# CS 537 Notes, Section #13: Storage Allocation

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Information stored in memory is used in many different ways. Some possible classifications are:

- Role in Programming Language:
  - Instructions (specify the operations to be performed and the operands to use in the operations).
  - Variables (the information that changes as the program runs: locals, owns, globals, parameters, dynamic storage).
  - Constants (information that is used as operands, but that never changes: pi for example).
- Changeability:
  - Read-only: *(code, constants)*.
  - Read & write: *(variables)*.

  Why is identifying non-changing memory useful or important?

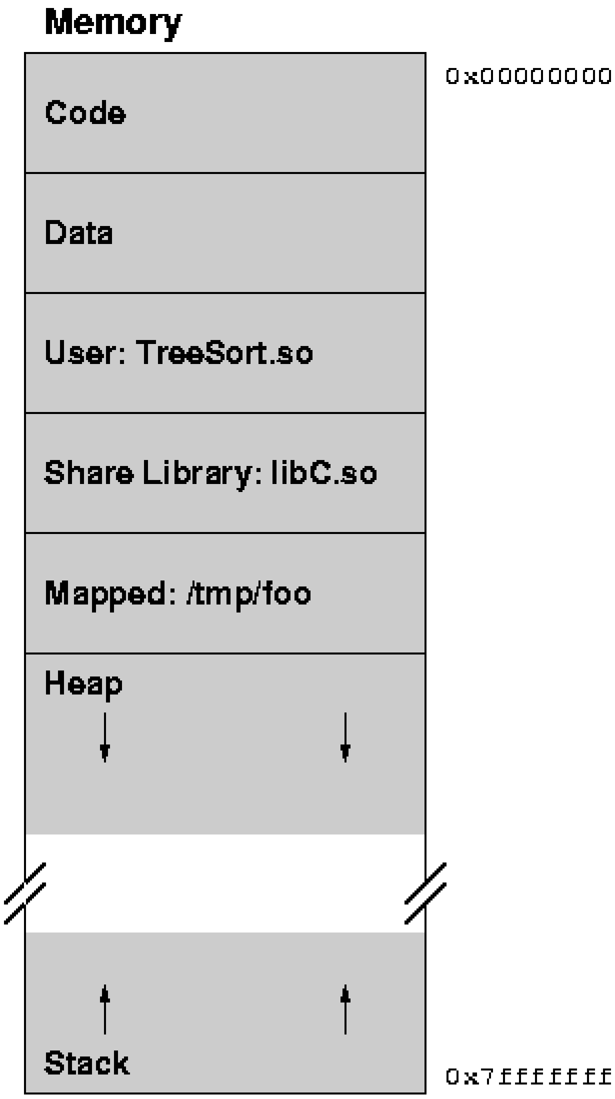
- Initialized:
  - Code, constants, some variables: yes.
  - Most variables: no.
- Addresses vs. Data: Why is this distinction useful or important?
- Binding time:
  - Static: arrangement determined once and for all, before the program starts running. May happen at *compile-time*, *link-time*, or *load-time*.
  - Dynamic: arrangement cannot be determined until runtime, and may change.

  Note that the classifications overlap: variables may be static or dynamic, code may be read-only or read&write, etc.

The compiler, linker, operating system, and run-time library all must cooperate to manage this information and perform allocation.

When a process is running, what does its memory look like? It is divided up into areas of stuff that the OS treats similarly, called *segments*. In Unix/Linux, each process has three segments:

- Code (called "text" in Unix terminology)
- Initialized data
- Uninitialized data
- User's dynamically linked libraries (*shared objects* (.so) or *dynamically linked libraries* (.dll))
- Shared libraries (system dynamically linked libraries)
- Mapped files
- Stack(s)




In some systems, can have many different kinds of segments.

One of the steps in creating a process is to load its information into main memory, creating the necessary segments. Information comes from a file that gives the size and contents of each segment (e.g. a.out in Unix/Linux and .exe in Windows). The file is called an *object file*.

Division of responsibility between various portions of system:

- Compiler: generates one object file for each source code file containing information for that file. Information is incomplete, since each source file generally uses some things defined in other source files.
- Linker: combines all of the object files for one program into a single object file, which is complete and self-sufficient.
- Operating system: loads object files into memory, allows several different processes to share memory at once, provides facilities for processes to get more memory after they have started running.
- Run-time library: provides dynamic allocation routines, such as *calloc* and *free* in C.

## Dynamic Memory Allocation

Why is not static allocation sufficient for everything? Unpredictability: cannot predict ahead of time how much memory, or in what form, will be needed:

- Recursive procedures. Even regular procedures are hard to predict (data dependencies).
- OS does not know how many jobs there will be or which programs will be run.
- Complex data structures, e.g. linker symbol table. If all storage must be reserved in advance (statically), then it will be used inefficiently (enough will be reserved to handle the worst possible case).

Need dynamic memory allocation both for main memory and for file space on disk.

Two basic operations in dynamic storage management:

- Allocate
- Free

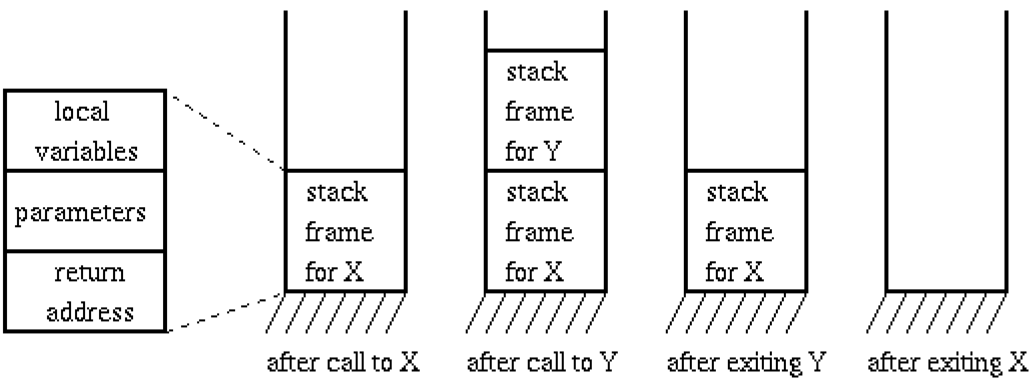
Dynamic allocation can be handled in one of two general ways:

- Stack allocation (hierarchical): restricted, but simple and efficient.
- Heap allocation: more general, but less efficient, more difficult to implement.

Stack organization: memory allocation and freeing are partially predictable (as usual, we do better when we can predict the future). Allocation is hierarchical: memory is freed in opposite order from allocation. If alloc(A) then alloc(B) then alloc(C), then it must be free(C) then free(B) then free(A).

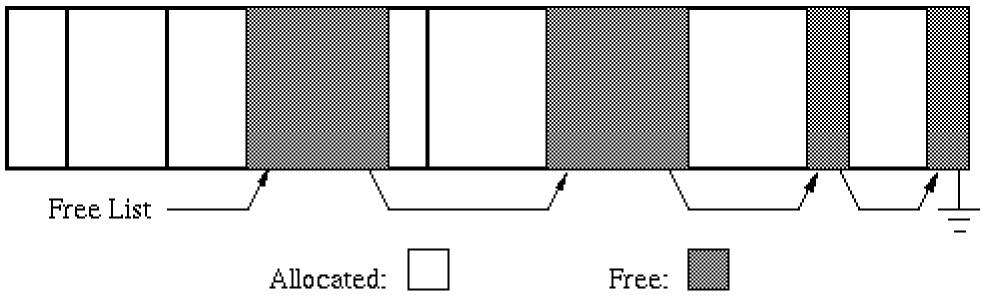
- Example: procedure call. Program calls Y, which calls X. Each call pushes another stack frame on top of the stack. Each stack frame has space for variable, parameters, and return addresses.
- Stacks are also useful for lots of other things: tree traversal, expression evaluation, top-down recursive descent parsers, etc.

A stack-based organization keeps all the free space together in one place.



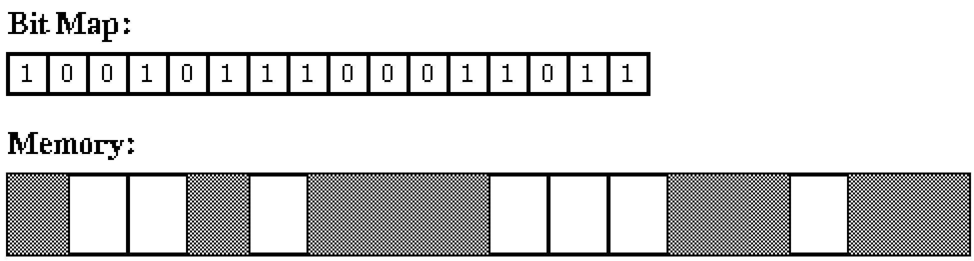
Heap organization: allocation and release are unpredictable. Heaps are used for arbitrary list structures, complex data organizations. Example: payroll system. Do not know when employees will join and leave the company, must be able to keep track of all them using the least possible amount of storage.

Heap Organization




- Inevitably end up with lots of holes. Goal: reuse the space in holes to keep the number of holes small, their size large.
- Fragmentation: inefficient use of memory due to holes that are too small to be useful. In stack allocation, all the holes are together in one big chunk.
- Refer to Knuth volume 1 for detailed treatment of what follows.
- Typically, heap allocation schemes use a *free list* to keep track of the storage that is not in use. Algorithms differ in how they manage the free list.
    - Best fit: keep linked list of free blocks, search the whole list on each allocation, choose block that comes closest to matching the needs of the allocation, save the excess for later. During release operations, merge adjacent free blocks.
    - First fit: just scan list for the first hole that is large enough. Free excess. Also merge on releases. Most first fit implementations are rotating first fit.

- Bit Map: used for allocation of storage that comes in fixed-size chunks (e.g. disk blocks, or 32-byte chunks). Keep a large array of bits, one for each chunk. If bit is 0 it means chunk is in use, if bit is 1 it means chunk is free. Will be discussed more when talking about file systems.




16 bits handles 16K of memory with the chunk (page) size of 1K

Pools: keep a separate allocation pool for each popular size. Allocation is fast, no fragmentation.

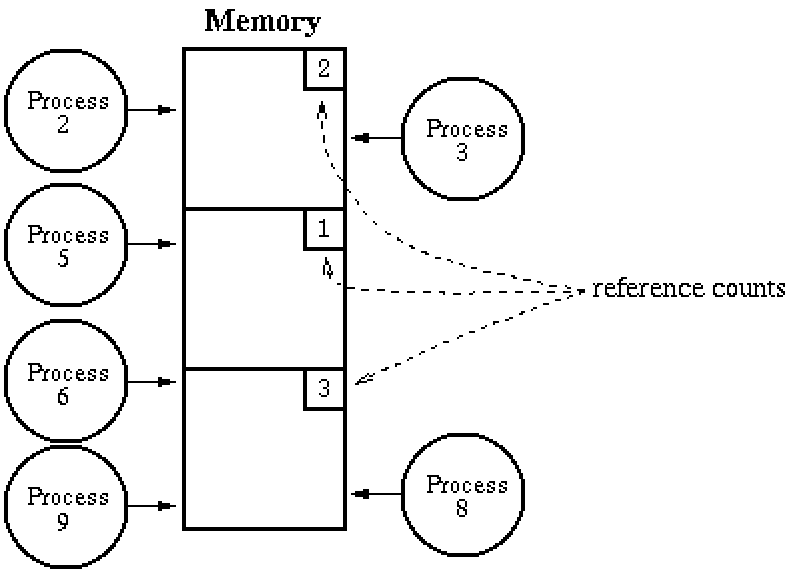
Reclamation Methods: how do we know when memory can be freed?

- It is easy when a chunk is only used in one place.
- Reclamation is hard when information is shared: it cannot be recycled until all of the sharers are finished. Sharing is indicated by the presence of *pointers* to the data (show example). Without a pointer, cannot access (cannot find it).

Two problems in reclamation:

- Dangling pointers: better not recycle storage while it is still being used.
- Core leaks: Better not "lose" storage by forgetting to free it even when it cannot ever be used again.

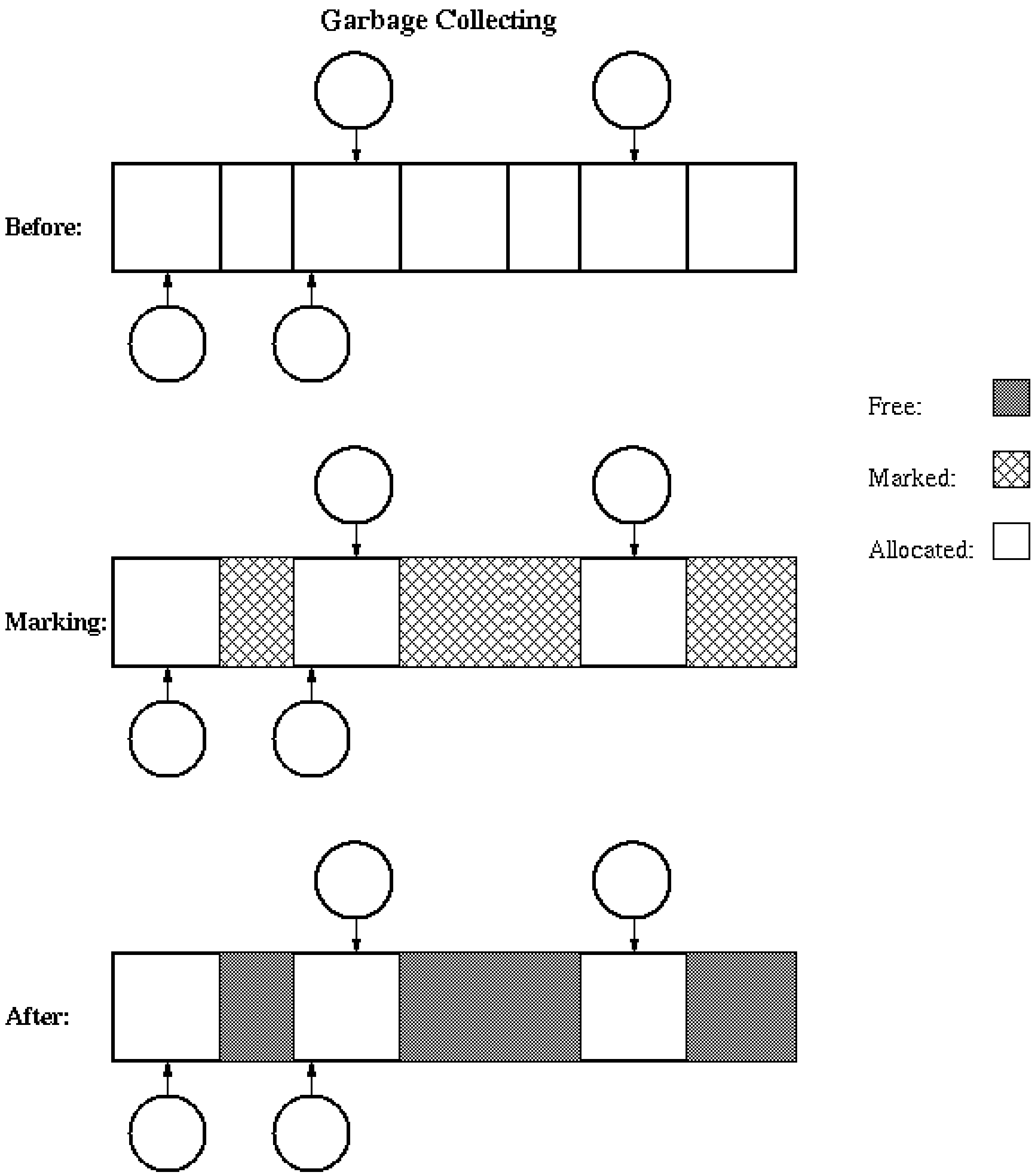
Reference Counts: keep track of the number of outstanding pointers to each chunk of memory. When this goes to zero, free the memory. Example: Smalltalk, file descriptors in Unix/Linux. Works fine for hierarchical structures. The reference counts must be managed automatically (by the system) so no mistakes are made in incrementing and decrementing them.




Garbage Collection: storage is not freed explicitly (using free operation), but rather implicitly: just delete pointers. When the system needs storage, it searches through all of the pointers (must be able to find them all!) and collects things that are not used. If structures are circular then this is the only way to reclaim space. Makes life easier on the application programmer, but garbage collectors are incredibly difficult to program and debug, especially if compaction is also done. Examples: Lisp, capability systems.

How does garbage collection work?

- Must be able to find all objects.
- Must be able to find all pointers to objects.
- Pass 1: mark. Go through all pointers that are known to be in use: local variables, global variables. Mark each object pointed to, and recursively mark all objects it points to.
- Pass 2: sweep. Go through all objects, free up those that are not marked.




Garbage collection is often expensive: 20% or more of all CPU time in systems that use it.

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