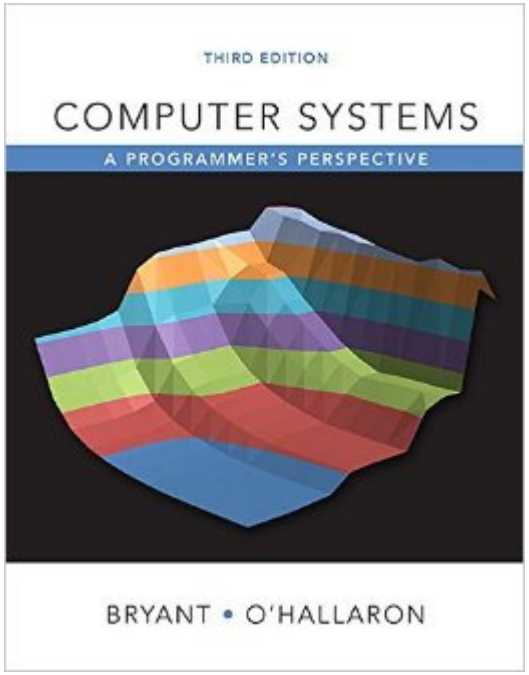
Computer Systems Principles

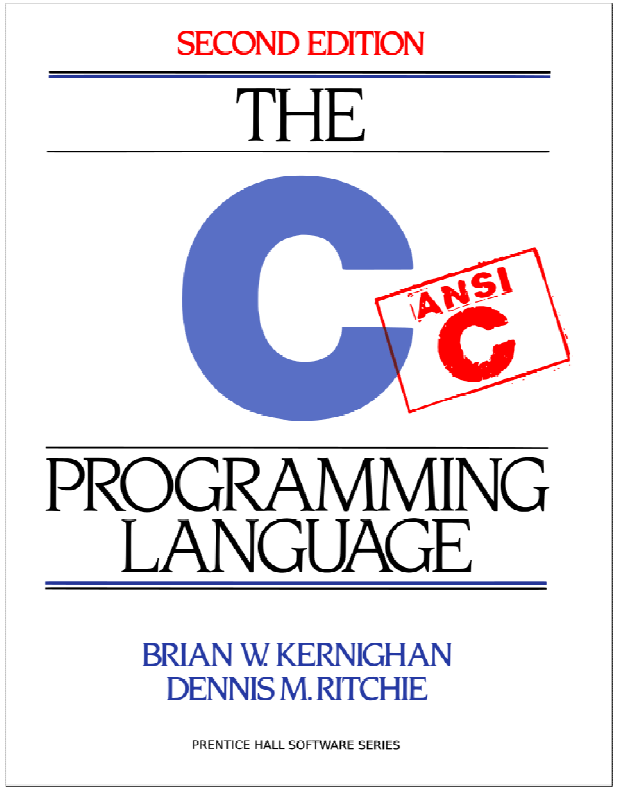
C Structures

UMASSCS
SCHOOL OF COMPUTER SCIENCE

Announcements

- Mid-term (Th, Feb 25) exam on paper, open book, close notes





Announcements

- Quiz 4 and HW3 are out

Learning Objectives

- To learn and apply C structures
- To understand a little about alignment
- To understand and apply C typedef

C Structures

- **Essential**
  - For building up interesting data structures
- **Definition**
  - A **C structure** is a collection of one or more variables, typically of different types, grouped together under a single name for convenient handling
  - Kind of like a Java class with public instance variables and no methods

C `struct`

- **Defines a new type**
  - A new kind of data type that the compiler regards as a unit or aggregate of variables/types.
- **Example:**

```
struct Date {
  int day;
  int month;
  int year;
};
```

C `struct`

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- **Example:**

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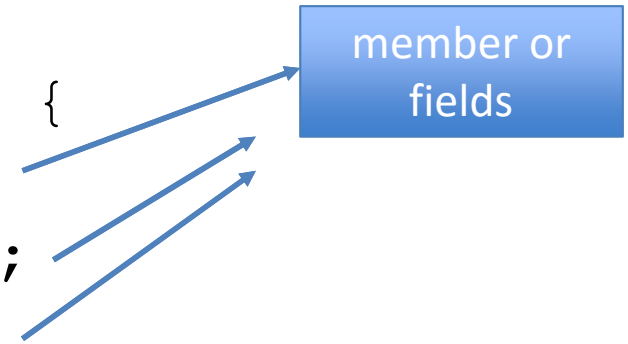

C `struct`

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  - A new kind of data type that the compiler regards as a unit or aggregate of variables/types.
- **Example:**

```
struct Date {
   int day;
   int month;
   int year;
};
```

A struct is named as a whole while individual members are named using field identifiers

More `struct` Examples

- **Examples:**

```
struct Date {
  int day;
  int month;
  int year;
};

struct Employee{
   char ename[20];
   int ssn;
   float salary;
   struct Date doj;
};
```

Members can be of different types (primitive, array, or struct)

More `struct` Examples

- **Examples:**

```
struct Date {
  int day;
  int month;
  int year;
};
```

struct Employee[3];

```
struct Employee{
   char ename[20];
   int ssn;
   float salary;
   struct Date doj;
};
```

Declaring a `struct` Variable

- Declaration of a variable of struct type:

  <struct type> <identifier list>;

- **Example:**

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};
struct StudentRecord student1;
```

Declaring a `struct` Variable

- Declaration of a variable of struct type:

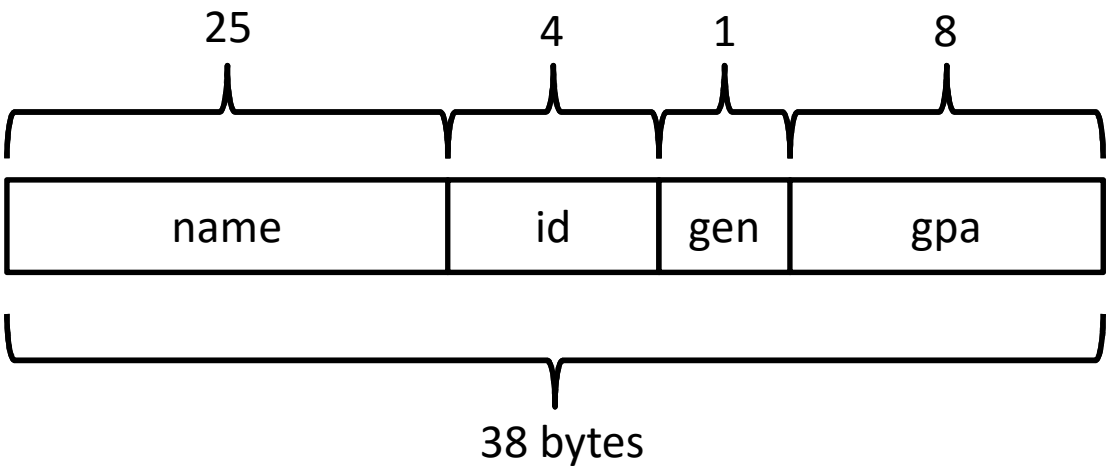
  <struct type> <identifier list>;

- **Example:**

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};
struct StudentRecord student1;
… = student1.name
student1.gpa = …
```

sizeof(struct StudentRecord)=?

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};
```



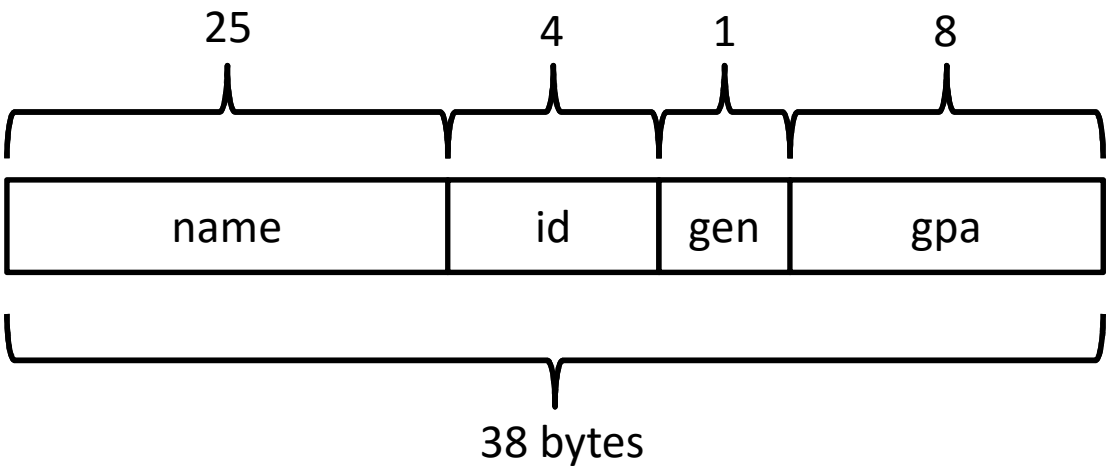
student-01.c example

- **Let us compile this example**
  - What did you notice about the output of this program?
  - Is the size of this struct the same as we predicted?
  - Why is this or is this not the case?

student-01.c example

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};
```

sizeof(struct StudentRecord) = 48



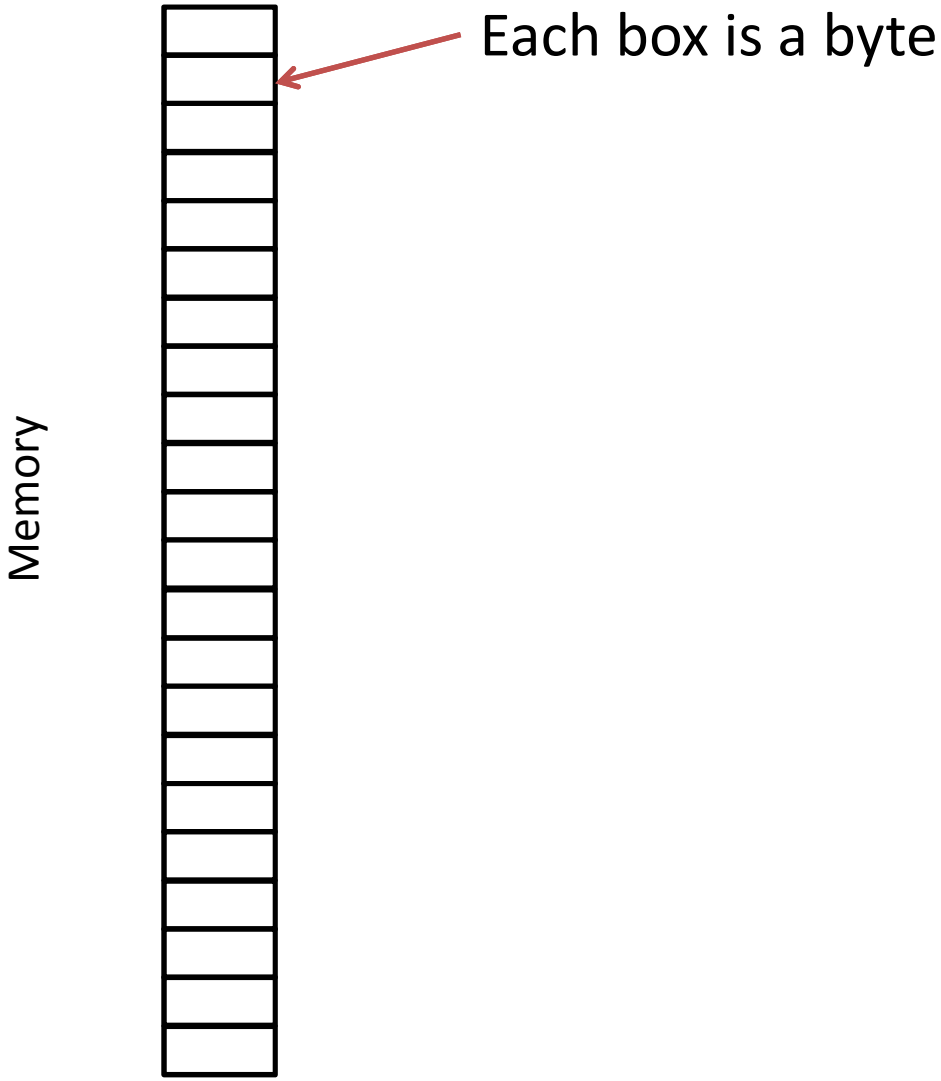
Data Allocation and Alignment

- **Data Allocation**
  - Each variable definition is allocated bytes in memory according the type of that variable
  - e.g., char = 1 byte, int = 4 bytes, double = 8 bytes
  - This is allocated in a special place in memory known as the **stack**.
- **Data Alignment**
  - Alignment helps the memory store data in a structured manner
    - e.g. 2-byte shorts must start on an even address
  - Machines are more efficient if allocated data is accessed in a structured manner

Data Alignment

- All types except char doesn’t normally start at an arbitrary address.
- A 1-byte char can start on any byte address
- A 2-byte short must start on an even address
- A 4-byte int/float must start on an address divisible by 4
- A 8-byte long/double must start on address divisible by 8

Alignment in Memory



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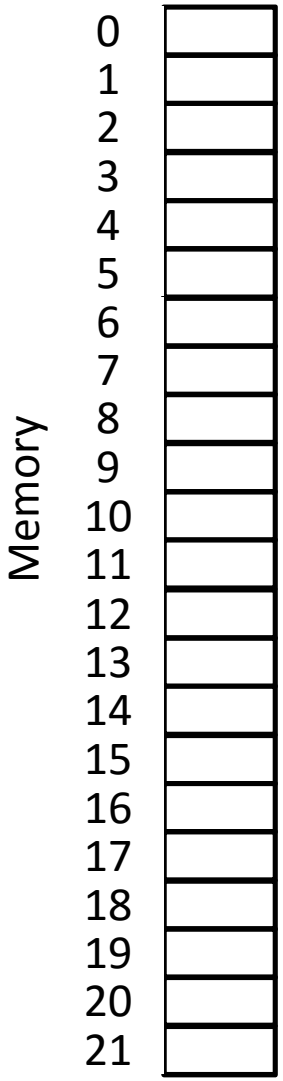
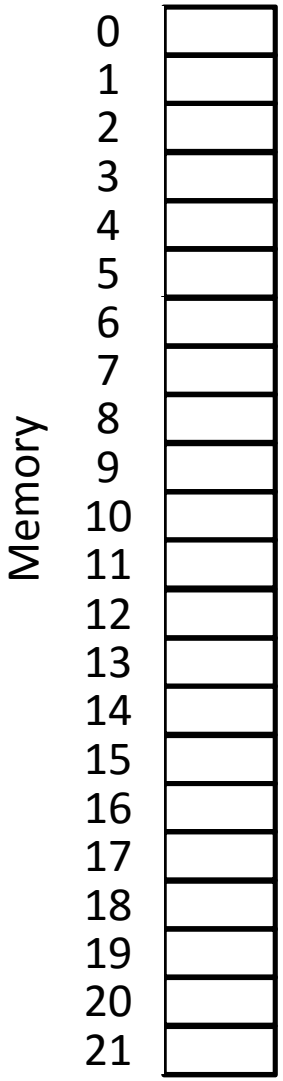


Each box is a byte
and has a location.

Memory is very much like a a giant character array!

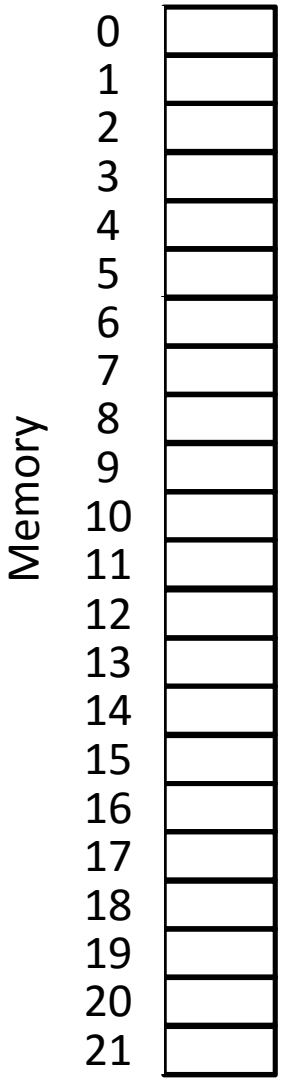
Alignment in Memory



So, how do we allocate memory for the variable declarations below?

```
long a;
char b;
int c;
```

Alignment in Memory



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```
long a;
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8 + 1 + 4 = 13 bytes ??

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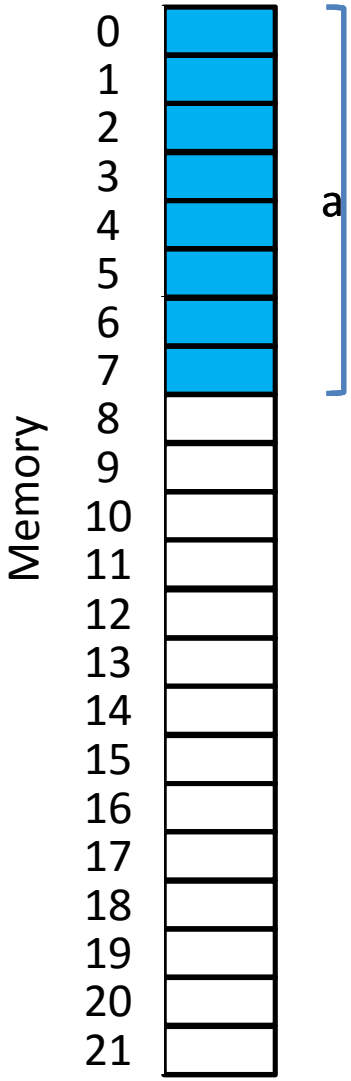

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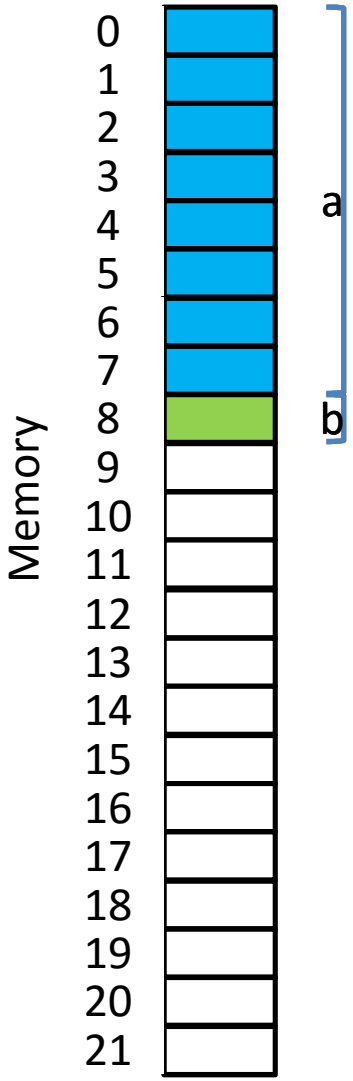

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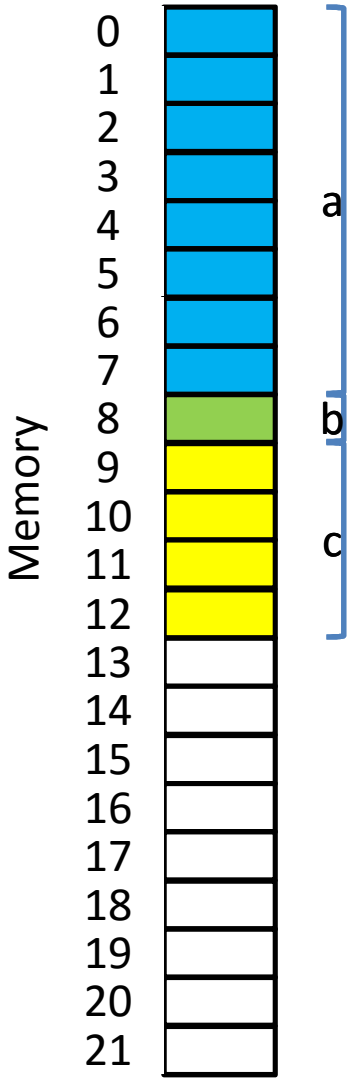

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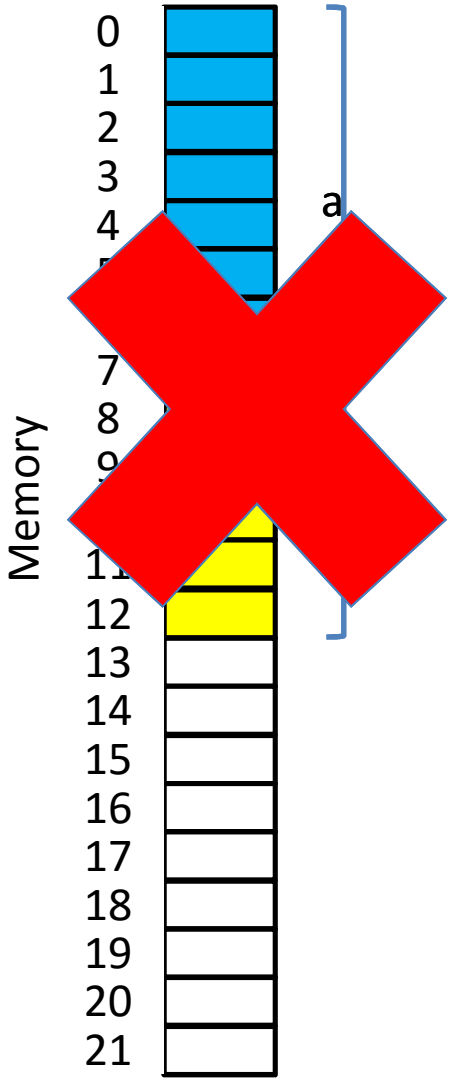

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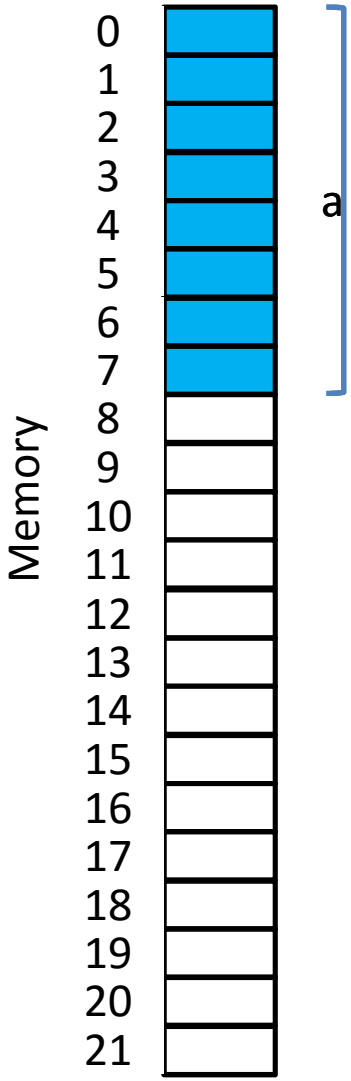

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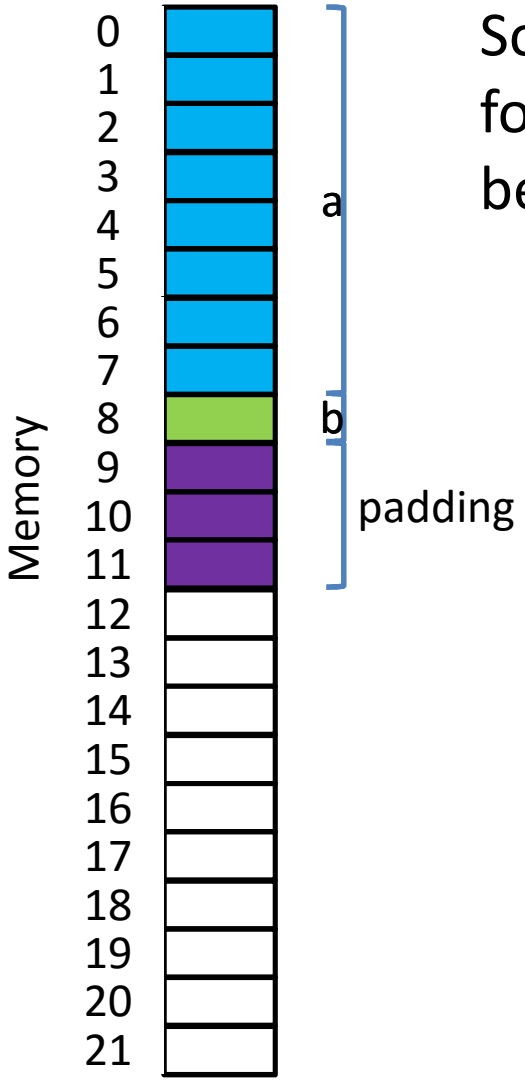

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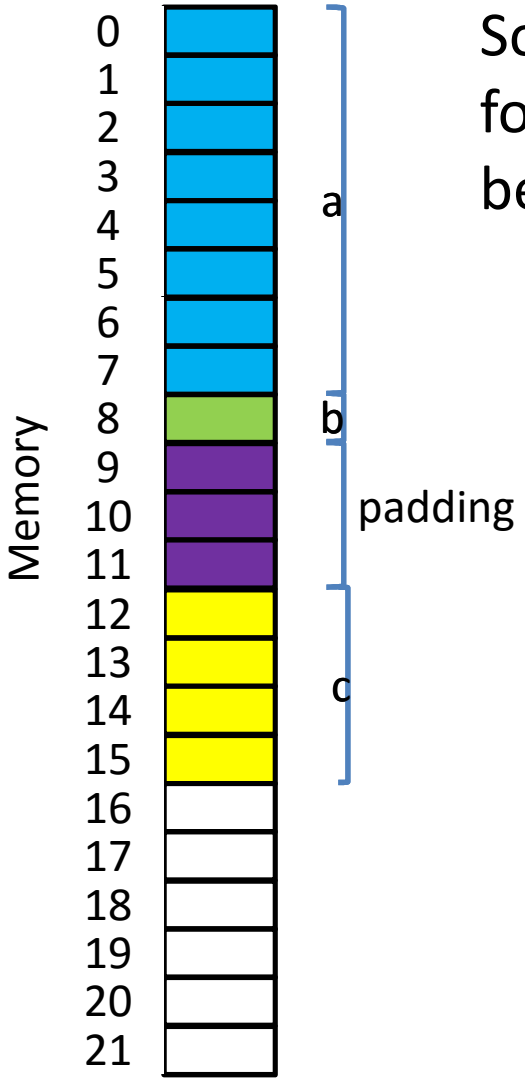
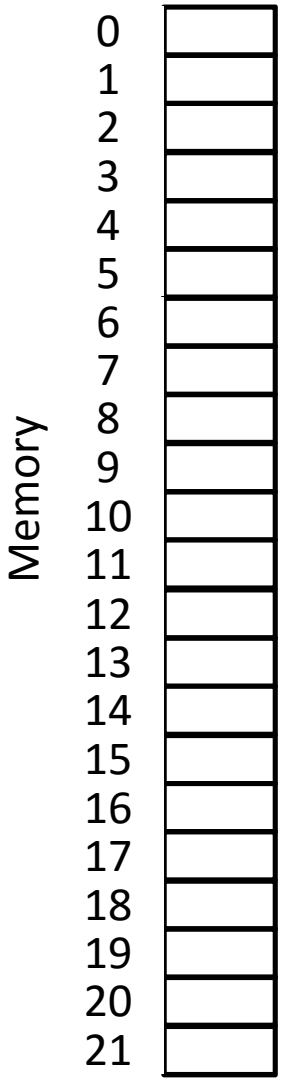


So, how do we allocate memory for the variable declarations below?

```
long a;
char b;
int c;
```

8 + 1 + 3+ 4 = 16 bytes

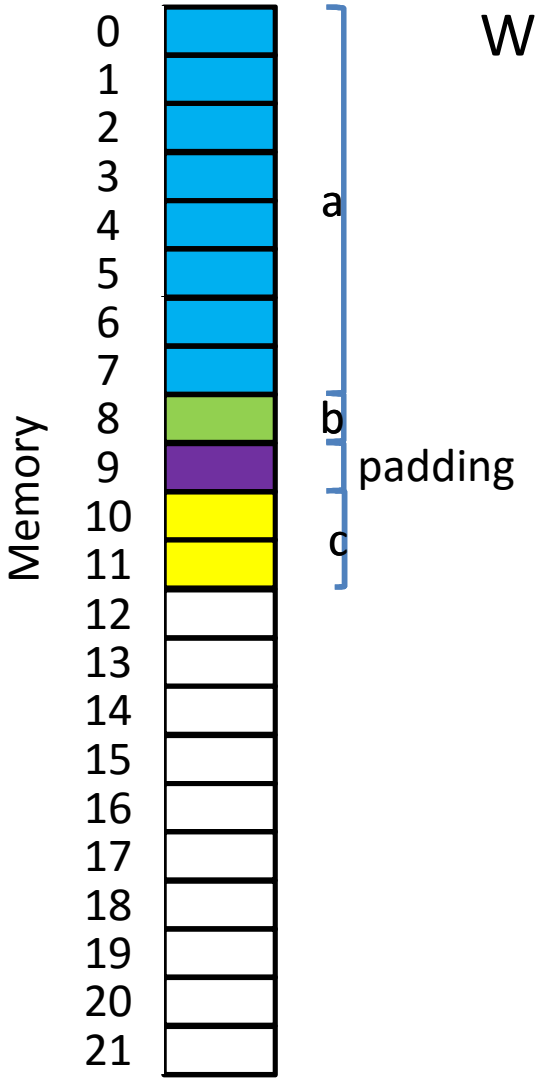
Alignment in Memory



What if c is a 2-byte short?

```
long a;
char b;
short c;
```

Alignment in Memory

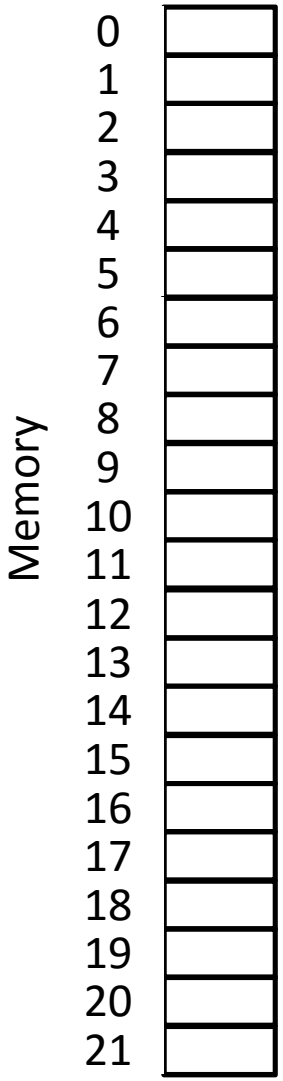


What if c is a 2-byte short?

```
long a;
char b;
short c;
```

8 + 1 + 1+ 2 = 12 bytes

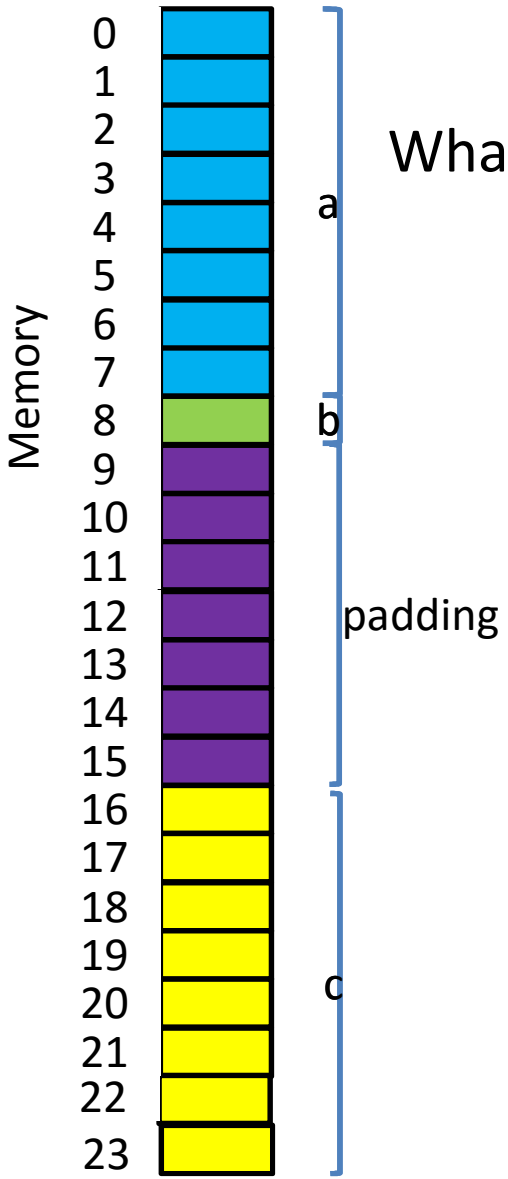
Alignment in Memory



What if c is a 8-byte long?

```
long a;
char b;
long c;
```

Alignment in Memory



What if c is a 8-byte long?

```
long a;
char b;
long c;
```

8 + 1 + 7+ 8 = 24 bytes

i-clicker question

What is the size of padding in bytes between a and c on a 64-bit machine?

```
char b;
long a;
int c;
```

A. 0
B. 1
C. 2
D. 3

i-clicker question

What is the size of padding in bytes between b and a on a 64-bit machine??

```
char b;
long a;
int c;
```

A. 0
B. Determined by the address of b
C. 7
D. 3

Reduce memory size

- We can reduce used memory size by reorder declaration statements

```
char b;
long a;
int c;
```

→

```
long a;
int c;
char b;
```

1 + 8 + 4 + ? = 13 + ?
bytes

8 + 4 + 1 = 13
bytes

Alignment in Memory

- There is ***no*** internal padding within a primitive type array
- But **there can be** internal padding within a struct
- **There can be** internal padding within struct array.

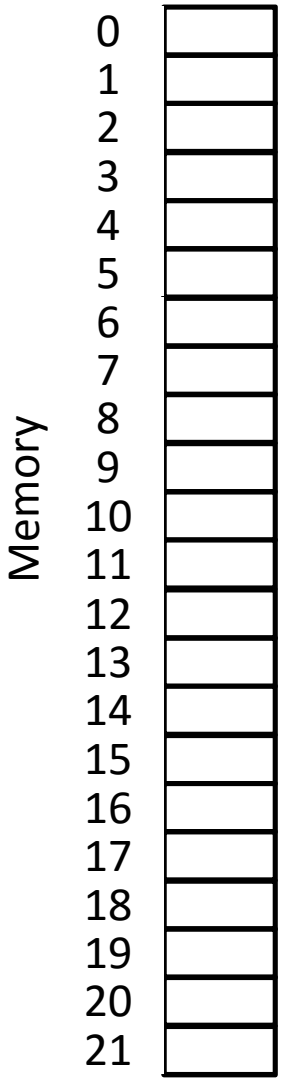
Structure alignment

- Structure alignment requirements:
  - Within a struct, each member has different alignment requirements.
  - The structure as a whole has the alignment of its widest scalar member

Structure alignment

- Structure alignment requirements:
  - Within a struct, each member has different alignment requirements.
  - The structure as a whole have the alignment of its widest scalar member
- Find memory layout
  - Step 1: Align each member as if these member has been separately declared
  - Step 2: Pad at the end so the structure has the alignment of its widest scalar member

Structure alignment



What's the memory layout of struct foo?

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struct foo {
  long a;
  char b;
  int c;
};
```
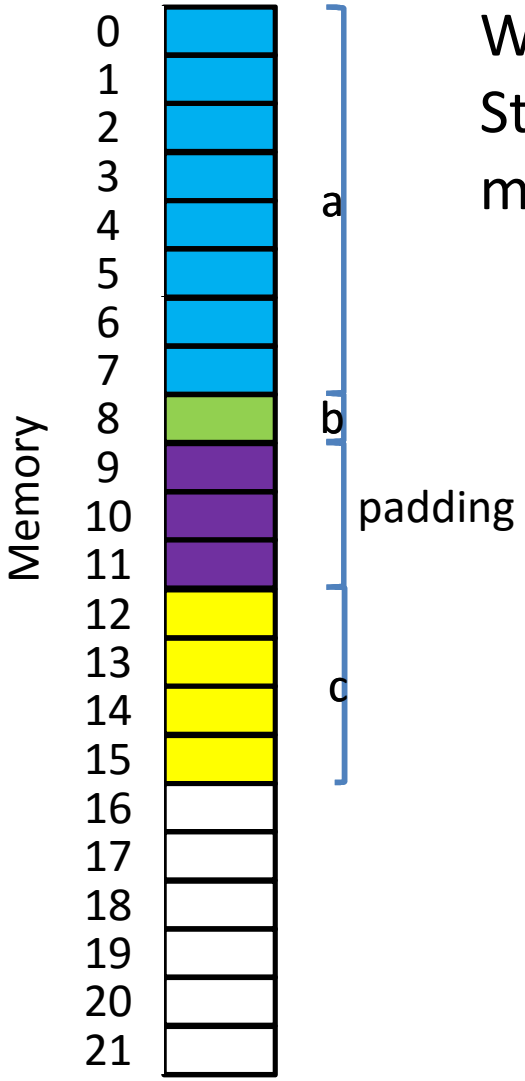

Structure alignment



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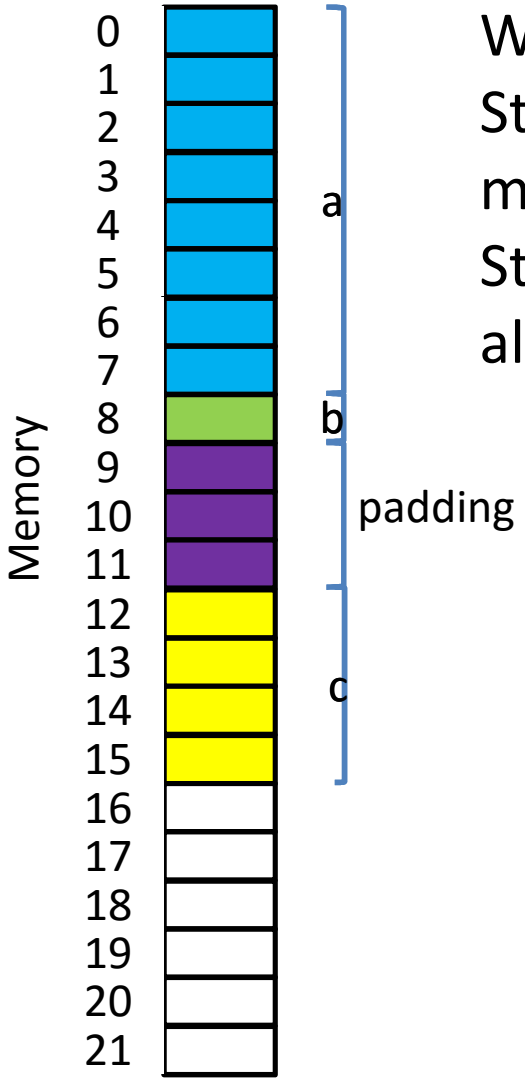

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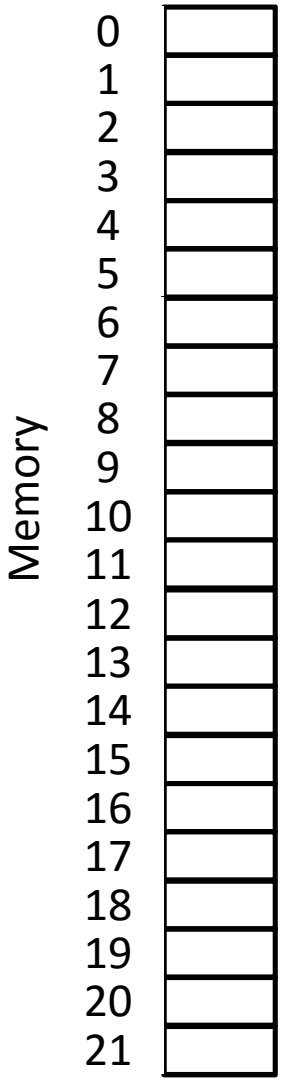
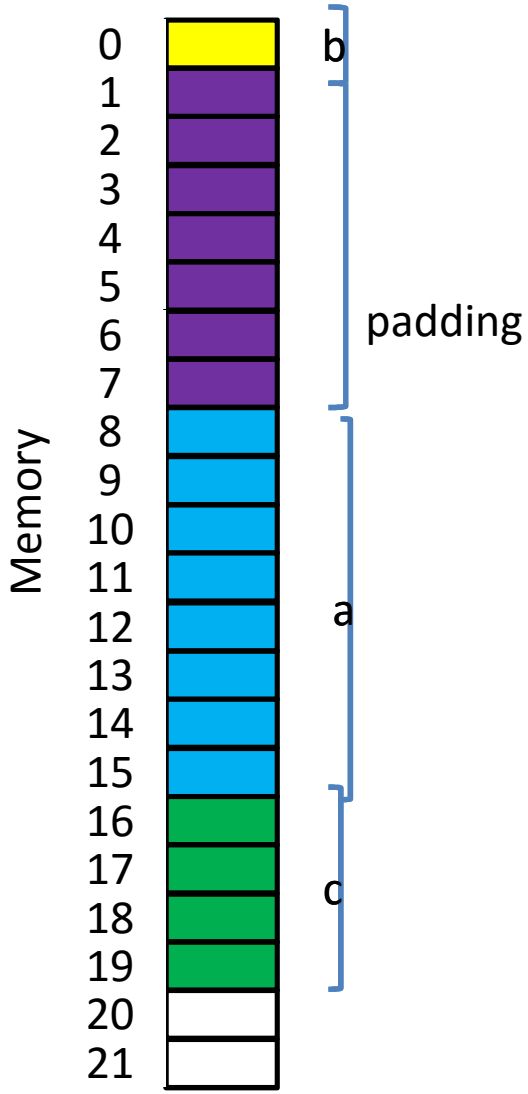
Structure alignment



What's the memory layout of struct bar?

```
struct bar{
  char b;
  long a;
  int c;
};
```

Structure alignment



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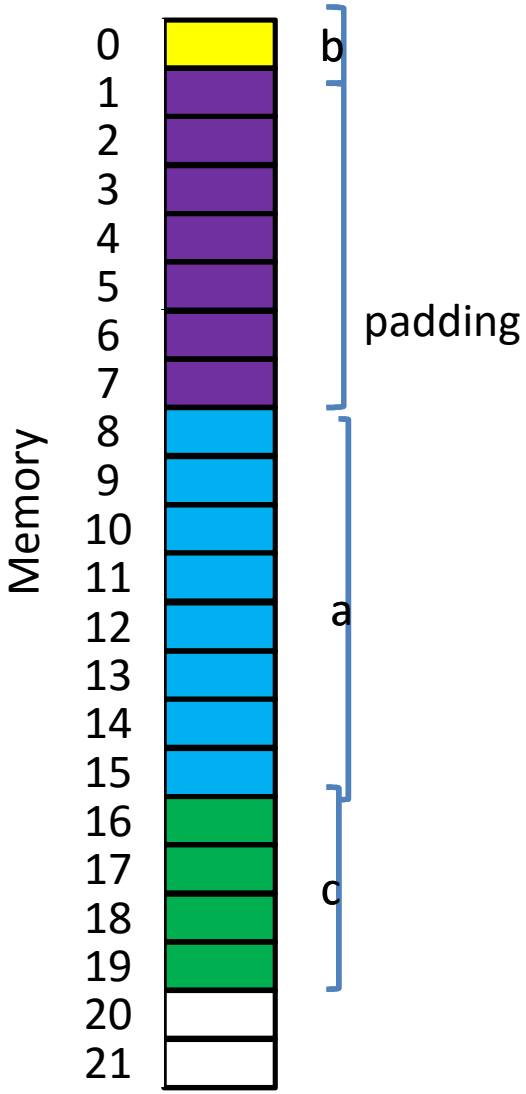

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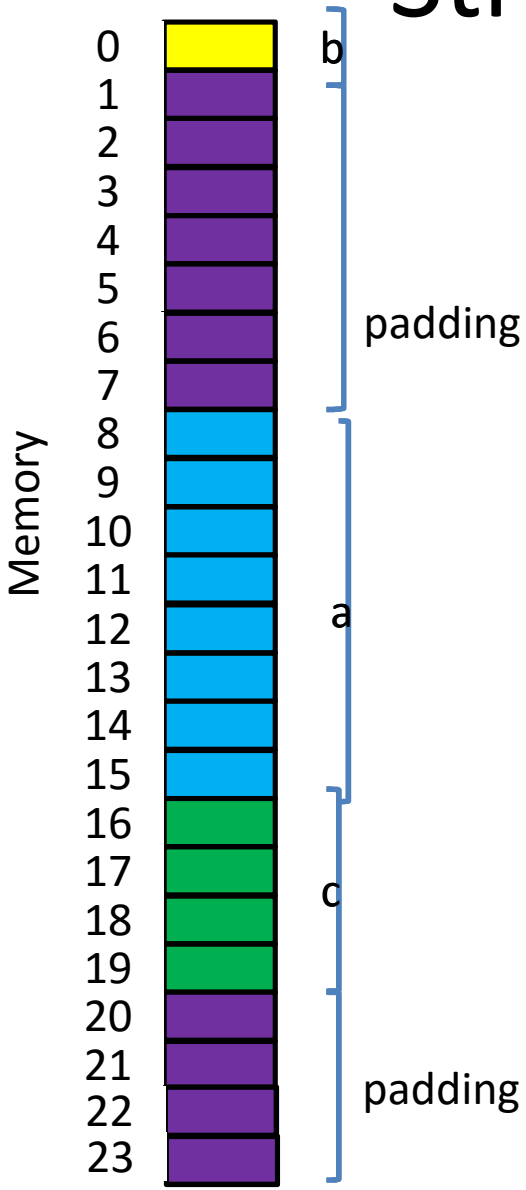

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```
struct bar{
  char b;
  long a;
  int c;
};
```

i-clicker question

What is the size of the following structure on a 64-bit machine?

```
struct baz {
 long a;
 char c;
};
```

A. 9
B. 24
C. 20
D. 16

i-clicker question

What is the size of the following structure on a 64-bit machine?

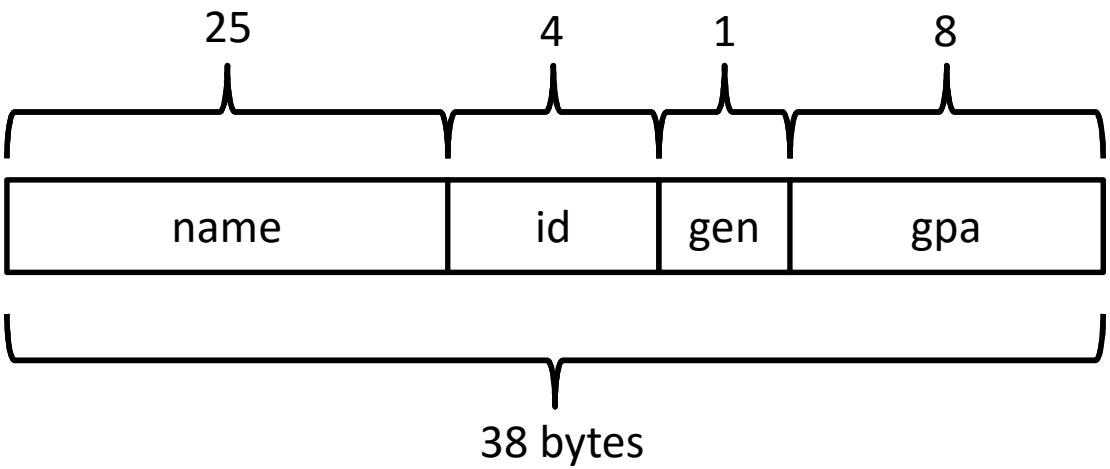
```
struct qux {
 char a;
 char b;
 char c;
 char d;
 char e;
};
```

A. 10
B. 20
C. 5
D. 8

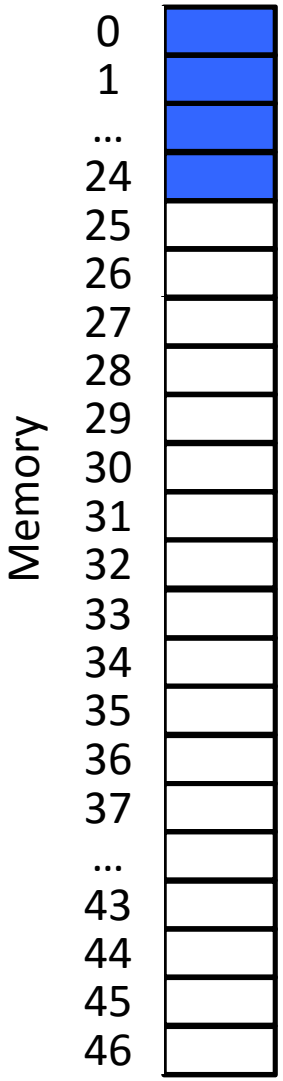
student-01.c example

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};
```

sizeof(struct StudentRecord) = 48



Alignment in Memory



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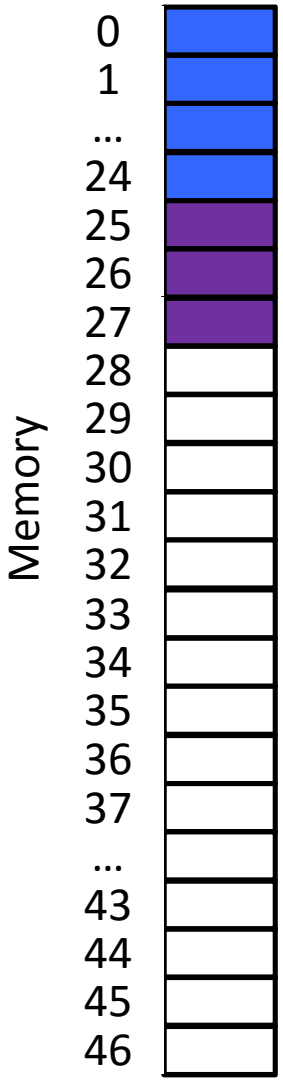
struct StudentRecord student1;
```

Alignment in Memory



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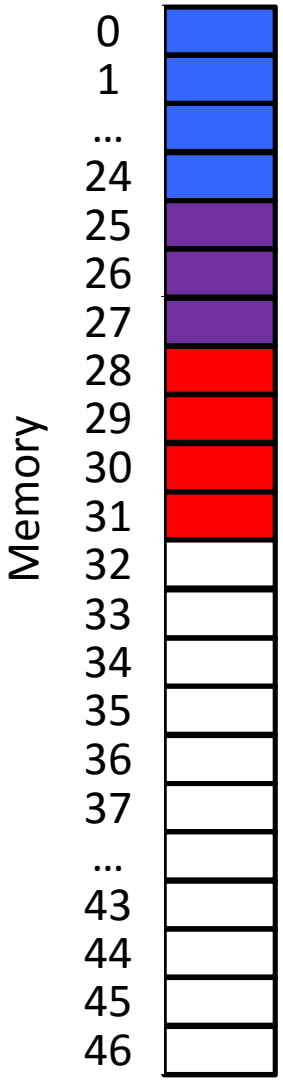

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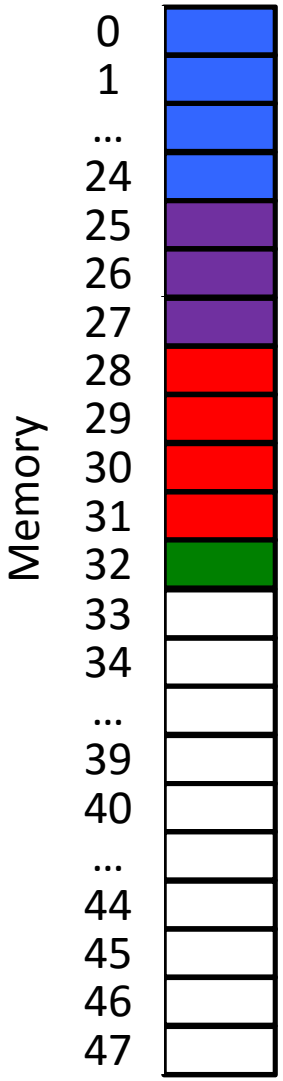

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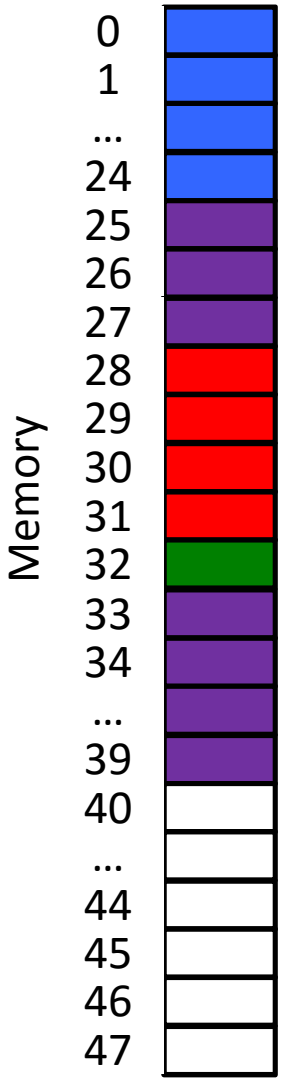

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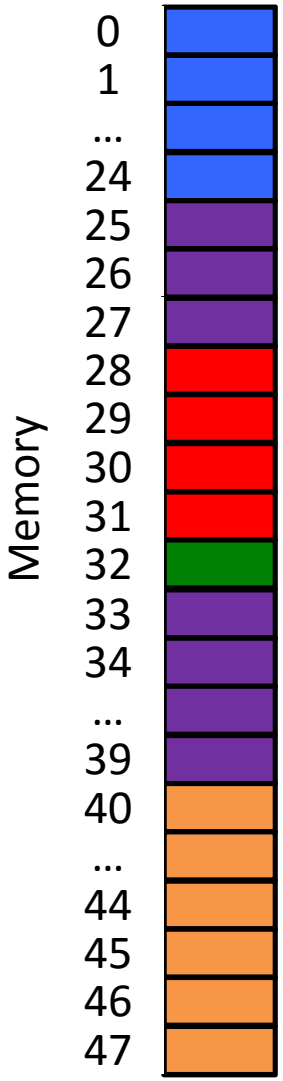

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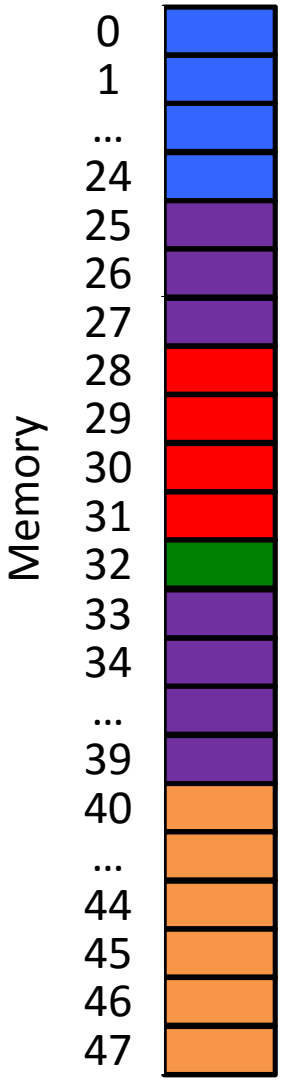

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```
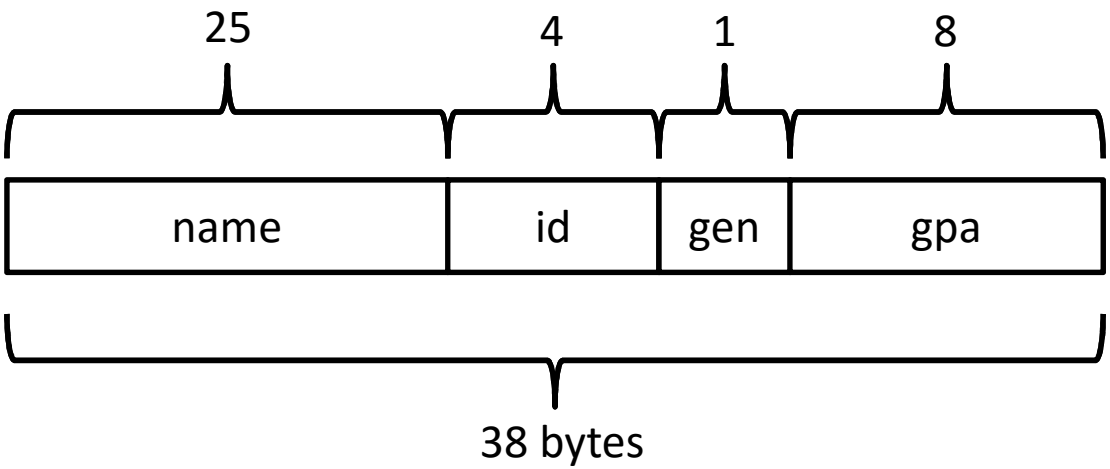

sizeof(struct StudentRecord) = 48



student-01_offsetof.c

- Explore the memory layout of a struct by yourself:
  - offsetof (type,member)

Structure Initialization

- **There are four ways to initialize a struct**
  - Positional initialization
  - Named initialization
  - Copy initialization
  - Initialize individual fields

Positional Initialization

Positional initialization allows you to provide the values for each of the fields based on the position of each structure member:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1 = {
  “John Doe”, 1234567, ‘M’, 3.95
};
```

Not a recommended way!

Positional Initialization

Positional initialization allows you to provide the values for each of the fields based on the position of each structure member:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1 = {
  “John Doe”, 1234567, ‘M’, 3.95
};
```

Not a recommended way!

Named Initialization

Named initialization allows you to provide the values for each of the fields based on the name of each structure member:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1 = {
  .id      = 1234567,
  .gpa     = 3.95,
  .gender  = 'M',
  .name= "Harry Potter"
};
```

Copy Initialization

Copy initialization allows you to initialize a structure by assigning an existing structure:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1 = {
  .id          = 1234567,
  .gpa     = 3.95,
  .gender  = 'M',
  .name = "Harry Potter"
};

struct StudentRecord student2 = student1;
```

Field Initialization

Field initialization allows you to initialize a structure by assigning to its fields:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1;

student1.id          = 1234567;
student1.gender      = 'M';
student1.gpa         = 3.95;
```

Field Initialization

Field initialization allows you to initialize a structure by assigning to its fields:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1;

student1.id          = 1234567;
student1.gender      = 'M';
student1.gpa         = 3.95;
student1.name     = "Harry Potter";
```

What about this one?

student-05.c example

- **Let us compile this example**
  - What problems do we encounter with this example?
  - Why can't we assign a string to a character array?
    - Arrays are not modifiable values, that is, you can't reassign them to "point" to different locations in memory.

Field Initialization

Field initialization allows you to initialize a structure by assigning to its fields:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1;

student1.id          = 1234567;
student1.gender      = 'M';
student1.gpa         = 3.95;
student1.name     = "Harry Potter";
```

So, how do we fix this?

strncpy

- **Copying Strings**
  - #include <string.h>
    A library for manipulating C strings

  - To assign a new string value to a C string (e.g., character array) you must use the *strncpy* function to **copy** the bytes into the array.

Field Initialization

Field initialization allows you to initialize a structure by assigning to its fields:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1;

student1.id          = 1234567;
student1.gender      = 'M';
student1.gpa         = 3.95;
strncpy(student1.name, "Harry Potter", 25);
```

Size of the *destination*

We use the strncpy function!

Field Initialization

Field initialization allows you to initialize a structure by assigning to its fields:

```
struct StudentRecord {
  char name[25];
  int id;
  char gender;
  double gpa;
};

struct StudentRecord student1;

student1.id          = 1234567;
student1.gender      = 'M';
student1.gpa         = 3.95;
strncpy(student1.name, "Harry Potter", 25);
```

Be careful about strncpy because of buffer overflow!

Size of the *destination*

We use the strncpy function!

strlen

- **Calculate the length of a string**
  - #include <string.h>
    A library for manipulating C strings
  - Return an unsigned integer
  - Example:
    - strlen("Revenant") == 8

Buffer overflow example

```
void f(char[] bar)
{
    char c[12];
    strncpy(c, bar, strlen(bar));
}
```