The Hardware/Software Interface
CSE351 Winter 2013

Data Structures II: Structs and Unions

Data Structures in Assembly

- Arrays
  - One-dimensional
  - Multi-dimensional (nested)
  - Multi-level
- Structs
  - Alignment
- Unions

Structures

```
struct rec {
  int i;
  int a[3];
  int *p;
};
```


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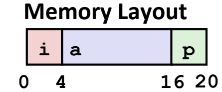
Memory Layout



- Characteristics
  - Contiguously-allocated region of memory
  - Refer to members within structure by names
  - Members may be of different types

Structures

- **Accessing Structure Member**
  - Given an instance of the struct, we can use the `.` operator, just like Java:
    - `struct rec r1;  r1.i = val;`
  - What if we have a *pointer* to a struct: `struct rec *r = &r1;`
    - Using `*` and `.` operators: `(*r).i = val;`
    - Or, use `->` operator for short: `r->i = val;`
  - Pointer indicates first byte of structure; access members with offsets

```
struct rec {
  int i;
  int a[3];
  int *p;
};
```

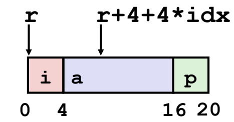
```
void
set_i(struct rec *r,
      int val)
{
     r->i = val;
}
```

IA32 Assembly

```
# %eax = val
# %edx = r
movl %eax,(%edx)    # Mem[r] = val
```


Generating Pointer to Structure Member

```
struct rec {
  int i;
  int a[3];
  int *p;
};
```



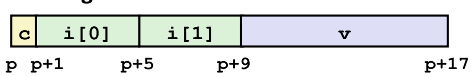
- **Generating Pointer to Array Element**
  - Offset of each structure member determined at compile time

```
int *find_a
  (struct rec *r, int idx)
{
   return &r->a[idx];
}
```

```
# %ecx = idx
# %edx = r
leal 0(,%ecx,4),%eax    # 4*idx
leal 4(%eax,%edx),%eax  # r+4*idx+4
```

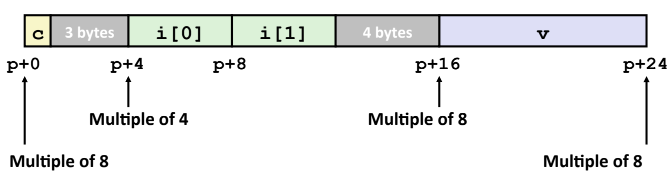

Structures & Alignment

- **Unaligned Data**




```
struct S1 {
  char c;
  int i[2];
  double v;
} *p;
```

- **Aligned Data**
  - Primitive data type requires K bytes
  - Address must be multiple of K



Alignment Principles

- **Aligned Data**
  - Primitive data type requires K bytes
  - Address must be multiple of K
- **Aligned data is required on some machines; it is *advised* on IA32**
  - Treated differently by IA32 Linux, x86-64 Linux, and Windows!
- **What is the motivation for alignment?**

Alignment Principles

- **Aligned Data**
  - Primitive data type requires K bytes
  - Address must be multiple of K
- **Aligned data is required on some machines; it is *advised* on IA32**
  - Treated differently by IA32 Linux, x86-64 Linux, and Windows!
- **Motivation for Aligning Data**
  - Physical memory is accessed by aligned chunks of 4 or 8 bytes (system-dependent)
    - Inefficient to load or store datum that spans quad word boundaries
  - Also, virtual memory is very tricky when datum spans two pages (later…)
- **Compiler**
  - Inserts gaps in structure to ensure correct alignment of fields
  - `sizeof()` should be used to get true size of structs

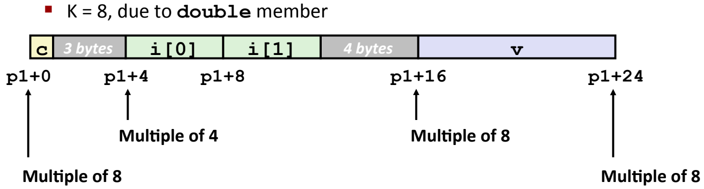
Specific Cases of Alignment (IA32)

- **1 byte: char, …**
  - no restrictions on address
- **2 bytes: short, …**
  - lowest 1 bit of address must be 0_2
- **4 bytes: int, float, char *, …**
  - lowest 2 bits of address must be 00_2
- **8 bytes: double, …**
  - Windows (and most other OSs & instruction sets): lowest 3 bits 000_2
  - Linux: lowest 2 bits of address must be 00_2
    - i.e., treated the same as a 4-byte primitive data type
- **12 bytes: long double**
  - Windows, Linux: lowest 2 bits of address must be 00_2

Satisfying Alignment with Structures

```
struct S1 {
  char c;
  int i[2];
  double v;
} *p1;
```

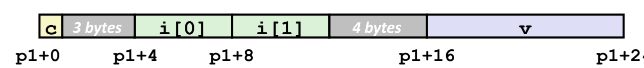
- **Within structure:**
  - Must satisfy element's alignment requirement
- **Overall structure placement**
  - Each structure has alignment requirement K
    - K = Largest alignment of any element
  - Initial address & structure length must be multiples of K
- **Example (under Windows or x86-64):** K = ?
  - K = 8, due to `double` member



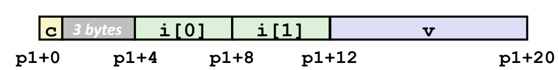
Different Alignment Conventions

```
struct S1 {
  char c;
  int i[2];
  double v;
} *p1;
```

- **IA32 Windows or x86-64:**
  - K = 8, due to `double` member



- **IA32 Linux:** K = ?
  - K = 4; `double` aligned like a 4-byte data type



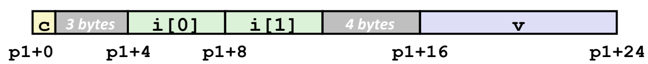
Saving Space

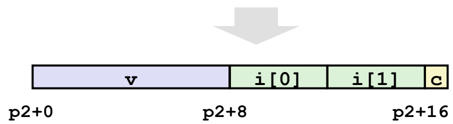
- Put large data types first:

```
struct S1 {
  char c;
  int i[2];
  double v;
} *p1;
```

```
struct S2 {
  double v;
  int i[2];
  char c;
} *p2;
```

- Effect (example x86-64, both have K=8)



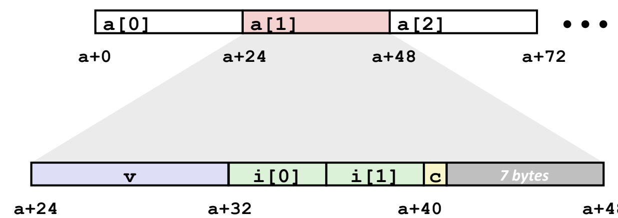


Unfortunately, doesn't satisfy requirement that struct's *total size* is a multiple of K

Arrays of Structures

- Satisfy alignment requirement for every element

```
struct S2 {
  double v;
  int i[2];
  char c;
} a[10];
```



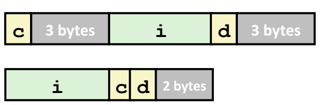
Saving Space

- Put large data types first:

```
struct S3 {
  char c;
  int i;
  char d;
} *p3;
```

```
struct S4 {
  int i;
  char c;
  char d;
} *p4;
```

- Effect (K=4)

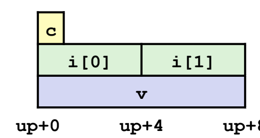


- This strategy *can* save some space for certain structs.

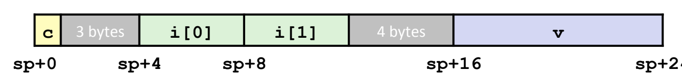
Unions

- Allocated according to largest element
- Can only use one member at a time

```
union U1 {
  char c;
  int i[2];
  double v;
} *up;
```




```
struct S1 {
  char c;
  int i[2];
  double v;
} *sp;
```



What Are Unions Good For?

- **Unions allow the same region of memory to be referenced as different types**
  - Different "views" of the same memory location
  - Can be used to circumvent C's type system (bad idea)
- **Better idea: use a struct inside a union to access some memory location either as a whole or by its parts**

Unions For Embedded Programming

```
typedef union
{
   unsigned char byte;
   struct {
      unsigned char b0:1;
      unsigned char b1:1;
      unsigned char b2:1;
      unsigned char b3:1;
      unsigned char reserved:4;
   } bits;
} hw_register;

hw_register reg;
reg.byte = 0x3F;        // 00111111₂
reg.bits.b2 = 0;        // 00111011₂
reg.bits.b3 = 0;        // 00110011₂
unsigned short a = reg.byte;
printf("0x%X\n", a);    // output: 0x33
```

(Note: the placement of these fields and other parts of this example are implementation-dependent)

Summary

- **Arrays in C**
  - Contiguous allocations of memory
  - No bounds checking
  - Can usually be treated like a pointer to first element
- **Structures**
  - Allocate bytes in order declared
  - Pad in middle and at end to satisfy alignment
- **Unions**
  - Provide different views of the same memory location