Package 'individual'

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Title Framework for Specifying and Simulating Individual Based Models

Version 0.1.7

Description A framework which provides users a set of useful primitive elements for specifying individual based simulation models, with special attention models for infectious disease epidemiology. Users build models by specifying variables for each characteristic of individuals in the simulated population by using data structures exposed by the package. The package provides efficient methods for finding subsets of individuals based on these variables, or cohorts. Cohorts can then be targeted for variable updates or scheduled for events. Variable updates queued during a time step are executed at the end of a discrete time step, and the code places no restrictions on how individuals are allowed to interact. These data structures are designed to provide an intuitive way for users to turn their conceptual model of a system into executable code, which is fast and memory efficient.

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`bernoulli_process` *Bernoulli process*

Description

Simulate a process where individuals in a given `from` state advance to the `to` state each time step with probability `rate`.

Usage

```
bernoulli_process(variable, from, to, rate)
```

Arguments

`variable`	a categorical variable.
`from`	a string representing the source category.
`to`	a string representing the destination category.
`rate`	the probability to move individuals between categories.

Value

a function which can be passed as a process to `simulation_loop`.

`Bitset` *A Bitset Class*

Description

This is a data structure that compactly stores the presence of integers in some finite set (`max_size`), and can efficiently perform set operations (union, intersection, complement, symmetric difference, set difference). WARNING: All operations are in-place so please use `$copy` if you would like to perform an operation without destroying your current bitset.

Public fields

`.bitset` a pointer to the underlying IterableBitset.

`max_size` the maximum size of the bitset.

Methods

Public methods:

- `Bitset$new()`
- `Bitset$insert()`
- `Bitset$remove()`
- `Bitset$size()`
- `Bitset$or()`
- `Bitset$and()`
- `Bitset$not()`
- `Bitset$xor()`
- `Bitset$set_difference()`
- `Bitset$sample()`
- `Bitset$choose()`
- `Bitset$copy()`
- `Bitset$to_vector()`
- `Bitset$clone()`

Method `new()`**:** create a bitset.

Usage:

```
Bitset$new(size, from = NULL)
```

Arguments:

`size` the size of the bitset.

`from` pointer to an existing IterableBitset to use; if `NULL` make empty bitset, otherwise copy existing bitset.

Method `insert()`: insert into the bitset.

Usage:

```
Bitset$insert(v)
```

Arguments:

`v` an integer vector of elements to insert.

Method `remove()`: remove from the bitset.

Usage:

```
Bitset$remove(v)
```

Arguments:

`v` an integer vector of elements (not indices) to remove.

Method `size()`: get the number of elements in the set.

Usage:

```
Bitset$size()
```

Method `or()`: to "bitwise or" or union two bitsets.

Usage:

```
Bitset$or(other)
```

Arguments:

`other` the other bitset.

Method `and()`: to "bitwise and" or intersect two bitsets.

Usage:

```
Bitset$and(other)
```

Arguments:

`other` the other bitset.

Method `not()`: to "bitwise not" or complement a bitset.

Usage:

```
Bitset$not(inplace)
```

Arguments:

`inplace` whether to overwrite the current bitset.

Method `xor()`: to "bitwise xor" or get the symmetric difference of two bitset (keep elements in either bitset but not in their intersection).

Usage:

```
Bitset$xor(other)
```

Arguments:

`other` the other bitset.

Method `set_difference()`: Take the set difference of this bitset with another (keep elements of this bitset which are not in `other`).

Usage:

```
Bitset$set_difference(other)
```

Arguments:

`other` the other bitset.

Method `sample()`**:** sample a bitset.

Usage:

```
Bitset$sample(rate)
```

Arguments:

`rate` the success probability for keeping each element, can be a single value for all elements or a vector of unique probabilities for keeping each element.

Method `choose()`**:** choose k random items in the bitset

Usage:

```
Bitset$choose(k)
```

Arguments:

`k` the number of items in the bitset to keep. The selection of these k items from N total items in the bitset is random, and k should be chosen such that $0 \leq k \leq N$.

Method `copy()`**:** returns a copy the bitset.

Usage:

```
Bitset$copy()
```

Method `to_vector()`**:** return an integer vector of the elements stored in this bitset.

Usage:

```
Bitset$to_vector()
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
Bitset$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

`CategoricalVariable` *CategoricalVariable Class*

Description

Represents a categorical variable for an individual. This class should be used for discrete variables taking values in a finite set, such as infection, health, or behavioral state. It should be used in preference to `IntegerVariable` if possible because certain operations will be faster.

Methods

Public methods:

- CategoricalVariable$new()
- CategoricalVariable$get_index_of()
- CategoricalVariable$get_size_of()
- CategoricalVariable$get_categories()
- CategoricalVariable$queue_update()
- CategoricalVariable$.update()
- CategoricalVariable$clone()

Method `new()`**:** Create a new CategoricalVariable

Usage:

```
CategoricalVariable$new(categories, initial_values)
```

Arguments:

`categories` a character vector of possible values

`initial_values` a character vector of the initial value for each individual

Method `get_index_of()`**:** return a `Bitset` for individuals with the given `values`

Usage:

```
CategoricalVariable$get_index_of(values)
```

Arguments:

`values` the values to filter

Method `get_size_of()`**:** return the number of individuals with the given `values`

Usage:

```
CategoricalVariable$get_size_of(values)
```

Arguments:

`values` the values to filter

Method `get_categories()`**:** return a character vector of possible values. Note that the order of the returned vector may not be the same order that was given when the variable was intitialized, due to the underlying unordered storage type.

Usage:

```
CategoricalVariable$get_categories()
```

Method `queue_update()`**:** queue an update for this variable

Usage:

```
CategoricalVariable$queue_update(value, index)
```

Arguments:

`value` the new value

`index` the indices of individuals whose value will be updated to the one specified in `value`. This may be either a vector of integers or a `Bitset`.

Method `.update()`**:**

Usage:

```
CategoricalVariable$.update()
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
CategoricalVariable$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

`categorical_count_renderer_process` *Render Categories*

Description

Renders the number of individuals in each category.

Usage

```
categorical_count_renderer_process(renderer, variable, categories)
```

Arguments

`renderer`	a `Render` object.
`variable`	a `CategoricalVariable` object.
`categories`	a character vector of categories to render.

Value

a function which can be passed as a process to `simulation_loop`.

DoubleVariable *DoubleVariable Class*

Description

Represents a continuous variable for an individual.

Methods

Public methods:

- DoubleVariable$new()
- DoubleVariable$get_values()
- DoubleVariable$get_index_of()
- DoubleVariable$get_size_of()
- DoubleVariable$queue_update()
- DoubleVariable$.update()
- DoubleVariable$clone()

Method `new()`**:** Create a new DoubleVariable.

Usage:

```
DoubleVariable$new(initial_values)
```

Arguments:

`initial_values` a numeric vector of the initial value for each individual.

Method `get_values()`**:** get the variable values.

Usage:

```
DoubleVariable$get_values(index = NULL)
```

Arguments:

`index` optionally return a subset of the variable vector. If `NULL`, return all values; if passed a `Bitset` or integer vector, return values of those individuals.

Method `get_index_of()`**:** return a `Bitset` giving individuals whose value lies in an interval $[a, b]$.

Usage:

```
DoubleVariable$get_index_of(a, b)
```

Arguments:

`a` lower bound

`b` upper bound

Method `get_size_of()`**:** return the number of individuals whose value lies in an interval Count individuals whose value lies in an interval $[a, b]$.

Usage:

```
DoubleVariable$get_size_of(a, b)
```

Arguments:

`a` lower bound

`b` upper bound

Method `queue_update()`**:** Queue an update for a variable. There are 4 types of variable update:

1. Subset update: The argument `index` represents a subset of the variable to update. The argument `values` should be a vector whose length matches the size of `index`, which represents the new values for that subset.
2. Subset fill: The argument `index` represents a subset of the variable to update. The argument `values` should be a single number, which fills the specified subset.
3. Variable reset: The index vector is set to `NULL` and the argument `values` replaces all of the current values in the simulation. `values` should be a vector whose length should match the size of the population, which fills all the variable values in the population
4. Variable fill: The index vector is set to `NULL` and the argument `values` should be a single number, which fills all of the variable values in the population.

Usage:

```
DoubleVariable$queue_update(values, index = NULL)
```

Arguments:

`values` a vector or scalar of values to assign at the index.

`index` is the index at which to apply the change, use `NULL` for the fill options. If using indices, this may be either a vector of integers or a `Bitset`.

Method `.update()`**:**

Usage:

```
DoubleVariable$.update()
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
DoubleVariable$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

`Event` *Event Class*

Description

Describes a general event in the simulation.

Methods

Public methods:

Method `new()`**:** Initialise an Event.

Usage:

```
Event$new()
```

Method `add_listener()`**:** Add an event listener.

Usage:

```
Event$add_listener(listener)
```

Arguments:

`listener` the function to be executed on the event, which takes a single argument giving the time step when this event is triggered.

Method `schedule()`**:** Schedule this event to occur in the future.

Usage:

```
Event$schedule(delay)
```

Arguments:

`delay` the number of time steps to wait before triggering the event, can be a scalar or a vector of values for events that should be triggered multiple times.

Method `clear_schedule()`**:** Stop a future event from triggering.

Usage:

```
Event$clear_schedule()
```

Method `.tick()`**:**

Usage:

```
Event$.tick()
```

Method `.process()`**:**

Usage:

```
Event$.process()
```

Method `.process_listener()`**:**

Usage:

```
Event$.process_listener(listener)
```

Method `.process_listener_cpp()`**:**

Usage:

```
Event$.process_listener_cpp(listener)
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
Event$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

`filter_bitset` *Filter a bitset*

Description

This non-modifying function returns a new `Bitset` object of the same maximum size as the original but which only contains those values at the indices specified by the argument `other`. Indices in `other` may be specified either as a vector of integers or as another bitset. Please note that filtering by another bitset is not a "bitwise and" intersection, and will have the same behavior as providing an equivalent vector of integer indices.

Usage

```
filter_bitset(bitset, other)
```

Arguments

`bitset`	the `Bitset` to filter
`other`	the values to keep (may be a vector of intergers or another `Bitset`)

`fixed_probability_multinomial_process` *Multinomial process*

Description

Simulates a two-stage process where all individuals in a given `source_state` sample whether to leave or not with probability `rate`; those who leave go to one of the `destination_states` with probabilities contained in the vector `destination_probabilities`.

Usage

```
fixed_probability_multinomial_process(
  variable,
  source_state,
  destination_states,
  rate,
  destination_probabilities
)
```

Arguments

variable	a CategoricalVariable object.
source_state	a string representing the source state.
destination_states	a vector of strings representing the destination states.
rate	probability of individuals in source state to leave.
destination_probabilities	probability vector of destination states.

Value

a function which can be passed as a process to simulation_loop.

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infection_age_process *Infection process for age-structured models*

Description

Simulates infection for age-structured models, where individuals contact each other at a rate given by some mixing (contact) matrix. The force of infection on susceptibles in a given age class is computed as:

$$\lambda_i = p \sum_j C_{i,j} \left(\frac{I_j}{N_j} \right)$$

Where C is the matrix of contact rates, p is the probability of infection per contact. The per-capita probability of infection for susceptible individuals is then:

$$1 - e^{-\lambda_i \Delta t}$$

.

Usage

```
infection_age_process(
  state,
  susceptible,
  exposed,
  infectious,
  age,
  age_bins,
  p,
  dt,
  mixing
)
```

Arguments

state	a CategoricalVariable object.
susceptible	a string representing the susceptible state (usually "S").
exposed	a string representing the state new infections go to (usually "E" or "I").
infectious	a string representing the infected and infectious state (usually "I").
age	a IntegerVariable giving the age of each individual.
age_bins	the total number of age bins (groups).
p	the probability of infection given a contact.
dt	the size of the time step (in units relative to the contact rates in mixing).
mixing	a mixing (contact) matrix between age groups.

Value

a function which can be passed as a process to simulation_loop.

IntegerVariable *IntegerVariable Class*

Description

Represents a integer valued variable for an individual. This class is similar to CategoricalVariable, but can be used for variables with unbounded ranges, or other situations where part of an individual's state is better represented by an integer, such as household or age bin.

Methods

Public methods:

- IntegerVariable$new()
- IntegerVariable$get_values()
- IntegerVariable$get_index_of()

- IntegerVariable$get_size_of()
- IntegerVariable$queue_update()
- IntegerVariable$.update()
- IntegerVariable$clone()

Method `new()`**:** Create a new IntegerVariable.

Usage:

```
IntegerVariable$new(initial_values)
```

Arguments:

`initial_values` a vector of the initial values for each individual

Method `get_values()`**:** Get the variable values.

Usage:

```
IntegerVariable$get_values(index = NULL)
```

Arguments:

`index` optionally return a subset of the variable vector. If `NULL`, return all values; if passed a `Bitset` or integer vector, return values of those individuals.

Method `get_index_of()`**:** Return a `Bitset` for individuals with some subset of values. Either search for indices corresponding to values in `set`, or for indices corresponding to values in range $[a, b]$. Either `set` or `a` and `b` must be provided as arguments.

Usage:

```
IntegerVariable$get_index_of(set = NULL, a = NULL, b = NULL)
```

Arguments:

`set` a vector of values (providing `set` means `a,b` are ignored)

`a` lower bound

`b` upper bound

Method `get_size_of()`**:** Return the number of individuals with some subset of values. Either search for indices corresponding to values in `set`, or for indices corresponding to values in range $[a, b]$. Either `set` or `a` and `b` must be provided as arguments.

Usage:

```
IntegerVariable$get_size_of(set = NULL, a = NULL, b = NULL)
```

Arguments:

`set` a vector of values (providing `set` means `a,b` are ignored)

`a` lower bound

`b` upper bound

Method `queue_update()`**:** Queue an update for a variable. There are 4 types of variable update:

1. Subset update: The argument `index` represents a subset of the variable to update. The argument `values` should be a vector whose length matches the size of `index`, which represents the new values for that subset.
2. Subset fill: The argument `index` represents a subset of the variable to update. The argument `values` should be a single number, which fills the specified subset.

3. Variable reset: The index vector is set to NULL and the argument values replaces all of the current values in the simulation. values should be a vector whose length should match the size of the population, which fills all the variable values in the population
4. Variable fill: The index vector is set to NULL and the argument values should be a single number, which fills all of the variable values in the population.

Usage:

```
IntegerVariable$queue_update(values, index = NULL)
```

Arguments:

values a vector or scalar of values to assign at the index

index is the index at which to apply the change, use NULL for the fill options. If using indices, this may be either a vector of integers or a Bitset.

Method .update()**:**

Usage:

```
IntegerVariable$.update()
```

Method clone()**:** The objects of this class are cloneable with this method.

Usage:

```
IntegerVariable$clone(deep = FALSE)
```

Arguments:

deep Whether to make a deep clone.

---

multi_probability_bernoulli_process

Overdispersed Bernoulli process

Description

Simulates a Bernoulli process where all individuals in a given source state from sample whether or not to transition to destination state to with a individual probability specified by the DoubleVariable object rate_variable.

Usage

```
multi_probability_bernoulli_process(variable, from, to, rate_variable)
```

Arguments

variable	a CategoricalVariable object.
from	a string representing the source state.
to	a string representing the destination state.
rate_variable	DoubleVariable giving individual probability of each individual in source state to leave.

Value

a function which can be passed as a process to simulation_loop.

multi_probability_multinomial_process *Overdispersed multinomial process*

Description

Simulates a two-stage process where all individuals in a given `source_state` sample whether to leave or not with a individual probability specified by the `DoubleVariable` object `rate_variable`; those who leave go to one of the `destination_states` with probabilities contained in the vector `destination_probabilities`.

Usage

```
multi_probability_multinomial_process(
  variable,
  source_state,
  destination_states,
  rate_variable,
  destination_probabilities
)
```

Arguments

`variable`	a `CategoricalVariable` object.
`source_state`	a string representing the source state.
`destination_states`	a vector of strings representing the destination states.
`rate_variable`	`DoubleVariable` giving individual probability of each individual in source state to leave
`destination_probabilities`	probability vector of destination states.

Value

a function which can be passed as a process to `simulation_loop`.

Render *Render*

Description

Class to render output for the simulation.

Methods

Public methods:

- Render$new()
- Render$set_default()
- Render$render()
- Render$to_dataframe()
- Render$clone()

Method `new()`**:** Initialise a renderer for the simulation, creates the default state renderers.

Usage:

```
Render$new(timesteps)
```

Arguments:

`timesteps` number of timesteps in the simulation.

Method `set_default()`**:** Set a default value for a rendered output renderers.

Usage:

```
Render$set_default(name, value)
```

Arguments:

`name` the variable to set a default for.

`value` the default value to set for a variable.

Method `render()`**:** Update the render with new simulation data.

Usage:

```
Render$render(name, value, timestep)
```

Arguments:

`name` the variable to render.

`value` the value to store for the variable.

`timestep` the time-step of the data point.

Method `to_dataframe()`**:** Return the render as a `data.frame`.

Usage:

```
Render$to_dataframe()
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
Render$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

reschedule_listener *Reschedule listener*

Description

Schedules a follow-up event as the result of an event firing.

Usage

```
reschedule_listener(event, delay)
```

Arguments

event	a TargetedEvent.
delay	the delay until the follow-up event.

simulation_loop *A premade simulation loop*

Description

Run a simulation where event listeners take precedence over processes for state changes.

Usage

```
simulation_loop(
  variables = list(),
  events = list(),
  processes = list(),
  timesteps
)
```

Arguments

variables	a list of Variables
events	a list of Events
processes	a list of processes to execute on each timestep
timesteps	the number of timesteps to simulate

Examples

```
population <- 4
timesteps <- 5
state <- CategoricalVariable$new(c('S', 'I', 'R'), rep('S', population))
renderer <- Render$new(timesteps)

transition <- function(from, to, rate) {
  return(function(t) {
    from_state <- state$get_index_of(from)
    state$queue_update(
      to,
      from_state$sample(rate)
    )
  })
}

processes <- list(
  transition('S', 'I', .2),
  transition('I', 'R', .1),
  transition('R', 'S', .05),
  categorical_count_renderer_process(renderer, state, c('S', 'I', 'R'))
)

simulation_loop(variables=list(state), processes=processes, timesteps=timesteps)
renderer$to_dataframe()
```

TargetedEvent *TargetedEvent Class*

Description

Describes a targeted event in the simulation. This is useful for events which are triggered for a sub-population.

Super class

individual::Event -> TargetedEvent

Methods

Public methods:

- TargetedEvent$new()
- TargetedEvent$schedule()
- TargetedEvent$get_scheduled()
- TargetedEvent$clear_schedule()
- TargetedEvent$.process_listener()
- TargetedEvent$.process_listener_cpp()

- TargetedEvent$clone()

Method `new()`**:** Initialise a TargetedEvent.

Usage:

```
TargetedEvent$new(population_size)
```

Arguments:

`population_size` the size of the population.

Method `schedule()`**:** Schedule this event to occur in the future.

Usage:

```
TargetedEvent$schedule(target, delay)
```

Arguments:

`target` the individuals to pass to the listener, this may be either a vector of integers or a `Bitset`.

`delay` the number of time steps to wait before triggering the event, can be a scalar in which case all targeted individuals are scheduled for for the same delay or a vector of values giving the delay for that individual.

Method `get_scheduled()`**:** Get the individuals who are scheduled as a `Bitset`.

Usage:

```
TargetedEvent$get_scheduled()
```

Method `clear_schedule()`**:** Stop a future event from triggering for a subset of individuals.

Usage:

```
TargetedEvent$clear_schedule(target)
```

Arguments:

`target` the individuals to clear, this may be either a vector of integers or a `Bitset`.

Method `.process_listener()`**:**

Usage:

```
TargetedEvent$.process_listener(listener)
```

Method `.process_listener_cpp()`**:**

Usage:

```
TargetedEvent$.process_listener_cpp(listener)
```

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
TargetedEvent$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

`update_category_listener` *Update category listener*

Description

Updates the category of a sub-population as the result of an event firing, to be used in the `TargetedEvent` class.

Usage

```
update_category_listener(variable, to)
```

Arguments

`variable`	a `CategoricalVariable` object.
`to`	a string representing the destination category.

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