Package 'fRagmentomics'

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Title Extract Fragmentomics Features and Mutational Status

Version 1.1.0

Description A user-friendly R package that enables the characterization of each cfDNA fragment overlapping one or multiple mutations of interest, starting from a sequencing file containing aligned reads (BAM file). fRagmentomics supports multiple mutation input formats (e.g., VCF, TSV, or string ``chr:pos:ref:alt'' representation), accommodates one-based and zero-based genomic conventions, handles mutation representation ambiguities, and accepts any reference file and species in FASTA format. For each cfDNA fragment, fRagmentomics outputs its size, its 3' and 5' sequences, and its mutational status.
Optionally, when users set apply_bcftools_norm = TRUE, fRagmentomics invokes the external command-line tool bcftools norm to left-align and normalize variants. If bcftools is not found on the system PATH while this option is enabled, the function errors. The package does not install external software; see the INSTALL file for per-OS instructions.

URL https://github.com/ElsaB-Lab/fRagmentomics

BugReports https://github.com/ElsaB-Lab/fRagmentomics/issues

License GPL (>= 3)

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Author Killian Maudet [aut, cre] (ORCID:
<https://orcid.org/0009-0003-3237-092X>),
Juliette Samaniego [aut] (ORCID:
<https://orcid.org/0009-0002-3421-1810>),
Yoann Pradat [aut] (ORCID: <https://orcid.org/0000-0002-4647-5779>),
Elsa Bernard [aut] (ORCID: <https://orcid.org/0000-0002-2057-7187>)

Maintainer Killian Maudet <killian.maudet@gustaveroussy.fr>

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`fRagmentomics-package` *fRagmentomics: Extract Fragmentomics Features and Mutational Status*

Description

A user-friendly R package that enables the characterization of each cfDNA fragment overlapping one or multiple mutations of interest, starting from a sequencing file containing aligned reads (BAM file). fRagmentomics supports multiple mutation input formats (e.g., VCF, TSV, or string "chr:pos:ref:alt" representation), accommodates one-based and zero-based genomic conventions, handles mutation representation ambiguities, and accepts any reference file and species in FASTA format. For each cfDNA fragment, fRagmentomics outputs its size, its 3' and 5' sequences, and its mutational status. Optionally, when users set apply_bcftools_norm = TRUE, fRagmentomics invokes the external command-line tool bcftools norm to left-align and normalize variants. If bcftools is not found on the system PATH while this option is enabled, the function errors. The package does not install external software; see the INSTALL file for per-OS instructions.

Author(s)

Maintainer: Killian Maudet <killian.maudet@gustaveroussy.fr> (ORCID)

Authors:

- Yoann Pradat <yoann.pradat@gustaveroussy.fr> (ORCID)
- Juliette Samaniego <juliette.samaniego@gustaveroussy.fr>
- Elsa Bernard <elsa.bernard@gustaveroussy.fr> (ORCID)

See Also

Useful links:

- https://github.com/ElsaB-Lab/fRagmentomics
- Report bugs at https://github.com/ElsaB-Lab/fRagmentomics/issues

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`apply_bcftools_norm` *Normalize a single variant using bcftools norm*

Description

This function normalizes a single variant by leveraging the external 'bcftools norm' command. It writes the variant to a temporary VCF file, executes 'bcftools norm' for left-alignment and parsimonious representation, and then reads the normalized result back into a data frame.

Usage

```
apply_bcftools_norm(chr, pos, ref, alt, fasta, tmp_folder, verbose)
```

Arguments

chr	A string representing the chromosome.
pos	An integer representing the position.
ref	A string representing the reference allele.
alt	A string representing the alternative allele.
fasta	Path to the FASTA file for the reference sequence used for generating the BAM file.
tmp_folder	Character vector for the temporary folder path.
verbose	Boolean. If set to TRUE, print all the warnings and the prints.

Value

A dataframe containing normalized variant information with bcftools.

---

check_bcftools_is_installed *Check that bcftools system dependency is available.*

Description

Check that bcftools system dependency is available.

Usage

```
check_bcftools_is_installed()
```

Value

The system path to the bcftools executable

---

check_parameters *Check and validate all input parameters for the analysis pipeline*

Description

This function serves as a centralized gatekeeper, validating all user-provided parameters before the main analysis begins. It calls a series of specialized helper functions to check each parameter for correctness (e.g., file existence, data type, valid values) and stops execution with an informative error message if any check fails.

Usage

```
check_parameters(
  mut,
  bam,
  fasta,
  sample_id,
  neg_offset_mate_search,
  pos_offset_mate_search,
  one_based,
  flag_bam_list,
  report_bam_info,
  report_softclip,
  report_5p_3p_bases_fragment,
  remove_softclip,
  retain_fail_qc,
  tmp_folder,
  output_path,
  verbose,
  n_cores
)
```

Arguments

mut	Path to a .vcf or .tsv file or string representation chr:pos:ref:alt of a mutation.
bam	Path to a BAM file.
fasta	Path to the FASTA file for the reference sequence used for generating the BAM file.
sample_id	Sample identifier.
neg_offset_mate_search	Integer. Use in read_bam. Represents the number of nucleotides to extend upstream (negative direction) from the position of interest when querying the BAM file with Rsamtools. his extension ensures that paired reads are retrieved, even if only one mate overlaps the queried position.
pos_offset_mate_search	Integer. Use in read_bam.
one_based	Boolean. TRUE if fasta is in one based. False if in 0 based.
flag_bam_list	A named list of logicals for filtering reads based on their SAM flag NA = Filter is ignored, TRUE = The read MUST have this flag, FALSE = The read MUST NOT have this flag.
report_bam_info	Boolean. Whether to include the bam information.
report_softclip	Boolean. Whether to include the number of soft-clipped bases at the fragment extremities in the output.
report_5p_3p_bases_fragment	Integer. Whether to include N fragment extremity bases in the output.
remove_softclip	Boolean. If set to TRUE, trim soft-clipped bases from the 5' end of Read 5p and from the 3' end of Read 3p.

retain_fail_qc	Boolean. If set to TRUE, retain fragments that failed the various quality checks in the output.
tmp_folder	Character vector for the temporary folder path.
output_path	Character vector for the fragmentomics table output path.
verbose	Boolean. If set to TRUE, print all the warnings and the prints.
n_cores	Number of cores for parallel computation.

Value

None. The function stops execution if error.

`compare_read_to_ref_wt_and_mut` *Compare a read sequence against reference and alternate alleles*

Description

A core comparison utility that classifies a read sequence by checking its compatibility with the expected wild-type (WT) and mutant (MUT) sequences.

Usage

```
compare_read_to_ref_wt_and_mut(
  read_seq,
  ref_seq_wt,
  ref_seq_mut,
  compare_len_wt,
  compare_len_mut
)
```

Arguments

read_seq	Base sequence of the read
ref_seq_wt	Base sequence of the wild-type ref
ref_seq_mut	Base sequence of the mutated ref
compare_len_wt	Number of bases to be compared in read vs wild-type ref comparison
compare_len_mut	Number of bases to be compared in read vs mutated ref comparison

Value

a character describing the mutation status of the read

`extract_fragment_features` *Process a single DNA fragment from paired-end reads*

Description

This is a high-level worker function that orchestrates the complete analysis of a single DNA fragment (represented by a pair of reads) at a specific variant locus. It performs quality control, identifies reads, extracts features, determines mutation status, and returns all results in a structured format.

Usage

```
extract_fragment_features(
  df_sam,
  fragment_name,
  sample_id,
  chr,
  pos,
  ref,
  alt,
  report_bam_info,
  report_softclip,
  report_5p_3p_bases_fragment,
  remove_softclip,
  fasta_fafile = NULL,
  fasta_seq = NULL,
  input_mutation_info
)
```

Arguments

`df_sam`	A dataframe containing sequencing reads.
`fragment_name`	Name of the fragment (paired-end reads).
`sample_id`	Sample identifier.
`chr`	Character vector representing the chromosome of interest.
`pos`	Numeric value representing the Genomic position of interest.
`ref`	Character vector representing reference base(s).
`alt`	Character vector representing alternative base(s).
`report_bam_info`	Boolean. Whether to include the bam information.
`report_softclip`	Boolean. Whether to include the number of soft-clipped bases at the fragment extremities in the output.
`report_5p_3p_bases_fragment`	Integer. Whether to include N fragment extremity bases in the output.
`remove_softclip`	Boolean. If set to TRUE, trim soft-clipped bases from the 5' end of Read 5p and from the 3' end of Read 3p.

fasta_fafile	An open connection to an object of class FaFile
fasta_seq	A list with the fasta sequence between two positions.
input_mutation_info	Character vector representing the input mutation.

Details

The function executes the following pipeline for each fragment:

1. It subsets the reads from 'df_sam' that match the given 'fragment_name'.
2. It performs quality control checks (e.g., proper pairing, chromosome consistency, strand orientation) via 'process_fragment_reads_qc'.
3. It identifies the 5' (forward strand) and 3' (reverse strand) reads based on their SAM FLAGs.
4. If 'remove_softclip' is 'TRUE', it trims soft-clipped bases from the sequences, qualities, and CIGAR strings.
5. It calls 'get_base_basq_mstat_from_read' to determine the allele and mutation status for each individual read at the variant position.
6. It calculates the precise fragment size using 'get_fragment_size'.
7. It consolidates the two read statuses into a final fragment status (e.g., 'MUT', 'N/I') using 'get_mutation_status_of_fragment'.
8. It assembles and returns a single-row data frame containing all extracted information.

Value

A dataframe with the processed fragment information.

---

get_base_basq_from_read_at_pos

Extract sequence and quality between two read indices

Description

Extracts the read sequence and base qualities corresponding to the region between two read indices, which are derived from genomic positions.

Usage

```
get_base_basq_from_read_at_pos(pos_cur, pos_pre, read_stats)
```

Arguments

pos_cur	current position request
pos_pre	previous position request
read_stats	A list of read-level statistics.

Value

A list with the base and the quality of the read aligning with the position provided. If the read contains a deletion, base is set to '-' and the quality to an empty string.

`get_base_basq_mstat_from_read` *Extract allele, quality, and mutation status from a read*

Description

This function serves as a primary parser for a single read at a variant locus. It determines if the read covers the variant, extracts the observed sequence and its base qualities, and assigns a detailed mutation status.

Usage

```
get_base_basq_mstat_from_read(
  chr,
  pos,
  ref,
  alt,
  read_stats,
  fasta_fafile = NULL,
  fasta_seq = NULL
)
```

Arguments

`chr`	Character vector representing the chromosome of interest.
`pos`	Numeric value representing the Genomic position of interest.
`ref`	Character vector representing reference base(s).
`alt`	Character vector representing alternative base(s).
`read_stats`	A list of read-level statistics.
`fasta_fafile`	An open connection to an object of class FaFile
`fasta_seq`	A list with the fasta sequence between two positions.

Value

A list containing 'base', 'basq', 'mstat'.

`get_fragment_bases_5p_3p` *Extract Fragment Bases and Quality Scores from Read Sequences*

Description

This function extracts a fixed number of bases ('n_bases') and their corresponding quality scores from the 5' and 3' ends of reads.

Usage

```
get_fragment_bases_5p_3p(n_bases, seq_5p, seq_3p, qual_5p, qual_3p)
```

Arguments

n_bases	The number of bases to extract from each end (5' and 3').
seq_5p	The nucleotide sequence of the 5' read.
seq_3p	The nucleotide sequence of the 3' read.
qual_5p	The quality string corresponding to the 5' read.
qual_3p	The quality string corresponding to the 3' read.

Value

A list containing four character elements: -fragment_bases_5p: The first 'n_bases' nucleotides from the 5' read. -fragment_bases_3p: The last 'n_bases' nucleotides from the 3' read. -fragment_basqs_5p: The first 'n_bases' qual chr from the 5' read. -fragment_basqs_3p: The last 'n_bases' qual chr from the 3' read.

---

get_fragment_bases_5p_3p_softclip

Extract Soft-Clipped Base Counts from CIGAR Strings

Description

This function extracts the number of soft-clipped bases at the 5' ends of 5' reads and 3' ends of 3' reads. If no soft clipping is detected, the count is set to 0.

Usage

```
get_fragment_bases_5p_3p_softclip(cigar_5p, cigar_3p)
```

Arguments

cigar_5p	Character string. The CIGAR string of the 5' read.
cigar_3p	Character string. The CIGAR string of the 3' read.

Value

A 'list' containing two integer:

- 'nb_softclip_5p': The number of soft-clipped bases at the start of the 5' read.
- 'nb_softclip_3p': The number of soft-clipped bases at the end of the 3' read.

get_fragment_size *Compute fragment size*

Description

Calculates the size of a DNA fragment from its aligned paired-end reads. The function provides a more precise estimate than the SAM/BAM TLEN field by accounting for complex alignment features like soft-clipping and indels not only based one genomic position.

Usage

```
get_fragment_size(read_stats_5p, read_stats_3p)
```

Arguments

read_stats_5p	5p read infos
read_stats_3p	3p read infos

Value

a integer corresponding to the fragment size

get_index_aligning_with_pos *Find the read sequence index for a genomic position*

Description

Parses a read's CIGAR string to find the 1-based index in the read's sequence that corresponds to a specific 1-based genomic coordinate.

Usage

```
get_index_aligning_with_pos(pos, read_stats)
```

Arguments

pos	Numeric value representing the Genomic position of interest.
read_stats	A list of read-level statistics.

Value

An integer scalar representing the 1-based index in the read sequence.

- Returns '-1' if the read does not cover the position.
- Returns '-2' if the position falls within a deletion or skipped region ('D' or 'N' CIGAR operation) in the read.

`get_mutation_status_of_fragment` *Get detailed and simplified fragment mutation statuses.*

Description

This function determines both the detailed and simplified mutation statuses of a DNA fragment based on the mutation status of each of the two reads from the fragment.

Usage

```
get_mutation_status_of_fragment(mstat_5p, mstat_3p)
```

Arguments

`mstat_5p`	The mutation status of read 5p (e.g., "MUT", "WT", "AMB", "WT but potentially MUT", etc.). Can be "NA" for no coverage.
`mstat_3p`	The mutation status of read 3p (e.g., "MUT", "WT", "AMB", "WT but potentially MUT", etc.). Can be "NA" for no coverage.

Value

A list containing two character strings:

- 'Fragment_Status_Detail': A detailed status reflecting the combination, retaining original text where applicable (e.g., "MUT & WT but potentially MUT").
- 'Fragment_Status_Simple': A simplified status (e.g., "MUT", "WT", "OTH", "N/I").

`get_mutation_status_of_read` *Get mutation status of read*

Description

The algorithm to determine if a read supports the mutation of interest is quite intuitive but requires careful considerations of insertions and deletions in repeated sequences to resolve ambiguities whenever possible. The core idea is to apply the mutation on the reference sequence and compare the mutated reference sequence to the read sequence starting from the position of the mutation of interest. The sequence of the read should be compared to the sequence of the reference sequence and of the mutated reference sequence for just enough bases to assign mutational status without ambiguity.

Usage

```
get_mutation_status_of_read(
  chr,
  pos,
  ref,
  alt,
  read_stats,
  read_index_at_pos,
  fasta_fafile = NULL,
  fasta_seq = NULL,
  n_match_base_before = 1,
  n_match_base_after = 1
)
```

Arguments

`chr`	Character vector representing the chromosome of interest.
`pos`	Numeric value representing the Genomic position of interest.
`ref`	Character vector representing reference base(s).
`alt`	Character vector representing alternative base(s).
`read_stats`	A list of read-level statistics.
`read_index_at_pos`	An integer representing the index of the nucleotide in sequence aligning with the position of interest.
`fasta_fafile`	An open connection to an object of class FaFile
`fasta_seq`	A list with the fasta sequence between two positions.
`n_match_base_before`	Number of bases to be matched before the alt allele in the sequences comparison
`n_match_base_after`	Number of bases to be matched after the last alt allele in the sequences comparison

Value

A character string indicating the mutational status of the read. Possible values include:

- 'WT': Wild-Type. The read matches the reference sequence.
- 'MUT': Mutant. The read matches the alternate allele.
- 'AMB': Ambiguous. The read is too short or the context is too complex to definitively assign a status.
- 'OTH': Other. An alteration is found, but it is not the one of intejest.
- The status may be combined with a descriptive message (e.g., 'MUT by CIGAR but potentially OTH').

get_number_of_common_first_char *Count common leading characters between two strings*

Description

Calculates the length of the common prefix for two given character strings.

Usage

```
get_number_of_common_first_char(str_a, str_b)
```

Arguments

str_a	a string
str_b	a string

Value

An integer

normalize_mut *Normalize a data frame of variants*

Description

This function serves as the main variant normalization pipeline. It iterates through a data frame of variants, applying a two-step normalization process to each one, ensuring they are represented in a canonical, left-aligned format suitable for downstream analysis.

Usage

```
normalize_mut(
  df_mut,
  fasta,
  fasta_fafile,
  one_based,
  apply_bcftools_norm,
  tmp_folder,
  verbose
)
```

Arguments

df_mut	a dataframe with mutations
fasta	Path to the FASTA file for the reference sequence used for generating the BAM file.
fasta_fafile	An open connection to an object of class FaFile
one_based	Boolean. TRUE if fasta is in one based. False if in 0 based.
apply_bcftools_norm	Boolean. If set to TRUE, apply bcftools norm on each input variant to normalize it. Require that bcftools command is installed and available in the PATH.
tmp_folder	Character vector for the temporary folder path.
verbose	Boolean. If set to TRUE, print all the warnings and the prints.

Value

a dataframe with normalized mutations representations containing columns CHROM, POS, REF, ALT

---

normalize_to_vcf_rep *Normalize a variant to VCF representation*

Description

This function converts a variant from a user-provided format into the standard VCF representation, which is crucial for handling indels. It also harmonizes chromosome names and validates the reference allele against a FASTA file.

Usage

```
normalize_to_vcf_rep(chr, pos, ref, alt, fasta_fafile, one_based, verbose)
```

Arguments

chr	A string representing the chromosome.
pos	An integer representing the position.
ref	A string representing the reference allele.
alt	A string representing the alternative allele.
fasta_fafile	An open connection to an object of class FaFile
one_based	Boolean. TRUE if fasta is in one based. False if in 0 based.
verbose	Boolean. If set to TRUE, print all the warnings and the prints.

Details

The normalization process involves several key steps:

1. **Coordinate Adjustment**: Converts the input 'pos' from 0-based to 1-based if 'one_based' is 'FALSE'.
2. **Chromosome Naming**: Standardizes the chromosome name (e.g., '1' vs 'chr1') to match the provided FASTA reference using 'harmonize_chr_to_fasta'.
3. **Indel Padding**: For insertions and deletions, it prepends an "anchor" base from the reference genome to both 'ref' and 'alt' alleles to create a valid VCF-style representation. The 'pos' is adjusted accordingly for deletions. SNVs and MNVs are not modified.
4. **Validation**: After normalization, it confirms that the final 'ref' allele matches the sequence in the FASTA file at the new coordinates.

Value

A list with chr, pos, ref and alt

`plot_freq_barplot` *Plot Overall Nucleotide Frequency*

Description

Creates a bar plot to compare the overall proportion of each nucleotide (A/C/G/T; optional 'Other') in the end motifs. Error bars show 95% confidence intervals.

Usage

```
plot_freq_barplot(
  df_fragments,
  end_motif_5p = "Fragment_Bases_5p",
  end_motif_3p = "Fragment_Bases_3p",
  motif_type = "Both",
  motif_size = 3,
  col_z = "Fragment_Status_Simple",
  vals_z = NULL,
  ...,
  colors_z = "Dark2",
  title = NULL,
  output_path = NA_character_,
 ggsave_params = list(width = 14, height = 5, units = "in", dpi = 300, bg = "white"),
  show_pvalue = FALSE,
  drop_non_acgt = TRUE
)
```

Arguments

`df_fragments`	The input data frame containing fragment sequence data.
`end_motif_5p`	Character string. Column name for 5' end sequences.
`end_motif_3p`	Character string. Column name for 3' end sequences.

motif_type	Character string. Which ends to analyze: 'Start', 'End', or 'Both'.
motif_size	A single integer (>= 1) specifying the k-mer length to analyze.
col_z	Character string or 'NULL'. Column name for grouping. If 'NULL', all fragments are pooled.
vals_z	A character vector of group names from 'col_z' to include. If 'NULL', all unique groups in 'col_z' are used.
...	Additional aesthetics/arguments passed to ggplot2::geom_col() and ggplot2::geom_errorbar() (e.g., 'alpha', 'position', or 'width').
colors_z	A character vector of colors for the groups, or a single RColorBrewer palette name (e.g., 'Set2'). Named vectors are aligned to 'vals_z'.
title	Character or 'NA'. Plot title. If 'NULL', 'NA', or empty, a default title is used.
output_path	Character or 'NA'. If provided and non-empty, the plot is saved to this path.
ggsave_params	A named list of arguments passed to ggplot2::ggsave().
show_pvalue	Logical. If 'TRUE' and there are at least two groups, append a global Chi-squared p-value to the caption.
drop_non_acgt	Logical. If 'FALSE', characters other than A/C/G/T are tallied into an 'Other' category.

Value

A 'ggplot' object. If 'output_path' is provided and non-empty, the plot is saved to file and the function returns 'invisible(NULL)'.

Examples

```
## --- Create a dataset for demonstration ---
set.seed(42)

# Helper to generate random DNA sequences with base bias
generate_biased_dna <- function(n_seq, len, prob) {
  bases <- c("A", "C", "G", "T")
  replicate(n_seq, paste(sample(bases, len, replace = TRUE, prob = prob), collapse = ""))
}

# 50 'MUT' fragments biased toward 'C'
df_mut <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
  Fragment_Status_Simple = "MUT"
)

# 50 'WT' fragments biased toward 'G'
df_wt <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Status_Simple = "WT"
)

# Combine into a single data frame
example_df <- rbind(df_mut, df_wt)

## --- Function calls ---
```

```
# 1) Default plot: compare MUT vs WT for 3-mers from both ends
p1 <- plot_freq_barplot(example_df)
p1

# 2) First-nucleotide only (k = 1) on 5' end, with custom colors
p2 <- plot_freq_barplot(
  df_fragments = example_df,
  motif_type   = "Start",
  motif_size   = 1,
  colors_z     = c("MUT" = "#d95f02", "WT" = "#1b9e77"),
  title        = "5' First Base Composition"
)
p2

# 3) Ungrouped: overall nucleotide frequencies across all fragments
p3 <- plot_freq_barplot(example_df, col_z = NULL, title = "Overall Composition")
p3

# 4) Subset of groups (if you had >2 groups, e.g., 'MUT', 'WT', 'AMB')
p4 <- plot_freq_barplot(
  df_fragments = example_df,
  vals_z       = c("MUT", "WT")
)
p4

# 5) Include non-ACGT characters tallied as 'Other'
example_df$Fragment_Bases_5p[1:3] <- c("NNNNNNNNNN", "ACGTNACGTN", "TTTNAAAAAA")
p5 <- plot_freq_barplot(example_df,
  motif_size = 2, drop_non_acgt = FALSE,
  title = "Including 'Other' (non-ACGT)"
)
p5

# 6) Save to file with specific dimensions
# plot_freq_barplot(
#   df_fragments = example_df,
#   output_path  = file.path(tempdir(), 'nucleotide_frequency.png'),
#   ggsave_params = list(width = 7, height = 5, units = 'in', dpi = 300, bg = 'white')
# )
```

`plot_ggseqlogo_meme` *Plot sequence motif composition*

Description

Creates a sequence logo plot showing the proportion of each nucleotide at each position, with flexible grouping/faceting.

Usage

```
plot_ggseqlogo_meme(
  df_fragments,
  end_motif_5p = "Fragment_Bases_5p",
```

```
  end_motif_3p = "Fragment_Bases_3p",
  motif_type = "Both",
  motif_size = 3,
  col_z = "Fragment_Status_Simple",
  vals_z = NULL,
  colors_z = NULL,
  title = NULL,
  output_path = NA_character_,
 ggsave_params = list(width = 12, height = 6, units = "in", dpi = 300, bg = "white"),
  ...
)
```

Arguments

df_fragments	Data frame containing fragment sequence data.
end_motif_5p	Character. Column name for 5' end sequences.
end_motif_3p	Character. Column name for 3' end sequences.
motif_type	Character. One of 'Start', 'End', or 'Both'.
motif_size	Integer (>=1). Length of the motif to analyze.
col_z	Character or NULL. Grouping/faceting column. If NULL, all fragments are pooled.
vals_z	Character vector or NULL. Subset of groups from 'col_z' to include. If NULL, all unique groups are used.
colors_z	NULL (use ggseqlogo defaults), a single RColorBrewer palette name (e.g., 'Dark2'), or a named vector for 'A/C/G/T', e.g. 'c(A='#1B9E77', C='#D95F02', G='#7570B3', T='#E7298A')'.
title	Character or NA. Plot title; if NULL/NA/'NA'/empty, a default title is used.
output_path	Character or NA. If provided and non-empty, the plot is saved to this file.
ggsave_params	Named list passed to ggplot2::ggsave().
...	Extra arguments forwarded to ggseqlogo::ggseqlogo() (e.g., 'stack_width', 'font', or 'col_scheme').

Value

A 'ggplot' object (invisibly NULL if saved).

Examples

```
## --- Create a dataset for demonstration ---
set.seed(42)

# Helper to generate random DNA sequences with base bias
generate_biased_dna <- function(n_seq, len, prob) {
  bases <- c("A", "C", "G", "T")
  replicate(n_seq, paste(sample(bases, len, replace = TRUE, prob = prob), collapse = ""))
}

# 50 'MUT' fragments biased toward 'C' at the ends
df_mut <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
```

```
  Fragment_Status_Simple = "MUT"
)

# 50 'WT' fragments biased toward 'G' at the ends
df_wt <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Status_Simple = "WT"
)

# Combine into a single data frame
example_df <- rbind(df_mut, df_wt)

## --- Function calls ---

# 1) Default plot: 3-mer from both 5' and 3' ends, separated by a dash,
#    faceted by group ('MUT' and 'WT').
p1 <- plot_ggseqlogo_meme(example_df)
p1

# 2) Single-end motif: 5-mer from the 5' end only.
p2 <- plot_ggseqlogo_meme(
  df_fragments = example_df,
  motif_type   = "Start",
  motif_size   = 5,
  title        = "5' motif (k=5)"
)
p2

# 3) Custom colors using an RColorBrewer palette (first 4 colors mapped to A/C/G/T).
#    Note: the '-' separator in 'Both' is not colored.
p3 <- plot_ggseqlogo_meme(
  df_fragments = example_df,
  motif_type   = "Both",
  motif_size   = 3,
  colors_z     = "Dark2",
  title        = "Both ends (palette = Dark2)"
)
p3

# 4) Fully custom nucleotide colors (named vector).
custom_cols <- c(A = "#1B9E77", C = "#D95F02", G = "#7570B3", T = "#E7298A")
p4 <- plot_ggseqlogo_meme(
  df_fragments = example_df,
  motif_type   = "Start",
  motif_size   = 3,
  colors_z     = custom_cols,
  title        = "Custom nucleotide colors"
)
p4

# 5) Ungrouped: analyze all fragments together (single facet).
p5 <- plot_ggseqlogo_meme(example_df, col_z = NULL, title = "All fragments pooled")
p5

# 6) Passing extra ggseqlogo options via '...' (e.g., stack width and font)
p6 <- plot_ggseqlogo_meme(
```

```
  df_fragments = example_df,
  motif_type   = "End",
  motif_size   = 4,
  stack_width  = 0.9,
  font         = "helvetica_regular",
  title        = "3' motif (k=4, custom stack width)"
)
p6

# 7) Save to file (commented out for CRAN)
# out_file <- file.path(tempdir(), 'motif_logo.png')
# plot_ggseqlogo_meme(
#   df_fragments  = example_df,
#   motif_type    = 'Both',
#   motif_size    = 3,
#   title         = 'Saved motif logo',
#   output_path   = out_file,
#   ggsave_params = list(width = 7, height = 5, units = 'in', dpi = 300, bg = 'white')
# )
```

`plot_motif_barplot` *Plot 3-base motif proportions with various representations*

Description

Creates a bar plot to visualize the proportion of 3-base motifs at fragment ends. Supports grouped analysis and three different visual representations: hierarchical faceting by base, log2 fold change, or side-by-side motifs.

Usage

```
plot_motif_barplot(
  df_fragments,
  end_motif_5p = "Fragment_Bases_5p",
  end_motif_3p = "Fragment_Bases_3p",
  motif_type = "Both",
  motif_start = NULL,
  col_z = "Fragment_Status_Simple",
  vals_z = NULL,
  representation = "split_by_base",
  ...,
  colors_z = NULL,
  title = NULL,
  output_path = NA_character_,
 ggsave_params = list(width = 10, height = 6, units = "in", dpi = 300, bg = "white")
)
```

Arguments

`df_fragments`	The input dataframe containing fragment sequence data.
`end_motif_5p`	Character string. Column name for 5' end sequences.

end_motif_3p	Character string. Column name for 3' end sequences.
motif_type	Character string. Which ends to analyze: 'Start', 'End', or 'Both'.
motif_start	Optional character vector ('A','C','G','T') to filter motifs by their starting base.
col_z	Character string. Column name for grouping. If NULL, no grouping is applied.
vals_z	A character vector of group names from 'col_z' to include. If NULL, all unique groups in 'col_z' are used.
representation	Character string. The type of plot to generate. • 'split_by_base' (default): A proportion plot with hierarchical axes, splitting motifs by each base position into facets. • 'differential': A log2 fold change plot comparing two groups. • 'split_by_motif': A proportion plot with motifs on the x-axis, with bars for different groups placed side-by-side.
...	Additional arguments passed on to 'ggplot2::geom_bar()'.
colors_z	Colors for the representation: • For 'split_by_base': 4 colors for A/C/G/T, or a single RColorBrewer palette name. • For 'differential': 2 colors for 'Positive'/'Negative' (named vector or palette). • For 'split_by_motif': colors per group (palette, unnamed vector, or a vector named by group names).
title	Character or NA. Plot title; if NULL/NA/'NA'/empty, a default title is used.
output_path	Character or NA. If provided and non-empty, the plot is saved to this file.
ggsave_params	A named list of arguments passed to 'ggplot2::ggsave()'.

Value

A ggplot object.

Examples

```
## --- Create a dataset for demonstration ---
set.seed(42)

# Helper function to generate random DNA sequences with a bias
generate_biased_dna <- function(n_seq, len, prob) {
  bases <- c("A", "C", "G", "T")
  replicate(n_seq, paste(sample(bases, len, replace = TRUE, prob = prob), collapse = ""))
}

# Create 50 'MUT' fragments with a high proportion of motifs starting with 'C'
df_mut <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.2, 0.5, 0.15, 0.15)),
  Fragment_Status_Simple = "MUT"
)

# Create 50 'WT' fragments with a high proportion of motifs starting with 'G'
df_wt <- data.frame(
  Fragment_Bases_5p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Bases_3p = generate_biased_dna(50, 10, prob = c(0.15, 0.15, 0.5, 0.2)),
  Fragment_Status_Simple = "WT"
```

```
)

# Combine into a single dataframe
example_df <- rbind(df_mut, df_wt)

## --- Function Calls for Each Representation ---

# 1. Hierarchical Plot (representation = 'split_by_base')
# This is the default. It creates nested facets for each base position.
p1 <- plot_motif_barplot(
  df_fragments   = example_df,
  representation = "split_by_base"
)
p1

# You can also filter this plot to show only motifs starting with certain bases.
p1_filtered <- plot_motif_barplot(
  df_fragments   = example_df,
  representation = "split_by_base",
  motif_start    = c("C", "G"),
  title          = "Motifs starting with C/G"
)
p1_filtered

# Optional: customize colors for the 2nd base (A/C/G/T) in split_by_base
p1_colors <- plot_motif_barplot(
  df_fragments   = example_df,
  representation = "split_by_base",
  colors_z       = c(A = "#FD96A9", C = "#E88B00", G = "#0D539E", T = "#6CAE75")
)
p1_colors

# 2. Differential Plot (representation = 'differential')
# Shows log2 fold-change in motif proportions between two groups (needs exactly two groups).
p2 <- plot_motif_barplot(
  df_fragments   = example_df,
  representation = "differential",
  vals_z         = c("MUT", "WT"),
  colors_z       = c(Positive = "#66C2A5", Negative = "#E78AC3"),
  title          = "MUT vs WT (log2FC)"
)
p2

# 3. Side-by-side Motif Plot (representation = 'split_by_motif')
# Motifs on the x-axis; bars for each group shown side-by-side.
p3 <- plot_motif_barplot(
  df_fragments   = example_df,
  representation = "split_by_motif",
  colors_z       = "Set2" # or a vector named by group names
)
p3

# 4. Save the default hierarchical plot (commented for CRAN)
# out_file1 <- file.path(tempdir(), 'motif_split_by_base.png')
# plot_motif_barplot(
#   df_fragments   = example_df,
#   representation = 'split_by_base',
```

```
#   title          = 'Motif proportions (hierarchical)',
#   output_path    = out_file1,
#   ggsave_params  = list(width = 8, height = 6, units = 'in', dpi = 300, bg = 'white')
# )

# 5. Save the differential plot with custom dimensions (commented for CRAN)
# out_file2 <- file.path(tempdir(), 'motif_differential.png')
# plot_motif_barplot(
#   df_fragments   = example_df,
#   representation = 'differential',
#   vals_z         = c('MUT', 'WT'),
#   title          = 'Differential motif usage',
#   output_path    = out_file2,
#   ggsave_params  = list(width = 12, height = 8, units = 'in', dpi = 300, bg = 'white')
# )
```

`plot_size_distribution` *Plot Fragment Size Distribution*

Description

Generates a plot visualizing the distribution of fragment lengths. Supports grouping by a categorical variable and can represent the distribution as a histogram, a density plot, or an overlay of both. The legend displays the sample size (N) per group. Groups with fewer than 2 observations are automatically removed when `show_density = TRUE`.

Usage

```
plot_size_distribution(
  df_fragments,
  size_col = "Fragment_Size",
  col_z = "Fragment_Status_Simple",
  vals_z = NULL,
  histo_args = list(),
  density_args = list(),
  colors_z = NULL,
  show_histogram = FALSE,
  show_density = TRUE,
  x_limits = c(0, 600),
  histogram_binwidth = 5,
  show_nuc_peaks = TRUE,
  title = NULL,
  output_path = NA_character_,
 ggsave_params = list(width = 10, height = 7, units = "in", dpi = 300, bg = "white")
)
```

Arguments

`df_fragments`	The input dataframe containing the fragment data.
`size_col`	A character string specifying the name of the numeric column that contains the fragment lengths.

col_z	A character string specifying the name of the column to use for grouping the data. If NULL, no grouping is applied.
vals_z	An optional character vector to filter and display only specific groups from col_z. If NULL, all groups are used.
histo_args	A named list of additional arguments passed to ggplot2::geom_histogram().
density_args	A named list of additional arguments passed to ggplot2::geom_density().
colors_z	A character vector of colors for the groups (named or unnamed), or a single string naming an RColorBrewer palette.
show_histogram	Logical. If TRUE, a histogram layer is added.
show_density	Logical. If TRUE, a density plot layer is added.
x_limits	Optional numeric vector of length 2 to set the x-axis limits (e.g., c(0, 700)).
histogram_binwidth	Numeric value specifying the bin width for the histogram.
show_nuc_peaks	Logical. If TRUE, adds dashed vertical lines for nucleosome peaks (mono/di/tri).
title	Character or NA. Plot title; if NULL/NA/'NA'/empty, a default title is used.
output_path	Character or NA. If provided and non-empty, the plot is saved to this file.
ggsave_params	A named list of arguments passed to ggplot2::ggsave().

Value

A ggplot object representing the size distribution plot (invisibly NULL if saved).

Examples

```
## --- Create a dataset for demonstration ---
set.seed(42)

# Generate fragment sizes for two groups with different distributions
# 'MUT' group: N=100, shorter fragments
mut_sizes <- rnorm(100, mean = 150, sd = 20)

# 'WT' group: N=150, centered around the mononucleosome peak
wt_sizes <- rnorm(150, mean = 170, sd = 25)

# Add some larger, dinucleosomal fragments to both groups
di_nuc_sizes <- rnorm(30, mean = 330, sd = 30)

# Combine into a single dataframe
example_df_size <- data.frame(
  Fragment_Size = c(mut_sizes, wt_sizes, di_nuc_sizes),
  Fragment_Status_Simple = c(
    rep("MUT", 100),
    rep("WT", 150),
    sample(c("MUT", "WT"), 30, replace = TRUE)
  )
)
# Ensure all fragment sizes are positive
example_df_size <- example_df_size[example_df_size$Fragment_Size > 0, ]

## --- Plotting Examples ---

# 1) Default plot: grouped density with nucleosome peaks.
```

```
p1 <- plot_size_distribution(example_df_size)
p1

# 2) Histogram only: add transparency so overlapping bars are visible.
p2 <- plot_size_distribution(
  df_fragments   = example_df_size,
  show_histogram = TRUE,
  show_density   = FALSE,
  histo_args     = list(alpha = 0.6)
)
p2

# 3) Combined: overlay density curves and histograms.
p3 <- plot_size_distribution(
  df_fragments   = example_df_size,
  show_histogram = TRUE,
  show_density   = TRUE,
  histo_args     = list(alpha = 0.4)
)
p3

# 4) Ungrouped + zoomed x-axis + no nucleosome peaks.
p4 <- plot_size_distribution(
  df_fragments   = example_df_size,
  col_z          = NULL,
  x_limits       = c(50, 400),
  show_nuc_peaks = FALSE,
  title          = "All fragments (zoomed)"
)
p4

# 5) Custom colors using an RColorBrewer palette.
p5 <- plot_size_distribution(
  df_fragments = example_df_size,
  colors_z     = "Set2",
  title        = "Fragment size (Set2 palette)"
)
p5

# 6) Save to file (commented for CRAN):
# out_png <- file.path(tempdir(), 'size_distribution.png')
# plot_size_distribution(
#   df_fragments  = example_df_size,
#   output_path   = out_png,
#   ggsave_params = list(width = 8, height = 6, units = 'in', dpi = 300, bg = 'white'),
#   title         = 'Size distribution (saved)'
# )
```

---

read_bam *Extract and filter paired-end reads for a target locus from a BAM file*

Description

This function performs a targeted extraction of sequencing reads from a BAM file. It first fetches reads within a specified genomic window around a variant of interest, then expands the selection to

include the mates of any reads covering the variant, ensuring complete fragments are retrieved for analysis.

Usage

```
read_bam(
  bam,
  chr,
  pos,
  neg_offset_mate_search,
  pos_offset_mate_search,
  flag_bam_list
)
```

Arguments

bam	Path to a BAM file.
chr	Character. Chromosome of interest.
pos	Integer. Genomic position of interest.
neg_offset_mate_search	Integer. Use in read_bam. Represents the number of nucleotides to extend upstream (negative direction) from the position of interest when querying the BAM file with Rsamtools. his extension ensures that paired reads are retrieved, even if only one mate overlaps the queried position.
pos_offset_mate_search	Integer. Use in read_bam.
flag_bam_list	A named list of logicals for filtering reads based on their SAM flag NA = Filter is ignored, TRUE = The read MUST have this flag, FALSE = The read MUST NOT have this flag.

Details

The read retrieval and filtering process follows a multi-step pipeline:

1. A genomic query region is defined around the target 'pos' using the 'neg_offset_mate_search' and 'pos_offset_mate_search' parameters.
2. 'Rsamtools::scanBam' is used to fetch all reads within this region that pass the filters specified by 'flag_bam_list'.
3. From this initial set, the function identifies the subset of reads that *directly* cover the specific 'pos'.
4. The names ('QNAME') of the fragments corresponding to these covering reads are collected.
5. The function then selects **all** reads from the initially fetched data that share these fragment names, thereby retrieving the mates even if they did not directly cover the variant position.
6. The function returns all reads belonging to the fragments of interest.

Value

A data.frame of reads belonging to fragments covering the position of interest, or NULL if no reads cover the position.

read_mut *Read variant information from multiple sources*

Description

This function acts as a dispatcher to read variant information from a file (VCF or TSV) or a character string. It automatically detects the input format and uses the appropriate parser. All multi-allelic sites are split into separate, bi-allelic rows.

Usage

```
read_mut(mut)
```

Arguments

mut	Path to a .vcf or .tsv file or string representation chr:pos:ref:alt of a mutation.

Value

A 'data.frame' where each row represents a single bi-allelic variant, with the columns 'CHROM', 'POS', 'REF', and 'ALT'.

remove_bad_mut *Remove bad mutations*

Description

This function verifies the validity of the mutation input data by checking the chromosome, position, reference, and alternative alleles. It only returns rows that pass all checks.

Usage

```
remove_bad_mut(df_mut)
```

Arguments

df_mut	A dataframe with mutation information.

Value

A filtered dataframe containing only valid mutations.

`run_fRagmentomics` *Analyze fragments*

Description

This is the main function of the package. It provides an end-to-end pipeline for analyzing the allelic state of individual DNA fragments covering specific genomic variants. It takes a list of mutations and an aligned sequencing file (BAM) as input, processes each fragment in parallel, and returns a detailed data frame of results.

Usage

```
run_fRagmentomics(
  mut,
  bam,
  fasta,
  sample_id = NA_character_,
  neg_offset_mate_search = -600,
  pos_offset_mate_search = 600,
  one_based = TRUE,
 flag_bam_list = list(isPaired = TRUE, isProperPair = NA, isUnmappedQuery = FALSE,
  hasUnmappedMate = FALSE, isMinusStrand = NA, isMateMinusStrand = NA, isFirstMateRead
  = NA, isSecondMateRead = NA, isSecondaryAlignment = FALSE, isSupplementaryAlignment =
    FALSE, isNotPassingQualityControls = NA, isDuplicate = NA),
  report_bam_info = FALSE,
  report_softclip = FALSE,
  report_5p_3p_bases_fragment = 5,
  remove_softclip = FALSE,
  retain_fail_qc = FALSE,
  apply_bcftools_norm = FALSE,
  tmp_folder = tempdir(),
  output_path = NA_character_,
  verbose = FALSE,
  n_cores = 1
)
```

Arguments

`mut`	Path to a .vcf or .tsv file or string representation chr:pos:ref:alt of a mutation.
`bam`	Path to a BAM file.
`fasta`	Path to the FASTA file for the reference sequence used for generating the BAM file.
`sample_id`	Sample identifier.
`neg_offset_mate_search`	Integer. Use in read_bam. Represents the number of nucleotides to extend upstream (negative direction) from the position of interest when querying the BAM file with Rsamtools. his extension ensures that paired reads are retrieved, even if only one mate overlaps the queried position.
`pos_offset_mate_search`	Integer. Use in read_bam.

`one_based` Boolean. TRUE if fasta is in one based. False if in 0 based.

`flag_bam_list` A named list of logicals for filtering reads based on their SAM flag NA = Filter is ignored, TRUE = The read MUST have this flag, FALSE = The read MUST NOT have this flag.

`report_bam_info`
Boolean. Whether to include the bam information.

`report_softclip`
Boolean. Whether to include the number of soft-clipped bases at the fragment extremities in the output.

`report_5p_3p_bases_fragment`
Integer. Whether to include N fragment extremity bases in the output.

`remove_softclip`
Boolean. If set to TRUE, trim soft-clipped bases from the 5' end of Read 5p and from the 3' end of Read 3p.

`retain_fail_qc` Boolean. If set to TRUE, retain fragments that failed the various quality checks in the output.

`apply_bcftools_norm`
Boolean. If set to TRUE, apply bcftools norm on each input variant to normalize it. Require that bcftools command is installed and available in the PATH.

`tmp_folder` Character vector for the temporary folder path.

`output_path` Character vector for the fragmentomics table output path.

`verbose` Boolean. If set to TRUE, print all the warnings and the prints.

`n_cores` Number of cores for parallel computation.

Details

The function executes a multi-step workflow for each variant provided in the 'mut' input:

1. **Input Validation**: All parameters are rigorously checked for correctness (e.g., file existence, data types). Required file indices ('.bai', '.fai') are created automatically if missing.
2. **Variant Normalization**: The input variants are parsed and normalized into a canonical, left-aligned representation using a combination of VCF-style indel padding and the external 'bcftools norm' command.
3. **BAM Read Extraction**: For each normalized variant, the function efficiently queries the BAM file to retrieve all read pairs that cover the genomic locus.
4. **Parallel Fragment Processing**: The core analysis is performed in parallel using the 'future' framework. Each unique DNA fragment is processed by the 'extract_fragment_features' worker function to determine its size, quality metrics, and mutation status (e.g., 'MUT', 'WT', 'AMB', 'N/I').
5. **VAF Calculation**: After all fragments for a variant are processed, the Variant Allele Frequency (VAF) is calculated.
6. **Output Generation**: Results from all variants are aggregated into a single data frame. If a value for `output_path` is provided, this data frame is also written to a tab-separated file.

Value

A `DataFrame` (S4Vectors) containing extracted fragment-level information.

Examples

```
# --- 1. Locate Example Files ---
# The package includes small example files to demonstrate its functionality.
# We locate them using system.file().
mut_file <- system.file(
  "extdata/mutation", "cfdna-egfr-del_chr7_55241864_55243064_10k.mutations.tsv",
  package = "fRagmentomics"
)
bam_file <- system.file(
  "extdata/bam", "cfdna-egfr-del_chr7_55241864_55243064_10k.bam",
  package = "fRagmentomics"
)
fasta_file <- system.file(
  "extdata/fasta", "hg19_chr7_55231864_55253064.fa",
  package = "fRagmentomics"
)

# --- 2. Run the Analysis ---
# This single call runs the full analysis pipeline on the example data.
# The output file is written to a temporary location to avoid cluttering
# the working directory. We use n_cores = 1L for examples.
results <- run_fRagmentomics(
  mut = mut_file,
  bam = bam_file,
  fasta = fasta_file,
  sample_id = "cfdna-egfr-del",
  n_cores = 1L
)

# --- 3. View the Results ---
# Print the first few rows of the output data frame to see the results.
head(results)
```

`search_for_indel_in_cigar` *Search for a specific indel within a read's CIGAR string*

Description

This internal function scans the CIGAR string of a single aligned read to determine if it contains a specific insertion or deletion at a precise genomic location.

Usage

```
search_for_indel_in_cigar(pos, ref, alt, read_stats, type)
```

Arguments

`pos`	Numeric value representing the Genomic position of interest.
`ref`	Character vector representing reference base(s).
`alt`	Character vector representing alternative base(s).
`read_stats`	A list of read-level statistics.
`type`	choose between 'INS' or 'DEL'

Value

a list with two booleans. The first boolean indicate if the INDEL searched was found. The second boolean indicate if another INDEL (different size and/or different sequence) was found.

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