Dynamic Memory Allocation

Dynamic 2D Arrays

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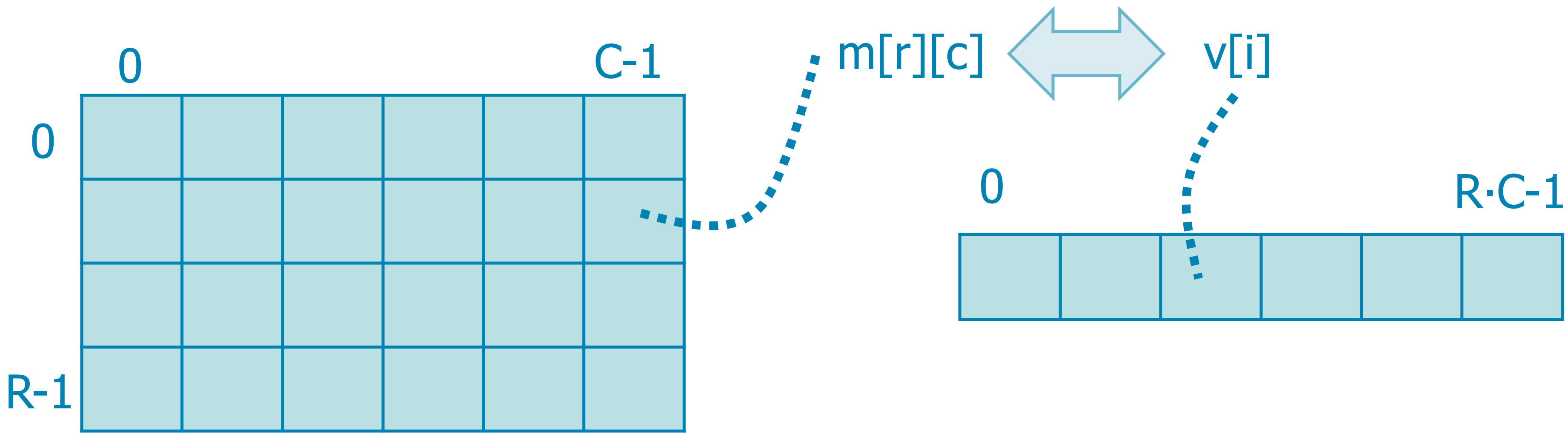
Problem definition

- Two-dimensional arrays can be allocated in two different ways
  - As a single 1D array including all elements
    - Easy syntax for allocation and manipulation
    - Difficult manipulation logic
  - As an array of pointers to 1D arrays of elements
    - Difficult syntax for allocation and manipulation
    - Standard manipulation logic

2D as 1D

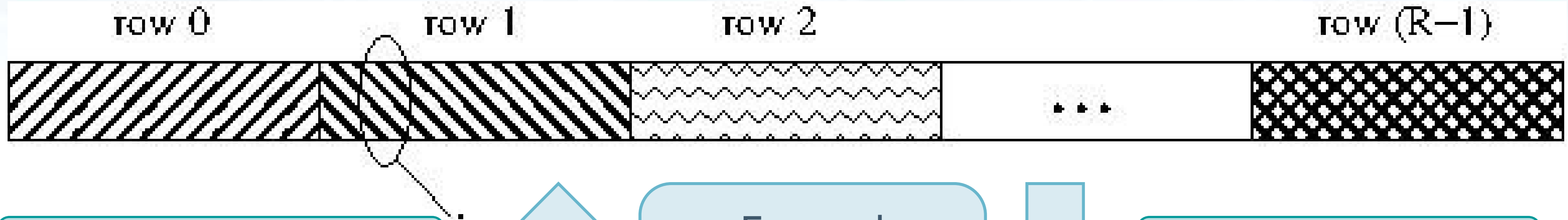
- To allocate a matrix of R rows and C columns we can allocate a one-dimensional array
  - We must reserve (R · C) contiguous elements
  - Perform on-the-fly conversion 2D→1D and vice-versa



2D as 1D

- The linearization is feasible following two different schemes
  - Row-major-order
    - Rows are allocated one after the other, with their elements in contiguous cells
    - Used in Pascal, C, C++, Python, and others
  - Column-major-order
    - Columns are allocated one after the other, with their elements in contiguous cells
    - Used in FORTRAN, OpenGL, Open CL ES, MATLAB, and others

Row-major-order

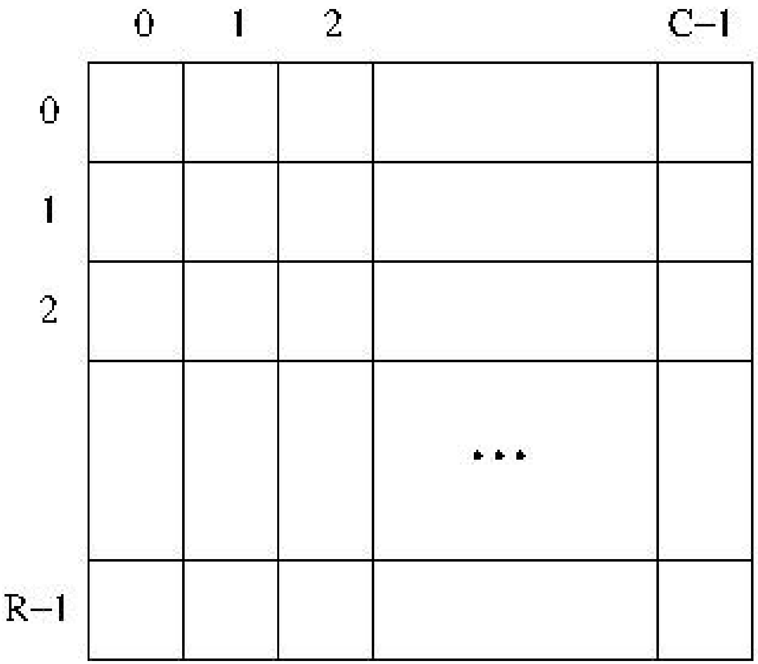


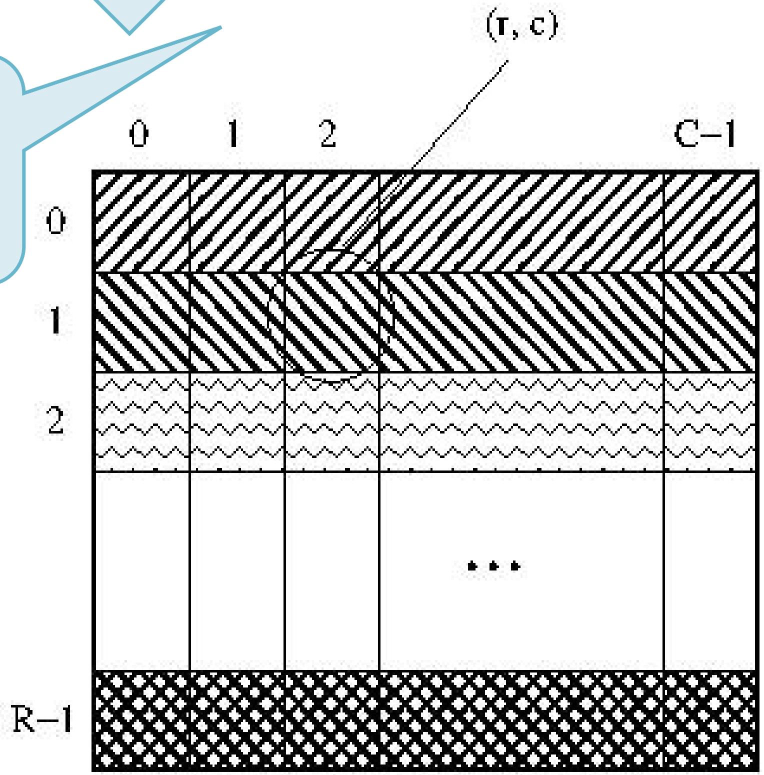
$i = r \cdot C + c$

Forward transfer from 2D to 1D

Backward transfer from 1D to 2D

$r = i \,/\, C$
$c = i \,\%\, C$





Considerations

- The row-major-order scheme is **automatically** used by any C compiler every time a multi-dimensional array is defined
  - As all other data structures, arrays are stored in the computer memory
  - The computer memory is a linear array of cell
  - Thus, all multi-dimensional data structure require linearization to be stored internally

2D as 2D

- To allocate an array of R pointers to arrays of C elements, we must
  - Allocate one array of R pointers
    - Each pointer references one entire array of basic elements representing the corresponding row
  - Allocate R arrays of C basic elements, i.e., one for each row, we make sure that the previous pointers reference the correct one

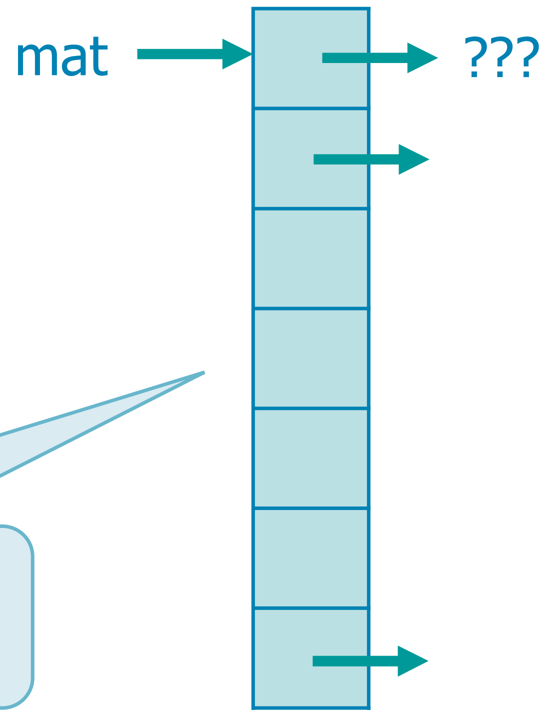
2D Allocation

We generate a pointer to poitners

Elements are pointers

```
mat = (int **) malloc (r * sizeof (int *));
if (mat == NULL) { ... }
```

We work on integer values. The same reasoning applies on all other variable types

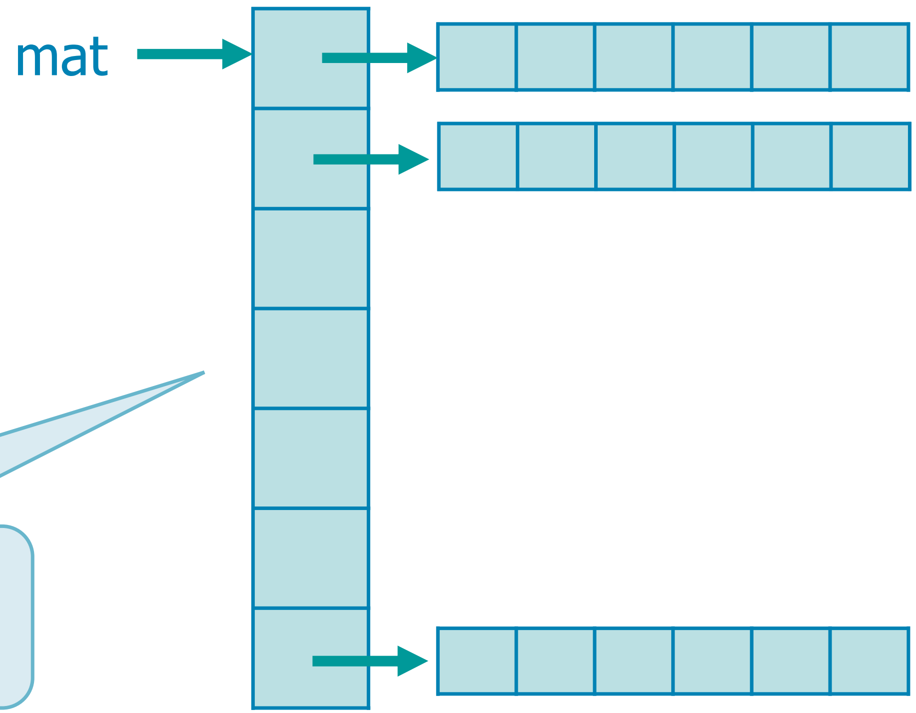


First, we allocate the main array of pointers

2D Allocation

```
for (i=0; i<r; i++) {
  mat[i] = (int *) malloc (c * sizeof (int));
  if (mat[i] == NULL) { ... }
}
```

We work on integer values.
The same reasoning applies on all other variable types



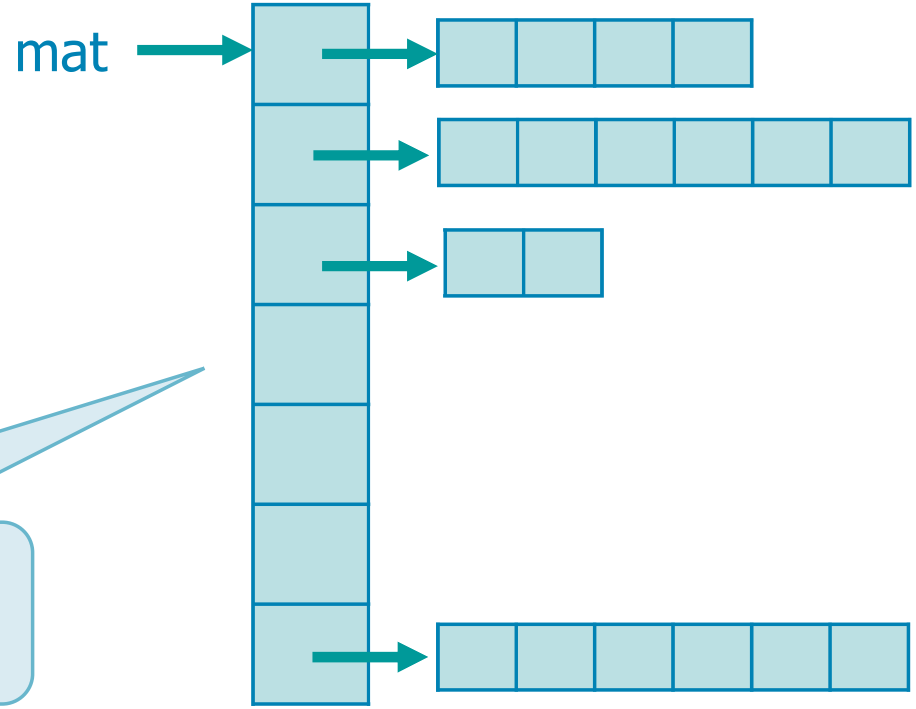
Then, we allocate the set of secondary arrays of elements

2D Allocation

```
for (i=0; i<r; i++) {
  mat[i] = (int *) malloc (c * sizeof (int));
  if (mat[i] == NULL) { ... }
}
```

The numbe of elements may vary in each row

We work on integer values. The same reasoning applies on all other variable types

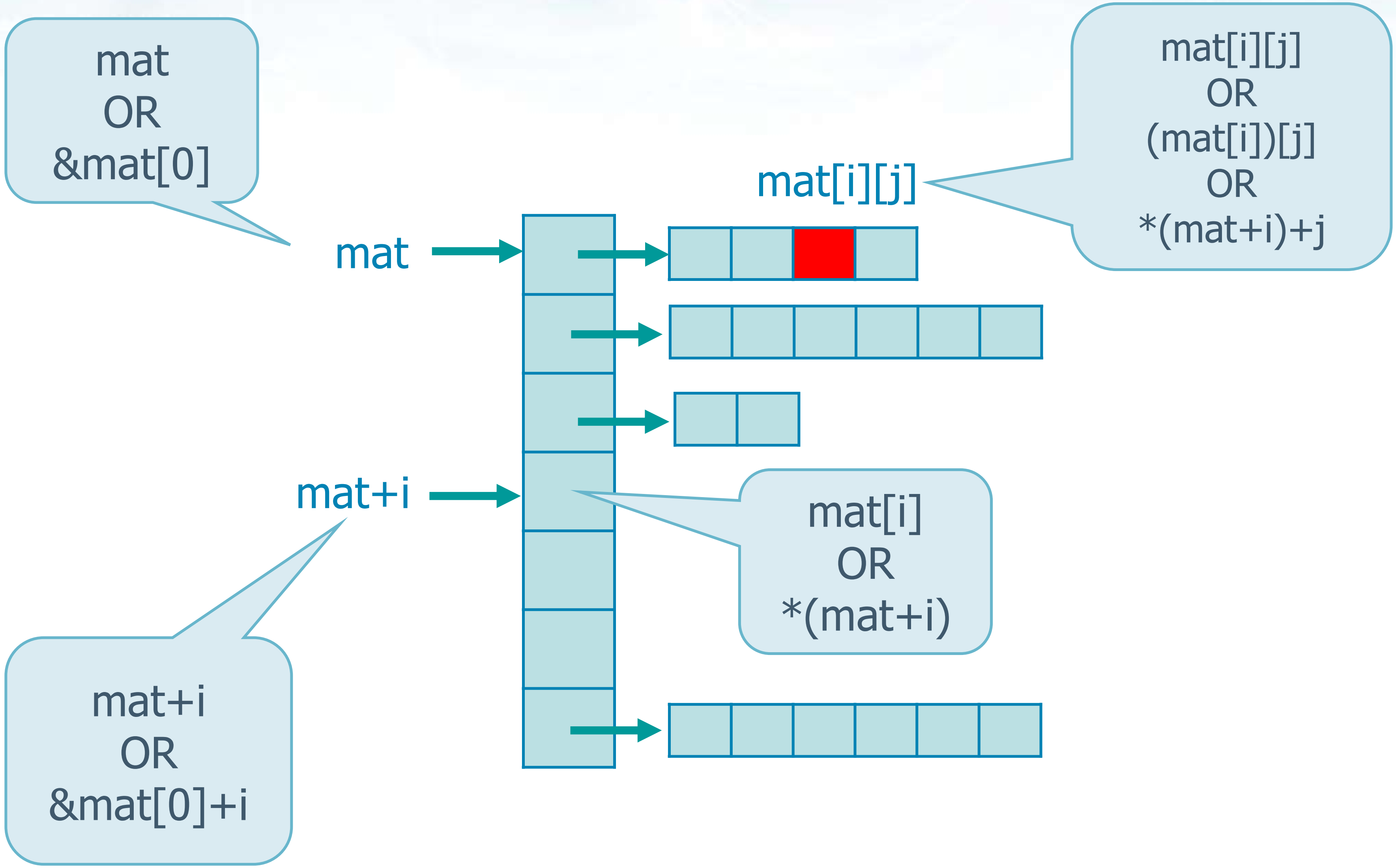


The secondary arrays can have different length

Matrix manipulation

- The easiest way to reach each matrix element is to use the standard matrix notation
  - mat[i][j] or (mat[i])[j]
    - Indicates a single element
    - It is a value
  - mat[i]
    - Indicates an entire row
    - It is a pointer to an array of values
  - mat
    - Indicates the entire matrix
    - It is a pointer to an array of pointers

Matrix manipulation



Example

2D matrix of integers

```
int r, c, i;
int **mat;
printf ("Number of rows: ");
scanf ("%d", &r);
mat = (int **) malloc (r * sizeof (int *));
if (mat == NULL) {
   fprintf (stderr, "Memory allocation error.\n");
   exit (1);
}
printf ("Number of columns: ");
scanf ("%d", &c);
for (i=0; i<r; i++) {
  mat[i] = (int *) malloc (c * sizeof (int));
  if (mat[i] == NULL) {
    fprintf (stderr, "Memory allocation error.\n");
    exit (1);
  }
}
```

Example

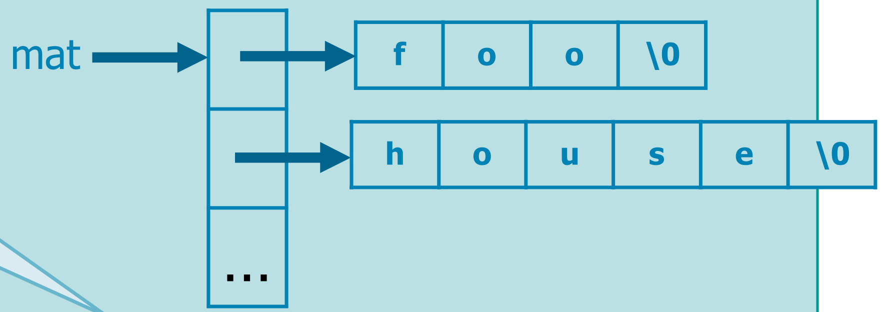
2D matrix of characters

The matrix can be used to store strings

```
int r, c, i;
char **mat;
printf ("Number of rows: ");
scanf ("%d", &r);
mat = (int **) malloc (r * sizeof (int *));
if (mat == NULL) {
    fprintf (stderr, "Memory allocation error.\n");
    exit (1);
}

for (i=0; i<r; i++) {
   scanf (“%s”, str);
   mat[i] = malloc ((strlen(str)+1) * sizeof (char));
   if (mat[i] == NULL) {
     fprintf (stderr, "Memory allocation error.\n");
     exit (1);
   }
}
```

Do not forget “+1”



Dispose the matrix

- As usual, dynamic data structure must be deallocated
- To free the data structure we must
  - First, free all secondary arrays (the rows)
  - Then, free the primary array pointers after

```
for (i=0; i<r; i++) {
  free (mat[i]);
}
free (mat);
```

Common errors

```
int mat[10][20];

sizeof (mat) ⇔ size of pointer, 4 or 8
sizeof (mat[i]) ⇔ 10 * sizeof(int)
sizeof (mat[i][j]) ⇔ sizeof(int)
```

2D arrays and modularity

- As for 1D arrays, also 2D arrays may be made visible outside the environment in which they have been allocated
- As for 1D arrays, it is possible to
  - Use **global** variables to contain the matrix pointer
  - Adopt the **return** statement to return it
  - Pass the pointer to the matrix by reference
    - Unfortunately, the pointer to the matrix is already a 2-star object (indirect reference)
    - To pass it by reference, we have to use a 3-star object (a reference to a reference of a reference)

Example

```
char **mat;
...
mat = malloc2d (nr, nc);
```

We return the pointer

```
char **malloc2d (int r, int c) {
  int i;
  char **mat;
  mat = (char **) malloc (r * sizeof(char *));
  if (mat == NULL) { ... }
  for (i=0; i<r; i++) {
    mat[i] = (char *) malloc(c * sizeof (char));
    if (mat[i]==NULL) { ... }
  }
  return (mat);
}
```

Example

```
char **mat;
...
malloc2d (&mat, nr, nc);
```

We use a 3-* object with a temporary 2* object as a support

```
void malloc2d (char ***m, int r, int c) {
  int i;
  char **mat;
  mat = (char **) malloc (r * sizeof(char *));
  if (mat == NULL) { ... }
  for (i=0; i<r; i++) {
    mat[i] = (char *) malloc(c * sizeof (char));
    if (mat[i]==NULL) { ... }
  }
  *m = mat;
  return;
}
```

Example

```
char **mat;
...
malloc2d (&mat, nr, nc);
```

We use a 3-* object without any support

```
void malloc2d (char ***m, int r, int c) {
  int i;
  (*m) = (char **) malloc (r * sizeof(char *));
  if (m == NULL) { ... }
  for (i=0; i<r; i++) {
    (*m)[i] = (char *) malloc(c * sizeof (char));
    if ((*m)[i]==NULL) { ... }
  }
  return;
}
```

The parenthesis are necessary

Example

- Do not forget to free the matrix …

```
void free2d (char **m, int r) {
  int i;
  for (i=0; i<r; i++) {
    free (m[i]);
  }
  free (m);
  return;
}
```

```
void free2d (char ***m, int r) {
  int **mat, i;
  mat = *m;
  for (i=0; i<r; i++) {
    free (mat[i]);
  }
  free (mat);
  m = NULL;
  return;
}
```

Version to set the original pointer to NULL

Observations

- All previous techniques can be applied to any type
  - Integer, float, character, C structures