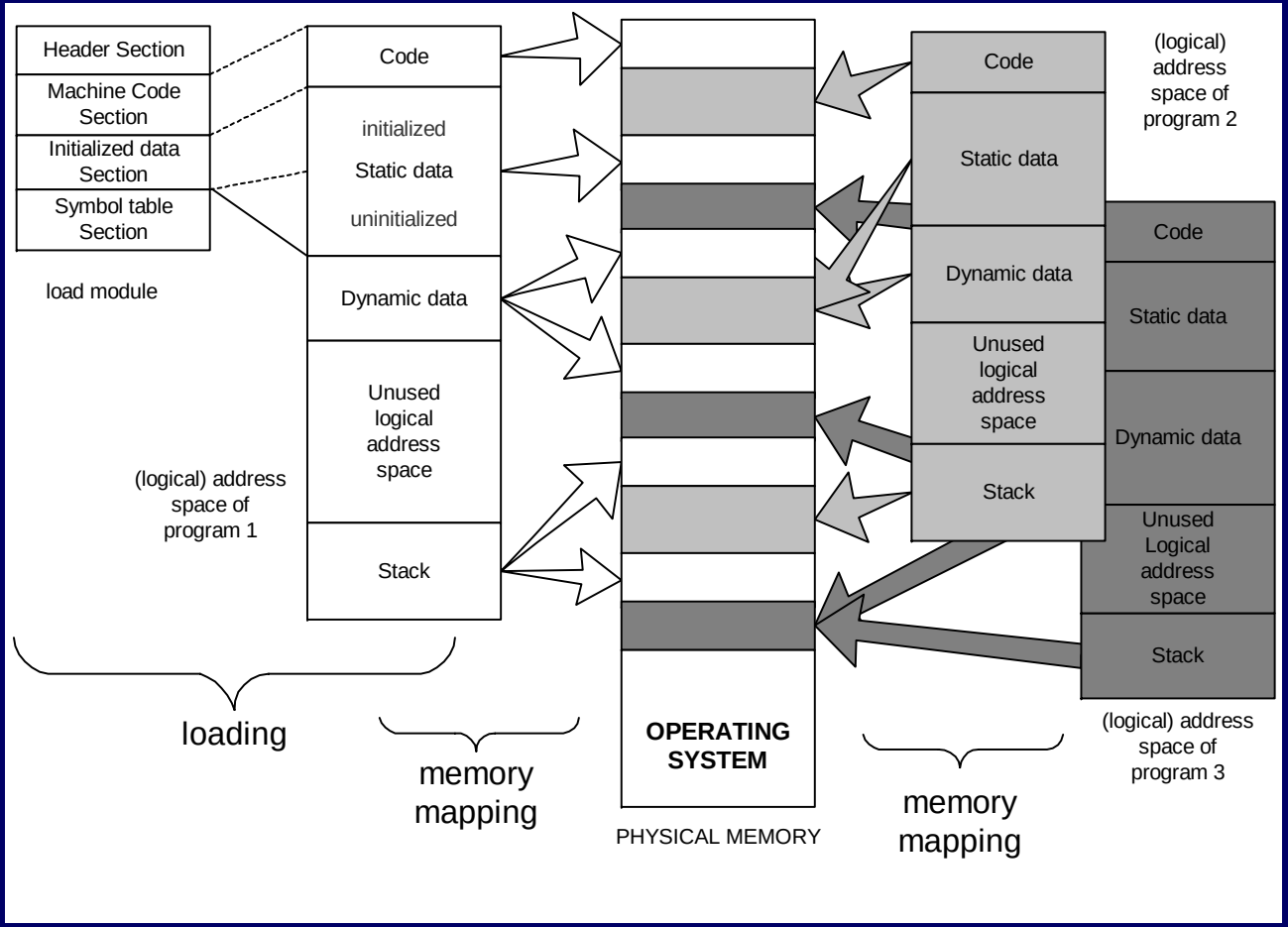


Creation of a load module



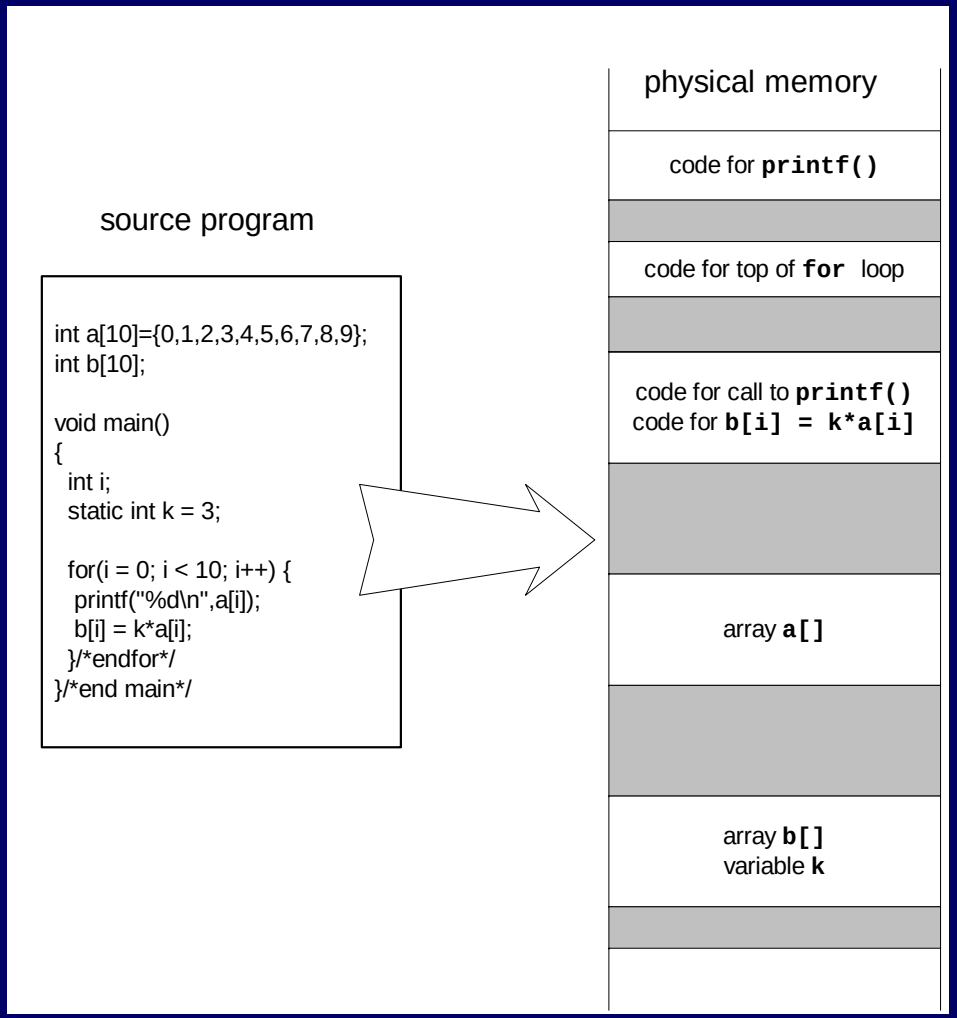
- Interleaved from multiple object modules
  - Sections must be “relocated”
- Addresses relative to beginning of a module
  - Necessary to translate from beginnings of object modules
- When loaded – OS will translate again to absolute addresses

Loading and memory mapping

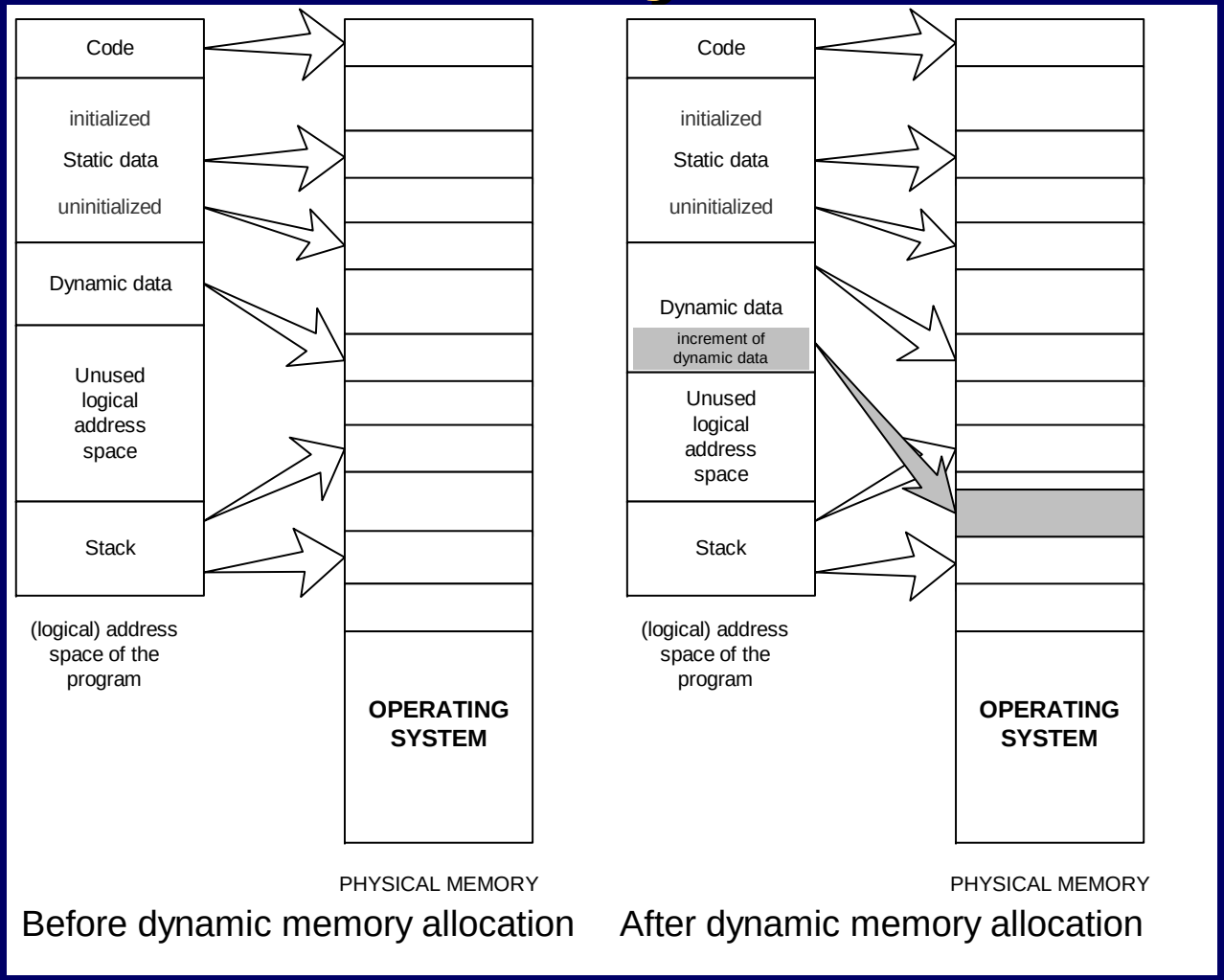


- Includes memory for stack, dynamic data (i.e., free store), and un-initialized global data
- Physical memory is shared by multiple programs

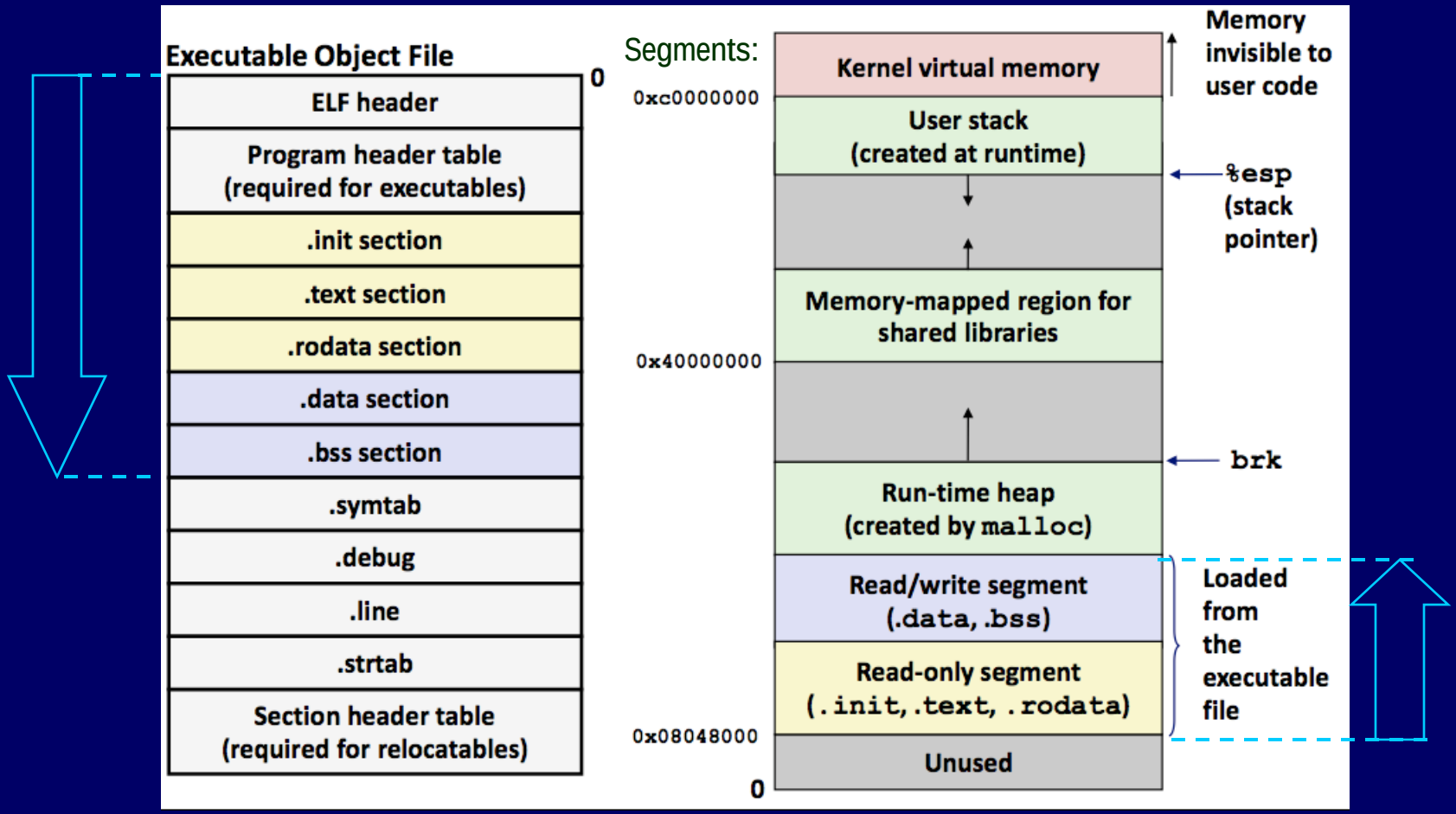
From source program to “placement” in memory during execution



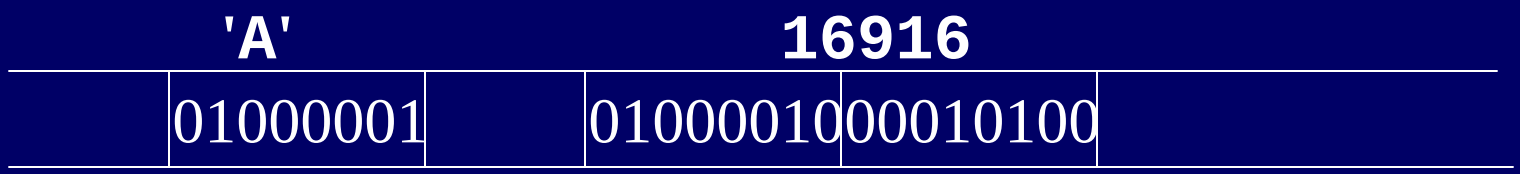
Dynamic memory allocation



Sections of an executable file



Variables and objects in memory

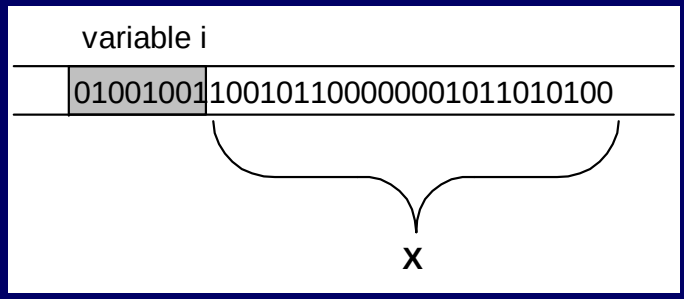


- Variables and data objects are data containers with names
- The value of the variable is the code stored in the container
- To evaluate a variable is to fetch the code from the container and interpret it properly
- To store a value in a variable is to code the value and store the code in the container
- The size of a variable is the size of its container

Overflow is when a data code is larger than the size of its container

- e.g., `char i;` // just 1 byte

```
int *p = (int*)&i; // legal
*p = 1673579060;
    // result if "big endian" storage:
```



- If whole space (X) belongs to this program:
  - Seems OK if X does not contain important data for rest of the program's execution
  - Bad results or crash if important data are overwritten
- If all or part of X belongs to another process, the program is terminated by the OS for a memory access violation (i.e., segmentation fault)

More about overflow

- Previous slide showed example of "right overflow" – result truncated (also warning)

- Compilers handle "left overflow" by truncating too (usually without any warning)
  - Easily happens: `unsigned char i = 255;`

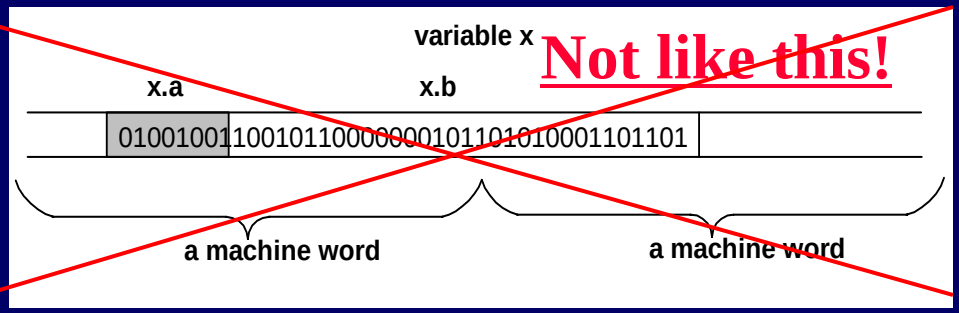
`i++;` // What is the result of this increment?

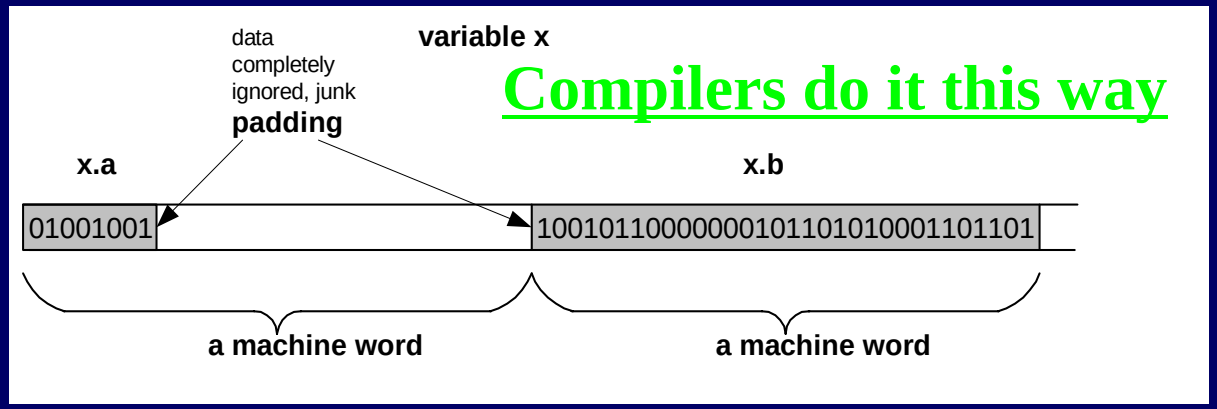
Placement & padding – word

- Compiler places data at word boundaries
  - e.g., word = 4 bytes
- Imagine:

```
struct {
   char a;
   int b;
} x;
```

  - Classes too

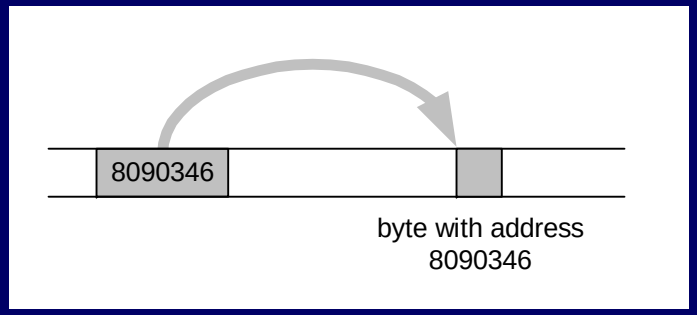


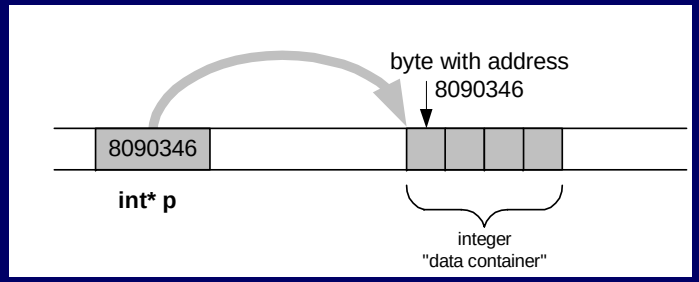


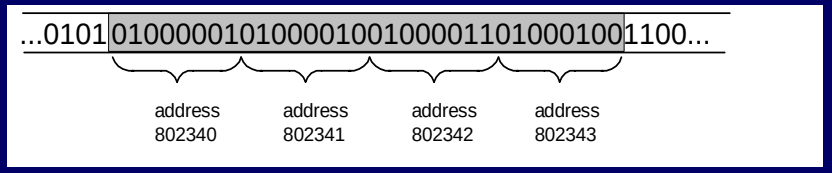
See/try `~mikec/cs32/demos/padding.cpp`

Pointers are data containers too

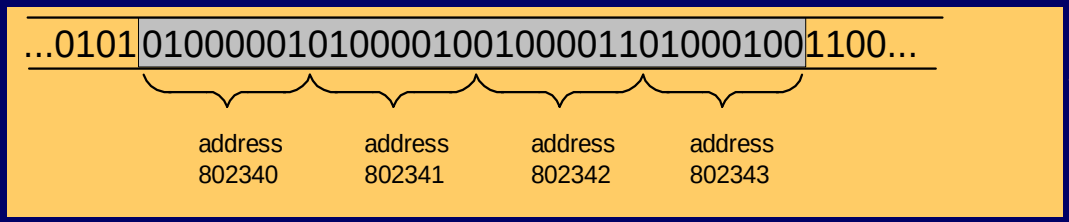
- As its *value* is a memory address, we say it "points" to a place in memory
- It points at just 1 byte, so it must "know" what data type starts at that address
  - How many bytes?
  - How to interpret the bits?
- Question: What is stored in the 4 bytes at addresses `802340..802343` in the diagram at right?
  - Continued next slide





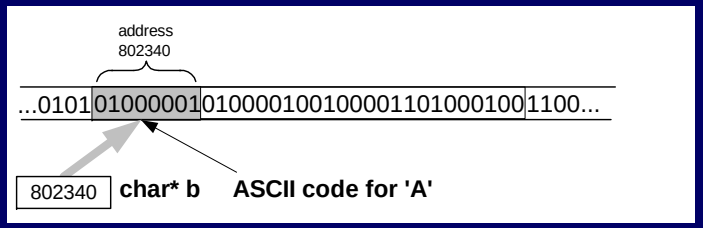


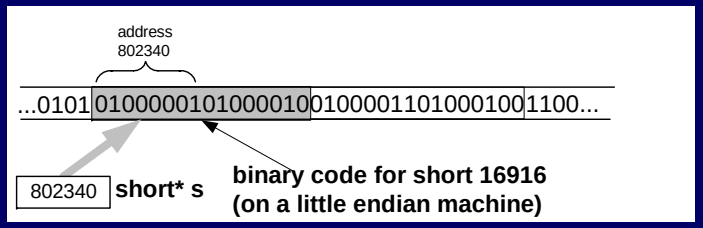
What is

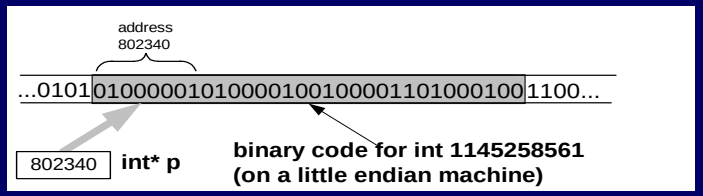


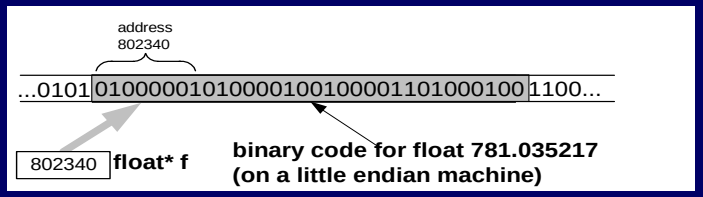
?

- Could be four chars: ‘A’, ‘B’, ‘C’, ‘D’
- Or it could be two shorts: 16961, 17475
  - All numerical values shown here are for a "little endian" machine (more about endian next slide)
- Maybe it’s a long or an int: 1145258561
- It could be a floating point number too: 781.035217









Beware: two different byte orders

- Matters to actual value of anything but chars
- Say: `short int x = 1;`
- On a big endian machine it looks like this:

		00000000	00000001		

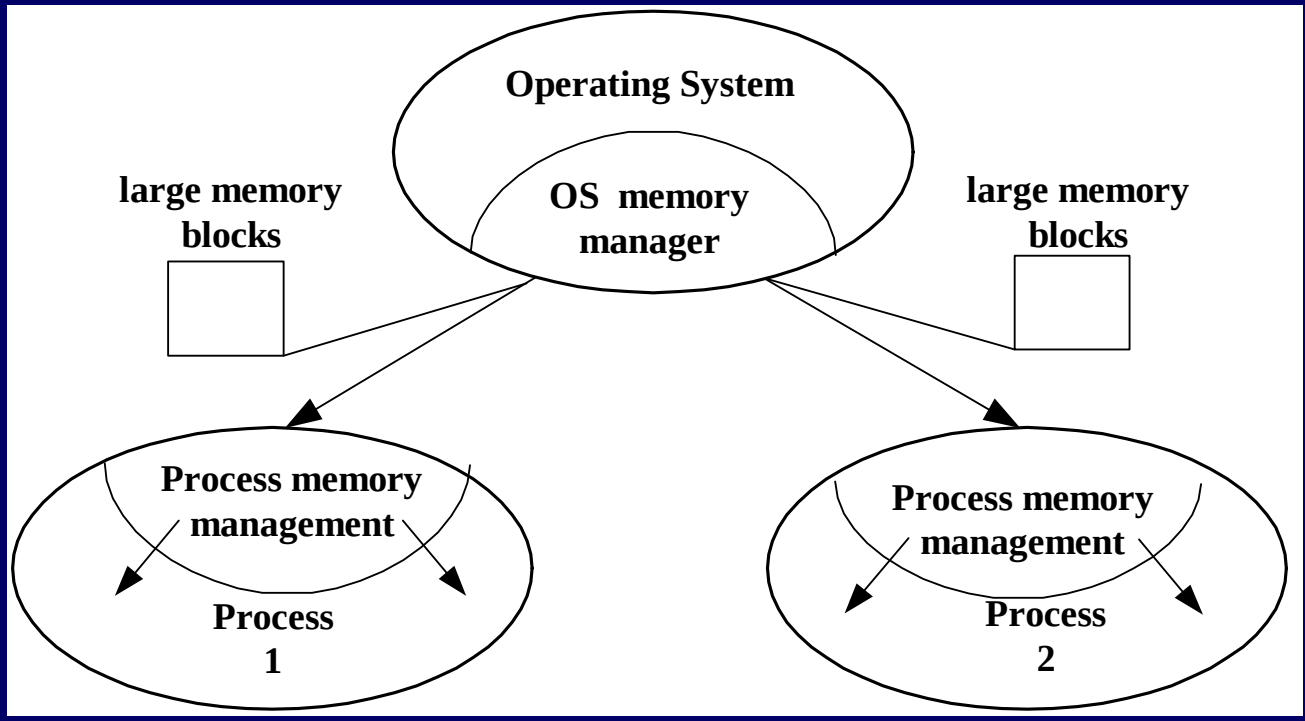
  - Some Macs, JVM, TCP/IP "Network Byte Order"
- On a little endian machine it looks like this:

		00000001	00000000		

  - Intel, most communication hardware
- Only important when dereferencing pointers
  - See/try `~mikec/cs32/demos/endian.c`

Dynamic memory allocation

- OS memory manager (OSMM) allocates large blocks at a time to individual processes
- A process memory manager (PMM) then takes over



Memory management by OSMM

- Essentially, a simple "accounting" of what process owns what part(s) of the memory
- Memory allocation – like making an entry in the accounting "book" that this segment is given to this process for keeps
- Memory deallocation – an entry that this segment is no longer needed (process died), so it’s "free"
- OSMM usually keeps track of allocated memory blocks in a binary heap, to quickly search for suitable free blocks – hence the name "system heap" (traditionally called "free store" in C++)

PMM handles a process's memory

- A "middle manager" – intermediary to OSMM
- Usually keeps a dynamic *list* of free segments
- When program requests more memory – PMM searches its list for a suitable segment
- If none found, asks OSMM for another block
  - OSMM searches its heap and delivers a block
  - Then PMM carves out a suitable segment
- Can be a significant time delay while all this goes on – which can slow performance if a program makes many allocation requests

Dynamic memory in C programs

- Use C standard functions – all in `<stdlib.h>`
  - All use `void*` – means "any type" – no dereferencing

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

  - Get at least `size` bytes; contents are arbitrary!

```
void *calloc(size_t n, size_t elsize);
```

  - Get at least `n*elsize` bytes; contents cleared!

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

  - Changes size of existing segment (at `ptr`)
  - IMPORTANT: `ptr` must have come by malloc or calloc
  - And beware dangling pointers if data must be moved
- To deallocate, use `void free(void *ptr);`

Easier, better in C++ programs

- Allocate memory by operator `new`
  - Easier than malloc and other C functions: just need to specify type – object's size is known
  - Better than the C functions: also calls a constructor to create the object properly
- Operator `delete` returns memory to the free store that was allocated by new
  - Also calls class destructor to keep things neat
  - Use `delete[]` if deallocating an array

Dynamic arrays of C++ objects

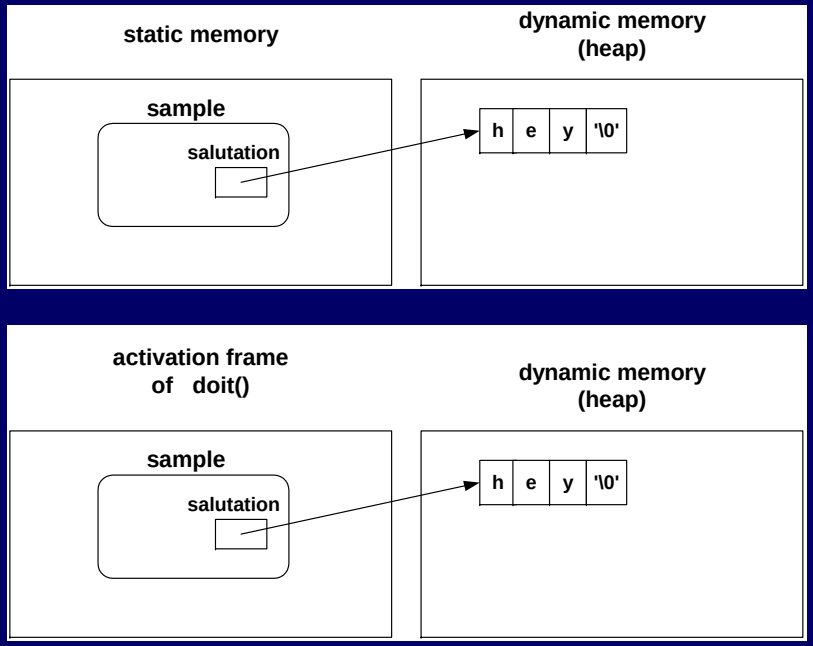
- `MyClass *array = new MyClass[5];`
  - Creates an array of 5 MyClass objects
  - Returns a pointer to the first object
- Default ctor is called for every object
- No way to call a different constructor
  - So class *must* have a no-argument ctor
- `delete [] array;`
  - Calls dtor on all 5 objects

`~mikec/cs32/demos/dynarray.cpp`

Using memory all over the place!

- Fairly simple in C: an object is either in static memory, *or* on stack, *or* on heap
- C++ objects can "be" more than one place!
- So important in C++ to manage memory even for stack objects (with dynamic parts)

(about program on Reader p. 190)



Don’t corrupt the PMM: guidelines

- Never pass an address to `free` that was not returned by `malloc`, `calloc`, or `realloc`
- Deallocate segments allocated by `malloc`, `calloc`, or `realloc` only by using `free`
- Never pass address to `delete` (or delete[]) that was not previously returned by `new`
- Deallocate segments allocated by `new` using exclusively `delete`
  - And exclusively `delete[]` if array allocated

BTW: in general, don’t mix C and C++ ways to do things.

Implementing generic types

With C++ templates

Starting Savitch Chapter 17

C++ templates

- Like “blueprints” for the compiler to use in creating class and function definitions
- Always involve one or more *parameterized types*
  - e.g., function template to compare object sizes:

```
template <typename T1, typename T2>
int sizeComp(T1 const &o1, T2 const &o2)
{ return (sizeof o1 – sizeof o2); }
```

  - e.g., class template for a list that holds any type:

```
template <typename DataType>
class List { /* here refer to DataType objects */ };
```

- Can use either keyword `typename` or `class` in a “template prefix” – e.g., `template <class T>`

Function templates

- An alternative to function overloading
  - But code for concrete types created only as needed
    - And the programmer does not have to write it!
  - Compiler deduces types if user doesn't specify:

```
int x = sizeComp('a', 7);
    // compiler uses template to create sizeComp(char, int)
```

  - To specify: `x = sizeComp<int, int>('a', 7.5);`

```
    // compiler uses template to create sizeComp(int, int)
```

- Better choice than macros too
  - Strictly type-checked, and no nasty side effects
- See `~mikec/cs32/demos/templates/greater.cpp`

More function template issues

- Template definition must be in header file – so compiler can know how to define the functions
  - i.e., cannot be defined in a separate `.cpp` file
- Sometimes *specialized* for particular types
  - Tells compiler to use specialized version instead of creating a new definition – e.g. greater for char*:

```
template <>   // <> does not show a type parameter
char * &greater<char *>(char *s, char *t)
{ /* would use strcmp to compare s and t, instead of operator< */ }
```

    - Empty parameter types – exact types everywhere else
  - No type conversions though (must be exact match), so usually better to just overload instead of specialize

Defining class templates

- Idea: “generalize” data that can be managed by a class

```
template<typename T>
class Pair {
public:
    Pair();
    Pair(T firstVal, T secondVal);
    void setFirst(T newVal);
    void setSecond(T newVal);
    T getFirst() const;
    T getSecond() const;
private:
    T first; T second;
};
```