

An Introduction to *Rbowtie*

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1 Introduction

The *Rbowtie* package provides an R wrapper around the popular *bowtie*[1] short read aligner and around *SpliceMap*[2] a de novo splice junction discovery and alignment tool, which makes use of the *bowtie* software package.

The package is used by the *QuasR*[3] bioconductor package to quantify and annotate short reads. We recommend to use the *QuasR* package instead of using *Rbowtie* directly. The *QuasR* package provides a simpler interface than *Rbowtie* and covers the whole analysis workflow of typical ultra-high throughput sequencing experiments, starting from the raw sequence reads, over pre-processing and alignment, up to quantification.

2 Preliminaries

2.1 Citing *Rbowtie*

If you use *Rbowtie*[4] in your work, you can cite it as follows:

```
> citation("Rbowtie")
```

The *Rbowtie* package contains code from two separate software projects. If using *bowtie* only, it can be cited as Langmead et al. (2009). If using also *SpliceMap*, it can be cited in addition Au et al. (2010). The *Rbowtie* package can be cited using the third reference below:

Langmead B, Trapnell C, Pop M, Salzberg SL. Ultrafast and memory-efficient alignment of short DNA sequences to the human genome. *Genome Biology* 10(3):R25 (2009).

Au KF, Jiang H, Lin L, Xing Y, Wong WH. Detection of splice junctions from paired-end RNA-seq data by *SpliceMap*. *Nucleic Acids Research*, 38(14):4570-8 (2010).

Hahne F, Lerch A, Stadler MB. *Rbowtie*: An R wrapper for *bowtie* and *SpliceMap* short read aligners. (unpublished)

This free open-source software implements academic research by the authors and co-workers. If you use it, please support the project by citing the appropriate journal articles.

To see these entries in BibTeX format, use `'print(<citation>, bibtex=TRUE)', 'toBibtex()'`, or set `'options(citation.bibtex.max=999)'`.

2.2 Installation

Rbowtie is a package for the R computing environment and it is assumed that you have already installed R. See the R project at <http://www.r-project.org>. To install the latest version of *Rbowtie*, you will need to be using the latest version of R. *Rbowtie* is part of the Bioconductor project at <http://www.bioconductor.org>. To get *Rbowtie* together with its dependencies you can use

```
> source("http://www.bioconductor.org/biocLite.R")
> biocLite("Rbowtie")
```

2.3 Loading of *Rbowtie*

In order to run the code examples in this vignette, the *Rbowtie* library need to be loaded.

```
> library(Rbowtie)
```

2.4 How to get help

Most questions about *Rbowtie* will hopefully be answered by the documentation or references. If you've run into a question which isn't addressed by the documentation, or you've found a conflict between the documentation and software itself, then there is an active support community which can offer help. The authors of the package (maintainer: maintainer("Rbowtie")) always appreciate receiving reports of bugs in the package functions or in the documentation.

The same goes for well-considered suggestions for improvements. Any other questions or problems concerning *Rbowtie* should be sent to the Bioconductor mailing list bioconductor@stat.math.ethz.ch. To subscribe to the mailing list, see <https://stat.ethz.ch/mailman/listinfo/bioconductor>. Please send requests for general assistance and advice to the mailing list rather than to the individual authors. Users posting to the mailing list for the first time should read the helpful posting guide at <http://www.bioconductor.org/doc/postingGuide.html>. Note that each function in *Rbowtie* has it's own help page, e.g. `help("bowtie")`. Mailing list etiquette requires that you read the relevant help page carefully before posting a problem to the list.

3 Example usage for individual *Rbowtie* functions

Please refer to the *Rbowtie* reference manual or the function documentation (e.g. using `?bowtie`) for a complete description of *Rbowtie* functions. The descriptions provided below are meant to give an overview over all functions and summarize the purpose of each one.

3.1 Build the reference index with `bowtie_build`

To be able to align short reads to a genome, an index has to be build first using the function `bowtie_build`. Information about arguments can be found with the help of the `bowtie_build_usage` function or in the manual page `?bowtie_build`.

```
> bowtie_build_usage()
[1] "Usage: bowtie2-build-s [options]* <reference_in> <ebwt_outfile_base>"
[2] "   reference_in           comma-separated list of files with ref sequences"
[3] "   ebwt_outfile_base      write Ebwt data to files with this dir/basename"
[4] "Options:"
[5] "   -f                     reference files are Fasta (default)"
[6] "   -c                     reference sequences given on cmd line (as <seq_in>)"
[7] "   -C/--color             build a colorspace index"
[8] "   -a/--noauto            disable automatic -p/--bmax/--dcv memory-fitting"
[9] "   -p/--packed            use packed strings internally; slower, uses less mem"
[10] "   --bmax <int>          max bucket sz for blockwise suffix-array builder"
[11] "   --bmaxdivn <int>      max bucket sz as divisor of ref len (default: 4)"
[12] "   --dcv <int>           diff-cover period for blockwise (default: 1024)"
[13] "   --nodc                disable diff-cover (algorithm becomes quadratic)"
[14] "   -r/--noref            don't build .3/.4.ebwt (packed reference) portion"
[15] "   -3/--justref          just build .3/.4.ebwt (packed reference) portion"
[16] "   -o/--offrate <int>    SA is sampled every 2^offRate BWT chars (default: 5)"
[17] "   -t/--ftabchars <int>  # of chars consumed in initial lookup (default: 10)"
[18] "   --ntoa                convert Ns in reference to As"
[19] "   --seed <int>          seed for random number generator"
[20] "   -q/--quiet            verbose output (for debugging)"
[21] "   -h/--help             print detailed description of tool and its options"
```

```
[22] "      --usage          print this usage message"
[23] "      --version        print version information and quit"
```

`refFiles` below is a vector with filenames of the reference sequence in FASTA format, and `indexDir` specifies an output directory for the index files that will be generated when calling `bowtie_build`:

```
> refFiles <- dir(system.file(package="Rbowtie", "samples", "refs"), full=TRUE)
> indexDir <- file.path(tempdir(), "refsIndex")
> tmp <- bowtie_build(references=refFiles, outdir=indexDir, prefix="index", force=TRUE)
> head(tmp)
[1] "Settings:"
[2] "  Output files: \"/tmp/RtmpEeyQTy/refsIndex/index.*.ebwt\"
[3] "  Line rate: 6 (line is 64 bytes)"
[4] "  Lines per side: 1 (side is 64 bytes)"
[5] "  Offset rate: 5 (one in 32)"
[6] "  FTable chars: 10"
```

3.2 Create alignment with bowtie

Information about the arguments supported by the `bowtie` function can be obtained with the help of the `bowtie_usage` function or in the manual page `?bowtie`.

```
> bowtie_usage()
[1] "Usage: "
[2] "bowtie-build-s [options]* <ebwt> {-1 <m1> -2 <m2> | --12 <r> | <s>} [<hit>]"
[3] ""
[4] "  <m1>      Comma-separated list of files containing upstream mates (or the"
[5] "            sequences themselves, if -c is set) paired with mates in <m2>"
[6] "  <m2>      Comma-separated list of files containing downstream mates (or the"
[7] "            sequences themselves if -c is set) paired with mates in <m1>"
[8] "  <r>        Comma-separated list of files containing Crossbow-style reads. Can be"
[9] "            a mixture of paired and unpaired. Specify \"-\" for stdin."
[10] "  <s>        Comma-separated list of files containing unpaired reads, or the"
[11] "            sequences themselves, if -c is set. Specify \"-\" for stdin."
[12] "  <hit>      File to write hits to (default: stdout)"
[13] "Input:"
[14] "  -q          query input files are FASTQ .fq/.fastq (default)"
[15] "  -f          query input files are (multi-)FASTA .fa/.mfa"
[16] "  -r          query input files are raw one-sequence-per-line"
[17] "  -c          query sequences given on cmd line (as <mates>, <singles>)"
[18] "  -C          reads and index are in colorspace"
[19] "  -Q/--quals <file> QV file(s) corresponding to CSFASTA inputs; use with -f -C"
[20] "  --Q1/--Q2 <file> same as -Q, but for mate files 1 and 2 respectively"
[21] "  -s/--skip <int> skip the first <int> reads/pairs in the input"
[22] "  -u/--qupto <int> stop after first <int> reads/pairs (excl. skipped reads)"
[23] "  -5/--trim5 <int> trim <int> bases from 5' (left) end of reads"
[24] "  -3/--trim3 <int> trim <int> bases from 3' (right) end of reads"
[25] "  --phred33-quals input quals are Phred+33 (default)"
[26] "  --phred64-quals input quals are Phred+64 (same as --solexa1.3-quals)"
[27] "  --solexa-quals input quals are from GA Pipeline ver. < 1.3"
[28] "  --solexa1.3-quals input quals are from GA Pipeline ver. >= 1.3"
[29] "  --integer-quals qualities are given as space-separated integers (not ASCII)"
[30] "Alignment:"
[31] "  -v <int>      report end-to-end hits w/ <=v mismatches; ignore qualities"
```

```

[32] "    or"
[33] " -n/--seedmms <int> max mismatches in seed (can be 0-3, default: -n 2)"
[34] " -e/--maqerr <int> max sum of mismatch quals across alignment for -n (def: 70)"
[35] " -l/--seedlen <int> seed length for -n (default: 28)"
[36] " --nomaqround      disable Maq-like quality rounding for -n (nearest 10 <= 30)"
[37] " -I/--minins <int> minimum insert size for paired-end alignment (default: 0)"
[38] " -X/--maxins <int> maximum insert size for paired-end alignment (default: 250)"
[39] " --fr/--rf/--ff    -1, -2 mates align fw/rev, rev/fw, fw/fw (default: --fr)"
[40] " --nofw/--norc     do not align to forward/reverse-complement reference strand"
[41] " --maxbts <int>    max # backtracks for -n 2/3 (default: 125, 800 for --best)"
[42] " --pairtries <int> max # attempts to find mate for anchor hit (default: 100)"
[43] " -y/--tryhard      try hard to find valid alignments, at the expense of speed"
[44] " --chunkmbs <int> max megabytes of RAM for best-first search frames (def: 64)"
[45] "Reporting:"
[46] " -k <int>          report up to <int> good alignments per read (default: 1)"
[47] " -a/--all          report all alignments per read (much slower than low -k)"
[48] " -m <int>          suppress all alignments if > <int> exist (def: no limit)"
[49] " -M <int>          like -m, but reports 1 random hit (MAPQ=0); requires --best"
[50] " --best           hits guaranteed best stratum; ties broken by quality"
[51] " --strata         hits in sub-optimal strata aren't reported (requires --best)"
[52] "Output:"
[53] " -t/--time         print wall-clock time taken by search phases"
[54] " -B/--offbase <int> leftmost ref offset = <int> in bowtie output (default: 0)"
[55] " --quiet           print nothing but the alignments"
[56] " --refout          write alignments to files refXXXXX.map, 1 map per reference"
[57] " --refidx          refer to ref. seqs by 0-based index rather than name"
[58] " --al <fname>      write aligned reads/pairs to file(s) <fname>"
[59] " --un <fname>      write unaligned reads/pairs to file(s) <fname>"
[60] " --max <fname>     write reads/pairs over -m limit to file(s) <fname>"
[61] " --suppress <cols> suppresses given columns (comma-delim'ed) in default output"
[62] " --fullref         write entire ref name (default: only up to 1st space)"
[63] "Colorspace:"
[64] " --snpphred <int> Phred penalty for SNP when decoding colorspace (def: 30)"
[65] "    or"
[66] " --snppfrac <dec> approx. fraction of SNP bases (e.g. 0.001); sets --snpphred"
[67] " --col-cseq        print aligned colorspace seqs as colors, not decoded bases"
[68] " --col-cqual       print original colorspace quals, not decoded quals"
[69] " --col-keepends    keep nucleotides at extreme ends of decoded alignment"
[70] "SAM:"
[71] " -S/--sam          write hits in SAM format"
[72] " --mapq <int>      default mapping quality (MAPQ) to print for SAM alignments"
[73] " --sam-nohead      suppress header lines (starting with @) for SAM output"
[74] " --sam-nosq        suppress @SQ header lines for SAM output"
[75] " --sam-RG <text>   add <text> (usually \"lab=value\") to @RG line of SAM header"
[76] "Performance:"
[77] " -o/--offrate <int> override offrate of index; must be >= index's offrate"
[78] " -p/--threads <int> number of alignment threads to launch (default: 1)"
[79] " --mm             use memory-mapped I/O for index; many 'bowtie's can share"
[80] " --shm            use shared mem for index; many 'bowtie's can share"
[81] "Other:"
[82] " --seed <int>      seed for random number generator"
[83] " --verbose         verbose output (for debugging)"
[84] " --version         print version information and quit"
[85] " -h/--help         print this usage message"

```

In the example below, `readsFiles` is the name of a file containing short reads to be aligned with `bowtie`, and `samFiles` specifies the name of the output file with the generated alignments.

```
> readsFiles <- system.file(package="Rbowtie", "samples", "reads", "reads.fastq")
> samFiles <- file.path(tempdir(), "alignments.sam")
> bowtie(sequences=readsFiles,
+       index=file.path(indexDir, "index"),
+       outfile=samFiles, sam=TRUE,
+       best=TRUE, force=TRUE)
> strtrim(readLines(samFiles), 65)
[1] "@HD\tVN:1.0\tSO:unsorted"
[2] "@SQ\tSN:chr1\tLN:100000"
[3] "@SQ\tSN:chr2\tLN:100000"
[4] "@SQ\tSN:chr3\tLN:100000"
[5] "@PG\tID:Bowtie\tVN:1.1.1\tCL:\"/private/tmp/RtmpsEriZC/Rinsta3ca1e938"
[6] "HWUSI-EAS1513_0012:6:48:5769:946#0/1\t0\tchr1\t819\t255\t101M\t*\t0\t0\tTG"
[7] "HWUSI-EAS1513_0012:6:48:6908:952#0/1\t0\tchr2\t1133\t255\t101M\t*\t0\t0\tA"
[8] "HWUSI-EAS1513_0012:6:48:8070:953#0/1\t0\tchr1\t7543\t255\t101M\t*\t0\t0\tG"
[9] "HWUSI-EAS1513_0012:6:48:9942:949#0/1\t4\t*\t0\t0\t*\t*\t0\t0\tCGGGTTCCTGTAT"
```

3.3 Create spliced alignment with SpliceMap

While `bowtie` only generates ungapped alignments, the `SpliceMap` function can be used to generate spliced alignments. `SpliceMap` is itself using `bowtie`. To use it, it is necessary to create an index of the reference sequence as described in 3.1. `SpliceMap` parameters are specified in the form of a named list, which follows closely the configure file format of the original `SpliceMap` program[2]. Be aware that `SpliceMap` can only be used for reads that are at least 50bp long.

```
> readsFiles <- system.file(package="Rbowtie", "samples", "reads", "reads.fastq")
> refDir <- system.file(package="Rbowtie", "samples", "refs", "chr1.fa")
> indexDir <- file.path(tempdir(), "refsIndex")
> samFiles <- file.path(tempdir(), "splicedAlignments.sam")
> cfg <- list(genome_dir=refDir,
+           reads_list1=readsFiles,
+           read_format="FASTQ",
+           quality_format="phred-33",
+           outfile=samFiles,
+           temp_path=tempdir(),
+           max_intron=400000,
+           min_intron=20000,
+           max_multi_hit=10,
+           seed_mismatch=1,
+           read_mismatch=2,
+           num_chromosome_together=2,
+           bowtie_base_dir=file.path(indexDir, "index"),
+           num_threads=4,
+           try_hard="yes",
+           selectSingleHit=TRUE)
> res <- SpliceMap(cfg)
> res
[1] "/tmp/RtmpEeyQTy/splicedAlignments.sam"
> strtrim(readLines(samFiles), 65)
[1] "@HD\tVN:1.0\tSO:coordinate"
[2] "@SQ\tSN:chr1\tLN:100000"
[3] "@PG\tID:SpliceMap\tVN:3.3.5.2 (55)"
```

```
[4] "HWUSI-EAS1513_0012:6:48:5769:946#0\t0\tchr1\t819\t255\t101M\t*\t0\t0\tTGGA"
[5] "HWUSI-EAS1513_0012:6:48:6908:952#0\t4\t*\t0\t0\t*\t*\t0\t0\tAACATAGTGAAGAA"
[6] "HWUSI-EAS1513_0012:6:48:8070:953#0\t0\tchr1\t7543\t255\t101M\t*\t0\t0\tGTC"
[7] "HWUSI-EAS1513_0012:6:48:9942:949#0\t4\t*\t0\t0\t*\t*\t0\t0\tCGGTTCTGTATCC"
```

4 Session information

The output in this vignette was produced under:

```
> sessionInfo()
R version 3.4.2 (2017-09-28)
Platform: x86_64-apple-darwin15.6.0 (64-bit)
Running under: OS X El Capitan 10.11.6

Matrix products: default
BLAS: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRblas.0.dylib
LAPACK: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRlapack.dylib

locale:
[1] C/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] stats      graphics  grDevices  utils      datasets  methods
[7] base

other attached packages:
[1] Rbowtie_1.18.0

loaded via a namespace (and not attached):
[1] compiler_3.4.2 parallel_3.4.2 tools_3.4.2
```

References

- [1] B. Langmead, C. Trapnell, M. Pop, and S.L. Salzberg. Ultrafast and memory-efficient alignment of short dna sequences to the human genome. *Genome Biology*, 10(3):R25, 2009.
- [2] K.F. Au, H. Jiang, L. Lin, Y. Xing, and W.H. Wong. Detection of splice junctions from paired-end rna-seq data by splicemap. *Nucleic Acids Research*, 38(14):4570–4578, 2010.
- [3] A. Lerch, D. Gaidatzis, F. Hahne, and M.B. Stadler. Quasr: Quantify and annotate short reads in r. unpublished, 2012.
- [4] F. Hahne, A. Lerch, and M.B. Stadler. bowtie: An r wrapper for bowtie and splicemap short read aligners. unpublished, 2012.