Programming Paradigms

Composite Types (Part 2)

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Summer 2020

Overview

- Records
- Arrays
- Pointers and Recursive Types

Arrays

- **Most common composite data type**
- **Conceptually: Mapping from index type to element type**
  - Index types: Usually a discrete type, e.g., integer
  - Element type: Usually any type

Syntax

Varies across PLs

- Declaration
  - C: `char upper[26];`
  - Fortran: `character (26) upper`
- Accessing elements
  - C: `upper[3]` (indices start at 0)
  - Fortran: `upper(3)` (indices start at 1)

Multi-Dimensional Arrays

- **Indexing along multiple dimensions**
  - Single dimension: Sequence of elements
  - Two dimensions: 2D matrix of elements
  - Three dimensions: 3D matrix of elements
  - etc.
- **E.g., two-dimensional array in C:**

```
int arr[3][4];
```

  - 3 rows, 4 columns

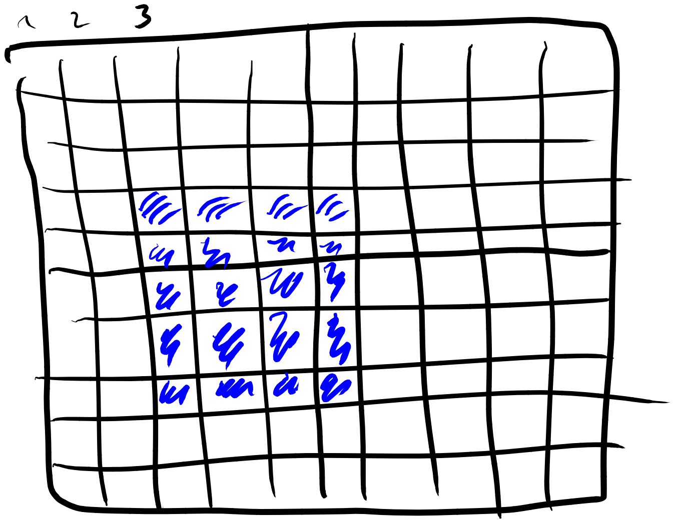
Array Operations (Beyond Element Access)

- **Slicing: Extract "rectangular" portion of array**
  - Some PLs: Along multiple dimensions
- **Comparison**
  - Element-wise comparison of arrays of equal length:

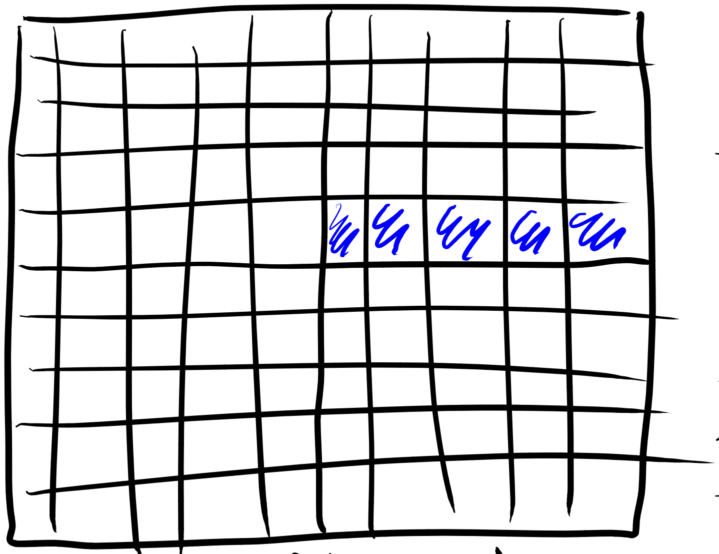
    `arr1 < arr2`
- **Mathematical operations**
  - Element-wise addition, subtraction, etc.

Example: Array Slicing in Fortran

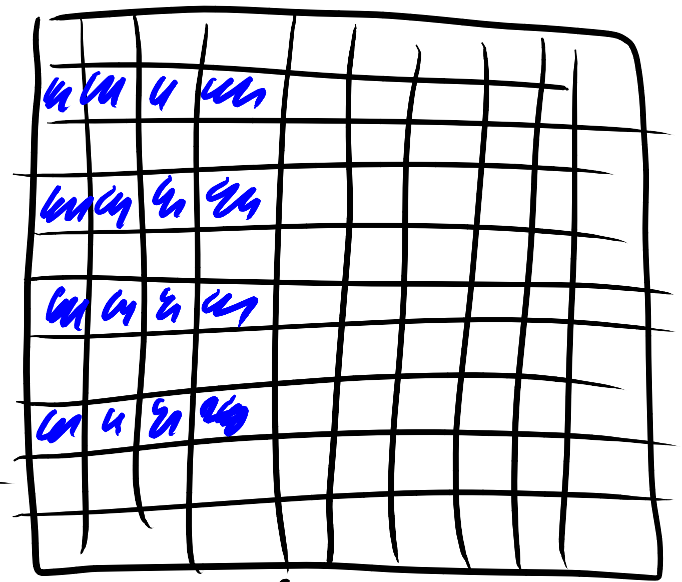
10 x 10 array : matrix



matrix (3:6, 4:7)



matrix (6:, 5)



matrix (:4, 2:8:2)

Note: Fortran use colum-major indexing, i.e., the fist index refers to the row and the second index refers to the column.

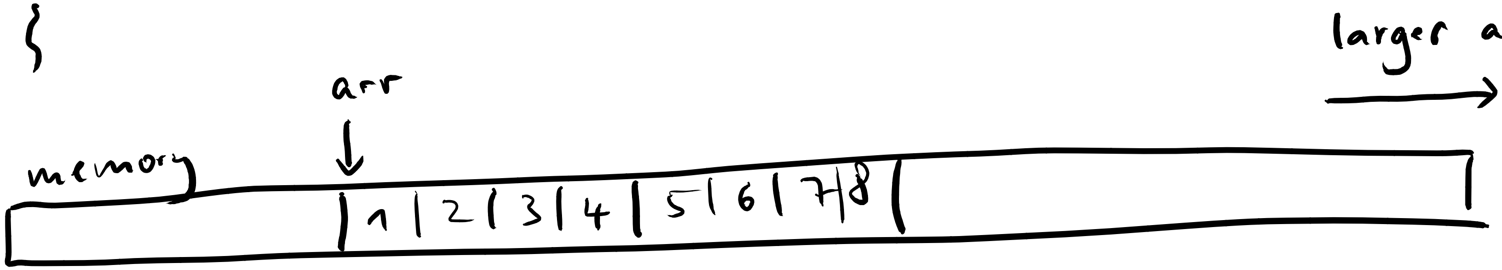
Memory Layout

- **Single dimension: Elements are contiguous in memory**
- **Multiple dimensions**
  - Option 1: Contiguous, row-major layout
    - E.g., in C
  - Option 2: Contiguous, column-major layout
    - E.g., in Fortran
  - Option 3: Row-pointer layout
    - E.g., in Java

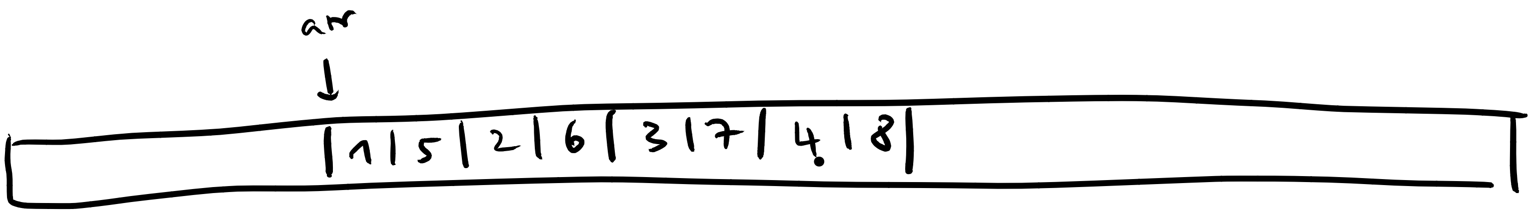
Example:

```
int arr[2][4] = {
    {1,2,3,4},
    {5,6,7,8}
}
```

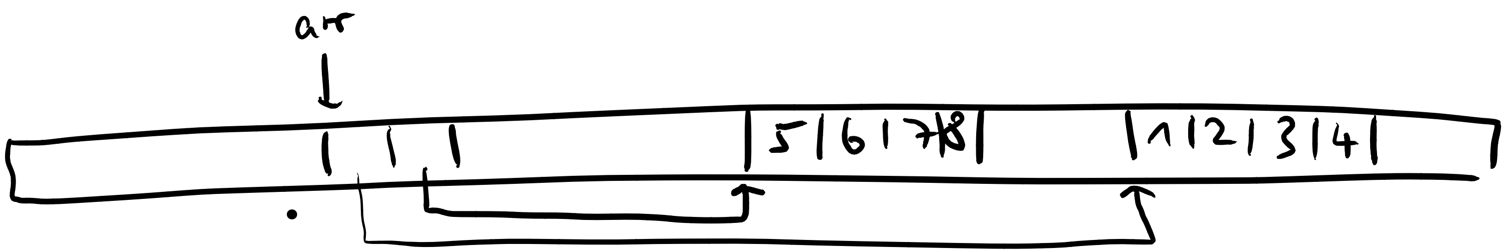
Row-major:



Column-major:



Row pointers:



Significance of Memory Layout

Layout determines efficiency of nested loops that iterate through multi-dimensional arrays

- CPU fetches entire cache lines from memory
- Accessing all data in a cache line is efficient
- Accessing data outside of current cache line: Cache miss
  - Causes expensive reading of another cache line

Quiz: Efficient Array Access

Given a large, two-dimensional array, which loop is faster in C and Fortran?

```c
// C code, option 1
for (i=0; i<N; i++) {
  for (j=0; j<N; j++) {
    // access arr[i][j]
  }
}
```

```fortran
! Fortran code, option 1
do i=1,N
  do j=1,N
    ! access arr(i,j)
  end do
end do
```

```c
// C code, option 2
for (j=0; j<N; j++) {
  for (i=0; i<N; i++) {
    // access arr[i][j]
  }
}
```

```fortran
! Fortran code, option 2
do j=1,N
  do i=1,N
    ! access arr(i,j)
  end do
end do
```

Please vote via Ilias.

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  for (i=0; i<N; i++) {
    // access arr[i][j]
  }
}
```

```fortran
! Fortran code, option 2
do j=1,N
  do i=1,N
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