CSED211 : Microprocessor & Assembly Programming

Lecture 7: Data

Jong Kim

Pohang Univ. of Sci. & Tech.
Dept. of Comp. Sci. & Eng.

Quiz #4

- https://goo.gl/forms/XqmMSiip2TQKCpH32

*Disclaimer:
Most slides are taken from author's lecture slides.

Today

- Arrays
  - One-dimensional
  - Multi-dimensional (nested)
  - Multi-level
- Structures
  - Allocation
  - Access
  - Alignment
- F-P

Basic Data Types

- Integral
  - Stored & operated on in general (integer) registers
  - Signed vs. unsigned depends on instructions used

Intel	ASM	Bytes	C
byte	**`b`**	1	**`[unsigned] char`**
word	**`w`**	2	**`[unsigned] short`**
double word	**`l`**	4	**`[unsigned] int`**
quad word	**`q`**	8	**`[unsigned] long int`** (x86-64)

- Floating Point
  - Stored & operated on in floating point registers

Intel	ASM	Bytes	C
Single	**`s`**	4	**`float`**
Double	**`l`**	8	**`double`**
Extended	**`t`**	10/12/16	**`long double`**

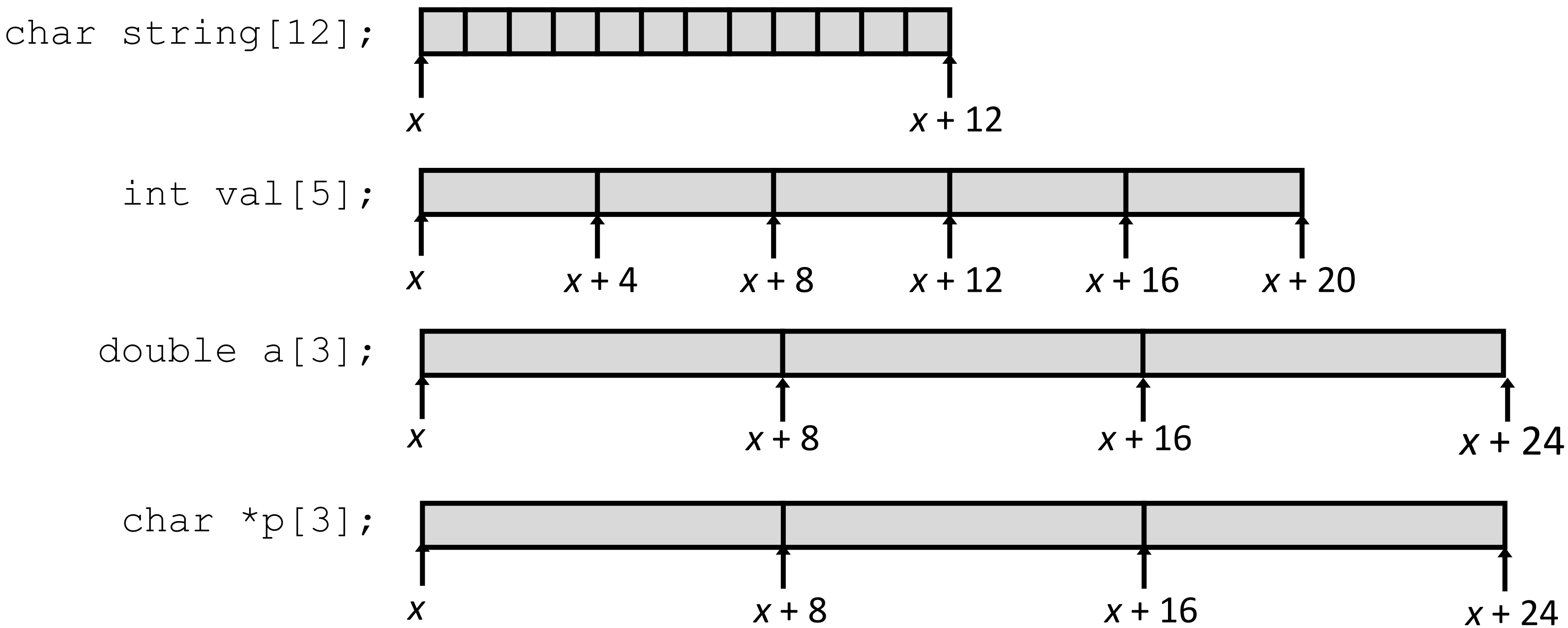
Array Allocation

- Basic Principle

  T **A[*L*];**

  – Array of data type *T* and length *L*

  – Contiguously allocated region of *L* * **sizeof**(*T*) bytes



Array Access

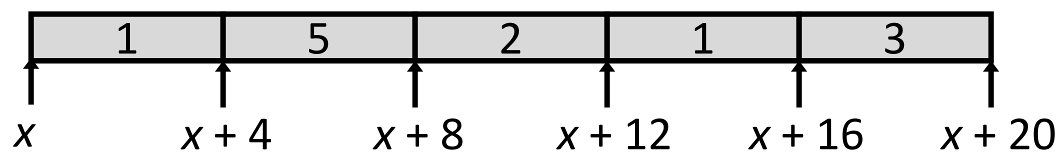
- Basic Principle

  T **A[*L*];**

  – Array of data type *T* and length *L*

  – Identifier **A** can be used as a pointer to array element 0: Type *T**

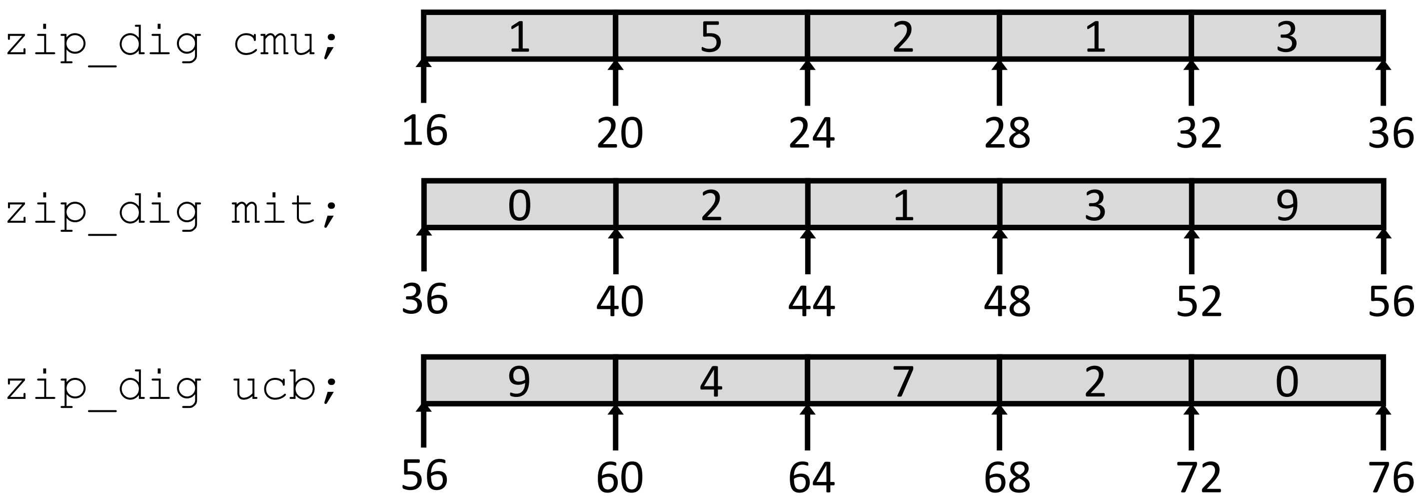
```
int val[5];
```



• Reference	Type	Value
`val[4]`	**`int`**	3
`val`	**`int *`**	x
`val+1`	**`int *`**	$x + 4$
`&val[2]`	**`int *`**	$x + 8$
`val[5]`	**`int`**	??
`*(val+1)`	**`int`**	5
`val +` ***`i`***	**`int *`**	$x + 4\,i$

Array Example

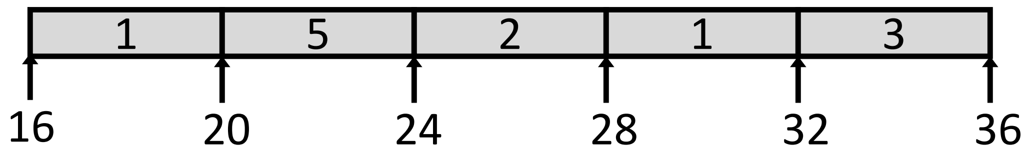
```
#define ZLEN 5
typedef int zip_dig[ZLEN];

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



- Declaration "zip_dig cmu" equivalent to "int cmu[5]"
- Example arrays were allocated in successive 20 byte blocks
  - Not guaranteed to happen in general

Array Accessing Example

`zip_dig cmu;`




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

IA64

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

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

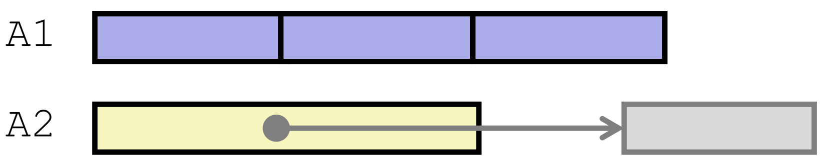
Array Loop Example

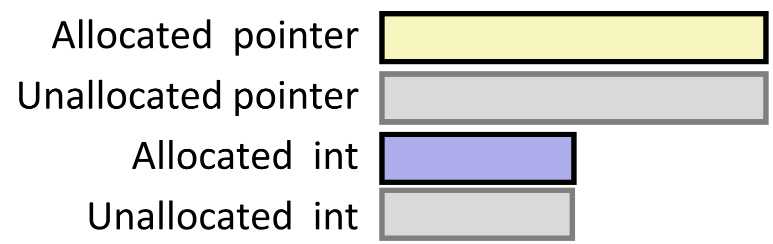
```
void zincr(zip_dig z) {
  size_t i;
  for (i = 0; i < ZLEN; i++)
    z[i]++;
}
```

```
  # rdi = z
  movl  $0, %eax              #   %eax = i
  jmp   .L3
.L4:                          # loop:
  addl  $1, (%rdi,%rax,4)     #   z[i]++
  addq  $1, %rax              #   i++
.L3:                          # middle
  cmpq  $4, %rax              #   i:4
  jbe   .L4                   #   if <=, goto loop
  rep; ret
```

Understanding Pointers & Arrays #1

Decl	A1 , A2			*A1 , *A2		
	Comp	Bad	Size	Comp	Bad	Size
`int A1[3]`						
`int *A2`						

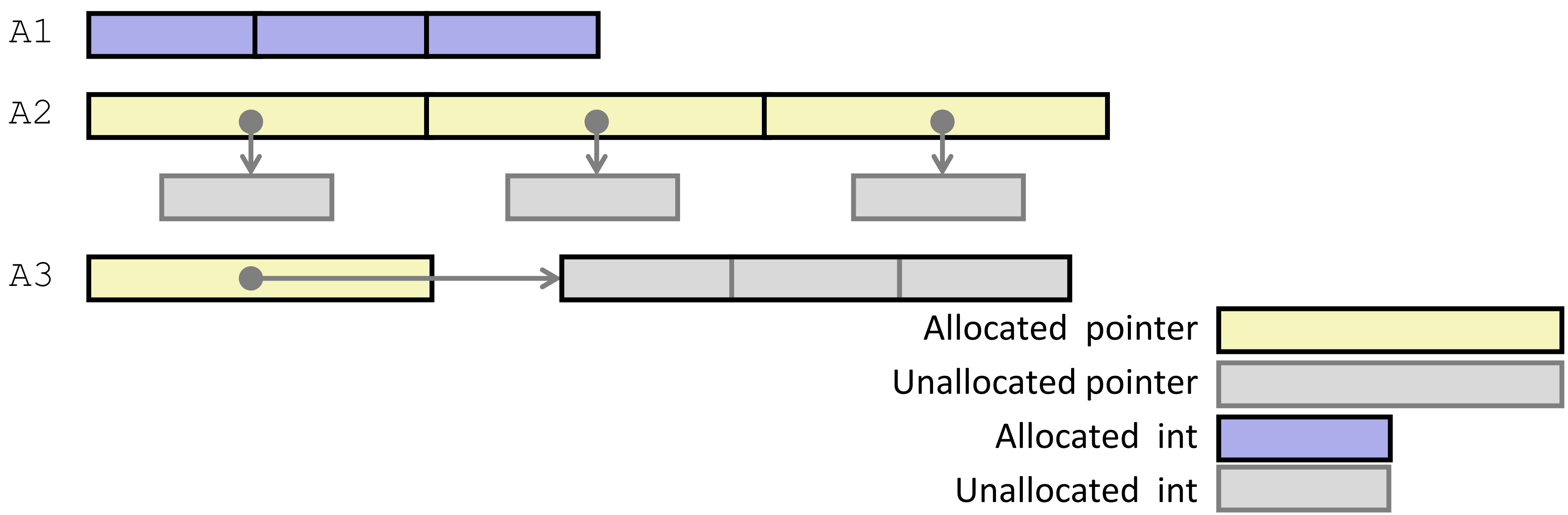




- Comp: Compiles (Y/N)
- Bad: Possible bad pointer reference (Y/N)
- Size: Value returned by `sizeof`

Understanding Pointers & Arrays #2

Decl	An			*An			**An		
	Cmp	Bad	Size	Cmp	Bad	Size	Cmp	Bad	Size
`int A1[3]`									
`int *A2[3]`									
`int (*A3)[3]`									



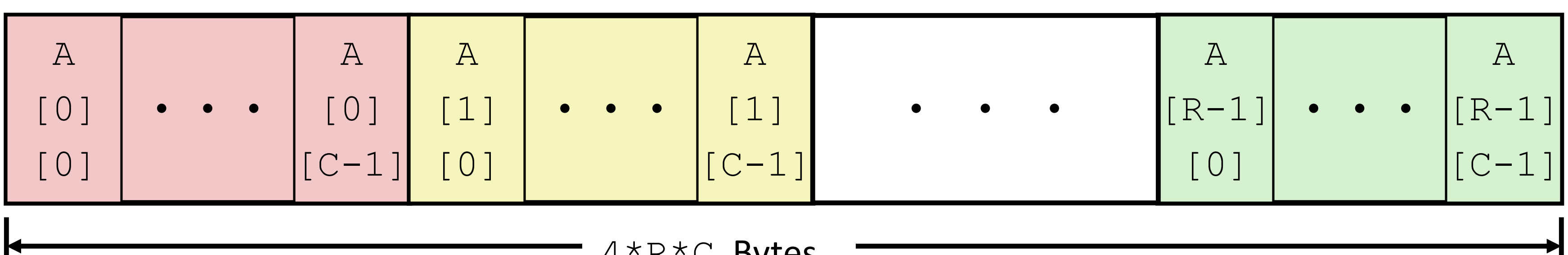
Multidimensional (Nested) Arrays

- 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

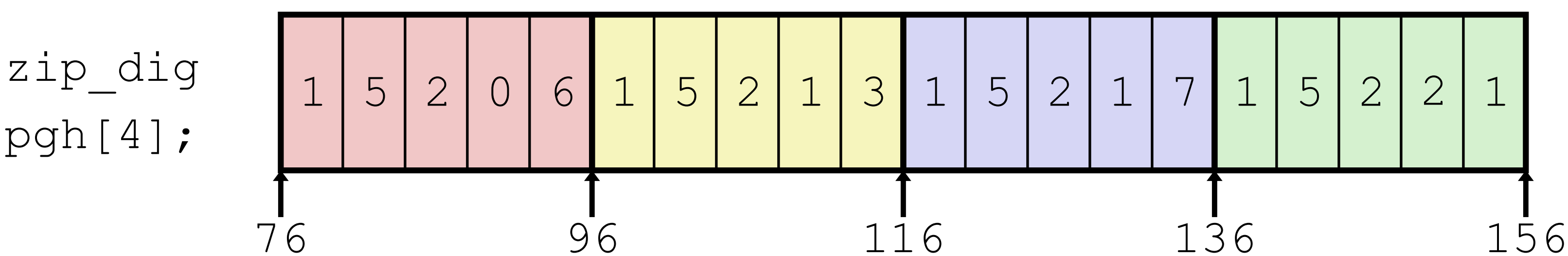
$$\begin{bmatrix} \texttt{A[0][0]} & \cdots & \texttt{A[0][C-1]} \\ \vdots & & \vdots \\ \texttt{A[R-1][0]} & \cdots & \texttt{A[R-1][C-1]} \end{bmatrix}$$

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



Nested Array Example

```
#define PCOUNT 4
zip_dig pgh[PCOUNT] =
  {{1, 5, 2, 0, 6},
   {1, 5, 2, 1, 3 },
   {1, 5, 2, 1, 7 },
   {1, 5, 2, 2, 1 }};
```

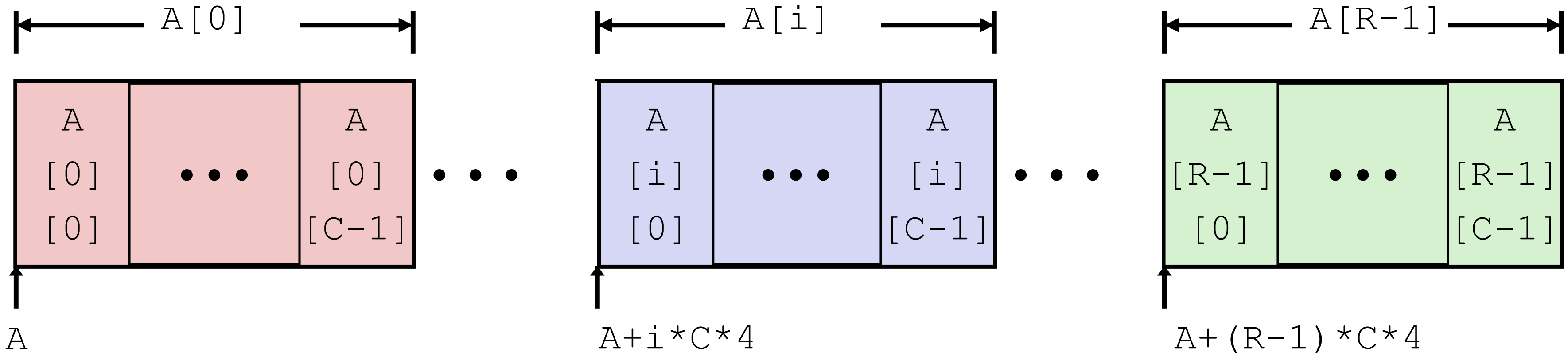


- "zip_dig pgh[4]" equivalent to "int pgh[4][5]"
  - Variable **pgh**: array of 4 elements, allocated contiguously
  - Each element is an array of 5 **int**'s, allocated contiguously
- "Row-Major" ordering of all elements guaranteed

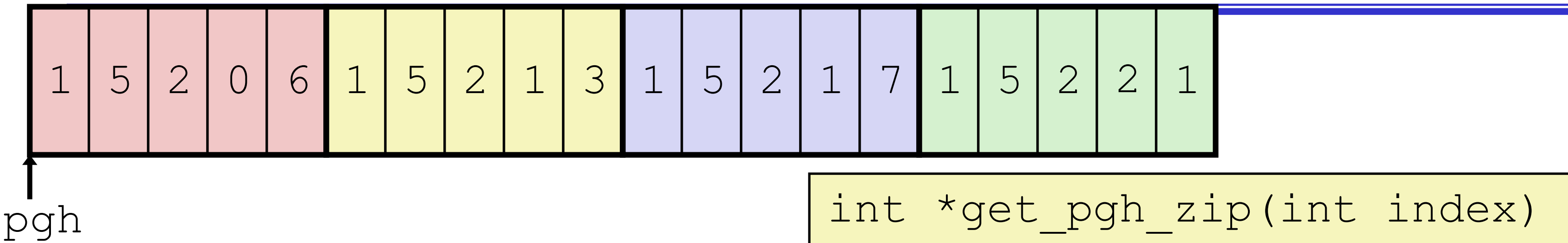
Nested Array Row Access

- 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_pgh_zip(int index)
{
  return pgh[index];
}
```

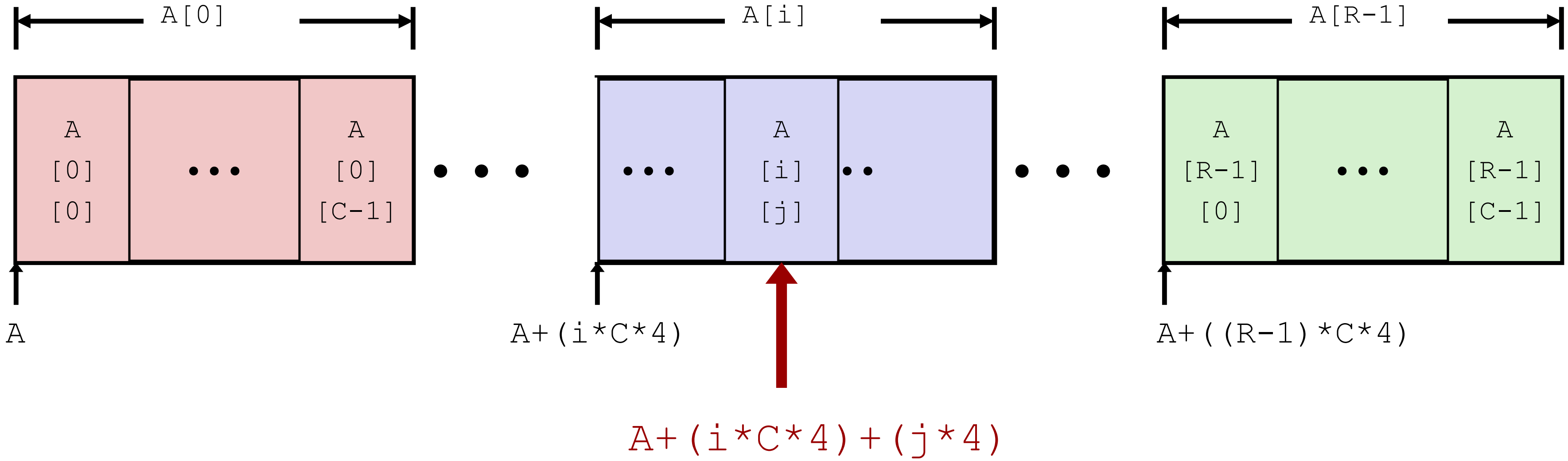
```
  # %rdi = index
  leaq (%rdi,%rdi,4),%rax # 5 * index
  leaq pgh(,%rax,4),%rax  # pgh + (20 * index)
```

- Row Vector
  - **pgh[index]** is array of 5 **int**'s
  - Starting address **pgh+20*index**
- Machine Code
  - Computes and returns address
  - Compute as **pgh + 4*(index+4*index)**

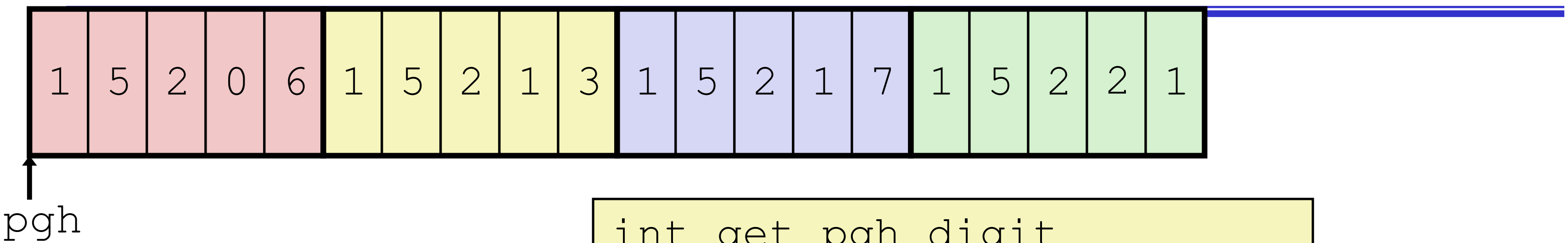
Nested Array Element Access

- 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_pgh_digit
   (int index, int dig)
{
  return pgh[index][dig];
}
```

```
leaq   (%rdi,%rdi,4), %rax     # 5*index
addl   %rax, %rsi              # 5*index+dig
movl   pgh(,%rsi,4), %eax      # M[pgh + 4*(5*index+dig)]
```

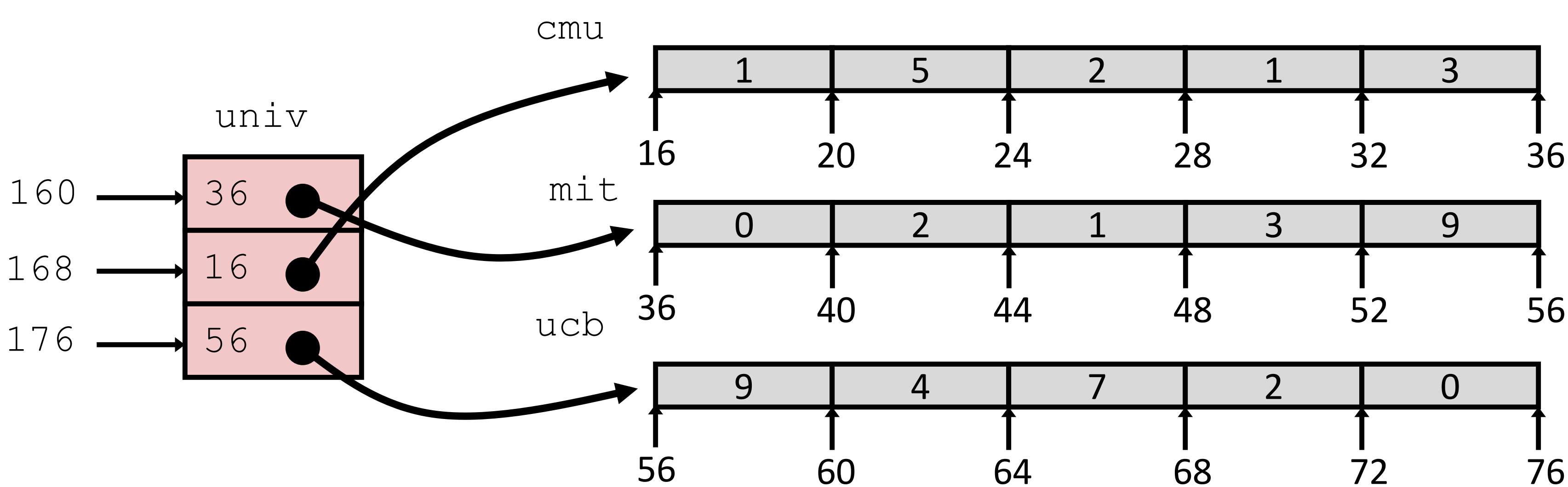
- Array Elements
  - **pgh[index][dig]** is **int**
  - Address: **pgh + 20*index + 4*dig**
    - = **pgh + 4*(5*index + dig)**

Multi-Level Array Example

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

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

- Variable univ denotes array of 3 elements
- Each element is a pointer
  - 8 bytes
- Each pointer points to array of int's



Element Access in Multi-Level Array

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

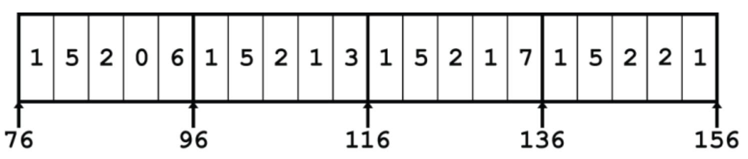
```
  salq    $2, %rsi              # 4*dig
  addq    univ(,%rdi,8), %rsi # p = univ[index] + 4*dig
  movl    (%rsi), %eax          # return *p
  ret
```

- Computation
  - Element access **Mem[Mem[univ+8*index]+4*dig]**
  - Must do two memory reads
    - First get pointer to row array
    - Then access element within array

Array Element Accesses

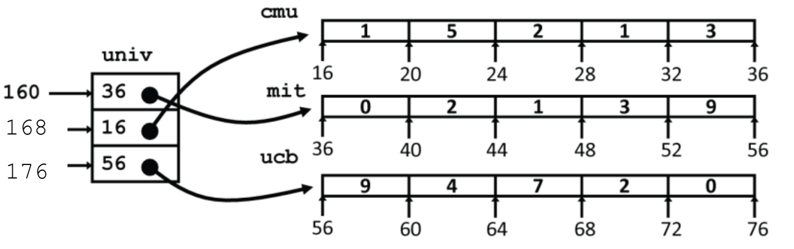
Nested array

```
int get_pgh_digit
  (int index, int dig)
{
  return pgh[index][dig];
}
```



Multi-level array

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



Accesses looks similar in C, but addresses computations very different:

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

`Mem[Mem[univ+8*index]+4*dig]`

N X N Matrix Code

- Fixed dimensions
  - Know value of N at compile time

```
#define N 16
typedef int fix_matrix[N][N];
/* Get element a[i][j] */
int fix_ele
  (fix_matrix a, int i, int j)
{
  return a[i][j];
}
```

- Variable dimensions, explicit indexing
  - Traditional way to implement dynamic arrays

```
#define IDX(n, i, j) ((i)*(n)+(j))
/* Get element a[i][j] */
int vec_ele
 (int n, int *a, int i, int j)
{
  return a[IDX(n,i,j)];
}
```

- Variable dimensions, implicit indexing
  - Now supported by gcc

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

16 X 16 Matrix Access

- **Array Elements**
  - Address **A +** i * (C * K) + j * K
  - C = 16, K = 4

```
/* Get element a[i][j] */
int fix_ele(fix_matrix a, size_t i, size_t j) {
  return a[i][j];
}
```

```
# a in %rdi, i in %rsi, j in %rdx
 salq    $6, %rsi                # 64*i
 addq    %rsi, %rdi              # a + 64*i
 movl    (%rdi,%rdx,4), %eax     # M[a + 64*i + 4*j]
 ret
```

n X n Matrix Access

- **Array Elements**
  - Address **A** + i * (C * K) + j * K
  - C = n, K = 4
  - Must perform integer multiplication

```
/* Get element a[i][j] */
int var_ele(size_t n, int a[n][n], size_t i, size_t j)
{
  return a[i][j];
}
```

```
 # n in %rdi, a in %rsi, i in %rdx, j in %rcx
  imulq   %rdx, %rdi             # n*i
  leaq    (%rsi,%rdi,4), %rax    # a + 4*n*i
  movl    (%rax,%rcx,4), %eax    # a + 4*n*i + 4*j
  ret
```

Example: Array Access

```
#include <stdio.h>
#define ZLEN 5
#define PCOUNT 4
typedef int zip_dig[ZLEN];

int main(int argc, char** argv) {
zip_dig pgh[PCOUNT] =
    {{1, 5, 2, 0, 6},
     {1, 5, 2, 1, 3 },
     {1, 5, 2, 1, 7 },
     {1, 5, 2, 2, 1 }};
    int *linear_zip = (int *) pgh;
    int *zip2 = (int *) pgh[2];
    int result =
        pgh[0][0] +
        linear_zip[7] +
        *(linear_zip + 8) +
        zip2[1];
    printf("result: %d\n", result);
    return 0;
}
```

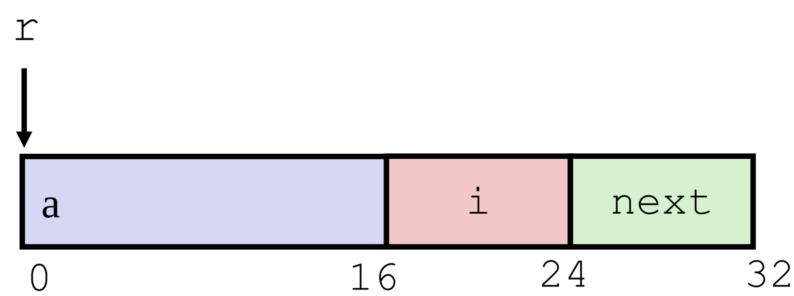
```
linux> ./array
result: 9
```

Today

- Arrays
  - One-dimensional
  - Multi-dimensional (nested)
  - Multi-level
- Structures
  - Allocation
  - Access
  - Alignment
- F-P

Structure Representation

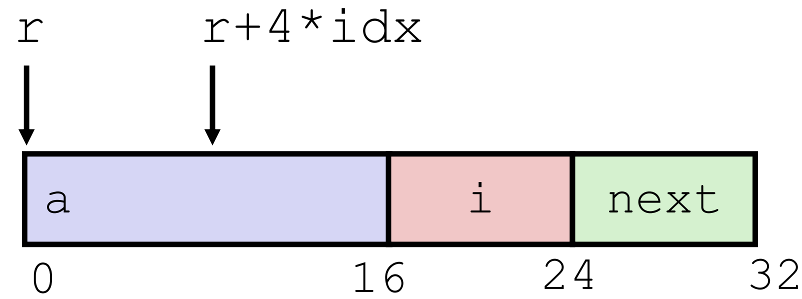
```
struct rec {
    int a[4];
    size_t i;
    struct rec *next;
};
```



- 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];
}
```

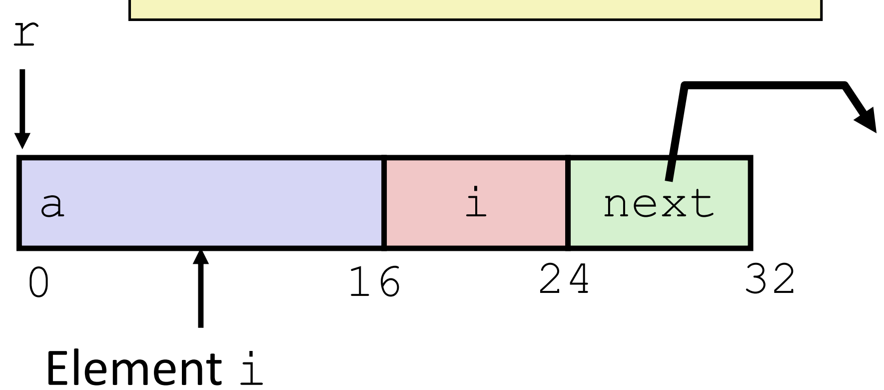
```
  # r in %rdi, idx in %rsi
  leaq  (%rdi,%rsi,4), %rax
  ret
```

Following Linked List

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

- C Code

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

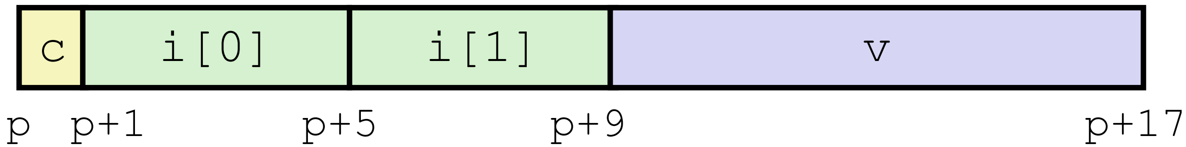


Register	Value
%rdi	**r**
%rsi	**val**

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

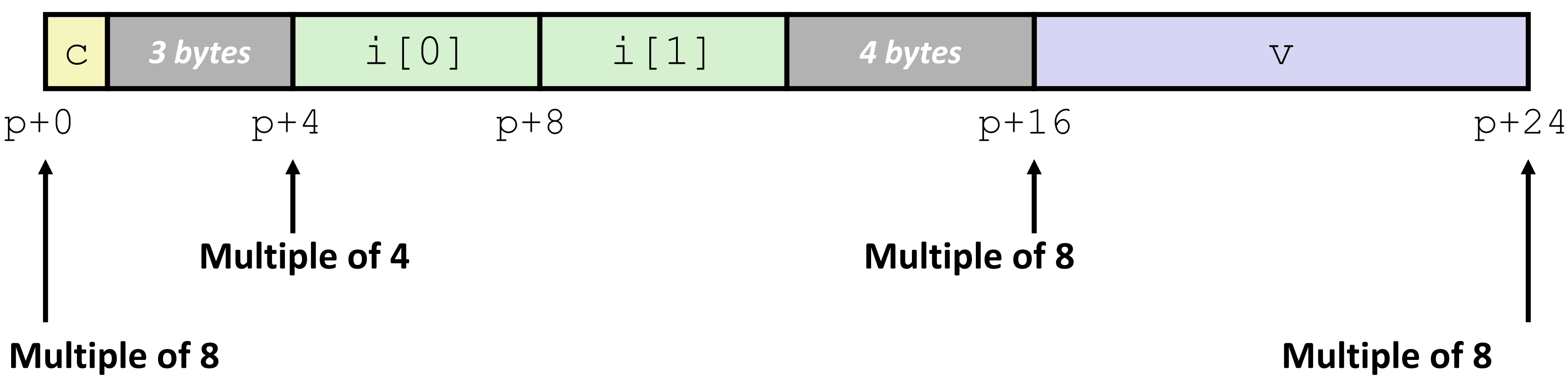
Structures & Alignment

- Unaligned Data




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

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



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

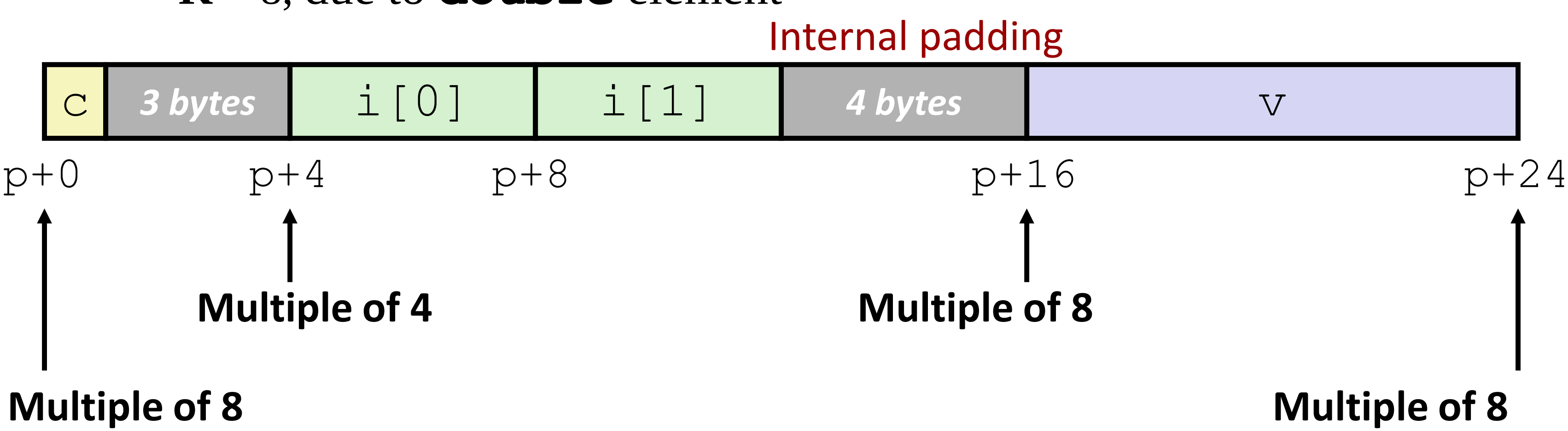
Specific Cases of Alignment (x86-64)

- 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**
- Example:
  - **K** = 8, due to **`double`** element

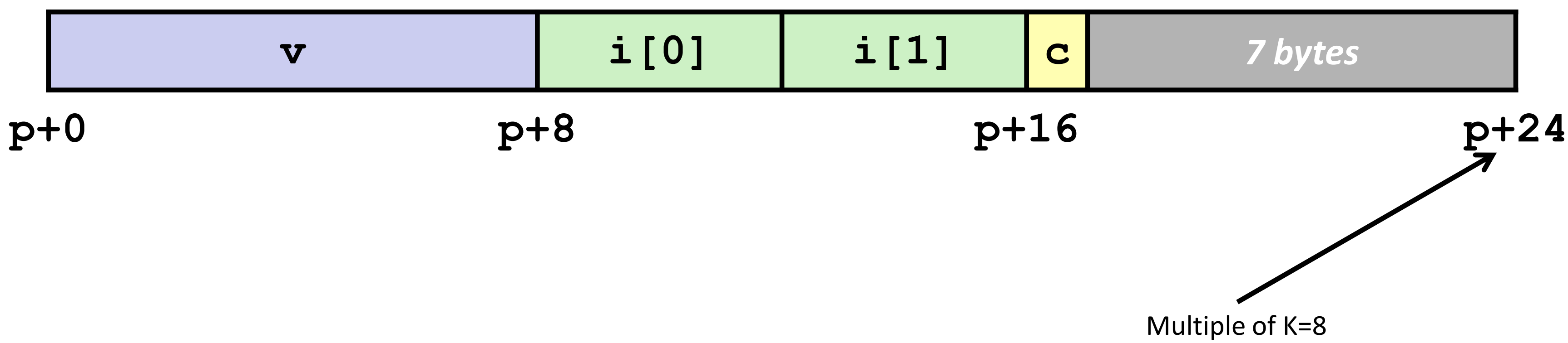
```
struct S1 {
  char c;
  int i[2];
  double v;
} *p;
```



Meeting Overall Alignment Requirement

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

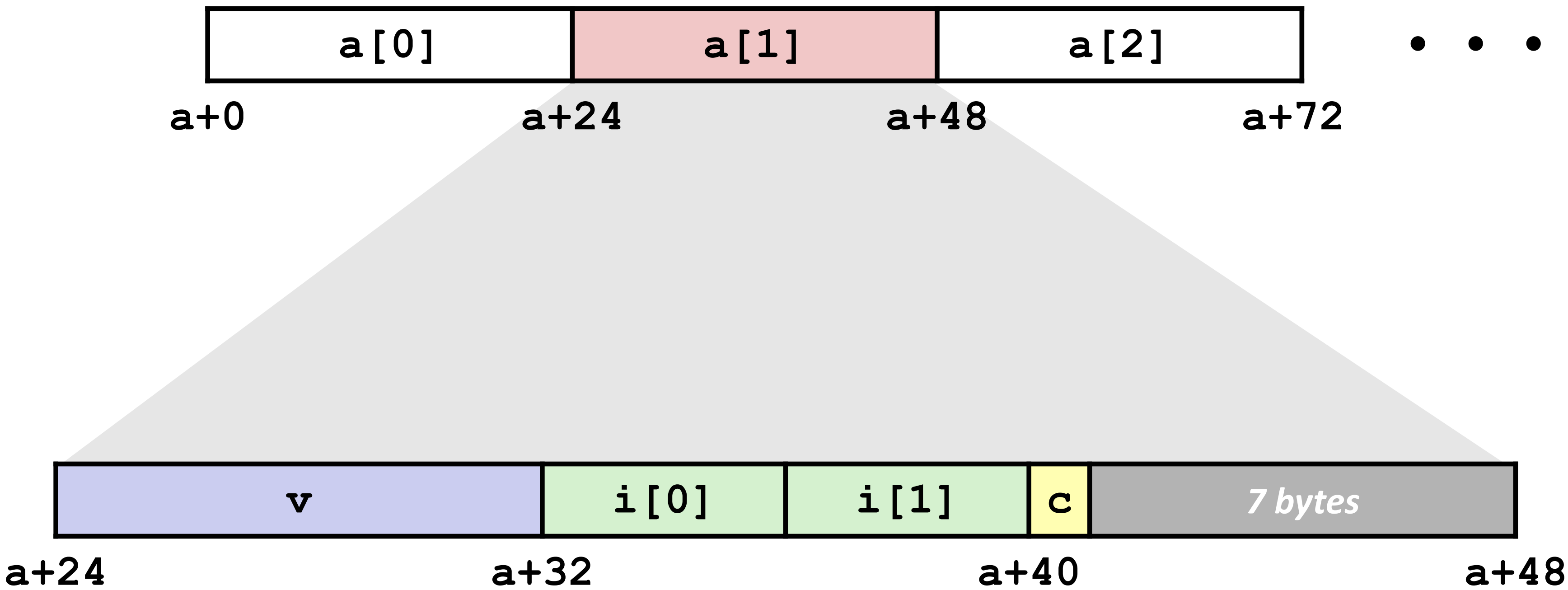
```
struct S2 {
  double v;
  int i[2];
  char c;
} *p;
```



Arrays of Structures

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

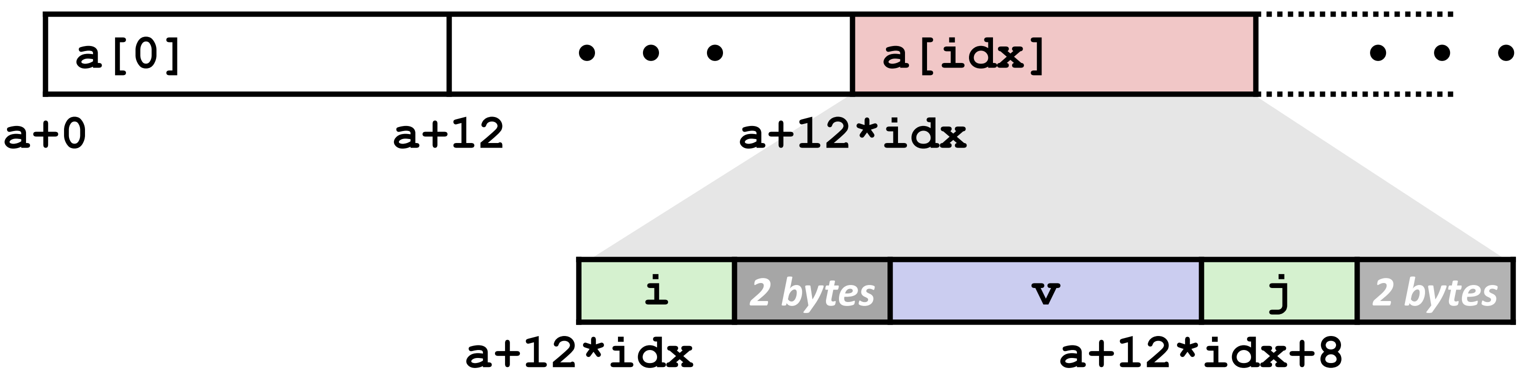
```
struct S2 {
  double v;
  int i[2];
  char c;
} a[10];
```



Accessing Array Elements

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

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




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

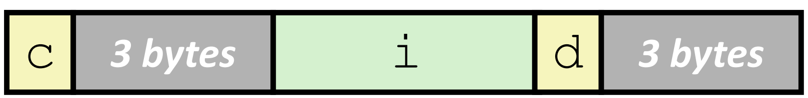
```
# %rdi = idx
leaq (%rdi,%rdi,2),%rax # 3*idx
movzwl a+8(,%rax,4),%eax
```

Saving Space

- Put large data types first

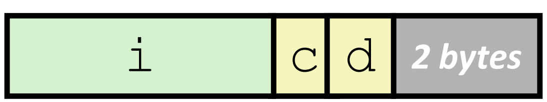
```
struct S4 {
  char c;
  int i;
  char d;
} *p;
```

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



12 bytes

- Effect (largest alignment requirement K=4)



8 bytes

Example Struct Exam Question

Problem 5. (8 points):

Struct alignment. Consider the following C struct declaration:

```
typedef struct {
  char a;
  long b;
  float c;
  char d[3];
  int *e;
  short *f;
} foo;
```

1. Show how `foo` would be allocated in memory on an x86-64 Linux system. Label the bytes with the names of the various fields and **clearly mark the end of the struct**. Use an X to denote space that is allocated in the struct as padding.

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

http://www.cs.cmu.edu/~213/oldexams/exam1-f12.pdf

Example Struct Exam Question

Problem 5. (8 points):

Struct alignment. Consider the following C struct declaration:

```
typedef struct {
  char a;
  long b;
  float c;
  char d[3];
  int *e;
  short *f;
} foo;
```

1. Show how `foo` would be allocated in memory on an x86-64 Linux system. Label the bytes with the names of the various fields and **clearly mark the end of the struct**. Use an X to denote space that is allocated in the struct as padding.

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|a |X |X |X |X |X |X |X |b |b |b |b |b |b |b |b |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|c |c |c |c |d |d |d |X |e |e |e |e |e |e |e |e |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|f |f |f |f |f |f |f |f |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

http://www.cs.cmu.edu/~213/oldexams/exam1-f12.pdf

Example Struct Exam Question (Cont'd)

Problem 5. (8 points):

Struct alignment. Consider the following C struct declaration:

```
typedef struct {
  char a;
  long b;
  float c;
  char d[3];
  int *e;
  short *f;
} foo;
```

2. Rearrange the elements of `foo` to conserve the most space in memory. Label the bytes with the names of the various fields and **clearly mark the end of the struct**. Use an X to denote space that is allocated in the struct as padding.

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

http://www.cs.cmu.edu/~213/oldexams/exam1-f12.pdf

Example Struct Exam Question (Cont'd)

Problem 5. (8 points):

Struct alignment. Consider the following C struct declaration:

```
typedef struct {
  char a;
  long b;
  float c;
  char d[3];
  int *e;
  short *f;
} foo;
```

2. Rearrange the elements of `foo` to conserve the most space in memory. Label the bytes with the names of the various fields and **clearly mark the end of the struct**. Use an X to denote space that is allocated in the struct as padding.

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|a |d |d |d |c |c |c |c |b |b |b |b |b |b |b |b |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|e |e |e |e |e |e |e |e |f |f |f |f |f |f |f |f |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

http://www.cs.cmu.edu/~213/oldexams/exam1-f12.pdf

Today

- Arrays
  - One-dimensional
  - Multi-dimensional (nested)
  - Multi-level
- Structures
  - Allocation
  - Access
  - Alignment
- Floating Point

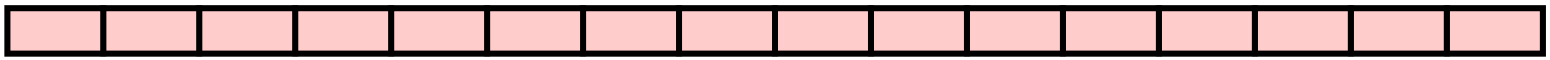
Background

- History
  - x87 FP
    - Legacy, very ugly
  - SSE FP
    - Supported by old machines
    - Special case use of vector instructions
  - AVX FP
    - Newest version
    - Similar to SSE
    - Documented in book

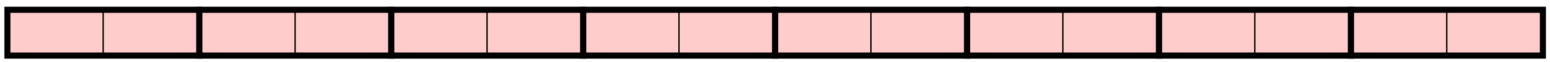
Programming with SSE3

XMM Registers

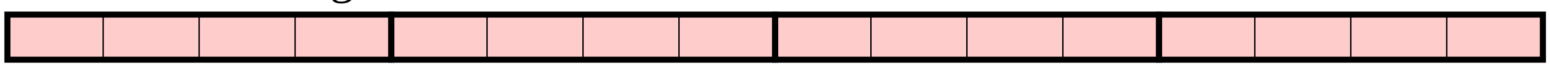
- 16 total, each 16 bytes
- 16 single-byte integers



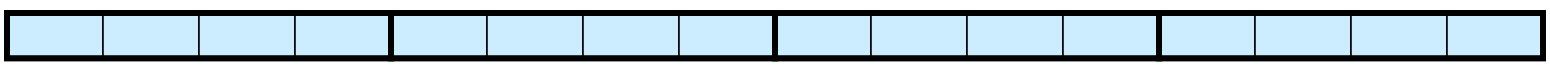
- 8 16-bit integers



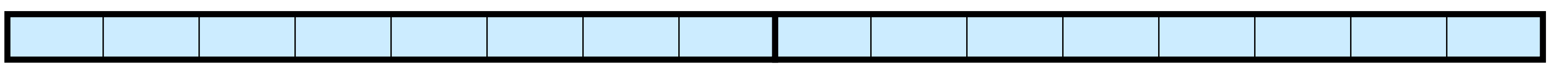
- 4 32-bit integers



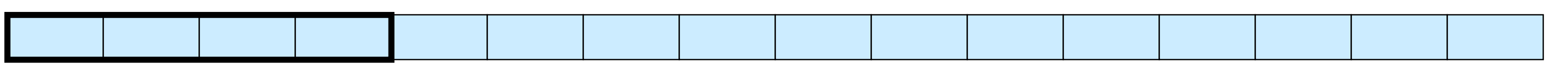
- 4 single-precision floats



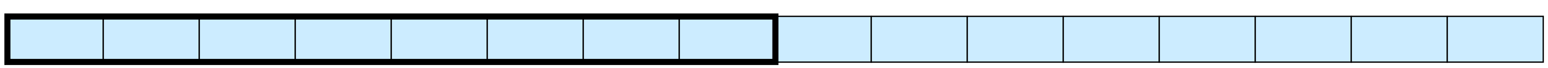
- 2 double-precision floats



- 1 single-precision float

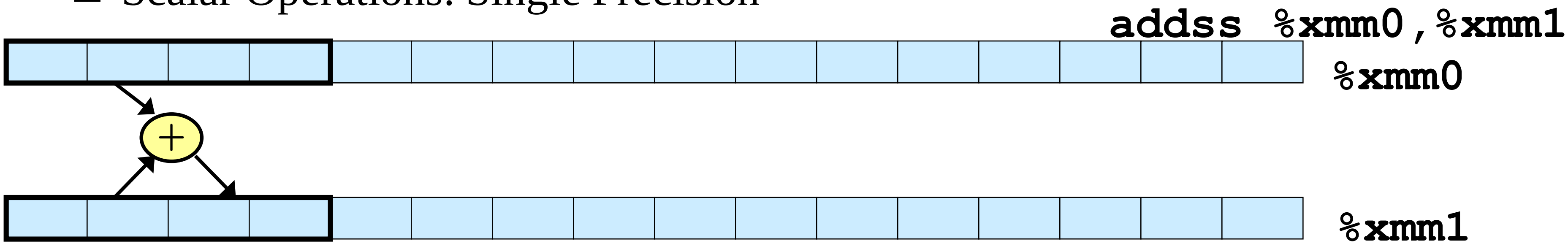


- 1 double-precision float

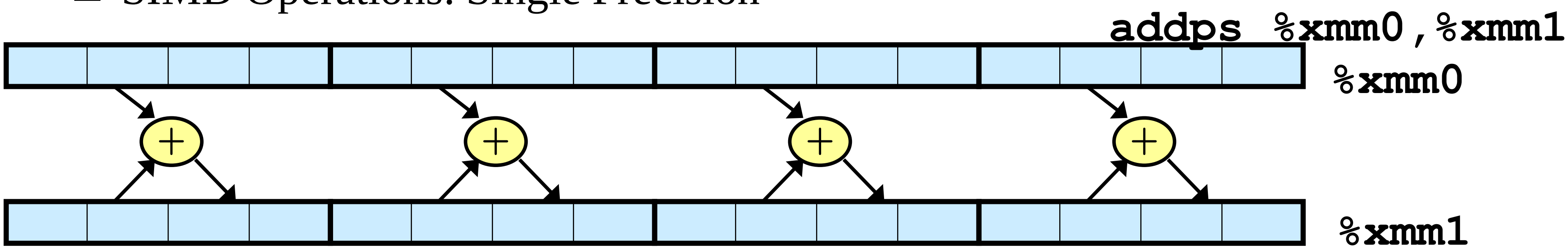


Scalar & SIMD Operations

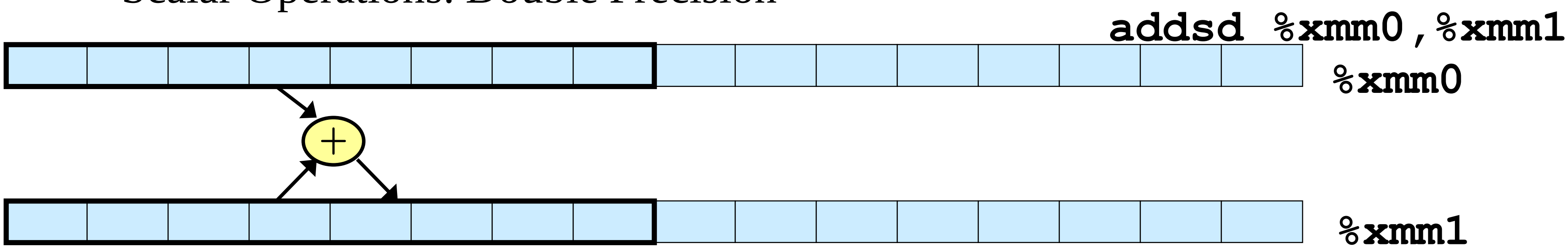
- Scalar Operations: Single Precision



- SIMD Operations: Single Precision



- Scalar Operations: Double Precision



FP Basics

- Arguments passed in `%xmm0`, `%xmm1`, ...
- Result returned in `%xmm0`
- All XMM registers caller-saved

```
float fadd(float x, float y)
{
    return x + y;
}
```

```
double dadd(double x, double y)
{
    return x + y;
}
```

```
  # x in %xmm0, y in %xmm1
  addss   %xmm1, %xmm0
  ret
```

```
 # x in %xmm0, y in %xmm1
  addsd   %xmm1, %xmm0
  ret
```

FP Memory Referencing

- Integer (and pointer) arguments passed in regular registers
- FP values passed in XMM registers
- Different mov instructions to move between XMM registers, and between memory and XMM registers

```
double dincr(double *p, double v)
{
    double x = *p;
    *p = x + v;
    return x;
}
```

```
  # p in %rdi, v in %xmm0
  movapd  %xmm0, %xmm1   # Copy v
  movsd   (%rdi), %xmm0  # x = *p
  addsd   %xmm0, %xmm1   # t = x + v
  movsd   %xmm1, (%rdi)  # *p = t
  ret
```

Other Aspects of FP Code

- *Lots* of instructions
  - Different operations, different formats, ...
- Floating-point comparisons
  - Instructions **`ucomiss`** and **`ucomisd`**
  - Set condition codes ZF, PF and CF
  - Zeros OF and SF

Parity Flag

UNORDERED: ZF,PF,CF←111
GREATER_THAN: ZF,PF,CF←000
LESS_THAN: ZF,PF,CF←001
EQUAL: ZF,PF,CF←100

- Using constant values
  - Set XMM0 register to 0 with instruction **`xorpd %xmm0, %xmm0`**
  - Others loaded from memory

Summary

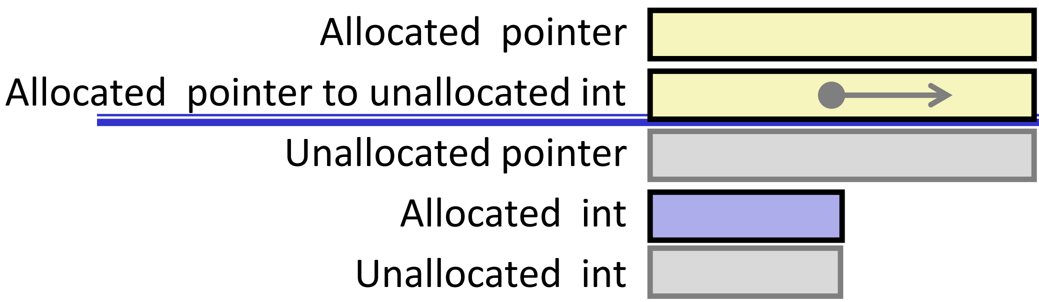
- Arrays
  - Elements packed into contiguous region of memory
  - Use index arithmetic to locate individual elements
- Structures
  - Elements packed into single region of memory
  - Access using offsets determined by compiler
  - Possible require internal and external padding to ensure alignment
- Combinations
  - Can nest structure and array code arbitrarily
- Floating Point
  - Data held and operated on in XMM registers

Understanding Pointers & Arrays #3

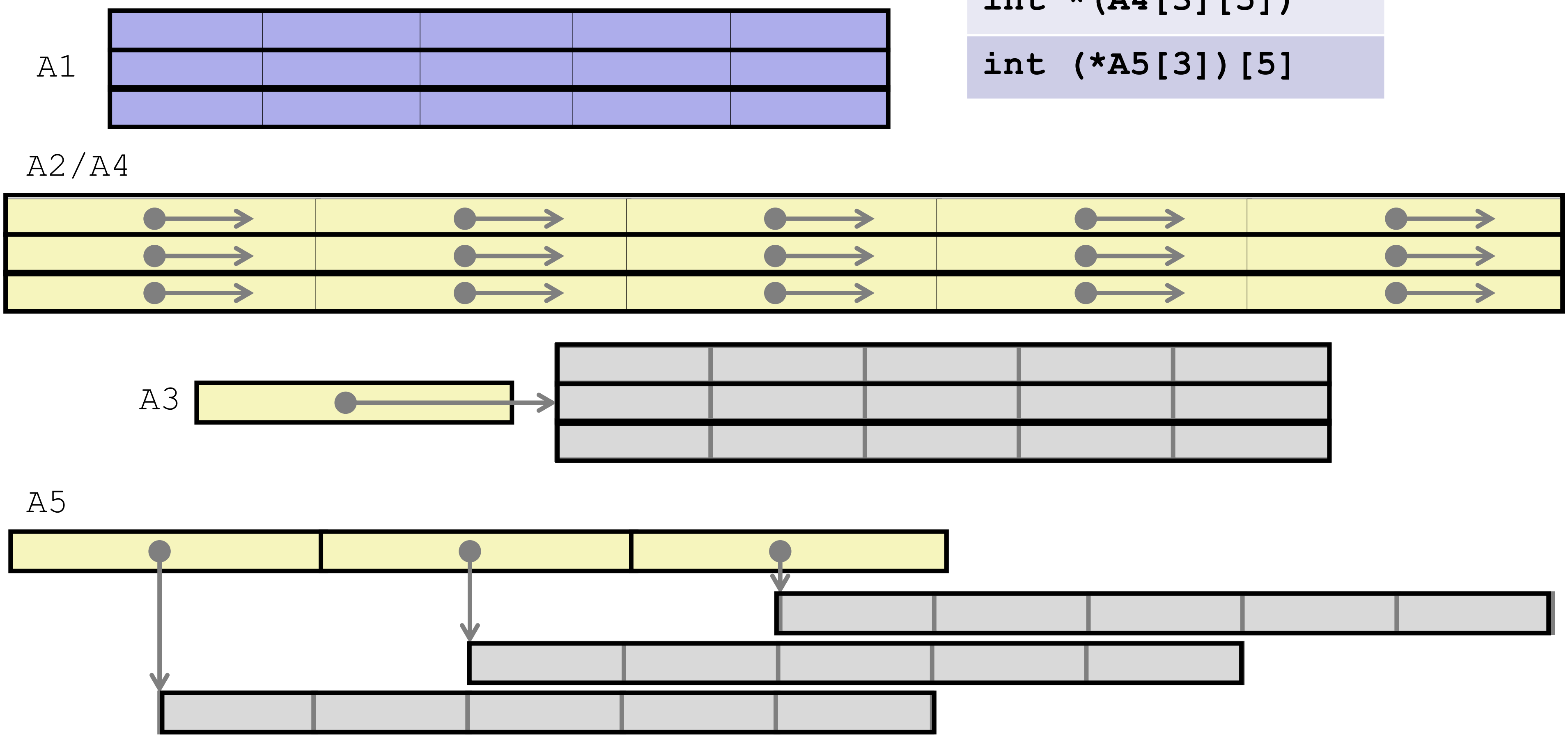
Decl	An			*An			**An		
	Cmp	Bad	Size	Cmp	Bad	Size	Cmp	Bad	Size
`int A1[3][5]`									
`int *A2[3][5]`									
`int (*A3)[3][5]`									
`int *(A4[3][5])`									
`int (*A5[3])[5]`									

Decl	***An		
	Cmp	Bad	Size
`int A1[3][5]`			
`int *A2[3][5]`			
`int (*A3)[3][5]`			
`int *(A4[3][5])`			
`int (*A5[3])[5]`			

- Cmp: Compiles (Y/N)
- Bad: Possible bad pointer reference (Y/N)
- Size: Value returned by `sizeof`



Declaration
`int A1[3][5]`
`int *A2[3][5]`
`int (*A3)[3][5]`
`int *(A4[3][5])`
`int (*A5[3])[5]`



Understanding Pointers & Arrays #3

Decl	An			*An			**An		
	Cmp	Bad	Size	Cmp	Bad	Size	Cmp	Bad	Size
`int A1[3][5]`	Y	N	60	Y	N	20	Y	N	4
`int *A2[3][5]`	Y	N	120	Y	N	40	Y	N	8
`int (*A3)[3][5]`	Y	N	8	Y	Y	60	Y	Y	20
`int *(A4[3][5])`	Y	N	120	Y	N	40	Y	N	8
`int (*A5[3])[5]`	Y	N	24	Y	N	8	Y	Y	20

Decl	***An		
	Cmp	Bad	Size
`int A1[3][5]`	N	-	-
`int *A2[3][5]`	Y	Y	4
`int (*A3)[3][5]`	Y	Y	4
`int *(A4[3][5])`	Y	Y	4
`int (*A5[3])[5]`	Y	Y	4

- Cmp: Compiles (Y/N)
- Bad: Possible bad pointer reference (Y/N)
- Size: Value returned by `sizeof`