University of Arizona

CSc 340

Foundations of Computer Systems

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Dynamic Relocation

Absolute Loader...

- Some loaders will load a program into the same location in memory every time.
- In the program on the next slide the executable file header contains

  loadAddr The address in memory at which the program should be loaded, and

  startAddr The address at which we should begin executing the program.

Slide 21–1

```
struct execFileHeader {
   unsigned int startAddr;
   unsigned int loadAddr;}

char* absoluteLoader (FILE *execFile) {
   struct execHeader header = readHeader(execFile);

   char *byteAddr = (char*) header.loadAddr;
   for all bytes b in execFile do {
      *byteAddr = b;
      byteAddr++;
   }
   return (char*) header.startAddr;
}
```

Slide 21–2

Two views of memory

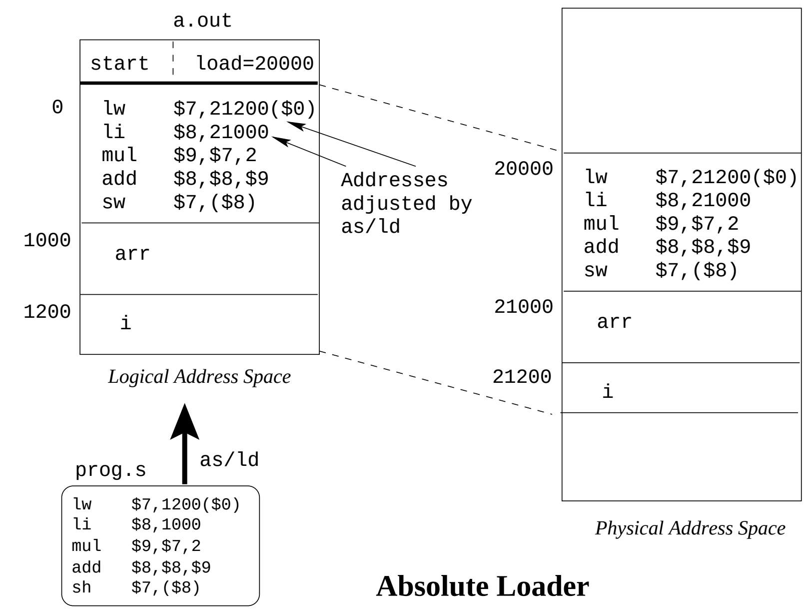
logical address space: This is memory from the program's point of view.

physical address space: This is memory from the machine's point of view.

```
      .data
arr:  .short 100        ; @1000
i:    .word             ; @1200

      .text
lw    $7,1200($0)       ; $7 = i
li    $8,1000           ; $8 = &arr
mul   $9,$7,2           ; $9 = 2*i
add   $8,$8,$9          ; $8 = 1000+4*i
sh    $7,($8)           ; arr[i] = i
```

Slide 21–3

Slide 21–4



Absolute Loader

Slide 21–5

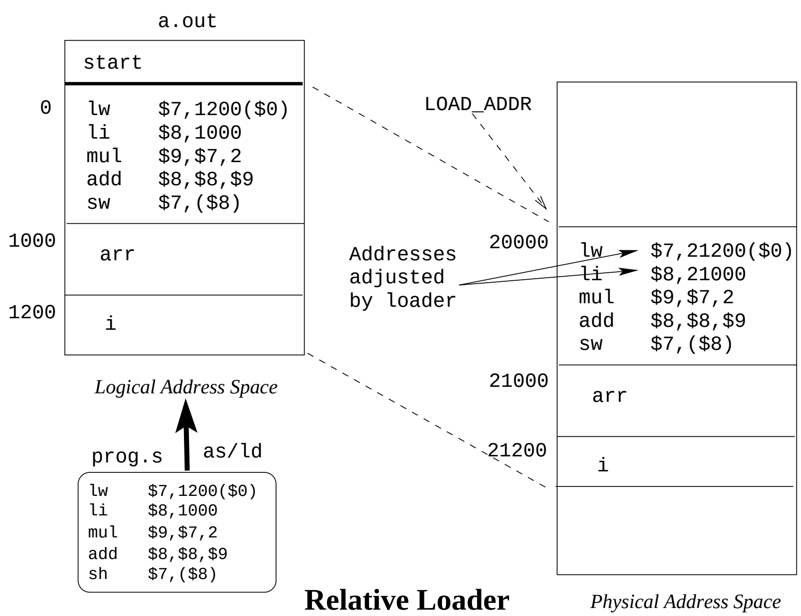
Static Relocation

- An absolute loader loads the program at an address specified by the file header. Addresses don't need to be adjusted; they've been calculated by the assembler/linker.
- A relative loader decides itself where in memory to load the program. Addresses need to be adjusted to reflect the load address.
- Static relocation means that the loader adjusts addresses before the program starts executing.

Slide 21–6

```
struct execFileHeader {
   unsigned int startAddr;}

char* relativeLoader (FILE *execFile) {
   struct execHeader header = readHeader(execFile);

   char *byteAddr = LOAD_ADDR;
   for all bytes b in execFile do {
      *byteAddr = b;
      byteAddr++;
   }
   return (char*) header.startAddr;
}
```

Slide 21–7



Relative Loader

Slide 21–8

Static Relocation – Problems

1. A relative loader must find a region of unused memory large enough to hold the program.
2. Same problem as heap allocation – use First-Fit, Best-Fit, etc.
3. Each segment (data,text,bss) can be relocated individually – allocate 3 small holes rather than 1 big one.
4. Can't relocate program while it's running ⇒ can't compact free space.
5. Programs can interfere with one another and the operating system. A bug in one program can cause another to crash.

Slide 21–9

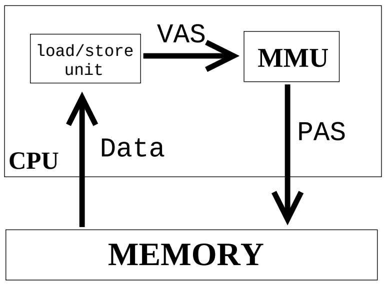
Dynamic Relocation

- Suppose, however, instead of relocating a program's addresses when it is loaded, we relocate them while it's running. This is called dynamic relocation, and the idea is to relocate (change) the address on every memory access.
  1. Once again a problem is solved via another level of indirection, the computer scientist's secret weapon.
  2. Think of it like call-forwarding – you call one number but your call is forwarded to another number.

Slide 21–10

Dynamic Relocation. . .

- Dynamic relocation is handled by hardware called the memory- management unit (MMU). The MMU sits between the CPU and the memory and relocates all addresses issued by the CPU.



Slide 21–11

Dynamic Relocation. . .

- These days the MMU is on the CPU chip.
- The MMU translates each program-generated address (called a logical or virtual address) into a real or physical address before it is given to the memory system.
- Dynamic relocation happens on *every* memory reference.

Slide 21–12

Dynamic Relocation. . .

- Dynamic relocation leads to two views of memory, called address spaces.
  1. The virtual address space (VAS) is what the program sees; addresses in the program are virtual addresses. The text segment starts at virtual address 0, followed by the data segment and stack segment.
  2. The physical address space (PAS) is what the memory system provides; it starts at physical address 0 and goes up to the amount of memory in the machine (ignore memory-mapped devices for now).

Slide 21–13

Advantages of dynamic relocation

1. Each process starts at virtual address 0.
2. No relocation during loading
3. A program can be moved to another location in physical memory without changing its virtual addresses: Simply change the way MMU does virtual-to-physical mapping so that the virtual addresses now refer to the new physical addresses.
4. If we limit the size of a program's VAS, programs cannot access each other's memory. This prevents one program from crashing another.

Slide 21–14

Disadvantages of dynamic relocation

1. Addresses must be relocated on every memory access, slowing them down.
2. Relocation must also be done before accessing the caches.

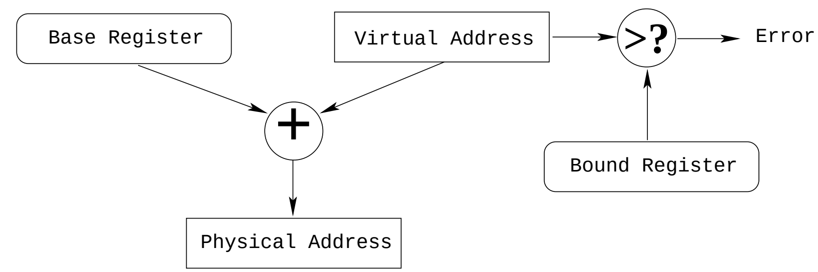
Slide 21–15

```
struct execFileHeader {
   unsigned int startAddr,textSize,dataSize,bssSize;}

char* dynamicLoader (FILE *execFile) {
   struct execHeader header = readHeader(execFile);
   unsigned int pgmSize = header.textSize +
         header.dataSize + header.bssSize;

   char* byteAddr = getMemory(pgmSize);
   for all bytes b in execFile do {
      *byteAddr = b;
      byteAddr++;
   }

   setMemoryMapping(byteAddr,pgmSize);
   return (char*) header.startAddr;
}
```

Slide 21–16

Base & Bound Relocation

- A simple dynamic relocation scheme uses an `MMU` that consists of two registers: a base register that contains the physical address (PA) of the start of the program, and a bound register that contains the last valid virtual address (VA) in the program's VAS.

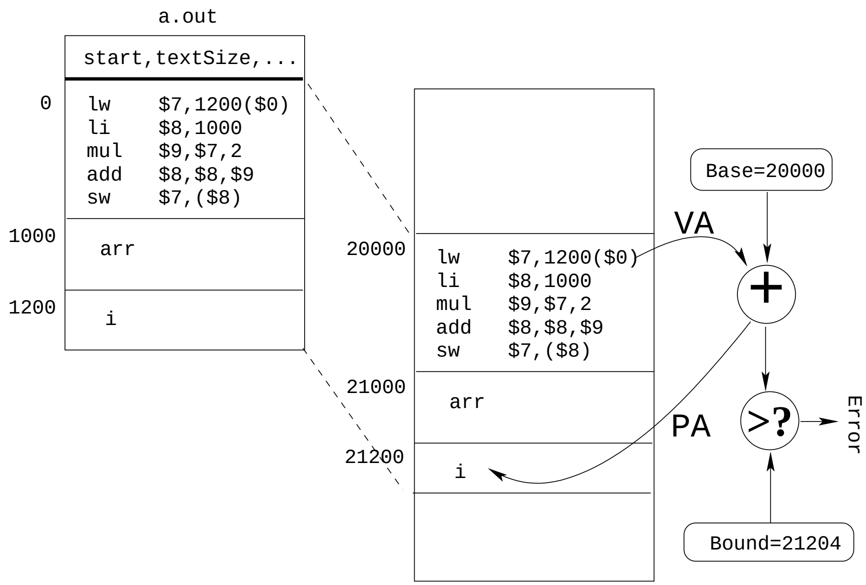


Slide 21–17

Base & Bound Relocation...

- On each memory reference, the VA is compared to the bound register, and added to the base register.
  1. If the `VA > bound`, a segmentation violation (fault) occurs.
  2. The `PA = VA + base` is passed to the memory system.
- Each program appears to have a completely private memory of size equal to the bound register plus 1. Programs are protected from each other. No static address relocation is necessary.

Slide 21–18



Slide 21–19

Base & Bound Relocation...

- Only the operating system (in supervisor mode) can modify the base and bound registers.
- Base & bound is cheap – only 2 registers – and fast – the add and compare can be done in parallel.
- Examples: CRAY-1

Slide 21–20

Problems with base & bound relocation

1. Can't grow existing program because stack grows downwards.
2. Only one segment. How can two processes share code while keeping private data areas (e.g. shared editor)?

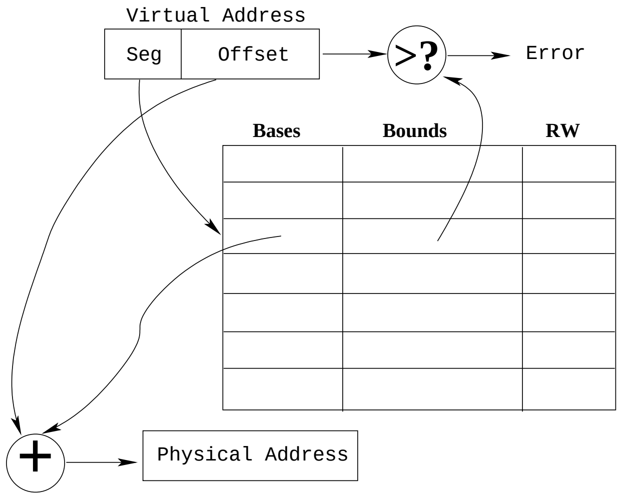
Slide 21–21

Solution: multiple segments per program

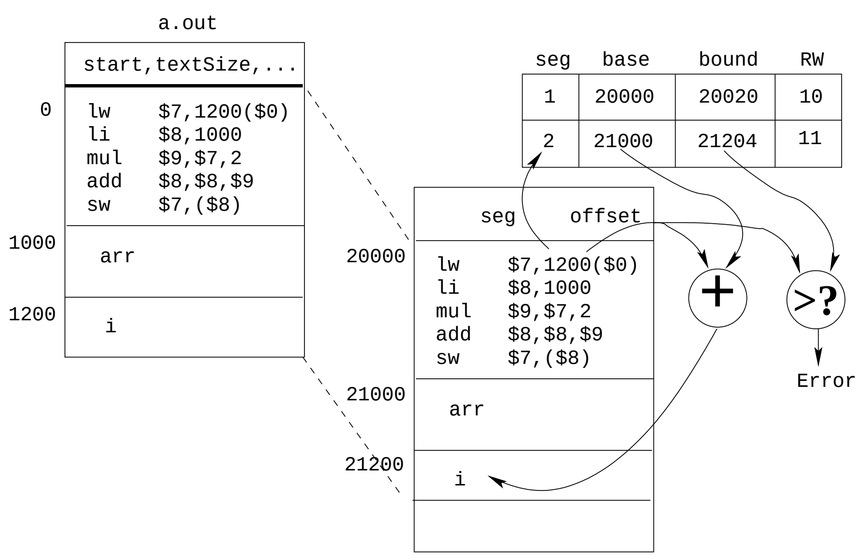
1. Split program between several areas of physical memory, e.g. separate area for text, data, and stack.
2. Use a separate base and bound for each segment, and also add two protection bits (read and write).
3. Programs can share segments (e.g. share text).
4. Different segments can have different permissions (e.g. text is read-only).

Slide 21–22

- The segment table holds the bases and bounds for all the segments of a program:



Slide 21–23



Slide 21–24

- Given a VA, which segment is it in? (which base/bound do we use?)
  1. Top bits of address select segment, low bits the offset (shown above). This is the most common, and the best.
  2. From operation underway (e.g. code vs. data segment).
  3. From segment register indicated by field in instruction.
- The last two are caused by too few bits in the virtual address space.

Slide 21–25

Segmentation example

- 2-bit segment number, 12-bit offset, 16-bit PA.

Segment table

Segment	Base (hex)	Bounds (hex)	RW (binary)
0	4000	6FF	10
1	0	4FF	11
2	3000	FFF	11
3	—	—	00

Slide 21–26

```
240:        la      $a0, 0x1108
244:        jal     360
...
360:        subu    $sp, $sp, 24
364         sw      $fp, 0($sp)
368         addu    $fp, $sp, 24
36c         lw      $t0, 0($a0)
370         la      $a0, 0x3000
374         sw      $t0, 0($a0)
378         lw      $fp, -24($sp)
37c         addu    $sp, $sp, 24
380         jr      $ra
...
1108:       42
```

Slide 21–27

Segmentation example...

- What PA corresponds to VA `0x240`?

```
00       0010 0100 0000
Seg=0    Offset=0010 0100 0000=0x240
+        0x4000 (=base)
---------------------------------------
         0x4240
```

- What PA corresponds to VA `0x1108`?

```
01       0001 0000 1000
Seg=1    Offset=0001 0000 1000=0x108
+        0x0 (=base)
---------------------------------------
         0x108
```

Segmentation example...

- Suppose `$sp` is initially set to VA `0x2650`. What is the corresponding PA?

```
10       0110 0101 0000
Seg=2    Offset=0110 0101 0000=0x650
+        0x3000 (=base)
------------------------------------
         0x3650
```


Readings and References

- MacCabe, pp. 377–388.