Arrays and Vectors

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Fortran dimension

```
real(8), dimension(100) :: x,y
integer :: i(10,20)
```

Static, obey scope.

1-based Indexing

```
integer,parameter :: N=8
real(4),dimension(N) :: x
do i=1,N
  ... x(i) ...
```

Lower bound

```
real,dimension(-1:7) :: x
do i=-1,7
  ... x(i) ...
```

Array initialization

```
real,dimension(5) :: real5 = [ 1.1, 2.2, 3.3, 4.4, 5.5 ]
/* ... */
real5 = [ (1.01*i,i=1,size(real5,1)) ]
/* ... */
real5 = (/ 0.1, 0.2, 0.3, 0.4, 0.5 /)
```

Array sections

Use the colon notation to indicate ranges:

```
real(4),dimension(4) :: y
real(4),dimension(5) :: x
x(1:4) = y
x(2:5) = x(1:4)
```

Use of sections

Code:

```
real(8),dimension(5) :: x = &
     [.1d0, .2d0, .3d0, .4d0, .5d0]
x(2:5) = x(1:4)
print '(f5.3)',x
```

Output
[arrayf] sectionassign:

```
0.100
0.100
0.200
0.300
0.400
```

Strided sections

Code:

```
integer,dimension(5) :: &
     y = [0,0,0,0,0]
integer,dimension(3) :: &
     z = [3,3,3]
y(1:5:2) = z(:)
print '(i3)',y
```

Output
[arrayf] sectionmg:

```
  3
  0
  3
  0
  3
```

Index arrays

```
integer,dimension(4) :: i = [2,4,6,8]
real(4),dimension(10) :: x
print *,x(i)
```

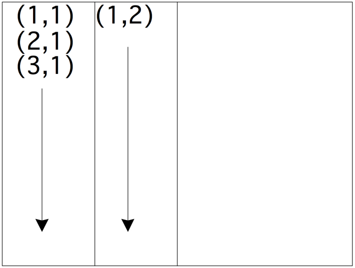
Multi-dimension arrays

```
real(8),dimension(20,30) :: array
array(i,j) = 5./2
```

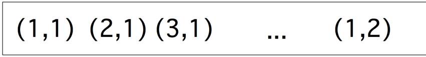
Array layout

Sometimes you have to take into account how a higher rank array is laid out in (linear) memory:

Fortran column major



Physical:



'First index varies quickest'

Array sections in multi-D

```
real(8),dimension(10) :: a,b
a(1:9) = b(2:10)
```

or

```
logical,dimension(25,3) :: a
logical,dimension(25)   :: b
a(:,2) = b
```

You can also use strides.

Query functions

- Bounds: `lbound`, `ubound`
- `size`

  ```
  integer :: x(8), y(5,4)
  size(x)
  size(y,2)
  ```

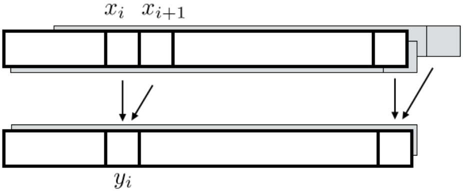
Pass array to subroutine

```
  real(8) function arraysum(x)
    implicit none
    real(8),intent(in),dimension(:) :: x
  /* ... */
    do i=1,size(x)
       tmp = tmp+x(i)
    end do
  /* ... */
Program ArrayComputations1D
    use ArrayFunction
    implicit none

    real(8),dimension(:) :: x(N)
  /* ... */
    print *,"Sum of one-based array:",arraysum(x)
```

(note: the function is in a module)

Exercise 1



Code $\forall_i$: $y_i = (x_i + x_{i+1})/2$:

- First with a do loop; then
- in a single array assignment statement by using sections.

Initialize the array `x` with values that allow you to check the correctness of your code.

Array allocation

```
real(8), dimension(:), allocatable :: x,y

n = 100
allocate(x(n), y(n))
```

You can `deallocate` the array when you don't need the space anymore.

Array intrinsics

- `MaxVal` finds the maximum value in an array.
- `MinVal` finds the minimum value in an array.
- `Sum` returns the sum of all elements.
- `Product` return the product of all elements.
- `MaxLoc` returns the index of the maximum element.
  `i = MAXLOC( array [, mask ] )`
- `MinLoc` returns the index of the minimum element.
- `MatMul` returns the matrix product of two matrices.
- `Dot_Product` returns the dot product of two arrays.
- `Transpose` returns the transpose of a matrix.
- `Cshift` rotates elements through an array.

Exercise 2

The 1-norm of a matrix is defined as the maximum sum of absolute values in any column:

$$\|A\|_1 = \max_j \sum_i |A_{ij}|$$

while the infinity-norm is defined as the maximum row sum:

$$\|A\|_\infty = \max_i \sum_j |A_{ij}|$$

Implement these functions using array intrinsics.

Exercise 3

Compare implementations of the matrix-matrix product.

1. Write the regular `i,j,k` implementation, and store it as reference.
2. Use the `DOT_PRODUCT` function, which eliminates the `k` index. How does the timing change? Print the maximum absolute distance between this and the reference result.
3. Use the `MATMUL` function. Same questions.
4. Bonus question: investigate the `j,k,i` and `i,k,j` variants. Write them both with array sections and individual array elements. Is there a difference in timing?

Does the optimization level make a difference in timing?

Timer routines

```
integer :: clockrate,clock_start,clock_end
call system_clock(count_rate=clockrate)
/* ... */
call system_clock(clock_start)
/* ... */
call system_clock(clock_end)
print *,"time:",(clock_end-clock_start)/REAL(clockrate)
```

operate where

```
where ( A<0 ) B = 0
```

Full form:

```
WHERE ( logical argument )
  sequence of array statements
ELSEWHERE
  sequence of array statements
END WHERE
```

Do concurrent

The *do concurrent* is a true do-loop. With the `concurrent` keyword the user specifies that the iterations of a loop are independent, and can therefore possibly be done in parallel:

```
do concurrent (i=1:n)
  a(i) = b(i)
  c(i) = d(i+1)
end do
```