Specifying Branch and Call Targets

- In assembly language, we indicate (direct) jumps and calls with a symbolic syntax.
  - `JMP Label`
  - `Jcc Label`
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- The machine-level ISA reference specifies these instructions as having an offset operand.

- This offset can be encoded in one of two ways.
  - As an absolute offset ("Go to this address").
  - As a relative offset ("Go so far from the address of the current instruction") — actually, from the address of *the sequential successor of* the current instruction.

Example: PC-Relative Offset

```
loop:   movq    %rdi, %rax
        jmp     .L2
.L3:    sarq    %rax
.L2:    testq   %rax, %rax
        jg      .L3
```

Example: PC-Relative Offset

```
loop:   movq    %rdi, %rax      0:   48 89 F8   movq    %rdi, %rax
        jmp     .L2             3:   EB 03      jmp     8 <loop+0x8>
.L3:    sarq    %rax            5:   48 D1 F8   sarq    %rax
.L2:    testq   %rax, %rax      8:   48 85 C0   testq   %rax, %rax
        jg      .L3             B:   7F F8      jg      5 <loop+0x5>
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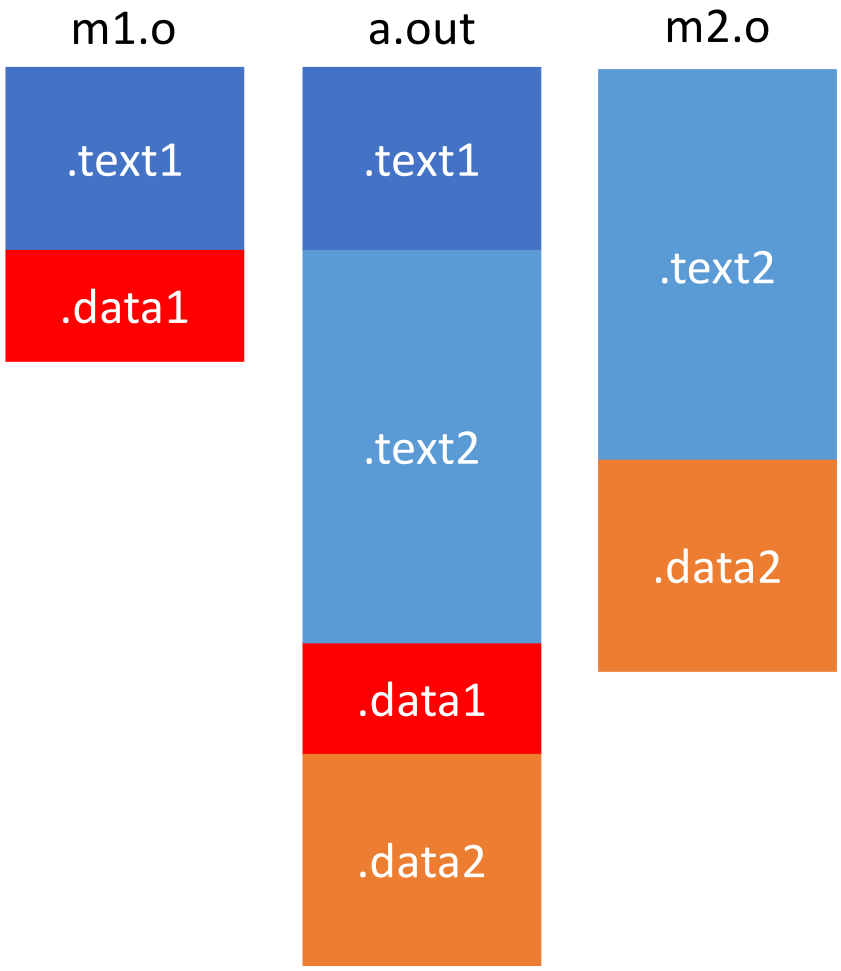
- The encoding remains unchanged even if the numerical value of `loop` changes.
- This is the most basic form of Position-Independent Code (PIC).
  - The non-sequential control transfer edge is “frozen” at compile-time and can be freely relocated to any memory address.
  - The offsets in the two jump instructions do not need to be patched at link-time.

Which Edges Are Position-Independent?



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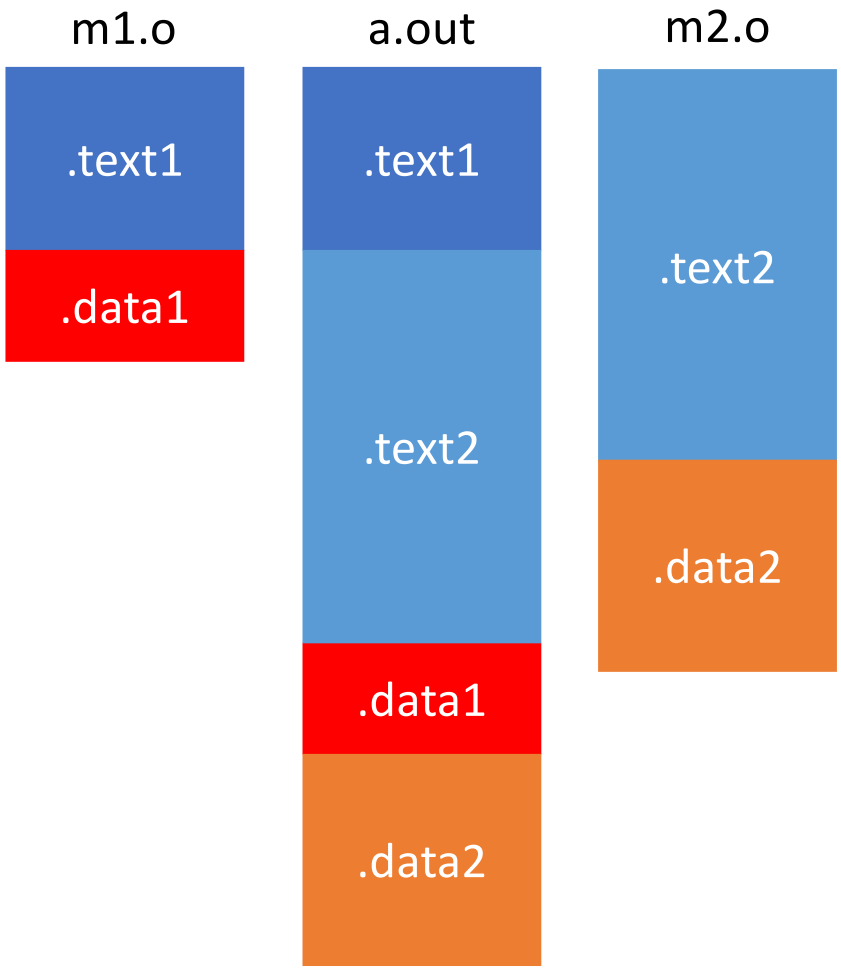

From	To	Example	PIC?
.text1	.text1	Intra-module call	Yes
.text1	.text2	Inter-module call	No
.text1	.data1	Ref to global data	No
.text1	.data2	Ref to external data	No
.data1	.text1	Init to global fn ptr	No
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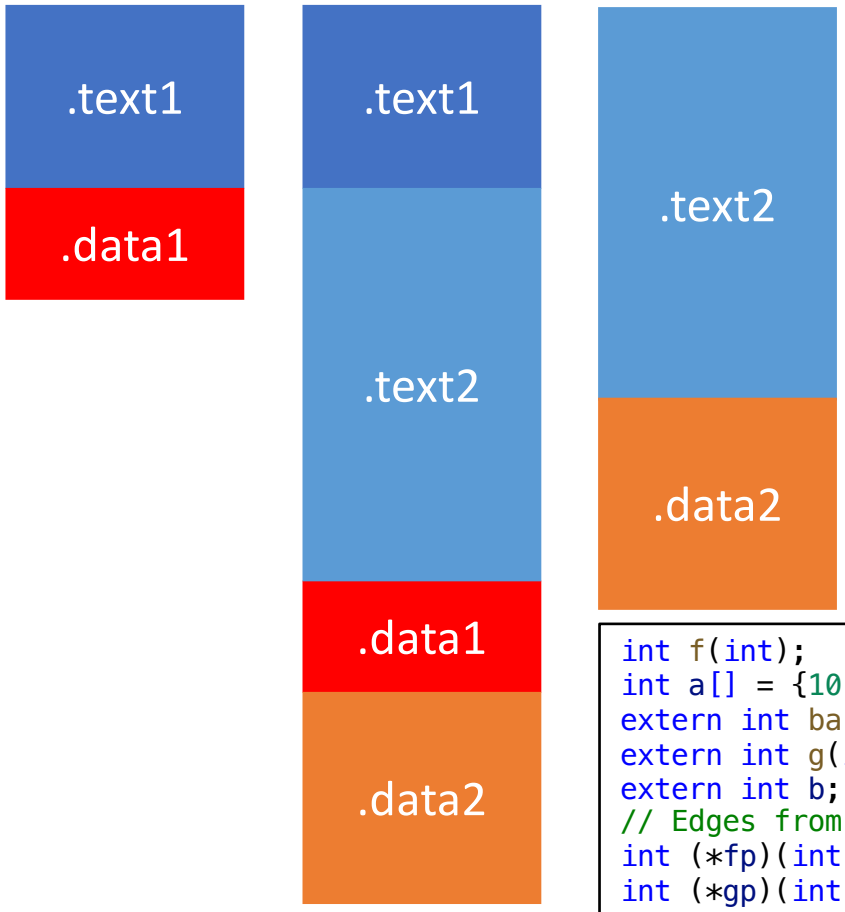

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m1.c

```
int f(int);
int a[] = {10, 20};
extern int bar(int*, int);
extern int g(int);
extern int b;
// Edges from .data1
int (*fp)(int) = f; // To .text1
int (*gp)(int) = g; // To .text2
int *ap = a; // To .data1
int *bp = &b; // To .data2
int f(int n) {return n*n;}
// Edges from .text1 to .data1 and to .text2
static int foo(void) {return bar(a, 2);}
// Edges from .text1 to .data2 and to .text1
// Also from .text1 through .data1 to .text1, .text2,
.data1, and .data2
int main(void) {return b+foo()+fp(*ap)+gp(*bp);}
```

m2.c

```
int b = 42;
int bar(int *a, int n) {
int sum = 0;
for (int i = 0; i < n; i++) sum += a[i];
b -= sum;
return sum;
}
int g(int n) {return 2*n+1;}
```

Why PIC Matters

- Consider a large library, e.g., the C standard library `libc`.
  - The library exposes a large number of definitions.
  - Any single program likely references a very small number of these definitions (e.g., file I/O but not signals). However, there may be a lot of references to these definitions.

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- If we link `libc` *statically* with application programs, we resolve and patch these references prior to load-time.
  - The entire library is embedded into each executable, increasing its size on disk and its virtual memory footprint.
  - The OS has to manage many distinct copies of the library, putting a greater load on the VM system.
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  - The OS has to manage many distinct copies of the library, putting a greater load on the VM system.
    - In principle, at least the read-only segment could be shared among all executables linking against `libc` that are running simultaneously.
- If we link `libc` *dynamically* with application programs, we defer patching the references to load-time (or possibly even run-time).
  - Multiple references to the same `libc` definition still need to be patched individually, resulting in a time overhead. Can we mitigate this overhead?
  - Can we also arrange to share a single copy of the read-only segment?