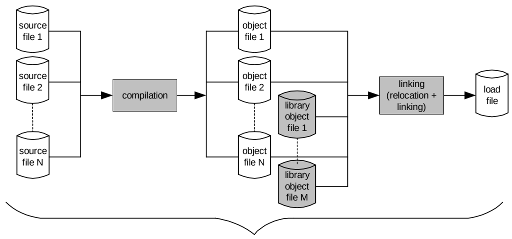
Reminder: compiling & linking



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

\177ELF
.text
…
.rodata
…
.data
…
.bss
…
.symtab
…
.rel.text
…
.rel.data
…
.debug
…
.line
…
Section header table

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

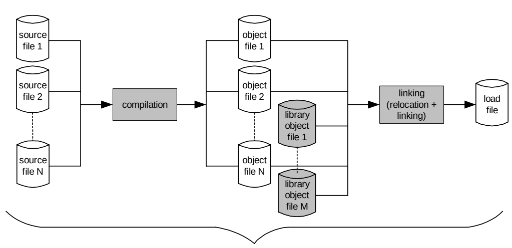
\177ELF
.text
…
.rodata
…
.data
…
.bss
…
.symtab
…
.rel.text
…
.rel.data
…
.debug
…
.line
…
Section header table

ELF Sections (cont.)

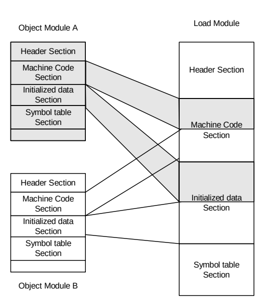
- .rel.text = list of locations in .text section that need to be modified when linked with other object files
- .rel.data = relocation information for global variables referenced but not defined
- .debug = debugging symbol table; only created if compiled with -g option
- .line = mapping between line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

\177ELF
.text
…
.rodata
…
.data
…
.bss
…
.symtab
…
.rel.text
…
.rel.data
…
.debug
…
.line
…
Section header table

Reminder again: … linking

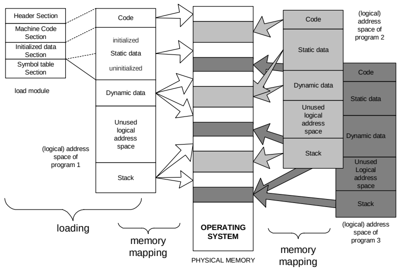


Creation of a load module



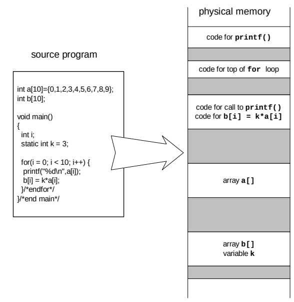
- Interleaved from multiple object modules
  - Sections must be "relocated"
- Addresses relative to beginning of a module
  - Necessary to translate from beginnings of object modules
- When loaded – OS will translate again to absolute addresses

Loading and memory mapping

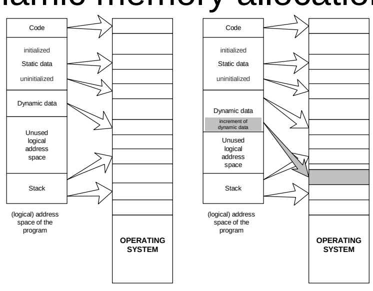


- Includes memory for stack, dynamic data (i.e., free store), and un-initialized global data
- Physical memory is shared by multiple programs

From source program to “placement” in memory during execution

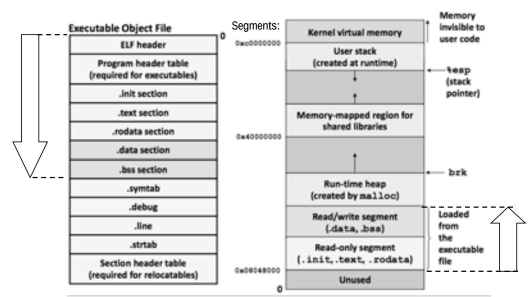


Dynamic memory allocation



Before dynamic memory allocation After dynamic memory allocation

Sections of an executable file



Variables and objects in memory

	'A'	16916	
	01000001	01000010	00010100

- 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

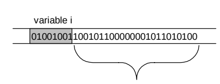
Overflow is when a data code is larger than the size of its container

- 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)

01000001|010001…

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

11111111

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

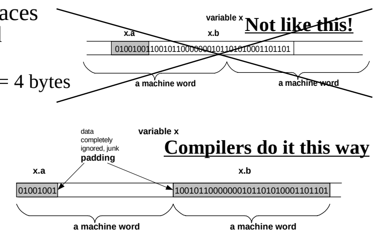
1|00000000

Placement & padding – word

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

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

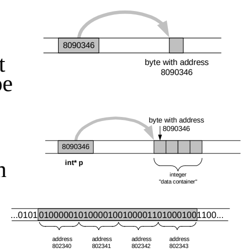
  - Classes too

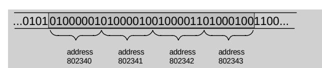


See/try `~mikec/cs32/demos/padding.cpp`

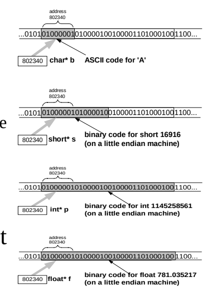
Pointers are data containers too

- 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	

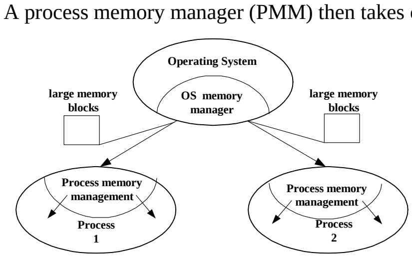
  - Some Macs, JVM, TCP/IP "Network Byte Order"
- On a little endian machine it looks like this:

	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

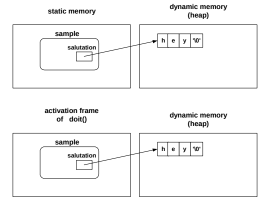
- `MyClass *array = new MyClass[5];`
  - Creates an array of 5 MyClass objects
  - Returns a pointer to the first object
- Default ctor is called for every object
- No way to call a different constructor
  - So class *must* have a no-argument ctor
- `delete [] array;`
  - Calls dtor on all 5 objects

`~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;
};
```