Package 'gp3sequences'

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Title Transparent Analysis of Ordered Categorical Sequences

Version 0.3.2

Description Provides transparent, reproducible, and auditable tools for validating, preparing, encoding, summarising, comparing, modelling, and diagnosing ordered categorical sequence data. Supports explicit preprocessing policies, contiguous motifs and bounded subsequences, consensus and group comparisons, edit and transition distances, clustering and stability diagnostics, transition networks, higher-order models, categorical, mixture, multichannel, and covariate hidden Markov models, longitudinal panel workflows, time-varying models, design-aware inference, analysis contracts and provenance audits, and guarded adapters to specialist sequence-analysis packages.

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`as_arules_sequences` *Convert sequence data to cSPADE transaction input*

Description

Convert sequence data to cSPADE transaction input

Usage

```
as_arules_sequences(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state"
)
```

Arguments

`data`	Long-format sequence data.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.

Value

An `arules` transactions object whose transaction information contains positive integer `sequenceID` and `eventID` fields required by `arulesSequences::cspade()`.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
if (requireNamespace("arules", quietly = TRUE) &&
    requireNamespace("arulesSequences", quietly = TRUE)) {
  as_arules_sequences(sequences)
}
```

---

as_grpstring_data *Create GrpString-compatible event and string inputs*

Description

Create GrpString-compatible event and string inputs

Usage

```
as_grpstring_data(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
```

```
  state_col = "state",
  alphabet = NULL
)
```

Arguments

`data`	Long-format sequence data.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`alphabet`	Optional single-character symbols. When omitted, printable ASCII characters are assigned deterministically.

Value

A list of class `gp3_grpstring_input` containing a wide event data frame, event-name vector, character vector, conversion key, and string vector.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
as_grpstring_data(sequences)
```

---

as_igraph_transition_network

Convert a transition network to an igraph object

Description

Convert a transition network to an igraph object

Usage

```
as_igraph_transition_network(network, directed = TRUE)
```

Arguments

`network`	A first-order transition network.
`directed`	Whether the resulting graph is directed.

Value

An igraph graph with edge attributes copied from the network.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
network <- create_transition_network(sequences)
if (requireNamespace("igraph", quietly = TRUE)) {
  as_igraph_transition_network(network)
}
```

---

as_seqhmm_sequences *Convert sequence data to seqHMM observations*

Description

Convert sequence data to seqHMM observations

Usage

```
as_seqhmm_sequences(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  ...
)
```

Arguments

data	Long-format sequence data.
sequence_id_col, order_col, state_col	Sequence columns.
...	Additional arguments passed to as_traminer_sequences().

Value

A TraMineR stslist suitable for seqHMM::build_hmm().

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
if (requireNamespace("TraMineR", quietly = TRUE) &&
    requireNamespace("seqHMM", quietly = TRUE)) {
  as_seqhmm_sequences(sequences)
}
```

---

as_traminer_sequences *Convert sequence data to a TraMineR state-sequence object*

Description

Convert sequence data to a TraMineR state-sequence object

Usage

```
as_traminer_sequences(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  missing = NA,
  right = "DEL",
  ...
)
```

Arguments

`data`	Long-format sequence data.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`missing`	Missing-state code passed to `TraMineR::seqdef()`.
`right`	Right-missing policy passed to `TraMineR::seqdef()`.
`...`	Additional arguments passed to `TraMineR::seqdef()`.

Value

A TraMineR `stslist` object with original sequence identifiers as row names.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
if (requireNamespace("TraMineR", quietly = TRUE)) {
  as_traminer_sequences(sequences)
}
```

`audit_sequence_analysis` *Audit a gp3sequences analysis object*

Description

Inspects supported gp3sequences objects for structural contract validity, recoverable provenance, identifiers, state levels, method settings, and randomness metadata. The audit does not reinterpret sequence structure as a psychological, diagnostic, cognitive, emotional, or causal construct.

Usage

```
audit_sequence_analysis(x, strict = FALSE, tolerance = 1e-08)
```

Arguments

`x`	A gp3sequences analysis result or supported structural object.
`strict`	Logical; if `TRUE`, fail when the audit status is `"fail"`.
`tolerance`	Numerical tolerance used for matrix/probability checks.

Value

An object of class `gp3_sequence_analysis_audit` containing `summary`, `issues`, `provenance`, `contract`, and `status`.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3"), each = 3L),
  sequence_order = rep(1:3, times = 3L),
  state = c(
    "A", "B", "C",
    "A", "B", "B",
    "C", "B", "A"
```

```
  )
)
distance <- compute_sequence_distance(
  sequences,
  method = "levenshtein"
)
audit_sequence_analysis(distance)
```

`audit_sequence_data` *Audit Long-Format Sequence Data*

Description

Examines a long-format data frame against the neutral `gp3sequences` sequence-data contract without modifying the input.

Usage

```
audit_sequence_data(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL
)
```

Arguments

`data`	A data frame containing ordered state observations.
`sequence_id_col`	Name of the sequence identifier column.
`order_col`	Name of the numeric sequence-order column.
`state_col`	Name of the categorical state column.
`duration_col`	Optional name of a numeric duration column.
`metadata_cols`	Optional character vector naming columns that should remain constant within each sequence.
`expected_states`	Optional vector of known or permitted state values.

Details

The audit checks column mappings, empty inputs, missing identifiers, missing or non-numeric order values, duplicated positions, integer order gaps, unordered rows, missing states, consecutive repeated states, single-row sequences, invalid durations, inconsistent metadata, unexpected states, and unused factor levels.

The function reports structural properties only. It does not infer psychological, cognitive, emotional, or diagnostic states.

Value

A data frame with one row per detected issue and the stable columns `sequence_id`, `row`, `column`, `issue_code`, `severity`, `value`, `message`, and `action`. Severity values are `error`, `review`, and `info`.

Examples

```
sequences <- data.frame(
  id = rep(c("s1", "s2"), each = 3L),
  position = rep(1:3, times = 2L),
  state = c("home", "search", "product", "home", "category", "product")
)

audit_sequence_data(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)
```

`bootstrap_sequence_clusters` *Bootstrap sequence-cluster stability*

Description

Uses repeated subsampling without replacement and records pairwise co-clustering agreement relative to the full-data solution.

Usage

```
bootstrap_sequence_clusters(
  distance,
  k,
  method = c("hierarchical", "pam", "clara"),
  n_boot = 100L,
  sample_fraction = 0.8,
```

```
  seed = 1L,
  linkage = "average",
  ...
)
```

Arguments

distance	Sequence distance object.
k	Number of clusters.
method	Clustering method.
n_boot	Number of subsamples.
sample_fraction	Fraction of sequences sampled in each iteration.
seed	Reproducibility seed.
linkage	Hierarchical linkage.
...	Additional clustering arguments.

Value

An object of class gp3_sequence_cluster_bootstrap.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
distance <- compute_sequence_distance(sequences)
bootstrap_sequence_clusters(distance, k = 2L, n_boot = 5L, seed = 1L)
```

---

bootstrap_sequence_group_difference

Bootstrap a sequence group difference

Description

Resamples declared independent units within groups and returns a percentile interval for the mean difference. This interval does not by itself license causal interpretation.

Usage

```
bootstrap_sequence_group_difference(
  inference,
  n_boot = 999L,
  level = 0.95,
  seed = 1L
)
```

Arguments

inference	A result from test_sequence_group_difference().
n_boot	Number of bootstrap samples.
level	Confidence level.
seed	Reproducibility seed.

Value

The inference object with a bootstrap component.

Examples

```
# See `test_sequence_group_difference()`.
```

---

bootstrap_transition_network

Bootstrap transition-network edge weights

Description

Bootstrap transition-network edge weights

Usage

```
bootstrap_transition_network(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  n_boot = 100L,
  level = 0.95,
  seed = 1L,
  include_self = TRUE
)
```

Arguments

`data`	Long-format sequence data.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`n_boot`	Number of bootstrap samples of whole sequences.
`level`	Confidence level for percentile intervals.
`seed`	Reproducibility seed.
`include_self`	Include self-transitions.

Value

A data frame containing observed edge weights, bootstrap means, standard deviations, and percentile intervals.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
bootstrap_transition_network(sequences, n_boot = 5L, seed = 1L)
```

`cluster_sequences` *Cluster sequences from a distance object*

Description

Cluster sequences from a distance object

Usage

```
cluster_sequences(
  distance,
  k,
  method = c("hierarchical", "pam", "clara"),
  linkage = "average",
  seed = 1L,
  ...
)
```

Arguments

distance	A dist object or square matrix.
k	Number of clusters.
method	"hierarchical", "pam", or "clara".
linkage	Hierarchical linkage method.
seed	Reproducibility seed for optional stochastic methods.
...	Additional arguments passed to the selected clustering function.

Value

A list of class gp3_sequence_clustering containing assignments, model object, medoid identifiers where available, and settings.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
distance <- compute_sequence_distance(sequences)
cluster_sequences(distance, k = 2L)
```

---

compare_sequence_analysis_results

Compare two gp3sequences analysis results

Description

Compares structural contracts and recoverable provenance from two analysis objects. This helper is intended for regression checks, sensitivity analyses, and reproducibility audits; it does not select a statistically or substantively "best" analysis.

Usage

```
compare_sequence_analysis_results(
  x,
  y,
  tolerance = 1e-08,
  compare_values = FALSE
)
```

Arguments

x, y	Two analysis objects.
tolerance	Numerical comparison tolerance.
compare_values	Logical; when TRUE, also run all.equal() on the complete objects after structural comparison.

Value

An object of class gp3_sequence_analysis_comparison containing per-field comparisons, both audits, optional whole-object comparison, and an overall equality flag.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3"), each = 3L),
  sequence_order = rep(1:3, times = 3L),
  state = c(
    "A", "B", "C",
    "A", "B", "B",
    "C", "B", "A"
  )
)
d1 <- compute_sequence_distance(
  sequences,
  method = "levenshtein"
)
d2 <- compute_sequence_distance(
  sequences,
  method = "levenshtein"
)
compare_sequence_analysis_results(d1, d2)
```

---

compare_sequence_groups

Compare sequence groups descriptively

Description

Produces descriptive state, transition and sequence-length comparisons. No hypothesis tests or causal interpretations are produced.

Usage

```
compare_sequence_groups(
  data,
  group_col,
  sequence_id_col = "sequence_id",
```

```
  order_col = "sequence_order",
  state_col = "state",
  reference = NULL,
  metrics = c("state", "transition", "length"),
  include_self = TRUE,
  transition_separator = " -> ",
  zero_policy = c("missing", "infinite")
)
```

Arguments

`data`	Long-format sequence data.
`group_col`	Grouping column that is constant within sequence.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`reference`	Optional reference group. When supplied, each other group is reported as `group_1` and the reference as `group_2`; differences and ratios are therefore other-minus-reference and other/reference. When omitted, all pairwise group contrasts are returned.
`metrics`	Any of `"state"`, `"transition"`, and `"length"`.
`include_self`	Include self-transitions.
`transition_separator`	Separator used in reported transition labels. It must not occur inside an observed state label.
`zero_policy`	Ratio policy when the reference value is zero.

Value

A list of class `gp3_sequence_group_comparison` containing group summaries and pairwise descriptive contrasts.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
compare_sequence_groups(sequences, group_col = "group")
```

compare_sequence_hmms *Compare fitted sequence HMMs descriptively*

Description

Compare fitted sequence HMMs descriptively

Usage

```
compare_sequence_hmms(...)
```

Arguments

...	Fitted HMM or mixture-HMM objects.

Value

A data frame containing log likelihood, AIC, BIC, parameter count, convergence status, and delta criteria. Criteria are descriptive and do not automatically select a substantive model.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
model_1 <- fit_sequence_hmm(sequences, 1L, max_iter = 5L)
model_2 <- fit_sequence_hmm(sequences, 2L, max_iter = 5L)
compare_sequence_hmms(one = model_1, two = model_2)
```

compare_sequence_panel_changes *Compare within-panel sequence changes*

Description

Computes distance and simple structural changes between consecutive panel occasions. The output is descriptive and does not establish a causal or psychological change.

Usage

```
compare_sequence_panel_changes(
  panel,
  method = c("levenshtein", "lcs", "optimal_matching", "transition"),
  normalise = c("none", "max_length", "path_length"),
  indel_cost = 1,
  substitution_cost = 1,
  substitution_matrix = NULL,
  transition_smoothing = 0
)
```

Arguments

panel	A sequence panel.
method	Distance method supported by compute_sequence_distance().
normalise	Distance normalisation.
indel_cost, substitution_cost	Costs for optimal matching.
substitution_matrix	Optional named substitution matrix.
transition_smoothing	Smoothing for transition-profile distance.

Value

A data frame of class gp3_sequence_panel_changes.

Examples

```
panel_data <- data.frame(
  participant_id = rep(c("p1", "p2"), each = 8L),
  occasion = rep(rep(c(1, 2), each = 4L), times = 2L),
  sequence_id = rep(c("a", "b", "c", "d"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "C", "C", "D",
            "D", "C", "B", "A", "D", "B", "B", "A")
)
compare_sequence_panel_changes(
  prepare_sequence_panel(panel_data, "participant_id", "occasion"),
  method = "lcs"
)
```

compare_sequence_subsequences *Compare subsequence prevalence between groups*

Description

Performs transparent contingency-table tests on sequence-level presence. Multiple testing is adjusted explicitly. Results are associational unless a randomized design independently justifies causal interpretation.

Usage

```
compare_sequence_subsequences(
  occurrences,
  group_col,
  test = c("auto", "chisq", "fisher"),
  p_adjust = "BH",
  min_sequence_count = 1L
)
```

Arguments

occurrences	A non-contiguous subsequence occurrence table.
group_col	Sequence-constant group column retained through metadata_cols during extraction.
test	"auto", "chisq", or "fisher".
p_adjust	Multiple-testing adjustment method.
min_sequence_count	Minimum total sequence count per subsequence.

Value

A data frame of prevalence contrasts and adjusted p-values.

Examples

```
data <- data.frame(
  sequence_id = rep(paste0("s", 1:4), each = 4L),
  sequence_order = rep(1:4, 4L),
  state = c("A", "B", "C", "D", "A", "B", "D", "D",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L)
)
occurrences <- extract_sequence_subsequences(data, metadata_cols = "group")
compare_sequence_subsequences(occurrences, "group")
```

compute_sequence_distance *Compute pairwise sequence distances*

Description

Provides transparent base-R implementations of Levenshtein edit distance, longest-common-subsequence distance, optimal matching, and a first-order transition-profile distance.

Usage

```
compute_sequence_distance(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  method = c("levenshtein", "lcs", "optimal_matching", "transition"),
  indel_cost = 1,
  substitution_cost = 1,
  substitution_matrix = NULL,
  transition_smoothing = 0,
  normalise = c("none", "max_length", "path_length")
)
```

Arguments

data	Long-format sequence data or a prepared gp3sequences result.
sequence_id_col, order_col, state_col	Sequence columns.
method	Distance method.
indel_cost	Non-negative insertion/deletion cost used by method = "optimal_matching".
substitution_cost	Non-negative default substitution cost used by method = "optimal_matching".
substitution_matrix	Optional named square substitution-cost matrix for method = "optimal_matching".
transition_smoothing	Non-negative smoothing for transition profiles.
normalise	One of "none", "max_length", or "path_length".

Value

A dist object with method and preprocessing metadata attached.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
compute_sequence_distance(sequences, method = "lcs")
```

---

create_consensus_sequence

Create an aligned-position consensus sequence

Description

Computes a descriptive consensus state at each observed sequence position. The function does not treat the consensus as a behavioural norm and does not infer psychological or causal meaning.

Usage

```
create_consensus_sequence(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  group_cols = NULL,
  weight_col = NULL,
  missing_state_policy = c("exclude", "state", "error"),
  missing_state_label = "<MISSING>",
  tie_method = c("first", "last", "missing", "all"),
  state_levels = NULL,
  min_support = 1L
)
```

Arguments

`data`	A long-format data frame, a prepared gp3sequences result, or a data frame containing canonical columns.
`sequence_id_col`, `order_col`, `state_col`	Column names defining sequences.
`group_cols`	Optional columns defining independent consensus groups.
`weight_col`	Optional non-negative row-weight column.
`missing_state_policy`	One of `"exclude"`, `"state"`, or `"error"`.

missing_state_label	Label used when missing states are retained.
tie_method	Deterministic tie policy: "first", "last", "missing", or "all".
state_levels	Optional preferred state ordering used for ties.
min_support	Minimum number of contributing sequences at a position.

Value

A data frame of class gp3_consensus_sequence containing group columns, sequence position, consensus state, support counts and weights, agreement proportion, tie count, tied states, and total group sequences.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
create_consensus_sequence(sequences, group_cols = "group")
```

---

create_sequence_cluster_ensemble

Create a sequence-cluster ensemble

Description

Combines multiple named cluster assignments through a co-association matrix and applies hierarchical clustering to 1 - co-association.

Usage

```
create_sequence_cluster_ensemble(..., k, linkage = "average")
```

Arguments

...	Two or more gp3_sequence_clustering objects or named assignment vectors.
k	Number of consensus clusters.
linkage	Hierarchical linkage applied to the co-association distance.

Value

An object of class gp3_sequence_cluster_ensemble containing the consensus assignments, co-association matrix, model, and source solutions.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
d1 <- compute_sequence_distance(sequences, method = "lcs")
d2 <- compute_sequence_distance(sequences, method = "transition")
create_sequence_cluster_ensemble(cluster_sequences(d1, 2L),
                                 cluster_sequences(d2, 2L), k = 2L)
```

`create_transition_network` *Create a transition network from ordered sequences*

Description

Create a transition network from ordered sequences

Usage

```
create_transition_network(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  group_cols = NULL,
  order = 1L,
  include_self = TRUE,
  normalise = c("count", "from", "global"),
  smoothing = 0,
  context_separator = " > "
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`group_cols`	Optional grouping columns constant within sequence.
`order`	Markov order. 1 creates ordinary state-to-state edges; larger values create context-to-next-state edges.
`include_self`	Include first-order self-transitions.

`normalise` Edge weight scale: counts, conditional probabilities from each context, or global shares.

`smoothing` Non-negative additive smoothing applied to observed edges.

`context_separator` Separator used for higher-order contexts.

Value

A data frame of class `gp3_transition_network` containing context, next state, counts, weights, sequence prevalence, and group columns.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
create_transition_network(sequences, normalise = "from")
```

---

declare_sequence_comparison_design

Declare a sequence group-comparison design

Description

Records the unit of assignment and the design under which a sequence-group contrast will be evaluated. Causal interpretation is permitted only for an explicitly randomized design and still depends on the validity of the study implementation.

Usage

```
declare_sequence_comparison_design(
  group_col,
  unit_col,
  design = c("observational", "randomized", "paired_randomized"),
  pair_col = NULL,
  cluster_col = NULL
)
```

Arguments

group_col	Group or treatment column.
unit_col	Independent assignment or analysis-unit column.
design	"observational", "randomized", or "paired_randomized".
pair_col	Pair or block column required for paired randomization.
cluster_col	Optional higher-level assignment cluster.

Value

An object of class gp3_sequence_comparison_design.

Examples

```
declare_sequence_comparison_design("group", "participant_id",
                                   design = "randomized")
```

---

decode_covariate_sequence_states

Decode states from a covariate-dependent HMM

Description

Decode states from a covariate-dependent HMM

Usage

```
decode_covariate_sequence_states(
  model,
  data = NULL,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  method = c("viterbi", "posterior")
)
```

Arguments

model	A fitted covariate HMM.
data	Optional new data. Training data are used when omitted.
sequence_id_col, order_col, state_col	Core columns for new data.
method	"viterbi" or "posterior".

Value

A long decoded-state data frame.

Examples

```
# See `fit_covariate_sequence_hmm()`.
```

`decode_multichannel_sequence_states` *Decode latent states from a multichannel HMM*

Description

Decode latent states from a multichannel HMM

Usage

```
decode_multichannel_sequence_states(
  model,
  data = NULL,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  channel_cols = NULL,
  method = c("viterbi", "posterior")
)
```

Arguments

`model`	A fitted multichannel HMM.
`data`	Optional new long-format multichannel data.
`sequence_id_col`, `order_col`	Core sequence columns for new data.
`channel_cols`	Channel columns for new data; defaults to training names.
`method`	`"viterbi"` or `"posterior"`.

Value

A long data frame of decoded states and posterior probabilities.

Examples

```
# See `fit_multichannel_sequence_hmm()`.
```

`decode_sequence_states` *Decode hidden states from a fitted HMM*

Description

Decode hidden states from a fitted HMM

Usage

```
decode_sequence_states(
  model,
  data = NULL,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  method = c("viterbi", "posterior"),
  component = NULL
)
```

Arguments

`model`	A fitted single HMM or HMM mixture.
`data`	Optional new long-format data. Training sequences are used when omitted.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns for new data.
`method`	`"viterbi"` or `"posterior"`.
`component`	Mixture component to decode. When omitted for a mixture, each sequence uses its highest-responsibility component.

Value

A long data frame containing decoded latent states and posterior probabilities where available.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
model <- fit_sequence_hmm(sequences, 2L, max_iter = 5L)
decode_sequence_states(model)
```

`detect_transition_communities` *Detect descriptive transition communities*

Description

Detect descriptive transition communities

Usage

```
detect_transition_communities(
  network,
  method = c("label_propagation", "components"),
  max_iter = 100L,
  seed = 1L
)
```

Arguments

`network`	A first-order transition network.
`method`	`"label_propagation"` or `"components"`.
`max_iter`	Maximum label-propagation iterations.
`seed`	Reproducibility seed used only to rotate update order.

Value

A data frame with states and deterministic community labels.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
network <- create_transition_network(sequences)
detect_transition_communities(network)
```

encode_sequence_data *Encode Ordered Sequence States*

Description

Creates a deterministic dictionary and adds integer and labelled state codes to long-format sequence data.

Usage

```
encode_sequence_data(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL,
  state_levels = NULL,
  prefix = "S",
  width = NULL
)
```

Arguments

data	A data frame containing ordered state observations.
sequence_id_col	Name of the sequence identifier column.
order_col	Name of the numeric sequence-order column.
state_col	Name of the categorical state column.
duration_col	Optional name of a numeric duration column.
metadata_cols	Optional character vector naming columns that should remain constant within each sequence.
expected_states	Optional vector of known or permitted state values.
state_levels	Optional atomic vector defining the complete state ordering. When omitted, factor levels are respected; otherwise observed state labels are sorted alphabetically.
prefix	Character prefix used for labelled codes.
width	Optional positive integer width for the numeric part of each labelled code. The default is determined from the dictionary size.

Details

The function does not reinterpret states. State codes are transparent identifiers derived from an explicit or deterministic state ordering.

Value

A named list containing:

- `data`: deterministically sorted canonical data with `state_index` and `state_code`;
- `dictionary`: state labels, integer indices, labelled codes, and an observed-state indicator;
- `audit`, `status`, and `mapping` from input validation;
- `settings`: the resolved code prefix and width.

Examples

```
sequences <- data.frame(
  id = c("s1", "s1", "s2", "s2"),
  position = c(1, 2, 1, 2),
  state = c("home", "search", "home", "product")
)

encoded <- encode_sequence_data(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

encoded$dictionary
encoded$data
```

---

extract_representative_sequences

Extract representative sequences from clusters

Description

Extract representative sequences from clusters

Usage

```
extract_representative_sequences(
  clustering,
  distance = NULL,
  n_per_cluster = 1L
)
```

Arguments

`clustering`	A clustering result.
`distance`	Optional distance when absent from `clustering`.
`n_per_cluster`	Number of representatives per cluster.

Value

A data frame with cluster, rank, representative ID, and mean within-cluster distance.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
distance <- compute_sequence_distance(sequences)
fit <- cluster_sequences(distance, k = 2L)
extract_representative_sequences(fit)
```

---

extract_sequence_ngrams

Extract Contiguous Sequence N-Grams

Description

Enumerates contiguous state motifs from validated long-format sequence data.

Usage

```
extract_sequence_ngrams(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL,
  min_length = 2L,
  max_length = 3L,
  overlap = c("allow", "disallow"),
  separator = " > ",
  state_levels = NULL
)
```

Arguments

data	A data frame containing ordered state observations.
sequence_id_col	Name of the sequence identifier column.

order_col	Name of the numeric sequence-order column.
state_col	Name of the categorical state column.
duration_col	Optional name of a numeric duration column.
metadata_cols	Optional character vector naming columns that should remain constant within each sequence.
expected_states	Optional vector of known or permitted state values.
min_length	Positive whole number giving the shortest motif length.
max_length	Positive whole number giving the longest motif length.
overlap	Character value specifying whether overlapping occurrences of the same motif within the same sequence are "allow"ed or "disallow"ed.
separator	Character value used only to display state labels in the human-readable motif column.
state_levels	Optional atomic vector defining the complete state ordering. When omitted, factor levels are respected; otherwise observed labels are sorted deterministically.

Details

Motifs are contiguous windows only. No subsequence gaps, edit distances, statistical tests, or substantive interpretations are introduced. Consecutive repeated states are used exactly as supplied; any repeat collapsing should be performed explicitly with prepare_sequence_data() before extraction.

With overlap = "disallow", overlap is resolved independently within each sequence-motif pair by a deterministic left-to-right greedy rule. Different motifs and different motif lengths do not compete for positions.

The collision-resistant motif_id and motif_key columns are derived from deterministic state codes. The display separator may therefore also occur inside a state label without changing motif identity.

Value

A named list containing:

- occurrences: one row per retained contiguous motif occurrence;
- motifs: the distinct motif dictionary;
- sequences: sequence-level counts of candidate and retained occurrences;
- state_dictionary: the deterministic state dictionary;
- audit, status, and mapping from input validation;
- settings: the resolved motif extraction settings.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "A", "A", "B", "A", "C")
)

ngrams <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state",
  min_length = 2,
  max_length = 3,
  overlap = "allow"
)

ngrams$occurrences
ngrams$motifs
```

`extract_sequence_subsequences` *Extract bounded non-contiguous sequence subsequences*

Description

Enumerates ordered non-contiguous subsequences under explicit length, gap, span, and safety limits. The implementation is transparent and intended for modest sequence collections; specialist mining packages remain preferable for very large search spaces.

Usage

```
extract_sequence_subsequences(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  metadata_cols = NULL,
  min_length = 2L,
  max_length = 5L,
  max_gap = Inf,
  max_span = Inf,
  repeated_state_policy = c("preserve", "collapse"),
  separator = " > ",
  max_combinations_per_sequence = 100000L
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`metadata_cols`	Optional sequence-constant metadata retained as attributes.
`min_length`, `max_length`	Minimum and maximum subsequence lengths.
`max_gap`	Maximum number of skipped positions between adjacent selected states. Use `Inf` for no restriction.
`max_span`	Maximum difference between the first and last selected sequence positions. Use `Inf` for no restriction.
`repeated_state_policy`	Preserve or collapse consecutive repeated states before mining.
`separator`	Separator used in stable motif labels.
`max_combinations_per_sequence`	Safety limit for the number of index combinations considered for any one sequence.

Value

A data frame of class `gp3_sequence_subsequences`, with one row per qualifying occurrence.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2"), each = 5L),
  sequence_order = rep(1:5, times = 2L),
  state = c("A", "B", "C", "D", "E", "A", "C", "B", "D", "E")
)
extract_sequence_subsequences(sequences, min_length = 2L, max_length = 3L,
                              max_gap = 2L)
```

`filter_sequence_motifs` *Filter Sequence Motif Summaries*

Description

Applies transparent count, prevalence, length, and top-ranking filters to sequence motif summaries.

Usage

```
filter_sequence_motifs(
  x,
  min_occurrences = 1L,
  min_sequences = 1L,
  min_prevalence = 0,
  motif_lengths = NULL,
  top_n = NULL,
  rank_by = c("sequence_prevalence", "n_occurrences", "n_sequences"),
  ties = c("include", "first")
)
```

Arguments

x	A motif extraction, motif summary, or filtered-motif object.
min_occurrences	Non-negative whole number giving the minimum total occurrence count.
min_sequences	Non-negative whole number giving the minimum number of sequences containing the motif.
min_prevalence	Minimum sequence prevalence between 0 and 1.
motif_lengths	Optional vector of positive whole-number motif lengths to retain.
top_n	Optional positive whole number giving the requested number of highest-ranked motifs.
rank_by	Metric used for deterministic top-ranking: one of "sequence_prevalence", "n_occurrences", or "n_sequences".
ties	Character value controlling the top-n boundary. "include" retains every motif tied on rank_by with the final selected motif; "first" retains exactly top_n motifs after deterministic secondary sorting.

Details

Filtering is descriptive and deterministic. When ties = "first", ties are resolved by sequence prevalence, occurrence count, sequence count, shorter motif length, and finally the collision-resistant motif key.

Value

A named list containing the filtered motifs table, the matching sequence-level rows in by_sequence, sequence and state dictionaries, validation metadata, filter settings, and counts before and after filtering.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "A", "A", "B", "A", "C")
```

```
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

filtered <- filter_sequence_motifs(
  extracted,
  min_sequences = 2,
  top_n = 5,
  ties = "include"
)

filtered$motifs
```

`filter_sequence_subsequences` *Filter non-contiguous subsequence summaries*

Description

Filter non-contiguous subsequence summaries

Usage

```
filter_sequence_subsequences(
  summary,
  min_sequences = 1L,
  min_prevalence = 0,
  max_mean_gap = Inf,
  top_n = NULL,
  ties = c("include", "exclude")
)
```

Arguments

`summary`	A data frame from `summarise_sequence_subsequences()`.
`min_sequences`	Minimum sequence count.
`min_prevalence`	Minimum sequence prevalence.
`max_mean_gap`	Optional maximum mean gap.
`top_n`	Optional number of rows retained after deterministic sorting.
`ties`	Include or exclude ties at the `top_n` boundary.

Value

A filtered summary data frame.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "B", "D"))
x <- summarise_sequence_subsequences(extract_sequence_subsequences(data))
filter_sequence_subsequences(x, min_sequences = 2L)
```

---

fit_covariate_sequence_hmm

Fit a covariate-dependent categorical hidden Markov model

Description

Fits a categorical HMM whose initial-state and transition probabilities may depend on explicitly declared numeric covariates. Multinomial-logit coefficients are estimated inside the EM algorithm with a small ridge penalty. Emission probabilities remain time-homogeneous.

Usage

```
fit_covariate_sequence_hmm(
  data,
  n_states,
  initial_covariate_cols = NULL,
  transition_covariate_cols = NULL,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  symbol_levels = NULL,
  state_names = NULL,
  emission_probs = NULL,
  max_iter = 100L,
  inner_maxit = 100L,
  tolerance = 1e-06,
  pseudocount = 1e-06,
  ridge = 1e-06,
  seed = 1L,
  keep_posteriors = FALSE
)
```

Arguments

data	Long-format sequence data.
n_states	Number of latent states.

`initial_covariate_cols`
: Numeric sequence-constant covariates for initial-state probabilities.

`transition_covariate_cols`
: Numeric row-level covariates for transition probabilities.

`sequence_id_col`, `order_col`, `state_col`
: Core sequence columns.

`symbol_levels` Optional observed-symbol order.

`state_names` Optional latent-state names.

`emission_probs` Optional starting emission matrix.

`max_iter` Maximum EM iterations.

`inner_maxit` Maximum BFGS iterations in each multinomial M-step.

`tolerance` Relative log-likelihood tolerance.

`pseudocount` Emission smoothing count.

`ridge` Non-negative coefficient penalty.

`seed` Reproducibility seed.

`keep_posteriors`
: Retain final posteriors.

Value

An object of class `gp3_covariate_sequence_hmm`.

Examples

```
sequences <- data.frame(
  sequence_id = rep(paste0("s", 1:8), each = 5L),
  sequence_order = rep(1:5, times = 8L),
  state = rep(c("A", "B", "C", "B", "A"), times = 8L),
  condition = rep(rep(c(0, 1), each = 4L), each = 5L),
  time_scaled = rep(seq(-1, 1, length.out = 5L), times = 8L)
)
fit_covariate_sequence_hmm(
  sequences, 2L,
  initial_covariate_cols = "condition",
  transition_covariate_cols = c("condition", "time_scaled"),
  max_iter = 3L, inner_maxit = 10L, seed = 1L
)
```

`fit_higher_order_transition_model` *Fit a higher-order transition model*

Description

Fit a higher-order transition model

Usage

```
fit_higher_order_transition_model(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  order = 2L,
  smoothing = 0.5,
  backoff = TRUE,
  context_separator = " > "
)
```

Arguments

`data`	Long-format sequence data.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`order`	Context order.
`smoothing`	Additive smoothing over observed next states.
`backoff`	Retain lower-order context tables for prediction backoff.
`context_separator`	Context separator.

Value

An object of class `gp3_higher_order_transition_model`.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
fit_higher_order_transition_model(sequences, order = 2L)
```

`fit_multichannel_sequence_hmm` *Fit a multichannel categorical hidden Markov model*

Description

Fits a finite-state, time-homogeneous HMM to two or more categorical channels under conditional independence of channels given the latent state. Latent states are statistical model states only.

Usage

```
fit_multichannel_sequence_hmm(
  data,
  n_states,
  channel_cols,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  symbol_levels = NULL,
  state_names = NULL,
  initial_probs = NULL,
  transition_probs = NULL,
  emission_probs = NULL,
  max_iter = 200L,
  tolerance = 1e-06,
  pseudocount = 1e-06,
  seed = 1L,
  keep_posteriors = FALSE
)
```

Arguments

`data`	Long-format multichannel sequence data.
`n_states`	Number of latent states.
`channel_cols`	Names of categorical observation channels.
`sequence_id_col`, `order_col`	Core sequence columns.
`symbol_levels`	Optional named list of symbol orders by channel.
`state_names`	Optional latent-state names.
`initial_probs`, `transition_probs`, `emission_probs`	Optional starting values.
`max_iter`	Maximum EM iterations.
`tolerance`	Relative log-likelihood tolerance.
`pseudocount`	Non-negative smoothing count.
`seed`	Reproducibility seed.
`keep_posteriors`	Retain final forward-backward results.

Value

An object of class `gp3_multichannel_sequence_hmm`.

Examples

```
multichannel <- data.frame(
  sequence_id = rep(paste0("s", 1:4), each = 5L),
  sequence_order = rep(1:5, times = 4L),
  action = c("A", "B", "C", "C", "D", "A", "B", "B", "C", "D",
             "D", "C", "B", "A", "A", "D", "C", "C", "B", "A"),
  context = rep(c("x", "x", "y", "y", "z"), times = 4L)
)
fit_multichannel_sequence_hmm(multichannel, 2L,
                              channel_cols = c("action", "context"),
                              max_iter = 5L, seed = 1L)
```

`fit_sequence_hmm` *Fit a categorical hidden Markov model*

Description

Fits a finite-state, time-homogeneous categorical HMM by Baum-Welch EM. Latent states are statistical model states only; they are not psychological, diagnostic, or causal constructs.

Usage

```
fit_sequence_hmm(
  data,
  n_states,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  symbol_levels = NULL,
  state_names = NULL,
  initial_probs = NULL,
  transition_probs = NULL,
  emission_probs = NULL,
  max_iter = 200L,
  tolerance = 1e-06,
  pseudocount = 1e-06,
  seed = 1L,
  keep_posteriors = FALSE
)
```

Arguments

`data`	Long-format sequence data.
`n_states`	Number of latent states.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`symbol_levels`	Optional observed-symbol ordering.

state_names	Optional latent-state names.
initial_probs, transition_probs, emission_probs	Optional starting values.
max_iter	Maximum EM iterations.
tolerance	Relative log-likelihood tolerance.
pseudocount	Non-negative smoothing count.
seed	Reproducibility seed.
keep_posteriors	Retain final forward-backward results.

Value

An object of class gp3_sequence_hmm containing fitted parameters, log likelihood, convergence diagnostics, symbol coding, and optional posteriors.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
fit_sequence_hmm(sequences, n_states = 2L, max_iter = 5L, seed = 1L)
```

---

fit_sequence_hmm_mixture

Fit a mixture of categorical hidden Markov models

Description

Fits sequence-level mixture components, each containing a categorical HMM. Component membership is a statistical clustering device and should not be interpreted as a substantive latent type without external validation.

Usage

```
fit_sequence_hmm_mixture(
  data,
  n_components,
  n_states,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
```

```
  state_col = "state",
  symbol_levels = NULL,
  max_iter = 200L,
  inner_initial_iter = 20L,
  tolerance = 1e-06,
  pseudocount = 1e-06,
  seed = 1L
)
```

Arguments

`data`	Long-format sequence data.
`n_components`	Number of mixture components.
`n_states`	Number of hidden states per component; scalar or vector.
`sequence_id_col`, `order_col`, `state_col`	Sequence columns.
`symbol_levels`	Optional symbol ordering.
`max_iter`	Maximum mixture-EM iterations.
`inner_initial_iter`	Initial single-HMM iterations per component.
`tolerance`	Relative log-likelihood tolerance.
`pseudocount`	Smoothing count.
`seed`	Reproducibility seed.

Value

An object of class `gp3_sequence_hmm_mixture`.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
fit_sequence_hmm_mixture(sequences, n_components = 2L, n_states = 2L,
                         max_iter = 5L, inner_initial_iter = 2L, seed = 1L)
```

`fit_time_varying_sequence_model` *Fit a time-varying sequence condition model*

Description

Fits a binary generalized additive model for either occupancy of a target state or occurrence of a target transition over aligned sequence time. Group specific smooths model time-varying condition differences, and a participant random-effect smooth accounts for repeated observations. The optional `mgcv` package is required.

Usage

```
fit_time_varying_sequence_model(
  data,
  group_col,
  participant_id_col,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  time_col = NULL,
  outcome = c("state", "transition"),
  target_state = NULL,
  from_state = NULL,
  to_state = NULL,
  k = 5L,
  method = "REML",
  include_random_effect = TRUE
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`group_col`	Group or condition column.
`participant_id_col`	Participant or repeated-unit column.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`time_col`	Optional numeric time column; defaults to `order_col`.
`outcome`	`"state"` or `"transition"`.
`target_state`	Target state for occupancy models.
`from_state`, `to_state`	Target transition for transition models.
`k`	Basis dimension for time smooths.

`method` Smoothing-parameter estimation method passed to `mgcv::gam()`.

`include_random_effect`
Include a participant random-effect smooth.

Value

An object of class `gp3_sequence_time_model`.

Examples

```
set.seed(2026)

n_participants <- 24L
n_positions <- 12L

participant_index <- rep(
  seq_len(n_participants),
  each = n_positions
)

sequence_order <- rep(
  seq_len(n_positions),
  times = n_participants
)

group_by_participant <- rep(
  c("control", "treatment"),
  each = n_participants %/% 2L
)

group <- rep(
  group_by_participant,
  each = n_positions
)

probability <- stats::plogis(
  -0.8 +
    0.08 * sequence_order +
    0.4 * (group == "treatment")
)

observed_b <- stats::rbinom(
  length(probability),
  size = 1L,
  prob = probability
)

sequences <- data.frame(
  participant_id = paste0("p", participant_index),
  sequence_id = paste0("s", participant_index),
  sequence_order = sequence_order,
  state = ifelse(observed_b == 1L, "B", "A"),
```

```
  group = group
)

if (requireNamespace("mgcv", quietly = TRUE)) {
  fit <- fit_time_varying_sequence_model(
    sequences,
    group_col = "group",
    participant_id_col = "participant_id",
    target_state = "B",
    k = 4L
  )
}
```

`format_consensus_sequence` *Format consensus sequences as paths*

Description

Format consensus sequences as paths

Usage

```
format_consensus_sequence(
  consensus,
  separator = " -> ",
  include_order = FALSE,
  include_agreement = FALSE,
  digits = 3L
)
```

Arguments

`consensus`	A consensus result.
`separator`	State separator.
`include_order`	Include position labels.
`include_agreement`	Include rounded agreement values.
`digits`	Number of decimal places for agreement values.

Value

One row per consensus group with a formatted path and position count.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
consensus <- create_consensus_sequence(sequences)
format_consensus_sequence(consensus)
```

---

format_sequence_motifs

Format Sequence Motif Summaries

Description

Produces a stable, report-ready table from motif extraction, summary, or filtered-motif output.

Usage

```
format_sequence_motifs(
  x,
  digits = 3L,
  prevalence = c("proportion", "percent"),
  include_rank = TRUE,
  rank_by = c("sequence_prevalence", "n_occurrences", "n_sequences"),
  ties = c("min", "first"),
  include_ids = TRUE
)
```

Arguments

x	A motif extraction, motif summary, or filtered-motif object.
digits	Whole number from 0 to 15 controlling numeric rounding.
prevalence	Character value specifying whether prevalence and occurrence share are shown as "proportion"s or "percent"ages.
include_rank	Logical value indicating whether to add a rank column.
rank_by	Metric used to order and rank motifs: one of "sequence_prevalence", "n_occurrences", or "n_sequences".
ties	Character value specifying "min" shared ranks or deterministic "first" ranks.
include_ids	Logical value indicating whether motif_id and motif_key should be included in the formatted table.

Details

Formatting changes display precision and units only. It does not change the underlying motif counts or introduce substantive interpretation.

Value

A named list containing `table`, validation metadata, and formatting settings. The table contains only structural motif measurements.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "A", "A", "B", "A", "C")
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

formatted <- format_sequence_motifs(
  extracted,
  prevalence = "percent",
  digits = 1
)

formatted$table
```

---

format_sequence_motif_positions

Format Sequence Motif Position Summaries

Description

Produces a deterministic report-ready table from positional motif summaries.

Usage

```
format_sequence_motif_positions(
  x,
  digits = 3L,
  position_units = c("proportion", "percent"),
  include_rank = TRUE
)
```

Arguments

x	An object returned by summarise_sequence_motif_positions().
digits	Whole number from 0 to 15 controlling numeric rounding.
position_units	Display units for relative positions: "proportion" or "percent". Absolute positions remain one-based sequence indices.
include_rank	Logical value indicating whether to include an earlier-to-later rank based on mean position. Ranking is performed within each supplied by group.

Details

Formatting copies and transforms the summary table only. The input object is not modified. Rows are ordered deterministically by grouping values, mean and median position, occurrence and sequence counts, motif length, and motif key. Equal mean positions receive the same minimum rank.

Value

A named list containing the formatted table, validation metadata, and formatting settings.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "C", "A", "B", "C", "B")
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

positions <- summarise_sequence_motif_positions(
  extracted,
  position = "centre",
  scale = "relative"
)

formatted <- format_sequence_motif_positions(
  positions,
  position_units = "percent",
  digits = 1
)

formatted$table
```

format_sequence_paths *Format Ordered Sequence Paths*

Description

Creates a compact one-row-per-sequence representation of ordered state paths.

Usage

```
format_sequence_paths(
  data,
  sequence_id_col,
  order_col,
  state_col,
  metadata_cols = NULL,
  expected_states = NULL,
  separator = " > ",
  collapse_repeats = FALSE
)
```

Arguments

data	A data frame containing ordered state observations.
sequence_id_col	Name of the sequence identifier column.
order_col	Name of the numeric sequence-order column.
state_col	Name of the categorical state column.
metadata_cols	Optional character vector naming columns that should remain constant within each sequence.
expected_states	Optional vector of known or permitted state values.
separator	Character value inserted between adjacent state labels.
collapse_repeats	Logical value indicating whether consecutive repeated states should be collapsed for path display.

Details

Repeat collapsing affects only the formatted representation. It does not modify the supplied data or alter non-consecutive repeated states. Input rows are ordered deterministically for formatting, but review-level diagnostics such as `unordered_rows` remain reflected in the returned `status` and `audit`.

Value

A named list containing:

- `paths`: one row per sequence with observation counts, formatted-state counts, unique-state counts, start and end states, and the path string;
- `audit`, `status`, and `mapping` from input validation;
- `settings`: the path separator and repeat-collapsing choice.

Examples

```
sequences <- data.frame(
  id = c("s1", "s1", "s1", "s2", "s2"),
  position = c(1, 2, 3, 1, 2),
  state = c("A", "B", "C", "A", "C")
)

paths <- format_sequence_paths(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

paths$paths
```

`plot_consensus_sequence` *Plot a consensus sequence*

Description

Plot a consensus sequence

Usage

```
plot_consensus_sequence(
  consensus,
  type = c("agreement", "states"),
  group = NULL,
  main = NULL,
  xlab = "Sequence position",
  ylab = NULL,
  ...
)
```

Arguments

consensus	A consensus result.
type	"agreement" or "states".
group	Optional group value, encoded group key, or named list of values when grouped consensus was created. It is required when more than one consensus group is present.
main, xlab, ylab	Plot labels.
...	Additional arguments passed to base graphics.

Value

The plotted data, invisibly.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
consensus <- create_consensus_sequence(sequences)
plot_consensus_sequence(consensus)
```

---

plot_multichannel_sequence_hmm

Plot multichannel HMM emission profiles

Description

Plot multichannel HMM emission profiles

Usage

```
plot_multichannel_sequence_hmm(model, channel = model$channel_names[1L], ...)
```

Arguments

model	A fitted multichannel HMM.
channel	Channel name to plot.
...	Additional arguments passed to graphics::barplot().

Value

The selected emission matrix, invisibly.

Examples

```
# See `fit_multichannel_sequence_hmm()`.
```

`plot_sequence_cluster_silhouette`
Plot sequence-cluster silhouette values

Description

Plot sequence-cluster silhouette values

Usage

```
plot_sequence_cluster_silhouette(clustering, distance = NULL, ...)
```

Arguments

`clustering`	A clustering result or named assignment vector.
`distance`	Optional distance when `clustering` is an assignment vector.
`...`	Additional arguments passed to `graphics::barplot()`.

Value

The ordered per-sequence silhouette table, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(paste0("s", 1:4), each = 4L),
                   sequence_order = rep(1:4, 4L),
                   state = c("A", "B", "C", "D", "A", "B", "C", "C",
                             "D", "C", "B", "A", "D", "C", "A", "A"))
distance <- compute_sequence_distance(data)
plot_sequence_cluster_silhouette(cluster_sequences(distance, 2L))
```

`plot_sequence_distance_heatmap` *Plot a sequence-distance heatmap*

Description

Plot a sequence-distance heatmap

Usage

```
plot_sequence_distance_heatmap(
  distance,
  order_by = NULL,
  palette = "Viridis",
  show_labels = TRUE,
  ...
)
```

Arguments

`distance`	A sequence distance object or square matrix.
`order_by`	Optional clustering or named assignment vector used to order the matrix.
`palette`	Base HCL palette.
`show_labels`	Draw sequence identifiers.
`...`	Additional arguments passed to `graphics::image()`.

Value

The ordered distance matrix, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(paste0("s", 1:4), each = 4L),
                   sequence_order = rep(1:4, 4L),
                   state = c("A", "B", "C", "D", "A", "B", "C", "C",
                             "D", "C", "B", "A", "D", "C", "A", "A"))
plot_sequence_distance_heatmap(compute_sequence_distance(data))
```

`plot_sequence_entropy` *Plot position-wise state entropy*

Description

Plot position-wise state entropy

Usage

```
plot_sequence_entropy(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  base = 2,
  normalise = TRUE,
  ...
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`sequence_id_col, order_col, state_col`	Core sequence columns.
`base`	Logarithm base.
`normalise`	Divide entropy by the maximum entropy for the observed alphabet.
`...`	Additional arguments passed to `graphics::plot()`.

Value

A data frame of position-wise entropy values, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "C", "D"))
plot_sequence_entropy(data)
```

`plot_sequence_group_comparison` *Plot a descriptive sequence-group comparison*

Description

Plot a descriptive sequence-group comparison

Usage

```
plot_sequence_group_comparison(
  comparison,
  component = c("state", "transition", "length"),
  measure = NULL,
  top_n = 12L,
  main = NULL,
  xlab = NULL,
  ylab = NULL,
  ...
)
```

Arguments

`comparison`	A result from `compare_sequence_groups()`.
`component`	`"state"`, `"transition"`, or `"length"`.
`measure`	Measure to display. Defaults depend on `component`.
`top_n`	Maximum states or transitions to display.
`main`, `xlab`, `ylab`	Plot labels.
`...`	Additional base-graphics arguments.

Value

The plotted summary data, invisibly.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
comparison <- compare_sequence_groups(sequences, group_col = "group")
plot_sequence_group_comparison(comparison, component = "state")
```

plot_sequence_group_inference *Plot sequence group inference*

Description

Plot sequence group inference

Usage

```
plot_sequence_group_inference(
  inference,
  type = c("permutation", "group_means"),
  ...
)
```

Arguments

inference	A sequence group-inference object.
type	"permutation" or "group_means".
...	Additional base-graphics arguments.

Value

The inference object, invisibly.

Examples

```
# See `test_sequence_group_difference()`.
```

plot_sequence_index *Plot a sequence index heatmap*

Description

Plot a sequence index heatmap

Usage

```
plot_sequence_index(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  sort_by = c("input", "length", "path"),
  state_levels = NULL,
  palette = "Dark 3",
  show_sequence_labels = TRUE,
  ...
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`sort_by`	`"input"`, `"length"`, or `"path"`.
`state_levels`	Optional state ordering.
`palette`	Base HCL palette.
`show_sequence_labels`	Draw sequence identifiers.
`...`	Additional arguments passed to `graphics::image()`.

Value

The plotted state-code matrix, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "C", "D"))
plot_sequence_index(data)
```

---

plot_sequence_motifs *Plot Sequence Motif Summaries*

Description

Draws a dependency-free base-R bar chart of structural motif measurements.

Usage

```
plot_sequence_motifs(
  x,
 metric = c("sequence_prevalence", "n_occurrences", "n_sequences", "occurrence_share"),
  top_n = 20L,
  motif_lengths = NULL,
  ties = c("include", "first"),
  horizontal = TRUE
)
```

Arguments

x	A motif extraction, summary, or filtered-motif object.
metric	Structural metric to plot: "sequence_prevalence", "n_occurrences", "n_sequences", or "occurrence_share".
top_n	Positive whole number giving the requested number of motifs.
motif_lengths	Optional vector of positive whole-number motif lengths to retain.
ties	Top-n boundary policy. "include" retains all motifs tied on the selected metric; "first" retains exactly top_n after deterministic secondary sorting.
horizontal	Logical value indicating whether bars should be horizontal.

Details

The plot is descriptive. It does not perform inferential testing or assign substantive meaning to motif frequency or prevalence. Empty inputs produce an informative blank plot and return an empty table.

Value

Invisibly returns the exact motif table used for plotting, including plot_rank, plot_value, plot_label, and bar_midpoint.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "C", "A", "B", "C", "B")
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

plot_sequence_motifs(
  extracted,
  metric = "sequence_prevalence",
```

```
  top_n = 10
)
```

`plot_sequence_motif_positions` *Plot Sequence Motif Positions*

Description

Shows occurrence locations for selected contiguous motifs.

Usage

```
plot_sequence_motif_positions(
  x,
  motifs = NULL,
  position = c("start", "centre", "end"),
  scale = c("absolute", "relative"),
  top_n = 10L,
  display = c("strip", "distribution")
)
```

Arguments

`x`	An object returned by `extract_sequence_ngrams()` or `summarise_sequence_motif_positions()`.
`motifs`	Optional character vector of motif identifiers, motif keys, or displayed motif labels. When omitted, motifs are selected deterministically by occurrence count, sequence count, motif length, and motif key.
`position`	Occurrence position represented by motif `"start"`, `"centre"`, or `"end"`.
`scale`	Position scale: one-based `"absolute"` sequence positions or `"relative"` positions from 0 to 1.
`top_n`	Positive whole number giving the number of motifs selected when `motifs` is `NULL`.
`display`	Base-R display type: occurrence `"strip"` or `"distribution"` boxplots.

Details

The strip display uses deterministic vertical stacking rather than random jitter. The distribution display uses one horizontal boxplot per motif. Empty inputs produce an informative blank plot and return an empty table. The function provides structural location summaries only.

Value

Invisibly returns the exact occurrence-level data used by the plot, including deterministic motif ranks and plotting coordinates where relevant.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "C", "A", "B", "C", "B")
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

plot_sequence_motif_positions(
  extracted,
  position = "centre",
  scale = "relative",
  top_n = 5,
  display = "strip"
)
```

---

plot_sequence_panel_changes

Plot longitudinal sequence changes

Description

Plot longitudinal sequence changes

Usage

```
plot_sequence_panel_changes(
  changes,
  metric = c("distance", "length_change", "transition_change"),
  type = c("individual", "summary"),
  ...
)
```

Arguments

changes	A result from compare_sequence_panel_changes().
metric	One of "distance", "length_change", or "transition_change".
type	Plot individual panel trajectories or occasion-transition means.
...	Additional graphical arguments passed to base plotting functions.

Value

The plotted data, invisibly.

Examples

```
panel_data <- data.frame(
  participant_id = rep(c("p1", "p2"), each = 6L),
  occasion = rep(rep(c(1, 2), each = 3L), times = 2L),
  sequence_id = rep(c("a", "b", "c", "d"), each = 3L),
  sequence_order = rep(1:3, times = 4L),
  state = c("A", "B", "C", "A", "C", "C", "C", "B", "A", "C", "B", "B")
)
changes <- compare_sequence_panel_changes(
  prepare_sequence_panel(panel_data, "participant_id", "occasion")
)
plot_sequence_panel_changes(changes)
```

---

plot_sequence_state_distribution

Plot state distributions over aligned positions

Description

Plot state distributions over aligned positions

Usage

```
plot_sequence_state_distribution(
  data,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  proportion = TRUE,
  state_levels = NULL,
  palette = "Dark 3",
  ...
)
```

Arguments

`data`	Long-format sequence data or a prepared result.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`proportion`	Plot position-wise proportions rather than counts.
`state_levels`	Optional state ordering.
`palette`	Base HCL palette.
`...`	Additional arguments passed to `graphics::matplot()`.

Value

A position-by-state matrix, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "C", "D"))
plot_sequence_state_distribution(data)
```

`plot_sequence_subsequences` *Plot non-contiguous subsequence summaries*

Description

Plot non-contiguous subsequence summaries

Usage

```
plot_sequence_subsequences(
  x,
  metric = "sequence_prevalence",
  top_n = 10L,
  decreasing = TRUE,
  ...
)
```

Arguments

`x`	A summary or group-comparison table.
`metric`	Numeric column to plot.
`top_n`	Maximum number of subsequences.
`decreasing`	Sort metric in decreasing order.
`...`	Additional arguments passed to `graphics::barplot()`.

Value

The plotted rows, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "B", "D"))
summary <- summarise_sequence_subsequences(extract_sequence_subsequences(data))
plot_sequence_subsequences(summary, top_n = 5L)
```

plot_time_varying_sequence_model

Plot predicted time-varying sequence probabilities

Description

Plot predicted time-varying sequence probabilities

Usage

```
plot_time_varying_sequence_model(
  model,
  time = NULL,
  level = 0.95,
  show_interval = TRUE,
  ...
)
```

Arguments

model	A fitted time-varying sequence model.
time	Optional prediction grid.
level	Pointwise confidence level.
show_interval	Draw pointwise confidence ribbons.
...	Additional arguments passed to graphics::plot().

Value

Prediction data, invisibly.

Examples

```
# See `fit_time_varying_sequence_model()`.
```

plot_transition_network

Plot a first-order transition network

Description

Plot a first-order transition network

Usage

```
plot_transition_network(
  network,
  weight_col = "weight",
  minimum_weight = 0,
  vertex_cex = 1,
  edge_scale = 5,
  ...
)
```

Arguments

network	A first-order network from create_transition_network().
weight_col	Edge-weight column.
minimum_weight	Minimum plotted edge weight.
vertex_cex	Vertex label size.
edge_scale	Edge-width multiplier.
...	Additional arguments passed to graphics::plot.window().

Value

The plotted network rows, invisibly.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "C", "D"))
plot_transition_network(create_transition_network(data, normalise = "from"))
```

---

predict_covariate_transition_probabilities

Predict covariate-dependent transition probabilities

Description

Predict covariate-dependent transition probabilities

Usage

```
predict_covariate_transition_probabilities(model, newdata)
```

Arguments

model	A fitted covariate HMM.
newdata	Data frame containing transition covariates.

Value

A long data frame with one row per input row, origin state, and destination state.

Examples

```
# See `fit_covariate_sequence_hmm()`.
```

`predict_next_state` *Predict the next state from a transition model*

Description

Predict the next state from a transition model

Usage

```
predict_next_state(model, history, top_n = NULL)
```

Arguments

`model`	A higher-order transition model.
`history`	Character vector of observed recent states.
`top_n`	Optional number of states to retain. Returned probabilities remain on the full-model scale and are not renormalised after truncation.

Value

A probability table ordered from highest to lowest probability, with the context order actually used.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
model <- fit_higher_order_transition_model(sequences, order = 2L)
predict_next_state(model, c("A", "B"))
```

predict_time_varying_sequence_model
Predict a time-varying sequence model

Description

Predict a time-varying sequence model

Usage

```
predict_time_varying_sequence_model(
  model,
  time = NULL,
  groups = NULL,
  level = 0.95
)
```

Arguments

model	A fitted time-varying sequence model.
time	Optional numeric prediction grid.
groups	Optional subset of fitted groups.
level	Confidence level for pointwise intervals.

Value

A data frame with fitted probabilities and pointwise intervals.

Examples

```
# See `fit_time_varying_sequence_model()`.
```

prepare_gp3tools_sequences
Prepare common gp3tools-style sequence outputs

Description

This optional compatibility helper recognises ordinary data frames or lists containing a data-frame component and maps common sequence-column names to the neutral gp3sequences contract. It does not require a gp3tools class.

Usage

```
prepare_gp3tools_sequences(
  data,
  sequence_id_col = NULL,
  order_col = NULL,
  state_col = NULL,
  duration_col = NULL,
  metadata_cols = NULL,
  ...
)
```

Arguments

`data`	A data frame or list with a data-frame `data` component.
`sequence_id_col`, `order_col`, `state_col`	Optional explicit mappings.
`duration_col`	Optional duration mapping.
`metadata_cols`	Optional constant-within-sequence metadata columns.
`...`	Additional arguments passed to `prepare_sequence_data()`.

Value

A standard gp3sequences preparation result.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
names(sequences)[names(sequences) == "sequence_order"] <- "position"
names(sequences)[names(sequences) == "state"] <- "aoi_label"
prepare_gp3tools_sequences(sequences)
```

---

prepare_sequence_data *Prepare Long-Format Sequence Data*

Description

Applies explicit preprocessing policies and returns a deterministic, canonical long-format representation.

Usage

```
prepare_sequence_data(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL,
  missing_state_policy = c("error", "drop"),
  duplicate_position_policy = c("error", "first", "last"),
  repeated_state_policy = c("preserve", "collapse"),
  zero_duration_policy = c("preserve", "drop", "error"),
  unknown_state_policy = c("preserve", "drop", "error"),
  unused_state_levels = c("preserve", "drop")
)
```

Arguments

`data`	A data frame containing ordered state observations.
`sequence_id_col`	Name of the sequence identifier column.
`order_col`	Name of the numeric sequence-order column.
`state_col`	Name of the categorical state column.
`duration_col`	Optional name of a numeric duration column.
`metadata_cols`	Optional character vector naming columns that should remain constant within each sequence.
`expected_states`	Optional vector of known or permitted state values.
`missing_state_policy`	Policy for missing states: `"error"` or `"drop"`.
`duplicate_position_policy`	Policy for duplicated sequence positions: `"error"`, `"first"`, or `"last"`.
`repeated_state_policy`	Policy for consecutive repeated states: `"preserve"` or `"collapse"`.
`zero_duration_policy`	Policy for zero durations: `"preserve"`, `"drop"`, or `"error"`.
`unknown_state_policy`	Policy for states absent from `expected_states`: `"preserve"`, `"drop"`, or `"error"`.
`unused_state_levels`	Policy for unused factor levels: `"preserve"` or `"drop"`.

Details

Rows are sorted deterministically by sequence identifier, sequence order, and original row number. When consecutive repeats are collapsed, the first row supplies non-duration values and available durations are summed.

Unresolved errors produce `status = "fail"` and `data = NULL`; diagnostics and decision records remain available.

Value

A named list containing:

- `data`: canonical prepared data, or `NULL` when unresolved errors remain;
- `audit`: input- and output-stage diagnostics;
- `decisions`: a machine-readable preprocessing decision log;
- `mapping`: source-to-contract column mappings;
- `status`: `pass`, `review`, or `fail`;
- row counts and final state levels.

The canonical columns are `sequence_id`, `sequence_order`, `state`, `original_row`, and optional `duration`. Unmapped columns are preserved.

Examples

```
sequences <- data.frame(
  id = c("s2", "s1", "s1", "s2"),
  position = c(2, 2, 1, 1),
  state = c("product", "search", "home", "home")
)

prepared <- prepare_sequence_data(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

prepared$status
prepared$data
```

`prepare_sequence_panel` *Prepare longitudinal or panel sequence data*

Description

Validates a collection of sequences observed repeatedly for the same panel units and creates an auditable panel index. Each sequence must map to exactly one panel unit and one occasion.

Usage

```
prepare_sequence_panel(
  data,
  panel_id_col,
  occasion_col,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  metadata_cols = NULL,
  require_unique_occasions = TRUE
)
```

Arguments

`data`	Long-format sequence data or a prepared gp3sequences result.
`panel_id_col`	Column identifying the repeatedly observed unit.
`occasion_col`	Column identifying the wave, visit, or occasion.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`metadata_cols`	Optional columns that must remain constant within each sequence.
`require_unique_occasions`	Require at most one sequence per panel unit and occasion.

Value

An object of class `gp3_sequence_panel` containing canonical data, a panel index, state levels, and mapping information.

Examples

```
panel <- data.frame(
  participant_id = rep(c("p1", "p2"), each = 8L),
  occasion = rep(rep(c(1, 2), each = 4L), times = 2L),
  sequence_id = rep(c("p1_w1", "p1_w2", "p2_w1", "p2_w2"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "C", "C", "D",
            "D", "C", "B", "A", "D", "B", "B", "A")
)
prepare_sequence_panel(panel, "participant_id", "occasion")
```

`sequence_capabilities` *Report gp3sequences capabilities and optional integrations*

Description

Returns a deterministic, machine-readable inventory of native analytical capabilities, optional adapters, reference implementations, and specialist handoffs relevant to the current gp3sequences development series.

Usage

```
sequence_capabilities(include_optional = TRUE, check_versions = TRUE)
```

Arguments

include_optional	Logical; include optional/reference capabilities.
check_versions	Logical; report installed optional-package versions.

Value

A data frame with capability family, capability, implementation role, backend, availability, and version information. The function never installs, attaches, or loads optional packages.

Examples

```
capabilities <- sequence_capabilities()
capabilities[c("family", "capability", "role", "available")]
```

---

summarise_consensus_agreement

Summarise consensus agreement

Description

Summarise consensus agreement

Usage

```
summarise_consensus_agreement(
  consensus,
  by = c("overall", "group", "position"),
  threshold = 0.5
)
```

Arguments

consensus	A result from create_consensus_sequence().
by	Summary level: "overall", "group", or "position".
threshold	Agreement threshold used to count low-agreement positions.

Value

A data frame with position counts, mean, median, minimum and maximum agreement, weighted agreement, tie counts, and low-agreement counts.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
consensus <- create_consensus_sequence(sequences)
summarise_consensus_agreement(consensus)
```

---

summarise_covariate_sequence_hmm

Summarise a covariate-dependent HMM

Description

Summarise a covariate-dependent HMM

Usage

```
summarise_covariate_sequence_hmm(model)
```

Arguments

model	A fitted covariate HMM.

Value

A list of fit, coefficient, and emission summaries.

Examples

```
# See `fit_covariate_sequence_hmm()`.
```

summarise_multichannel_sequence_hmm

Summarise a multichannel sequence HMM

Description

Summarise a multichannel sequence HMM

Usage

```
summarise_multichannel_sequence_hmm(model)
```

Arguments

model	A fitted multichannel HMM.

Value

A list of convergence, fit, transition, initial, and channel-specific emission summaries.

Examples

```
# See `fit_multichannel_sequence_hmm()`.
```

summarise_sequence_cluster_stability

Summarise sequence-cluster stability

Description

Summarise sequence-cluster stability

Usage

```
summarise_sequence_cluster_stability(bootstrap, threshold = 0.8)
```

Arguments

bootstrap	A result from bootstrap_sequence_clusters().
threshold	Pairwise stability threshold.

Value

Overall, cluster-level, and low-stability pair summaries.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
distance <- compute_sequence_distance(sequences)
boot <- bootstrap_sequence_clusters(distance, k = 2L, n_boot = 5L)
summarise_sequence_cluster_stability(boot)
```

---

summarise_sequence_distance

Summarise a sequence-distance object

Description

Summarise a sequence-distance object

Usage

```
summarise_sequence_distance(distance)
```

Arguments

distance	A distance object returned by compute_sequence_distance().

Value

A list containing an overall summary and per-sequence mean, median, minimum, and maximum distances.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
distance <- compute_sequence_distance(sequences)
summarise_sequence_distance(distance)
```

summarise_sequence_group_inference

Summarise sequence group inference

Description

Summarise sequence group inference

Usage

```
summarise_sequence_group_inference(inference)
```

Arguments

inference	A sequence group-inference object.

Value

A list containing the estimate, optional interval, design, and interpretation statement.

Examples

```
# See `test_sequence_group_difference()`.
```

summarise_sequence_hmm

Summarise a fitted sequence HMM

Description

Summarise a fitted sequence HMM

Usage

```
summarise_sequence_hmm(model)
```

Arguments

model	A single or mixture HMM.

Value

A list of convergence, fit, initial, transition, emission, and mixture summaries.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
model <- fit_sequence_hmm(sequences, 2L, max_iter = 5L)
summarise_sequence_hmm(model)
```

---

summarise_sequence_motifs

Summarise Contiguous Sequence Motifs

Description

Aggregates extracted contiguous motif occurrences by sequence and overall.

Usage

```
summarise_sequence_motifs(x)
```

Arguments

x	An object returned by `extract_sequence_ngrams()`.

Details

Sequence prevalence uses every validated sequence in the extraction object as its denominator, including sequences too short to contain a requested motif. Results are sorted deterministically by sequence prevalence, occurrence count, motif length, and motif key.

The function reports structural recurrence only. It does not perform significance testing or infer psychological, cognitive, emotional, or diagnostic attributes.

Value

A named list containing:

- `by_sequence`: occurrence counts for each sequence-motif pair;
- `overall`: total occurrence counts, sequence counts, sequence prevalence, occurrence share, and mean occurrence rates;
- `sequences` and `state_dictionary` from extraction;
- `audit`, `status`, `mapping`, and extraction settings;
- scalar counts for sequences, occurrences, and distinct motifs.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "A", "A", "B", "A", "C")
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state",
  min_length = 2,
  max_length = 3
)

summaries <- summarise_sequence_motifs(extracted)
summaries$by_sequence
summaries$overall
```

---

summarise_sequence_motif_positions

Summarise Sequence Motif Positions

Description

Summarises where contiguous motif occurrences appear within sequences.

Usage

```
summarise_sequence_motif_positions(
  x,
  position = c("start", "centre", "end"),
  scale = c("absolute", "relative"),
  by = NULL
)
```

Arguments

x	An object returned by `extract_sequence_ngrams()`.
position	Position represented by each occurrence: motif `"start"`, `"centre"`, or `"end"`.
scale	Position scale: one-based `"absolute"` sequence positions or `"relative"` positions from 0 to 1.
by	Optional character vector naming preserved metadata columns used to produce separate summaries, such as `"group"` or `"condition"`.

Details

Absolute positions use the one-based state index within each validated sequence. Relative positions are calculated as `(absolute_position - 1) / (n_states - 1)` and are constrained to the interval from 0 to 1. A sequence containing one state is assigned relative position 0.

Grouping is descriptive. The function does not test differences or attach behavioural, psychological, cognitive, or causal interpretations to motif location.

Value

A named list containing:

- `summary`: one row per motif and optional metadata group;
- `occurrences`: occurrence-level absolute, relative, and selected-scale positions;
- `sequences`, validation metadata, and extraction settings;
- `settings`: the resolved position basis, scale, and grouping columns.

The summary reports motif identifiers and labels, motif length, occurrence and sequence counts, and minimum, maximum, mean, and median positions.

Examples

```
sequences <- data.frame(
  id = c(rep("s1", 5L), rep("s2", 4L)),
  position = c(1:5, 1:4),
  state = c("A", "B", "A", "B", "C", "A", "B", "C", "B"),
  group = c(rep("g1", 5L), rep("g2", 4L))
)

extracted <- extract_sequence_ngrams(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state",
  metadata_cols = "group",
  min_length = 2,
  max_length = 3
)

positions <- summarise_sequence_motif_positions(
  extracted,
  position = "centre",
  scale = "relative",
  by = "group"
)

positions$summary
```

summarise_sequence_panel *Summarise a sequence panel*

Description

Summarise a sequence panel

Usage

```
summarise_sequence_panel(panel)
```

Arguments

panel	A result from prepare_sequence_panel().

Value

A list with occasion-level sequence summaries and state prevalence.

Examples

```
panel_data <- data.frame(
  participant_id = rep(c("p1", "p2"), each = 6L),
  occasion = rep(rep(c(1, 2), each = 3L), times = 2L),
  sequence_id = rep(c("a", "b", "c", "d"), each = 3L),
  sequence_order = rep(1:3, times = 4L),
  state = c("A", "B", "C", "A", "C", "C", "C", "B", "A", "C", "B", "B")
)
summarise_sequence_panel(prepare_sequence_panel(panel_data, "participant_id", "occasion"))
```

summarise_sequence_states *Summarise Sequence States*

Description

Produces per-sequence and overall state-frequency summaries from validated ordered sequence data.

Usage

```
summarise_sequence_states(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL
)
```

Arguments

data	A data frame containing ordered state observations.
sequence_id_col	Name of the sequence identifier column.
order_col	Name of the numeric sequence-order column.
state_col	Name of the categorical state column.
duration_col	Optional name of a numeric duration column.
metadata_cols	Optional character vector naming columns that should remain constant within each sequence.
expected_states	Optional vector of known or permitted state values.

Details

Observation proportions use state rows as the denominator. Sequence proportions report the proportion of sequences in which each state occurs. Missing durations are excluded from duration calculations; an all-missing duration group returns NA.

Value

A named list containing:

- by_sequence: state counts and proportions within each sequence;
- overall: state counts and proportions across all sequences;
- audit, status, and mapping from input validation.

When duration_col is supplied, both tables also include duration sums, duration proportions, and mean durations.

Examples

```
sequences <- data.frame(
  id = c("s1", "s1", "s1", "s2", "s2"),
  position = c(1, 2, 3, 1, 2),
  state = c("A", "B", "A", "B", "C")
)
```

```
summaries <- summarise_sequence_states(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

summaries$by_sequence
summaries$overall
```

`summarise_sequence_subsequences` *Summarise non-contiguous subsequences*

Description

Summarise non-contiguous subsequences

Usage

```
summarise_sequence_subsequences(occurrences)
```

Arguments

`occurrences`	A result from `extract_sequence_subsequences()`.

Value

A data frame with occurrence counts, sequence prevalence, and span diagnostics.

Examples

```
data <- data.frame(sequence_id = rep(c("a", "b"), each = 4L),
                   sequence_order = rep(1:4, 2L),
                   state = c("A", "B", "C", "D", "A", "C", "B", "D"))
summarise_sequence_subsequences(extract_sequence_subsequences(data))
```

summarise_sequence_transitions
Summarise Adjacent Sequence Transitions

Description

Counts transitions between adjacent ordered states for each sequence and across the complete data set.

Usage

```
summarise_sequence_transitions(
  data,
  sequence_id_col,
  order_col,
  state_col,
  metadata_cols = NULL,
  expected_states = NULL,
  include_self = TRUE
)
```

Arguments

data	A data frame containing ordered state observations.
sequence_id_col	Name of the sequence identifier column.
order_col	Name of the numeric sequence-order column.
state_col	Name of the categorical state column.
metadata_cols	Optional character vector naming columns that should remain constant within each sequence.
expected_states	Optional vector of known or permitted state values.
include_self	Logical value indicating whether transitions from a state to the same state should be included.

Details

A transition is defined only between adjacent rows after deterministic ordering by sequence identifier, sequence order, and original row. Sequences with one state contribute no transitions.

Value

A named list containing:

- by_sequence: transition counts, proportions within each sequence, and conditional proportions within each origin state;

- `overall`: transition counts, sequence coverage, global proportions, and conditional origin-state proportions;
- `audit`, `status`, `mapping`, and the resolved `include_self` setting.

Examples

```
sequences <- data.frame(
  id = c("s1", "s1", "s1", "s2", "s2"),
  position = c(1, 2, 3, 1, 2),
  state = c("A", "B", "C", "A", "C")
)

transitions <- summarise_sequence_transitions(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

transitions$by_sequence
transitions$overall
```

`summarise_time_varying_sequence_model` *Summarise a time-varying sequence model*

Description

Summarise a time-varying sequence model

Usage

```
summarise_time_varying_sequence_model(model)
```

Arguments

`model`	A fitted time-varying sequence model.

Value

A list containing model metadata, parametric terms, smooth terms, deviance explained, and convergence information.

Examples

```
# See `fit_time_varying_sequence_model()`.
```

summarise_transition_centrality
Summarise transition-network centrality

Description

Summarise transition-network centrality

Usage

```
summarise_transition_centrality(
  network,
  directed = TRUE,
  pagerank_damping = 0.85,
  pagerank_tolerance = 1e-10,
  pagerank_max_iter = 1000L
)
```

Arguments

network	A first-order transition network.
directed	Treat the network as directed.
pagerank_damping	Damping factor for PageRank.
pagerank_tolerance	Convergence tolerance.
pagerank_max_iter	Maximum PageRank iterations.

Value

A data frame containing degree, strength, weighted closeness, unweighted betweenness, and PageRank centrality.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
network <- create_transition_network(sequences)
summarise_transition_centrality(network)
```

`test_sequence_group_difference` *Test a sequence group difference*

Description

Aggregates sequence metrics to the declared independent unit and performs a permutation or randomization test. For observational data the p-value tests exchangeability-based association only; it is not a causal estimate.

Usage

```
test_sequence_group_difference(
  data,
  design,
  metric = c("sequence_length", "transition_count", "state_prevalence",
    "subsequence_presence"),
  target_state = NULL,
  target_subsequence = NULL,
  sequence_id_col = "sequence_id",
  order_col = "sequence_order",
  state_col = "state",
  separator = " > ",
  n_permutations = 999L,
  alternative = c("two.sided", "greater", "less"),
  seed = 1L
)
```

Arguments

`data`	Long-format sequence data.
`design`	A comparison design.
`metric`	`"sequence_length"`, `"transition_count"`, `"state_prevalence"`, or `"subsequence_presence"`.
`target_state`	Required for state prevalence.
`target_subsequence`	Required for subsequence presence, expressed using `separator`.
`sequence_id_col`, `order_col`, `state_col`	Core sequence columns.
`separator`	Subsequence label separator.
`n_permutations`	Number of permutations.
`alternative`	Alternative hypothesis.
`seed`	Reproducibility seed.

Value

An object of class gp3_sequence_group_inference.

Examples

```
data <- data.frame(
  participant_id = rep(paste0("p", 1:8), each = 4L),
  sequence_id = rep(paste0("s", 1:8), each = 4L),
  sequence_order = rep(1:4, times = 8L),
  state = c(rep(c("A", "B", "C", "D"), 4L),
            rep(c("A", "A", "C", "D"), 4L)),
  group = rep(rep(c("control", "treatment"), each = 4L), each = 4L)
)
design <- declare_sequence_comparison_design("group", "participant_id",
                                             design = "randomized")
test_sequence_group_difference(data, design, metric = "state_prevalence",
                               target_state = "A", n_permutations = 99L)
```

---

validate_sequence_clusters

Validate sequence clusters descriptively

Description

Validate sequence clusters descriptively

Usage

```
validate_sequence_clusters(clustering, distance = NULL)
```

Arguments

clustering	A result from cluster_sequences() or a named assignment vector.
distance	Optional distance object when clustering is an assignment vector.

Value

A list containing overall validation metrics, cluster sizes, and per-sequence silhouette values.

Examples

```
sequences <- data.frame(
  sequence_id = rep(c("s1", "s2", "s3", "s4"), each = 4L),
  sequence_order = rep(1:4, times = 4L),
  state = c("A", "B", "C", "D", "A", "B", "C", "C",
            "D", "C", "B", "A", "D", "C", "A", "A"),
  group = rep(c("g1", "g2"), each = 8L),
  stringsAsFactors = FALSE
)
```

```
distance <- compute_sequence_distance(sequences)
fit <- cluster_sequences(distance, k = 2L)
validate_sequence_clusters(fit)
```

`validate_sequence_data` *Validate Long-Format Sequence Data*

Description

Produces a compact validation result based on `audit_sequence_data()` without modifying the input.

Usage

```
validate_sequence_data(
  data,
  sequence_id_col,
  order_col,
  state_col,
  duration_col = NULL,
  metadata_cols = NULL,
  expected_states = NULL
)
```

Arguments

`data`	A data frame containing ordered state observations.
`sequence_id_col`	Name of the sequence identifier column.
`order_col`	Name of the numeric sequence-order column.
`state_col`	Name of the categorical state column.
`duration_col`	Optional name of a numeric duration column.
`metadata_cols`	Optional character vector naming columns that should remain constant within each sequence.
`expected_states`	Optional vector of known or permitted state values.

Value

A named list containing `valid`, `status`, issue counts, the complete `audit` table, the column `mapping`, row and sequence counts, and observed `state_levels`. A result is valid when no error-severity issue is present. Review-severity issues do not automatically invalidate the input.

Examples

```
sequences <- data.frame(
  id = rep(c("s1", "s2"), each = 2L),
  position = rep(1:2, times = 2L),
  state = c("home", "search", "home", "product")
)

validation <- validate_sequence_data(
  sequences,
  sequence_id_col = "id",
  order_col = "position",
  state_col = "state"
)

validation$status
validation$valid
```

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