Applications of Pointers (1A)

Please send corrections (or suggestions) to youngwlim@hotmail.com.

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Array of Pointers

Array of Pointers

```
int     a [4];

int *   b [4];
```

No. of elements = 4

int a [4]

Type of each element

int value
int value
int value
int value

No. of elements = 4

int * b [4]

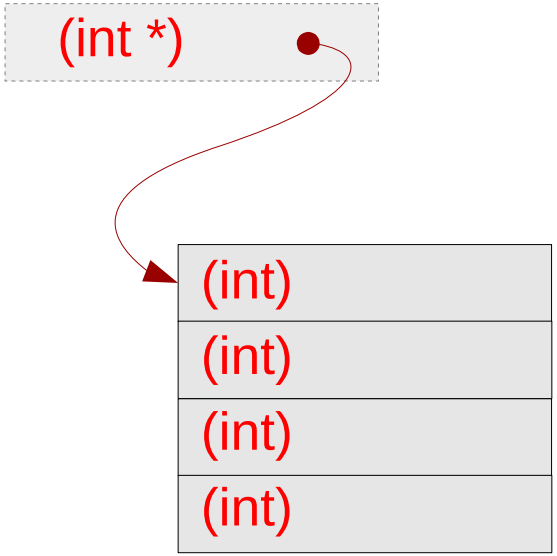
Type of each element

int pointer
int pointer
int pointer
int pointer

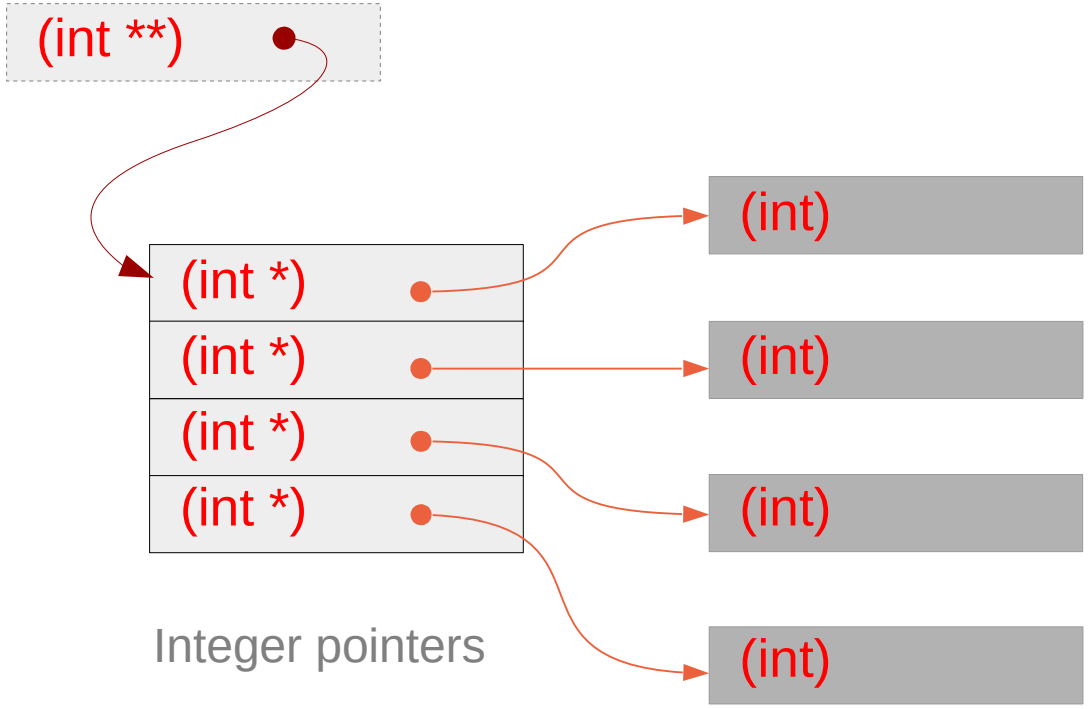
Array of Pointers – a type view

```
int     a [4];
```

```
int *   b [4];
```



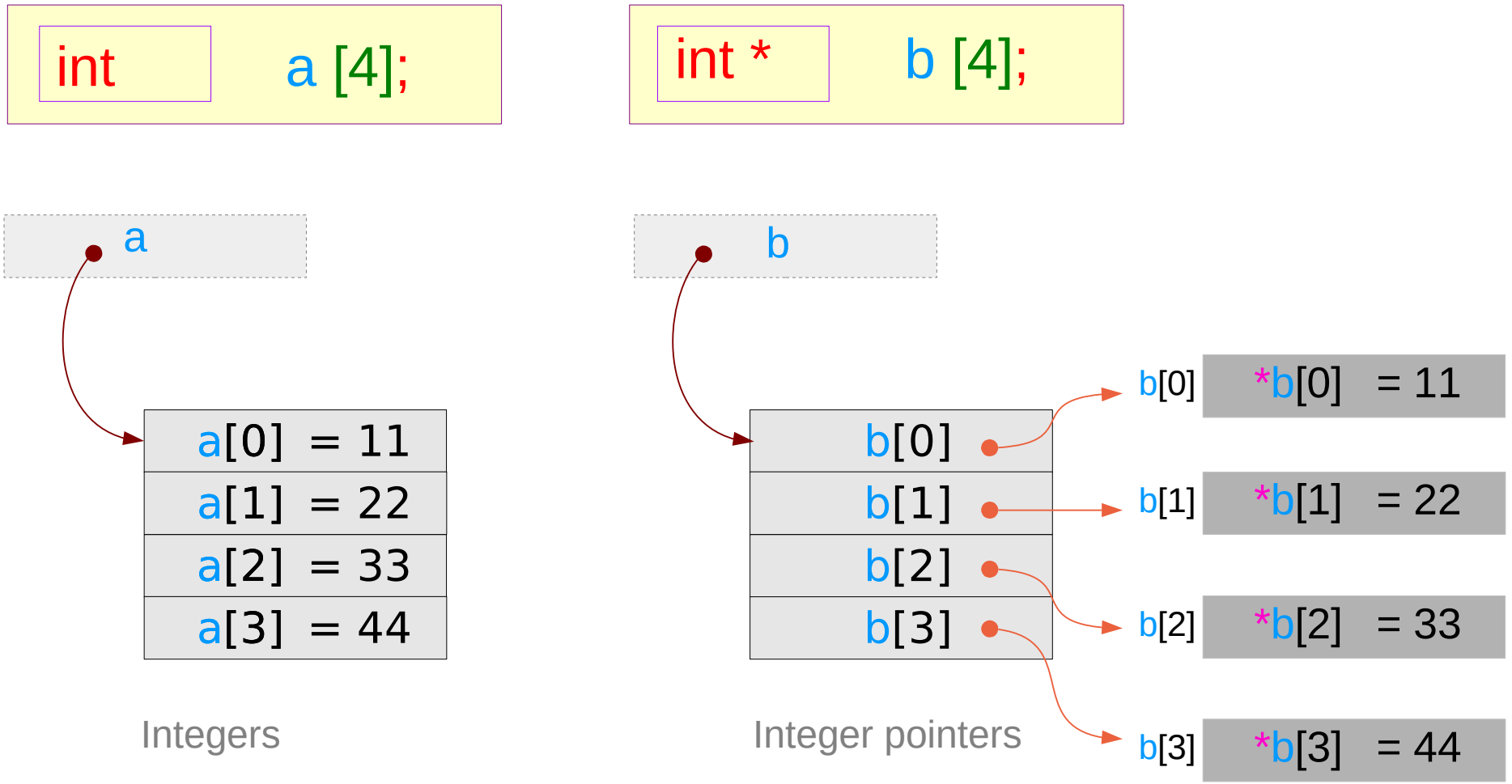
Integers



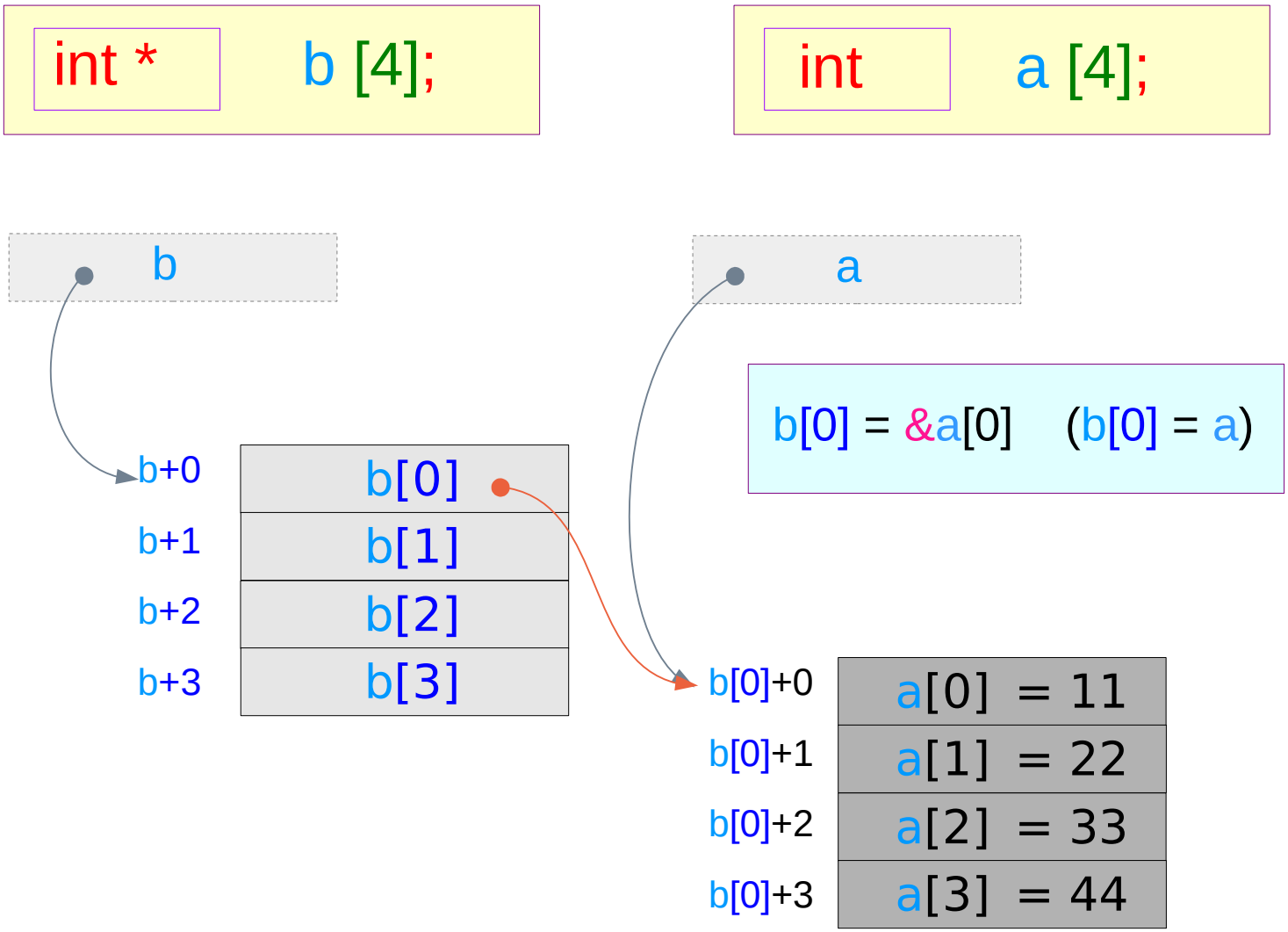
Integer pointers

taking actual
memory locations

Array of Pointers – a variable view



Array of Pointers – assigning a **1-d** array name



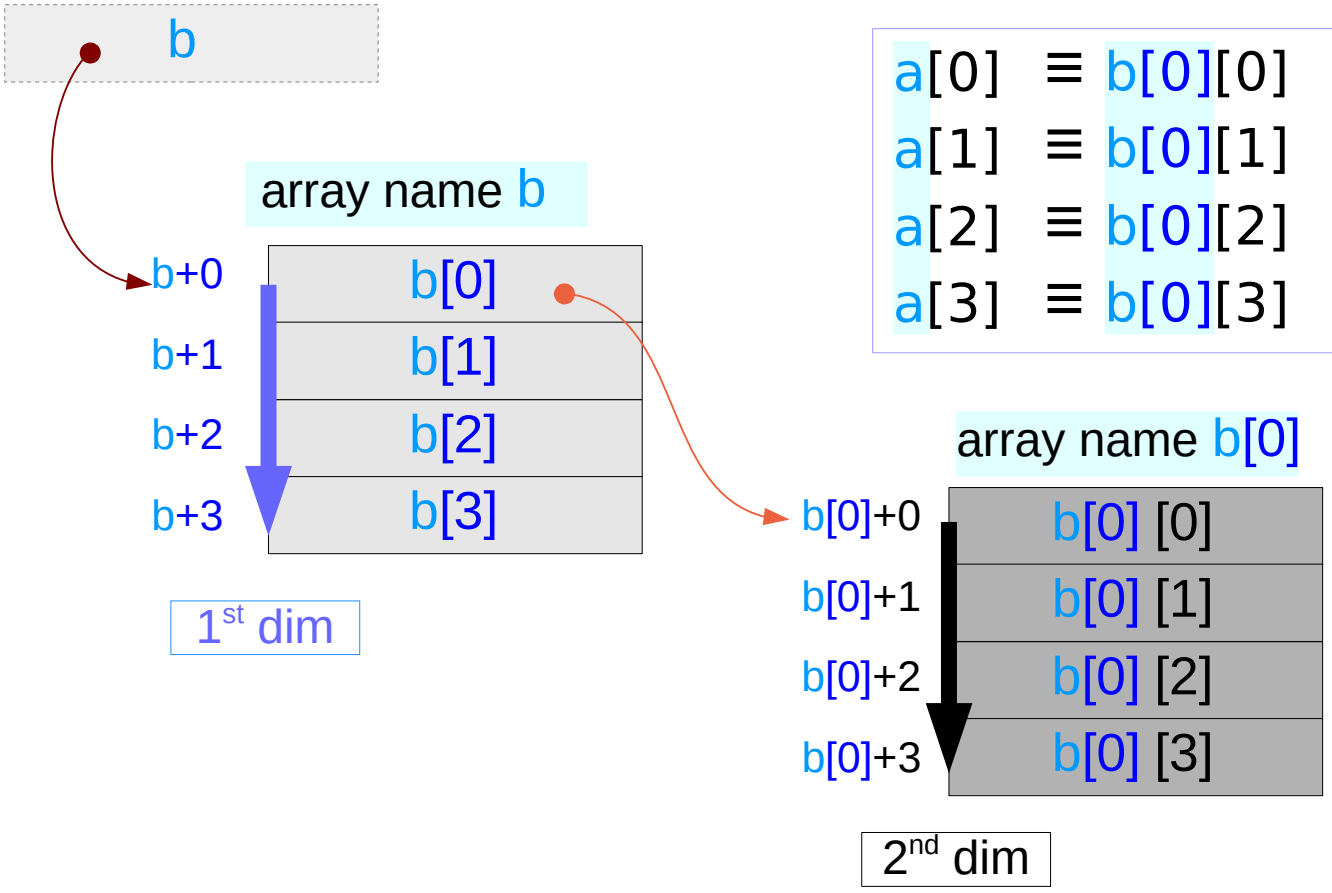
Array of Pointers – an extended dimension

```
int *   b [4];
```

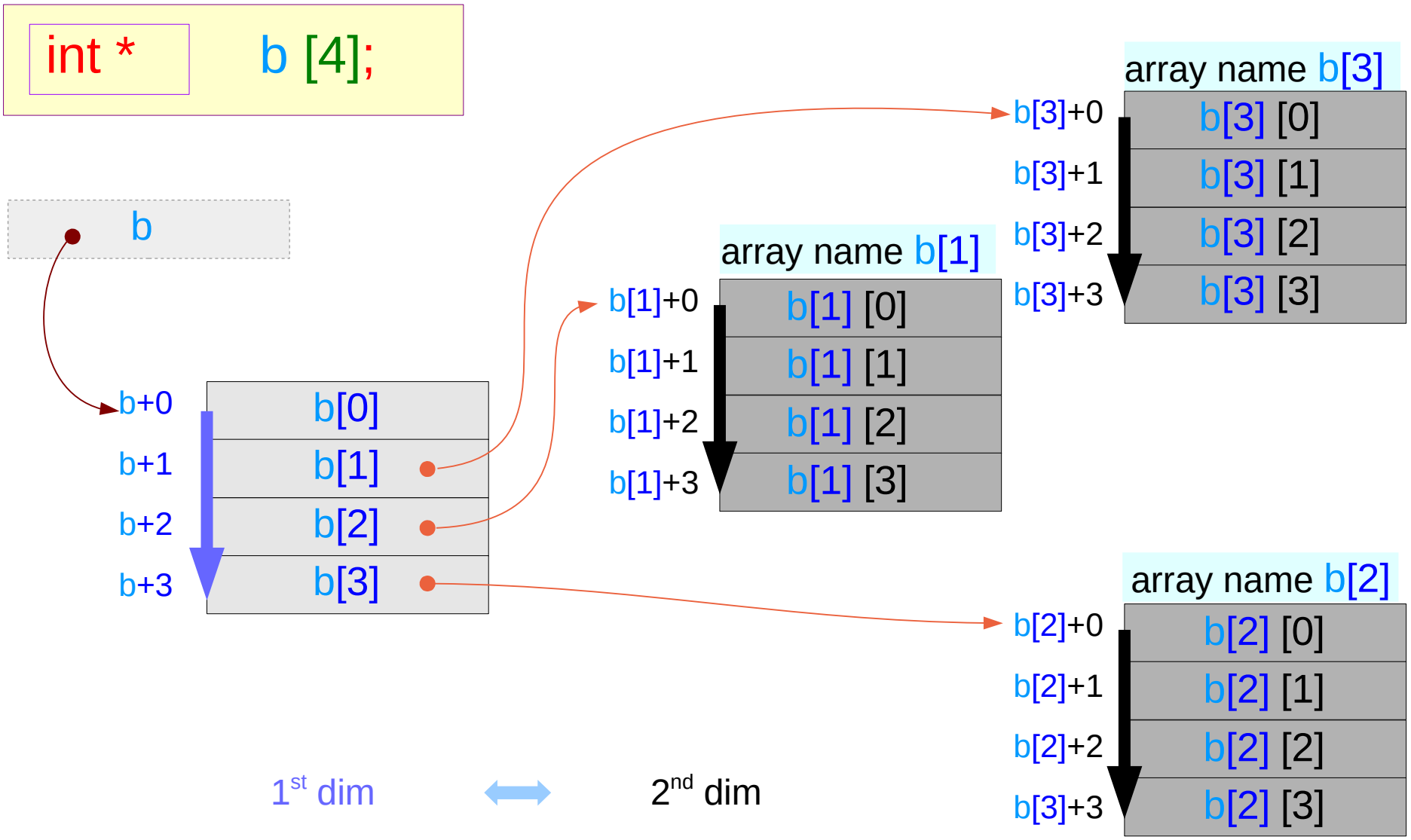
assignment b[0] = a

equivalence

a[0] ≡ b[0][0] ≡ *(*(b+0)+0)
a[1] ≡ b[0][1] ≡ *(*(b+0)+1)
a[2] ≡ b[0][2] ≡ *(*(b+0)+2)
a[3] ≡ b[0][3] ≡ *(*(b+0)+3)



Array of Pointers – assigning other **1-d** array names



2-d access of a **1-d** array – using a pointer array

```
int *   b [4];
```

```
int     a [4*4];
```

```
b[0] = &a[0*4]   (b[0] = a+  0)
b[1] = &a[1*4]   (b[1] = a+  4)
b[2] = &a[2*4]   (b[2] = a+  8)
b[3] = &a[3*4]   (b[3] = a+12)
```

2-d access of a **1-d** array

```
b[i][j]     ≡ *(*(b+i)+j)

a[i*4+j]  ≡ *(a + i*4+j)
```

1-d access of a **1-d** array

3-d access of a **1-d** array – using pointer arrays

int	a [4*4*4];
int *	b [4*4];
int **	c [4];

a[i] ≡ *(a+i)
b[i][j] ≡ *(*(b+i)+j)
c[i][j][k] ≡ *(*(*(c+i)+j)+k)

3-d access of a **1-d** array – pointer array assignment

int	a [4*4*4];
int *	b [4*4];
int **	c [4];

a[i] ≡ *(a+i)
b[i][j] ≡ *(*(b+i)+j)
c[i][j][k] ≡ *(*(*(c+i)+j)+k)

```
for (i=0; i<4; ++i)
    c[i] = &b[i*4];

for (i=0; i<4*4; ++i)
    b[i] = &a[i*4]
```

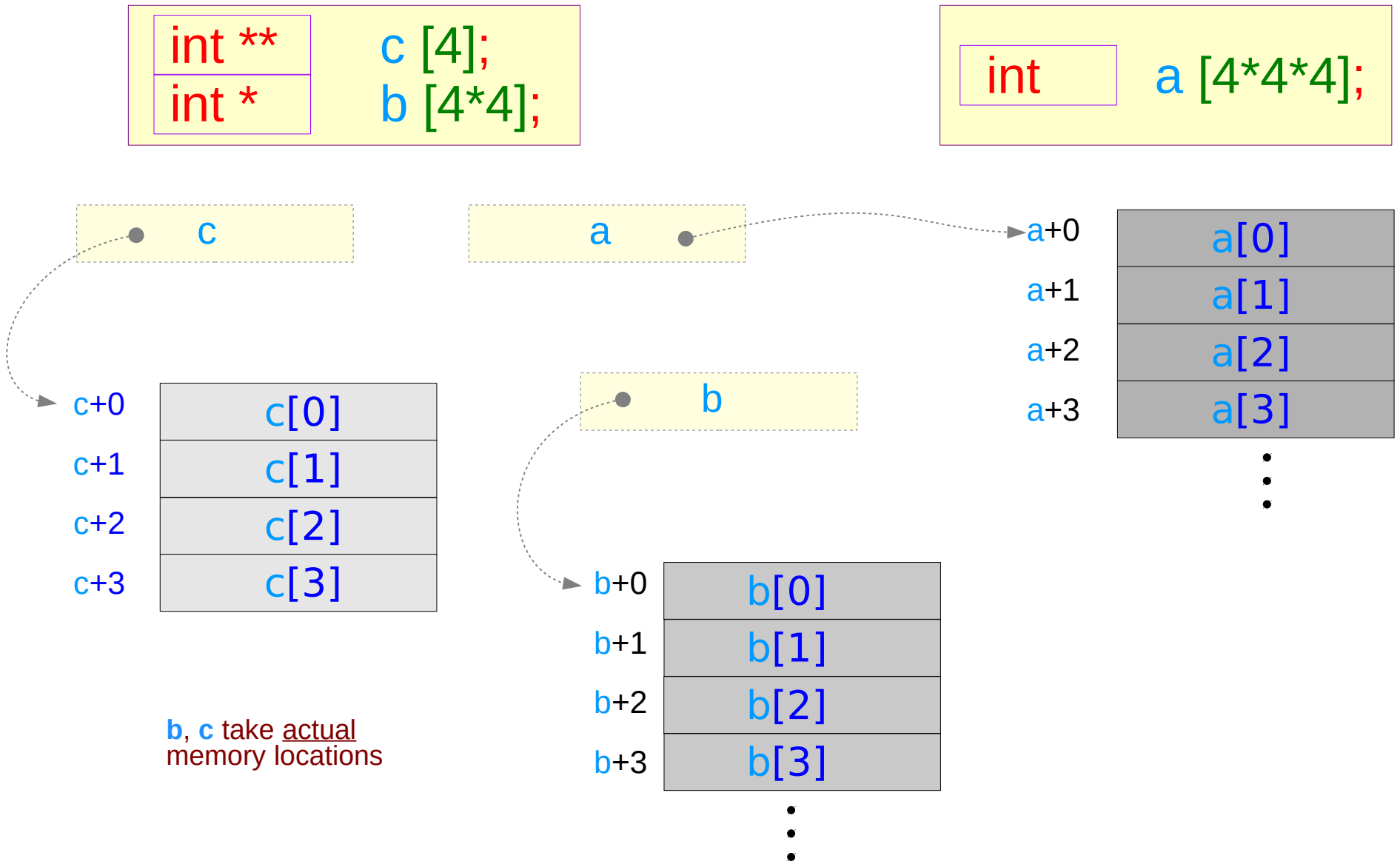
3-d access of a **1-d** array

c[i][j][k] ≡
a[i*M*N+j*N+k] ≡
a[(i*M + j)*N+k]

1-d access of a **1-d** array

Initialization of pointer arrays b and c

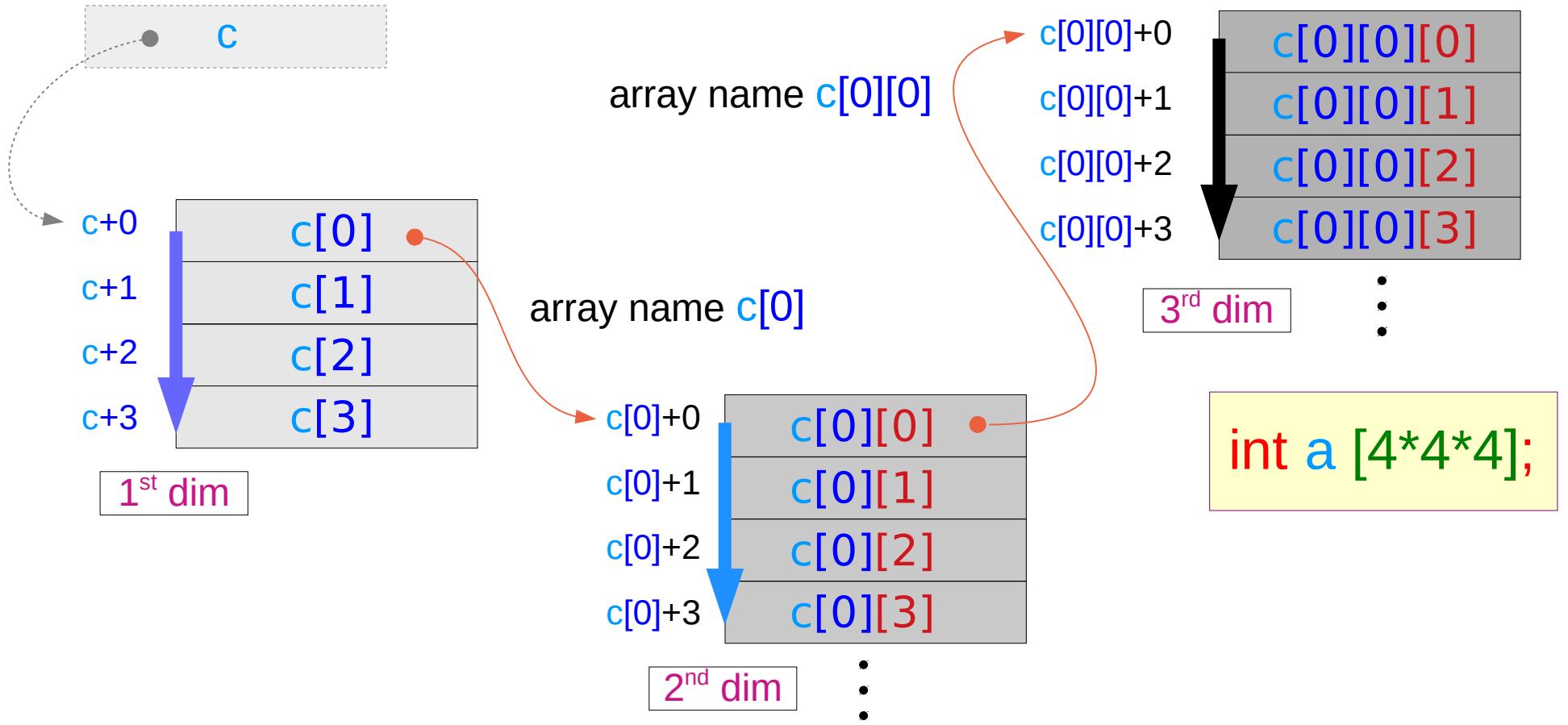
3-d Array – using pointer arrays **b**, **c**



3-d Array – pointer arrays extend dimensions

```
int **   c [4];
int *    b [4*4];
```

```
c[0] = b;        (c[0] = &b[0];)
b[0] = a;        (b[0] = &a[0];)
```




```
int a [4*4*4];
```

Using recursive pointers and brackets

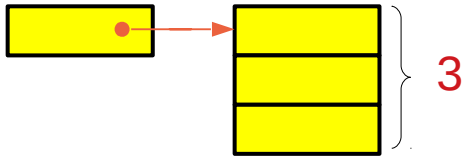
c[i][j][k]	➡	*(c[i][j] +k)	X[k] = *(X+k)
*(c[i][j] +k)	➡	*(*(c[i] +j) +k)	Y[j] = *(Y+j)
((c[i] +j) +k)	➡	*(*(*(c +i) +j) +k)	Z[i] = *(Z+i)

c[i][j][k] ⟺ *(*(*(c+i)+j)+k)

Initializing two **1-d** pointer arrays **b**, **c**

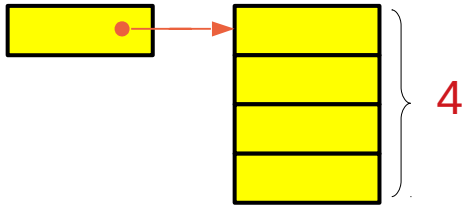
```
int     a [2*3*4];
int*    b [2*3];
int**   c [2];
```

```
c[0] = &b[0*3];
c[1] = &b[1*3];
```




```
int c[2];
int b[2*3];
```

```
b[0] = &a[0*4];
b[1] = &a[1*4];
b[2] = &a[2*4];
b[3] = &a[3*4];
b[4] = &a[4*4];
b[5] = &a[5*4];
```




```
int b[2*3];
int a[2*3*4];
```

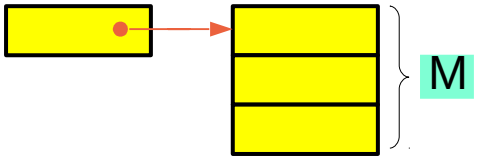
Initialization of pointer arrays – a general case

```
int     a [L*M*N];
```

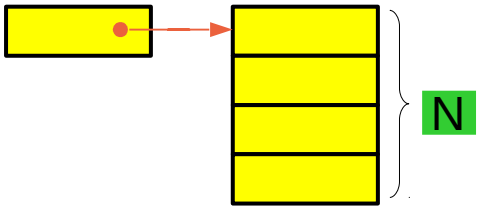
```
int*    b [L*M];
int**   c [L];
```

pointer arrays b, c

```
int **      c[L];
int *       b[L*M];

for (i=0; i<L; ++i)
      c[i] = &b[i*M];
```



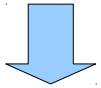

```
int *       b[L*M];
int         a[L*M*N];

for (j=0; j<L*M; ++j)
      b[j] = &a[j*N];
```



```
int     c [L][M][N];
```

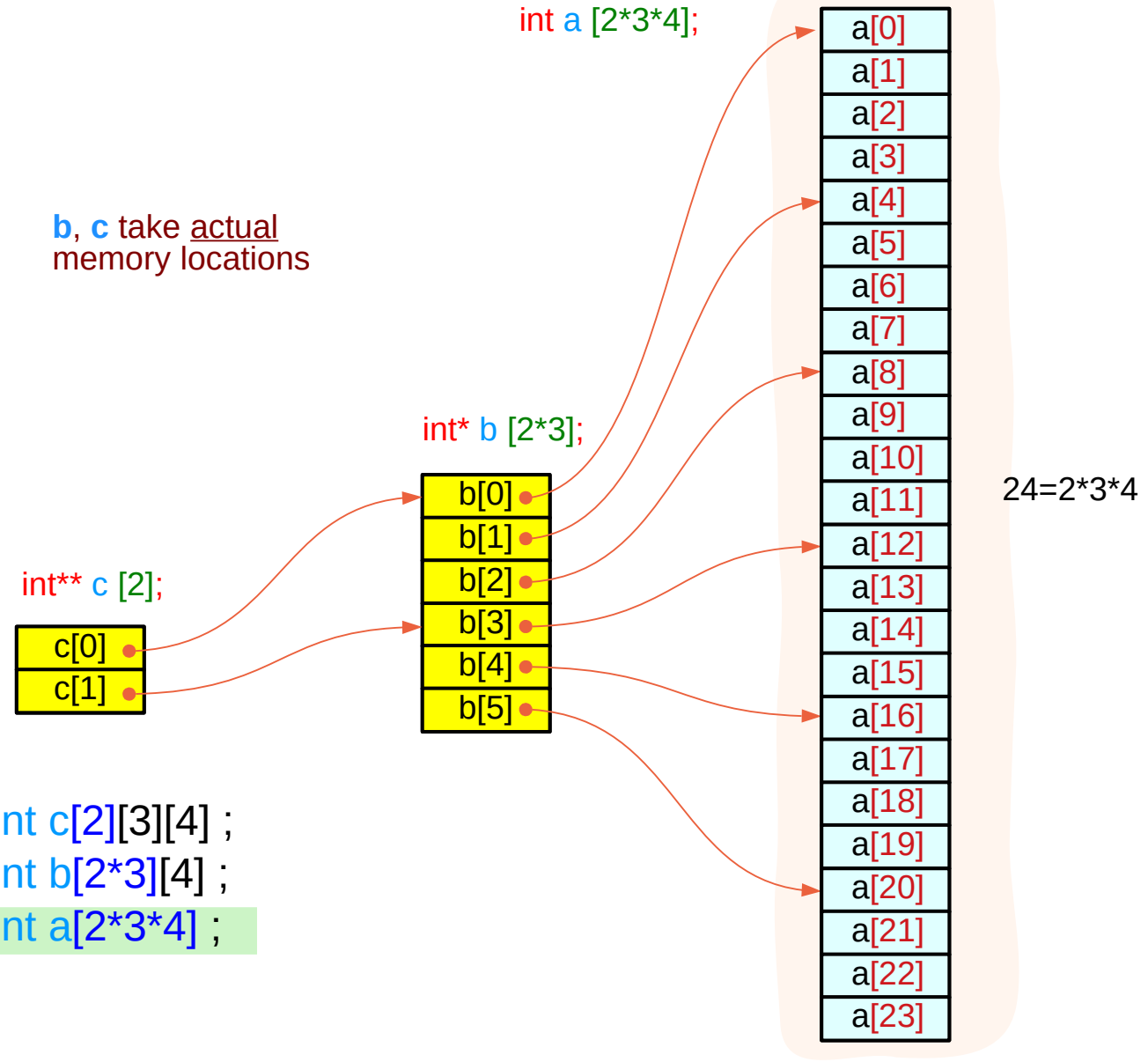
Accessing the array **a** as a **1-d** array

```
int     a [2*3*4];
int*    b [2*3];
int**   c [2];
```



```
int     a [24];
```

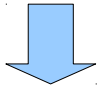
b, **c** take actual memory locations



c[i][j][k]	≡ *(*(*(c+i)+j)+k)	int c[2][3][4] ;
b[i][j]	≡ *(*(b+i)+j)	int b[2*3][4] ;
a[i]	≡ *(a+i)	int a[2*3*4] ;

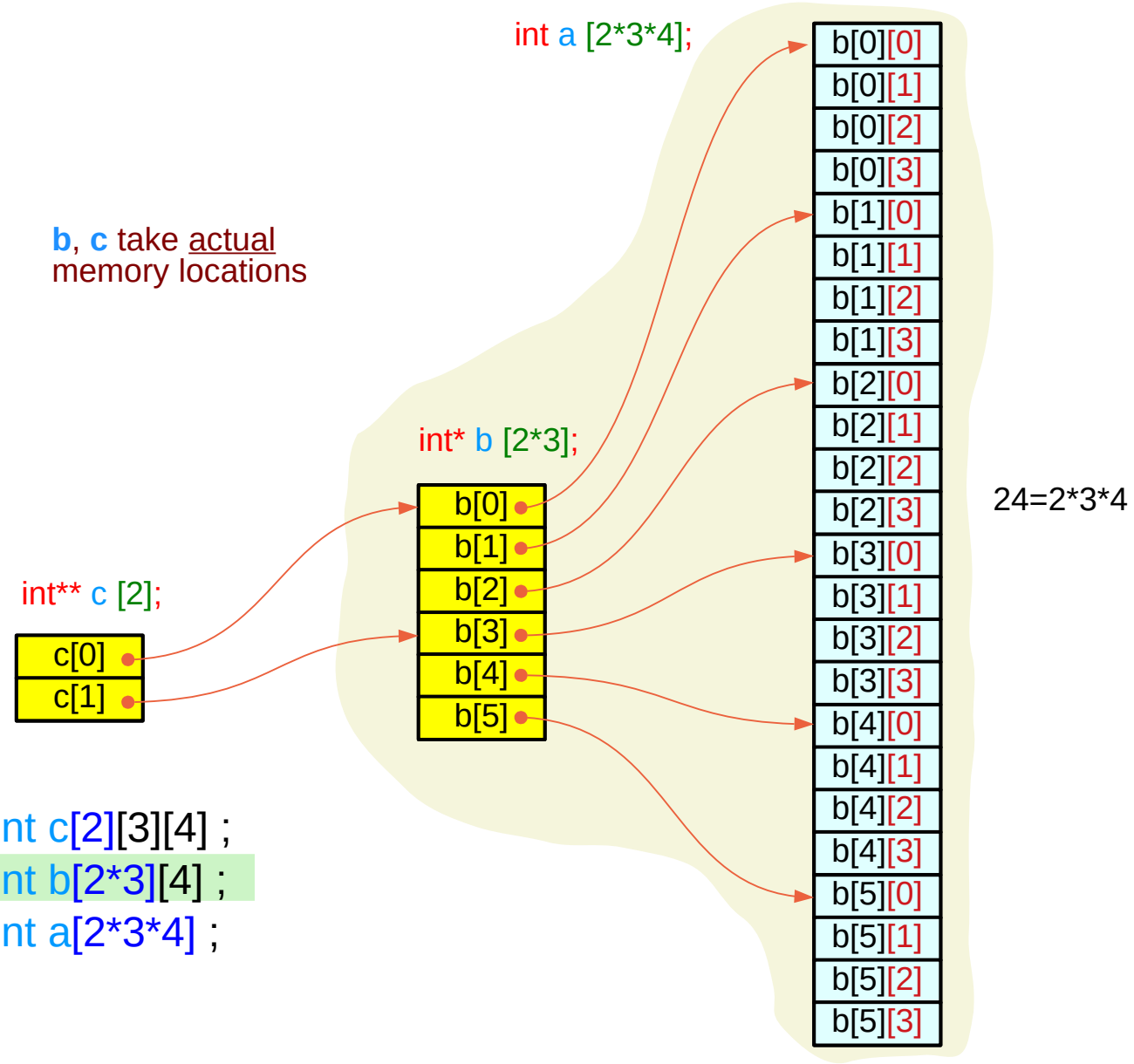
Accessing the array **a** as a **2-d** array using **b**

```
int     a [2*3*4];
int*    b [2*3];
int**   c [2];
```



```
int     b [6][4];
```

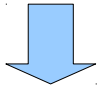
b, **c** take actual memory locations



c[i][j][k]	≡ *(*(*(c+i)+j)+k)	int c[2][3][4] ;
b[i][j]	≡ *(*(b+i)+j)	int b[2*3][4] ;
a[i]	≡ *(a+i)	int a[2*3*4] ;

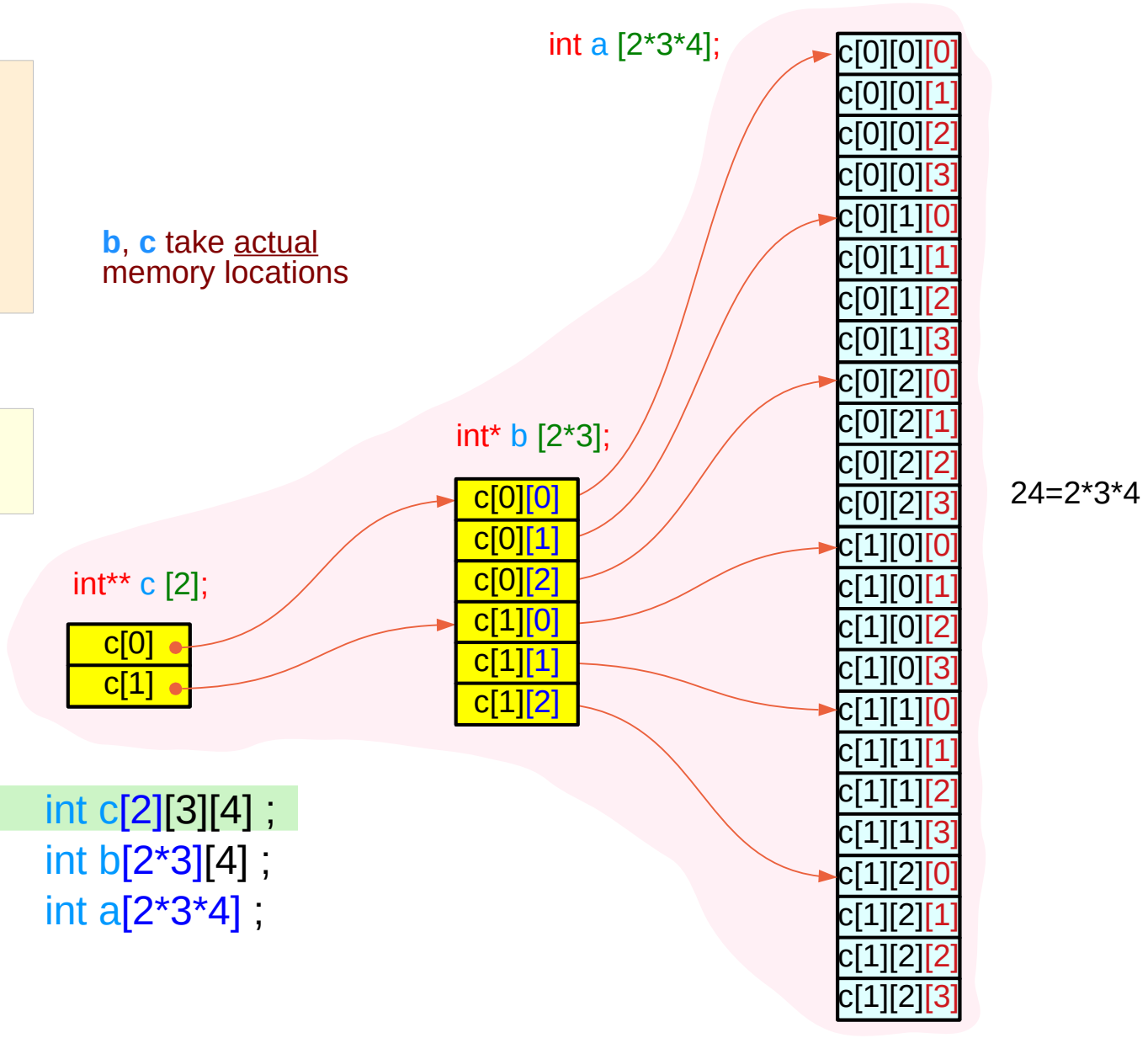
Accessing the array **a** as a **3-d** array using **c**

```
int     a [2*3*4];
int*    b [2*3];
int**   c [2];
```



```
int     c [2][3][4];
```

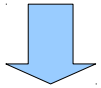
b, **c** take actual memory locations



c[i][j][k]	≡ *(*(*(c+i)+j)+k)	int c[2][3][4] ;
b[i][j]	≡ *(*(b+i)+j)	int b[2*3][4] ;
a[i]	≡ *(a+i)	int a[2*3*4] ;

Array names of **2-d** and **1-d** sub-arrays

```
int     a [2*3*4];
int*    b [2*3];
int**   c [2];
```



```
int     c [2][3][4];
```

c[0] array name of a 2-d array [M][N]
c[1] array name of a 2-d array [M][N]

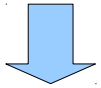
	starting elements
c[0][0][0] = a[0*M*N]	&c[0][0][0] = c[0][0]
c[1][0][0] = a[1*M*N]	&c[1][0][0] = c[1][0]

c[0][0] array name of a 1-d array [N]
c[0][1] array name of a 1-d array [N]
c[0][2] array name of a 1-d array [N]
c[1][0] array name of a 1-d array [N]
c[1][1] array name of a 1-d array [N]
c[1][2] array name of a 1-d array [N]

	starting elements
c[0][0][0] = a[(0*M+0)*N]	&c[0][0][0] = c[0][0]
c[0][1][0] = a[(0*M+1)*N]	&c[0][1][0] = c[0][1]
c[0][2][0] = a[(0*M+2)*N]	&c[0][2][0] = c[0][2]
c[1][0][0] = a[(1*M+0)*N]	&c[1][0][0] = c[1][0]
c[1][1][0] = a[(1*M+1)*N]	&c[1][1][0] = c[1][1]
c[1][2][0] = a[(1*M+2)*N]	&c[1][2][0] = c[1][2]

Starting element Index

```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```



```
int     c [L][M][N];
```

L=2

i=0	i*3*4 = 0
i=1	i*3*4 = 12

M=3

j=0	j*4 = 0
j=1	j*4 = 4
j=2	j*4 = 8

N=4

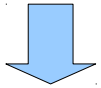
k=0	k*1= 0
k=1	k*1= 1
k=2	k*1= 2
k=3	k*1= 3

```
c[0][0][0] = a[ 0]      0
c[1][0][0] = a[12]      12

c[0][0][0] = a[ 0]      0+0
c[0][1][0] = a[ 4]      0+4
c[0][2][0] = a[ 8]      0+8
c[1][0][0] = a[12]      12+0
c[1][1][0] = a[16]      12+4
c[1][2][0] = a[20]      12+8
```

c[0][0][0]	a[0]
c[0][0][1]	a[1]
c[0][0][2]	a[2]
c[0][0][3]	a[3]
c[0][1][0]	a[4]
c[0][1][1]	a[5]
c[0][1][2]	a[6]
c[0][1][3]	a[7]
c[0][2][0]	a[8]
c[0][2][1]	a[9]
c[0][2][2]	a[10]
c[0][2][3]	a[11]
c[1][0][0]	a[12]
c[1][0][1]	a[13]
c[1][0][2]	a[14]
c[1][0][3]	a[15]
c[1][1][0]	a[16]
c[1][1][1]	a[17]
c[1][1][2]	a[18]
c[1][1][3]	a[19]
c[1][2][0]	a[20]
c[1][2][1]	a[21]
c[1][2][2]	a[22]
c[1][2][3]	a[23]

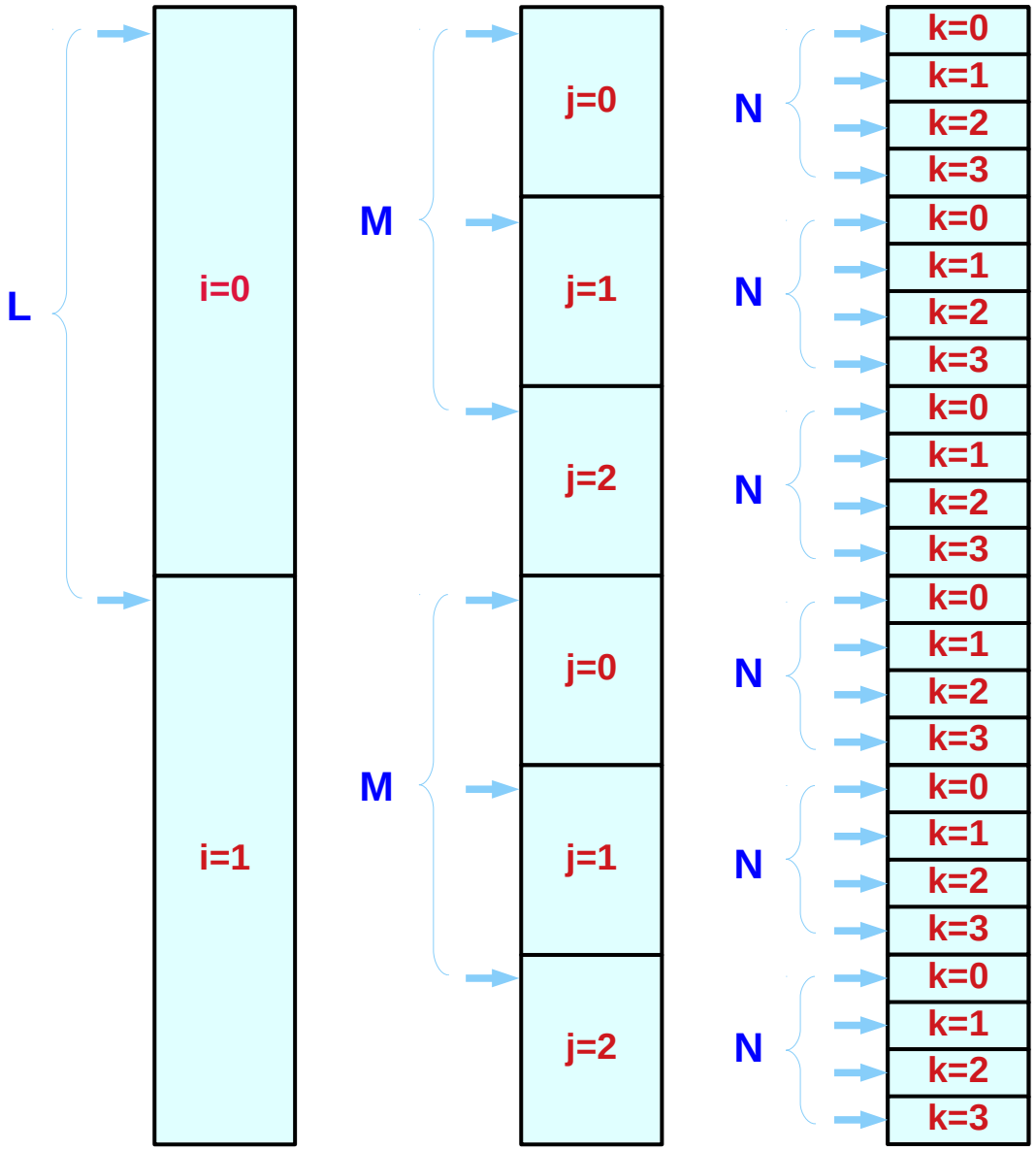
L, M, N – the number of index values

```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```



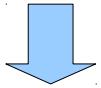
```
int     c [L][M][N];
```

L	M	N
i	j	k
[0..L-1]	[0..M-1]	[0..N-1]



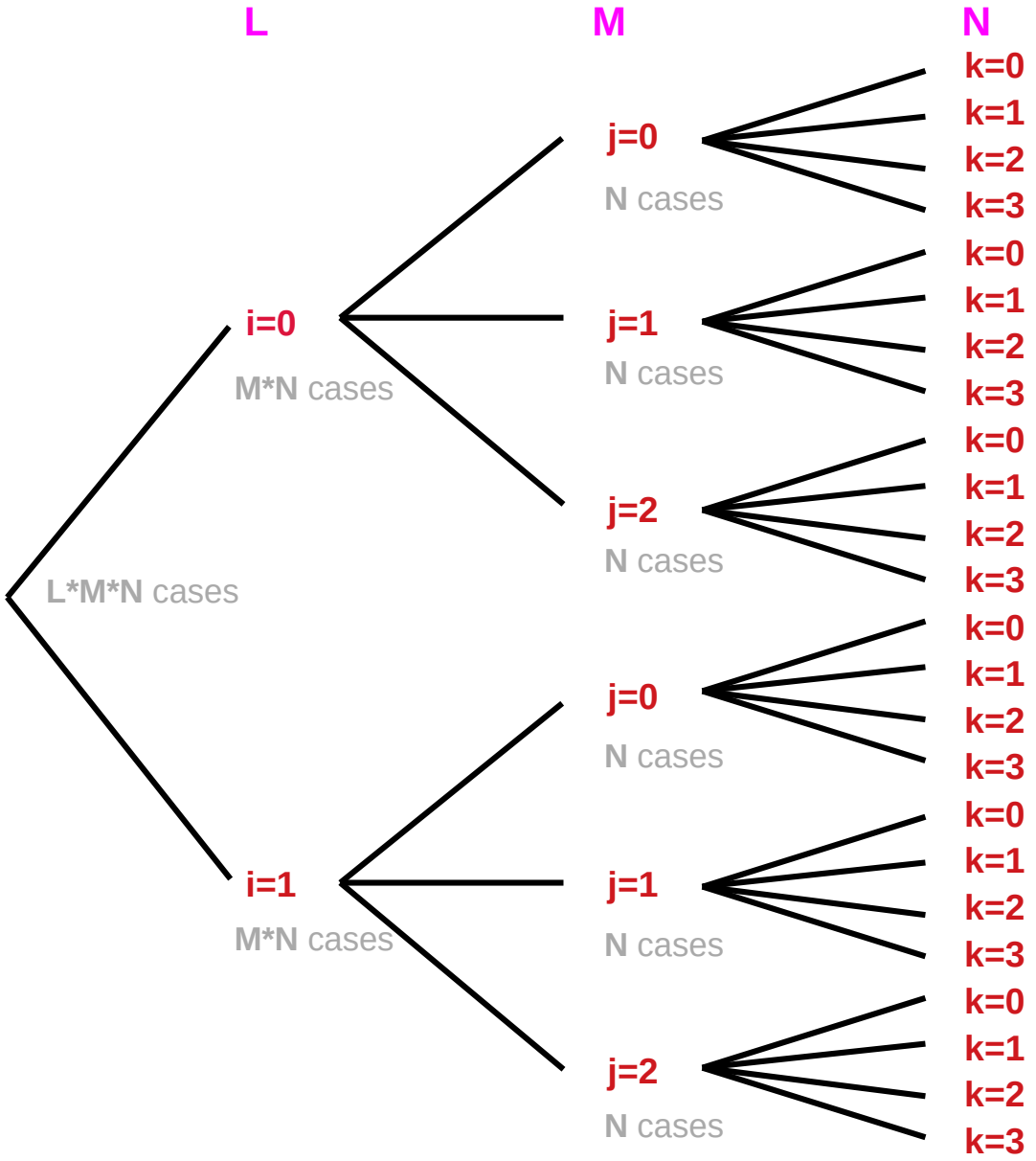
Index value tree – all possible combinations

```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```



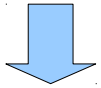
```
int     c [L][M][N];
```

L	M	N
i	j	k
[0..L-1]	[0..M-1]	[0..N-1]



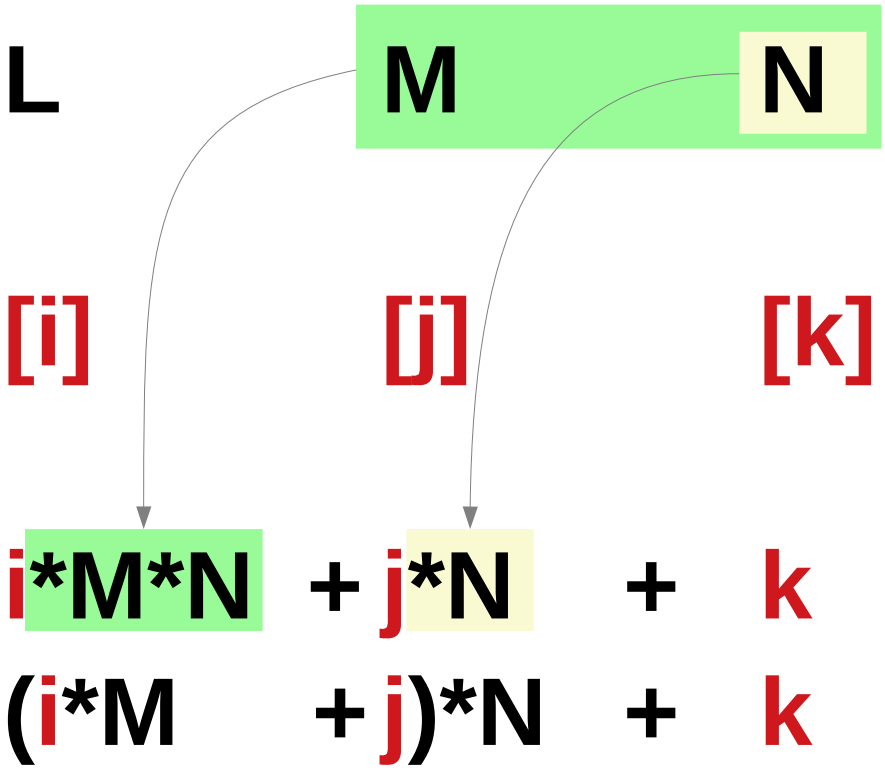
Converting a **3-d** index into a **1-d** index

```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```



```
int     c [L][M][N];
```

L	M	N
i [0..L-1]	j [0..M-1]	k [0..N-1]
i*M*N	j*N	k



3-d and 1-d accesses (recursive pointers vs. brackets)

```
c[i] = &b[i*M];
b[j] = &a[j*N];
```

```
c[i][j][k]      ≡   a[i*M*N + j*N + k]
                ≡   a[(i*M + j)*N + k]
```

```
int **      c[L];
int *       b[L*M];
```

```
for (i=0; i<L; ++i)
    c[i] = &b[i*M];
```

```
int *       b[L*M];
int         a[L*M*N];
```

```
for (j=0; j<L*M; ++j)
    b[j] = &a[j*N];
```

```
c[i][j][k]
= *(*(*(c+i)+j)+k)
= *(*(c[i]+j)+k)          ← c[i] =&b[i*M]
= *(*(&b[i*M]+j)+k)       ← *(*(b+i*M+j)+k)
= *(b[i*M+j]+k)           ← b[m] = &a[m*N]
= *(&a[(i*M+j)*N]+k)      ← *(a+(i*M+j)*N+k)
= a[(i*M+j)*N+k]
```

i*M*N, j*N, k – index offset values

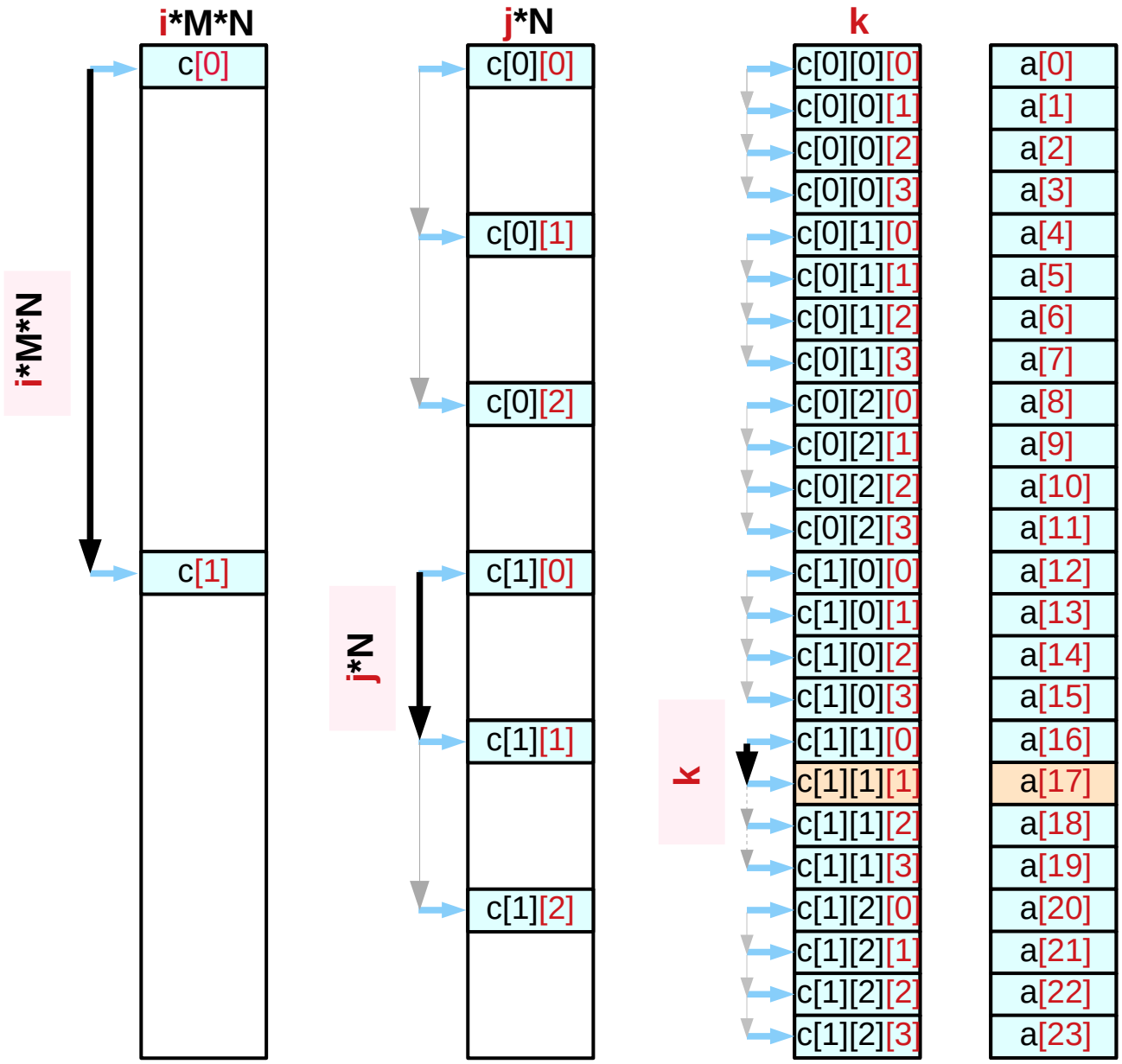
```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```

```
int     c [L][M][N];
```

c [1][1][1]

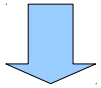
i=1	j=1	k=1

a [(1*3 + 1)*4 + 1]



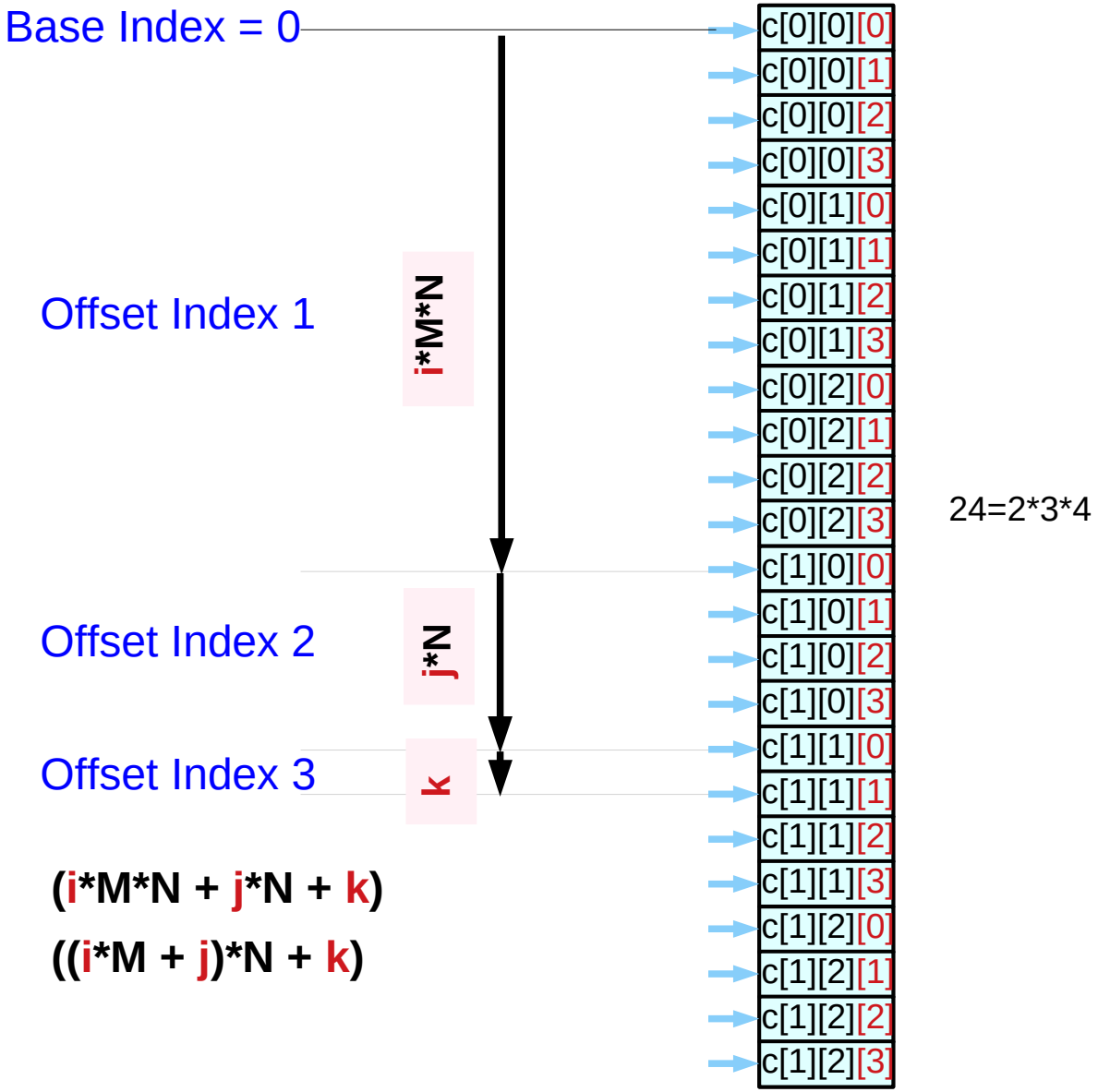
Accessing **a** by base and offset indices

```
int     a [L*M*N];
int*    b [L*M];
int**   c [L];
```

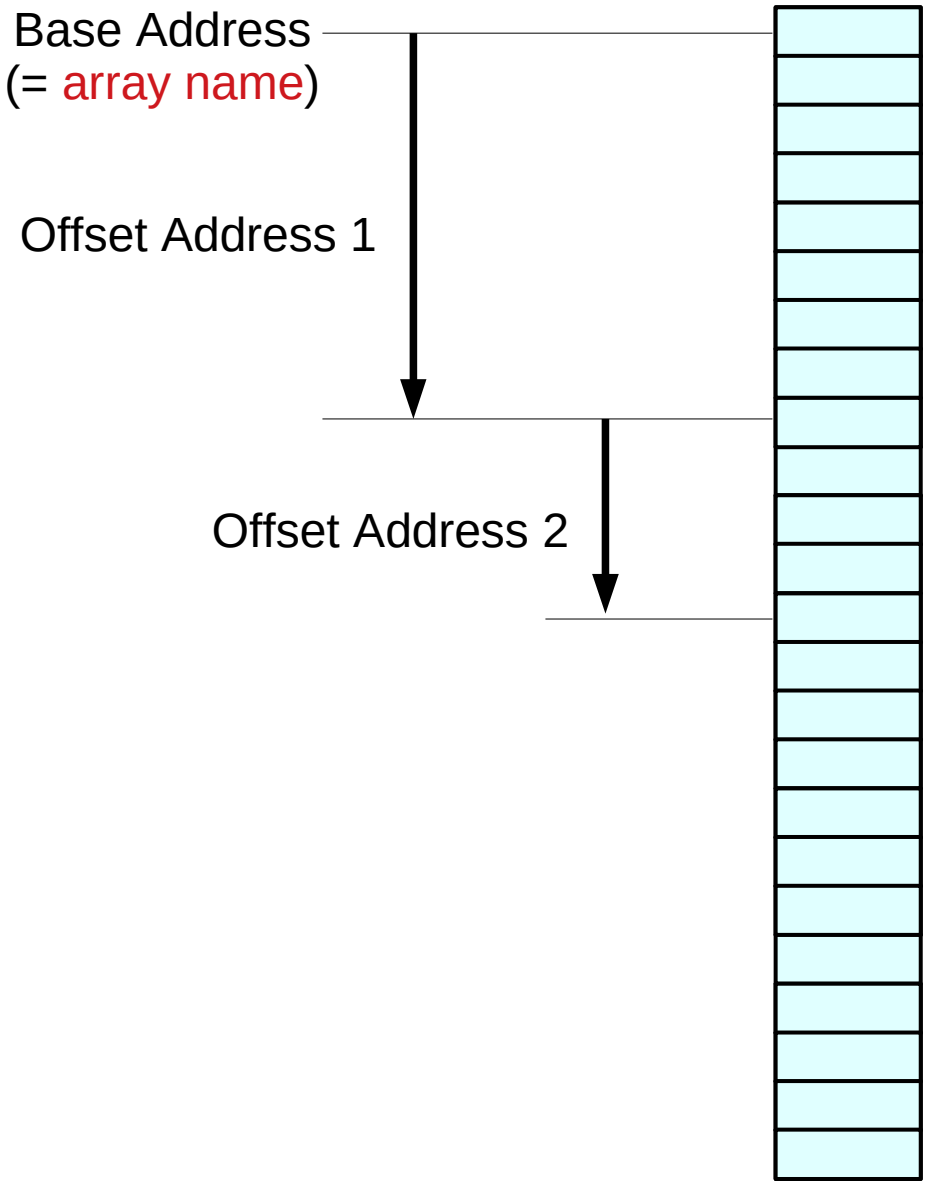


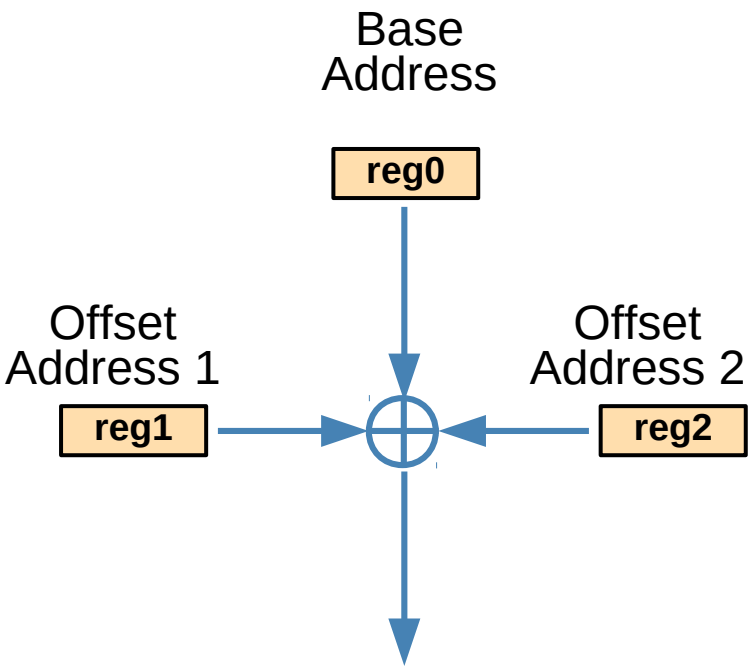
```
int     c [L][M][N];
```

L	M	N
i [0..L-1]	**j** [0..M-1]	**k** [0..N-1]
i*M*N	**j*N**	**k**



Base and Offset Addressing



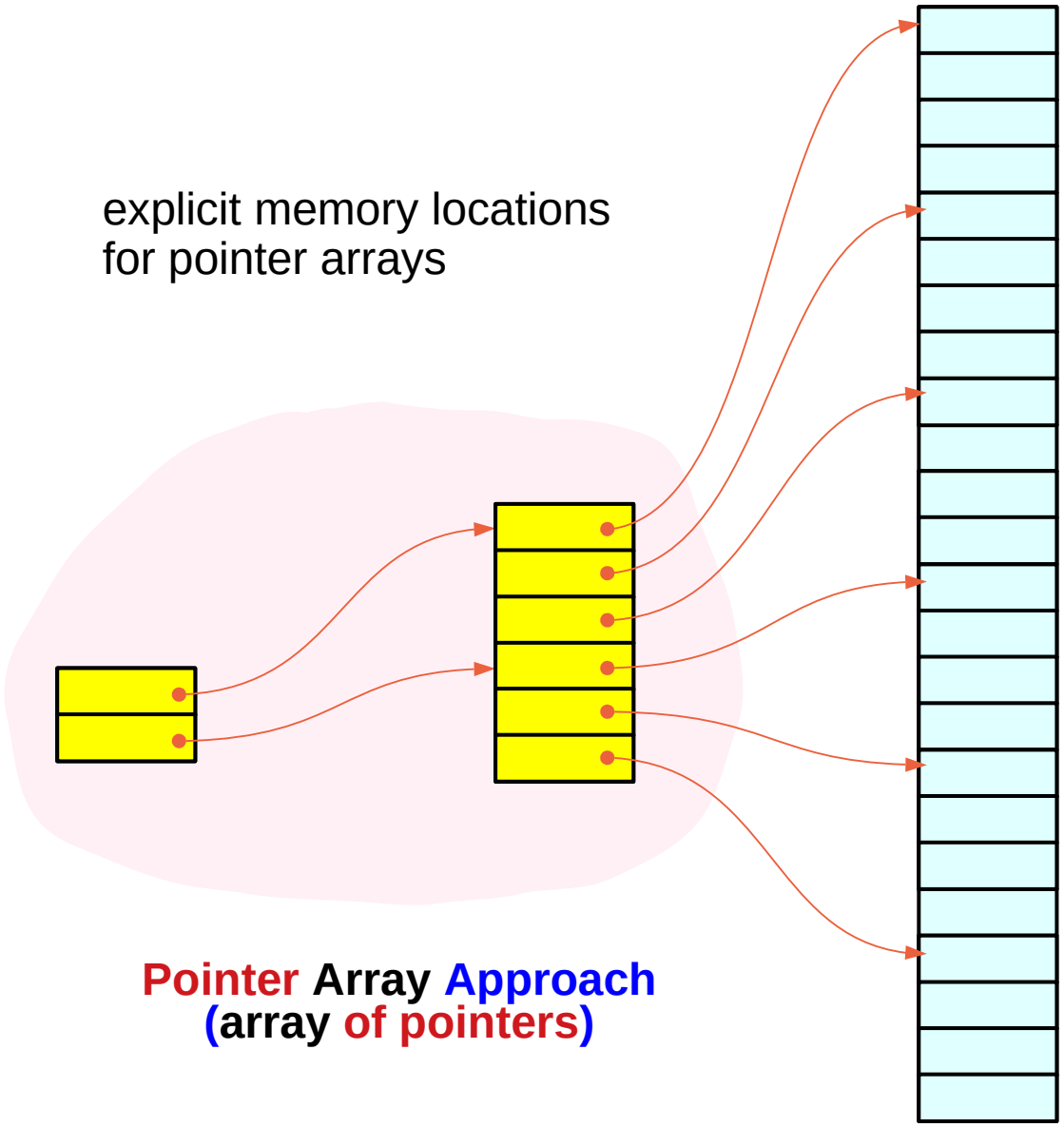


compiler

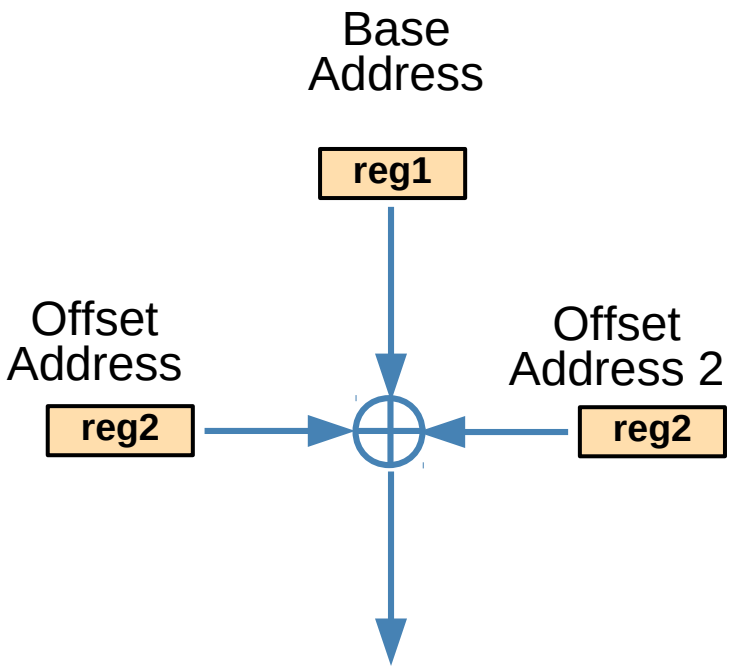
assembly instruction

CPU registers

Pointer Array vs. Array Pointer



Pointer Array Approach
(array of pointers)



CPU register based address **computations** eliminate the pointer arrays

Array Pointer Approach
(pointer to arrays)

Pointer to an array – variable declarations

```
int   m ;
int  *n ;
```

an integer pointer

Array Pointer Approach
(pointer to arrays)

```
int   a   [4]
int  (*p) [4]
```

an array pointer

```
int  func  (int  a,  int  b) ;
int  (* fp)  (int  a,  int  b) ;
```

a function pointer

Pointer to an array – a type view

int 4 byte data

int *

an integer pointer

array pointer:
a pointer to an array

pointer array:
an array of pointers

int [4] 4*4 byte data

int (*) [4]

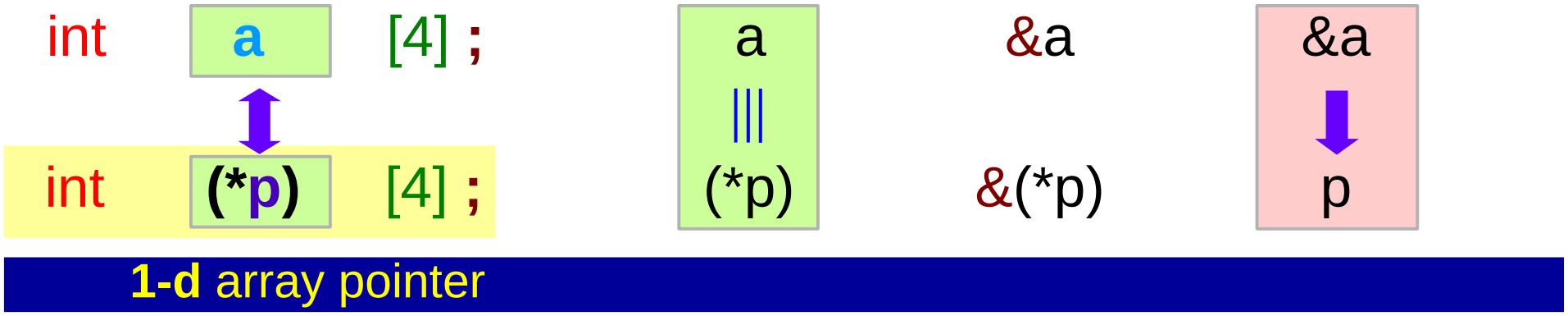
an array pointer

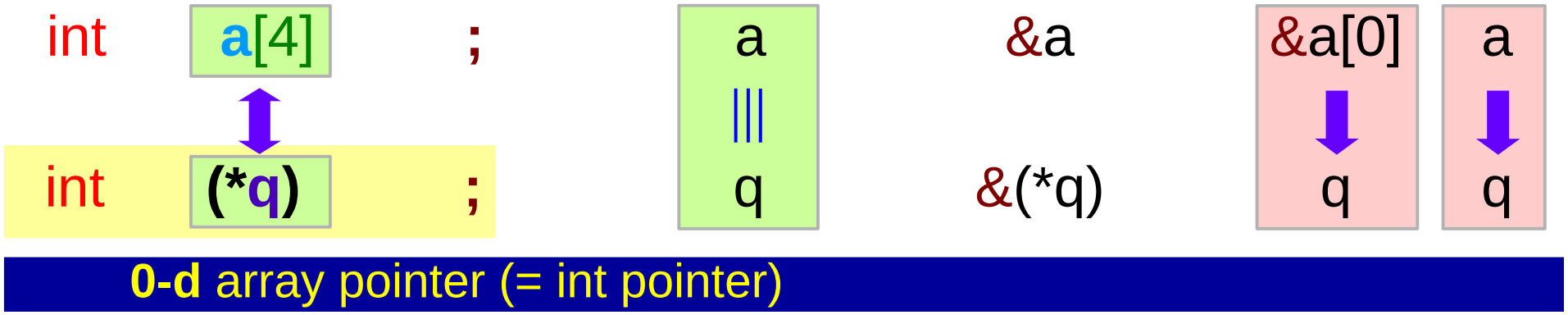
int (int, int) instructions

int (*) (int, int)

a function pointer

Pointer to an array : assignment and equivalence





Pointer to an array : size of array

```
int     a     [4] ;
```

```
int     (*p)  [4] ;
```

1-d array pointer

p = &a;

sizeof(p)= 8 bytes : the size of a pointer
sizeof(*p)= 4*4 bytes : the whole size of the pointed 1-d array

```
int     a[4]      ;
```

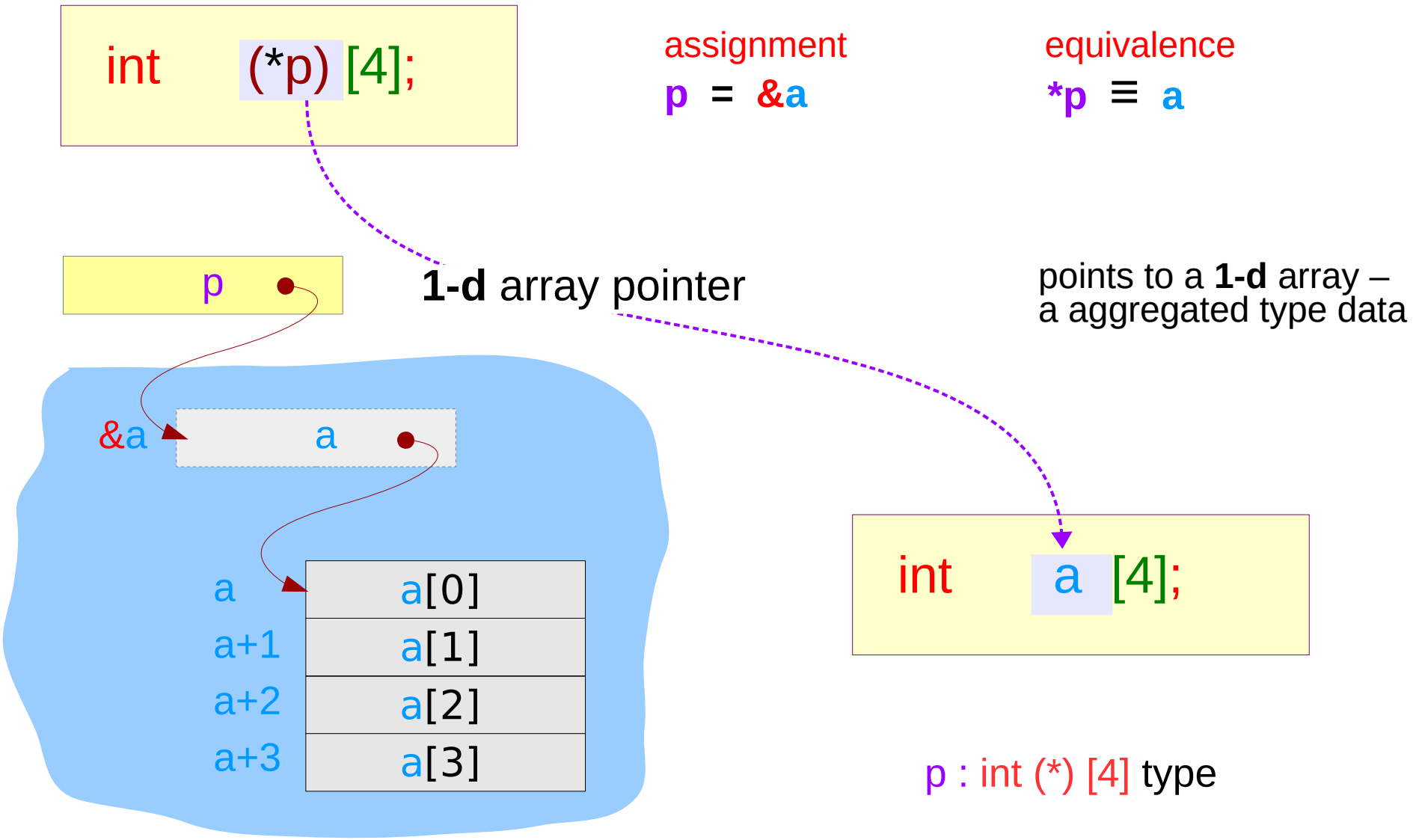
```
int     (*q)      ;
```

0-d array pointer

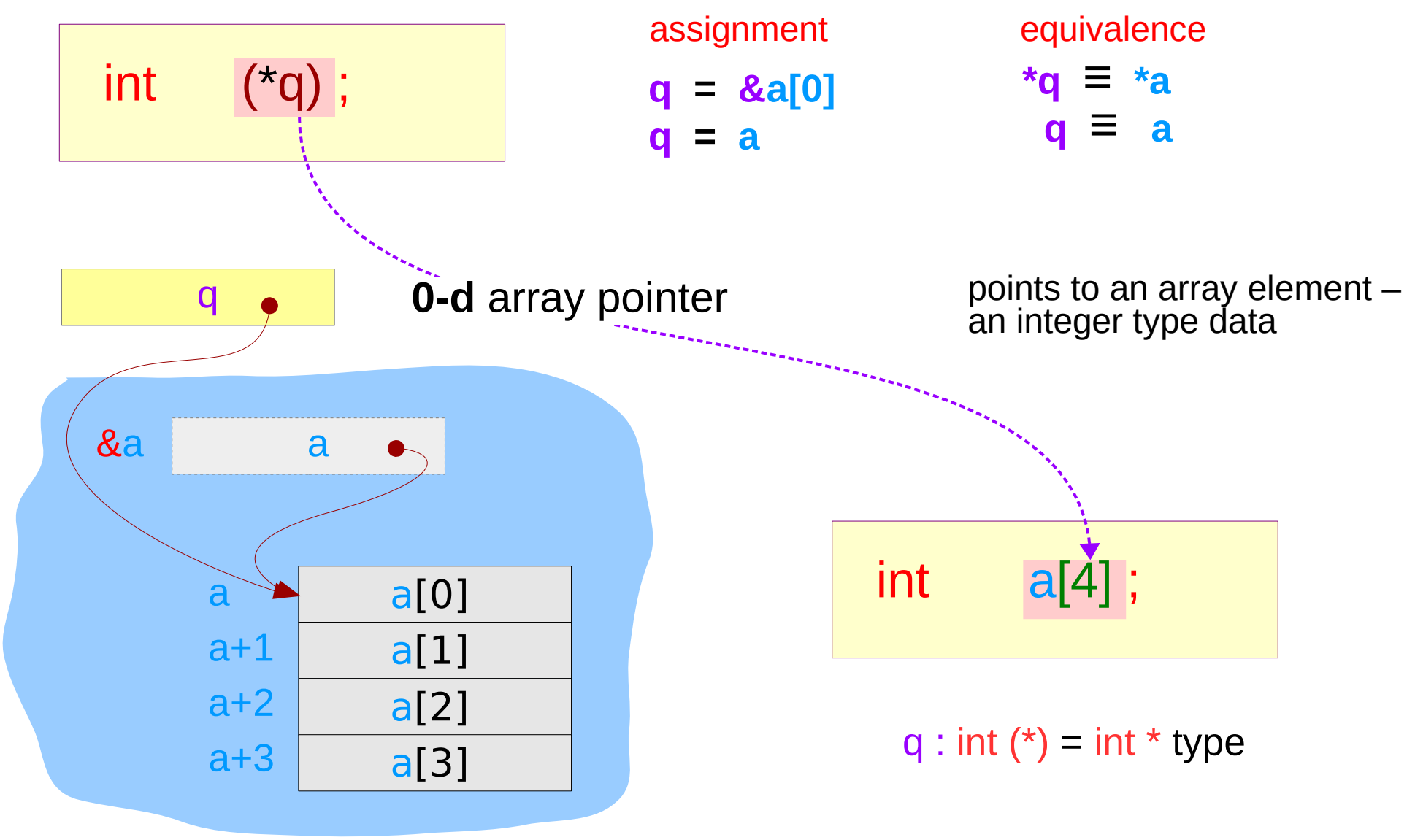
q = a;

sizeof(q)= 8 bytes : the size of a pointer
sizeof(*q)= 4 bytes : the whole size of the pointed 0-d array

Pointer to an array – a variable view (1)



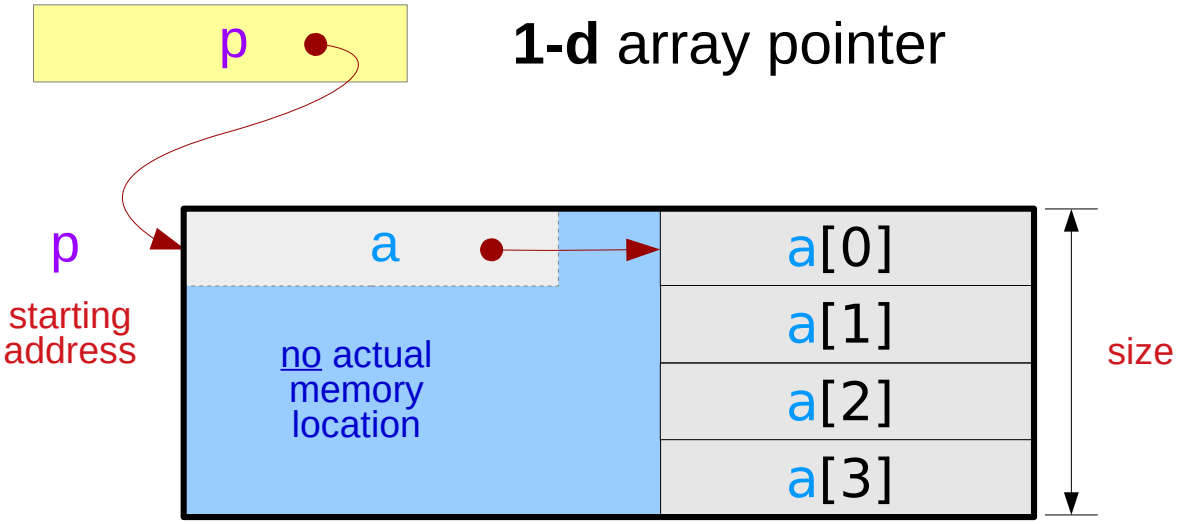
Pointer to an array – a variable view (2)



Pointer to a **1-d** array – an aggregated type view

```
int     (*p) [4];
```

An aggregated type
- starting address (&a)
- size of all the array elements (16 bytes)



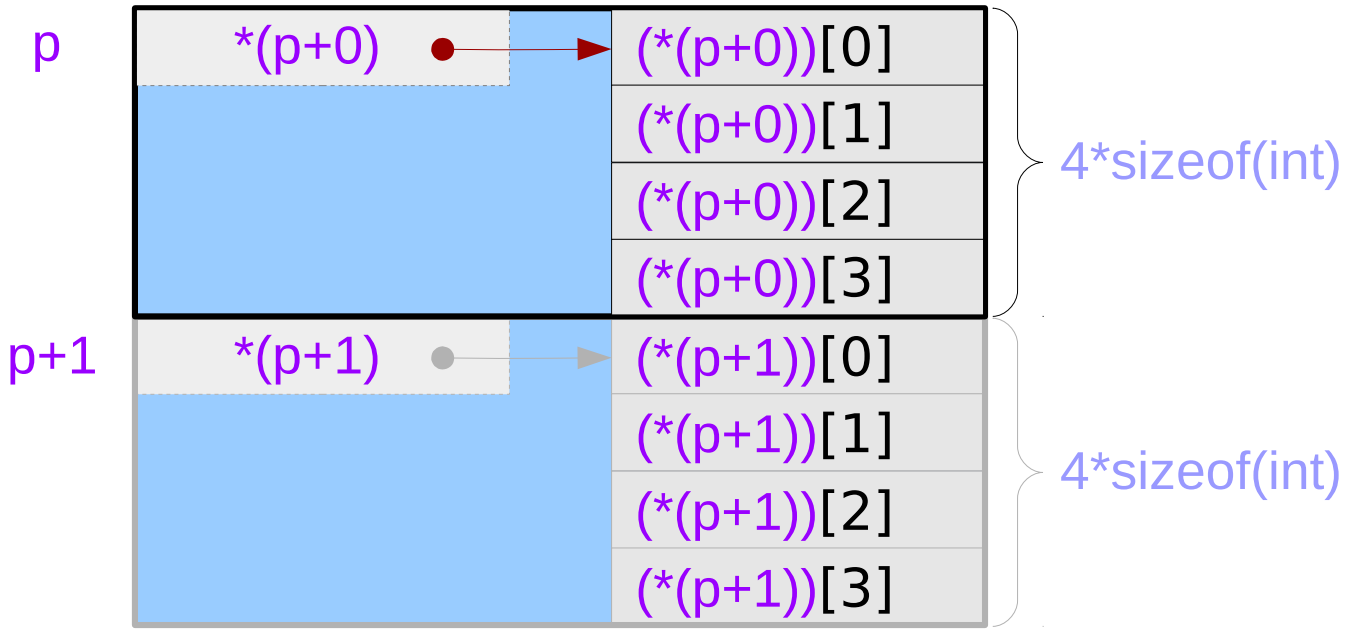
Incrementing an array pointer

```
int     (*p) [4];
```

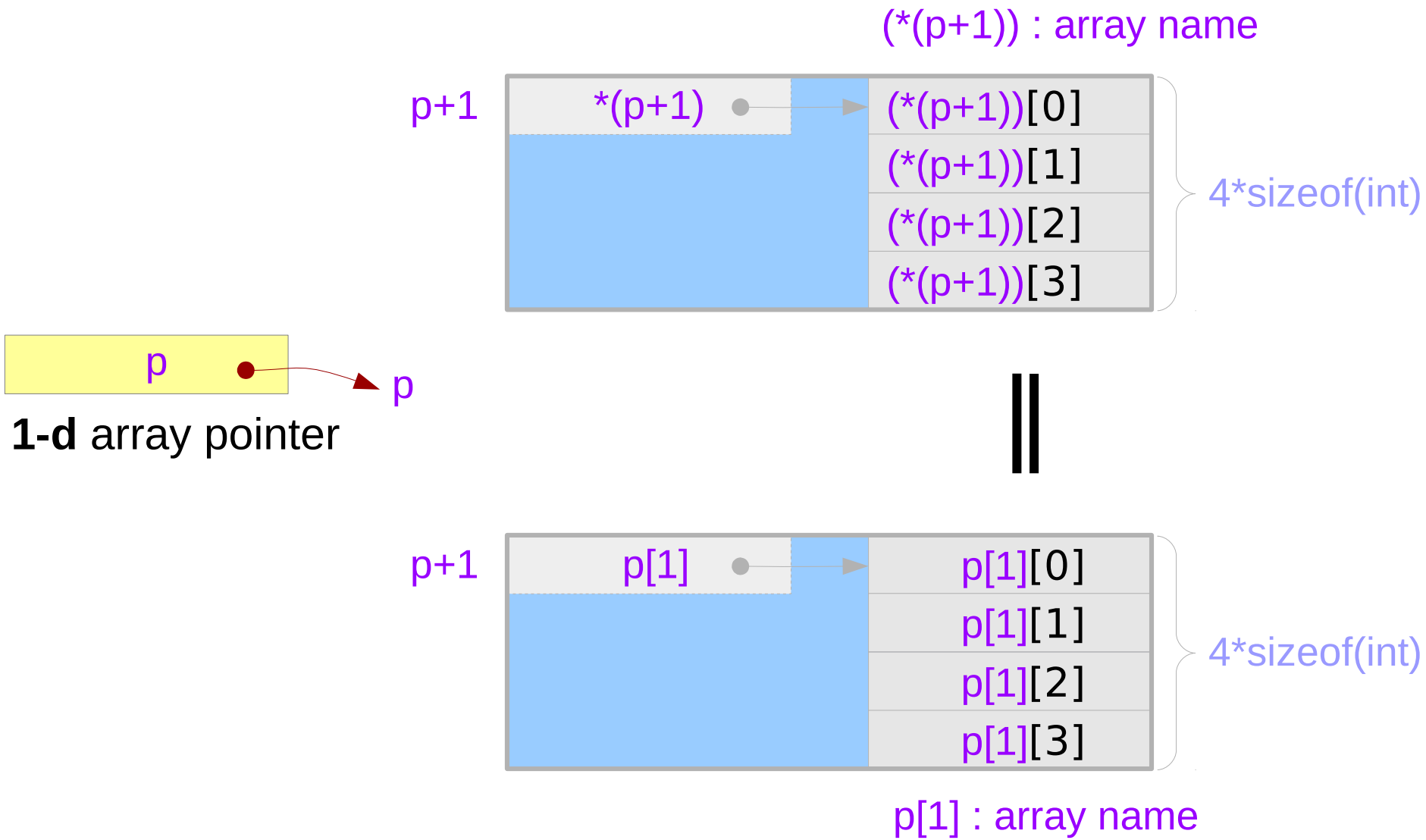
Aggregated Type Size

address p+1 – **address** p
= (long) (p+1) - (long) (p) = 4 * sizeof(int)

1-d array pointer



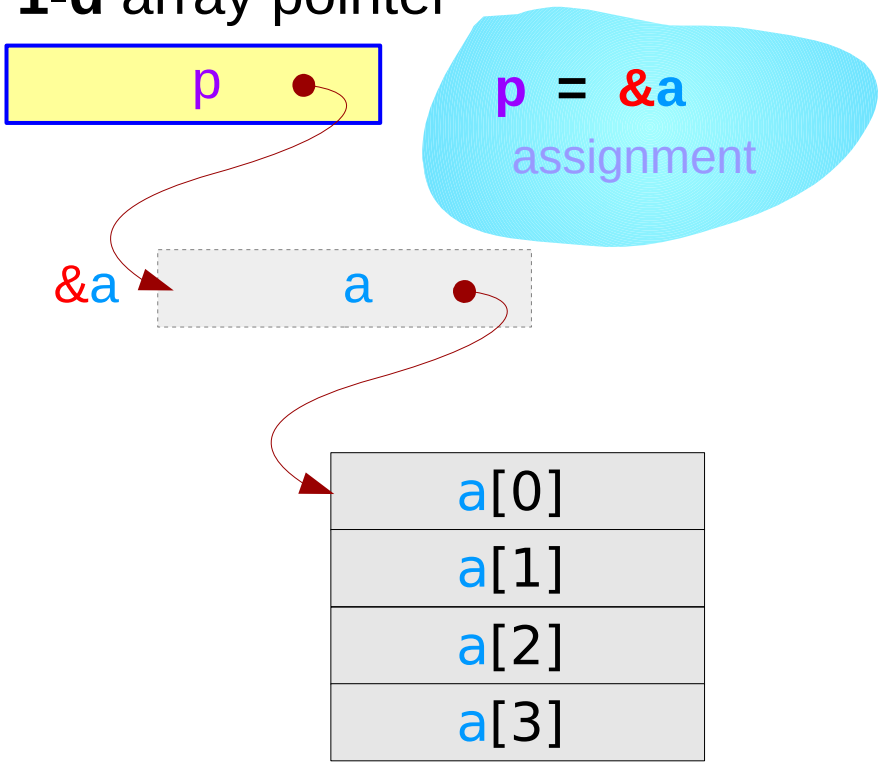
Incrementing an array pointer – extending a dimension



A **1-d** array pointer and a **1-d** array

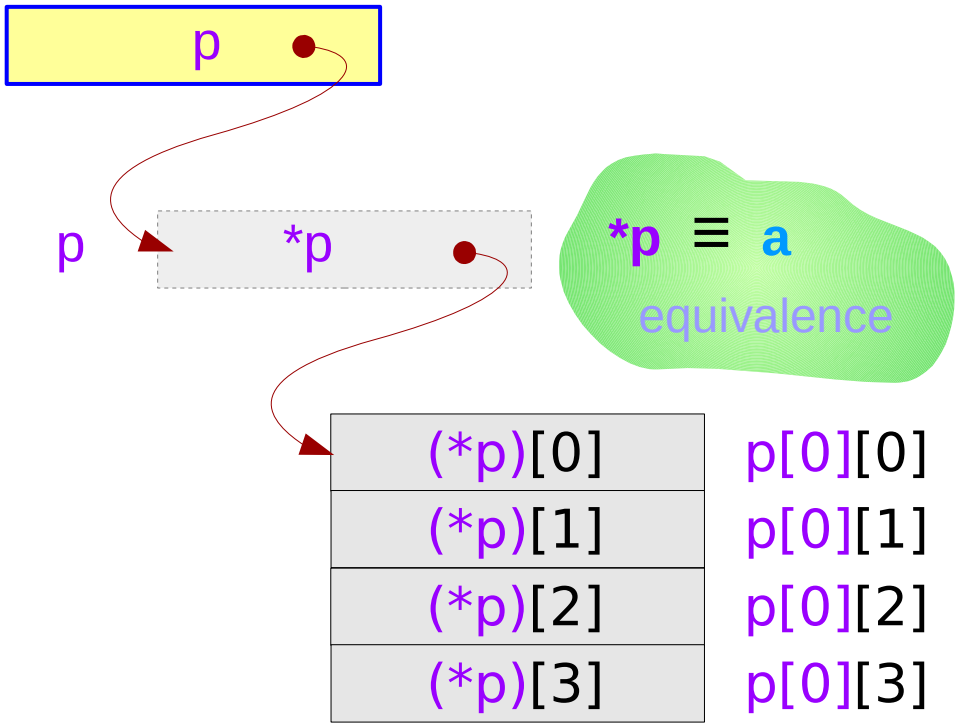
```
int         a [4];
```

1-d array pointer




```
int  (*p) [4]  = &a;
```

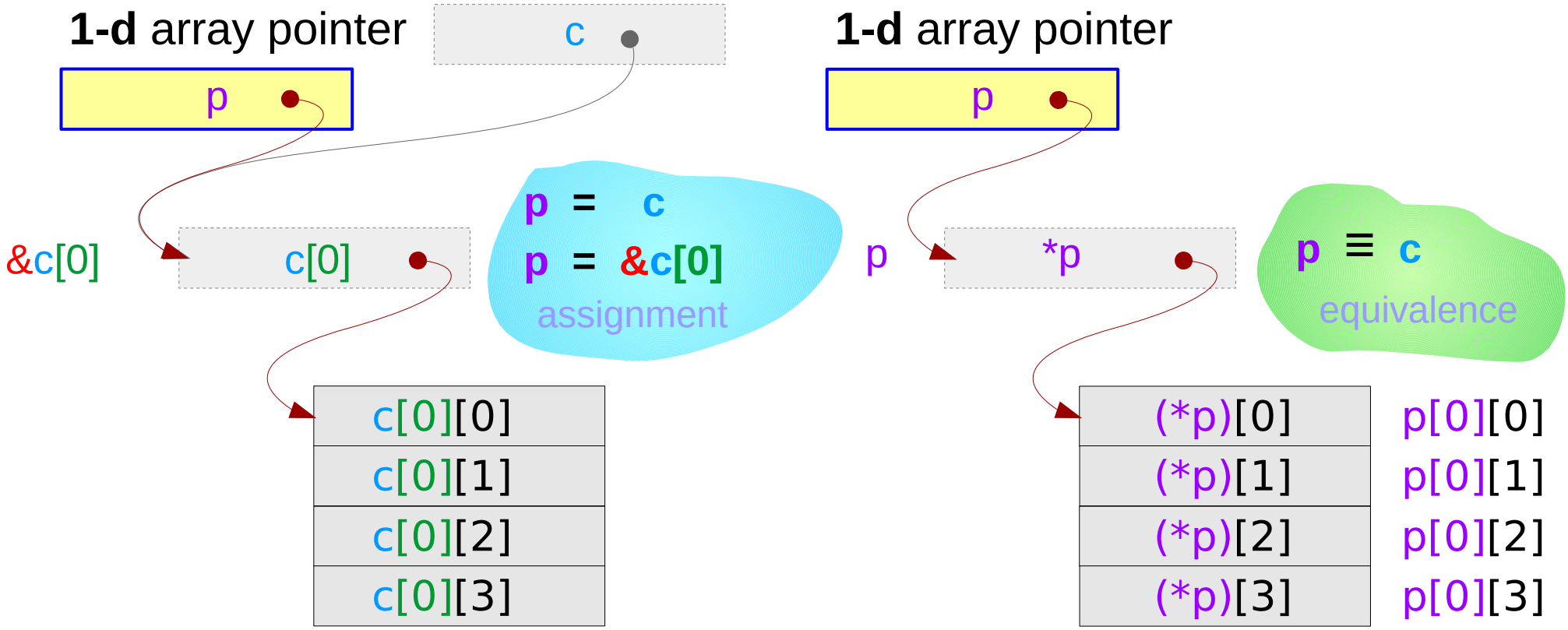
1-d array pointer



A **1-d** array pointer and a **2-d** array

```
int         c [4][4];
```

```
int  (*p) [4]  = &c[0];
```

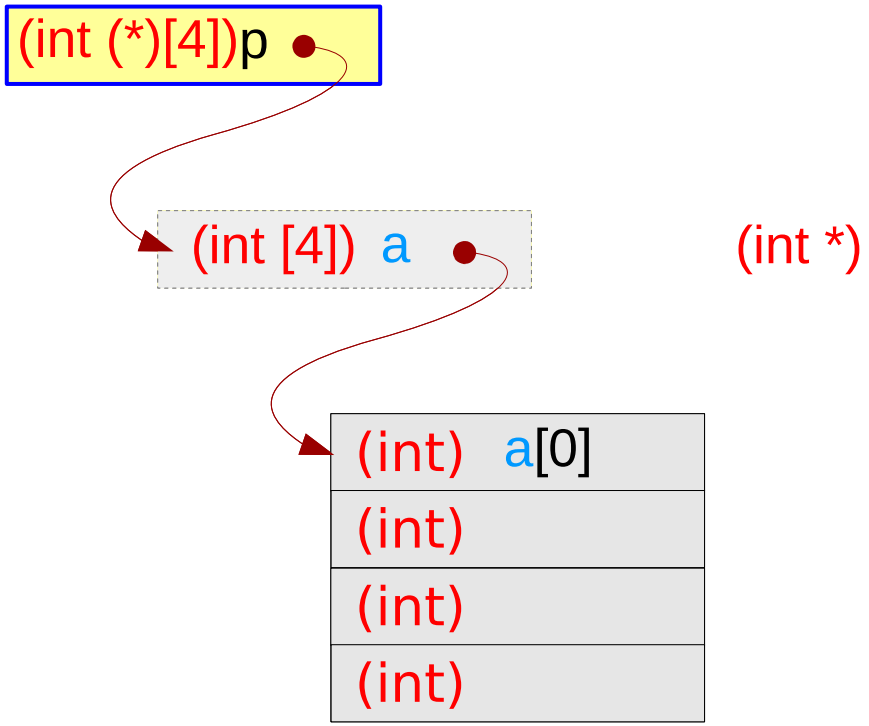


A **1-d** array pointer and a **1-d** array – a type view

```
int         a [4];
```

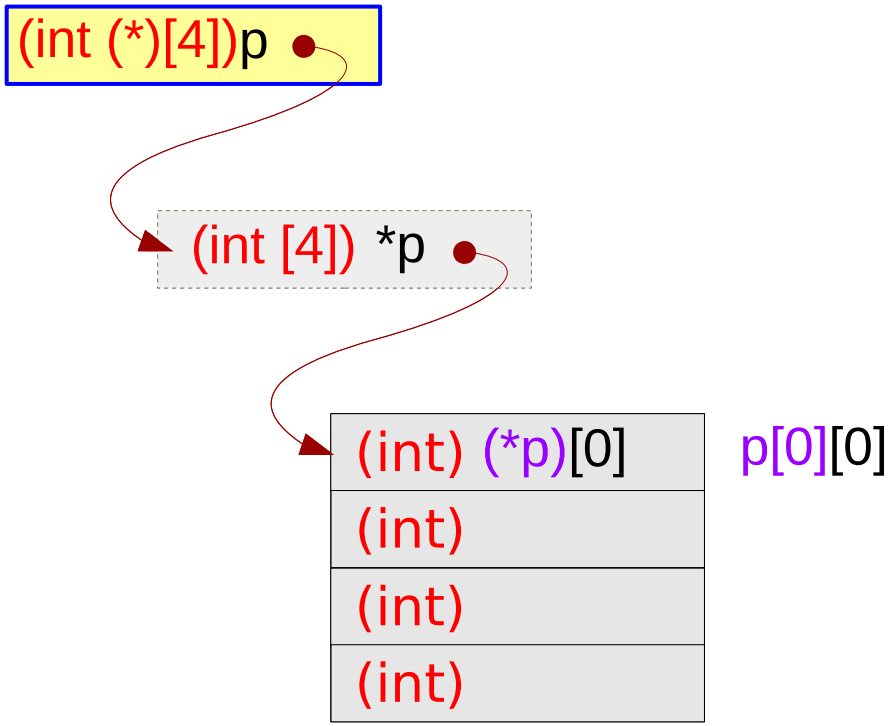
```
int  (*p) [4]  = &a;
```

1-d array pointer



(int *)

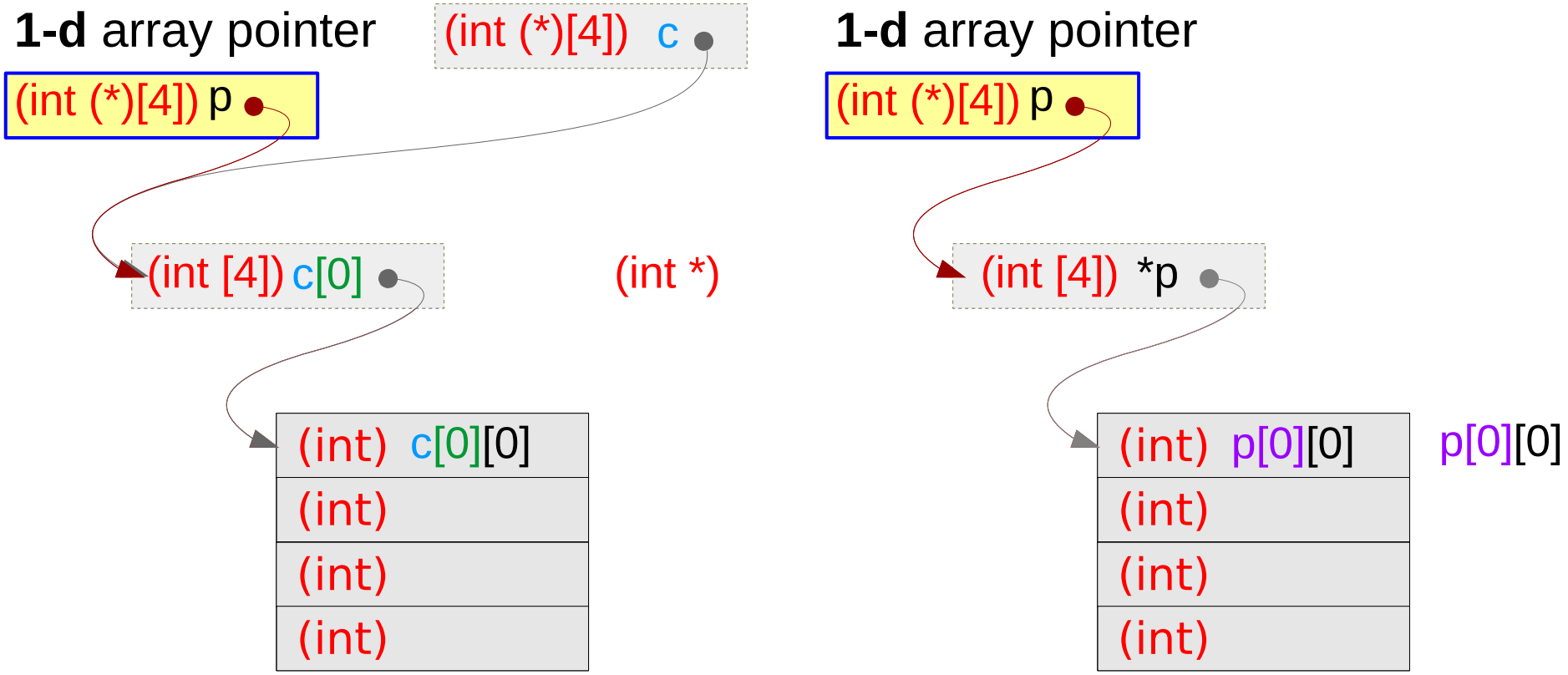
1-d array pointer



A **1-d** array pointer and a **2-d** array – a type view

```
int         c [4][4];
```

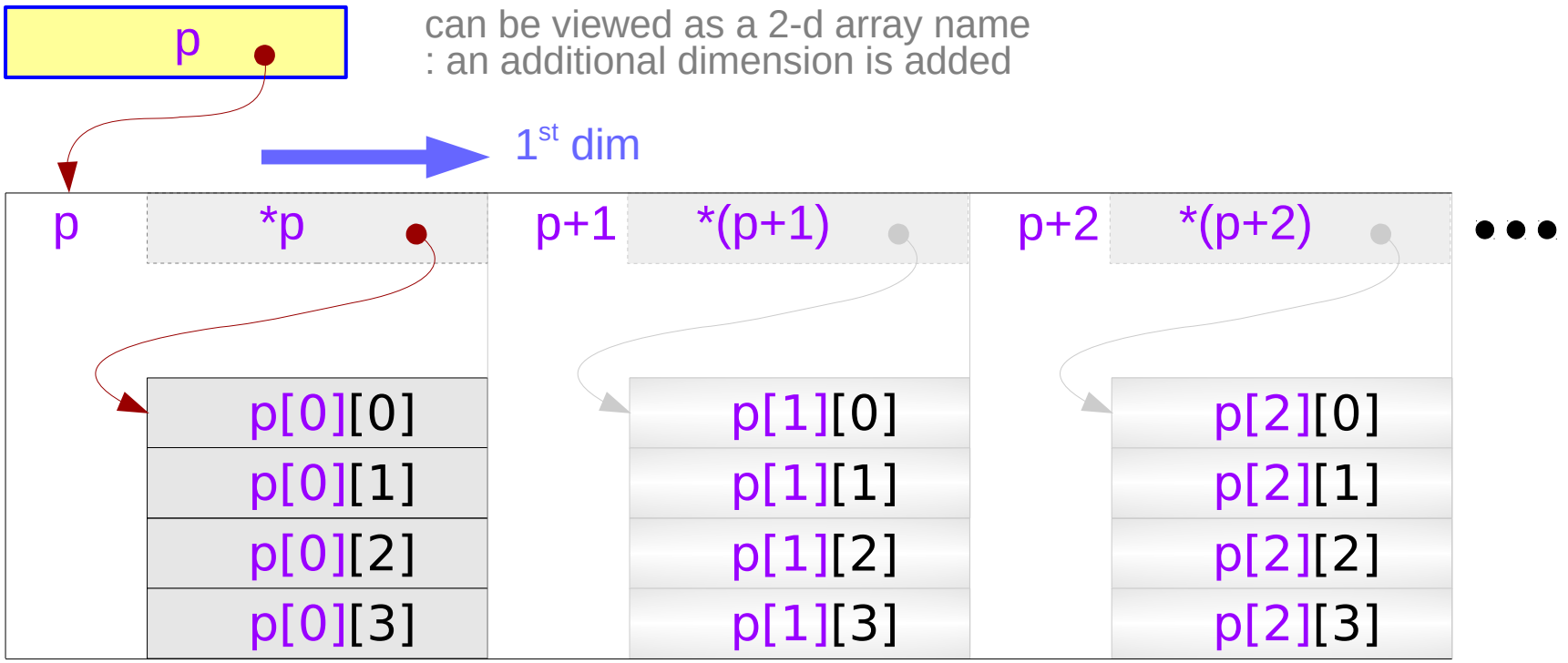
```
int  (*p) [4]  = &c[0];
```



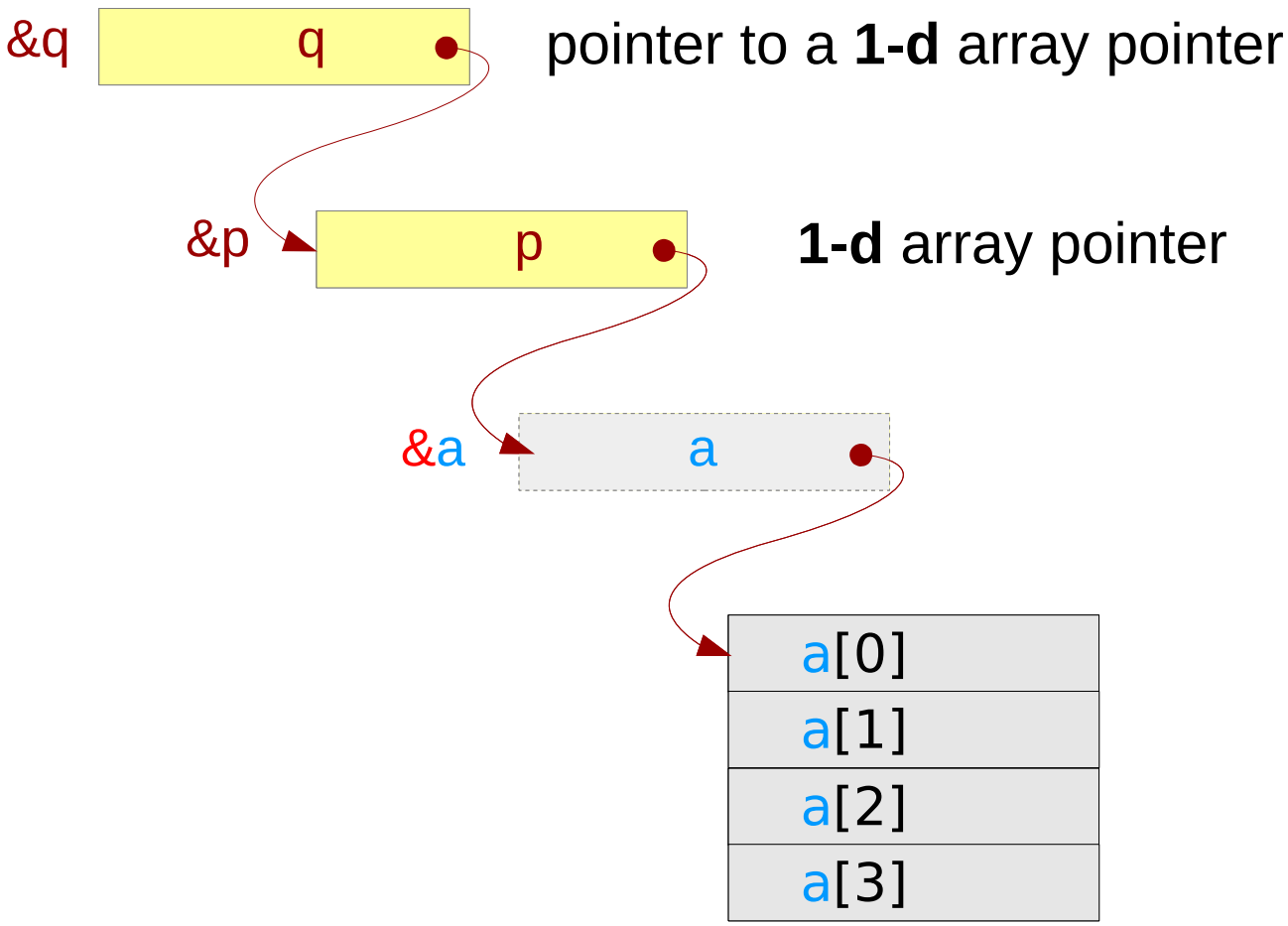
A **1-d** array pointer – extending a dimension

```
int  (*p) [4]  ;
```

1-d array pointer



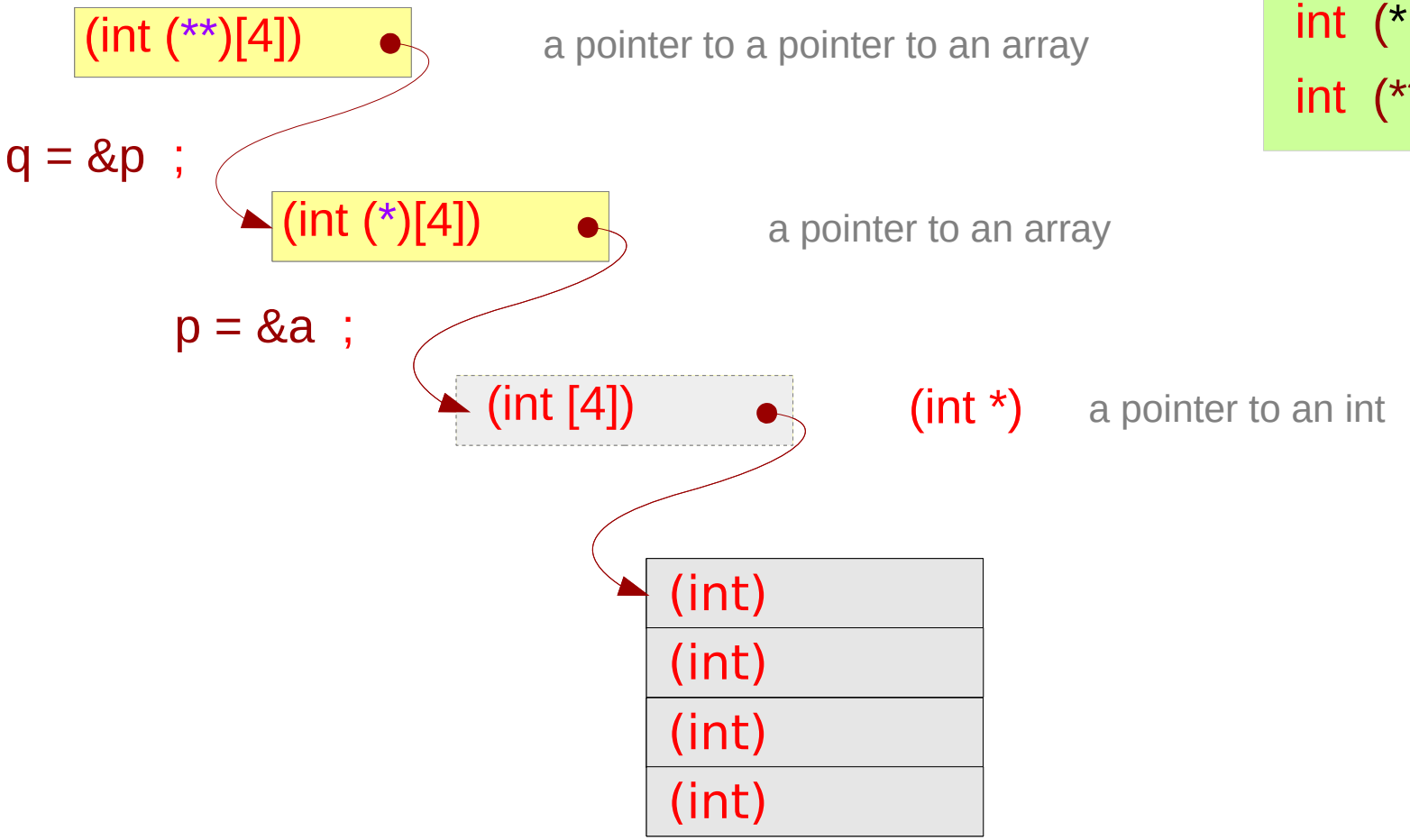
Double pointer to a **1-d** array – a variable view




```
int  a[4]  ;
int  (*p) [4] = &a ;
int  (**q) [4] = &p ;
```

Double pointer to a **1-d** array – a type view

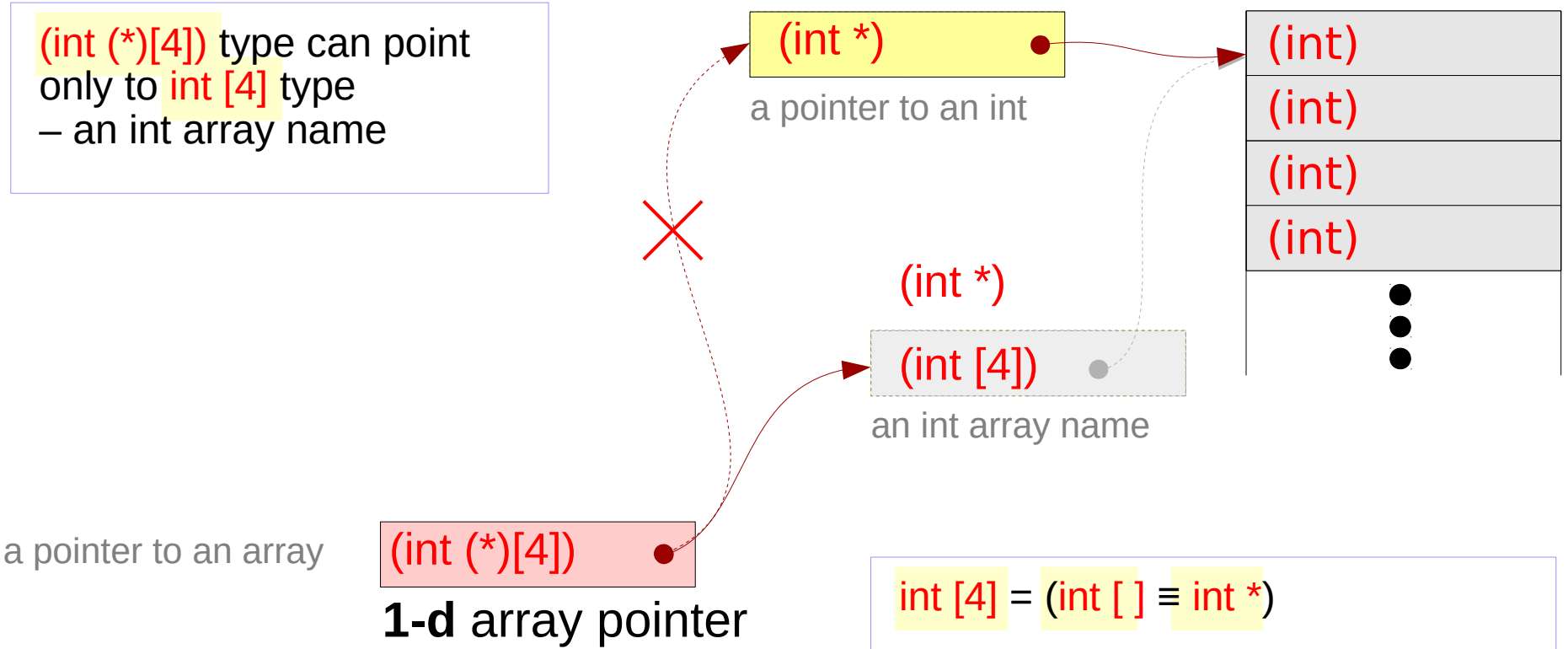
```
int  a[4]  ;
int  (*p) [4] = &a ;
int  (**q) [4] = &p ;
```



Pointer to Multi-dimensional Arrays

Integer pointer type

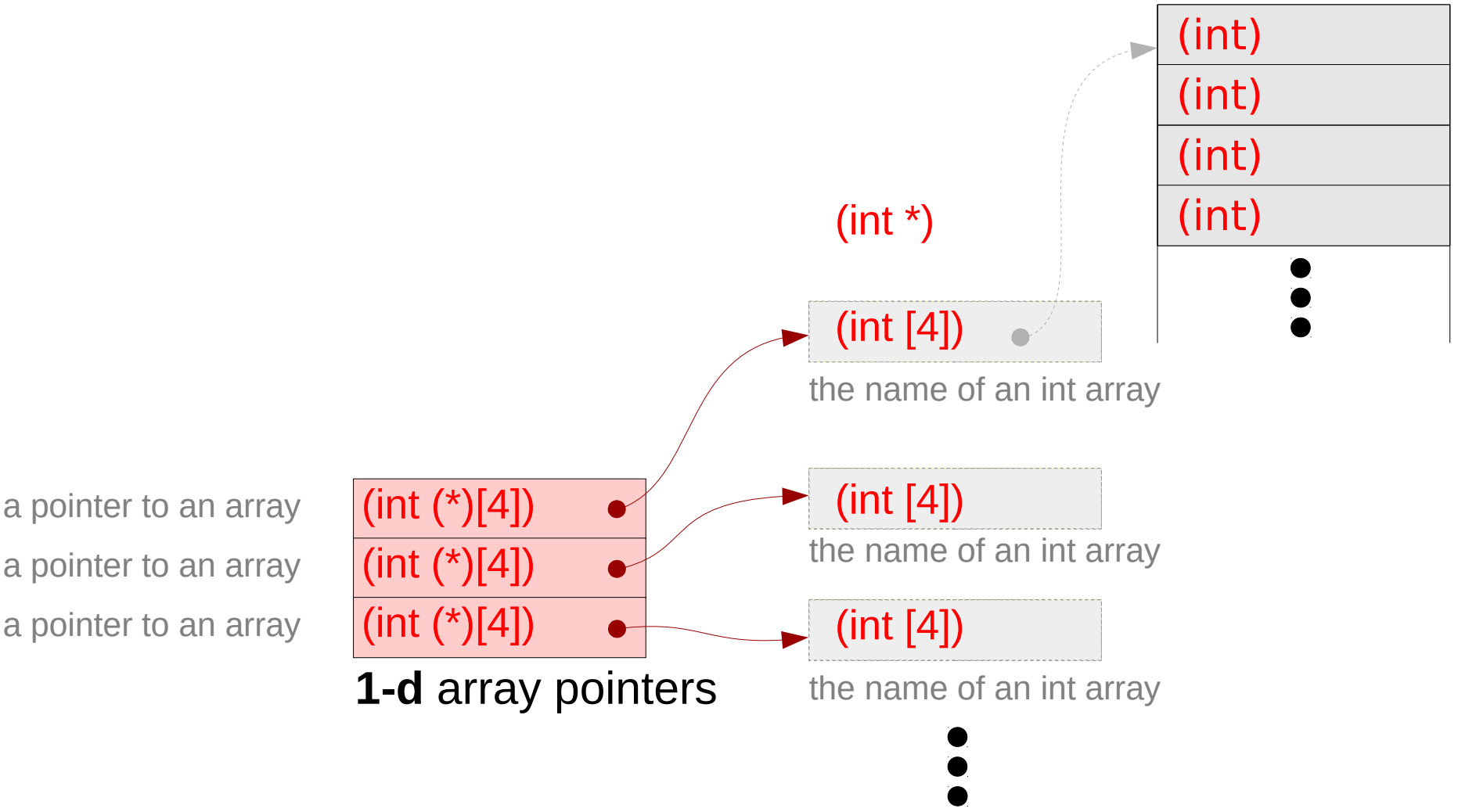
(int (*)[4]) type can point only to int [4] type
– an int array name



int [4] = (int [ ] ≡ int *)

equivalent in the sense that each of these types points to an int type data

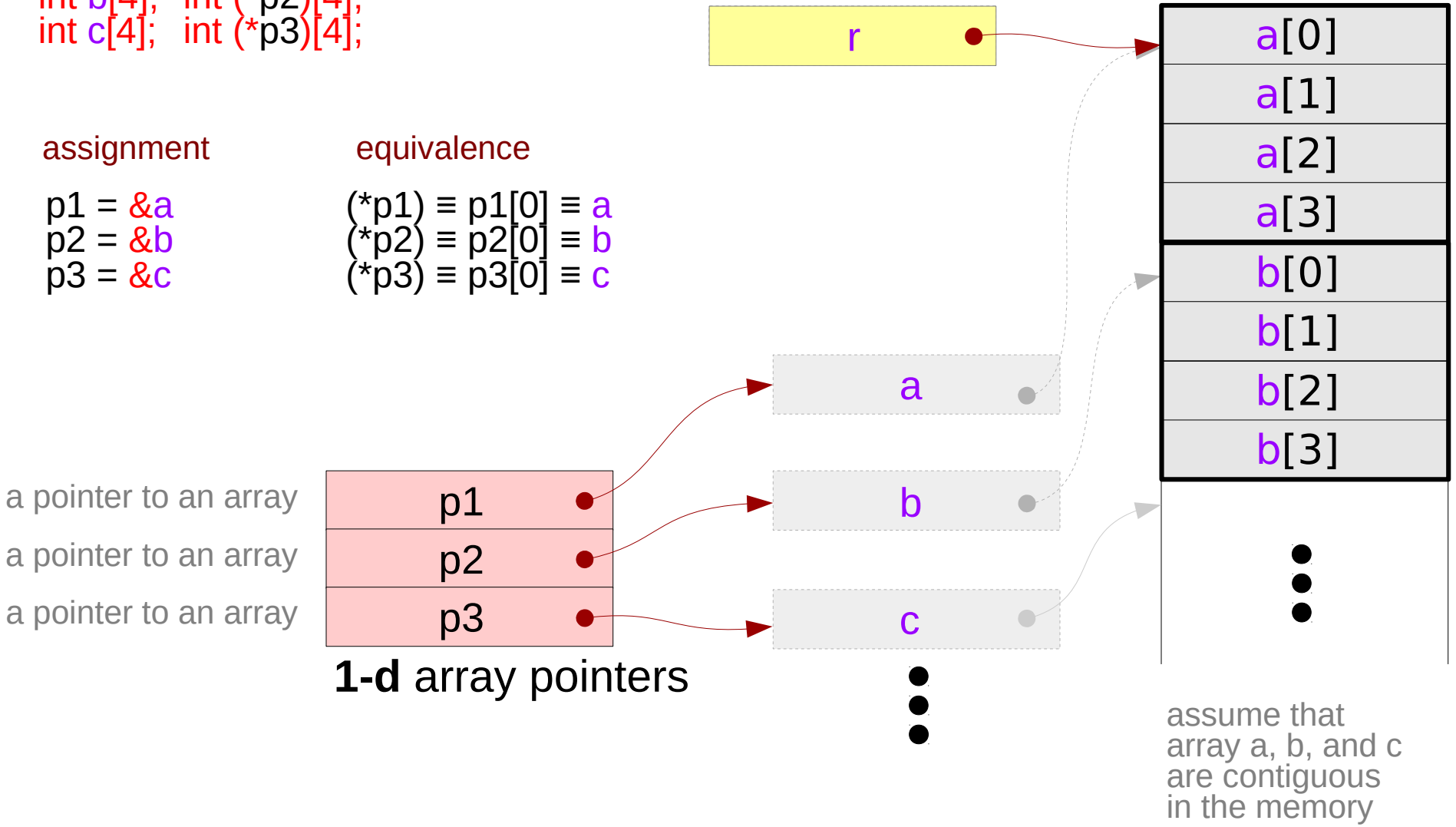
Series of array pointers – a type view



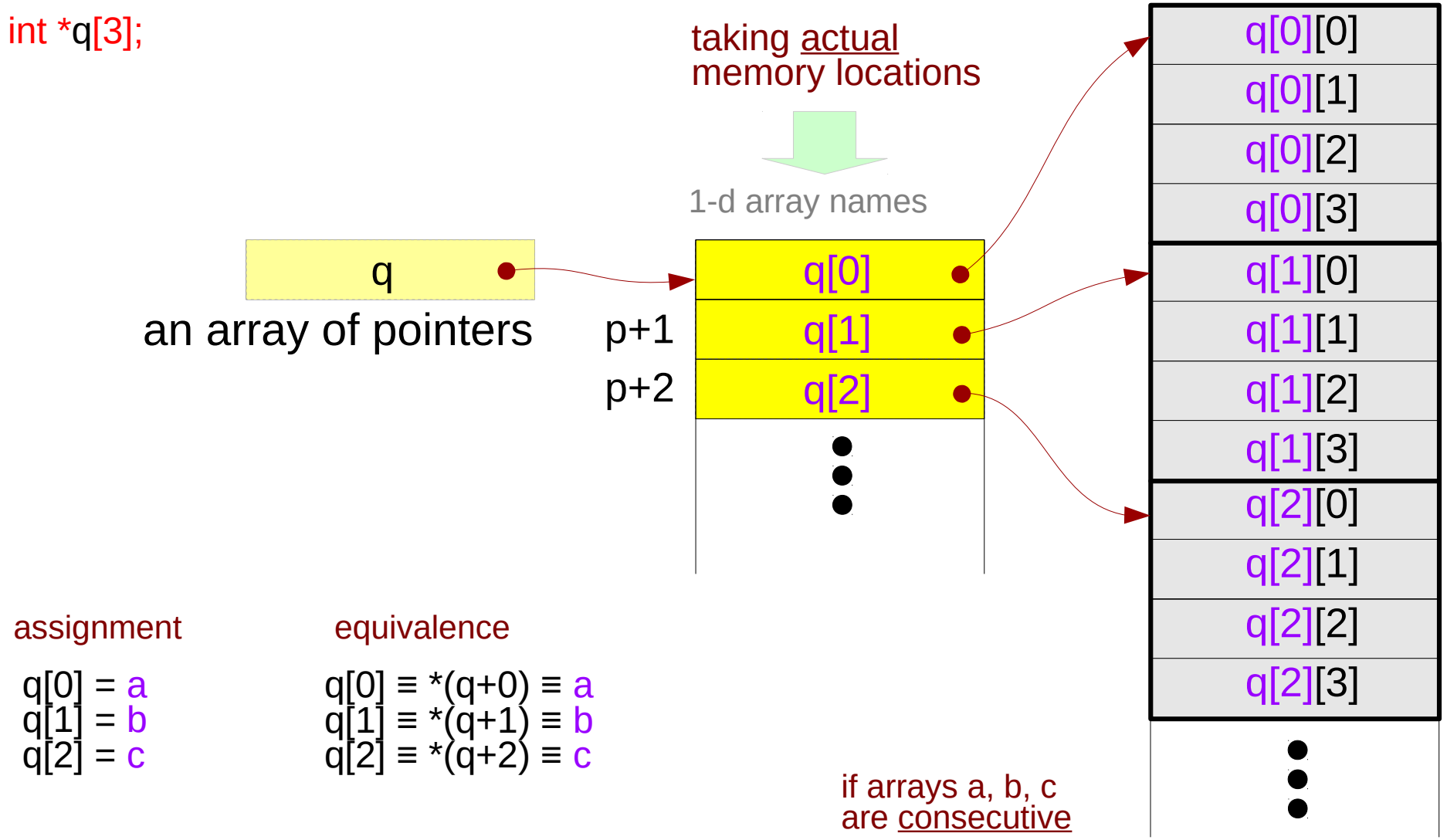
Series of array pointers – a variable view

```
int a[4];  int (*p1)[4];   int  (*r);
int b[4];  int (*p2)[4];
int c[4];  int (*p3)[4];
```

assignment	equivalence
p1 = &a	(*p1) ≡ p1[0] ≡ a
p2 = &b	(*p2) ≡ p2[0] ≡ b
p3 = &c	(*p3) ≡ p3[0] ≡ c



Pointer array – a variable view

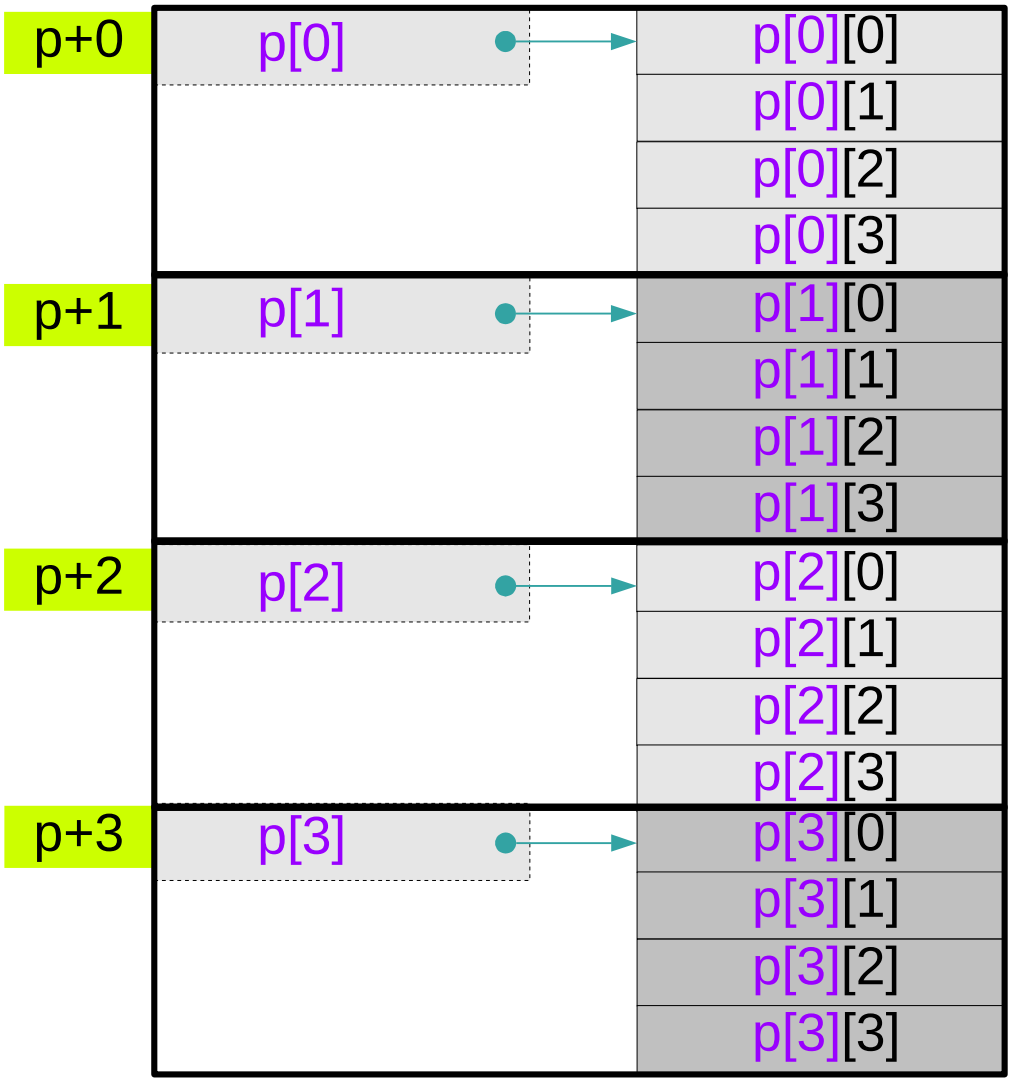


Array pointer to consecutive **1-d** arrays

```
int (*p)[4];
```

a pointer to an array

1-d array pointer



assignment

p = &a

equivalence

*(p+0) ≡ p[0] ≡ a
*(p+1) ≡ p[1] ≡ b
*(p+2) ≡ p[2] ≡ c
*(p+2) ≡ p[2] ≡ d

if arrays a, b, c, d
are consecutive

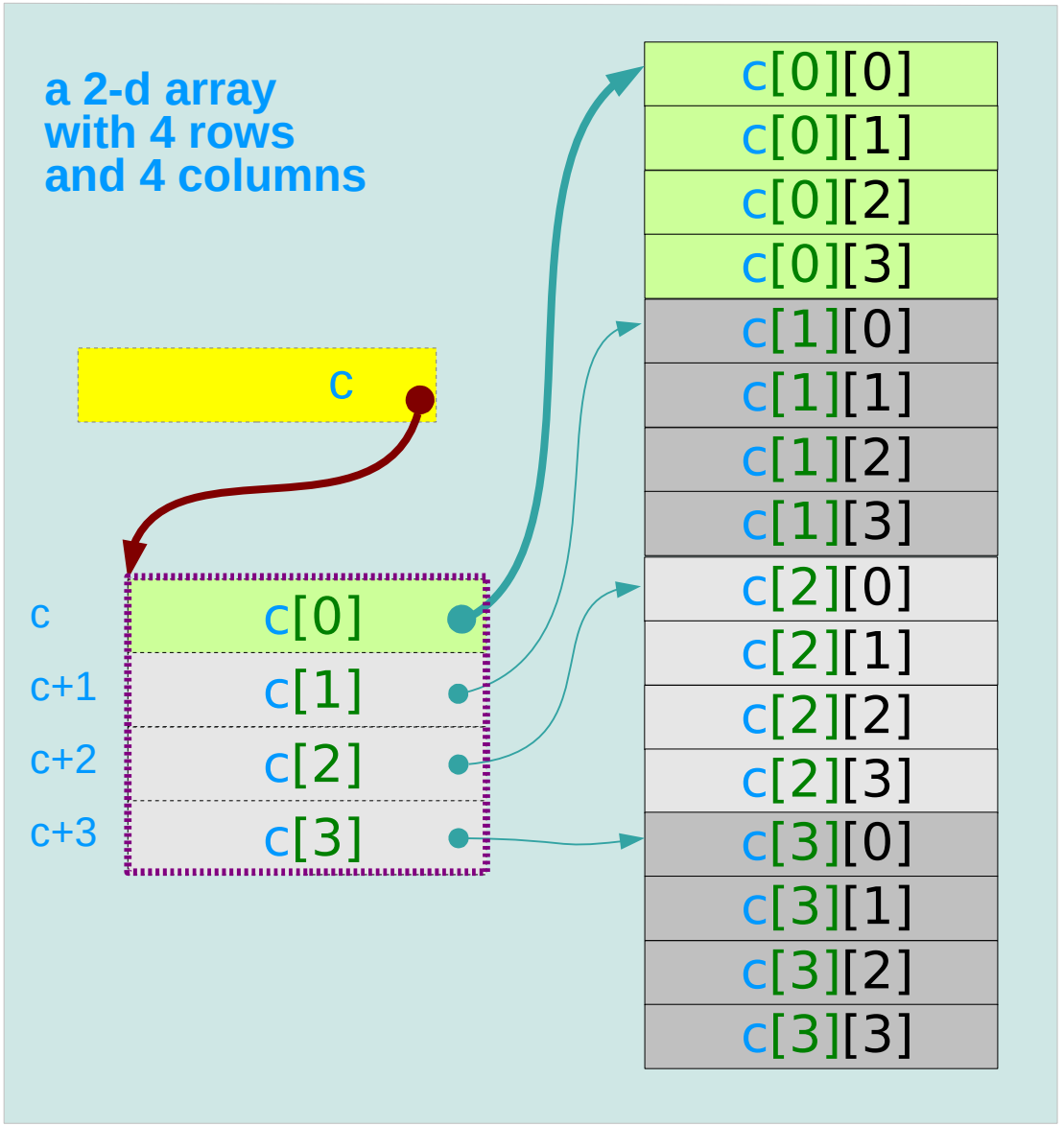
A **2-d** array and its sub-arrays – a variable view

the array name **c** of a **2-d** array as a **1-d** array pointer which points to its 1st **1-d** sub-array

c is the **1-d** array pointer
c[i]'s are the **1-d** sub-array name

c[0]	the 1st	1-d sub-array name
c[1]	the 2nd	1-d sub-array name
c[2]	the 3rd	1-d sub-array name
c[3]	the 4th	1-d sub-array name

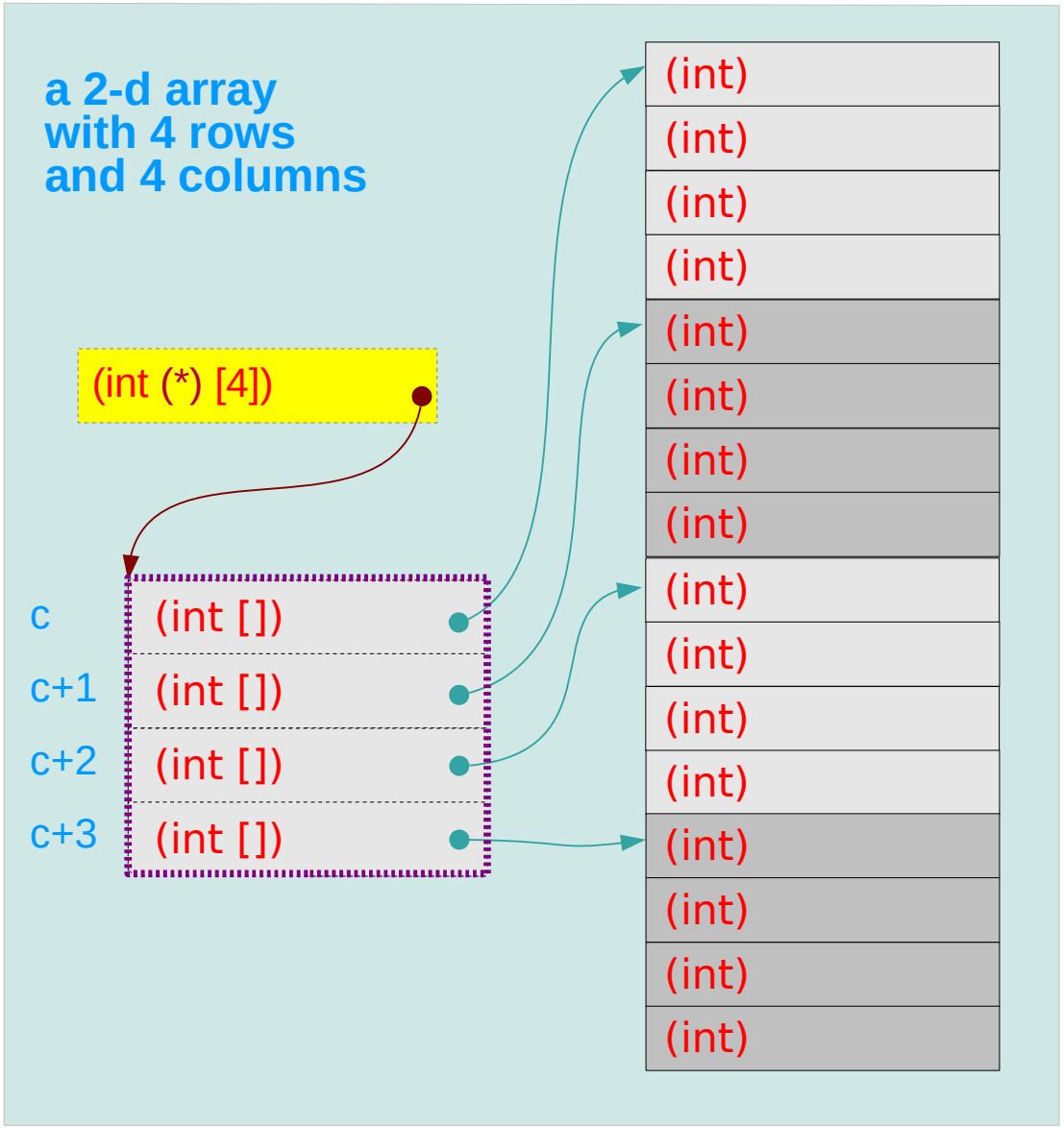
Compilers can make **c[i]**'s require no actual memory locations



A **2-d** array and its sub-arrays – a type view

1-d array pointer

1-d array name
1-d array name
1-d array name
1-d array name



1-d subarray aggregated data type

The 1st subarray c[0] (=array name)

sizeof(**c[0]**) = 16 bytes

The 2nd subarray c[1] (=array name)

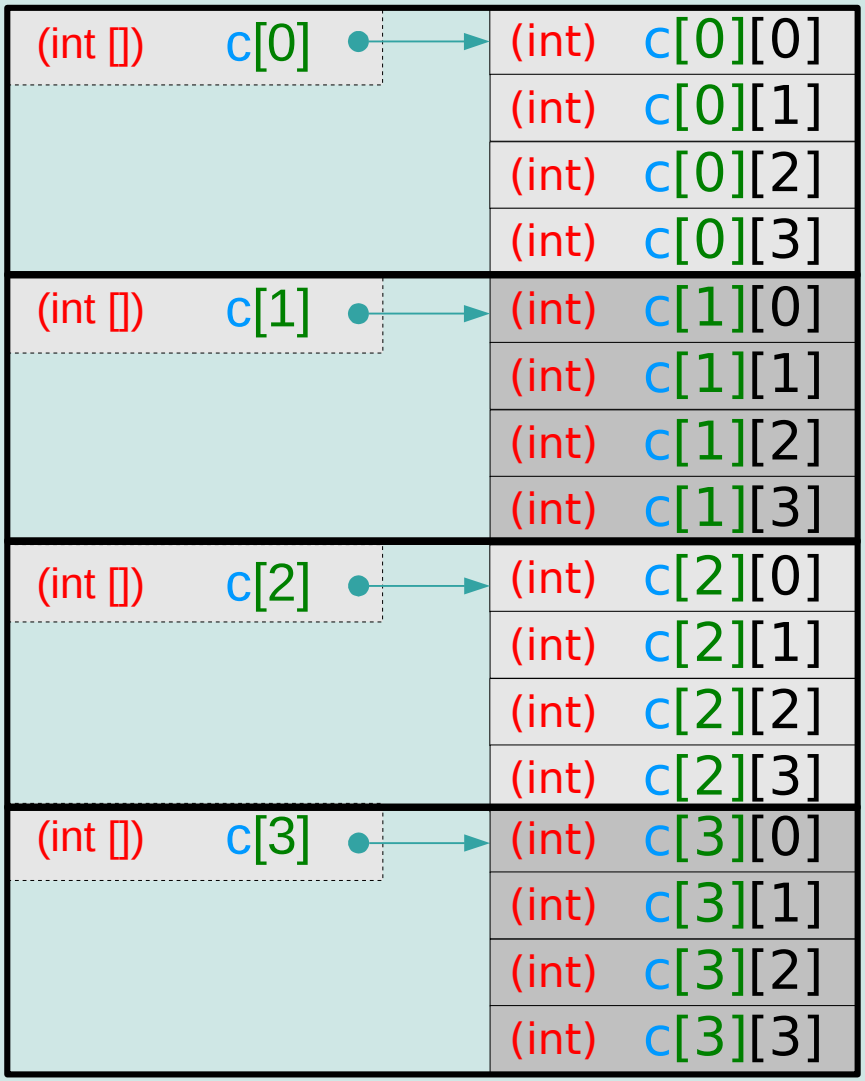
sizeof(**c[1]**) = 16 bytes

The 3rd subarray c[2] (=array name)

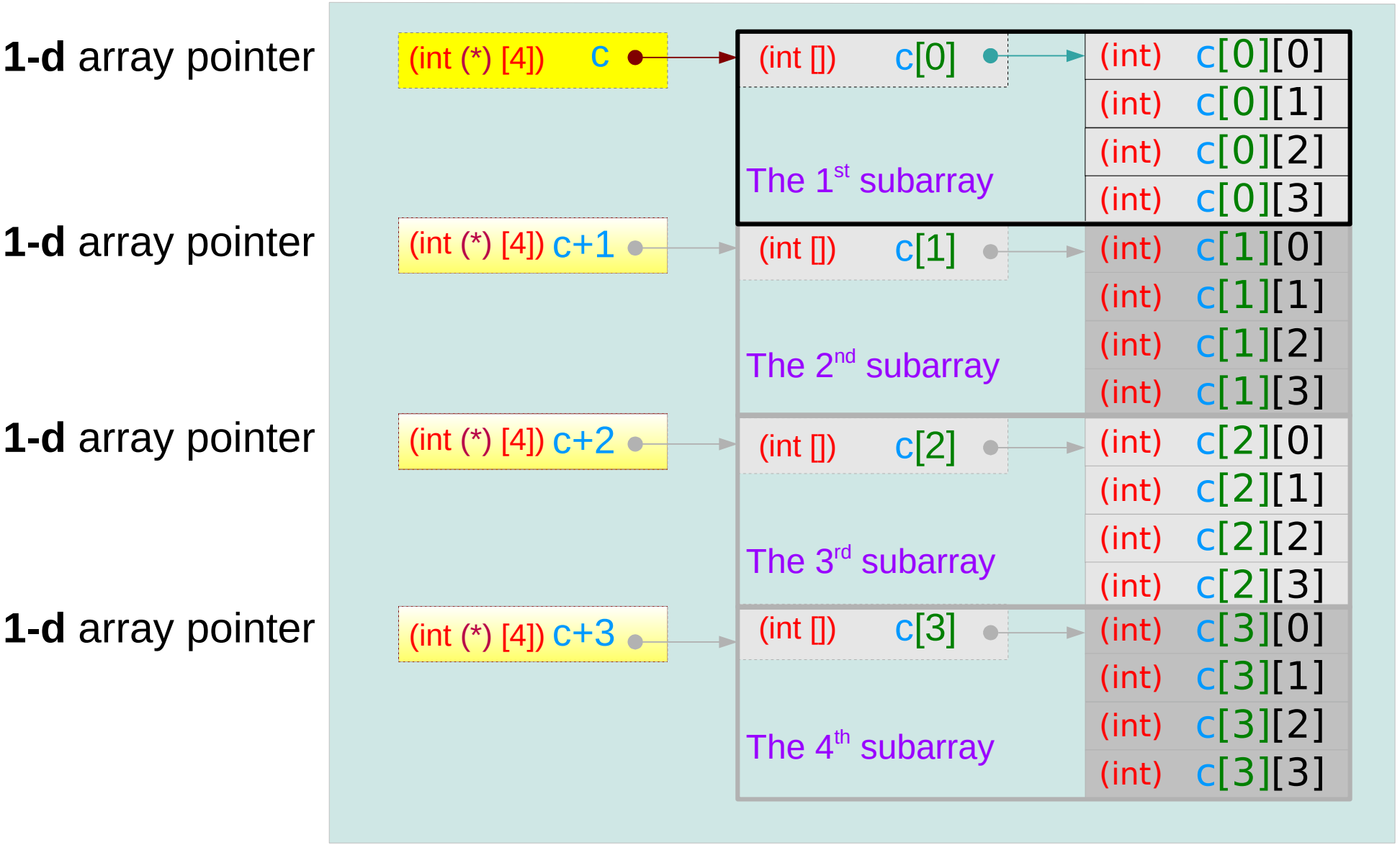
sizeof(**c[2]**) = 16 bytes

The 4th subarray c[3] (=array name)

sizeof(**c[3]**) = 16 bytes

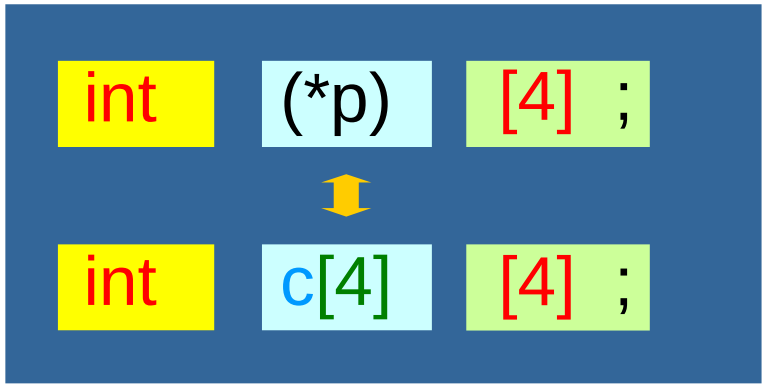


2-d array name as a pointer to a 1-d subarray



2-d array and **1-d** and **2-d** array pointers

1-d array pointer

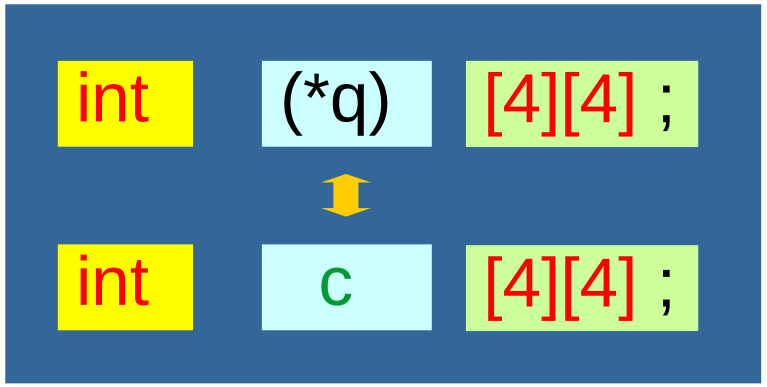


(int (*) [4])

```
p = &c[0];
p = c;
```

p[0] ≡ c[0]
p[1] ≡ c[1]
p[2] ≡ c[2]
p[3] ≡ c[3]

2-d array pointer



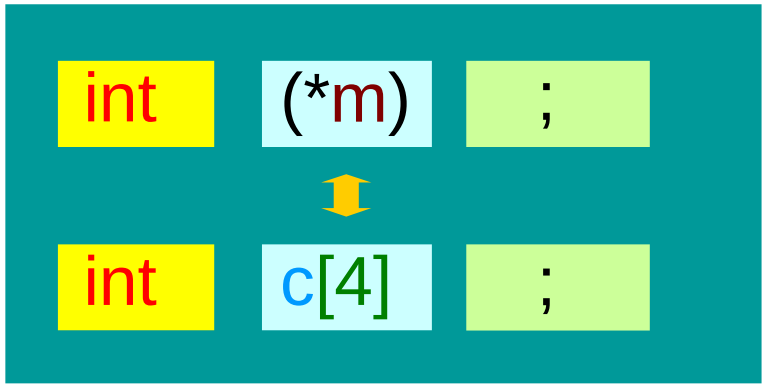
(int(*)[4][4])

```
q = &c;
```

(*q)[0] ≡ q[0][0] ≡ c[0]
(*q)[1] ≡ q[0][0] ≡ c[1]
(*q)[2] ≡ q[0][0] ≡ c[2]
(*q)[3] ≡ q[0][0] ≡ c[3]

1-d array and **0-d** and **1-d** array pointers

0-d array pointer : int pointer

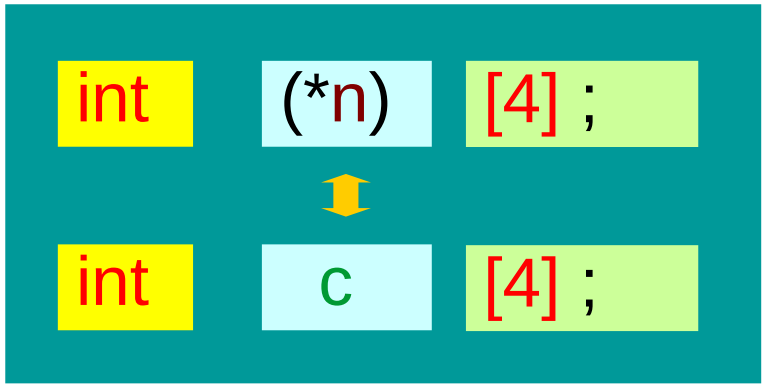


(int (*))

```
m = &c[0];
m = c;
```

```
m[0] ≡ c[0]
m[1] ≡ c[1]
m[2] ≡ c[2]
m[3] ≡ c[3]
```

1-d array pointer

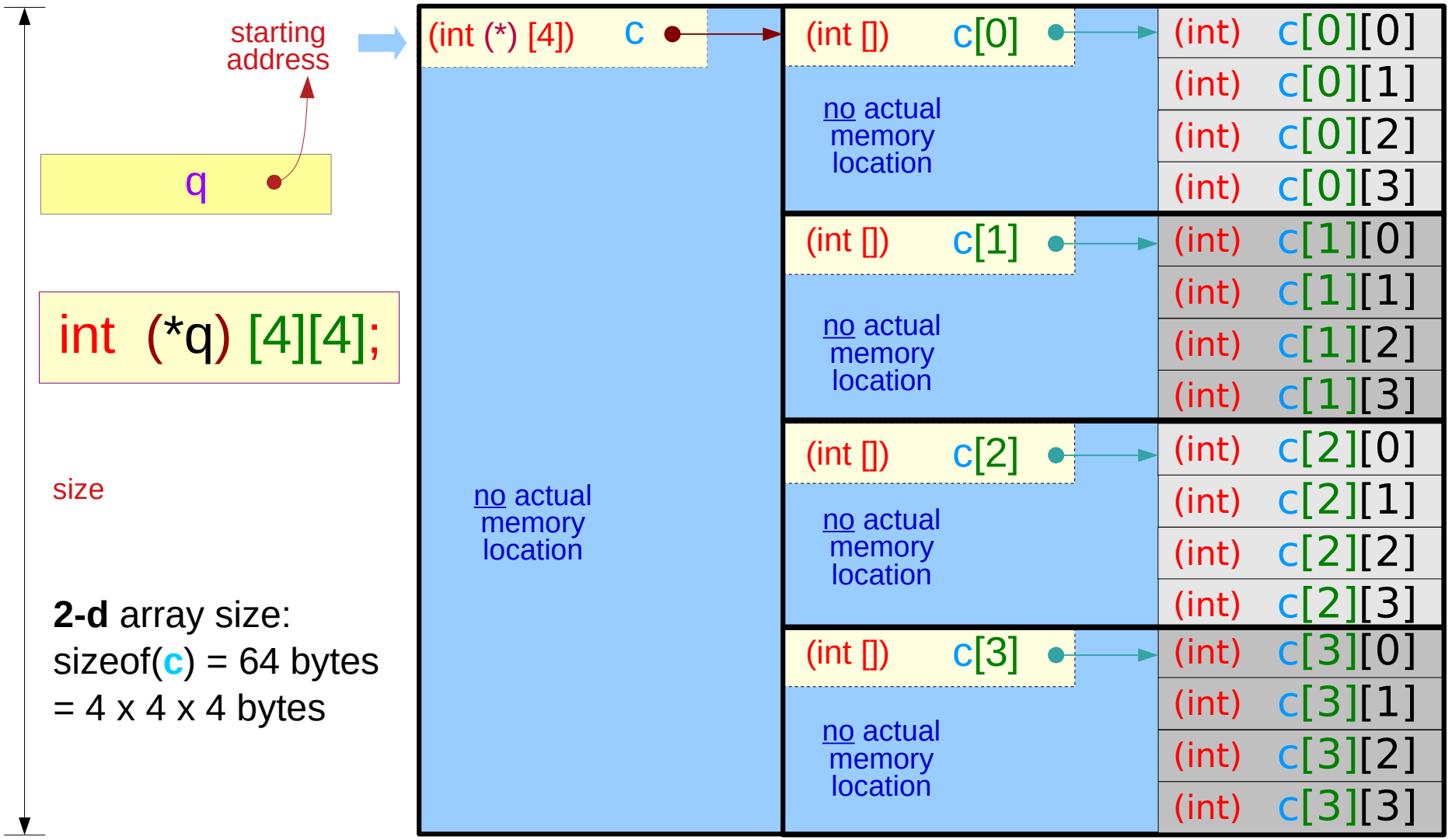


(int(*)[4])

```
n = &c;
```

```
(*n)[0] ≡ n[0][0] ≡ c[0]
(*n)[1] ≡ n[0][0] ≡ c[1]
(*n)[2] ≡ n[0][0] ≡ c[2]
(*n)[3] ≡ n[0][0] ≡ c[3]
```

Pointer to a **2-d** array – an aggregated type view

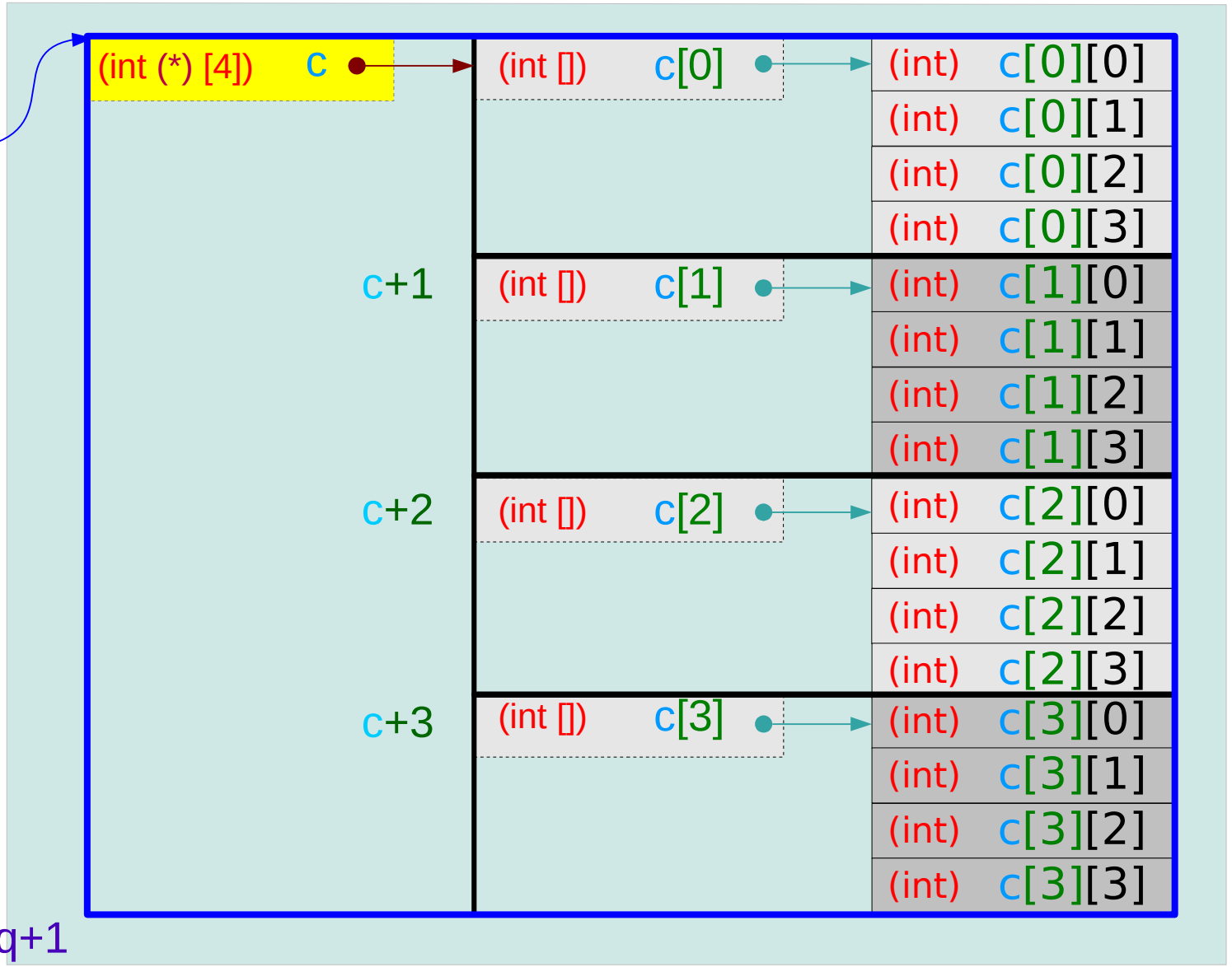


2-d array pointer to a **2-d** array

2-d array pointer

&q (int(*)[4][4]) q

q = &c;



An array pointer:
sizeof(**q**) = 8 bytes

1-d sub-arrays :
sizeof(***q**) = 64 bytes

1-d array pointer to a **2-d** array

1-d array pointer

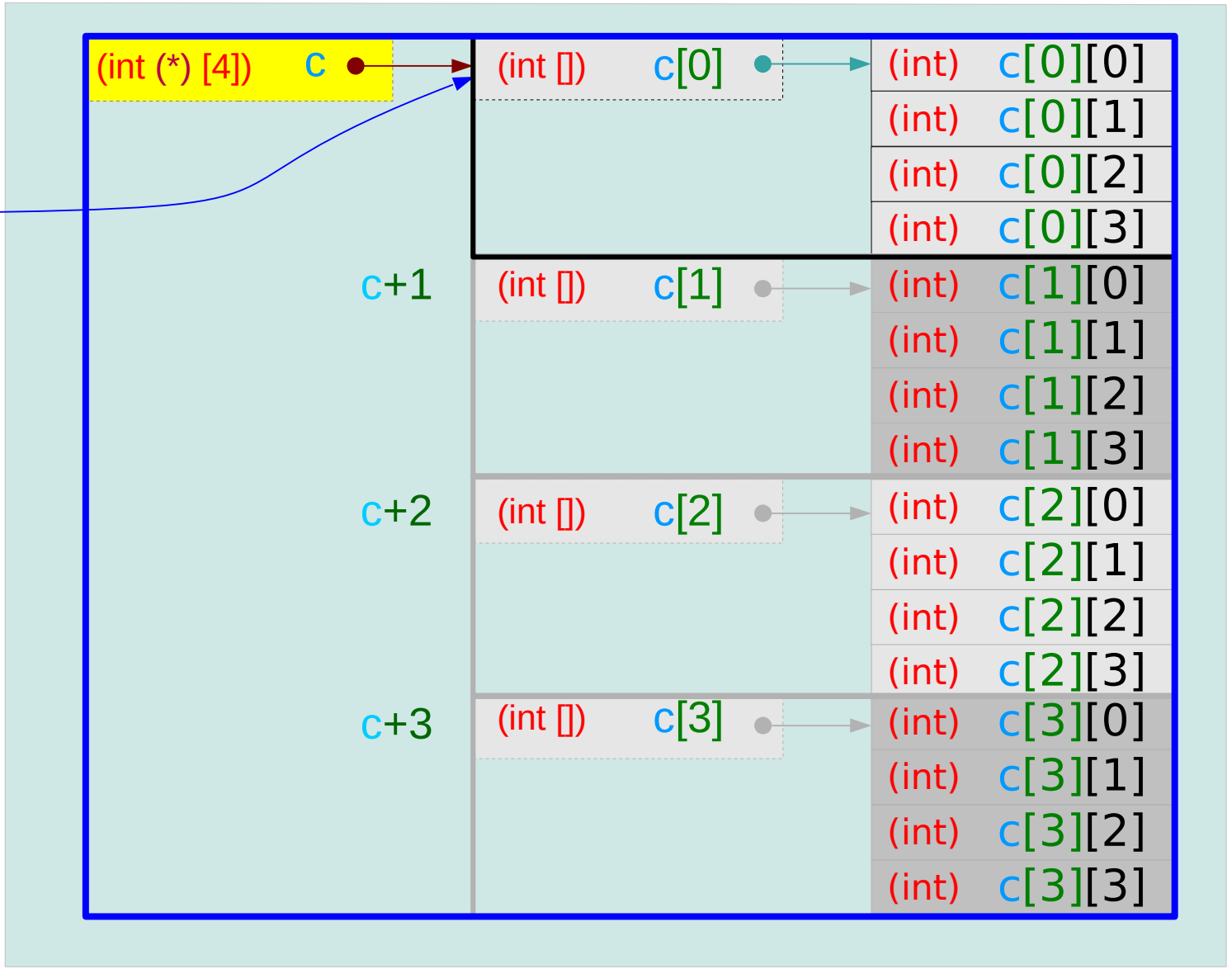
&p (int (*) [4]) p

p = c;

p = &c[0];

An array pointer:
sizeof(p) = 8 bytes

1-d sub-arrays :
sizeof(*p) = 16 bytes

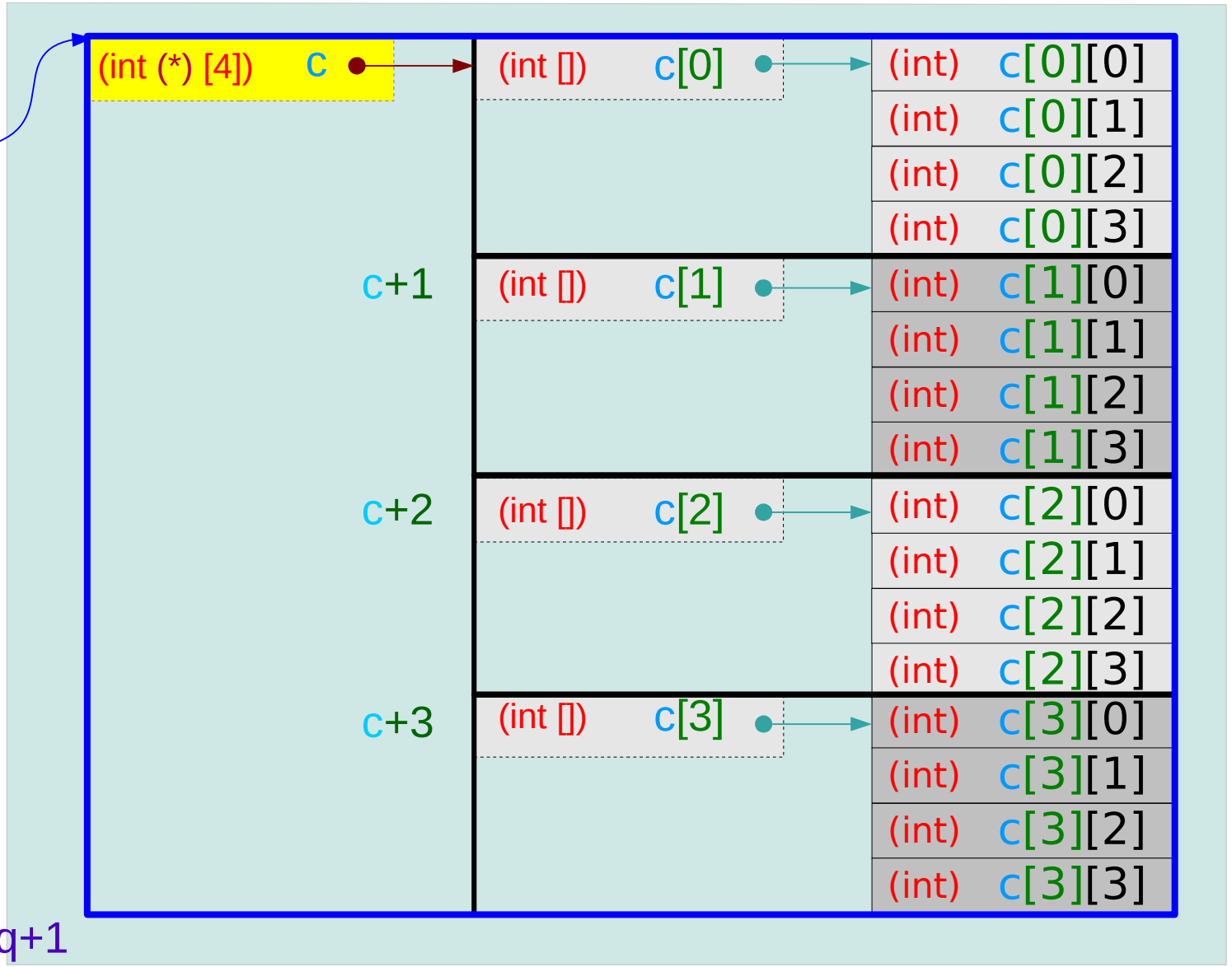


2-d array pointer to a **2-d** array

2-d array pointer

&q (int(*)[4][4]) q

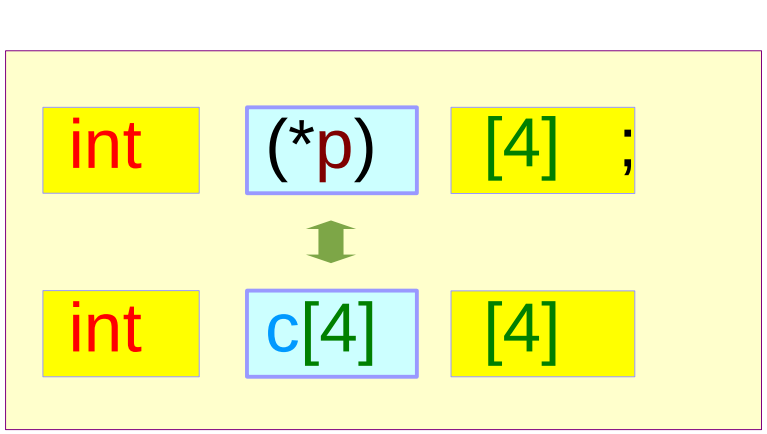
q = &c;



An array pointer:
sizeof(**q**) = 8 bytes

1-d sub-arrays :
sizeof(***q**) = 64 bytes

Using a **1-d** array pointer to a **2-d** array

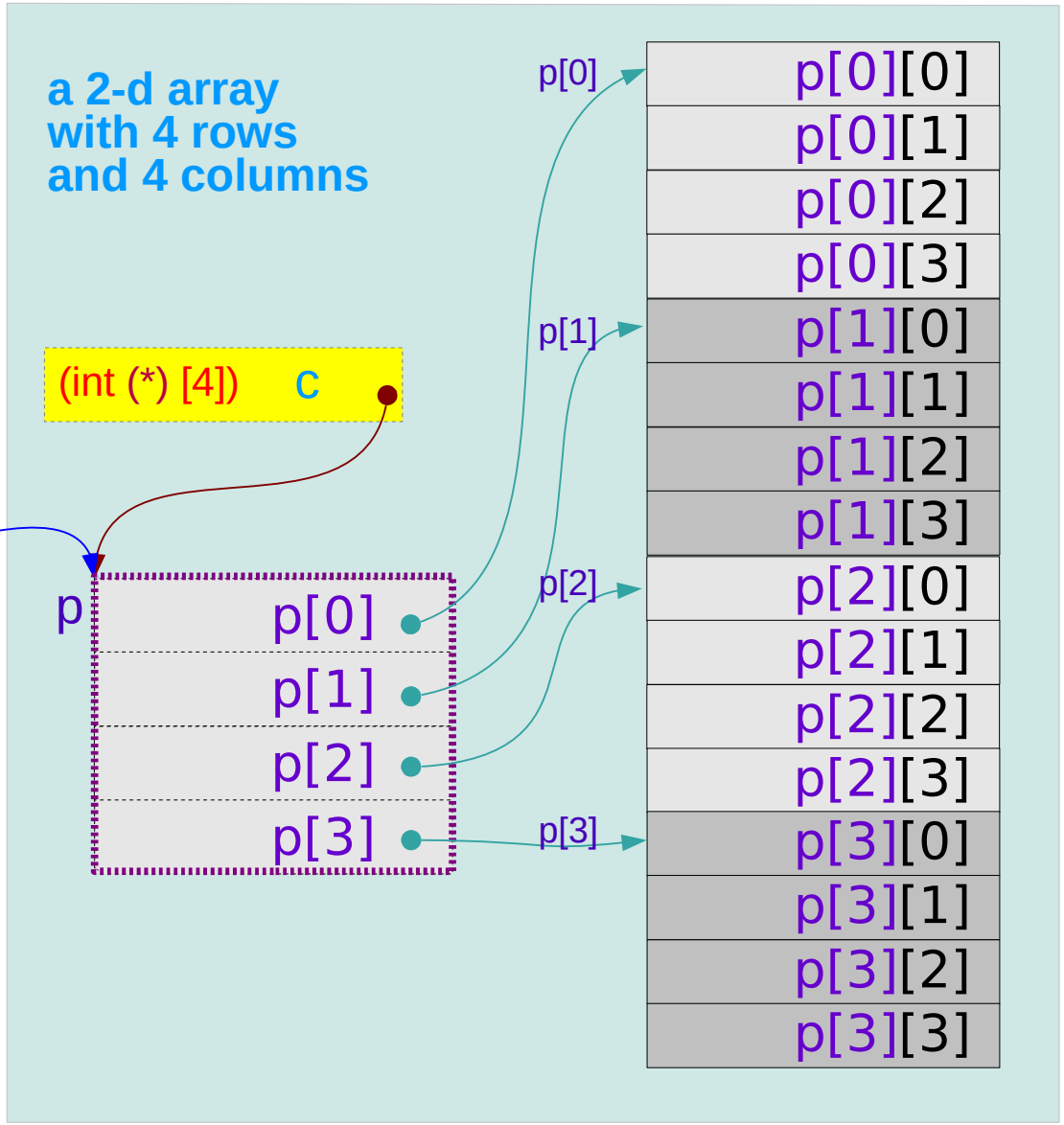


1-d array pointer

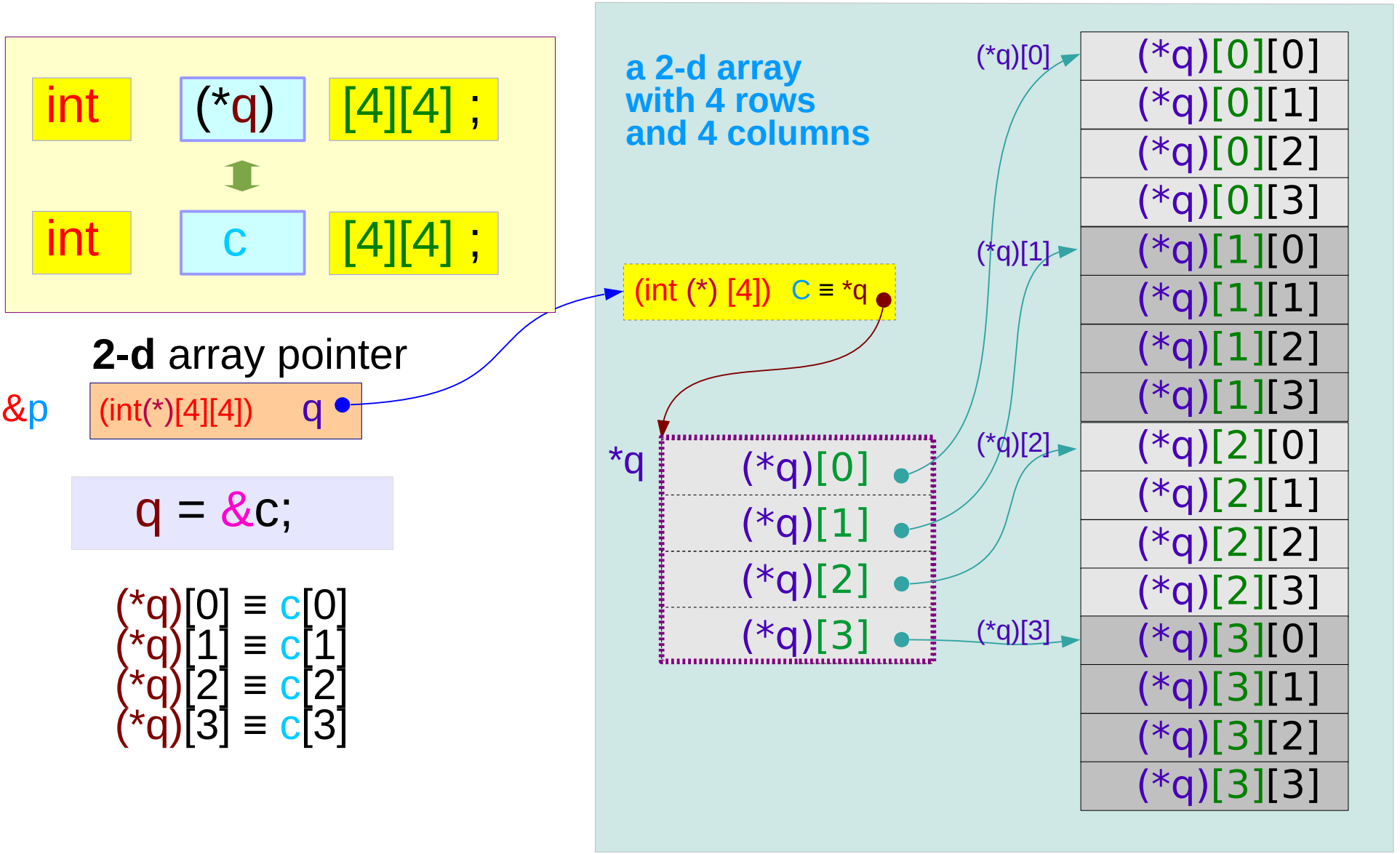
&p (int (*) [4]) p

p = c;

p[0] ≡ c[0]
p[1] ≡ c[1]
p[2] ≡ c[2]
p[3] ≡ c[3]



Using a **2-d** array pointer to a **2-d** array



(*n-1*)-d array pointer to a *n*-d array

```
int a[4] ;
int (*p) ;
```
1-d array
0-d array pointer

```
int b[4]  [2];
int (*q)  [2];
```
2-d array
1-d array pointer

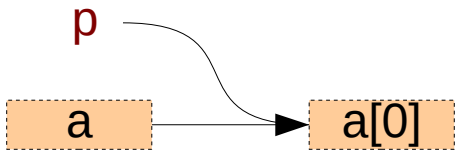
```
int c[4]  [2][3];
int (*r)  [2][3];
```
3-d array
2-d array pointer

```
int d[4]  [2][3][4];
int (*s)  [2][3][4];
```
4-d array
3-d array pointer

***n*-d** array name : **(*n-1*)-d** array pointer

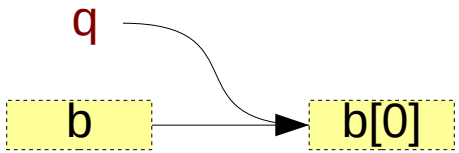
```
int a[4] ;
int (*p) ;
```

```
p = &a[0];
p = a;
```



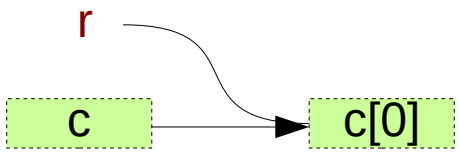

```
int b[4] [2];
int (*q) [2];
```

```
q = &b[0];
q = b;
```



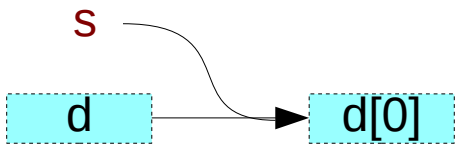

```
int c[4] [2][3];
int (*r) [2][3];
```

```
r = &c[0];
r = c;
```

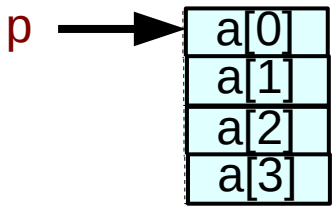


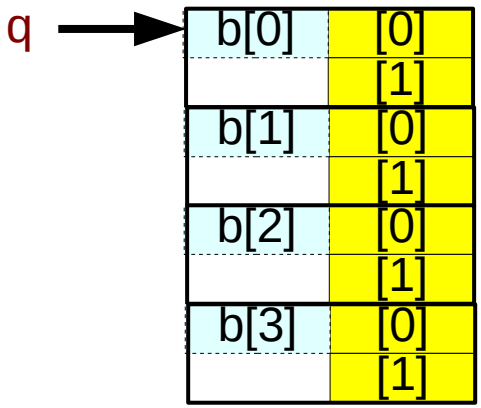

```
int d[4] [2][3][4];
int (*s) [2][3][4];
```

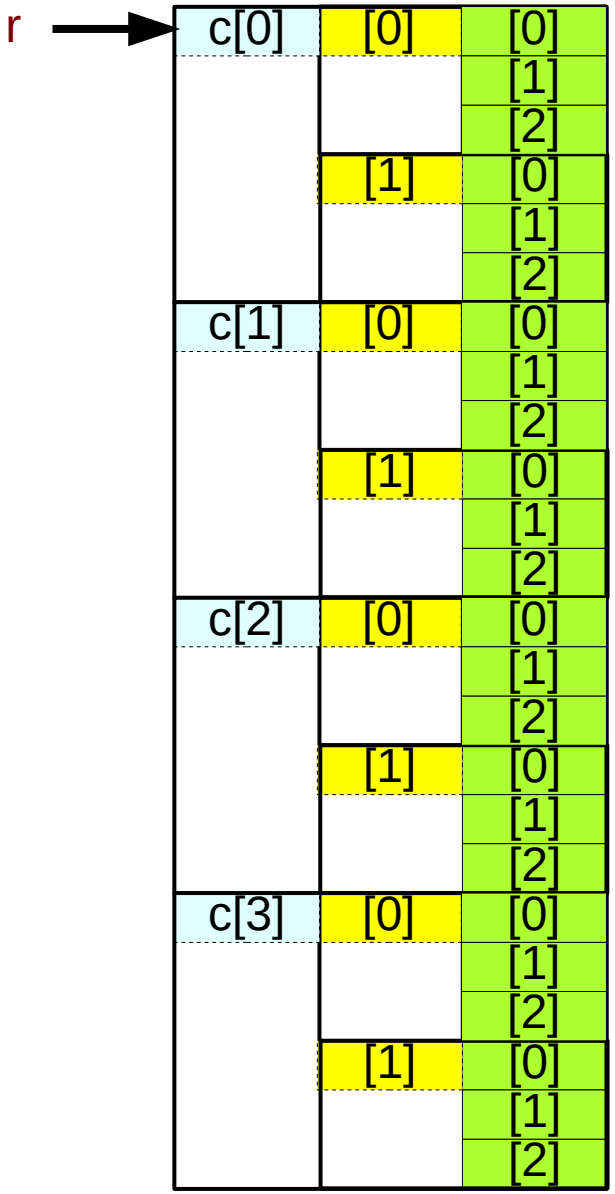
```
s = &d[0];
s = d;
```



multi-dimensional array pointers



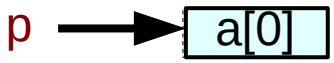


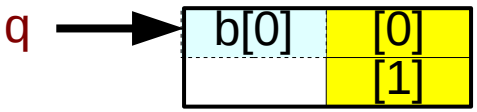


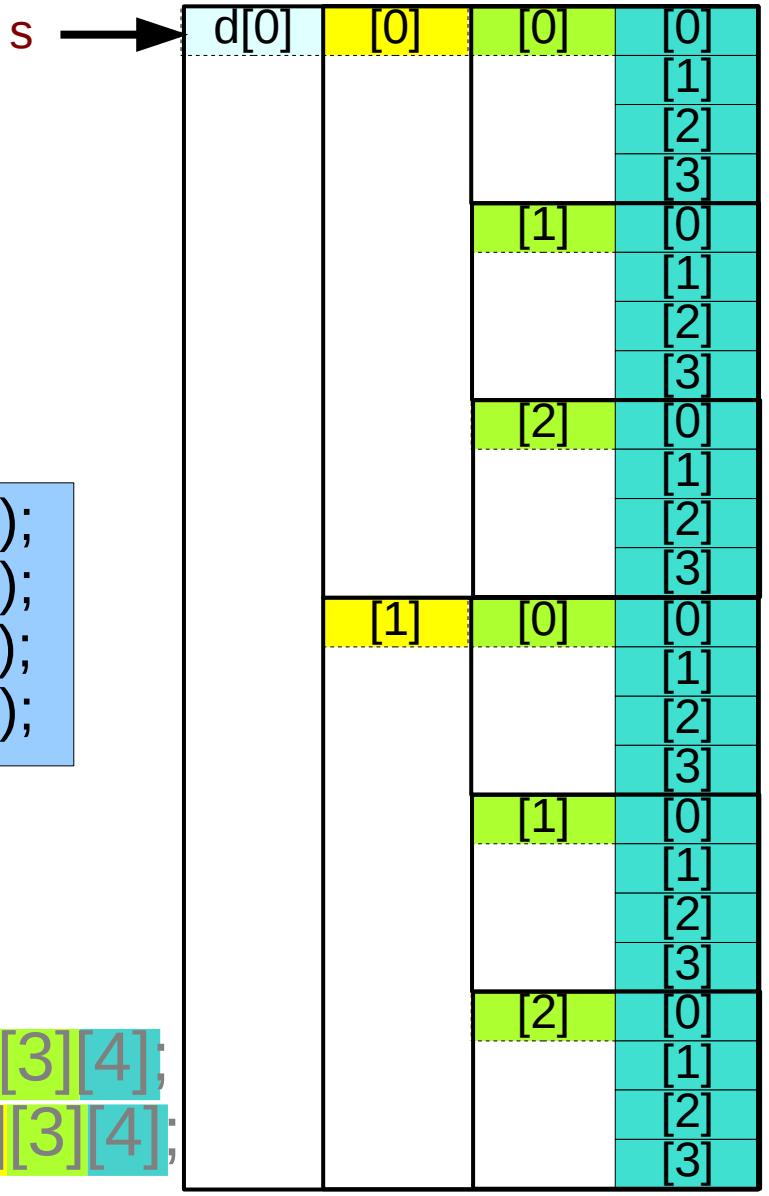

```
int a[4] ;
int b[4]  [2];
int c[4]  [2][3];
int d[4]  [2][3][4];
```

```
int (*p) ;
int (*q)  [2];
int (*r)  [2][3];
int (*s)  [2][3][4];
```

multi-dimensional array pointers

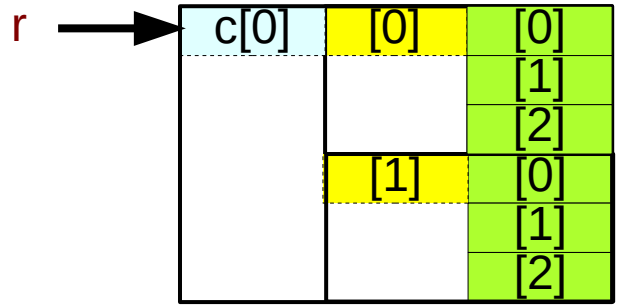







```
int a[4] ;
int (*p) ;
```

```
int b[4] [2];
int (*q) [2];
```

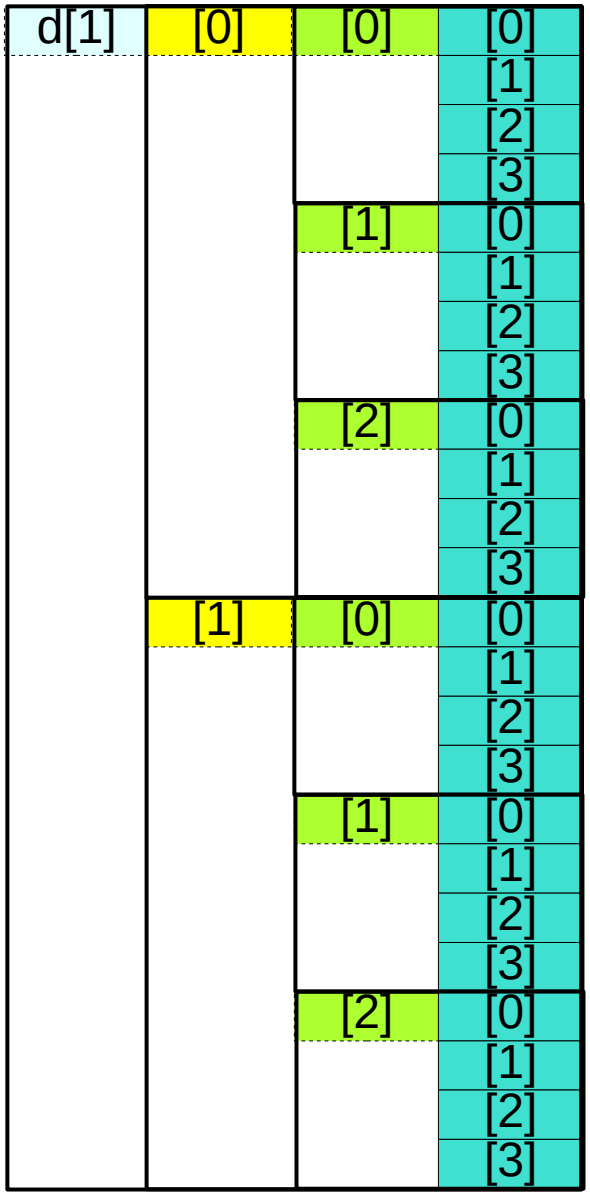


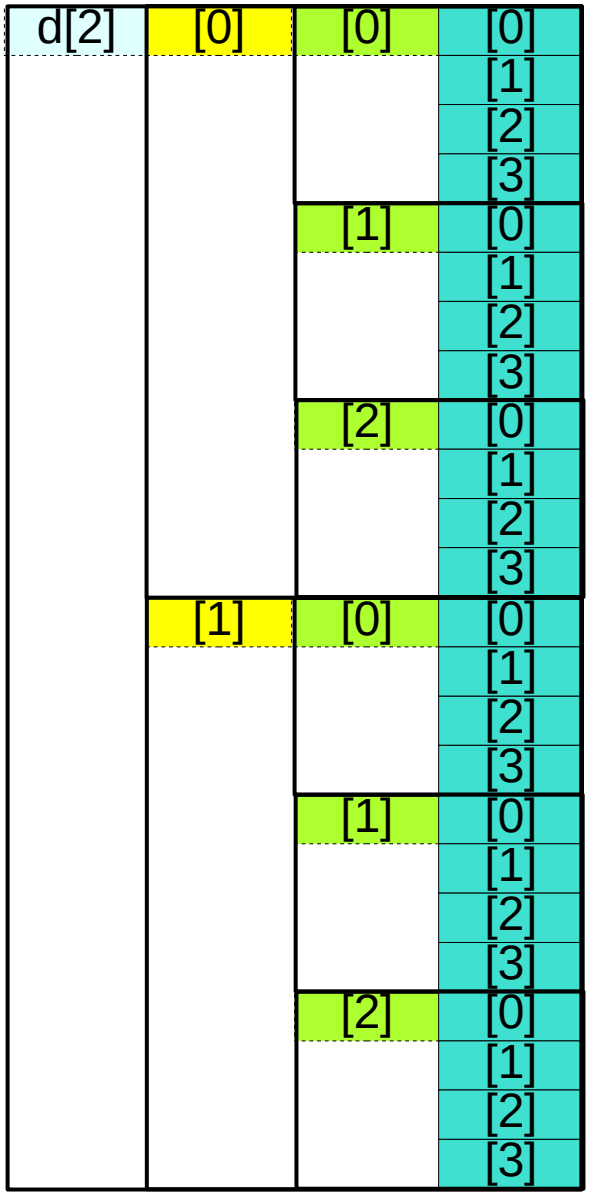

```
p = a;   (=&a[0]);
q = b;   (=&b[0]);
r  = c;  (=&c[0]);
s = d;   (=&d[0]);
```

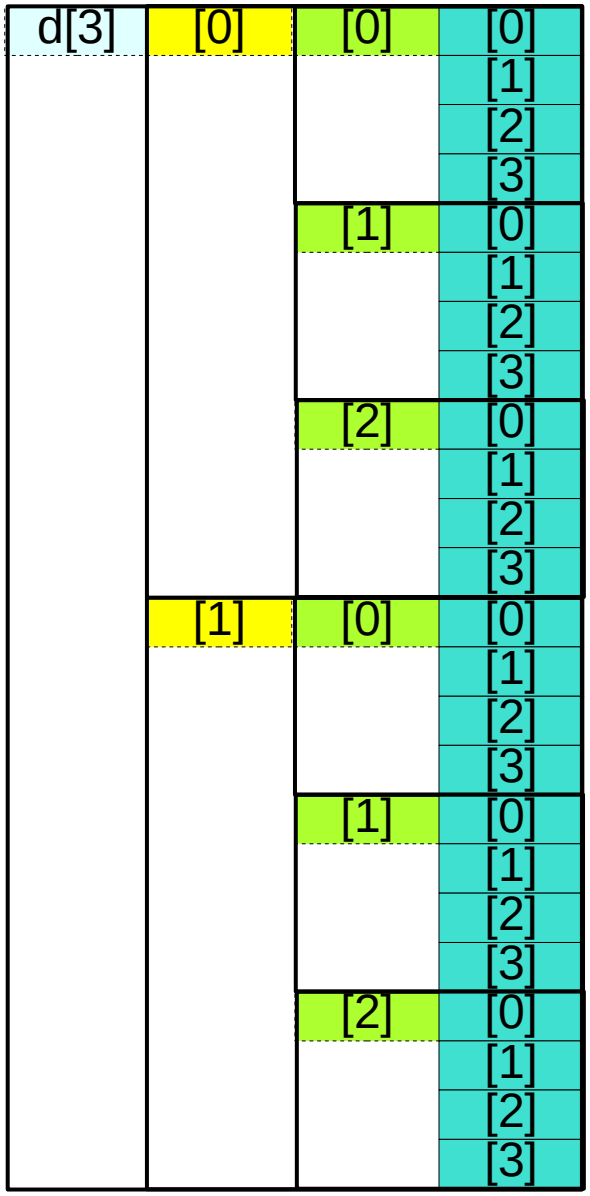
```
int c[4] [2][3];
int (*r) [2][3];
```

```
int d[4] [2][3][4];
int (*s)  [2][3][4];
```

multi-dimensional array pointers





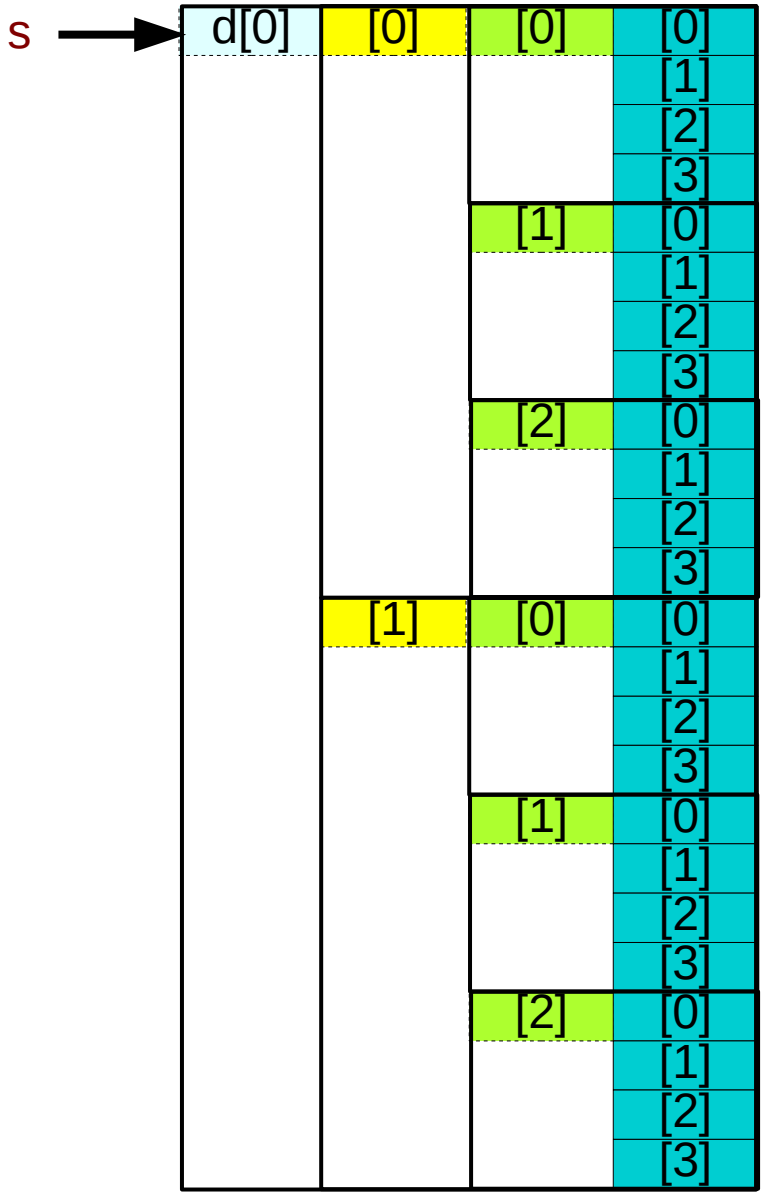


multi-dimensional array pointers

```
int d[4] [2][3][4];
int (*s)  [2][3][4];
```

d	4-d array name	d[4] [2][3][4]
	3-d array pointer	(*d) [2][3][4]
d[i]	3-d array name	d[i][2][3][4]
	2-d array pointer	(*d[i])[3][4]
d[i][j]	2-d array name	d[i][j][3][4]
	1-d array pointer	(*d[i][j])[4]
d[i][j][k]	1-d array name	d[i][j][k][4]
	0-d array pointer	(*d[i][j][k])

i =[0..3], j = [0..1], k= [0..2]



To pass multidimensional array names

```
int a[4] ;
int (*p) ;
```

call

```
funa(a, …);
```

prototype

```
void funa(int (*p), …);
```

```
int b[4] [2];
int (*q) [2];
```

call

```
funb(b, …);
```

prototype

```
void funb(int (*q)[2], …);
```

```
int c[4] [2][3];
int (*r) [2][3];
```

call

```
func(c, …);
```

prototype

```
void func(int (*r)[2][3], …);
```

```
int d[4] [2][3][4];
int (*s) [2][3][4];
```

call

```
fund(d, …);
```

prototype

```
void fund(int (*s)[2][3][4], …);
```

References

[1] Essential C, Nick Parlante

[2] Efficient C Programming, Mark A. Weiss

[3] C A Reference Manual, Samuel P. Harbison & Guy L. Steele Jr.

[4] C Language Express, I. K. Chun