

Bits, Bytes, and Precision

- Bit: Smallest amount of information in a computer.
 - Binary: A bit holds either a 0 or 1.
 - Series of bits make up a number.
- Byte: 8 bits.
- Single precision variable: 4 bytes (32 bits)
 - Essentially 10 significant digits.
- Double precision variable: 8 bytes (64 bits)
 - Essentially 19 significant digits

Example: Quality controlling hourly station reports on a local mesonet (25 stations)

- Read in temperatures and dew points from a file.
- Find the average temperature and dew point
- Print stations that have temperature and/or dew points greater than ± 5 °F from the mean, sorted so that stations with the largest deviation are printed first
- How do I accomplish this task?
- You could try and read and re-read the file over and over, but this is inefficient. What do you do?

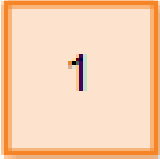
FORTRAN 90: Arrays

Meteorology 2270

Data Structures

- Data structure to store and organize the collection of temperatures and dew points.
- Structure should allow data storage and retrieval.
- Data should be stored in main memory.
- 1-D array: Stores a fixed number of data values, all of the same type.

Variables vs. Arrays

exam_score 

Array: Indexes 0 1 2 3 4

exam_scores	1	3	8	23	99
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1-D Arrays

- In FORTRAN 90, the type statement would look like:
 - `REAL, DIMENSION(25) :: TEMP`
 - `REAL, DIMENSION(25) :: DEW`
 - `REAL, DIMENSION(25) :: TEMP, DEW`
- Creates two arrays named TEMP and DEW consisting of 25 memory locations for each in which reals can be stored.

Accessing an Array

- Two methods of accessing an array
- Use array-variable (TEMP, DEW) to refer to the entire array.
 - TEMP = 0
- Use a subscripting variable and an index to refer to an individual element
 - TEMP(5), DEW(6) is the 5th temperature and the 6th dew point.
 - Each subscript variable refers to a memory location.
- By default, FORTRAN indexing starts at 1 unless otherwise stated.
 - TEMP(1) is the first element, TEMP(2) is the second, etc.

Examples

- TEMP(5) = 68
DEW(5) = 66
DEPRESSION(5) = TEMP(5) – DEW(5)
PRINT *, “Dew Point Depression = “, DEPRESSION(5)
- READ(10,*) TEMP(N), DEW(N)
 - How might this be used?
- DO N=1, 25
 READ(10,*) TEMP(N), DEW(N)
END DO
- Mean-time to failure program in book.

Implied DO loops

- Can be used to simplify input and output
 - Useful, but does sacrifice readability.
- (list-of-variables, control-var = init-value, limit, step)
- `READ(10,*) (TEMP(N), DEW(N), N=1,25)`
 - This is equivalent to the loop on the previous slide.

Compile time and Allocatable Arrays

- What do we currently know?
- Size of arrays are fixed at compile time.
- Small dataset: wasted memory
- Large dataset: Too large to store and process correctly.

Compile time arrays

- type, DIMENSION(l:u) :: list-of-array-names
- type :: list-of-array specifiers
 - array-name(l:u)
- FORTRAN does allow a subscript to be any integer value, positive, negative, or zero
 - Must not fall outside of the range specified.
- INTEGER, PARAMETER :: LowerLimit_1= -1, UpperLimit_1 = 3, &
LowerLimit_2 = 0, UpperLimit_2 = 5
INTEGER, DIMENSION(LowerLimit_1 : UpperLimit_1) :: Alpha
REAL, DIMENSION(LowerLimit_2 : UpperLimit_2) :: Beta

Run-time or Allocatable arrays

- ALLOCATE attribute
 - REAL, DIMENSION(:), ALLOCATABLE :: list-of-array-names
 - REAL, DIMENSION(:), ALLOCATABLE :: A, B
- Later in program.....
 - ALLOCATE(list, STAT = status-variable)
 - List is a list of array specifications of the form array-name(l:u)
 - Status-variable is an integer variable that:
 - 0 is allocation of array is successful.
 - Non-zero if an error occurred.
- Even later in the program
 - DEALLOCATE(list, STAT=status-variable)
 - Status-variable is identical to ALLOCATE statement except for deallocating the array.

Array Constants

- Arrays may be filled by a list of values enclosed between (/ and /)
 - `A = (/ 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 /)`
- This may be simplified with an implied do loop
 - `A = (/ (2*N, N = 1, 10) /)`
 - `A = (/ 2, 4, (N, N = 6, 18, 2), 20 /)`
- How do we use this?
 - `INTEGER, DIMENSION(10) :: A`
`A = (/ 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 /)`
`A = (/ (2*N, N = 1, 10) /)`
`A = (/ 2, 4, (N, N = 6, 18, 2), 20 /)`
- Each of these are the same as:
 - `DO N = 1, 10`
`A(N) = 2*N`
`END DO`

Quick Digression: Modulus

- $\text{MOD}(A,P) = A - \text{INT}(A/P) * P$
- Returns the remainder when A is divided by P .
- Examples
 - $Z = \text{MOD}(9,3)$
 - $Z = \text{MOD}(10,3)$
 - $Z = \text{MOD}(\text{Hours_into_model_run},24)$
- Arguments can be integer or real.

Array Expressions

- Operators and functions normally applied to simple expressions may also be applied to arrays having the **same number of elements**.
 - Operations are carried out element by element.
- INTEGER, DIMENSION(4) :: A, B
INTEGER, DIMENSION(0:3) :: C
INTEGER, DIMENSION(6:9) :: D
LOGICAL, DIMENSION(4) :: P
A = (/ 1, 2, 3, 4 /)
B = (/ 5, 6, 7, 8 /)
C = (/ -1, 3, -5, 7 /)
A = A+B
D = 2 * ABS(C) + 1
P = (C > 0) .AND. (MOD(B,3) == 0)
- What are A, D, and P?
- A = 6, 8, 10, 12
D = 3, 7, 11, 15
P = .false., .true., .false., .false.

Array Assignment

- Array-variable = expression
- The value of expression assigned to an array variable must be either:
 - An array of the same size as the array variable, or
 - A simple value.
- In the second case, the value is broadcast to all members of the array.

Array Sections and Subarrays

- Allows you to construct new arrays by selecting elements from another array
 - Array-name(subscript-triplet)
 - Array-name(vector-subscript)
- Subscript triplet: lower : upper : stride
 - If lower (upper) is omitted, the lower (upper) bound in the array declaration is used.
- ```
INTEGER, DIMENSION(10) :: A
INTEGER, DIMENSION(5) :: B, I
A = (/ 11, 22, 33, 44, 55, 66, 77, 88, 99, 110 /)
B = A(2 : 10 : 2)
```
- What is B?

# Array sections cont.: Vector-subscripts

- $A = (/ 11, 22, 33, 44, 55, 66, 77, 88, 99, 110 /)$   
 $N = (/ 6, 5, 3, 9, 1 /)$   
 $B = A(N)$
- Assigns to B the element locations from array A listed by N.
  - Values in N become indices.
  - $B = 66, 55, 33, 99, 11$
- $B = A((/ 5, 3, 3, 4, 3 /))?$
- $A(1 : 10 : 2) = (/ N^{**}2, N = 1, 5 /)?$

# Subarrays cont.: Input/Output

- DO N = 1, NumTemps  
    READ(10,\*) Temp(N)  
END DO
- READ(10,\*) (Temp(N), N = 1, NumTemps)
- READ(10, \*) Temp(1:NumTemps)
- PRINT \*, Temp(1:NumTemps)

# WHERE construct

- Used to assign values to arrays depending on the value of a logical array expression
- WHERE (logical-array-expr)

array-var = array-expr

....

ELSEWHERE

array-var = array-expr

END WHERE

- Logical expression is evaluated element by element.
- INTEGER, DIMENSION(5) :: A = (/ 0, 2, 5, 0, 10 /)
- REAL, DIMENSION(5) :: B

WHERE (A > 0)

B = 1.0/ REAL(A)

ELSEWHERE

B = -1.0

END WHERE

- What is B?
- B = -1.0, 0.5, 0.2, -1.0, 0.1

# Arrays as Arguments

- Several intrinsic functions exist for arrays
- ALLOCATED(A)
  - Returns true if memory has been allocated to the allocatable array A and false otherwise
- MAXVAL(A)
  - Returns the maximum value of A
- MINVAL(A)
  - Returns the minimum value of A
- MAXLOC(A)
  - Returns a one-dimensional array containing one element whose value is the position of the first occurrence of the maximum value in A.
  - MINLOC(A)
- DOT\_PRODUCT(A,B)
  - Returns the dot product of arrays A and B.
- SUM(A)
  - Returns the sum of the elements in A.
- PRODUCT(A)
  - Returns the product of the elements in A.
- SIZE(A)
  - Returns the number of elements in A.
- Others can be found in appendix A.

# Multi-Dimensional Arrays

- Many applications
  - Data naturally fits into a table.
    - Times series of temperature measurements from multiple stations.
  - Data is on a grid.
- Example: Hourly data from Flory MicroNet.
  - 50 stations reporting hourly output.
  - Construct table/form array to hold data.
- `REAL, DIMENSION(24,50) :: Temperature`
  - Indices are arranged as (hour, station)

`REAL, DIMENSION(1:24,1:50) :: Temperature`
- Question: What is `Temperature(12,12)`?

# Multi-Dimensional Arrays cont.

- This array only holds data for one day, what if I want multiple days?
- `REAL, DIMENSION(365,24,50) :: Temperature`
  - Indices are arranged as (day, hour, station).
- What is `Temperature(180,12,20)`?
- Temperature from the 20<sup>th</sup> station on the 180<sup>th</sup> day of year at the 12<sup>th</sup> hour.

# Declarations – Compile time

- type,  $\text{DIMENSION}(L_1:U_1, L_2:U_2, \dots, L_k:U_k) :: \text{list}$
- type, list-of-array-specifiers
  - Number of dimensions,  $k$ , is called the “rank” of the array.
- $\text{REAL, DIMENSION}(1:2, -1:3) :: \text{Alpha}$   
 $\text{REAL, DIMENSION}(0:2, 0:3, 1:2) :: \text{Beta}$
- List all of the valid references to each array?

# Declarations - Allocatable

- `type, DIMENSION(:, :, :, ..., :), ALLOCATABLE :: list`
- `REAL, DIMENSION (:, :, :), ALLOCATABLE :: Beta`  
`REAL, DIMENSION (:, :), ALLOCATABLE :: Alpha`
- `ALLOCATE(Beta(0:2,0:3,1:2), Alpha(1:2,-1:3), &  
STAT = AllocateStatus)`
- Example: Table of temperatures.

# Sorting and Searching

- Section 8.4
- Sorting: Arranging items in a list so that they are in ascending or descending order.
  - Selection sort, quick sort, bubble sort
- Searching: Finding a specified item and retrieving information associated with that item.
  - Linear search, binary search

# Selection Sort

- Traverse the list, or part of the list, several times, each time selecting one item to be correctly positioned.
- Method (ascending order):
  1. Find smallest item and move it to the first position by exchanging it with that number.
  2. Scan the rest of the list starting from position #2 and repeat.
  3. Continue in this manner until the list is sorted.
    1. 3<sup>rd</sup> element in the list to the end of the list, etc.
- Let's practice.

# Quick Sort (Recursive sorting)

- More efficient than a selection sort.
- One of the fastest sorting methods.
- Method:
  - Select pivot element (typically first element).
  - Perform exchanges so that all elements on left of pivot are less than the pivot and all elements on the right are greater than the pivot.
    - Correctly positions the pivot element.
    - Divides the list into two sub-lists.
  - Sort sub-lists independently in the same way.
    - Divide and conquer approach.
- 50, 30, 20, 80, 90, 70, 95, 85, 10, 15, 75, 25

# Searching

- Linear Search
  - Begin with first item in list and search sequentially until desired item is found or end of list is reached.
- Binary Search
  - If a list has been sorted, a binary search can be used more efficiently.
  - Method
    - Examine middle element in the list. Is it the desired element?
    - If not, determine if desired item in the first or second half of list.
    - Search that half of the list using the same approach.