Making and Utilizing TxDb Objects

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1 Introduction

The GenomicFeatures package retrieves and manages transcript-related features from the UCSC Genome Bioinformatics\(^1\) and BioMart\(^2\) data resources. The package is useful for ChIP-chip, ChIP-seq, and RNA-seq analyses.

```r
suppressPackageStartupMessages(library('GenomicFeatures'))
```

2 TxDb Objects

The GenomicFeatures package uses TxDb objects to store transcript metadata. This class maps the 5' and 3' untranslated regions (UTRs), protein coding sequences (CDSs) and exons for a set of mRNA transcripts to their associated genome. TxDb objects have numerous accessors functions to allow such features to be retrieved individually or grouped together in a way that reflects the underlying biology.

All TxDb objects are backed by a SQLite database that manages genomic locations and the relationships between pre-processed mRNA transcripts, exons, protein coding sequences, and their related gene identifiers.

3 Retrieving Data from TxDb objects

3.1 Loading Transcript Data

There are two ways that users can load pre-existing data to generate a TxDb object. One method is to use the `loadDb` method to load the object directly from an appropriate .sqlite database file.

Here we are loading a previously created TxDb object based on UCSC known gene data. This database only contains a small subset of the possible annotations for human and is only included to demonstrate and test the functionality of the GenomicFeatures package as a demonstration.
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```r
samplefile <- system.file("extdata", "hg19_knownGene_sample.sqlite",
                          package="GenomicFeatures")

txdb <- loadDb(samplefile)

## Db object:
## # Db type: TxDb
## # Supporting package: GenomicFeatures
## # Data source: UCSC
## # Genome: hg19
## # Organism: Homo sapiens
## # UCSC Table: knownGene
## # Resource URL: http://genome.ucsc.edu/
## # Type of Gene ID: Entrez Gene ID
## # Full dataset: no
## # mirBase build ID: NA
## # transcript_nrow: 178
## # exon_nrow: 620
## # cds_nrow: 523
## # Db created by: GenomicFeatures package from Bioconductor
## # GenomicFeatures version at creation time: 1.17.21
## # RSQLite version at creation time: 0.11.4
## # DBSCHEMAVERSION: 1.0
```

In this case, the *TxDb* object has been returned by the `loadDb` method.

More commonly however, we expect that users will just load a TxDb annotation package like this:

```r
library(TxDb.Hsapiens.UCSC.hg19.knownGene)

txdb <- TxDb.Hsapiens.UCSC.hg19.knownGene #shorthand (for convenience)

## Db object:
## # Db type: TxDb
## # Supporting package: GenomicFeatures
## # Data source: UCSC
## # Genome: hg19
## # Organism: Homo sapiens
## # Taxonomy ID: 9606
## # UCSC Table: knownGene
## # Resource URL: http://genome.ucsc.edu/
## # Type of Gene ID: Entrez Gene ID
## # Full dataset: yes
## # mirBase build ID: GRCh37
## # transcript_nrow: 82960
```
Loading the package like this will also create a \texttt{TxDb} object, and by default that object will have the same name as the package itself.

### 3.2 Pre-filtering data based on Chromosomes

It is possible to filter the data that is returned from a \texttt{TxDb} object based on it’s chromosome. This can be a useful way to limit the things that are returned if you are only interested in studying a handful of chromosomes.

To determine which chromosomes are currently active, use the \texttt{seqlevels} method. For example:

```r
head(seqlevels(txdb))
```

```r
## [1] "chr1" "chr2" "chr3" "chr4" "chr5" "chr6"
```

Will tell you all the chromosomes that are active for the \texttt{TxDb.Hsapiens.UCSC.hg19.knownGene} \texttt{TxDb} object (by default it will be all of them).

If you then wanted to only set Chromosome 1 to be active you could do it like this:

```r
seqlevels(txdb) <- "chr1"
```

So if you ran this, then from this point on in your R session only chromosome 1 would be consulted when you call the various retrieval methods... If you need to reset back to the original \texttt{seqlevels} (i.e. to the \texttt{seqlevels} stored in the db), then set the \texttt{seqlevels} to \texttt{seqlevels0(txdb)}.

```r
seqlevels(txdb) <- seqlevels0(txdb)
```

Exercise 1

Use \texttt{seqlevels} to set only chromosome 15 to be active. \textbf{BTW, the rest of this vignette will assume you have succeeded at this.}

Solution:

```r
seqlevels(txdb) <- "chr15"
seqlevels(txdb)
```
3.3 Retrieving data using the select method

The *TxDb* objects inherit from *AnnotationDb* objects (just as the *ChipDb* and *OrgDb* objects do). One of the implications of this relationship is that these object ought to be used in similar ways to each other. Therefore we have written supporting *columns*, *keytypes*, *keys* and *select* methods for *TxDb* objects.

These methods can be a useful way of extracting data from a *TxDb* object. And they are used in the same way that they would be used to extract information about a *ChipDb* or an *OrgDb* object. Here is a simple example of how to find the UCSC transcript names that match with a set of gene IDs.

```r
keys <- c("100033416", "100033417", "100033420")
columns(txdb)
## [1] "CDSCHROM" "CDSEND" "CDSID" "CDSNAME" "CDSSTART"
## [6] "CDSSTRAND" "EXONCHROM" "EXONEND" "EXONID" "EXONNAME"
## [11] "EXONRANK" "EXONSTART" "EXONSTRAND" "GENEID" "TXCHROM"
## [16] "TXEND" "TXID" "TXNAME" "TXSTART" "TXSTRAND"
## [21] "TXTYPE"
keytypes(txdb)
## [1] "CDSID" "CDSNAME" "EXONID" "EXONNAME" "GENEID" "TXID"
## [7] "TXNAME"
select(txdb, keys = keys, columns="TXNAME", keytype="GENEID")
## 'select()' returned 1:1 mapping between keys and columns
##    GENEID    TXNAME
## 1 100033416 uc001yxl.4
## 2 100033417 uc001yxo.3
## 3 100033420 uc001yxr.3
```

**Exercise 2**

*For the genes in the example above, find the chromosome and strand information that will go with each of the transcript names.*

**Solution:**

```r
columns(txdb)
## [1] "CDSCHROM" "CDSEND" "CDSID" "CDSNAME" "CDSSTART"
## [6] "CDSSTRAND" "EXONCHROM" "EXONEND" "EXONID" "EXONNAME"
```
## Making and Utilizing TxDb Objects

```r
# cols <- c("TXNAME", "TXSTRAND", "TXCHROM")
select(txdb, keys=keys, columns=cols, keytype="GENEID")

## 'select()' returned 1:1 mapping between keys and columns

## GENEID TXNAME TXCHROM TXSTRAND
## 1 100033416 uc001yxl.4 chr15 +
## 2 100033417 uc001yxo.3 chr15 +
## 3 100033420 uc001yxr.3 chr15 +
```

### 3.4 Methods for returning GRanges objects

Retrieving data with select is useful, but sometimes it is more convenient to extract the result as GRanges objects. This is often the case when you are doing counting or specialized overlap operations downstream. For these use cases there is another family of methods available.

Perhaps the most common operations for a TxDb object is to retrieve the genomic coordinates or ranges for exons, transcripts or coding sequences. The functions transcripts, exons, and cds return the coordinate information as a GRanges object.

As an example, all transcripts present in a TxDb object can be obtained as follows:

```r
GR <- transcripts(txdb)
GR[1:3]
```

The transcripts function returns a GRanges class object. You can learn a lot more about the manipulation of these objects by reading the GenomicRanges introductory vignette. The show method for a GRanges object will display the ranges, seqnames (a chromosome or a contig), and strand on the left side and then present related metadata on the right side. At the bottom, the seqlengths display all the possible seqnames along with the length of each sequence.
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The `strand` function is used to obtain the strand information from the transcripts. The sum of the lengths of the `Rle` object that `strand` returns is equal to the length of the `GRanges` object.

```r
tx_strand <- strand(GR)
rx_strand
## factor-Rle of length 3337 with 2 runs
## Lengths: 1732 1605
## Values:  +  -
## Levels(3):  +  -  *

sum(runLength(tx_strand))
## [1] 3337

length(GR)
## [1] 3337
```

In addition, the `transcripts` function can also be used to retrieve a subset of the transcripts available such as those on the `+`-strand of chromosome 1.

```r
GR <- transcripts(txdb, filter=list(tx_chrom = "chr15", tx_strand = "+"))
length(GR)
## [1] 1732

unique(strand(GR))
## [1] +
## Levels:  +  -  *
```

The `promoters` function computes a `GRanges` object that spans the promoter region around the transcription start site for the transcripts in a `TxDb` object. The `upstream` and `downstream` arguments define the number of bases upstream and downstream from the transcription start site that make up the promoter region.

```r
PR <- promoters(txdb, upstream=2000, downstream=400)
PR
## GRanges object with 3337 ranges and 2 metadata columns:
## seqnames ranges strand  |  tx_id tx_name
## <Rle> <IRanges> <Rle>   | <integer> <character>
## uc001yte.1 chr15 20360688-20363087 +  |  53552 uc001yte.1
## uc001ytf.1 chr15 20485997-20488396 +  |  53553 uc001ytf.1
## uc001ytj.3 chr15 20721929-20724328 +  |  53554 uc001ytj.3
## uc021sex.1 chr15 20737312-20739711 +  |  53555 uc021sex.1
## uc010tzb.1 chr15 20740235-20742634 +  |  53556 uc010tzb.1
## ... ... ... ... ... ... ... ... ...
## uc021syy.1 chr15 102302656-102305055 -  |  56884 uc021syy.1
```
The `exons` and `cds` functions can also be used in a similar fashion to retrieve genomic coordinates for exons and coding sequences.

**Exercise 3**

*Use `exons` to retrieve all the exons from chromosome 15. How does the length of this compare to the value returned by `transcripts`?*

**Solution:**

```r
EX <- exons(txdb)
EX[1:4]
## GRanges object with 4 ranges and 1 metadata column:
## seqnames ranges strand | exon_id
## <Rle> <IRanges> <Rle> | <integer>
## [1] chr15 20362688-20362858 + | 192986
## [2] chr15 20362943-20363123 + | 192987
## [3] chr15 20364397-20364420 + | 192988
## [4] chr15 20487997-20488227 + | 192989
## seqinfo: 1 sequence from hg19 genome
```

```
length(EX)
## [1] 10771
```

```
length(GR)
## [1] 1732
```

### 3.5 Working with Grouped Features

Often one is interested in how particular genomic features relate to each other, and not just their location. For example, it might be of interest to group transcripts by gene or to group exons by transcript. Such groupings are supported by the `transcriptsBy`, `exonsBy`, and `cdsBy` functions.

The following call can be used to group transcripts by genes:
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```r
GRList <- transcriptsBy(txdb, by = "gene")
length(GRList)
## [1] 799
names(GRList)[10:13]
## [1] "100033424" "100033425" "100033427" "100033428"
GRList[11:12]
## GRangesList object of length 2:
## $`100033425`
## GRanges object with 1 range and 2 metadata columns:
## seqnames ranges strand | tx_id tx_name
## <Rle> <IRanges> <Rle> | <integer> <character>
## [1] chr15 25324204-25325381 + | 53638 uc001yxw.4
## -------
## seqinfo: 1 sequence from hg19 genome
## $`100033427`
## GRanges object with 1 range and 2 metadata columns:
## seqnames ranges strand | tx_id tx_name
## <Rle> <IRanges> <Rle> | <integer> <character>
## [1] chr15 25326433-25326526 + | 53640 uc001yxz.3
## -------
## seqinfo: 1 sequence from hg19 genome
```

The `transcriptsBy` function returns a `GRangesList` class object. As with `GRanges` objects, you can learn more about these objects by reading the `GenomicRanges` introductory vignette. The `show` method for a `GRangesList` object will display as a list of `GRanges` objects. And, at the bottom the seqinfo will be displayed once for the entire list.

For each of these three functions, there is a limited set of options that can be passed into the `by` argument to allow grouping. For the `transcriptsBy` function, you can group by gene, exon or cds, whereas for the `exonsBy` and `cdsBy` functions can only be grouped by transcript (`tx`) or gene.

So as a further example, to extract all the exons for each transcript you can call:

```r
GRList <- exonsBy(txdb, by = "tx")
length(GRList)
## [1] 3337
names(GRList)[10:13]
## [1] "53561" "53562" "53563" "53564"
```
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As you can see, the `GRangesList` objects returned from each function contain locations and identifiers grouped into a list like object according to the type of feature specified in the `by` argument. The object returned can then be used by functions like `findOverlaps` to contextualize alignments from high-throughput sequencing.

The identifiers used to label the `GRanges` objects depend upon the data source used to create the `TxDb` object. So the list identifiers will not always be Entrez Gene IDs, as they were in the first example. Furthermore, some data sources do not provide a unique identifier for all features. In this situation, the group label will be a synthetic ID created by `GenomicFeatures` to keep the relations between features consistent in the database; this was the case in the 2nd example. Even though the results will sometimes have to come back to you as synthetic IDs, you can still always retrieve the original IDs.

**Exercise 4**

Starting with the `tx_ids` that are the names of the `GRList` object we just made, use `select` to retrieve that matching transcript names. Remember that the list used a `by` argument = "tx", so the list is grouped by transcript IDs.

**Solution:**

```r
GRList <- exonsBy(txdb, by = "tx")
tx_ids <- names(GRList)
head(select(txdb, keys=tx_ids, columns="TXNAME", keytype="TXID"))
```

```
# 'select()' returned 1:1 mapping between keys and columns

## TXID TXNAME
## 1 53552 uc001yte.1
## 2 53553 uc001ytf.1
## 3 53554 uc001ytj.3
## 4 53555 uc021sex.1
## 5 53556 uc010tzb.1
## 6 53557 uc021sey.1
```

Finally, the order of the results in a `GRangesList` object can vary with the way in which things were grouped. In most cases the grouped elements of the `GRangesList` object will be listed in the order that they occurred along the chromosome. However,
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when exons or CDS are grouped by transcript, they will instead be grouped according to their position along the transcript itself. This is important because alternative splicing can mean that the order along the transcript can be different from that along the chromosome.

3.6 Predefined grouping functions

The \texttt{intronsByTranscript}, \texttt{fiveUTRsByTranscript} and \texttt{threeUTRsByTranscript} are convenience functions that provide behavior equivalent to the grouping functions, but in prespecified form. These functions return a \texttt{GRangesList} object grouped by transcript for introns, 5' UTR's, and 3' UTR's, respectively. Below are examples of how you can call these methods.

\begin{verbatim}
length(intronsByTranscript(txdb))
## [1] 3337
length(fiveUTRsByTranscript(txdb))
## [1] 1825
length(threeUTRsByTranscript(txdb))
## [1] 1803
\end{verbatim}

3.7 Getting the actual sequence data

The \texttt{GenomicFeatures} package also provides functions for converting from ranges to actual sequence (when paired with an appropriate \texttt{BSgenome} package).

\begin{verbatim}
library(BSgenome.Hsapiens.UCSC.hg19)
## Loading required package: BSgenome
## Loading required package: Biostrings
## Loading required package: XVector

## Loading required package: rtracklayer

tx_seqs1 <- extractTranscriptSeqs(Hsapiens, TxDb.Hsapiens.UCSC.hg19.knownGene, use.names=TRUE)
\end{verbatim}
And, once these sequences have been extracted, you can translate them into proteins with `translate`:

```r
suppressWarnings(translate(tx_seqs1))
```

```r
## AAStringSet object of length 3337:
##   width  seq names
## [1] 125  EDQDDEARVQYEGFRPGMYVR\e YTPQHMHCGAAFWa+ FSDSCh uc010yte.1
## [2] 288  RIAS+GRAEFSSAQTSIEQRR\eAEESVFYSVYFNYNNGCNFFTVD uc010ytf.1
## [3] 588  RSGQRLPSEPOAEAGDPGKQR\eAE RDLENETHYLCSIKIFC uc010ytj.3
## [4] 10   HHLNCRPQTG uc021sex.1
## [5] 9    STVTLPHSQ uc010tzb.1
```

Exercise 5

*But of course this is not a meaningful translation, because the call to `extractTranscriptSeqs` will have extracted all the transcribed regions of the genome regardless of whether or not they are translated. Look at the manual page for `extractTranscriptSeqs` and see how you can use `cdsBy` to only translate only the coding regions.*

Solution:

```r
cds_seqs <- extractTranscriptSeqs(Hsapiens,
                                      cdsBy(txdb, by="tx", use.names=TRUE))
translate(cds_seqs)
```

```r
## AAStringSet object of length 1875:
##   width  seq names
## [1] 102  MYVRVEIENVPCFVQPINIDPH\e AE RQRLLKYPQHMHCAGAFWA+ FSDSCh uc010yte.1
## [2] 435  MEWKLEQSMREQLKAQLTG\eAE LGSNCCVPFFCAWPPRRR+* KSCTIRPLOLCAHFWL uc010tzc.1
## [3] 317  MKIANNTVVFTEFILLGLTQS\eAE SMKRLLSRHVCQVDIIFNR ur010yc.1
## [4] 314  METANYTKVTEFVLTGSQTP\eAE KVEKAAAMKLVTKYILCEKE ur010tzu.2
## [5] 317  MKIANNTVVFTEFILLGLTQS\eAE SMKRLLSRHVCQVDIIFNR ur010tzu.2
## [6] 186  MAGGVLPLRGLRACVLLFL\eAE CLGRSEFKDICQQMNQFLQVY ur010ush.1
## [7] 258  MYNKLWESGHQHWNMENMF\eAE PVNFKKDRLWTLTTWWIVHH ur002bx.1
## [8] 803  MAEALAAEAVASLRFQED\eAE AIDKLNRLKTRTLMNEAES ur002bx.3
## [9] 306  MTEFIFDLGLDSQLOQTFLF\eAE DMTAIRRLKWRDAHSSVK ur002cd.1
## [10] 134  MSESINFSHNLGQLLSPPRCV\eAE KGETQESVESRVLPGPRHRH ur010utv.1
```
4 Creating New *TxDb* Objects or Packages

The *GenomicFeatures* package provides functions to create *TxDb* objects based on data downloaded from UCSC Genome Bioinformatics or BioMart. The following subsections demonstrate the use of these functions. There is also support for creating *TxDb* objects from custom data sources using `makeTxDb`; see the help page for this function for details.

4.1 Using `makeTxDbFromUCSC`

The function `makeTxDbFromUCSC` downloads UCSC Genome Bioinformatics transcript tables (e.g. "knownGene", "refGene", "ensGene") for a genome build (e.g. "mm9", "hg19"). Use the `supportedUCSCtables` utility function to get the list of tables known to work with `makeTxDbFromUCSC`.

```r
supportedUCSCtables(genome="mm9")
```

```r
##   tablename       track subtrack
## 1  knownGene      UCSC  Genes <NA>
## 2 knownGeneOld8   Old    UCSC Genes <NA>
## 3 knownGeneOld7   Old    UCSC Genes <NA>
## 4 knownGeneOld6   Old    UCSC Genes <NA>
## 5 knownGeneOld4   Old    UCSC Genes <NA>
## 6 knownGeneOld3   Old    UCSC Genes <NA>
## 7     ccdsGene    CCDS       <NA>
## 8       refGene    RefSeq  Genes <NA>
## 9  xenoRefGene    Other RefSeq <NA>
##10      vegaGene     Vega Genes Vega Protein Genes
##11  vegaPseudoGene     Vega Genes Vega Pseudogenes
##12      ensGene     Ensembl Genes <NA>
##13     acembly      AceView Genes <NA>
##14 nscanPasaGene  N-SCAN     N-SCAN PASA-EST
##15      nscanGene    N-SCAN  N-SCAN
##16       sgpGene      SGP  Genes <NA>
##17       geneid       Geneid Genes <NA>
##18     genscan      Genscan Genes <NA>
##19     exoniphy    Exoniphy       <NA>
```

```r
mm9KG_txdb <- makeTxDbFromUCSC(genome="mm9", tablename="knownGene")
```
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4.2 Using `makeTxDbFromBiomart`

Retrieve data from BioMart by specifying the mart and the data set to the `makeTxDbFromBiomart` function (not all BioMart data sets are currently supported):

```r
mmusculusEnsembl <- makeTxDbFromBiomart(dataset="mmusculus_gene_ensembl")
```

As with the `makeTxDbFromUCSC` function, the `makeTxDbFromBiomart` function also has a `circ_seqs` argument that will default to using the contents of the `DEFAULT_CIRC_SEQS` vector. And just like those UCSC sources, there is also a helper function called `getChromInfoFromBiomart` that can show what the different chromosomes are called for a given source.

Using the `makeTxDbFromBiomart` `makeTxDbFromUCSC` functions can take a while and may also require some bandwidth as these methods have to download and then assemble a database from their respective sources. It is not expected that most users will want to do this step every time. Instead, we suggest that you save your annotation objects and label them with an appropriate time stamp so as to facilitate reproducible research.

4.3 Using `makeTxDbFromEnsembl`

The `makeTxDbFromEnsembl` function creates a `TxDb` object for a given organism by importing the genomic locations of its transcripts, exons, CDS, and genes from an Ensembl database.

See `?makeTxDbFromEnsembl` for more information.

4.4 Using `makeTxDbFromGFF`

You can also extract transcript information from either GFF3 or GTF files by using the `makeTxDbFromGFF` function. Usage is similar to `makeTxDbFromBiomart` and `makeTxDbFromUCSC`.

4.5 Saving and Loading a `TxDb` Object

Once a `TxDb` object has been created, it can be saved to avoid the time and bandwidth costs of recreating it and to make it possible to reproduce results with identical genomic feature data at a later date. Since `TxDb` objects are backed by a SQLite database, the save format is a SQLite database file (which could be accessed from programs other than R if desired). Note that it is not possible to serialize a `TxDb` object using R’s `save` function.
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```r
code
saveDb(mm9KG_txdb, file="fileName.sqlite")
```

And as was mentioned earlier, a saved TxDb object can be initialized from a .sqlite file by simply using `loadDb`.

```r
code
mm9KG_txdb <- loadDb("fileName.sqlite")
```

#### 4.6 Using `makeTxDbPackageFromUCSC` and `makeTxDbPackageFromBiomart`

It is often much more convenient to just make an annotation package out of your annotations. If you are finding that this is the case, then you should consider the convenience functions: `makeTxDbPackageFromUCSC` and `makeTxDbPackageFromBiomart`. These functions are similar to `makeTxDbFromUCSC` and `makeTxDbFromBiomart` except that they will take the extra step of actually wrapping the database up into an annotation package for you. This package can then be installed and used as of the standard TxDb packages found on in the Bioconductor repository.

### 5 Session Information

```r
code
## R Under development (unstable) (2020-01-28 r77731)
## Platform: x86_64-pc-linux-gnu (64-bit)
## Running under: Ubuntu 18.04.3 LTS
##
## Matrix products: default
## BLAS: /home/biocbuild/bbs-3.11-bioc/R/lib/libRblas.so
## LAPACK: /home/biocbuild/bbs-3.11-bioc/R/lib/libRlapack.so
##
## locale:
## [1] LC_CTYPE=en_US.UTF-8 LC_NUMERIC=C
## [3] LC_TIME=en_US.UTF-8 LC_COLLATE=C
## [5] LC_MONETARY=en_US.UTF-8 LC_MESSAGES=en_US.UTF-8
## [7] LC_PAPER=en_US.UTF-8 LC_NAME=C
## [9] LC_ADDRESS=C LC_TELEPHONE=C
##
## attached base packages:
## [1] stats4  parallel  stats  graphics  grDevices  utils  datasets
## [8] methods  base
##
## other attached packages:
## [1] BSgenomes.Hsapiens.UCSC.hg19_1.4.0
## [2] BSgenomes_1.55.3
```
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```r
## [3] rtracklayer_1.47.0
## [4] Biostrings_2.55.4
## [5] XVector_0.27.0
## [8] AnnotationDbi_1.49.1
## [9] Biobase_2.47.2
## [10] GenomicRanges_1.39.2
## [12] IRanges_2.21.3
## [13] S4Vectors_0.25.12
## [14] BiocGenerics_0.33.0
##
## loaded via a namespace (and not attached):
## [1] Rcpp_1.0.3 lattice_0.20-38
## [3] prettyunits_1.1.1 Rsamtools_2.3.4
## [5] assertthat_0.2.1 digest_0.6.24
## [7] BiocFileCache_1.11.4 R6_2.4.1
## [9] RSQLite_2.2.0 evaluate_0.14
## [11] httr_1.4.1 highr_0.8
## [13] pillar_1.4.3 zlibbioc_1.33.1
## [15] rlang_0.4.4 progress_1.2.2
## [17] curl_4.3 blob_1.2.1
## [19] Matrix_1.2-18 rmarkdown_2.1
## [21] BiocParallel_1.21.2 stringr_1.4.0
## [23] RCurl_1.98-1.1 bit_1.1-15.2
## [25] biomaRt_2.43.3 DelayedArray_0.13.4
## [27] compiler_4.0.0 xfun_0.12
## [29] pkgconfig_2.0.3 askpass_1.1
## [31] htmltools_0.4.0 openssl_1.4.1
## [33] tidyeval_1.0.0 SummarizedExperiment_1.17.2
## [35] tibble_2.1.3 GenomeInfoDbData_1.2.2
## [37] matrixStats_0.55.0 XML_3.99-0.3
## [39] crayon_1.3.4 dplyr_0.8.4
## [41] dbplyr_1.4.2 GenomicAlignments_1.23.1
## [43] bitops_1.0-6 rappdirs_0.3.1
## [45] grid_4.0.0 DBI_1.1.0
## [47] magrittr_1.5 stringi_1.4.5
## [49] vctrs_0.2.2 BiocStyle_2.15.6
## [51] tools_4.0.0 bit64_0.9-7
## [53] glue_1.3.1 purrr_0.3.3
## [55] hms_0.5.3 yaml_2.2.1
## [57] BiocManager_1.30.10 memoise_1.1.0
## [59] knitr_1.28
```