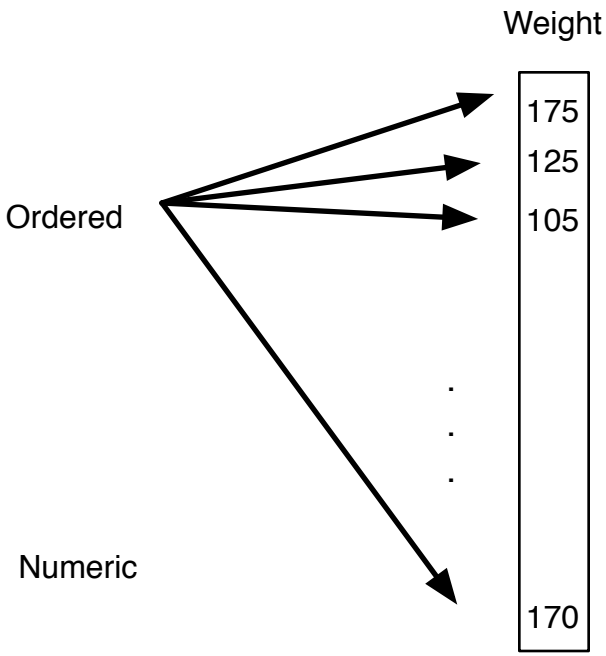
Lists and Matrices

AND the Apply Family of Functions

load(url(”http://www.stat.berkeley.edu/users/nolan/data/anExampleList.rda"))

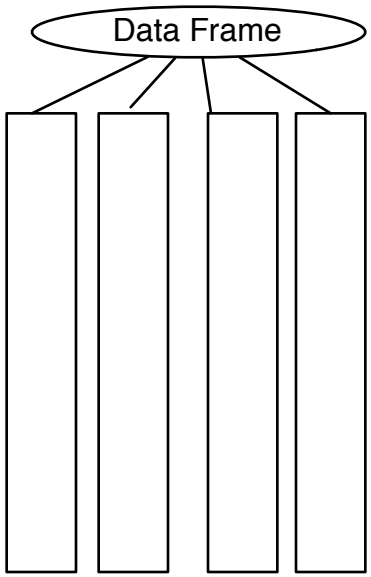
Vector

- *Ordered* container of literals
- Elements must be *same type*



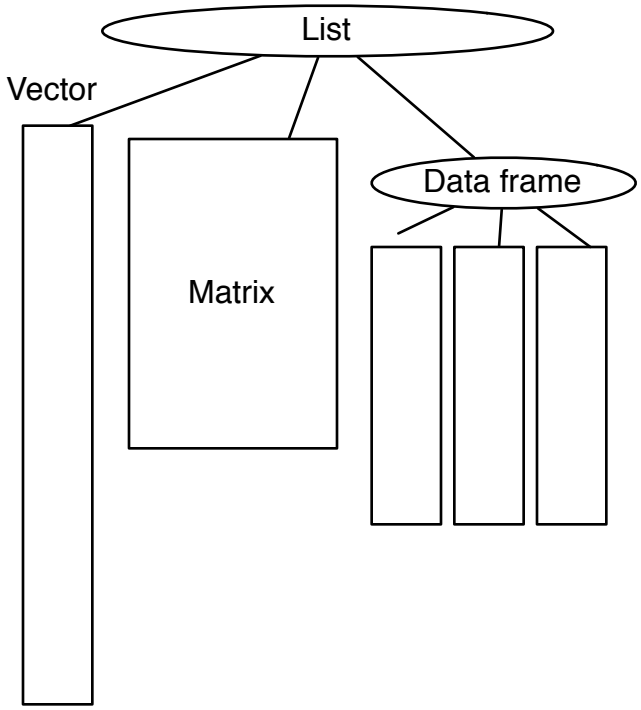
Data Frame

- *Ordered* container of vectors
- Vectors must all be the *same length*
- Vectors can be *different types*

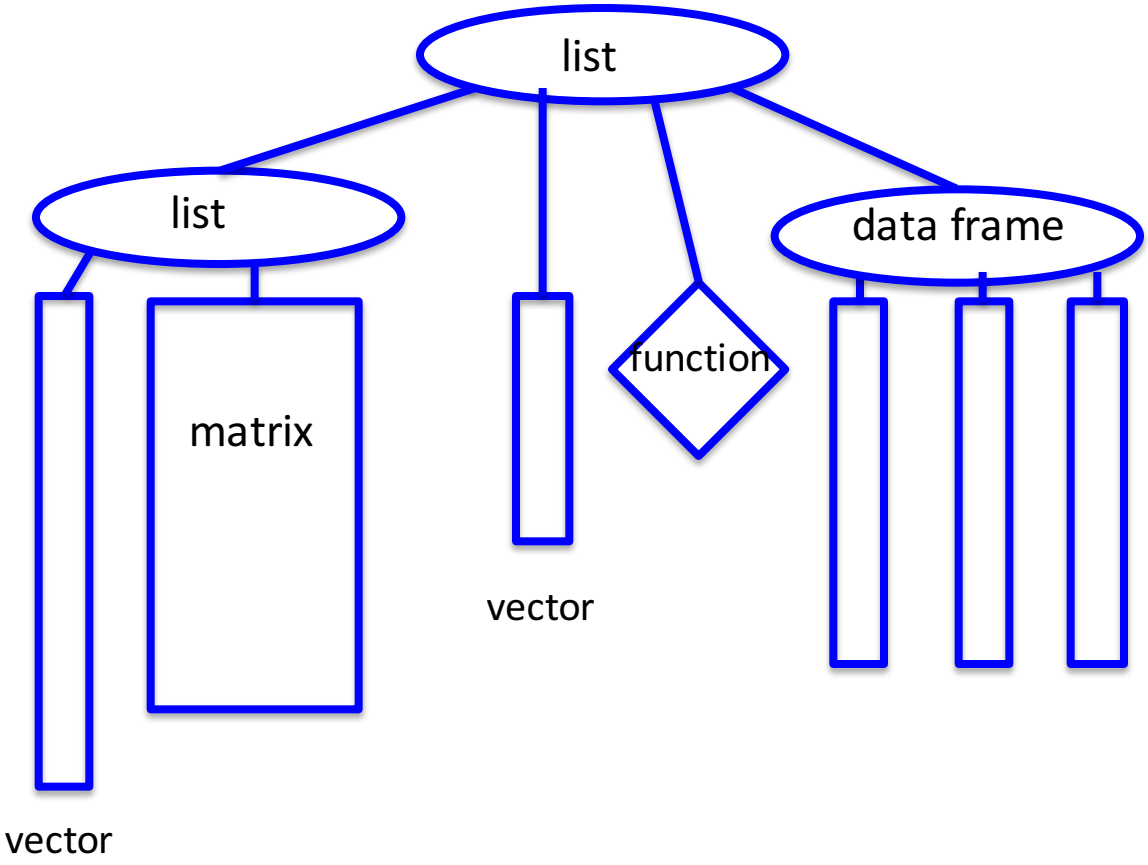


List

- Ordered collection of arbitrary objects
- Each element can be either a list, data frame, vector, matrix, …
- Data frames are a special kind of *list* where all elements are vectors of the same length



An Example List



Let’s inspect this List

Description of Structure: `str()`

```
List of 4
 $ listToo:List of 2
  ..$ aVec: num [1:4] 1 3 5 7
  ..$ aMat: num [1:3, 1:2] 10 14 18 12 16 20
 $ aVex    : chr [1:7] "a" "b" "c" "d" ...
 $ aFunc   :function (x)
  ..- attr(*, "srcref")=Class 'srcref'  atomic
[1:8] 1 140 1 159 140 159 1 1
  .. .. ..- attr(*, "srcfile")=Classes
'srcfilecopy', 'srcfile' <environment:
0x10f2b2b10>
 $ aDF     :'data.frame': 4 obs. of  3 variables:
  ..$ id     : num [1:4] 101 102 103 104
  ..$ height: num [1:4] 60 72 66 70
  ..$ sex    : Factor w/ 2 levels "f","m": 1 2 1 2
```

```
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 $ listToo:List of 2
  ..$ aVec: num [1:4] 1 3 5 7
  ..$ aMat: num [1:3, 1:2] 10 14 18 12 16 20
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0x10f2b2b10>
 $ aDF    :'data.frame': 4 obs. of  3 variables:
  ..$ id    : num [1:4] 101 102 103 104
  ..$ height: num [1:4] 60 72 66 70
  ..$ sex   : Factor w/ 2 levels "f","m": 1 2 1 2
```

Taking a Subset of a List

Ways to subset

- 5 types of subsetting work here too
  - Name, position, exclusion, logical, all
- **$**-sign notation accesses one element, if the elements have names
- Special subsetting for lists with **[[ ]]** – double square brackets - to access 1 element
- Take a subset of a subset with consecutive square brackets

5 ways to subset

`aList["listToo"]`	returns a list with 1 element (listToo), i.e. a list with 1 element
`aList[ c(3, 2)]`	returns a list with 2 elements (3rd, 2nd)
`aList[ -(1:3) ]`	Returns a list with 4th element

$-sign and [[ ]]

`aList$listToo`	returns the list listToo
`aList[[2]]`	Returns the vector aVec

Subset of a Subset

`aList$listToo$aVec`	returns the vector `[1] 1 3 5 7`
`aList[[1]]$aVec`	Returns the vector `[1] 1 3 5 7`
`aList[[1]][[1]]`	Ditto
`aList$listToo[[1]]`	Ditto

Subset of a Subset

```
aList$aVec[1:3]
```

returns the vector

[1] "a" "b" "c"

```
aList[[4]]$id
```

Returns the vector

[1] 101 102 103 104

```
aList[[4]][1:2, 2:3]
```

Returns the data frame

	height	sex
1	60	f
2	72	m

Subset of a Subset

```
aList[[3]](2:3)
```

A. returns the vector

[1] "a" "b" "c”

B. Returns an error

C. Returns 13

D. Returns the data frame

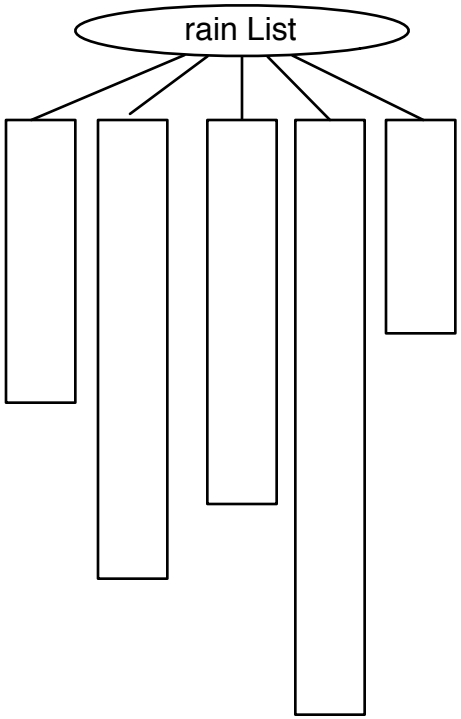
	height	sex
1	60	f
2	72	m
3	66	f
4	70	m

E. None of the above

Rainfall in Colorado Front Range

Rainfall

- Daily rainfall collected at 5 weather stations
- **rain** is a list of length 5
  - One element for each station
  - Each element is a numeric vector of rain measurements
  - Stations not in operation for the same length of time



```
load(url("http://www.stat.berkeley.edu/users/nolan/data/rainfallCO.rda"))
```

```
> class(rain)
[1] "list"
> length(rain)
[1] 5
> names(rain)
[1] "st050183" "st050263" "st050712"
"st050843" "st050945"
```

Or

```
> str(rain)
List of 5
 $ st050183: atomic [1:9878] 0 10 11 1 0 0 0 0 0 0 ...
  ..- attr(*, "Csingle")= logi TRUE
 $ st050263: atomic [1:6751] 0 0 0 0 0 0 0 0 0 0 ...
  ..- attr(*, "Csingle")= logi TRUE
 $ st050712: atomic [1:3959] 0 0 16 78 42 0 0 0 0 0 ...
  ..- attr(*, "Csingle")= logi TRUE
 $ st050843: atomic [1:11122] 0 5 7 14 2 0 0 0 0 0 ...
  ..- attr(*, "Csingle")= logi TRUE
 $ st050945: atomic [1:3692] 0 0 1 0 26 0 0 0 0 0 ...
  ..- attr(*, "Csingle")= logi TRUE
```

Accessing a Station's Data

- We can index 1 station by name, using $.

```
> class(rain$st050183)
[1] "numeric"
> length(rain$st050183)
[1] 9878
> head(rain$st050183)
[1]  0 10 11  1  0  0
```

- Or by [[ ]] with position or name

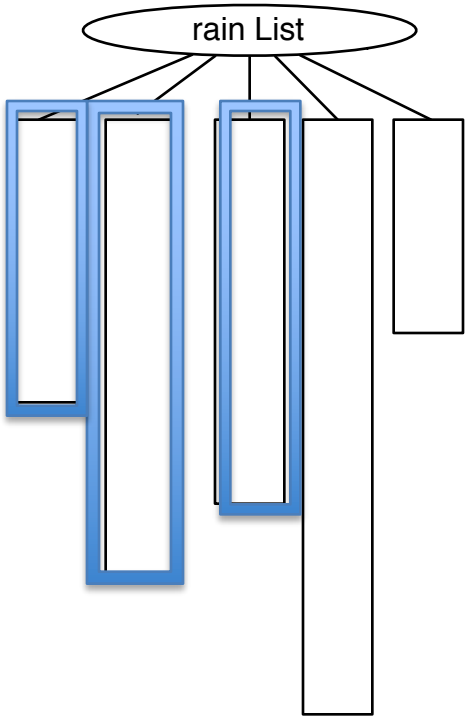
```
> class(rain[["st050945"]])
[1] "numeric"
> length(rain[["st050945"]])
[1] 3692
> head(rain[[5]])
[1]  0  0  1  0 26  0
```

- Sometimes we want an operation to be applied to each element of a list, to each vector in a data frame – e.g., that maximum rainfall at each weather station
- R provides the *apply* mechanism to do this.
- There are several apply functions:
  - sapply(), lapply(), mapply() for lists and data frames
  - apply() for matrices
  - tapply() for “tables”, i.e., ragged arrays as vectors

Apply Functions

Rainfall

- **Apply** the mean function to each element of **`rain`**
- Finds: average precipitation of first station,
- Second station,
- Third station,
- Etc.



lapply() and sapply()

- The **lapply** and **sapply** both apply a specified function to each element of a list (remember data frames are special types of lists).
- The former returns a list object and the latter a vector when possible.

Mean rainfall at each station

```
> lapply(rain, mean)
$st050183
[1] 6.631707

$st050263
[1] 3.798993

$st050712
[1] 5.102299

$st050843
[1] 6.084607

$st050945
[1] 4.549296
```

```
> sapply(rain, mean)
st050183 st050263 st050712
6.631707 3.798993 5.102299

st050843 st050945
6.084607 4.549296
```

Notice that lapply returns a *list*
and
sapply returns a *vector* (when it can)

Additional arguments

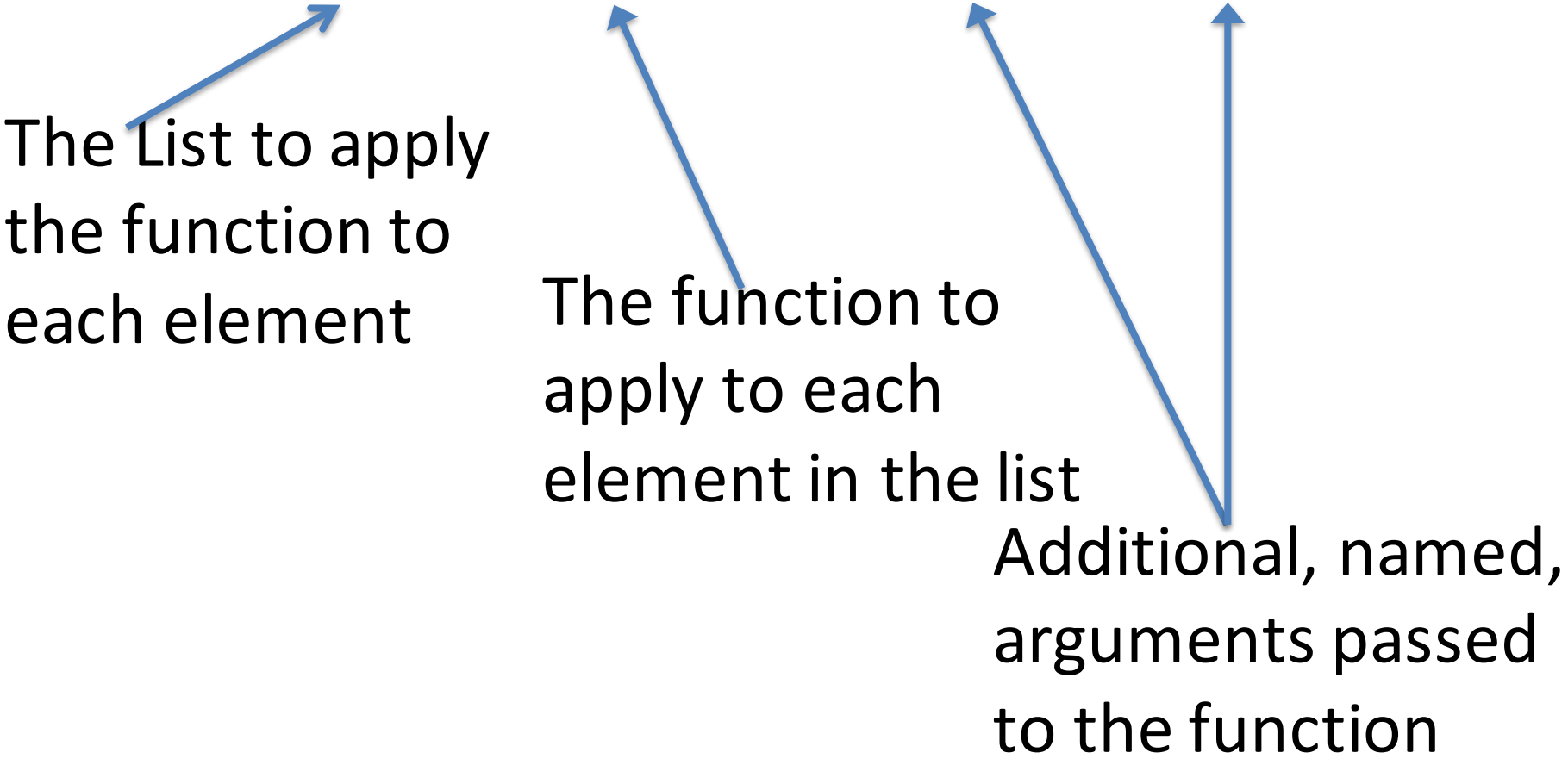
```
> lapply(rain, mean, na.rm = TRUE,
          trim = 0.1)
$st050183
[1] 2.393978

$st050263
[1] 0.9875949

$st050712
[1] 0.7895235

$st050843
[1] 1.238481

$st050945
[1] 0.7366283
```

```
> args(lapply)
function (x, FUN, ...)
```

- x takes the list object
- FUN is the function to apply to each element in X
- **...** allows any number of arguments to be passed to FUN

Format

lapply(a_list, a_function, arg1 = xx, arg2 = yy)



Rainfall data

- Maximum rainfall at each station

```
sapply(rain, max)
```

- 99th percentile of rainfall at each station

```
sapply(rain, quantile, probs = 0.99)
```

Find Proportion of Rainy Days

For one station:

```
stat1 = rain[[1]]
sum(stat1 > 0) / length(stat1)
```

How can we incorporate this sequence of functions into one call to an apply function?

Find Proportion of Rainy Days

We can break the expression up into smaller pieces and put it all back together

```
numDays = sapply(rain, length)
rainDays = lapply(rain, '>', 0)
numRainyDays = sapply(rainDays, sum)
numRainyDays / numDay
```

This is dissatisfying –

- many steps for a simple calculation
- many intermediate copies of the list/vector

Advanced

For any one station:

```
sum(stat1 > 0) / length(stat1)
```

We want to apply this composition of functions to each element of rain.

```
sapply(rain, sum(? > 0) / length(?))
```

We can create our own function to do this:

```
sapply(rain, function(x) sum(x > 0) / length(x))
```

Matrices and Arrays

Matrices and Arrays

- Rectangular collection of elements
- Dimensions are two, three, or more
- Homogeneous primitive elements (e.g., all numeric or all character)

- You can create a matrix in R using the `matrix` function.
- By default, matrices in R are assigned by *column-major* order.
- You can assign them by *row-major* order by setting the `byrow` argument to TRUE. Note that the first argument to `matrix` is a vector, so all elements must be of the same type (numeric, character, or logical).

```
> m = matrix(1:6, nrow = 2)
> m
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
> m = matrix(1:6, nrow = 2, byrow = TRUE)
 m
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
```

- Assign names to the rows and columns of a matrix:

```
> rownames(m) = letters[1:2]
> colnames(m) = letters[3:5]

> m
  c d e
a 1 2 3
b 4 5 6
```

- Find the dimensions of a matrix:

```
> dim(m)
[1] 2 3

> nrow(m)
[1] 2

> ncol(m)
[1] 3
```

- To index elements of a matrix, use the same five methods of indexing we covered for vectors, but with the first index for rows and the second for columns.
- What will each line return?

```
> m
  c d e
a 1 3 5
b 2 4 6
> m[-1, 2]     # Exclusion & position
> m["a",]      # Row by name, all cols
> m[, c(TRUE, TRUE, FALSE)] #logical cols
```

Apply Functions for Matrices

apply()

- **apply(m, 1, sum)** for the matrix x, the sum function is applied across the columns so that the row dimension (i.e. dim 1) is preserved.

```
> m
   c d e
 a 1 2 3
 b 4 5 6
> apply(m, 1, sum)
 a  b
 6 15
```

apply()

- **`apply(x, 2, sum)`** for the matrix x, the sum function is applied down the rows so that the column dimension (i.e. dim 2) is preserved.

```
> m
  c d e
a 1 2 3
b 4 5 6
> apply(m, 2, sum)
c d e
5 7 9
```

Arrays – matrices in higher dimensions

```
> x = array(1:24, c(4, 3, 2))
> x
, , 1
     [,1] [,2] [,3]
[1,]    1    5    9
[2,]    2    6   10
[3,]    3    7   11
[4,]    4    8   12

, , 2
     [,1] [,2] [,3]
[1,]   13   17   21
[2,]   14   18   22
[3,]   15   19   23
[4,]   16   20   24
```

- The integers 1, 2, … , 24 are arranged in a 3-dimensional array
- The array has:
  - 4 rows
  - 3 columns
  - 2 panels

```
> x[1:2, 3, 2]
[1] 21 22

> x[ , 2, 1]
[1] 5 6 7 8

> x[3:4, c(3, 1), 1]
     [,1] [,2]
[1,]   11    3
[2,]   12    4
```

Arrays – matrices in higher dimensions

```
> x = array(1:24, c(4, 3, 2))
> x
, , 1
     [,1] [,2] [,3]
[1,]    1    5    9
[2,]    2    6   10
[3,]    3    7   11
[4,]    4    8   12

, , 2
     [,1] [,2] [,3]
[1,]   13   17   21
[2,]   14   18   22
[3,]   15   19   23
[4,]   16   20   24
```

```
> apply(x, 1:2, sum)
     [,1] [,2] [,3]
[1,]   14   22   30
[2,]   16   24   32
[3,]   18   26   34
[4,]   20   28   36
```

```
> apply(x, 1, median)
[1] 11 12 13 14
```