Linking & Loading

CS-3013 Operating Systems
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(Slides include materials from
Slides include materials from *Modern Operating Systems*, 3rd ed., by Andrew Tanenbaum
and from *Operating System Concepts*, 7th ed., by Silbershatz, Galvin, & Gagne)

What happens to your program …

…after it is compiled, but before it can be run?

Executable files

- Every OS expects executable files to have a specific format
  - *Header info*
    - Code locations
    - Data locations
  - Code & data
  - *Symbol Table*
    - List of *names* of things defined in your program and where they are located within your program.
    - List of *names* of things defined elsewhere that are used by your program, and where they are used.

Example

```
#include <stdio.h>

int main () {

  printf ("hello,
  world\n")

}
```

- Symbol defined in your program and used elsewhere
  - `main`
- Symbol defined elsewhere and used by your program
  - `printf`

Example

```
#include <stdio.h>
extern int errno;

int main () {

  printf ("hello,
  world\n")

  <check errno for
  errors>
}
```

- Symbol defined in your program and used elsewhere
  - **`main`**
- Symbol defined elsewhere and used by your program
  - **`printf`**
  - **`errno`**

Two-step operation

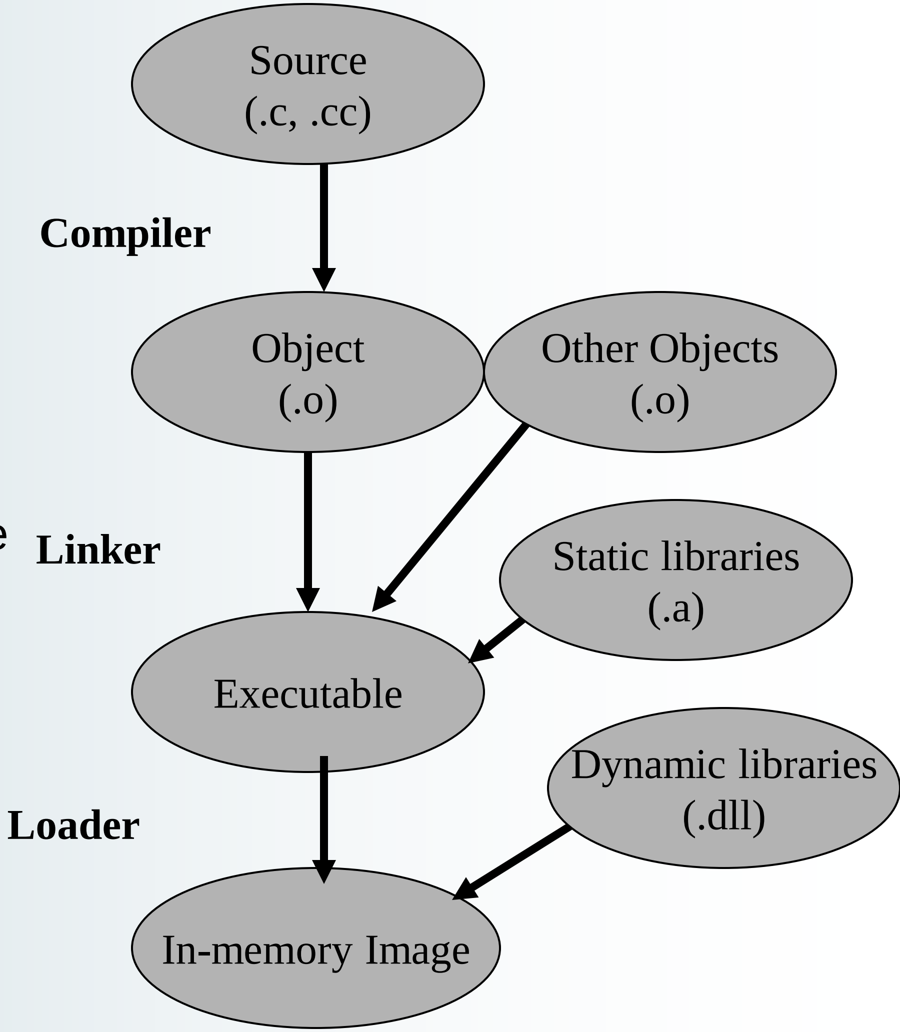
(in most systems)

- *Linking*: Combining a set of programs, including library routines, to create a *loadable image*
  a) Resolving symbols defined within the set
  b) Listing symbols needing to be resolved by loader

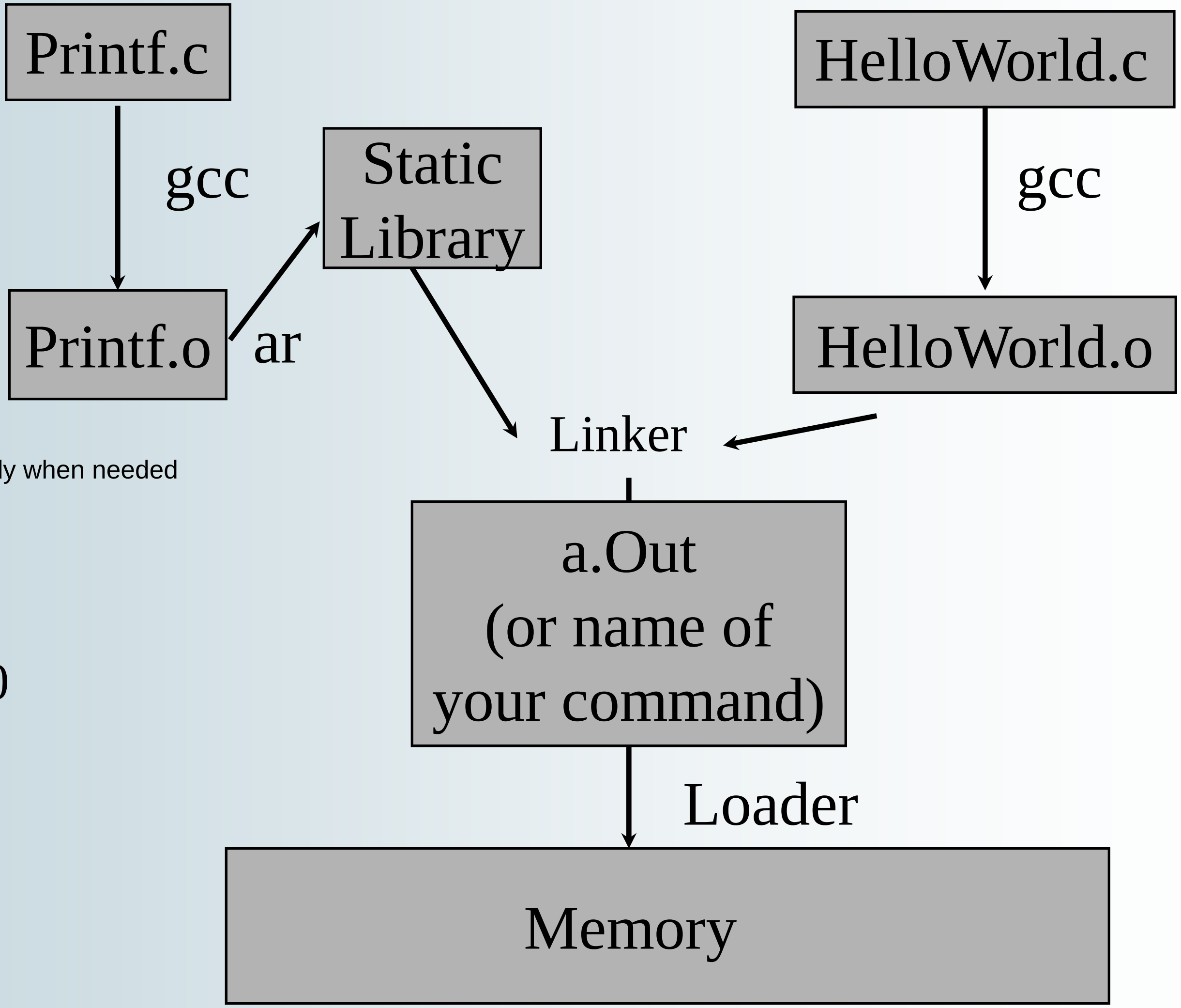
- *Loading:* Copying the loadable image into memory, connecting it with any other programs already loaded, and updating addresses as needed
  - (In Unix) interpreting file to initialize the process address space
  - (in all systems) kernel image is special (own format)

From source code to a process

- *Binding* is the act of connecting *names* to *addresses*
- Most compilers produce *relocatable object code*
    - Addresses relative to *zero*
- The linker combines multiple object files and library modules into a single executable file
    - Addresses also relative to *zero*
- The Loader reads the executable file
    - Allocates memory
    - Maps addresses within file to memory addresses
    - Resolves names of dynamic library items



Static Linking and Loading



static linking you don't know
the address but when linking
we know the address later on
and load the library dynamically when needed

See also Fig 1-30
in Tanenbaum

Classic Unix

- Linker lives inside of *cc* or *gcc* command
- Loader is part of *exec* system call
- Executable image contains *all* object and library modules needed by program
- Entire image is loaded at once

- Every image contains its own copy of common library routines
- Every loaded program contain duplicate copy of library routines

Dynamic Loading

- Routine is not loaded until it is called
- Better memory-space utilization; unused routines are never loaded.
- Useful when large amounts of code needed to handle infrequently occurring cases. There are 2 diff version of dynamic loading implicit and explicit!
- Must be implemented through program design
  - Needs OS support to for loading on demand

Program-controlled Dynamic Loading

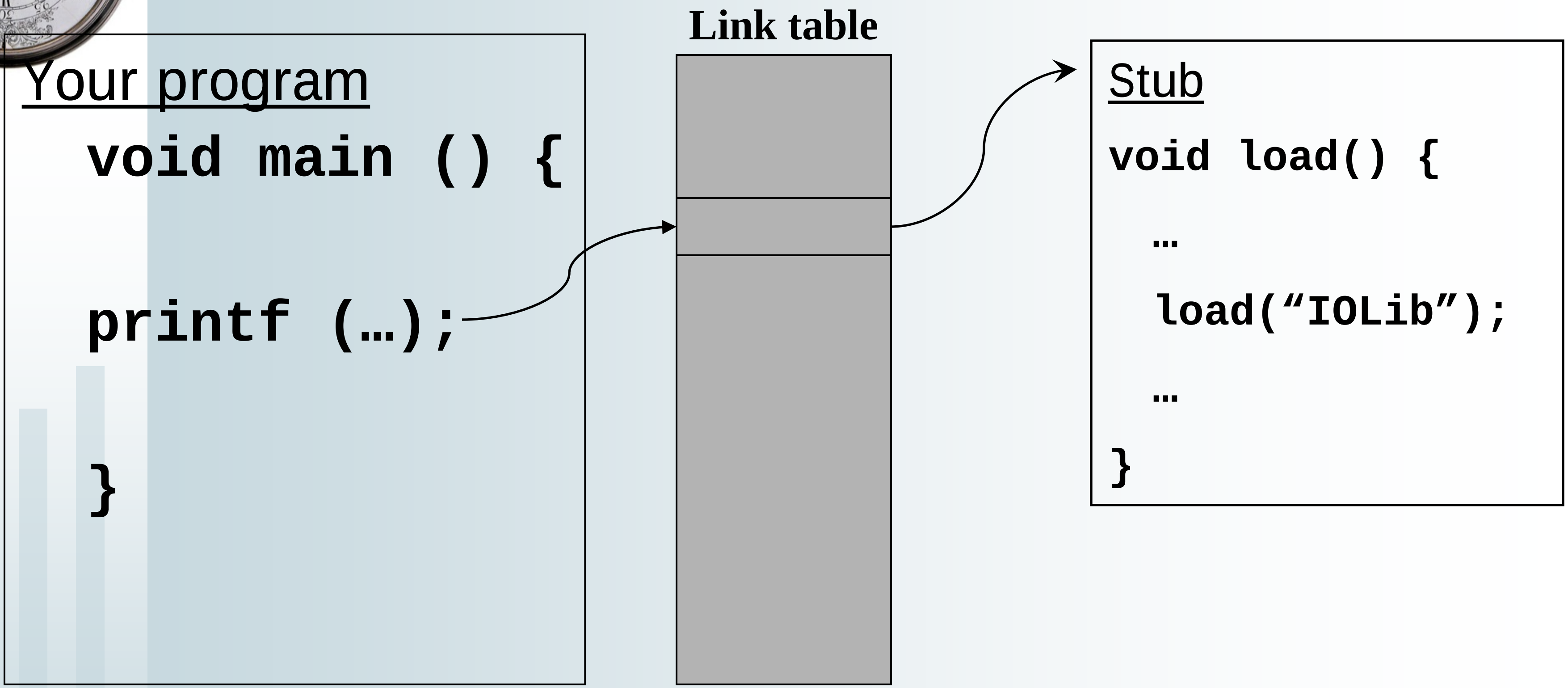
- Requires:
  - A *load* system call to invoke loader (not in classical Unix)
  - ability to leave symbols unresolved and resolve at run time (not in classical Unix)
- E.g.,

```
void myPrintf (**arg) {
  static int loaded = 0;
  if (!loaded ) {
    load (“printf”);
    loaded = 1;
  printf(arg);
  }
}
```

Linker-assisted Dynamic Loading

- Programmer marks modules as “dynamic” to linker
- For function call to a dynamic function
  - Call is indirect through a *link table*
  - Each link table entry is initialized with address of small *stub* of code to locate and load module.
  - When loaded, loader replaces link table entry with address of loaded function
  - When unloaded, loader restores table entry with stub address
  - Works only for *function calls*, not *static data*

Example – Linker-assisted loading (before)



Your program

```
void main () {

printf (…);

}
```

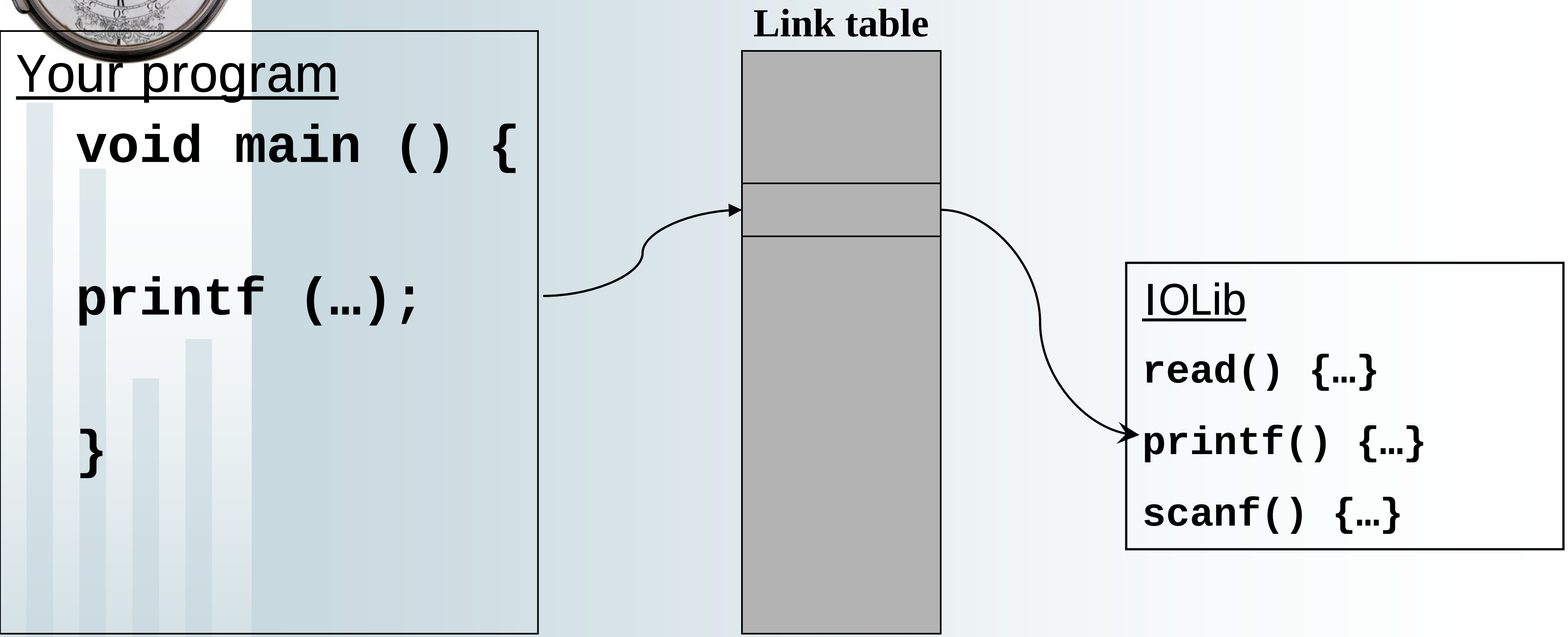
Link table

Stub

```
void load() {
  …
  load(“IOLib”);
  …
}
```

Dynamic linking means that you don't know the addr of the functin
until executed, but link table is not kept void sinc you don't know the addresss
at run time, instead of linking the true q sort you link a miny void routine
which will essentially do the job at runtime! Which means it is dynamic linking.
all this is done to be able to use shared library. Because they cannot belong
to the address space.

Example – Linker-assisted loading (after)



Your program

```
void main () {

printf (…);

}
```

Link table

IOLib

```
read() {…}
printf() {…}
scanf() {…}
```

A shared library is read only! If something has to become
a shared library the person who is writing that func should be aware of that.

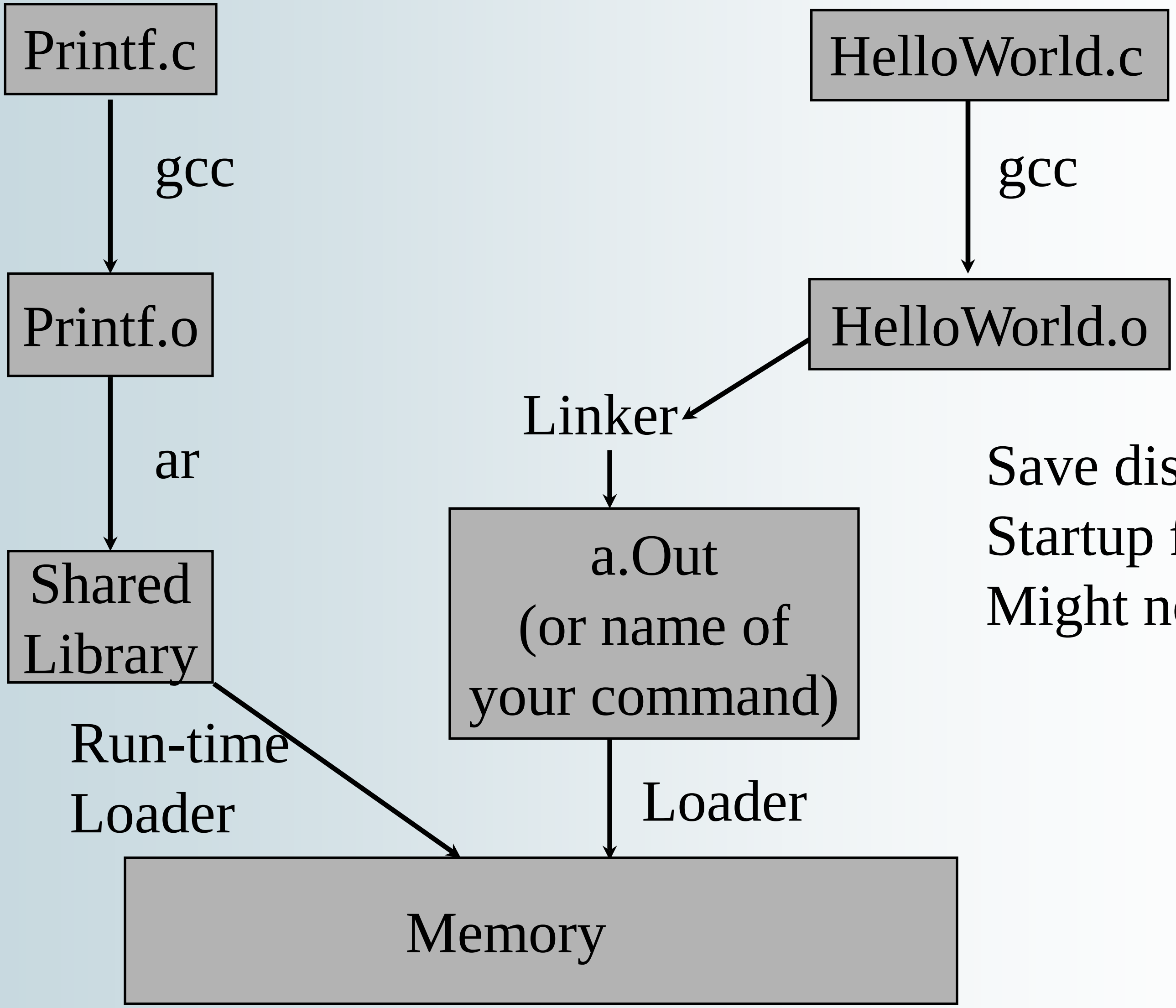
Shared Libraries

- Observation – “everyone” links to standard libraries (*libc.a*, etc.)
- These consume space in
  - every executable image
  - every process memory at runtime
- Would it be possible to share the common libraries?
  - Automatically load at runtime?

Shared libraries (continued)

- Libraries designated as “shared”
  - .so, .dll, etc.
  - Supported by corresponding “.a” libraries containing symbol information
- *Linker* sets up symbols to be resolved at runtime
- *Loader:* Is library already in memory?
  - If yes, *map* into new process space
    - “map,” an operation to be defined later in course
  - If not, load and then *map*

Run-time Linking/Loading



Save disk space.

Startup faster.

Might not need all.

Dynamic Linking

- Complete linking postponed until execution time.
- *Stub* used to locate the appropriate memory-resident library routine.
- Stub replaces itself with the address of the routine, and executes the routine.
- Operating system needs to check if routine is in address space of process
- Dynamic linking is particularly useful for libraries.

Dynamic Shared Libraries

- Static shared libraries requires address space pre-allocation
- Dynamic shared libraries – address binding at runtime
  - Code must be position independent
  - At runtime, references are resolved as
    - Library_relative_address + library_base_address
- See Tanenbaum, §3.5.6

Linking – Summary

- Linker – key part of OS – not in kernel
  - Combines object files and libraries into a “standard” format that the OS loader can interpret
  - Resolves references and does static relocation of addresses
  - Creates information for loader to complete binding process
  - Supports dynamic shared libraries

Loader

- An integral part of the OS
- Resolves addresses and symbols that could not be resolved at link-time
- May be small or large
  - Small: Classic Unix
  - Large: Linux, Windows XP, etc.
- May be invoke explicitly or implicitly
  - Explicitly by stub or by program itself
  - Implicitly as part of *exec*

Questions?