C Structs

A **`struct`** combines multiple field values:

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};

struct element h = {"Hydrogen",
                    "H",
                    1,
                    1.00794};

void report(struct element e) {
  printf("%s is atomic number %d\n",
         e.name,
         e.atom_no);
}
```

C Structs and Typedefs

Common to give a short name with **`typedef`**

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};

typedef struct element ELT;

ELT h = {"Hydrogen", ....};

void report(ELT e) {
  ....
}
```

C Structs and Typedefs

Common to recycle the **`struct`** name with **`typedef`**

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};

typedef struct element element;

element h = {"Hydrogen", ....};

void report(element e) {
  ....
}
```

C Structs and Typedefs

Shorthand: declare **`struct`** and **`typedef`** at once

```
typedef struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
} element;

element h = {"Hydrogen", ....};

void report(element e) {
  ....
}
```

C Structs and Typedefs

... but must use **`struct`** for self-reference

```
typedef struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
  struct element *next_in_table;
} element;
```

C Struct Pointers and Fields

Structs are more like integers than arrays

```
void add_neutrons(element e) {
  e.mass++;
}

int main() {
   element h = {"Hydrogen", "H", 1, 1.00794};
   add_neutrons(h);
   printf("%f\n", h.mass);
}
```

Prints 1.00794

C Struct Pointers and Fields

Structs are more like integers than arrays

```
void add_neutrons(element *e) {
  (*e).mass++;
}

int main() {
   element h = {"Hydrogen", "H", 1, 1.00794};
   add_neutrons(&h);
   printf("%f\n", h.mass);
}
```

Prints 2.00794

C Struct Pointers and Fields

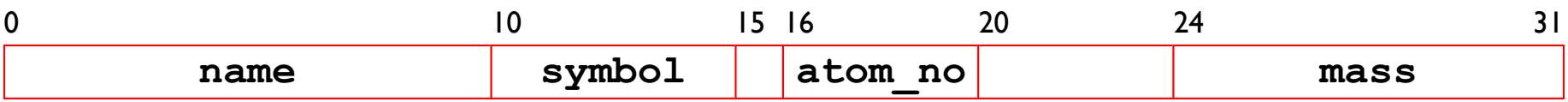
Use `_->_` as a shorthand for `(*_).__`

```
void add_neutrons(element *e) {
  printf("Old mass: %f\n", e->mass);
  e->mass++;
}
```

Structure Layout

A **`struct`** value has its fields' values in order

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};
```



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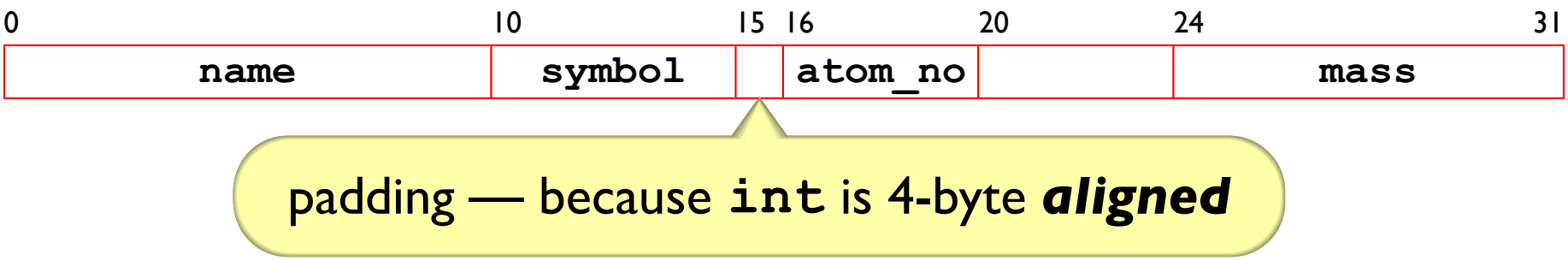

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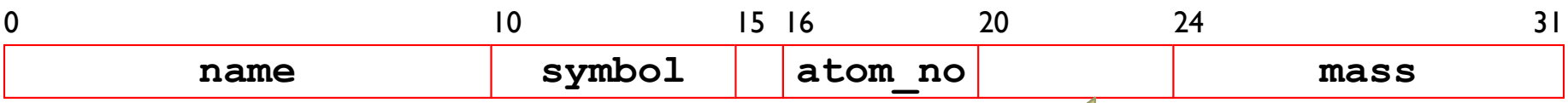


padding — because **`double`** is 8-byte ***aligned***

Inspecting Structure Layout

```
#include <stdio.h>
#include <stddef.h>

typedef struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
} element;

int main() {
  element e;
  printf("%ld\n", (char *)&e.atom_no - (char *)&e);
  return 0;
}
```

Copy

Alignment Rules

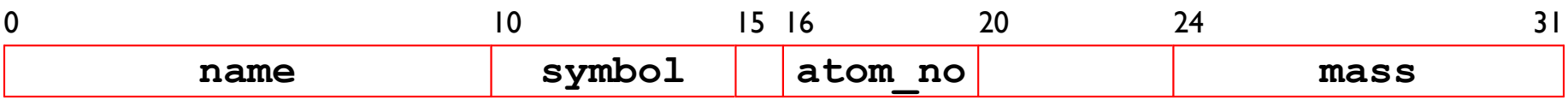
Why align?

- Load or store that spans quad-word boundaries is inefficient
- Virtual memory is trickier when a datum spans pages

Alignment Rules

Roughly, primitive data of size $N \Rightarrow$ align on N bytes

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};
```



Alignment Rules

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```
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  char   name[10];
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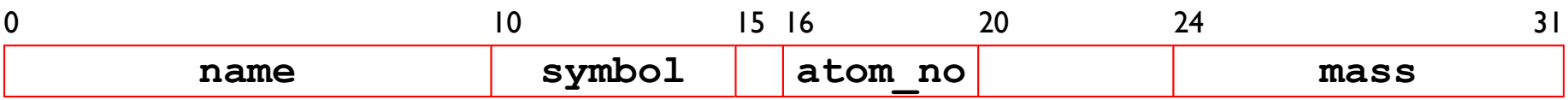
```



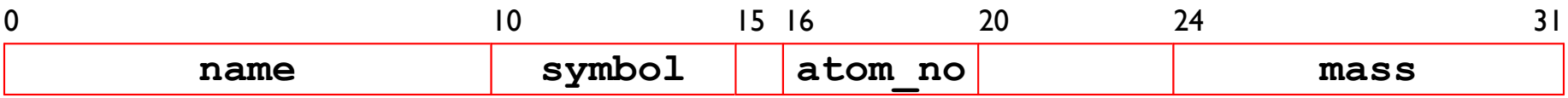
Required on some machines

Advised on x86-64

Alignment Rules

Pad struct size to multiple of largest alignment

```
struct element {
  char   name[10];
  char   symbol[5];
  int    atom_no;
  double mass;
};
```



Alignment Rules

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```
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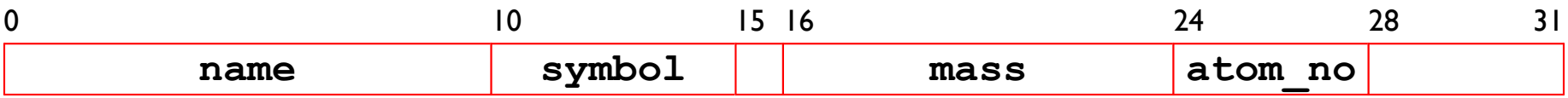

Alignment Rules

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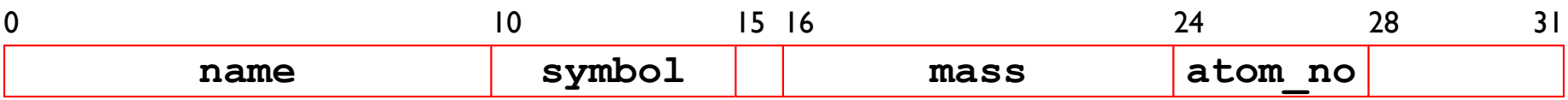
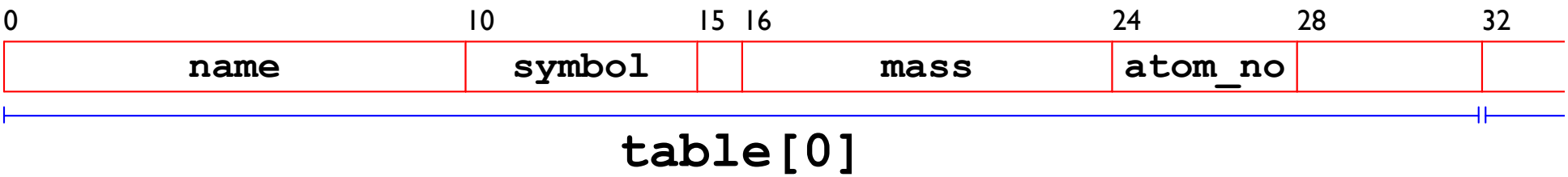
  int    atom_no;
};
```



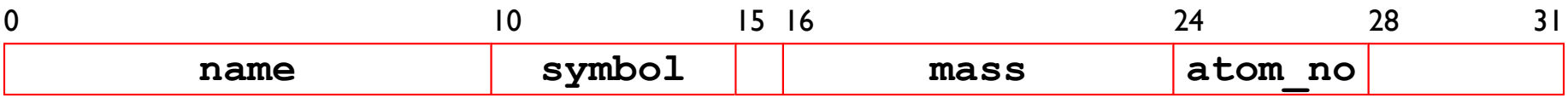

```
struct element table[2];
```



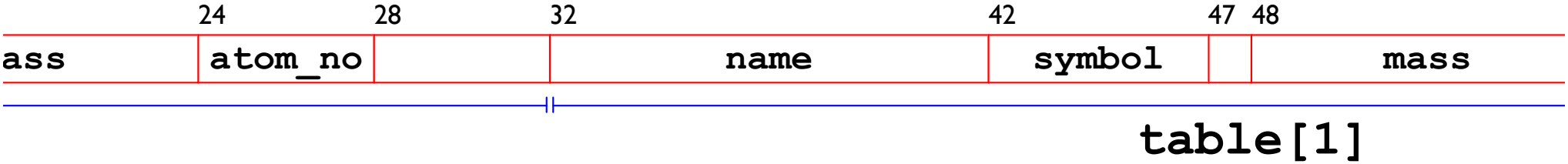
Alignment Rules

Pad struct size to multiple of largest alignment

```
struct element {
  char   name[10];
  char   symbol[5];
  double mass;
  int    atom_no;
};
```

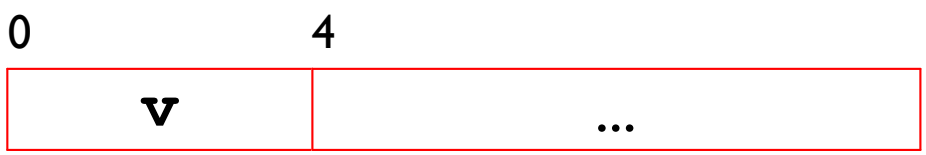


struct element table[2];



Linked Lists

```
struct int_list {
  int v;
  struct int_list next;
};
```



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struct int_list {
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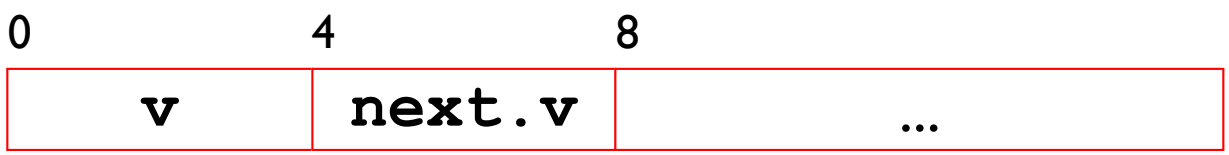
};
```



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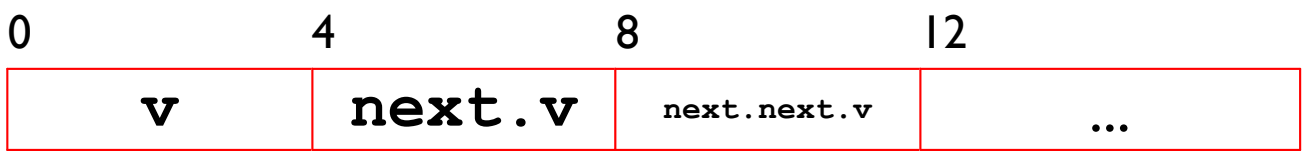

Linked Lists

```
struct int_list {
  int v;
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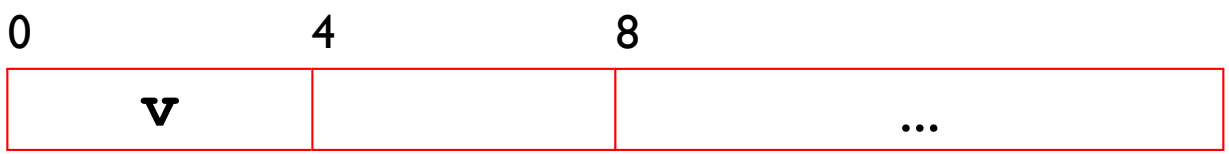
};
```



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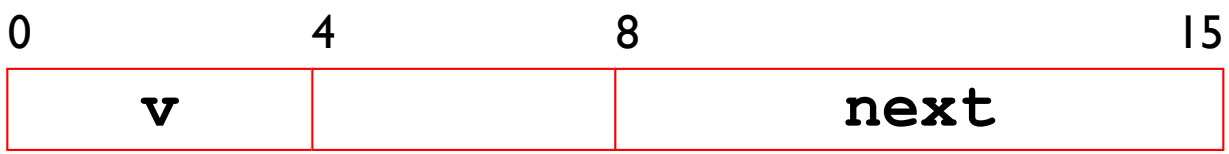

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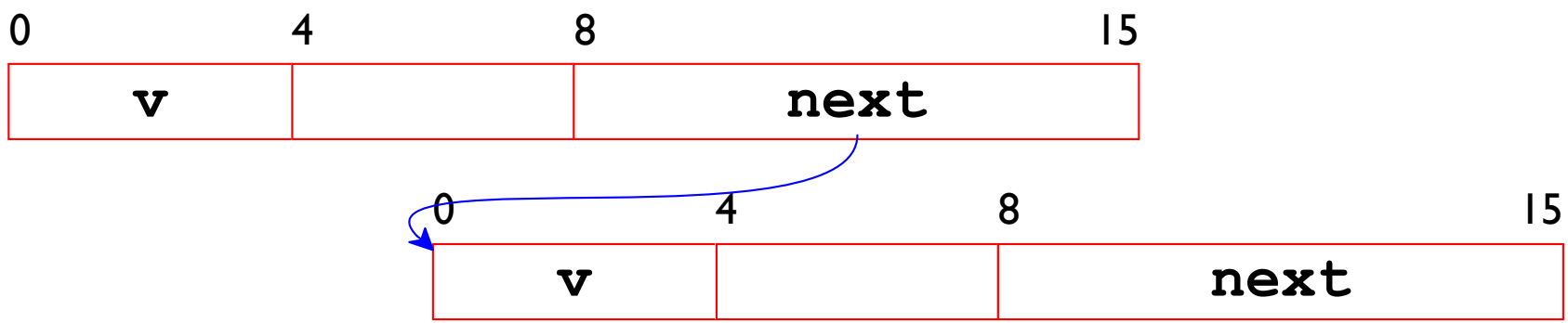

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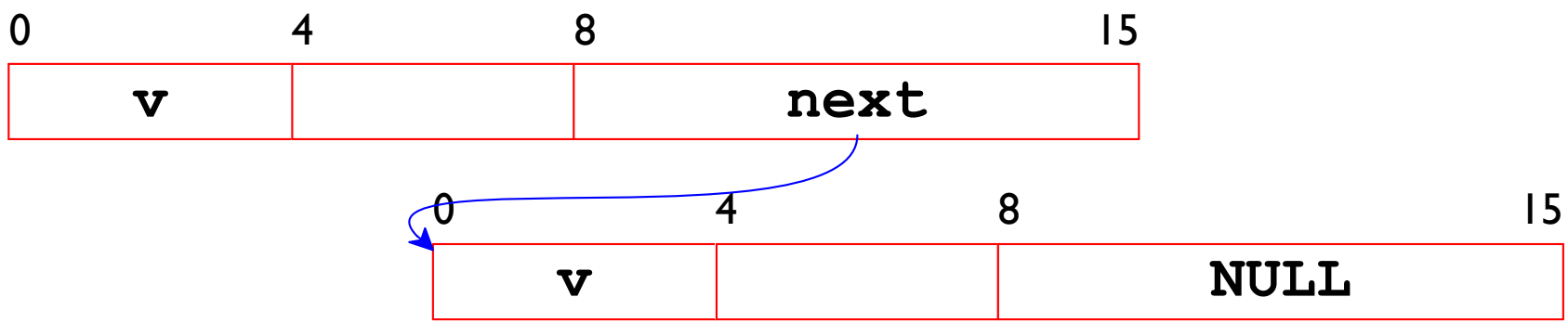

Example: Traversing a Linked List

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

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

Copy

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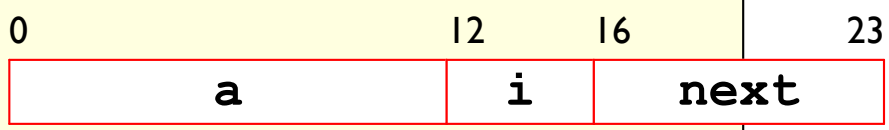

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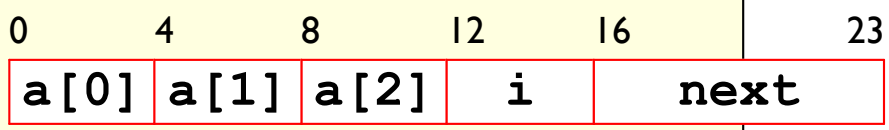

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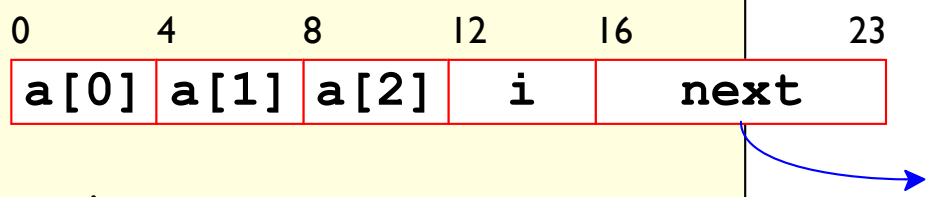



```
.L3:
  movslq  12(%rdi), %rax
  movl    %esi, (%rdi,%rax,4)
  movq    16(%rdi), %rdi
  testq   %rdi, %rdi
  jne     .L3
```

%rdi = **r**

%esi = **val**

loop:

i = M[**r**+12]

M[**r**+4×**i**] = **val**

r = M[**r**+16]

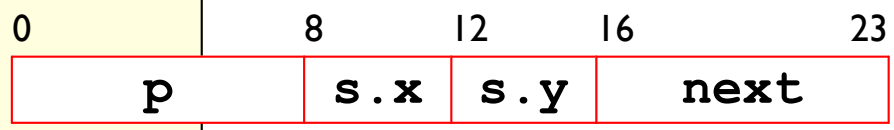
Test **r**

if **!NULL** goto **loop**

Exercise: Machine Code with Structs

```
struct prob {
  int* p;
  struct {
    int x;
    int y;
  } s;
  struct prob* next;
};

void sp_init(struct prob* sp) {
  sp->s.x = __;
  sp->p = __;
  sp->next = __;
}
```



%rdi = sp

```
movl 12(%rdi),%edx
movl %edx,8(%rdi)
leaq 8(%rdi),%rdx
movq %rdx,(%rdi)
movq %rdi,16(%rdi)
```

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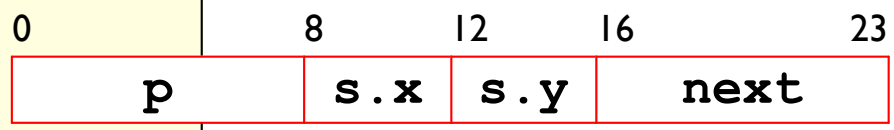

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void sp_init(struct prob* sp) {
  sp->s.x = sp->s.y;
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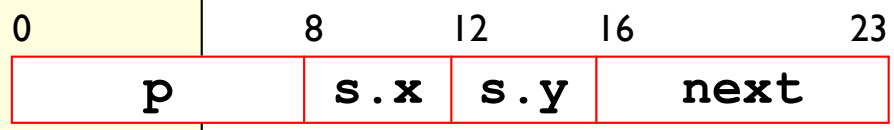
```



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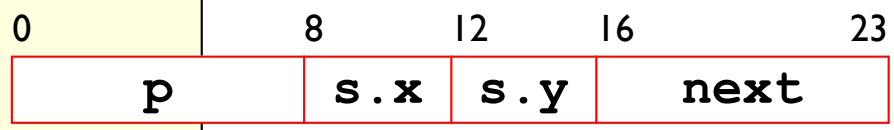

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```

C Unions

A **`struct`** is an *and* of field values:

```
/* a number *and* a string */
struct t_shirt {
  int   size;
  char *color;
};
```

C Unions

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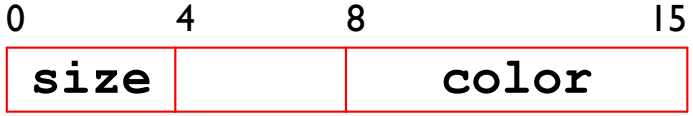

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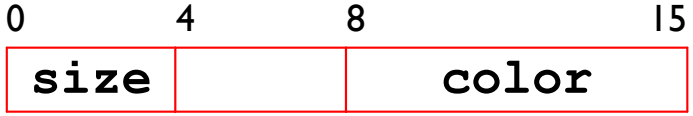

A **`union`** is an *or* of field values:

```
/* a number *or* a string */
union homework_result {
  int   grade;
  char *excuse;
};
```

C Unions

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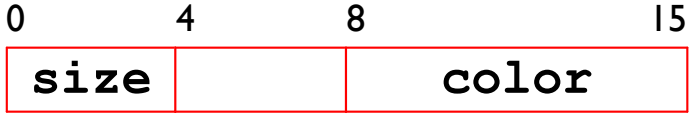

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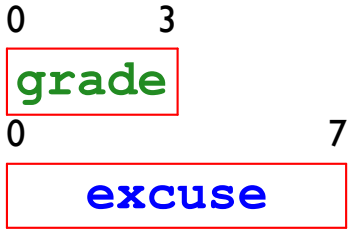

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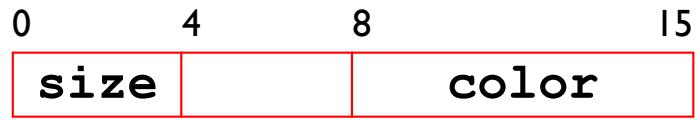

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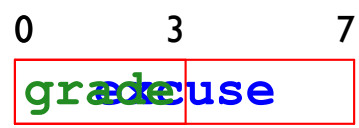

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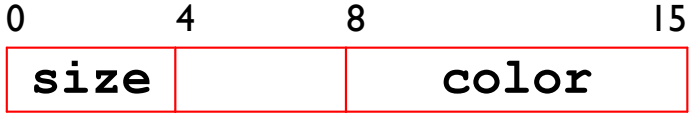

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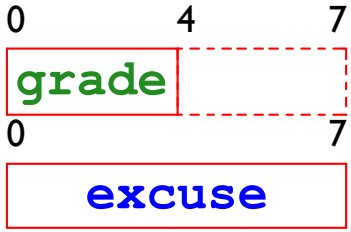

Setting Union Fields

```
#include <stdio.h>

union homework_result {
  int   grade;
  char *excuse;
};

void got_doctor_note(union homework_result *h) {
   h->excuse = "illness";
}

int main() {
   union homework_result h;

   h.grade = 0;
   got_doctor_note(&h);
   printf("%d\n", h.grade);

   return 0;
}
```

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Using Union Fields

Combine to combine **`union`** with **`struct`** field to select variant

```
struct homework_record {
  int graded;
  union homework_result r;
};

void got_doctor_note(struct homework_record *h) {
   h->graded = 0;
   h->r.excuse = "illness";
}

int main() {
   struct homework_record h;

   h.graded = 1;
   h.r.grade = 0;

   got_doctor_note(&h);

   if (h.graded)
     printf("%d\n", h.r.grade);
   else
     printf("%s\n", h.r.excuse);

   return 0;
}
```

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Using a Union to Reinterpret Bytes

```
#include <stdio.h>

union i_or_f {
  int i;
  float f;
};

int main() {
  union i_or_f v;
  v.i = 0x24400000;
  printf("%g\n", v.f);
  return 0;
}
```

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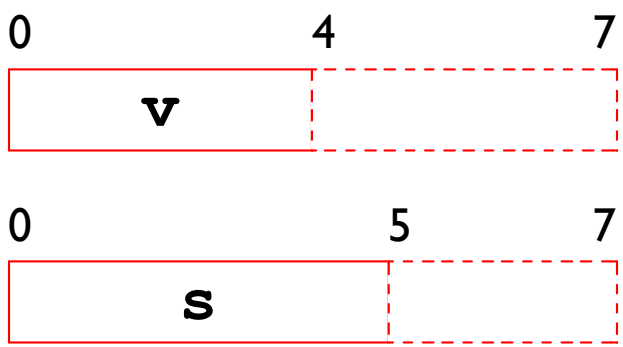
Union Alignment

Alignment is ≥ max field size and multiple of alignment

```
union u {
  float v;
  char  s[5];
}
```

`sizeof(union u)` is 8:



Controlling Struct Alignment

```
typedef struct step {
  char mode;
  double height;
} step_t;
```

Controlling Struct Alignment

```
/* select 1-byte alignment for everything */
#pragma pack(1)

typedef struct step {
  char mode;
  double height;
} step_t;

/* resume default alignments */
#pragma pack()
```