Data Structures in Memory!

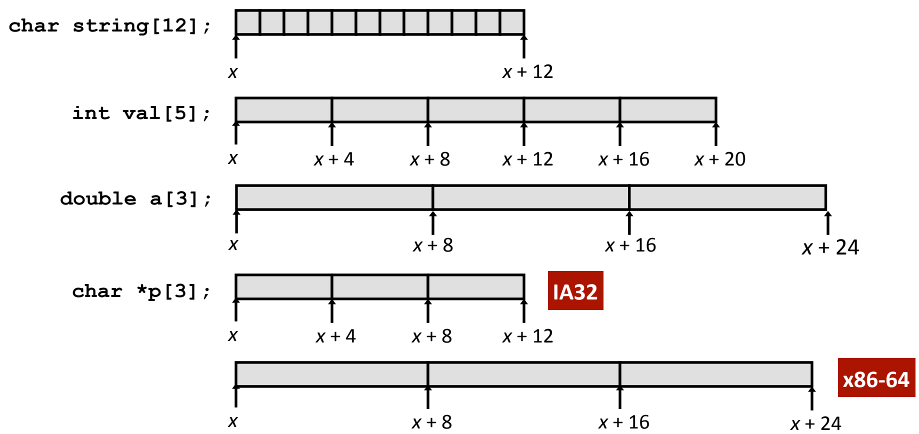
- **Arrays**
  - One-dimensional
  - Multi-dimensional (nested)
  - Multi-level
- **Structs**
  - Alignment
- **Unions**

Data Structures in Assembly…

- **Arrays?**
- **Strings?**
- **Structs?**

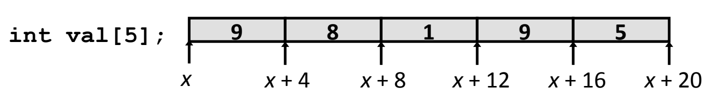
Array Allocation

- **Basic Principle**
  - T A[N];
  - Array of data type T and length N
  - Contiguously allocated region of N * sizeof(T) bytes



Array Access

- **Basic Principle**
  - T A[N];
  - Array of data type T and length N
  - Identifier A can be used as a pointer to array element 0: Type T*

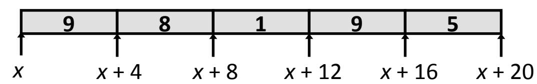


- **Reference Type Value**
  - val[4] int
  - val int *
  - val+1 int *
  - &val[2] int *
  - val[5] int
  - *(val+1) int
  - val + i int *

Array Access

- **Basic Principle**
  - T A[N];
  - Array of data type T and length N
  - Identifier A can be used as a pointer to array element 0: Type T*

```
int val[5];
```



Reference	Type	Value
val[4]	int	5
val	int *	x
val+1	int *	x + 4
&val[2]	int *	x + 8
val[5]	int	??
*(val+1)	int	8
val + i	int *	x + 4 i

Array Example

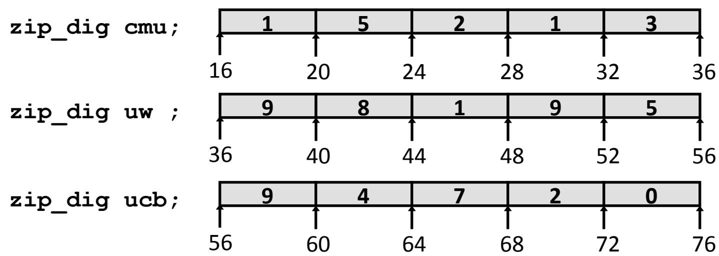
```
typedef int zip_dig[5];

zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig uw  = { 9, 8, 1, 9, 5 };
zip_dig ucb = { 9, 4, 7, 2, 0 };
```

Array Example

```
typedef int zip_dig[5];

zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig uw  = { 9, 8, 1, 9, 5 };
zip_dig ucb = { 9, 4, 7, 2, 0 };
```



- Declaration “`zip_dig uw`” equivalent to “`int uw[5]`”
- Example arrays were allocated in successive 20 byte blocks
  - Not guaranteed to happen in general

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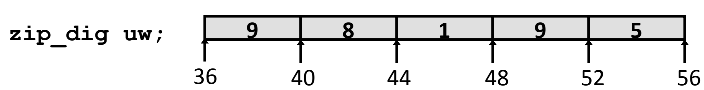
Array Accessing Example




```
int get_digit
  (zip_dig z, int dig)
{
  return z[dig];
}
```

IA32

```
# %edx = z
# %eax = dig
movl (%edx,%eax,4),%eax  # z[dig]
```

- Register `%edx` contains starting address of array
- Register `%eax` contains array index
- Desired digit at `4*%eax + %edx`
- Use memory reference `(%edx,%eax,4)`

Referencing Examples

`zip_dig cmu;`

1	5	2	1	3	
16	20	24	28	32	36

`zip_dig uw ;`

9	8	1	9	5	
36	40	44	48	52	56

`zip_dig ucb;`

9	4	7	2	0	
56	60	64	68	72	76

- **Reference** **Address** **Value** **Guaranteed?**

  `uw[3]`
  `uw[6]`
  `uw[-1]`
  `cmu[15]`

  What are these values?

Referencing Examples

`zip_dig cmu;`

1	5	2	1	3	
16	20	24	28	32	36

`zip_dig uw ;`

9	8	1	9	5	
36	40	44	48	52	56

`zip_dig ucb;`

9	4	7	2	0	
56	60	64	68	72	76

- **Reference**

Reference	Address	Value	Guaranteed?
`uw[3]`	`36 + 4* 3 = 48`	`9`	
`uw[6]`	`36 + 4* 6 = 60`	`4`	
`uw[-1]`	`36 + 4*-1 = 32`	`3`	
`cmu[15]`	`16 + 4*15 = 76`	`??`	

  - No bound checking
  - Out-of-range behavior implementation-dependent
  - No guaranteed relative allocation of different arrays

Referencing Examples

`zip_dig cmu;`

1	5	2	1	3	
16	20	24	28	32	36

`zip_dig uw ;`

9	8	1	9	5	
36	40	44	48	52	56

`zip_dig ucb;`

9	4	7	2	0	
56	60	64	68	72	76

Reference	Address	Value	Guaranteed?
`uw[3]`	`36 + 4* 3 = 48`	`9`	Yes
`uw[6]`	`36 + 4* 6 = 60`	`4`	No
`uw[-1]`	`36 + 4*-1 = 32`	`3`	No
`cmu[15]`	`16 + 4*15 = 76`	`??`	No

- No bound checking
- Out-of-range behavior implementation-dependent
- No guaranteed relative allocation of different arrays

Array Loop Example

```
int zd2int(zip_dig z)
{
  int i;
  int zi = 0;
  for (i = 0; i < 5; i++) {
    zi = 10 * zi + z[i];
  }
  return zi;
}
```

Array Loop Example

- **Original**

```
int zd2int(zip_dig z)
{
  int i;
  int zi = 0;
  for (i = 0; i < 5; i++) {
    zi = 10 * zi + z[i];
  }
  return zi;
}
```

- **Transformed**
  - Eliminate loop variable i
  - Convert array code to pointer code
  - Express in do-while form (no test at entrance)

```
int zd2int(zip_dig z)
{
  int zi = 0;
  int *zend = z + 4;
  do {
    zi = 10 * zi + *z;
    z++;
  } while (z <= zend);
  return zi;
}
```


Array Loop Implementation (IA32)

```
int zd2int(zip_dig z)
{
  int zi = 0;
  int *zend = z + 4;
  do {
    zi = 10 * zi + *z;
    z++;
  } while(z <= zend);
  return zi;
}
```

```
  # %ecx = z
  xorl %eax,%eax
  leal 16(%ecx),%ebx
.L59:
  leal (%eax,%eax,4),%edx
  movl (%ecx),%eax
  addl $4,%ecx
  leal (%eax,%edx,2),%eax
  cmpl %ebx,%ecx
  jle .L59
```

Translation?

Array Loop Implementation (IA32)

- **Registers**
  `%ecx  z`
  `%eax  zi`
  `%ebx  zend`
- **Computations**
  - `10*zi + *z` implemented as `*z + 2*(zi+4*zi)`
  - `z++` increments by 4

```
int zd2int(zip_dig z)
{
  int zi = 0;
  int *zend = z + 4;
  do {
    zi = 10 * zi + *z;
    z++;
  } while(z <= zend);
  return zi;
}
```

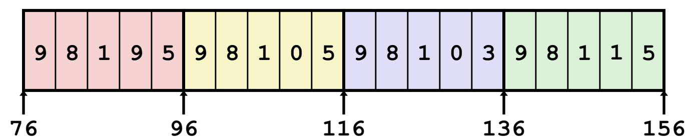
```
  # %ecx = z
  xorl %eax,%eax             # zi = 0
  leal 16(%ecx),%ebx         # zend  = z+4
.L59:
  leal (%eax,%eax,4),%edx  # 5*zi
  movl (%ecx),%eax           # *z
  addl $4,%ecx               # z++
  leal (%eax,%edx,2),%eax  # zi = *z + 2*(5*zi)
  cmpl %ebx,%ecx             # z : zend
  jle .L59                   # if <= goto loop
```


Nested Array Example

```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```

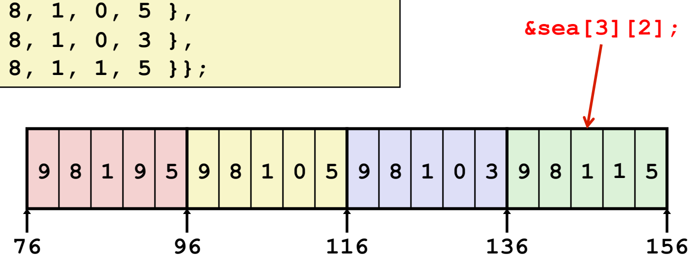
Nested Array Example

```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```



Nested Array Example

```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```



- "row-major" ordering of all elements
- Guaranteed?

Multidimensional (Nested) Arrays

- **Declaration**
  - T   A[R][C];
  - 2D array of data type T
  - R rows, C columns
  - Type T element requires K bytes
- **Array size?**

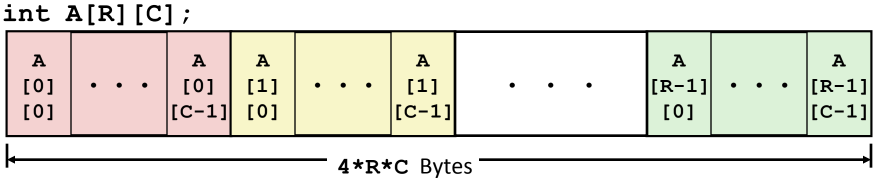
$$\begin{bmatrix} \texttt{A[0][0]} & \cdots & \texttt{A[0][C-1]} \\ \vdots & & \vdots \\ \texttt{A[R-1][0]} & \cdots & \texttt{A[R-1][C-1]} \end{bmatrix}$$

Multidimensional (Nested) Arrays

- **Declaration**
  - T   A[R][C];
  - 2D array of data type T
  - R rows, C columns
  - Type T element requires K bytes
- **Array size**
  - R * C * K bytes
- **Arrangement**
  - Row-major ordering

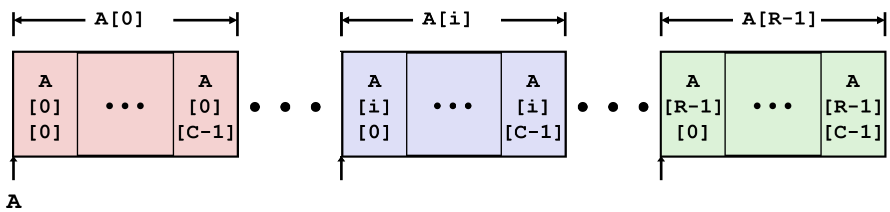
$$\begin{bmatrix} \texttt{A[0][0]} & \cdots & \texttt{A[0][C-1]} \\ \vdots & & \vdots \\ \texttt{A[R-1][0]} & \cdots & \texttt{A[R-1][C-1]} \end{bmatrix}$$

```
int A[R][C];
```



Nested Array Row Access

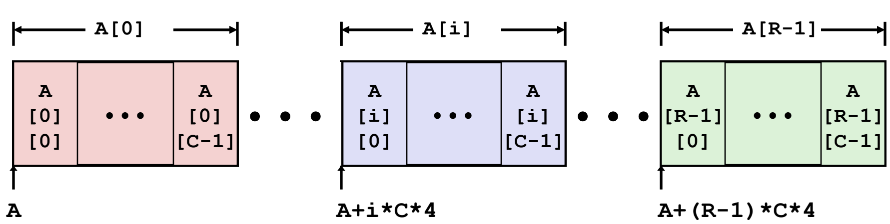
```
int A[R][C];
```



Nested Array Row Access

- **Row vectors**
  - A[i] is array of C elements
  - Each element of type T requires K bytes
  - Starting address A + i * (C * K)

```
int A[R][C];
```



Nested Array Row Access Code

```
int *get_sea_zip(int index)
{
  return sea[index];
}
```

```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```


Nested Array Row Access Code


```
int *get_sea_zip(int index)
{
  return sea[index];
}
```

```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```


- What data type is `sea[index]`?
- What is its starting address?

```
 # %eax = index
  leal (%eax,%eax,4),%eax
  leal sea(,%eax,4),%eax
```

Translation?

Nested Array Row Access Code

```
int *get_sea_zip(int index)
{
  return sea[index];
}
```

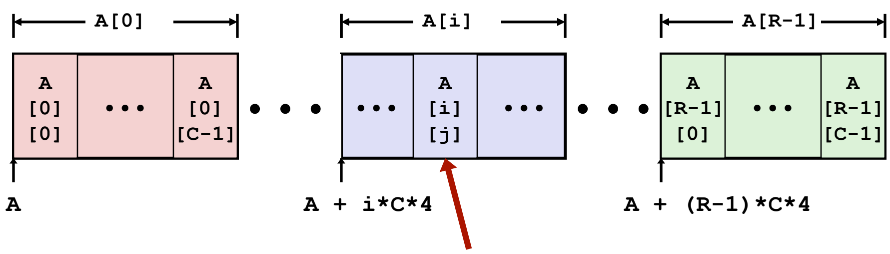
```
#define PCOUNT 4
zip_dig sea[PCOUNT] =
  {{ 9, 8, 1, 9, 5 },
   { 9, 8, 1, 0, 5 },
   { 9, 8, 1, 0, 3 },
   { 9, 8, 1, 1, 5 }};
```

```
 # %eax = index
  leal (%eax,%eax,4),%eax # 5 * index
  leal sea(,%eax,4),%eax  # sea + (20 * index)
```

- **Row Vector**
  - **`sea[index]`** is array of 5 **`int`**s
  - Starting address **`sea+20*index`**
- **IA32 Code**
  - Computes and returns address
  - Compute as **`sea+4*(index+4*index)=sea+20*index`**

Nested Array Row Access

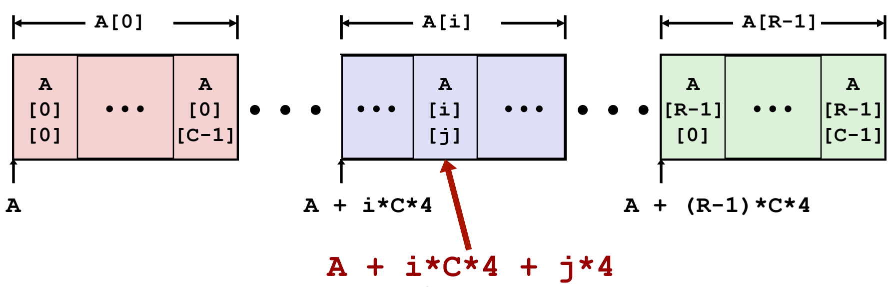
```
int A[R][C];
```



Nested Array Row Access

- **Array Elements**
  - A[i][j] is element of type T, which requires K bytes
  - Address A + i * (C * K) + j * K = A + (i * C + j)* K

```
int A[R][C];
```



Nested Array Element Access Code

```
int get_sea_digit
  (int index, int dig)
{
  return sea[index][dig];
}
```

```
# %ecx = dig
# %eax = index
leal 0(,%ecx,4),%edx          # 4*dig
leal (%eax,%eax,4),%eax       # 5*index
movl sea(%edx,%eax,4),%eax    # *(sea + 4*dig + 20*index)
```

- **Array Elements**
  - sea[index][dig] is int
  - Address: sea + 20*index + 4*dig
- **IA32 Code**
  - Computes address sea + 4*dig + 4*(index+4*index)
  - movl performs memory reference

Strange Referencing Examples

```
zip_dig
sea[4];
```

9	8	1	9	5	9	8	1	0	5	9	8	1	0	3	9	8	1	1	5

76 96 116 136 156

- **Reference** **Address** **Value** **Guaranteed?**

  sea[3][3]
  sea[2][5]
  sea[2][-1]
  sea[4][-1]
  sea[0][19]
  sea[0][-1]

Strange Referencing Examples

```
zip_dig
sea[4];
```

9	8	1	9	5	9	8	1	0	5	9	8	1	0	3	9	8	1	1	5

76 96 116 136 156

- **Reference, Address, Value, Guaranteed?**

Reference	Address	Value	Guaranteed?
sea[3][3]	76+20*3+4*3 = 148	1	
sea[2][5]	76+20*2+4*5 = 136	9	
sea[2][-1]	76+20*2+4*-1 = 112	5	
sea[4][-1]	76+20*4+4*-1 = 152	5	
sea[0][19]	76+20*0+4*19 = 152	5	
sea[0][-1]	76+20*0+4*-1 = 72	??	

  - Code does not do any bounds checking
  - Ordering of elements within array guaranteed

Strange Referencing Examples

```
zip_dig
sea[4];
```

9	8	1	9	5	9	8	1	0	5	9	8	1	0	3	9	8	1	1	5

`76` `96` `116` `136` `156`

Reference	Address	Value	Guaranteed?
`sea[3][3]`	`76+20*3+4*3 = 148`	`1`	Yes
`sea[2][5]`	`76+20*2+4*5 = 136`	`9`	Yes
`sea[2][-1]`	`76+20*2+4*-1 = 112`	`5`	Yes
`sea[4][-1]`	`76+20*4+4*-1 = 152`	`5`	Yes
`sea[0][19]`	`76+20*0+4*19 = 152`	`5`	Yes
`sea[0][-1]`	`76+20*0+4*-1 = 72`	`??`	No

- Code does not do any bounds checking
- Ordering of elements within array guaranteed

Multi-Level Array Example

```
zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig uw  = { 9, 8, 1, 9, 5 };
zip_dig ucb = { 9, 4, 7, 2, 0 };
```

```
#define UCOUNT 3
int *univ[UCOUNT] = {uw, cmu, ucb};
```

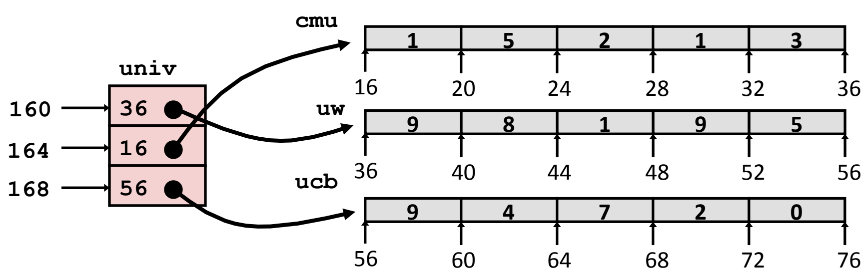
Same thing as a 2D array?

Multi-Level Array Example

```
zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig uw  = { 9, 8, 1, 9, 5 };
zip_dig ucb = { 9, 4, 7, 2, 0 };
```

```
#define UCOUNT 3
int *univ[UCOUNT] = {uw, cmu, ucb};
```

NB: This is how Java represents multi-dimensional arrays.

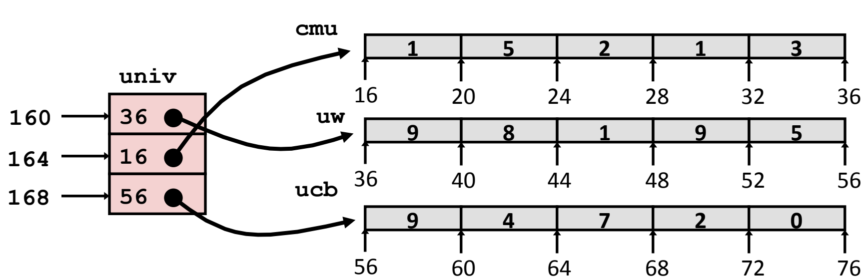


Multi-Level Array Example

```
zip_dig cmu = { 1, 5, 2, 1, 3 };
zip_dig uw  = { 9, 8, 1, 9, 5 };
zip_dig ucb = { 9, 4, 7, 2, 0 };
```

```
#define UCOUNT 3
int *univ[UCOUNT] = {uw, cmu, ucb};
```

- **Variable `univ` denotes array of 3 elements**
- **Each element is a pointer**
  - 4 bytes
- **Each pointer points to array of `int`s**



Element Access in Multi-Level Array

```
int get_univ_digit
  (int index, int dig)
{
  return univ[index][dig];
}
```

```
  # %ecx = index
  # %eax = dig
  leal 0(,%ecx,4),%edx
  movl univ(%edx),%edx
  movl (%edx,%eax,4),%eax
```


Element Access in Multi-Level Array

```
int get_univ_digit
  (int index, int dig)
{
  return univ[index][dig];
}
```

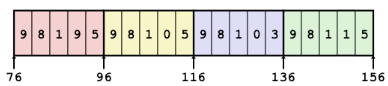
```
  # %ecx = index
  # %eax = dig
  leal 0(,%ecx,4),%edx     # 4*index
  movl univ(%edx),%edx     # Mem[univ+4*index]
  movl (%edx,%eax,4),%eax  # Mem[...+4*dig]
```

- **Computation (IA32)**
  - Element access **`Mem[Mem[univ+4*index]+4*dig]`**
  - Must do two memory reads
    - First get pointer to row array
    - Then access element within array

Array Element Accesses

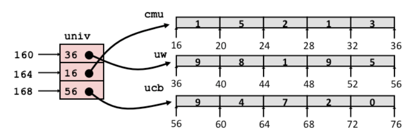
Nested array

```
int get_sea_digit
  (int index, int dig)
{
  return sea[index][dig];
}
```



Multi-level array

```
int get_univ_digit
  (int index, int dig)
{
  return univ[index][dig];
}
```

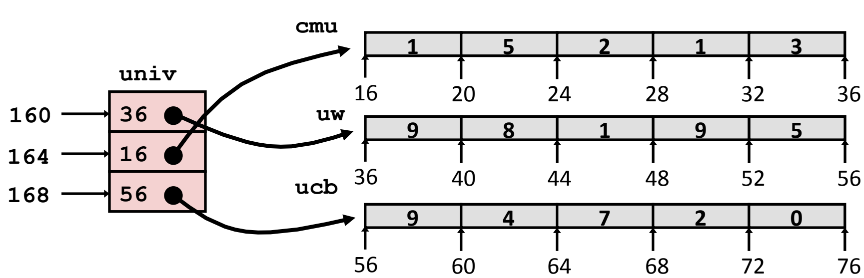


Access looks similar, but it isn't:

`Mem[sea+20*index+4*dig]`

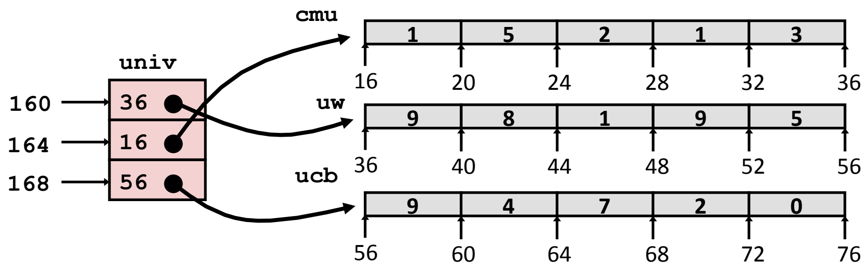
`Mem[Mem[univ+4*index]+4*dig]`

Strange Referencing Examples



Reference	Address	Value	Guaranteed?
`univ[2][3]`	What values go here?		
`univ[1][5]`			
`univ[2][-1]`			
`univ[3][-1]`			
`univ[1][12]`			

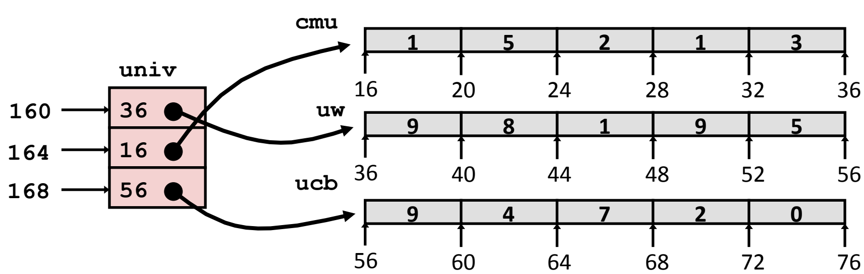
Strange Referencing Examples



Reference	Address	Value	Guaranteed?
`univ[2][3]`	`56+4*3 = 68`	`2`	
`univ[1][5]`	`16+4*5 = 36`	`9`	
`univ[2][-1]`	`56+4*-1 = 52`	`5`	
`univ[3][-1]`	`??`	`??`	
`univ[1][12]`	`16+4*12 = 64`	`7`	

- Code does not do any bounds checking
- Ordering of elements in different arrays not guaranteed

Strange Referencing Examples



Reference	Address	Value	Guaranteed?
`univ[2][3]`	`56+4*3 = 68`	`2`	Yes
`univ[1][5]`	`16+4*5 = 36`	`9`	No
`univ[2][-1]`	`56+4*-1 = 52`	`5`	No
`univ[3][-1]`	`??`	`??`	No
`univ[1][12]`	`16+4*12 = 64`	`7`	No

- Code does not do any bounds checking
- Ordering of elements in different arrays not guaranteed

Using Nested Arrays

```
#define N 16
typedef int fix_matrix[N][N];
```

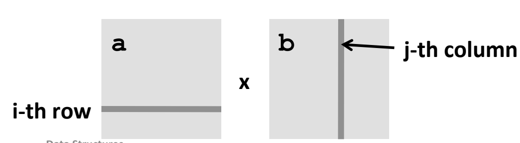
```
/* Compute element i,k of
   fixed matrix product */
int fix_prod_ele
(fix_matrix a, fix_matrix b,
 int i, int k)
{
  int j;
  int result = 0;
  for (j = 0; j < N; j++)
    result += a[i][j]*b[j][k];
  return result;
}
```


Using Nested Arrays

- **Strengths**
  - C compiler handles doubly subscripted arrays
  - Generates very efficient code
  - Avoids multiply in index computation
- **Limitation**
  - Only works for fixed array size

```
#define N 16
typedef int fix_matrix[N][N];
```

```
/* Compute element i,k of
   fixed matrix product */
int fix_prod_ele
(fix_matrix a, fix_matrix b,
 int i, int k)
{
  int j;
  int result = 0;
  for (j = 0; j < N; j++)
    result += a[i][j]*b[j][k];
  return result;
}
```



Dynamic Nested Arrays

- **Strength**
  - Can create matrix of any size
- **Programming**
  - Must do index computation explicitly
- **Performance**
  - Accessing single element costly
  - Must do multiplication

```
int * new_var_matrix(int n)
{
  return (int *)
    calloc(sizeof(int), n*n);
}
```

```
int var_ele
  (int *a, int i, int j, int n)
{
  return a[i*n+j];
}
```

```
movl 12(%ebp),%eax       # i
movl 8(%ebp),%edx        # a
imull 20(%ebp),%eax      # n*i
addl 16(%ebp),%eax       # n*i+j
movl (%edx,%eax,4),%eax  # Mem[a+4*(i*n+j)]
```


Structures

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

Structures

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  int i;
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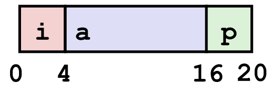
Memory Layout



- **Concept**
  - Contiguously-allocated region of memory
  - Refer to members within structure by names
  - Members may be of different types
- **Accessing structure member**

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

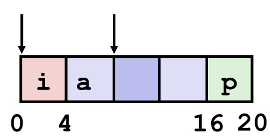
```
In java: r.i = val;
```

IA32 Assembly

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

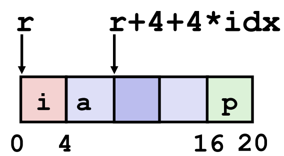

Generating Pointer to Structure Member

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



Generating Pointer to 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

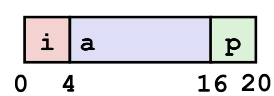
```
int *find_a  //  r.a[idx]
 (struct rec *r, int idx)
{
   return &r->a[idx];
// return &(*((*r).a + idx));
}
```

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


Structure Referencing (Cont.)

- **C Code**

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

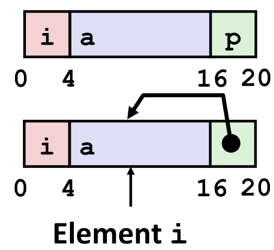



```
void set_p(struct rec *r)
{
     r->p = &r->a[r->i];
// (*r).p = &(*((*r).a+(*r).i));
}
```

Structure Referencing (Cont.)

- **C Code**

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




```
void set_p(struct rec *r)
{
     r->p = &r->a[r->i];
// (*r).p = &(*((*r).a+(*r).i)));
}
```

```
 # %edx = r
 movl (%edx),%ecx         # r->i
 leal 0(,%ecx,4),%eax     # 4*(r->i)
 leal 4(%edx,%eax),%eax   # r+4+4*(r->i)
 movl %eax,16(%edx)       # Update r->p
```


Alignment

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

Alignment

- **Aligned Data**
  - Primitive data type requires K bytes
  - Address must be multiple of K
  - Required on some machines; advised on IA32
    - treated differently by IA32 Linux, x86-64 Linux, and Windows!
- **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 very tricky when datum spans two pages (later…)
- **Compiler**
  - Inserts gaps in structure to ensure correct alignment of fields

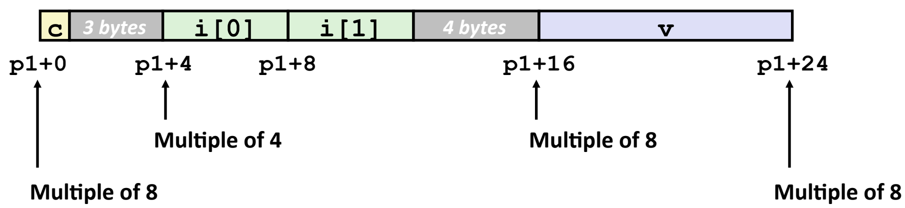
Specific Cases of Alignment (IA32)

- **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 OS's & 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: (same as Linux double)

Satisfying Alignment with Structures

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

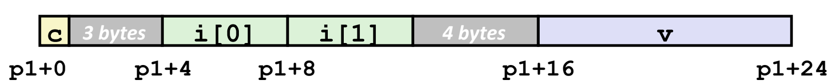
- **Within structure:**
  - Must satisfy element's alignment requirement
- **Overall structure placement**
  - Each structure has alignment requirement K
    - K = Largest alignment of any element
  - Initial address & structure length must be multiples of K
- **Example (under Windows or x86-64):**
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



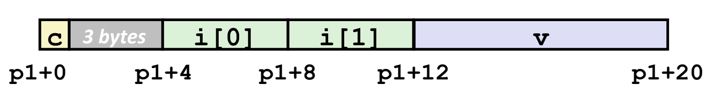
Different Alignment Conventions

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

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

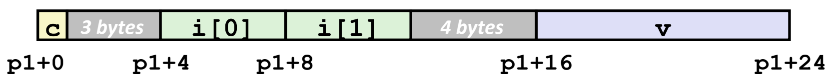


- **IA32 Linux**
  - K = 4; double treated like a 4-byte data type



Saving Space

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



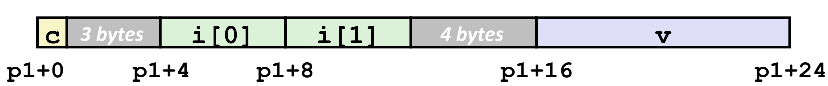
Saving Space

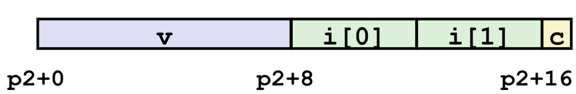
- Put large data types first

```
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)

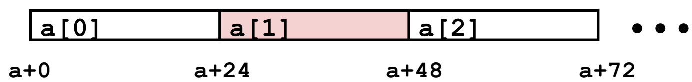




Arrays of Structures

- Satisfy alignment requirement for every element

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



Arrays of Structures

- Satisfy alignment requirement for every element

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struct S2 {
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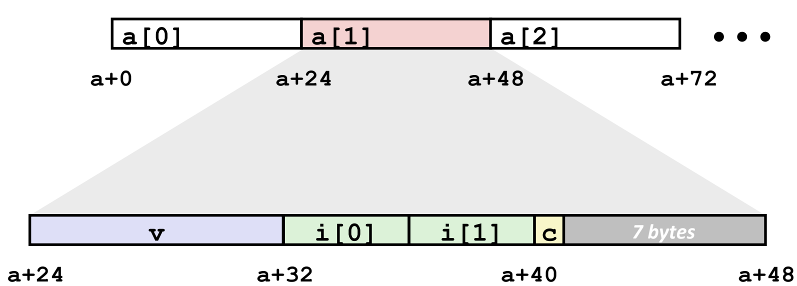
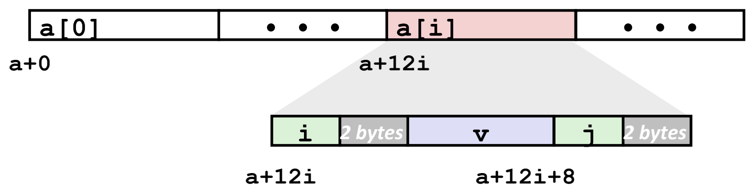


Accessing Array Elements

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

- **Compute array offset 12i**
- **Compute offset 8 with structure**
- **Assembler gives offset a+8**
  - Resolved during linking




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

```
# %eax = idx
leal (%eax,%eax,2),%eax # 3*idx
movswl a+8(,%eax,4),%eax
```


Unions

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

```
union urec {
  int i;
  int a[3];
  int *p;
};
```

- **Concept**
  - Allow same regions of memory to be referenced as different types
  - Aliases for the same memory location

Unions

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

```
union urec {
  int i;
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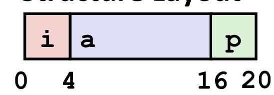
- **Concept**
  - Allow same regions of memory to be referenced as different types
  - Aliases for the same memory location

Structure Layout



Unions

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

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union urec {
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};
```

- **Concept**
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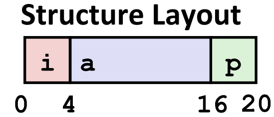
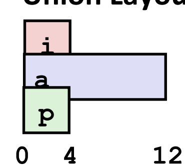
Structure Layout



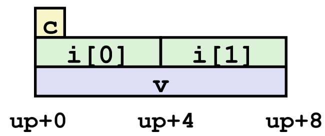
Union Layout



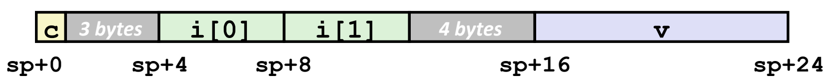
Union Allocation

- Allocate according to largest element
- Can only use one field at a time

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

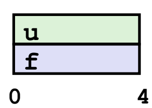



```
struct S1 {
  char c;
  int i[2];
  double v;
} *sp;
```



Using Union to Access Bit Patterns

```
typedef union {
  float f;
  unsigned u;
} bit_float_t;
```




```
float bit2float(unsigned u)
{
  bit_float_t arg;
  arg.u = u;
  return arg.f;
}
```

```
unsigned float2bit(float f)
{
  bit_float_t arg;
  arg.f = f;
  return arg.u;
}
```

Same as `(float) u` ?

Same as `(unsigned) f` ?

Summary

- **Arrays in C**
  - Contiguous allocation of memory
  - Aligned to satisfy every element's alignment requirement
  - Pointer to first element
  - No bounds checking
- **Structures**
  - Allocate bytes in order declared
  - Pad in middle and at end to satisfy alignment
- **Unions**
  - Overlay declarations
  - Way to circumvent type system