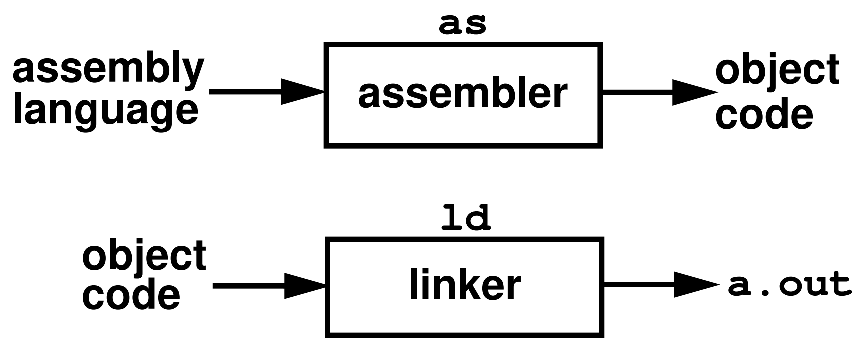
Linking and Loading

- Generating an `a.out` is a ***two-step*** process



- Why two steps?
- ***Linkers*** combine multiple ***object files*** into ***one executable file***

  e.g., `a.out`, and perform external symbol ***resolution*** and ***relocation***

- Other linker capabilities: segments, e.g., text & data, library searching...

Example

- **main.c**:

```
static int a;
extern int b;
int c[10];

main() {
    f(a, b);
    g(a, b);
}
```

- **f.c**:

```
int b;

f(int a, int b) {
    return a + b;
}

g(int a, int b) {
    return a - b;
}
```

- Compiling and linking

```
% lcc -v -c main.c
/usr/princeton/lib/gnu/gcc-cpp ... main.c |
    /usr/princeton/lib/rcc -v -o /tmp/lcc24417.s
/bin/as -o main.o /tmp/lcc24417.s
rm /tmp/lcc24417.s
% nm main.o
00000050 b _a
         U _b
00000028 C _c
         U _f
         U _g
00000000 T _main
%
```

```
% lcc -c f.c
% nm f.o
00000004 C _b
00000000 T _f
0000000c T _g
% lcc -v main.o f.o
/bin/ld -o a.out -dc -dp
    -e start -X /usr/lib/crt0.o
    main.o f.o -lm -lc
```

Relocation

- ***Relocation***: assembler assumes each module begins at address 0
- When **`main.o`** and **`f.o`** are linked, addresses must be ***relocated***, why?
- Modules are concatenated in the order in which they are given to **`ld`**;

  but the compiler might ***rearrange*** data or functions arbitrarily

```
% lcc main.o f.o
% nm a.out
00004000 d __DYNAMIC
000040c8 b _a
00004098 B _b
000040a0 B _c
00004098 D _edata
000040d0 B _end
00004090 D _environ
000024c4 T _etext
000022e0 T _f
000022ec T _g
00002290 T _main
...
```

```
% lcc f.o main.o
% nm a.out
00004000 d __DYNAMIC
000040c8 b _a
00004098 B _b
000040a0 B _c
00004098 D _edata
000040d0 B _end
00004090 D _environ
000024c4 T _etext
00002290 T _f
0000229c T _g
000022a8 T _main
...
```

- Object code contains information about ***relocation sites***

Symbol Resolution

- Linking must ***resolve all symbols***; undefined symbols are errors

```
% lcc main.o
ld: Undefined symbol
   _b
   _f
   _g
```

- Linking must ***define each symbol once***; multiple definitions are errors

```
% cp f.o g.o
% lcc main.o f.o g.o
ld: g.o: _f: multiply defined
g.o: _g: multiply defined
```

- Linkers ***do not type check*** across modules; types of undefined and defined symbols must agree
- Linkers combine all modules specified, even if some are not referenced
- Undefined symbols drive ***library searching***

  `lcc -o cw main.o` **`/u/cs217/lib/lib217.a`** **`-lc`**

  `main.o` references but does not define **`parse`**, **`Table_*`**, and C library functions

  only those modules that define one of these symbols are linked from **`lib217.a`** and from the C library (specified by **`-lc`**)

Linking and Loading, cont'd

- "Linking loaders" consume object files, produce an executable file
- "Link editors" consume object files, produce executable ***or object file***
- Link editors (like **ld**) can build an object file iteratively

```
% ld -o ab.o -r a.o b.o
% ld -o a.out ab.o c.o
```

-r causes **ld** to keep ***relocation information*** and generate an object file
executable files normally have no relocation information

- Executable files do contain a ***symbol table***, which is useful for debugging but takes space; it can removed by "stripping" the executable

```
% lcc -o cw main.o lib217.a
% ls -l cw
24576 cw
% nm cw
000028a0 T _Table_install
...
00002d88 T _parse
...
% strip cw
% ls -l cw
16384 cw
% nm cw
nm: cw: no name list
```