

# Today

## ■ Arrays

- One-dimensional
- Multi-dimensional (nested)
- Multi-level

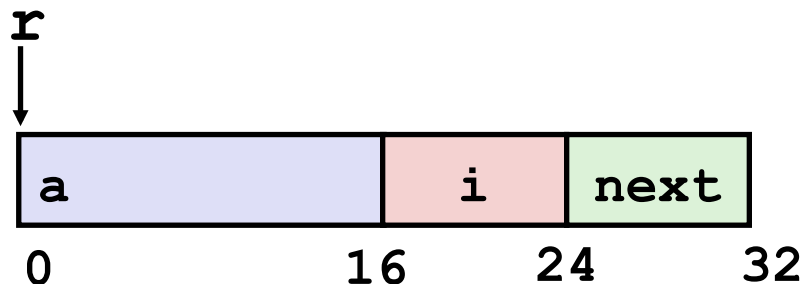
## ■ Structures

- Allocation
- Access
- Alignment

## ■ Floating Point

# Structure Representation

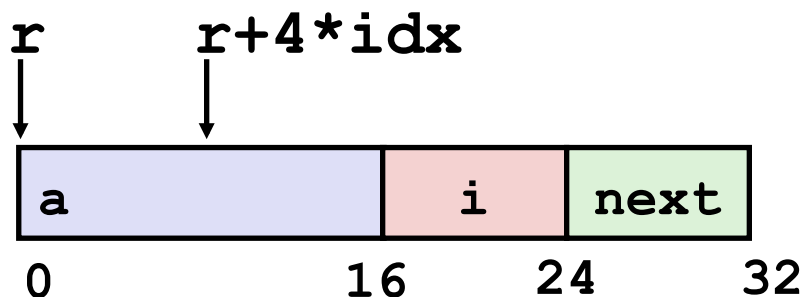
```
struct rec {  
    int a[4];  
    size_t i;  
    struct rec *next;  
};
```



- **Structure represented as block of memory**
  - Big enough to hold all of the fields
- **Fields ordered according to declaration**
  - Even if another ordering could yield a more compact representation
- **Compiler determines overall size + positions of fields**
  - Machine-level program has no understanding of the structures in the source code

# Generating Pointer to Structure Member

```
struct rec {
    int a[4];
    size_t i;
    struct rec *next;
};
```



## ■ Generating Pointer to Array Element

- Offset of each structure member determined at compile time
- Compute as  $r + 4 * idx$

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

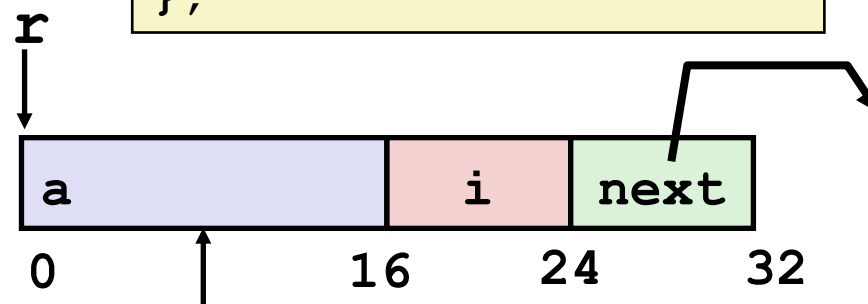
```
# r in %rdi, idx in %rsi
leaq (%rdi,%rsi,4), %rax
ret
```

# Following Linked List

## ■ C Code

```
void set_val
(struct rec *r, int val)
{
    while (r) {
        int i = r->i;
        r->a[i] = val;
        r = r->next;
    }
}
```

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



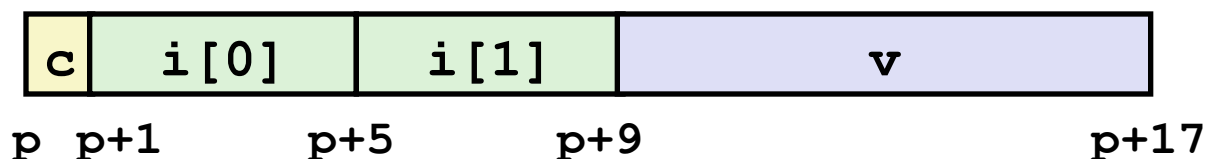
Element `i`

Register	Value
<code>%rdi</code>	<code>r</code>
<code>%rsi</code>	<code>val</code>

```
.L11:                                # loop:
    movslq    16(%rdi), %rax          # i = M[r+16]
    movl      %esi, (%rdi,%rax,4)     # M[r+4*i] = val
    movq      24(%rdi), %rdi         # r = M[r+24]
    testq     %rdi, %rdi             # Test r
    jne       .L11                   # if !=0 goto loop
```

# Structures & Alignment

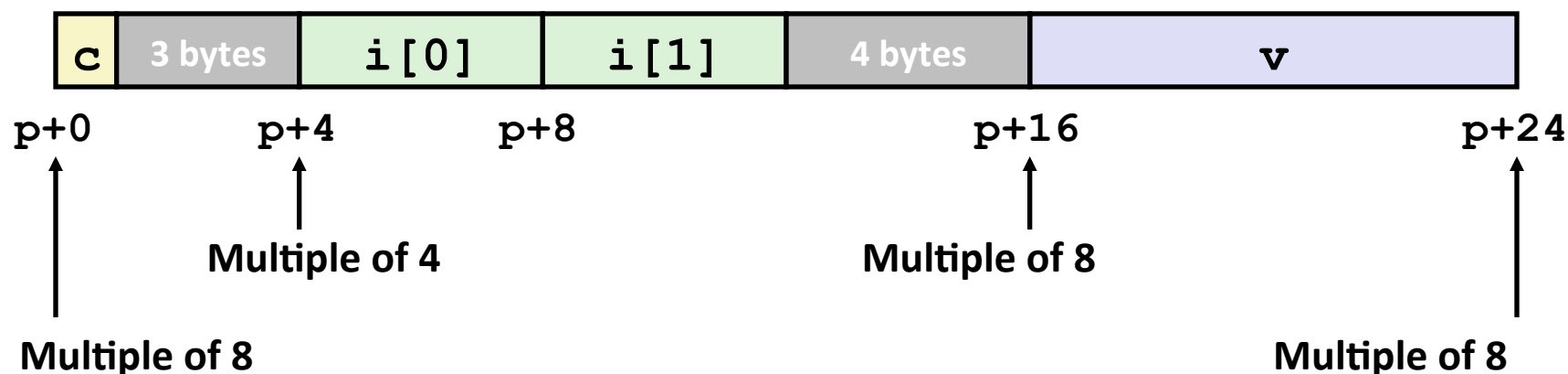
## ■ Unaligned Data



```
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
- Required on some machines; advised on x86-64

## ■ Motivation for Aligning Data

- Memory accessed by (aligned) chunks of 4 or 8 bytes (system dependent)
  - Inefficient to load or store datum that spans quad word boundaries
  - Virtual memory trickier when datum spans 2 pages

## ■ Compiler

- Inserts gaps in structure to ensure correct alignment of fields

# Specific Cases of Alignment (x86-64)

- **1 byte: `char`, ...**
  - no restrictions on address
- **2 bytes: `short`, ...**
  - lowest 1 bit of address must be  $0_2$
- **4 bytes: `int`, `float`, ...**
  - lowest 2 bits of address must be  $00_2$
- **8 bytes: `double`, `long`, `char *`, ...**
  - lowest 3 bits of address must be  $000_2$
- **16 bytes: `long double` (GCC on Linux)**
  - lowest 4 bits of address must be  $0000_2$

# Satisfying Alignment with Structures

## ■ Within structure:

- Must satisfy each element's alignment requirement

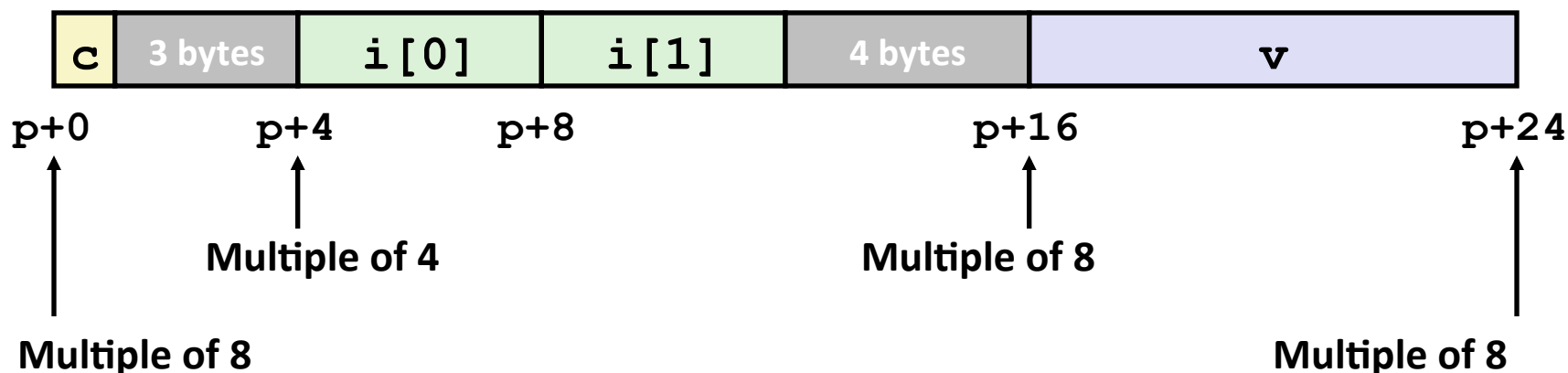
## ■ Overall structure placement

- Each structure has alignment requirement  $K$ 
  - $K$  = Largest alignment of any element
- Initial address & structure length must be multiples of  $K$

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

## ■ Example:

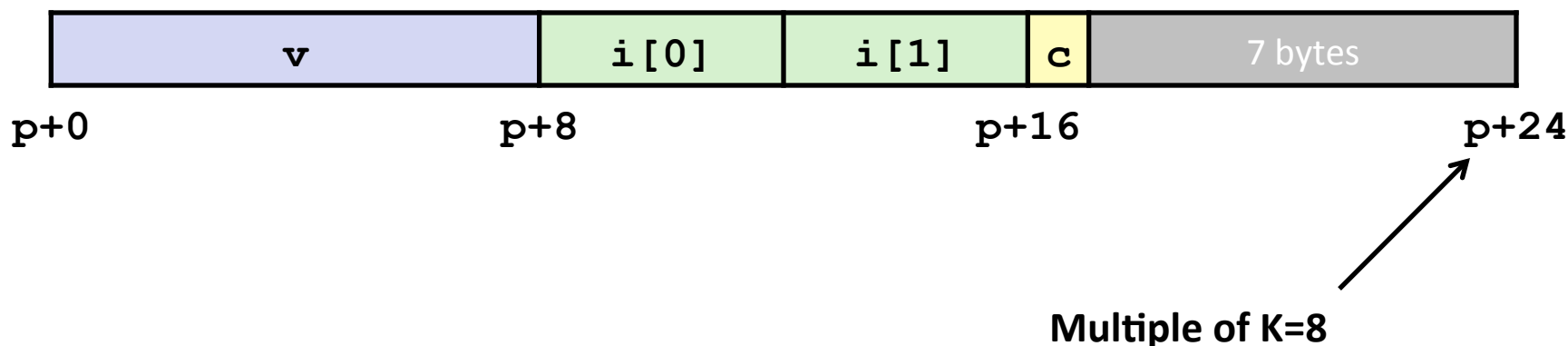
- $K = 8$ , due to `double` element



# Meeting Overall Alignment Requirement

- For largest alignment requirement  $K$
- Overall structure must be multiple of  $K$

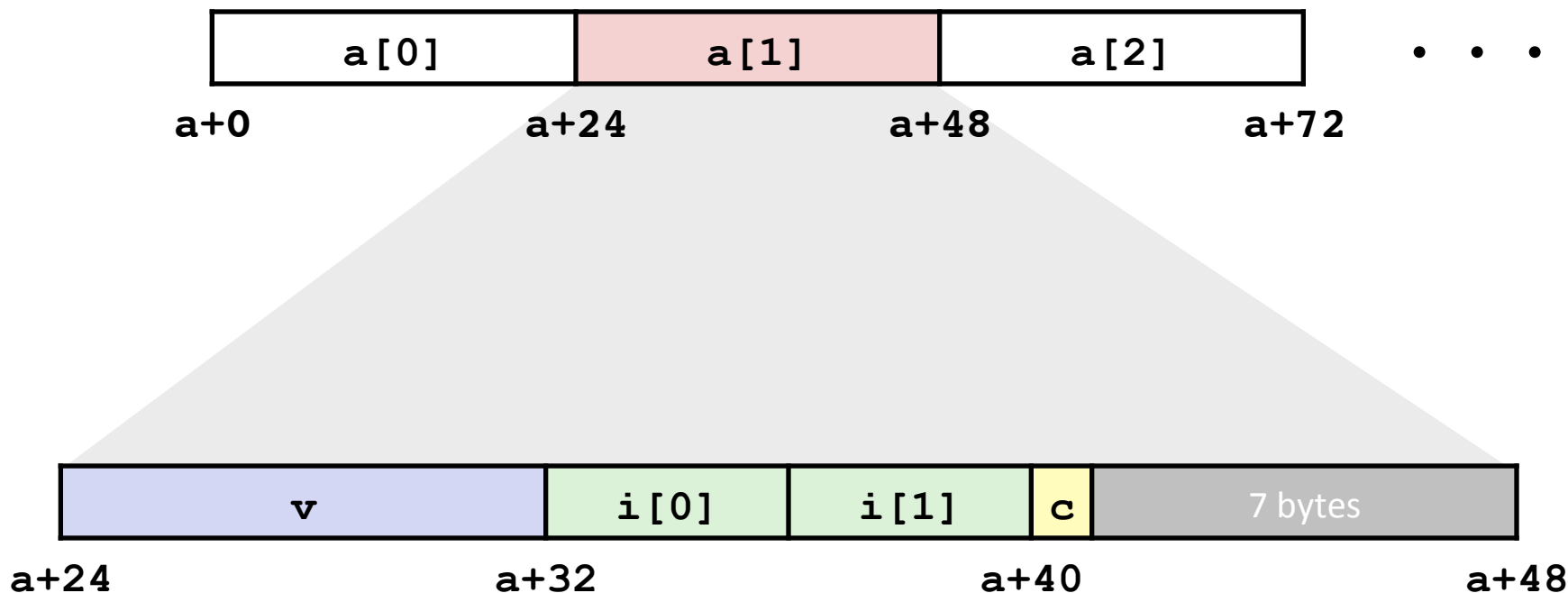
```
struct S2 {  
    double v;  
    int i[2];  
    char c;  
} *p;
```



# Arrays of Structures

- Overall structure length multiple of K
- Satisfy alignment requirement for every element

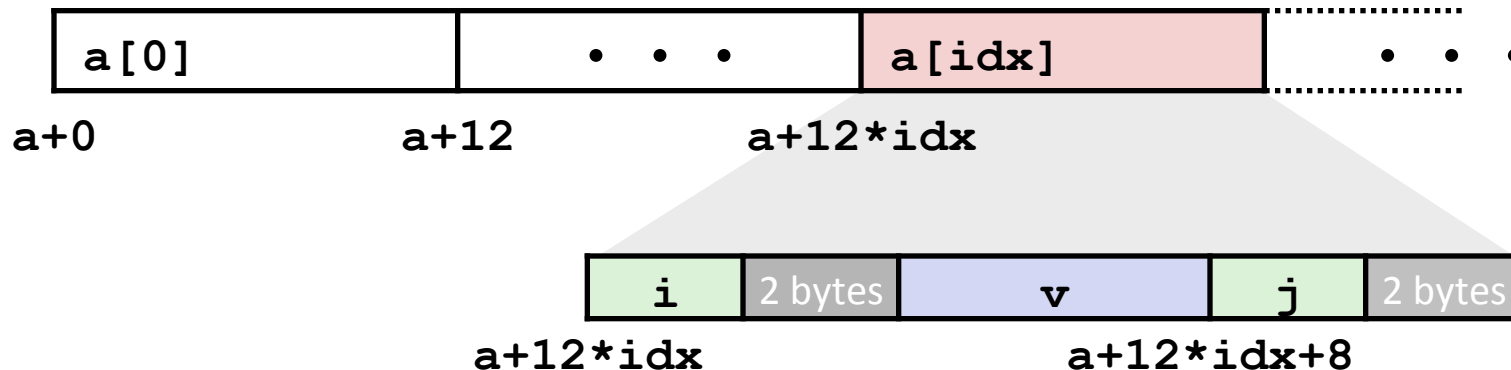
```
struct S2 {  
    double v;  
    int i[2];  
    char c;  
} a[10];
```



# Accessing Array Elements

- **Compute array offset  $12 \cdot \text{idx}$** 
  - `sizeof(S3)`, including alignment spacers
- **Element `j` is at offset 8 within structure**
- **Assembler gives offset `a+8`**
  - Resolved during linking

```
struct S3 {
    short i;
    float v;
    short j;
} a[10];
```



```
short get_j(int idx)
{
    return a[idx].j;
}
```

```
# %rdi = idx
leaq (%rdi,%rdi,2),%rax # 3*idx
movzwl a+8(,%rax,4),%eax
```

# Saving Space

- Put large data types first

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



```
struct S5 {
    int i;
    char c;
    char d;
} *p;
```

- Effect (K=4)

