An Introduction to the GenomicRanges Package

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1 Introduction

The GenomicRanges package serves as the foundation for representing genomic locations within the Bioconductor project. In the Bioconductor package hierarchy, it builds upon the IRanges (infrastructure) package and provides support for the BSgenome (infrastructure), Rsamtools (I/O), ShortRead (I/O & QA), rtracklayer (I/O), GenomicFeatures (infrastructure), GenomicAlignments (sequence reads), VariantAnnotation (called variants), and many other Bioconductor packages.

This package lays a foundation for genomic analysis by introducing three classes (GRanges, GPos, and GRangesList), which are used to represent genomic ranges, genomic positions, and groups of genomic ranges. This vignette focuses on the GRanges and GRangesList classes and their associated methods.

The GenomicRanges package is available at https://bioconductor.org and can be installed via biocLite:

> source("https://bioconductor.org/biocLite.R")
> biocLite("GenomicRanges")

A package only needs to be installed once. Load the package into an R session with

> library(GenomicRanges)


2 GRanges: Genomic Ranges

The GRanges class represents a collection of genomic ranges that each have a single start and end location on the genome. It can be used to store the location of genomic features such as contiguous binding sites, transcripts, and exons. These objects can be created by using the GRanges constructor function. For example,

```r
> gr <- GRanges(
+   seqnames = Rle(c("chr1", "chr2", "chr1", "chr3"), c(1, 3, 2, 4)),
+   ranges = IRanges(101:110, end = 111:120, names = head(letters, 10)),
+   strand = Rle(strand(c("-", "+", "+", "+", "-")), c(1, 2, 2, 3, 2)),
+   score = 1:10,
+   GC = seq(1, 0, length=10))
> gr
```

GRanges object with 10 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2</td>
<td>0.8888888888888889</td>
<td></td>
</tr>
<tr>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3</td>
<td>0.7777777777777778</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8</td>
<td>0.2222222222222222</td>
<td></td>
</tr>
<tr>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9</td>
<td>0.1111111111111111</td>
<td></td>
</tr>
<tr>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome; no seqlengths

```r
> options(warn=2)
```

creates a GRanges object with 10 genomic ranges. The output of the GRanges show method separates the information into a left and right hand region that are separated by | symbols. The genomic coordinates (seqnames, ranges, and strand) are located on the left-hand side and the metadata columns (annotation) are located on the right. For this example, the metadata is comprised of score and GC information, but almost anything can be stored in the metadata portion of a GRanges object.

The components of the genomic coordinates within a GRanges object can be extracted using the seqnames, ranges, and strand accessor functions.

```r
> seqnames(gr)
```

factor-Rle of length 10 with 4 runs
Lengths: 1 3 2 4
Values : chr1 chr2 chr1 chr3
Levels(3): chr1 chr2 chr3

```r
> ranges(gr)
```

IRanges object with 10 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>start</th>
<th>end</th>
<th>width</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;integer&gt;</td>
<td>&lt;integer&gt;</td>
<td>&lt;integer&gt;</td>
</tr>
<tr>
<td>a 101</td>
<td>111</td>
<td>11</td>
</tr>
<tr>
<td>b 102</td>
<td>112</td>
<td>11</td>
</tr>
<tr>
<td>c 103</td>
<td>113</td>
<td>11</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>h 108</td>
<td>118</td>
<td>11</td>
</tr>
<tr>
<td>i 109</td>
<td>119</td>
<td>11</td>
</tr>
<tr>
<td>j 110</td>
<td>120</td>
<td>11</td>
</tr>
</tbody>
</table>

```r
> strand(gr)
```
factor-Rle of length 10 with 5 runs

Lengths: 1 2 2 3 2
Values: - + * + -
Levels(3): + - *

The genomic ranges can be extracted without corresponding metadata with granges

\[
\text{> granges(gr)}
\]

GRanges object with 10 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
</tr>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
</tr>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome; no seqlengths

Annotations for these coordinates can be extracted as a DataFrame object using the mcols accessor.

\[
\text{> mcols(gr)}
\]

Dataframe with 10 rows and 2 columns

<table>
<thead>
<tr>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;integer&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

\[
\text{> mcols(gr)$score}
\]

[1] 1 2 3 4 5 6 7 8 9 10

Information about the lengths of the various sequences that the ranges are aligned to can also be stored in the GRanges object. So if this is data from Homo sapiens, we can set the values as:

\[
\text{> seqlengths(gr) <- c(249250621, 243199373, 198022430)}
\]

And then retrieves as:

\[
\text{> seqlengths(gr)}
\]

<table>
<thead>
<tr>
<th>chr1</th>
<th>chr2</th>
<th>chr3</th>
</tr>
</thead>
<tbody>
<tr>
<td>249250621</td>
<td>243199373</td>
<td>198022430</td>
</tr>
</tbody>
</table>

Methods for accessing the length and names have also been defined.

\[
\text{> names(gr)}
\]

[1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j"

\[
\text{> length(gr)}
\]

[1] 10
2.1 Splitting and combining GRanges objects

GRanges objects can be divided into groups using the split method. This produces a GRangesList object, a class that will be discussed in detail in the next section.

```r
> sp <- split(gr, rep(1:2, each=5))
> sp
```

GRangesList object of length 2:

```
$1
GRanges object with 5 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td>0.777777777777778</td>
</tr>
<tr>
<td>d</td>
<td>chr2 [104, 114]</td>
<td>*</td>
<td>4 0.666666666666667</td>
<td>0.666666666666667</td>
</tr>
<tr>
<td>e</td>
<td>chr1 [105, 115]</td>
<td>*</td>
<td>5 0.555555555555556</td>
<td>0.555555555555556</td>
</tr>
</tbody>
</table>

$2
GRanges object with 5 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>chr1 [106, 116]</td>
<td>+</td>
<td>6 0.4444444444444444</td>
<td>0.4444444444444444</td>
</tr>
<tr>
<td>g</td>
<td>chr3 [107, 117]</td>
<td>+</td>
<td>7 0.3333333333333333</td>
<td>0.3333333333333333</td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8 0.2222222222222222</td>
<td>0.2222222222222222</td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.1111111111111111</td>
<td>0.1111111111111111</td>
</tr>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10 0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

-----

seqinfo: 3 sequences from an unspecified genome

Separate GRanges instances can be concatenated by using the c and append methods.

```r
> c(sp[[1]], sp[[2]])
```

GRanges object with 10 ranges and 2 metadata columns:

```
<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td>0.777777777777778</td>
</tr>
<tr>
<td>.</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8 0.2222222222222222</td>
<td>0.2222222222222222</td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.1111111111111111</td>
<td>0.1111111111111111</td>
</tr>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10 0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

-----

seqinfo: 3 sequences from an unspecified genome

2.2 Subsetting GRanges objects

GRanges objects act like vectors of ranges, with the expected vector-like subsetting operations available

```r
> gr[2:3]
```

GRanges object with 2 ranges and 2 metadata columns:

```
<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td>0.777777777777778</td>
</tr>
<tr>
<td>.</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8 0.2222222222222222</td>
<td>0.2222222222222222</td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.1111111111111111</td>
<td>0.1111111111111111</td>
</tr>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10 0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

-----

seqinfo: 3 sequences from an unspecified genome
An Introduction to the GenomicRanges Package

b chr2 [102, 112] + | 2 0.888888888888889

A second argument to the [ subset operator can be used to specify which metadata columns to extract from the GRanges object. For example, 

> gr[2:3, "GC"]

GRanges object with 2 ranges and 1 metadata column:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>b chr2</td>
<td>[102, 112]</td>
<td>+</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>c chr2</td>
<td>[103, 113]</td>
<td>+</td>
<td>0.777777777777778</td>
</tr>
</tbody>
</table>

Elements can also be assigned to the GRanges object. Here is an example where the second row of a GRanges object is replaced with the first row of gr:

> singles <- split(gr, names(gr))
> grMod <- gr
> grMod[2] <- singles[[1]]
> head(grMod, n=3)

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>a chr1</td>
<td>[101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b chr1</td>
<td>[101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>c chr2</td>
<td>[103, 113]</td>
<td>+</td>
<td>3</td>
<td>0.777777777777778</td>
</tr>
</tbody>
</table>

Here is a second example where the metadata for score from the third element is replaced with the score from the second row etc.

> grMod[2,1] <- singles[[3]][,1]
> head(grMod, n=3)

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>a chr1</td>
<td>[101, 111]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b chr2</td>
<td>[103, 113]</td>
<td>+</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>c chr2</td>
<td>[103, 113]</td>
<td>+</td>
<td>3</td>
<td>0.777777777777778</td>
</tr>
</tbody>
</table>

There are methods to repeat, reverse, or select specific portions of GRanges objects.

> rep(singles[[2]], times = 3)

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
<td>&lt;numeric&gt;</td>
</tr>
<tr>
<td>b chr2</td>
<td>[102, 112]</td>
<td>+</td>
<td>2</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>b chr2</td>
<td>[102, 112]</td>
<td>+</td>
<td>2</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>b chr2</td>
<td>[102, 112]</td>
<td>+</td>
<td>2</td>
<td>0.888888888888889</td>
</tr>
</tbody>
</table>
seqinfo: 3 sequences from an unspecified genome

> rev(gr)

GRanges object with 10 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.111111111111111</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8 0.222222222222222</td>
<td></td>
</tr>
<tr>
<td>. . . . .</td>
<td>. . . . .</td>
<td>. . . . .</td>
<td>. . . . .</td>
<td>. . . . .</td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1 1</td>
<td></td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome

> head(gr,n=2)

GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [101, 111]</td>
<td>-</td>
<td>1 1</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td></td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome

> tail(gr,n=2)

GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.111111111111111</td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>chr3 [110, 120]</td>
<td>-</td>
<td>10 0</td>
<td></td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome

> window(gr, start=2,end=4)

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>chr2 [104, 114]</td>
<td>*</td>
<td>4 0.666666666666667</td>
<td></td>
</tr>
</tbody>
</table>

seqinfo: 3 sequences from an unspecified genome

> gr[IRanges(start=c(2,7), end=c(3,9))]

GRanges object with 5 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>chr2 [102, 112]</td>
<td>+</td>
<td>2 0.888888888888889</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 113]</td>
<td>+</td>
<td>3 0.777777777777778</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>chr3 [107, 117]</td>
<td>+</td>
<td>7 0.333333333333333</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>chr3 [108, 118]</td>
<td>+</td>
<td>8 0.222222222222222</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>chr3 [109, 119]</td>
<td>-</td>
<td>9 0.111111111111111</td>
<td></td>
</tr>
</tbody>
</table>
2.3 Basic interval operations for GRanges objects

Basic interval characteristics of GRanges objects can be extracted using the start, end, width, and range methods.

```r
> g <- gr[1:3]
> g <- append(g, singles[[10]])
> start(g)
[1] 101 102 103 110
> end(g)
[1] 111 112 113 120
> width(g)
> range(g)
```

GRanges object with 3 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[101, 111]</td>
<td>-</td>
</tr>
<tr>
<td>chr2</td>
<td>[102, 113]</td>
<td>+</td>
</tr>
<tr>
<td>chr3</td>
<td>[110, 120]</td>
<td>-</td>
</tr>
</tbody>
</table>

The GRanges class also has many methods for manipulating the ranges. The methods can be classified as intra-range methods, inter-range methods, and between-range methods.

**Intra-range methods** operate on each element of a GRanges object independent of the other ranges in the object. For example, the flank method can be used to recover regions flanking the set of ranges represented by the GRanges object.

So to get a GRanges object containing the ranges that include the 10 bases upstream of the ranges:

```r
> flank(g, 10)
```

GRanges object with 4 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[112, 121]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>chr2</td>
<td>[92, 101]</td>
<td>+</td>
<td>2</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>chr2</td>
<td>[93, 102]</td>
<td>+</td>
<td>3</td>
<td>0.777777777777778</td>
</tr>
<tr>
<td>chr3</td>
<td>[121, 130]</td>
<td>-</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

And to include the downstream bases:

```r
> flank(g, 10, start=FALSE)
```

GRanges object with 4 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[91, 100]</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>chr2</td>
<td>[113, 122]</td>
<td>+</td>
<td>2</td>
<td>0.888888888888889</td>
</tr>
<tr>
<td>chr2</td>
<td>[114, 123]</td>
<td>+</td>
<td>3</td>
<td>0.777777777777778</td>
</tr>
</tbody>
</table>
j chr3 [100, 109] - | 10 0
-------
seqinfo: 3 sequences from an unspecified genome

Other examples of intra-range methods include resize and shift. The shift method will move the ranges by a specific number of base pairs, and the resize method will extend the ranges by a specified width.

```r
> shift(g, 5)
```

GRanges object with 4 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [106, 116] -</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [107, 117] +</td>
<td>2</td>
<td>0.888888888888889</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>chr2 [108, 118] +</td>
<td>3</td>
<td>0.777777777777778</td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>chr3 [115, 125] -</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
-------
seqinfo: 3 sequences from an unspecified genome

```r
> resize(g, 30)
```

GRanges object with 4 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>chr1 [ 82, 111] -</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>chr2 [102, 131] +</td>
<td>2</td>
<td>0.888888888888889</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>chr2 [103, 132] +</td>
<td>3</td>
<td>0.777777777777778</td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>chr3 [ 91, 120] -</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
-------
seqinfo: 3 sequences from an unspecified genome

The *GenomicRanges* help page ?"intra-range-methods" summarizes these methods.

*Inter-range methods* involve comparisons between ranges in a single *GRanges* object. For instance, the reduce method will align the ranges and merge overlapping ranges to produce a simplified set.

```r
> reduce(g)
```

GRanges object with 3 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] chr1 [101, 111] -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[2] chr2 [102, 113] +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[3] chr3 [110, 120] -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
-------
seqinfo: 3 sequences from an unspecified genome

Sometimes one is interested in the gaps or the qualities of the gaps between the ranges represented by your *GRanges* object. The gaps method provides this information: reduced version of your ranges:

```r
> gaps(g)
```

GRanges object with 12 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] chr1 [ 1, 249250621] +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[2] chr1 [ 1, 100] -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[3] chr1 [112, 249250621] -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... ... ... ...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[10] chr3 [ 1, 109] -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The disjoin method represents a GRanges object as a collection of non-overlapping ranges:

```r
> disjoin(g)
GRanges object with 5 ranges and 0 metadata columns:
  seqnames   ranges   strand
  <Rle>  <IRanges>  <Rle>
[1] chr1 [101, 111] -
[2] chr2 [102, 102] +
[3] chr2 [103, 112] +
[4] chr2 [113, 113] +
[5] chr3 [110, 120] -
```

The coverage method quantifies the degree of overlap for all the ranges in a GRanges object.

```r
> coverage(g)
RleList of length 3
$chr1
integer-Rle of length 249250621 with 3 runs
  Lengths:  100 11 249250510
  Values :  0 1 0

$chr2
integer-Rle of length 243199373 with 5 runs
  Lengths: 101 10 1 243199260
  Values : 0 1 2 1 0

$chr3
integer-Rle of length 198022430 with 3 runs
  Lengths: 109 11 198022310
  Values : 0 1 0
```

See the GenomicRanges help page ?"inter-range-methods" for additional help.

Between-range methods involve operations between two GRanges objects; some of these are summarized in the next section.

### 2.4 Interval set operations for GRanges objects

Between-range methods calculate relationships between different GRanges objects. Of central importance are find-Overlaps and related operations; these are discussed below. Additional operations treat GRanges as mathematical sets of coordinates; union(g, g2) is the union of the coordinates in g and g2. Here are examples for calculating the union, the intersect and the asymmetric difference (using setdiff).

```r
> g2 <- head(gr, n=2)
> union(g, g2)
GRanges object with 3 ranges and 0 metadata columns:
  seqnames   ranges   strand
  <Rle>  <IRanges>  <Rle>
```
> intersect(g, g2)
GRanges object with 2 ranges and 0 metadata columns:

\[
\begin{array}{lll}
\text{seqnames} & \text{ranges} & \text{strand} \\
<\text{Rle}> & <\text{IRanges}> & <\text{Rle}> \\
[1] & \text{chr1 [101, 111]} & - \\
[2] & \text{chr2 [102, 112]} & + \\
\end{array}
\]

seqinfo: 3 sequences from an unspecified genome

> setdiff(g, g2)
GRanges object with 2 ranges and 0 metadata columns:

\[
\begin{array}{lll}
\text{seqnames} & \text{ranges} & \text{strand} \\
<\text{Rle}> & <\text{IRanges}> & <\text{Rle}> \\
[1] & \text{chr2 [113, 113]} & + \\
[2] & \text{chr3 [110, 120]} & - \\
\end{array}
\]

seqinfo: 3 sequences from an unspecified genome

Related methods are available when the structure of the \textit{GRanges} objects are 'parallel' to one another, i.e., element 1 of object 1 is related to element 1 of object 2, and so on. These operations all begin with a \texttt{p}, which is short for parallel. The methods then perform element-wise, e.g., the union of element 1 of object 1 with element 1 of object 2, etc. A requirement for these operations is that the number of elements in each \textit{GRanges} object is the same, and that both of the objects have the same seqnames and strand assignments throughout.

> g3 <- g[1:2]
> ranges(g3[1]) <- IRanges(start=105, end=112)
> punion(g2, g3)
GRanges object with 2 ranges and 0 metadata columns:

\[
\begin{array}{lll}
\text{seqnames} & \text{ranges} & \text{strand} \\
<\text{Rle}> & <\text{IRanges}> & <\text{Rle}> \\
a & \text{chr1 [101, 112]} & - \\
b & \text{chr2 [102, 112]} & + \\
\end{array}
\]

seqinfo: 3 sequences from an unspecified genome

> pintersect(g2, g3)
GRanges object with 2 ranges and 3 metadata columns:

\[
\begin{array}{lllll}
\text{seqnames} & \text{ranges} & \text{strand} & \text{score} & \text{GC} & \text{hit} \\
<\text{Rle}> & <\text{IRanges}> & <\text{Rle}> & <\text{integer}> & <\text{numeric}> & <\text{logical}> \\
a & \text{chr1 [105, 111]} & - & 1 & 1 & 1 \\
b & \text{chr2 [102, 112]} & + & 2 & 0.888888888888889 & 1 \\
\end{array}
\]

seqinfo: 3 sequences from an unspecified genome

> psetdiff(g2, g3)
GRanges object with 2 ranges and 0 metadata columns:

\[
\begin{array}{lll}
\text{seqnames} & \text{ranges} & \text{strand} \\
<\text{Rle}> & <\text{IRanges}> & <\text{Rle}> \\
a & \text{chr1 [101, 104]} & - \\
\end{array}
\]
b. chr2 [102, 101] +

seqinfo: 3 sequences from an unspecified genome

For more information on the GRanges classes be sure to consult the manual page.

> ?GRanges

A relatively comprehensive list of available methods is discovered with

> methods(class="GRanges")

## 3 GRangesList: Groups of Genomic Ranges

Some important genomic features, such as spliced transcripts that are comprised of exons, are inherently compound structures. Such a feature makes much more sense when expressed as a compound object such as a GRangesList. Whenever genomic features consist of multiple ranges that are grouped by a parent feature, they can be represented as a GRangesList object. Consider the simple example of the two transcript GRangesList below created using the GRangesList constructor.

> gr1 <- GRanges(
  + seqnames = "chr2",
  + ranges = IRanges(103, 106),
  + strand = "+",
  + score = 5L, GC = 0.45)
> gr2 <- GRanges(
  + seqnames = c("chr1", "chr1"),
  + ranges = IRanges(c(107, 113), width = 3),
  + strand = c("+", "-"),
  + score = 3:4, GC = c(0.3, 0.5))
> grl <- GRangesList("txA" = gr1, "txB" = gr2)
> grl

GRangesList object of length 2:

$txA
GRanges object with 1 range and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[103, 106]</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
</tbody>
</table>

$txB
GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[107, 109]</td>
<td>+</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>chr1</td>
<td>[113, 115]</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

The show method for a GRangesList object displays it as a named list of GRanges objects, where the names of this list are considered to be the names of the grouping feature. In the example above, the groups of individual exon ranges are represented as separate GRanges objects which are further organized into a list structure where each element name is a transcript name. Many other combinations of grouped and labeled GRanges objects are possible of course, but this example is expected to be a common arrangement.
3.1 Basic GRangesList accessors

Just as with GRanges object, the components of the genomic coordinates within a GRangesList object can be extracted using simple accessor methods. Not surprisingly, the GRangesList objects have many of the same accessors as GRanges objects. The difference is that many of these methods return a list since the input is now essentially a list of GRanges objects. Here are a few examples:

> seqnames(grl)
RleList of length 2
$txA
factor-Rle of length 1 with 1 run
  Lengths: 1
  Values : chr2
  Levels(2): chr2 chr1

$txB
factor-Rle of length 2 with 1 run
  Lengths: 2
  Values : chr1
  Levels(2): chr2 chr1

> ranges(grl)
IRangesList of length 2
$txA
IRanges object with 1 range and 0 metadata columns:
   start   end    width
<integer> <integer>     <integer>
[1]  103   106       4

$txB
IRanges object with 2 ranges and 0 metadata columns:
   start   end    width
<integer> <integer>     <integer>
[1]   107    109       3
[2]   113    115       3

> strand(grl)
RleList of length 2
$txA
factor-Rle of length 1 with 1 run
  Lengths: 1
  Values : +
  Levels(3): + - *

$txB
factor-Rle of length 2 with 2 runs
  Lengths: 1 1
  Values : + -
  Levels(3): + - *

The length and names methods will return the length or names of the list and the seqlengths method will return the set of sequence lengths.

> length(grl)
[1] 2
> names(grl)
[1] "txA" "txB"
>
> seqlengths(grl)
chr2 chr1
NA NA

The `elementNROW` method returns a list of integers corresponding to the result of calling `NROW` on each individual `GRanges` object contained by the `GRangesList`. This is a faster alternative to calling `lapply` on the `GRangesList`.

> elementNROWs(grl)
txA txB
1 2

`isEmpty` tests if a `GRangesList` object contains anything.

> isEmpty(grl)
[1] FALSE

In the context of a `GRangesList` object, the `mcols` method performs a similar operation to what it does on a `GRanges` object. However, this metadata now refers to information at the list level instead of the level of the individual `GRanges` objects.

> mcols(grl) <- c("Transcript A","Transcript B")
> mcols(grl)

Data Frame with 2 rows and 1 column

value
<character>
1 Transcript A
2 Transcript B

Element-level metadata can be retrieved by unlisting the `GRangesList`, and extracting the metadata

> mcols(unlist(grl))

Data Frame with 3 rows and 2 columns

score GC
<integer> <numeric>
1 5 0.45
2 3 0.30
3 4 0.50

### 3.2 Combining `GRangesList` objects

`GRangesList` objects can be unlisted to combine the separate `GRanges` objects that they contain as an expanded `GRanges`.

> ul <- unlist(grl)
> ul

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt; &lt;numeric&gt;</td>
</tr>
<tr>
<td>txA</td>
<td>chr2 [103, 106]</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>txB</td>
<td>chr1 [107, 109]</td>
<td>+</td>
<td>3</td>
<td>0.30</td>
</tr>
<tr>
<td>txB</td>
<td>chr1 [113, 115]</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths
Append lists using `append` or `c`.

A support site user had two `GRangesList` objects with ‘parallel’ elements, and wanted to combine these element-wise into a single `GRangesList`. One solution is to use `pc()` – parallel (element-wise) `c()`. A more general solution is to concatenate the lists and then re-group by some factor, in this case the names of the elements.

```r
> grl1 <- GRangesList(
+   gr1 = GRanges("chr2", IRanges(3, 6)),
+   gr2 = GRanges("chr1", IRanges(c(7,13), width = 3)))
> grl2 <- GRangesList(
+   gr1 = GRanges("chr2", IRanges(9, 12)),
+   gr2 = GRanges("chr1", IRanges(c(25,38), width = 3)))
> pc(grl1, grl2)
GRangesList object of length 2:

$gr1
GRanges object with 2 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[3, 6]</td>
<td>*</td>
</tr>
<tr>
<td>chr2</td>
<td>[9, 12]</td>
<td>*</td>
</tr>
</tbody>
</table>

$gr2
GRanges object with 4 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[7, 9]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[13, 15]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[25, 27]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[38, 40]</td>
<td>*</td>
</tr>
</tbody>
</table>

-------
seqinfo: 2 sequences from an unspecified genome; no seqlengths

> grl3 <- c(grl1, grl2)
> regroup(grl3, names(grl3))
GRangesList object of length 2:

$gr1
GRanges object with 2 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[3, 6]</td>
<td>*</td>
</tr>
<tr>
<td>chr2</td>
<td>[9, 12]</td>
<td>*</td>
</tr>
</tbody>
</table>

$gr2
GRanges object with 4 ranges and 0 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[7, 9]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[13, 15]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[25, 27]</td>
<td>*</td>
</tr>
<tr>
<td>chr1</td>
<td>[38, 40]</td>
<td>*</td>
</tr>
</tbody>
</table>

-------
seqinfo: 2 sequences from an unspecified genome; no seqlengths
3.3 Basic interval operations for GRangesList objects

For interval operations, many of the same methods exist for GRangesList objects that exist for GRanges objects.

\[
\begin{align*}
&> \text{start(grl)} \\
&\text{IntegerList of length 2} \\
&[\text{["txA"], 103, ["txB"], 107, 113}] \\
&> \text{end(grl)} \\
&\text{IntegerList of length 2} \\
&[\text{["txA"], 106, ["txB"], 109, 115}] \\
&> \text{width(grl)} \\
&\text{IntegerList of length 2} \\
&[\text{["txA"], 4, ["txB"], 3, 3}] \\
\end{align*}
\]

These operations return a data structure representing, e.g., IntegerList, a list where all elements are integers; it can be convenient to use mathematical and other operations on *List objects that work on each element, e.g.,

\[
> \text{sum(width(grl))} \quad \# \text{sum of widths of each grl element}
\]

\[
\begin{align*}
\text{txA} & \quad \text{txB} \\
4 & \quad 6 \\
\end{align*}
\]

Most of the intra-, inter- and between-range methods operate on GRangesList objects, e.g., to shift all the GRanges objects in a GRangesList object, or calculate the coverage. Both of these operations are also carried out across each GRanges list member.

\[
> \text{shift(grl, 20)}
\]

GRangesList object of length 2:

\[
\begin{align*}
&\text{txA} \\
&\text{GRanges object with 1 range and 2 metadata columns:} \\
&\text{seqnames ranges strand | score GC} \\
&<\text{Rle}> <\text{IRanges}> <\text{Rle}> | <\text{integer}> <\text{numeric}> \\
&[1] \text{chr2 [123, 126] + | 5 0.45} \\
\end{align*}
\]

\[
\begin{align*}
&\text{txB} \\
&\text{GRanges object with 2 ranges and 2 metadata columns:} \\
&\text{seqnames ranges strand | score GC} \\
&[1] \text{chr1 [127, 129] + | 3 0.3} \\
&[2] \text{chr1 [133, 135] - | 4 0.5} \\
\end{align*}
\]

seqinfo: 2 sequences from an unspecified genome; no seqlengths

\[
> \text{coverage(grl)}
\]

RleList of length 2

\[
\begin{align*}
&\text{chr2} \\
&\text{integer-Rle of length 106 with 2 runs} \\
&\text{Lengths: 102 4} \\
&\text{Values : 0 1}
\end{align*}
\]

\[
> \text{chr1}
\]

\[
\]

\[
\]

\[
\]

\[
\]
integer-Rle of length 115 with 4 runs
   Lengths:  106  3  3  3
   Values :  0  1  0  1

3.4 Subsetting GRangesList objects

A GRangesList object is behaves like a list: [ returns a GRangesList containing a subset of the original object; [[ or $ returns the GRanges object at that location in the list.

> grl[1]
> grl[[1]]
> grl["txA"]
> grl$txB

In addition, subsetting a GRangesList also accepts a second parameter to specify which of the metadata columns you wish to select.

> grl[1, "score"]

GRangesList object of length 1:
$txA
GRanges object with 1 range and 1 metadata column:
   seqnames ranges strand | score
        <Rle>  <IRanges> <Rle> | <integer>

-------
seqinfo: 2 sequences from an unspecified genome; no seqlengths

> grl["txB", "GC"]

GRangesList object of length 1:
$txB
GRanges object with 2 ranges and 1 metadata column:
   seqnames ranges strand | GC
        <Rle>  <IRanges> <Rle> | <numeric>
    [1]  chr1 [107, 109] + | 0.3
    [2]  chr1 [113, 115] - | 0.5

-------
seqinfo: 2 sequences from an unspecified genome; no seqlengths

The head, tail, rep, rev, and window methods all behave as you would expect them to for a list object. For example, the elements referred to by window are now list elements instead of GRanges elements.

> rep(grl[[1]], times = 3)

GRanges object with 3 ranges and 2 metadata columns:
   seqnames ranges strand | score  GC
        <Rle>  <IRanges> <Rle> | <integer> <numeric>
    [1]  chr2 [103, 106] + |   5 0.45
    [2]  chr2 [103, 106] + |   5 0.45
    [3]  chr2 [103, 106] + |   5 0.45

-------
seqinfo: 2 sequences from an unspecified genome; no seqlengths

> rev(grl)
GRangesList object of length 2:
	$txB
GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[107, 109]</td>
<td>+</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>chr1</td>
<td>[113, 115]</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

GRanges object with 1 range and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[103, 106]</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

> head(grl, n=1)
GRangesList object of length 1:
	$txA
GRanges object with 1 range and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[103, 106]</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

> tail(grl, n=1)
GRangesList object of length 1:
	$txB
GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr1</td>
<td>[107, 109]</td>
<td>+</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>chr1</td>
<td>[113, 115]</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

> window(grl, start=1, end=1)
GRangesList object of length 1:
	$txA
GRanges object with 1 range and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>chr2</td>
<td>[103, 106]</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

> grl[IRanges(start=2, end=2)]
GRangesList object of length 1:
	$txB
GRanges object with 2 ranges and 2 metadata columns:
### 3.5 Looping over GRangesList objects

For `GRangesList` objects there is also a family of apply methods. These include `lapply`, `sapply`, `mapply`, `endoapply`, `mendoapply`, `Map`, and `Reduce`.

The different looping methods defined for `GRangesList` objects are useful for returning different kinds of results. The standard `lapply` and `sapply` behave according to convention, with the `lapply` method returning a list and `sapply` returning a more simplified output.

```r
> lapply(grl, length)

$txA
[1] 1

$txB
[1] 2

> sapply(grl, length)
txA txB
1 2
```

As with `IRanges` objects, there is also a multivariate version of `sapply`, called `mapply`, defined for `GRangesList` objects. And, if you don’t want the results simplified, you can call the `Map` method, which does the same things as `mapply` but without simplifying the output.

```r
> grl2 <- shift(grl, 10)
> names(grl2) <- c("shiftTxA", "shiftTxB")
> mapply(c, grl, grl2)

$txA
GRanges object with 2 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
</tr>
<tr>
<td>[1]</td>
<td>chr2</td>
<td>[103, 106]</td>
<td>+</td>
<td>5</td>
</tr>
<tr>
<td>[2]</td>
<td>chr2</td>
<td>[113, 116]</td>
<td>+</td>
<td>5</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths

$txB
GRanges object with 4 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Rle&gt;</td>
<td>&lt;IRanges&gt;</td>
<td>&lt;Rle&gt;</td>
<td>&lt;integer&gt;</td>
</tr>
<tr>
<td>[1]</td>
<td>chr1</td>
<td>[107, 109]</td>
<td>+</td>
<td>3</td>
</tr>
<tr>
<td>[2]</td>
<td>chr1</td>
<td>[113, 115]</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>[3]</td>
<td>chr1</td>
<td>[117, 119]</td>
<td>+</td>
<td>3</td>
</tr>
<tr>
<td>[4]</td>
<td>chr1</td>
<td>[123, 125]</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>

seqinfo: 2 sequences from an unspecified genome; no seqlengths
> Map(c, grl, grl2)

$txA

GRanges object with 2 ranges and 2 metadata columns:

  seqnames ranges strand | score GC
  <Rle>  <IRanges>  <Rle> | <integer> <numeric>
[1] chr2 [103, 106]  + | 5 0.45
[2] chr2 [113, 116]  + | 5 0.45

-------

seqinfo: 2 sequences from an unspecified genome; no seqlengths

$txB

GRanges object with 4 ranges and 2 metadata columns:

  seqnames ranges strand | score GC
  <Rle>  <IRanges>  <Rle> | <integer> <numeric>
[1] chr1 [107, 109]  + | 3 0.3
[2] chr1 [113, 115]  - | 4 0.5
[3] chr1 [117, 119]  + | 3 0.3
[4] chr1 [123, 125]  - | 4 0.5

-------

seqinfo: 2 sequences from an unspecified genome; no seqlengths

Sometimes you will want to get back a modified version of the \texttt{GRangesList} that you originally passed in.

An endomorphism is a transformation of an object to another instance of the same class. This is achieved using the \texttt{endoapply} method, which will return the results as a \texttt{GRangesList} object.

> endoapply(grl, rev)

GRangesList object of length 2:

$txA

GRanges object with 1 range and 2 metadata columns:

  seqnames ranges strand | score GC
  <Rle>  <IRanges>  <Rle> | <integer> <numeric>
[1] chr2 [103, 106]  + | 5 0.45

$txB

GRanges object with 2 ranges and 2 metadata columns:

  seqnames ranges strand | score GC
[1] chr1 [113, 115]  - | 4 0.5
[2] chr1 [107, 109]  + | 3 0.3

-------

seqinfo: 2 sequences from an unspecified genome; no seqlengths

> mendoapply(c, grl, grl2)

GRangesList object of length 2:

$txA

GRanges object with 2 ranges and 2 metadata columns:

  seqnames ranges strand | score GC
  <Rle>  <IRanges>  <Rle> | <integer> <numeric>
[1] chr2 [103, 106]  + | 5 0.45
[2] chr2 [113, 116]  + | 5 0.45

$txB

GRanges object with 4 ranges and 2 metadata columns:

  seqnames ranges strand | score GC
The Reduce method will allow the GRanges objects to be collapsed across the whole of the GRangesList object.

```r
> Reduce(c, grl)
```

GRanges object with 3 ranges and 2 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[1] chr2</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>[2] chr1</td>
<td>+</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>[3] chr1</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Explicit element-wise operations (lapply() and friends) on GRangesList objects with many elements can be slow. It is therefore beneficial to explore operations that work on *List objects directly (e.g., many of the ‘group generic’ operators, see ?S4GroupGeneric, and the set and parallel set operators (e.g., union, punion). A useful and fast strategy is to unlist the GRangesList to a GRanges object, operate on the GRanges object, then relist the result, e.g.,

```r
> gr <- unlist(grl)
> gr$log_score <- log(gr$score)
> grl <- relist(gr, grl)
> grl
```

GRangesList object of length 2:

\$txA

GRanges object with 1 range and 3 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
<th>log_score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>txA chr2</td>
<td>+</td>
<td>5</td>
<td>0.45</td>
<td>1.6094379124341</td>
</tr>
</tbody>
</table>

\$txB

GRanges object with 2 ranges and 3 metadata columns:

<table>
<thead>
<tr>
<th>seqnames</th>
<th>ranges</th>
<th>strand</th>
<th>score</th>
<th>GC</th>
<th>log_score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>txB chr1</td>
<td>+</td>
<td>3</td>
<td>0.3</td>
<td>1.09861228866811</td>
</tr>
<tr>
<td></td>
<td>txB chr1</td>
<td>-</td>
<td>4</td>
<td>0.5</td>
<td>1.38629436111989</td>
</tr>
</tbody>
</table>

See also ?extractList.

For more information on the GRangesList classes be sure to consult the manual page and available methods

```r
> ?GRangesList
> methods(class="GRangesList")
```
4 Interval overlaps involving GRanges and GRangesList objects

Interval overlapping is the process of comparing the ranges in two objects to determine if and when they overlap. As such, it is perhaps the most common operation performed on GRanges and GRangesList objects. To this end, the GenomicRanges package provides a family of interval overlap functions. The most general of these functions is findOverlaps, which takes a query and a subject as inputs and returns a Hits object containing the index pairings for the overlapping elements.

```r
> mtch <- findOverlaps(gr, grl)
> as.matrix(mtch)

queryHits subjectHits
[1,] 1 1
[2,] 2 2
[3,] 3 2
```

As suggested in the sections discussing the nature of the GRanges and GRangesList classes, the index in the above matrix of hits for a GRanges object is a single range while for a GRangesList object it is the set of ranges that define a "feature".

Another function in the overlaps family is countOverlaps, which tabulates the number of overlaps for each element in the query.

```r
> countOverlaps(gr, grl)

taxA txB txB
1 1 1
```

A third function in this family is subsetByOverlaps, which extracts the elements in the query that overlap at least one element in the subject.

```r
> subsetByOverlaps(gr, grl)
GRanges object with 3 ranges and 3 metadata columns:

  seqnames ranges strand | score GC log_score
  <Rle> <IRanges> <Rle> | <integer> <numeric> <numeric>
  txA chr2 [103, 106] + | 5 0.45 1.6094379124341
  txB chr1 [107, 109] + | 3 0.3 1.09861228866811
  txB chr1 [113, 115] - | 4 0.5 1.38629436111989
```

Finally, you can use the select argument to get the index of the first overlapping element in the subject for each element in the query.

```r
> findOverlaps(gr, grl, select="first")
[1] 1 2 2
```

5 Session Information

All of the output in this vignette was produced under the following conditions:

```r
> sessionInfo()

R version 3.4.0 (2017-04-21)
Platform: x86_64-pc-linux-gnu (64-bit)
Running under: Ubuntu 16.04.2 LTS
Matrix products: default
BLAS: /home/biocbuild/bbs-3.6-bioc/R/lib/libRblas.so
LAPACK: /home/biocbuild/bbs-3.6-bioc/R/lib/libRlapack.so

locale:
[1] LC_CTYPE=en_US.UTF-8 LC_NUMERIC=C LC_TIME=en_US.UTF-8
[4] LC_COLLATE=C LC_MONETARY=en_US.UTF-8 LC_MESSAGES=en_US.UTF-8
[7] LC_PAPER=en_US.UTF-8 LC_NAME=C LC_ADDRESS=C
[10] LC_TELEPHONE=C LC_MEASUREMENT=en_US.UTF-8 LC_IDENTIFICATION=C

attached base packages:
[1] parallel stats4 stats graphics grDevices utils datasets methods
[9] base

other attached packages:
[1] BSgenome.Scerevisiae.UCSC.sacCer2_1.4.0 KEGGgraph_1.35.1
[3] KEGG.db_3.2.3 BSgenome.Hsapiens.UCSC.hg19_1.4.0
[5] BSgenome_1.45.1 rtracklayer_1.37.2
[9] DESeq2_1.17.3 AnnotationHub_2.9.5
[13] TxDb.Dmelanogaster.UCSC.dm3.ensGene_3.2.2 GenomicFeatures_1.29.6
[15] AnnotationDbi_1.39.1 GenomicAlignments_1.13.2
[17] Rsamtools_1.29.0 Biostrings_2.45.2
[19] XVector_0.17.0 SummarizedExperiment_1.7.5
[21] DelayedArray_0.3.16 matrixStats_0.52.2
[23] Biobase_2.37.2 pasillaBamSubset_0.15.0
[25] GenomeInfoDb_1.13.4 GenomeInfoDb_1.13.4
[27] IRanges_2.11.5 S4Vectors_0.15.4
[29] BiocGenerics_0.23.0

loaded via a namespace (and not attached):
[1] bitops_1.0-6 bit64_0.9-7
[3] RColorBrewer_1.1-2 progress_1.1.2
[5] httr_1.2.1 rprojroot_1.2
[7] tools_3.4.0 backports_1.1.0
[9] R6_2.2.2 rpart_4.1-11
[11] Hmisc_4.0-3 DBI_0.7
[13] lazyeval_0.2.0 colorspace_1.3-2
[15] nnet_7.3-12 gridExtra_2.2.1
[17] prettyunits_1.0.2 bit_1.1-12
[19] curl_2.6 compiler_3.4.0
[21] graph_1.55.0 htmlTable_1.9
[23] scales_0.4.1 checkmate_1.8.2
[25] genefilter_1.59.0 stringr_1.2.0
[27] digest_0.6.12 foreign_0.8-68
[29] rmarkdown_1.6 base64enc_0.1-3
[31] pkgconfig_2.0.1 htmltools_0.3.6
[33] htmlwidgets_0.8 rlang_0.1.1
[35] GenomeInfoDbData_0.99.1 Formula_1.2-1
[37] shiny_1.0.3 BiocParallel_1.11.2
[39] acepack_1.4.1 VariantAnnotation_1.23.4
[41] RCurl_1.95-4.8 magrittr_1.5
[43] GenomeInfoDbData_0.99.1 Formula_1.2-1
[45] Matrix_1.2-10 Rcpp_0.12.11
[47] munsell_0.4.3 stringi_1.1.5
[49] yam_2.1.14 zlibbioc_1.23.0
<table>
<thead>
<tr>
<th>Package 1</th>
<th>Package 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>plyr_1.8.4</td>
<td>grid_3.4.0</td>
</tr>
<tr>
<td>blob_1.1.0</td>
<td>lattice_0.20-35</td>
</tr>
<tr>
<td>splines_3.4.0</td>
<td>annotate_1.55.0</td>
</tr>
<tr>
<td>locfit_1.5-9.1</td>
<td>knitr_1.16</td>
</tr>
<tr>
<td>geneplotter_1.55.0</td>
<td>biomaRt_2.33.3</td>
</tr>
<tr>
<td>XML_3.98-1.9</td>
<td>evaluate_0.10</td>
</tr>
<tr>
<td>latticeExtra_0.6-28</td>
<td>data.table_1.10.4</td>
</tr>
<tr>
<td>httpuv_1.3.3</td>
<td>gtable_0.2.0</td>
</tr>
<tr>
<td>assertthat_0.2.0</td>
<td>ggplot2_2.2.1</td>
</tr>
<tr>
<td>mime_0.5</td>
<td>xtable_1.8-2</td>
</tr>
<tr>
<td>survival_2.41-3</td>
<td>tibble_1.3.3</td>
</tr>
<tr>
<td>memoise_1.1.0</td>
<td>cluster_2.0.6</td>
</tr>
<tr>
<td>interactiveDisplayBase_1.15.0</td>
<td>BiocStyle_2.5.2</td>
</tr>
</tbody>
</table>