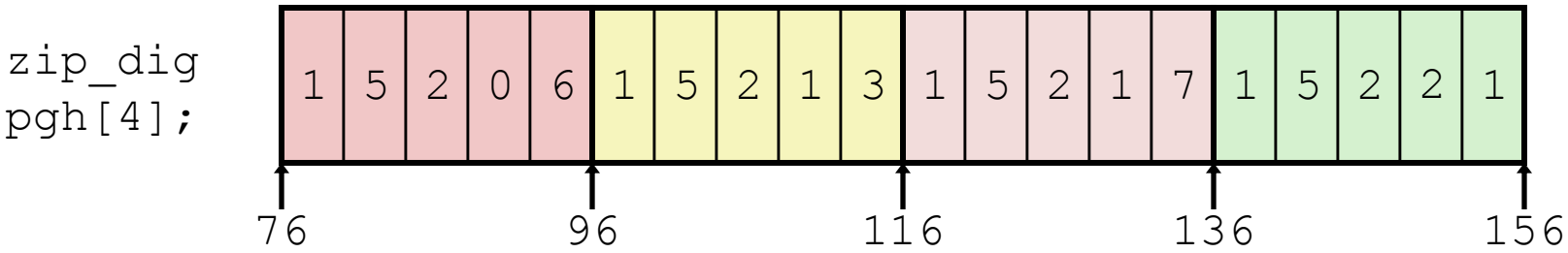
Strange Referencing Examples



- Reference Address Value Guaranteed?

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

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

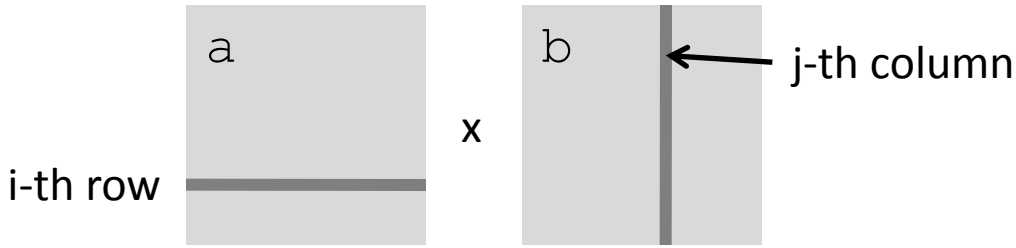
Using Nested Arrays

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

- Strengths
  - C compiler handles doubly subscripted arrays
  - Generates very efficient code
  - Avoids multiply in index computation
  - (See figure 3.28)

```
/* 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;
}
```

- Limitation
  - Only works for fixed array size



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)]
```

Dynamic Array Multiplication

- Without Optimizations
  - Multiplies: 3
    - 2 for subscripts
    - 1 for data
  - Adds: 4
    - 2 for array indexing
    - 1 for loop index
    - 1 for data

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

Optimizing Dynamic Array Multiplication

- Optimizations
  - Performed when set optimization level to **`-O2`**
- Code Motion
  - Expression **`i*n`** can be computed outside loop
- Strength Reduction
  - Incrementing **`j`** has effect of incrementing **`j*n+k`** by **`n`**
- Operations count
  - 4 adds, 1 mult

- Compiler can optimize regular access patterns

```
{
  int j;
  int result = 0;
  for (j = 0; j < n; j++)
    result +=
      a[i*n+j] * b[j*n+k];
  return result;
}
```

```
{
  int j;
  int result = 0;
  int iTn = i*n;
  int jTnPk = k;
  for (j = 0; j < n; j++) {
    result +=
      a[iTn+j] * b[jTnPk];
    jTnPk += n;
  }
  return result;
}
```

Structures

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

Memory Layout

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

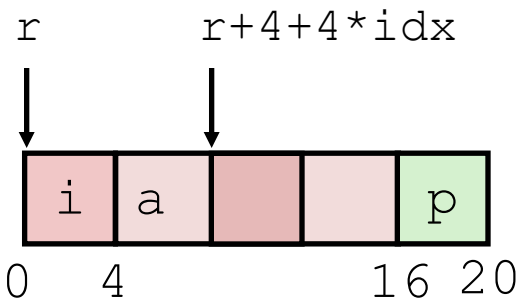
```
void
set_i(struct rec *r,
      int val)
{
  r->i = val;
}
```

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 Array Element
  - Offset of each structure member determined at compile time

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

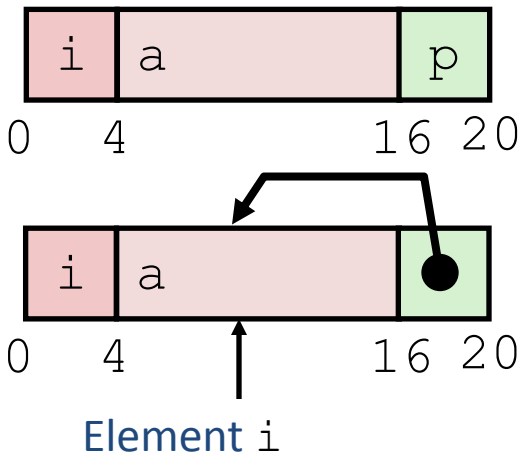
```
# %ecx = idx
# %edx = r
leal 0(,%ecx,4),%eax    # 4*idx
leal 4(%eax,%edx),%eax # r+4*idx+4
```

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];
}
```




```
 # %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
```