Chapter 13

Relational Operators

The relational operators $>$, $\geq$, $<$, $\leq$, $=$, and $\neq$ can be used to compare the elements of an object. These relational operators return either the logical value TRUE or the logical value FALSE. The relational operators considered here are implemented in R as

\[ > \quad \geq \quad < \quad \leq \quad == \quad != \]

The double equals $==$ is used for testing equality because the single equals $=$ has already been used as an assignment operator and to identify named arguments in function calls. The relational operators are vectorized so that they can be applied element-wise to the objects under consideration. The three topics considered in this chapter are (a) relational operators applied to objects, (b) conditional execution via ifelse, and (c) conditional execution via switch.

13.1 Relational operators applied to objects

Although the illustrations used in this chapter are applied to vectors, they are easily adapted for more complicated data structures, such as matrices or arrays. To illustrate the use of relational operators, begin by defining a vector $x$ that contains four numeric elements:

\[
> x = c(2, -3, 0, 8) \quad \# \text{a vector of numeric elements}
\]

\[
> x \quad \# \text{display x}
\]

\[
[1] 2 -3 0 8
\]

Next, to check whether any of the elements of $x$ assume the value 7, type

\[
> x == 7 \quad \# \text{which elements in x, if any, equal 7?}
\]

\[
[1] \text{FALSE FALSE FALSE TRUE}
\]

The value 7 is effectively recycled, and the equality operator $==$ returns a vector of four FALSE elements because none of the elements of the vector $x$ equal 7. In the same fashion, to check whether any elements in $x$ are equal to 8, type

\[
> x == 8 \quad \# \text{which elements in x equal 8?}
\]

\[
[1] \text{FALSE FALSE FALSE TRUE}
\]

The last element in $x$ is 8, so a TRUE is returned in that position.

The discussion concerning floating point representations from Chapter 9 also applies to relational operators. Consider the R commands...
> sqrt(3) * sqrt(3)  # the square root of 3 squared is 3
[1] 3
> sqrt(3) * sqrt(3) == 3  # test for equality
[1] FALSE

What happened? The square root of 3, which is irrational, does not have an exact binary representation, so although $\sqrt{3} \cdot \sqrt{3}$ rounds to 3, it might not be equal to 3 in its binary representation. This was the case in the computation above, which can be confirmed with the R commands

> options(digits = 20)  # display 20 digits
> sqrt(3) * sqrt(3)  # the square root of 3 squared is approximately 3
[1] 2.9999999999999995559

The alternative all.equal function includes a tolerance argument (with a default which can be adjusted) when testing for equality.

> all.equal(sqrt(3) * sqrt(3), 3)
[1] TRUE

This returns the intuitive result. There is another alternative to using the == relational operator. The identical function returns TRUE if the internal representations of its first two arguments are identical and FALSE otherwise. Consider comparing 7 stored as the integer 7L and 7 stored as a numeric.

> 7L == 7  # compare integer 7 and numeric 7
[1] TRUE
> identical(7L, 7)  # compare integer 7 and numeric 7
[1] FALSE

The == relational operator does not check the internal representations of 7L and 7, but the identical function does. The key take-away here is to be very careful with the == relational operator because of the limitations associated with computer arithmetic.

The not equal relational operator is an exclamation point followed immediately by =, as illustrated by

> x  # display x
[1] 2 -3 0 8
> x != 0  # which elements in x are nonzero?
[1] TRUE TRUE FALSE TRUE

The first, second, and fourth elements of x are nonzero, resulting in the vector of logical values displayed. To determine which elements of the vector x are negative, type

> x < 0  # which elements in x are negative?
[1] FALSE TRUE FALSE FALSE

Only the second element is negative. The logical vectors that are generated by the relational operators can be manipulated in the same manner as any other vectors. For example, using the c function

> c(x == 0, x != 0)  # vector of eight logical elements
[1] FALSE FALSE TRUE FALSE TRUE FALSE TRUE
concatenates the two four-element vectors of logical elements together to form an eight-element vector of logical elements. The next R command locates all of the positions of the negative elements in the vector x and replaces their values with 17.

```r
> x[x < 0] = 17  # set all negative elements in x to 17
> x
[1] 2 17 0 8
```

In this case, the logical values are used as subscripts as they were in the previous chapter.

Although all of the examples in this chapter use relational operators to compare numeric values, they can also be applied to strings. To compare the strings "C" and "R", for example, type

```r
> "C" < "R"  # is "C" less than "R"?
[1] TRUE
```

The internal representations of these two strings are compared, and the value for "C" is less than the value for "R", so TRUE is returned. Longer strings are compared in a lexicographic manner (a lexicographic ordering is a generalization of alphabetical ordering to include numbers and symbols), for example,

```r
> "C3PO" > "R2D2"  # is "C3PO" greater than "R2D2"?
[1] FALSE
```

Relational operators can also be applied to two objects in a component-wise fashion. Begin by assigning the values 1, 4, 2, and 5 to the four-element numeric vector y.

```r
> y = c(1, 4, 2, 5)  # another vector of numeric elements
> y
[1] 1 4 2 5
```

The vectors x (which currently contains the elements 2, 17, 0, 8) and y can be compared in an element-wise fashion with

```r
> x > y  # which elements of x are greater than y
[1] TRUE TRUE FALSE TRUE
```

In this case, the vectors x and y were of the same length. If this were not the case, then R would recycle the values in the shorter vector in the usual fashion. In a minor extension of this example, you can display the elements of x in which the corresponding element of x is greater than the associated element of y with

```r
> x[x > y]  # elements of x in which x is greater than y
[1] 2 17 8
```

If you would like to take those elements associated with x > y and multiply each of the associated elements of the x vector by 4, type

```r
> x[x > y] = x[x > y] * 4  # multiply elements of x in which x > y by four
> x  # display x
[1] 8 68 0 32
```

The which function is useful for identifying the index values that satisfy a particular logical relationship. The which function accepts a vector of logical elements as an argument and returns the indexes of TRUE values in the vector, not the values of the associated elements themselves. The R command
> which(x < 10)  # indexes of elements in x that are less than 10
[1] 1 3

indicates that the first and third elements of x (x currently contains the numeric values 8, 68, 0, 32) are the elements that are less than 10. Notice that the x < 10 portion of this R command creates a vector of four logical elements, and the which function then returns the index or indexes of the TRUE elements in the vector. As a second example, which determines the indexes of those values of x that are less than the sample mean:

> which(x < mean(x))  # indexes of elements in x that are less than xbar
[1] 1 3

The first and third elements of x are less than the sample mean.

Finally, the following R commands assign the four-element vectors name, age, and va to elements that are character strings, numeric values, and logical values, respectively, then finds the names of all people under the age of 21 who live in Virginia.

> name = c("Joe", "Ian", "Liz", "Ali")  # vector of names
> age = c(19, 21, 18, 20)  # vector of ages
> va = c(TRUE, FALSE, TRUE, FALSE)  # vector of Va. residency statuses
> name[age < 21 & va]  # names of young Virginians
[1] "Joe" "Liz"

This example combines operators on logical elements from last chapter and relational operators from this chapter with subscripting to produce efficient, vectorized calculations. In the last command in this example, R had to choose between the relational operator < and the vectorized and operator & in terms of precedence. R chose to execute the < before the &. The table below gives the precedence rules for the operators that we have encountered thus far, with the operator with highest precedence ranked first. Exceptions to these precedences can be accomplished by adding parentheses. A more complete list of the operator preferences is available in an R session by typing

> help(Syntax)  # list of operator precedences

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<thead>
<tr>
<th>operator</th>
<th>description</th>
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<td>^</td>
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<td>-</td>
<td>unary minus</td>
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<td>%, %, %%</td>
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<td>+, -</td>
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Now that you are familiar with the use of relational operations, the versatile ifelse function can be introduced.