Timewave Documentation

Release 0.6 [4 - Beta]

sonntagsgesicht, based on a fork of Deutsche Postbank [pbrisk

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CHAPTER 1

Introduction

1.1 Python library *timewave*

a stochastic process evolution simulation engine in python.

1.1.1 simulation engine

timewave consists of four building blocks.

1.2 The State

which evolves over time during a simulation path. It is the nucleus or node which marks a point of time in a path.

1.3 The Producer

is the objects that provides states to the simulation and does the actual time evolution. Think of the producer building as the constructor of a stochastic process like a Brownian motion or, less mathematical, future stock prices or future rain intensities.

1.4 The Consumer

is an object that takes a state as a point in time provided by the producer and consumes it, i.e. does something with it - the actual calculation if you like.

1.5 The Engine

finally, which organizes the creation of states by the producer and the consumption by the consumer. The engine uses, if present, multiprocessing, i.e. takes full advantage of multi cpu frameworks. Therefore the engine splits the simulation into equal but distinct chunks of path for the number of workers (by default the number of cpu) and loops over the set of dedicated path in each worker. Each path is evolved by the producer in states which are at each point in time consumed directly by consumers. States are, due to limits of resources, not stored during the simulation. If you like to, use the storage consumer to save all states.

1.6 main frame workflow

setup simulation by

```
engine = Engine(Producer(), Consumer())
engine.run(range(20))
```

then run loop starts by

```
producer/initialize()
```

setup workers (by default by the number of cpu's) on each worker start loop by

```
producer/consumer.initialize_worker()
```

and invoke loop over paths and start again with

```
producer/consumer.initialize_path()
```

then do time evolution of a path

```
producer.evolve() / consumer.consume()
```

and finish with last consumer in consumer stack

```
consumer[-1].finalize_path()
```

and

```
consumer[-1].finalize_worker()
```

put results into queue and take them out by

```
consumer[-1].put()/get(result)
```

finish simulation (kind of reduce method)

```
consumer[-1].finalize()
```

before returning results from run.

1.7 Development Version

The latest development version can be installed directly from GitHub:

```
$ pip install --upgrade git+https://github.com/sonntagsgesicht/timewave.git
```

1.8 Contributions

Issues and Pull Requests are always welcome.

1.9 License

Code and documentation are available according to the Apache Software License (see LICENSE).

CHAPTER 2

Tutorial

setup simulation by

```
engine = Engine(Producer(), Consumer())
engine.run(range(20))
```

then run loop starts by

```
producer/initialize()
```

setup workers (by default by the number of cpu's) on each worker start loop by

```
producer/consumer.initialize_worker()
```

and invoke loop over paths and start again with

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then do time evolution of a path

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consumer[-1].finalize_path()
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put results into queue and take them out by

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consumer[-1].put()/get(result)
```

finish simulation (kind of reduce method)

```
consumer[-1].finalize()
```

before returning results from run.

CHAPTER 3

API Documentation

3.1 Timewave Engine

Engine	This class implements Monte Carlo engine
State	simulation state
Producer	abstract class implementing simple producer for a model between grid dates
Consumer	base class for simulation consumers

module containing simulation method related classes incl. multiprocessing support

class `timewave.engine.`**`Producer`**(*func=None*, *initial_state=None*)

Bases: `object`

abstract class implementing simple producer for a model between grid dates

`initialize`(*grid*, *num_of_paths*, *seed*)

inits producer for a simulation run

`initialize_worker`(*process_num=None*)

inits producer for a simulation run on a single process

`initialize_path`(*path_num=None*)

inits producer for next path, i.e. sets current state to initial state

`evolve`(*new_date*)

evolve to the new process state at the next date, i.e. do one step in the simulation

Parameters **`new_date`** (*`date`*) – date of the new state

Return State

class `timewave.engine.`**`State`**(*value=0.0*)

Bases: `object`

simulation state

class `timewave.engine.`**`Engine`**(*producer=None*, *consumer=None*)

Bases: `object`

This class implements Monte Carlo engine

run (*grid=None*, *num_of_paths=2000*, *seed=0*, *num_of_workers=4*, *profiling=False*)
implements simulation

Parameters

- **grid** (`list (date)`) – list of Monte Carlo grid dates
- **num_of_paths** (`int`) – number of Monte Carlo paths
- **seed** (`hashable`) – seed used for rnds initialisation (additional adjustment in place)
- **or None num_of_workers** (`int`) – number of parallel workers (default: cpu_count()), if None no parallel processing is used
- **profiling** (`bool`) – signal whether to use profiling, True means used, else not

Return object final consumer state

It returns a list of lists. The list contains per path a list produced by consumer at observation dates

class `timewave.engine.`**Consumer** (*func=None*)
Bases: `object`

base class for simulation consumers

initiatlizes consumer by providing a function :param func: consumer function with exact 1 argument which will consume the producer state. Default will return *state.value*

initialize (*grid=None*, *num_of_paths=None*, *seed=None*)
initialize consumer for simulation :param num_of_paths: number of path :type num_of_paths: int :param grid: list of grid point :type grid: list(date) :param seed: simulation seed :type seed: hashable

initialize_worker (*process_num=None*)
reinitialize consumer for process in multiprocesing

initialize_path (*path_num=None*)
initialize consumer for next path

consume (*state*)
consume new producer state

finalize_path (*path_num=None*)
finalize last path for consumer

finalize_worker (*process_num=None*)
finalize process for consumer

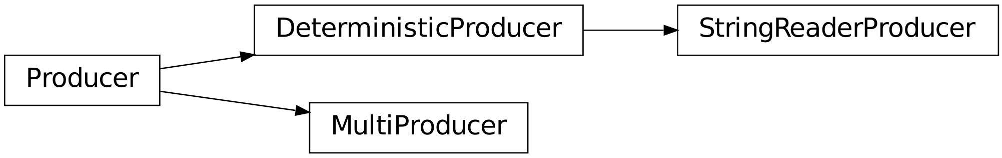
finalize ()
finalize simulation for consumer

put ()
to put state into multiprocessing.queue

get (*queue_get*)
to get states from multiprocessing.queue

3.2 Timewave Producer

DeterministicProducer	
StringReaderProducer	
MultiProducer	initializer



module containing brownian motion model related classes

class timewave.producers.**MultiProducer**(**producers*)

Bases: `timewave.engine.Producer`

initializer

Parameters or produces (`list (Producer)`) – list of producers to be used one after another

producers = None

list of consumers to be used one after another

Type list(*Producer*)

initialize(*grid, num_of_paths, seed*)

inits producer for a simulation run

initialize_worker(*process_num=None*)

inits producer for a simulation run on a single process

initialize_path(*path_num=None*)

inits producer for next path, i.e. sets current state to initial state

evolve(*new_date*)

evolve to the new process state at the next date, i.e. do one step in the simulation

Parameters new_date (`date`) – date of the new state

Return State

class timewave.producers.**DeterministicProducer**(*sample_list, func=None, initial_state=None*)

Bases: `timewave.engine.Producer`

evolve(*new_date*)

evolve to the new process state at the next date, i.e. do one step in the simulation

Parameters new_date (`date`) – date of the new state

Return State

class timewave.producers.**StringReaderProducer**(*data_str, str_decoder=None*)

Bases: `timewave.producers.DeterministicProducer`

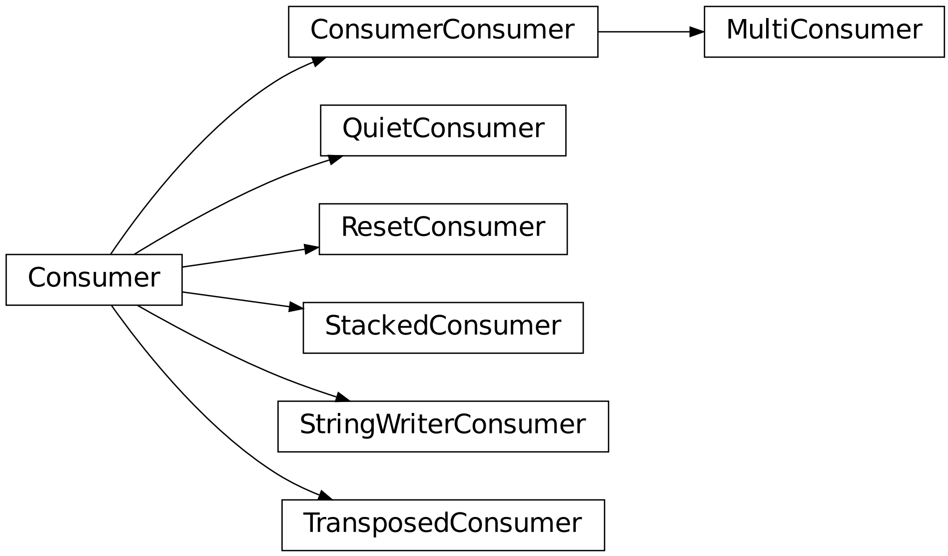
3.3 Timewave Consumer

`QuietConsumer`	QuietConsumer returns nothing, since QuietConsumer does simply not populate result in finalize_path()
`StringWriterConsumer`	
`StackedConsumer`	stacked version of consumer, i.e.

Continued on next page

Table 3 – continued from previous page

ConsumerConsumer	class implementing the consumer interface several consumers can be saved and are executed one after another only the result of the last consumer is returned (see finalize_worker)
MultiConsumer	initializer
ResetConsumer	FunctionConsumer that admits a reset function for each path
TransposedConsumer	TransposedConsumer returns sample distribution per grid point not per sample path



class timewave.consumers.**QuietConsumer**(*func=None*)

Bases: *timewave.engine.Consumer*

QuietConsumer returns nothing, since QuietConsumer does simply not populate result in finalize_path()

initiatlizes consumer by providing a function :param func: consumer function with exact 1 argument which will consume the producer state. Default will return *state.value*

finalize_path(*path_num=None*)

QuietConsumer does simply not populate result in finalize_path()

finalize()

finalize simulation for consumer

class timewave.consumers.**StringWriterConsumer**(*str_decoder=None*)

Bases: *timewave.engine.Consumer*

finalize()

finalize simulation for consumer

class timewave.consumers.**ResetConsumer**(*fixing_func=None*, *reset_func=None*)

Bases: *timewave.engine.Consumer*

FunctionConsumer that admits a reset function for each path

initialize_path (*path_num=None*)
initialize consumer for next path

finalize ()
finalize simulation for consumer

class timewave.consumers.**StackedConsumer** (**consumers*)
Bases: *timewave.engine.Consumer*

stacked version of consumer, i.e. a following consumer is populated with out state of the preceding one

initialize (*num_of_paths=None*, *grid=None*, *seed=None*)
initialize StackedConsumer

initialize_path (*path_num=None*)
make the consumer_state ready for the next MC path

Parameters **path_num** (*int*) –

consume (*state*)
consume new producer state

finalize_path (*path_num=None*)
finalize path and populate result for ConsumerConsumer

finalize ()
finalize for ConsumerConsumer

put ()
to put state into multiprocessing.queue

get (*queue_get*)
to get states from multiprocessing.queue

class timewave.consumers.**ConsumerConsumer** (**consumers*)
Bases: *timewave.engine.Consumer*

class implementing the consumer interface several consumers can be saved and are executed one after another only the result of the last consumer is returned (see finalize_worker)

initializer

Parameters **list (Consumer)** –

initial_state = None
list of consumers to be used one after another

Type list(*Consumer*)

initialize (*grid=None*, *num_of_paths=None*, *seed=None*)
initialize ConsumerConsumer

initialize_path (*path_num=None*)
make the consumer_state ready for the next MC path

Parameters **path_num** (*int*) –

consume (*state*)
returns pair containing the result of consumption and consumer state the returned state is equal to the state.get_short_rate() the returned consume state is None

Parameters **state** (State) – specific process state

Return object the new consumer state

finalize_path (*path_num=None*)
finalize path and populate result for ConsumerConsumer

finalize ()
finalize for ConsumerConsumer

get (*queue_get*)
get to given consumer states. This function is used for merging of results of parallelized MC. The first state is used for merging in place. The states must be disjoint.

Parameters **queue_get** (*object*) – second consumer state

class timewave.consumers.**MultiConsumer** (**consumers*)
Bases: *timewave.consumers.ConsumerConsumer*

initializer

Parameters **list (Consumer)** –

consume (*state*)
returns pair containing the result of consumption and consumer state the returned state is equal to the state.get_short_rate() the returned consume state is None

Parameters **state** (State) – specific process state

Return object the new consumer state

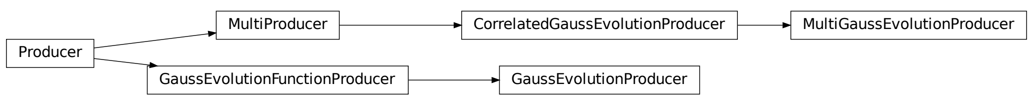
class timewave.consumers.**TransposedConsumer** (*func=None*)
Bases: *timewave.engine.Consumer*

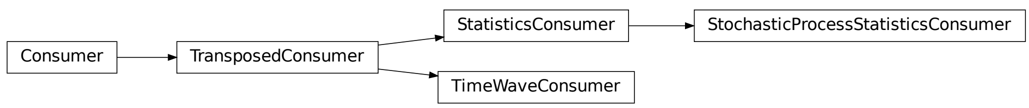
TransposedConsumer returns sample distribution per grid point not per sample path

initiatlizes consumer by providing a function :param func: consumer function with exact 1 argument which will consume the producer state. Default will return *state.value*

finalize ()
finalize for PathConsumer

3.4 Stochastic Process Simulation





module containing stochastic process model producer

class timewave.stochasticproducer.**GaussEvolutionFunctionProducer** (*func=None, initial_state=None, length=None*)
Bases: *timewave.engine.Producer*

class implementing general Gauss process between grid dates

Parameters

- **func** (*callable*) – evolve function, e.g. *lambda x, s, e, q: x + sqrt(e - s) * q* by default with *x* current state value, *s* current point in time, i.e. start point of next evolution step, *e* next point in time, i.e. end point of evolution step, *q* standard normal random number to do step
- **initial_state** – initial state (value) of evolution,
- **or None length** (*int*) – length of *q* as a list of Gauss random numbers, if *None* or *0* the evolution function *func* will be invoked with *q* not as a list but a float random number.

class implementing general Gauss process between grid dates and provides state to any evolve style function *foo(x, s, e, q)* with *x* last state, *s* last state time, *e* current point in time and *q* current Gauss process state

evolve (*new_date*)
evolve to the new process state at the next date

Parameters new_date (*date*) – date or point in time of the new state

Return State

class timewave.stochasticproducer.**GaussEvolutionProducer** (*process*)
Bases: *timewave.stochasticproducer.GaussEvolutionFunctionProducer*

producer to bring diffusion process to life

Parameters process (StochasticProcess) – diffusion process to evolve

class timewave.stochasticproducer.**CorrelatedGaussEvolutionProducer** (*producers, correlation=None, diffusion_driver=None*)
Bases: *timewave.producers.MultiProducer*

class implementing general correlated Gauss process between grid dates

Parameters

- **producers** (*list (GaussEvolutionProducer)*) – list of producers to evolve
- **or dict((StochasticProcess, StochasticProcess)** (*list(list(float))*) – float) or None correlation: correlation matrix of underlying multivariate Gauss process of diffusion drivers. If *dict* keys must be pairs of diffusion drivers, diagonal and zero entries can be omitted. If not give, all drivers evolve independently.
- **or None diffusion_driver** (*list(StochasticProcess)*) – list of diffusion drivers indexing the correlation matrix. If not given and *correlation* is not an IndexMatrix, e.g. comes already with list of drivers, it is assumed that each process producer has different drivers and the correlation is order in the same way.

evolve (*new_date*)
evolve to the new process state at the next date

Parameters new_date (*date*) – date or point in time of the new state

Return State

class timewave.stochasticproducer.**MultiGaussEvolutionProducer** (*process_list, correlation=None, diffusion_driver=None*)
Bases: *timewave.stochasticproducer.CorrelatedGaussEvolutionProducer*

class implementing multi variant GaussEvolutionProducer

class timewave.stochasticconsumer.**StatisticsConsumer**(*func=None*, *statistics=None*, ***kwargs*)

Bases: *timewave.consumers.TransposedConsumer*

run basic statistics on storage consumer result per time slice

finalize()

finalize for StatisticsConsumer

class timewave.stochasticconsumer.**StochasticProcessStatisticsConsumer**(*func=None*, *statistics=None*, ***kwargs*)

Bases: *timewave.stochasticconsumer.StatisticsConsumer*

run basic statistics on storage consumer result as a stochastic process

finalize()

finalize for StochasticProcessStatisticsConsumer

class timewave.stochasticconsumer.**TimeWaveConsumer**(*func=None*)

Bases: *timewave.consumers.TransposedConsumer*

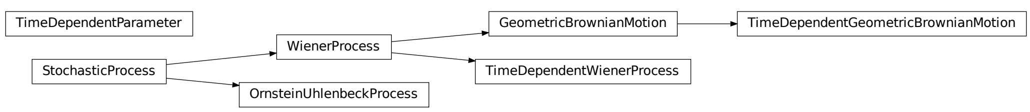
initiatlizes consumer by providing a function :param func: consumer function with exact 1 argument which will consume the producer state. Default will return *state.value*

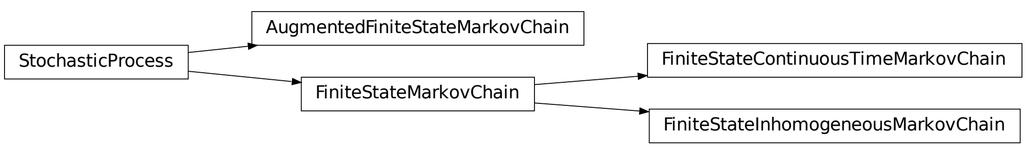
finalize()

finalize for PathConsumer

3.5 Stochastic Process Definition

stochasticprocess.base.StochasticProcess	base class for stochastic process X, e.g. Wiener process W or Markov chain M
stochasticprocess.base.MultivariateStochasticProcess	base class for stochastic process X, e.g. Wiener process W or Markov chain M





class timewave.stochasticprocess.base.**StochasticProcess** (*start*)
Bases: object

base class for stochastic process X, e.g. Wiener process W or Markov chain M

Parameters **start** – initial state X_0

classmethod random ()
initializes stochastic process with some randomly generated parameters

Return type *StochasticProcess*

diffusion_driver
diffusion driver are the underlying *dW* of each process *X* in a SDE like *dX = m dt + s dW*

Return list(StochasticProcess)

evolve (*x, s, e, q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)
expected value of time t increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time t increment

median (*t*)

variance (*t*)
second central moment of time t increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time t increment

stdev (*t*)

skewness (*t*)

kurtosis (*t*)

class timewave.stochasticprocess.base.**MultivariateStochasticProcess** (*start*)
Bases: *timewave.stochasticprocess.base.StochasticProcess*

base class for stochastic process X, e.g. Wiener process W or Markov chain M

Parameters **start** – initial state X_0

class timewave.stochasticprocess.gauss.**WienerProcess** (*mu=0.0, sigma=1.0, start=0.0*)
Bases: *timewave.stochasticprocess.base.StochasticProcess*

class implementing general Gauss process between grid dates

evolve (*x*, *s*, *e*, *q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)
expected value of time t increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time t increment

median (*t*)

variance (*t*)
second central moment of time t increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time t increment

class timewave.stochasticprocess.gauss.**OrnsteinUhlenbeckProcess** (*theta=0.1*, *mu=0.1*, *sigma=0.1*, *start=0.0*)

Bases: *timewave.stochasticprocess.base.StochasticProcess*

class implementing Ornstein Uhlenbeck process

Parameters

- **theta** (*flaot*) – mean reversion speed
- **mu** (*float*) – drift
- **sigma** (*float*) – diffusion
- **start** (*float*) – initial value

$$dx_t = \theta(\mu - x_t)dt + \sigma dW_t, x_0 = a$$

evolve (*x*, *s*, *e*, *q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)
expected value of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time *t* increment

variance (*t*)
second central moment of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time *t* increment

class timewave.stochasticprocess.gauss.**GeometricBrownianMotion** (*mu=0.0*, *sigma=1.0*, *start=1.0*)

Bases: *timewave.stochasticprocess.gauss.WienerProcess*

class implementing general Gauss process between grid dates

evolve (*x*, *s*, *e*, *q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)
expected value of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time *t* increment

median (*t*)

variance (*t*)
second central moment of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time *t* increment

skewness (*t*)

kurtosis (*t*)

class timewave.stochasticprocess.gauss.**TimeDependentParameter** (*parameter=0.0*, *time=1.0*)

Bases: object

integrate (*s*, *e*)

class timewave.stochasticprocess.gauss.**TimeDependentWienerProcess**(*mu=0.0, sigma=1.0, time=1.0, start=0.0*)

Bases: *timewave.stochasticprocess.gauss.WienerProcess*

class implementing a Gauss process with time depending drift and diffusion

class timewave.stochasticprocess.gauss.**TimeDependentGeometricBrownianMotion**(*mu=0.0, sigma=1.0, time=1.0, start=1.0*)

Bases: *timewave.stochasticprocess.gauss.GeometricBrownianMotion*

class timewave.stochasticprocess.markovchain.**FiniteStateMarkovChain**(*transition=None, r_squared=1.0, start=None*)

Bases: *timewave.stochasticprocess.base.StochasticProcess*

Parameters

- **transition** (*list*) – stochastic matrix of transition probabilities, i.e. np.ndarray with shape=2 and sum of each line equal to 1 (optional) default: identity matrix
- **r_squared** (*float*) – square of systematic correlation in factor simulation (optional) default: 1.
- **start** (*list*) – initial state distribution, i.e. np.ndarray with shape=1 or list, adding up to 1, (optional) default: unique distribution

transition

r_squared

classmethod random(*d=5*)

initializes stochastic process with some randomly generated parameters

Return type *StochasticProcess*

evolve(*x, s, e, q*)

evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean(*t*)

expected value of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time *t* increment

variance(*t*)

second central moment of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time t increment

covariance (*t*)

class timewave.stochasticprocess.markovchain.**FiniteStateContinuousTimeMarkovChain** (*transitio r_square start=N*

Bases: *timewave.stochasticprocess.markovchain.FiniteStateMarkovChain*

class timewave.stochasticprocess.markovchain.**FiniteStateInhomogeneousMarkovChain** (*transition r_squared start=Nor*

Bases: *timewave.stochasticprocess.markovchain.FiniteStateMarkovChain*

classmethod random (*d=5*, *l=3*)
initializes stochastic process with some randomly generated parameters

Return type *StochasticProcess*

class timewave.stochasticprocess.markovchain.**AugmentedFiniteStateMarkovChain** (*underlying, augmentation=None*)

Bases: *timewave.stochasticprocess.base.StochasticProcess*

Parameters

- **underlying** (FiniteStateMarkovChain) – underlying Markov chain stochastic process
- **augmentation** (*callable*) – function $f : S \to \mathbb{R}$ defined on single states to weight augmentation (aggregate) of state distributions (optional) default: $f = id$ Augmentation argument can be list or tuple, too. In this case `__getitem__` is called.

classmethod random (*d=5*, *augmentation=None*)
initializes stochastic process with some randomly generated parameters

Return type *StochasticProcess*

diffusion_driver
diffusion driver are the underlying *dW* of each process *X* in a SDE like *dX = m dt + s dW*

Return list(StochasticProcess)

start

evolve (*x*, *s*, *e*, *q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

eval (*s*)

mean (*t*)
expected value of time t increment

Parameters t (*float*) –

Return type float

Returns expected value of time *t* increment

variance (*t*)
second central moment of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time *t* increment

class timewave.stochasticprocess.multifactor.**SABR** (*alpha=0.1, beta=0.2, nu=0.3, rho=-0.2, start=0.05*)
Bases: *timewave.stochasticprocess.base.MultivariateStochasticProcess*

class implementing the Hagan et al SABR model

evolve (*x, s, e, q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)
expected value of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time *t* increment

variance (*t*)
second central moment of time *t* increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time *t* increment

class timewave.stochasticprocess.multifactor.**MultiGauss** (*mu=[0.0], covar=[[1.0]], start=[0.0]*)
Bases: *timewave.stochasticprocess.base.MultivariateStochasticProcess*

class implementing multi dimensional brownian motion

evolve (*x, s, e, q*)
evolves process state *x* from *s* to *e* in time depending of standard normal random variable *q*

Parameters

- **x** (*object*) – current state value, i.e. value before evolution step
- **s** (*float*) – current point in time, i.e. start point of next evolution step
- **e** (*float*) – next point in time, i.e. end point of evolution step
- **q** (*float*) – standard normal random number to do step

Returns next state value, i.e. value after evolution step

Return type object

mean (*t*)

expected value of time t increment

Parameters **t** (*float*) –

Return type float

Returns expected value of time t increment

variance (*t*)

second central moment of time t increment

Parameters **t** (*float*) –

Return type float

Returns variance, i.e. second central moment of time t increment

CHAPTER 4

Releases

These changes are listed in decreasing version number order.

4.1 Release 0.6

Release date was Wednesday, 18 September 2019

4.2 Release 0.5

Release date was July 14th, 2018

4.3 Release 0.4

Release date was July 7th, 2017

4.4 Release 0.3

Release date was April 27th, 2017

4.5 Release 0.2

Release date was April 2nd, 2017

4.6 Release 0.1

Release date was April 2nd, 2016

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