QMCPy

Release 1.3

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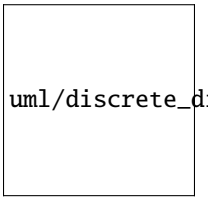
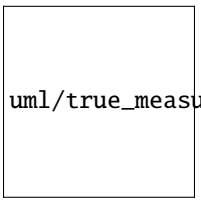
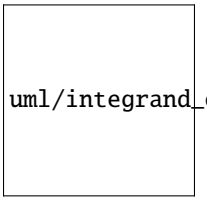
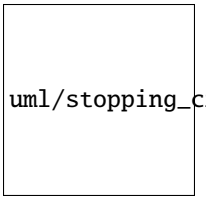
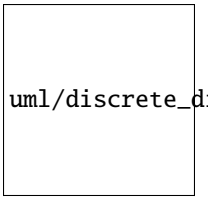








3.1 Discrete Distribution Class



3.1.1 Abstract Discrete Distribution Class

3.1.2 Digital Net Base 2

3.1.3 Lattice

class qmcpy.discrete_distribution.lattice.lattice.**Lattice**(*dimension=1*, *randomize=True*, *order='natural'*, *seed=None*, *generating_vector='lattice_vec.3600.20.npy'*, *d_max=None*, *m_max=None*)

Quasi-Random Lattice nets in base 2.

```
>>> l = Lattice(2,seed=7)
>>> l.gen_samples(4)
array([[0.04386058, 0.58727432],
       [0.54386058, 0.08727432],
       [0.29386058, 0.33727432],
       [0.79386058, 0.83727432]])
>>> l.gen_samples(1)
array([[0.04386058, 0.58727432]])
>>> l
Lattice (DiscreteDistribution Object)
    d               2^(1)
    dvec            [0 1]
    randomize       1
    order           natural
    entropy         7
    spawn_key       ()
>>> Lattice(dimension=2,randomize=False,order='natural').gen_samples(4, warn=False)
array([[0.  , 0.  ],
       [0.5 , 0.5 ],
       [0.25, 0.75],
       [0.75, 0.25]])
>>> Lattice(dimension=2,randomize=False,order='linear').gen_samples(4, warn=False)
array([[0.  , 0.  ],
       [0.25, 0.75],
       [0.5 , 0.5 ],
       [0.75, 0.25]])
>>> Lattice(dimension=2,randomize=False,order='mps').gen_samples(4, warn=False)
array([[0.  , 0.  ],
       [0.5 , 0.5 ],
       [0.25, 0.75],
       [0.75, 0.25]])
```

References

[1] Sou-Cheng T. Choi, Yuhan Ding, Fred J. Hickernell, Lan Jiang, Lluis Antoni Jimenez Rugama, Da Li, Jagadeeswaran Rathinavel, Xin Tong, Kan Zhang, Yizhi Zhang, and Xuan Zhou, GAIL: Guaranteed Automatic Integration Library (Version 2.3) [MATLAB Software], 2019. Available from http://gailgithub.github.io/GAIL_Dev/

[2] F.Y. Kuo & D. Nuyens. Application of quasi-Monte Carlo methods to elliptic PDEs with random diffusion coefficients - a survey of analysis and implementation, Foundations of Computational Mathematics, 16(6):1631-1696, 2016. springer link: https://link.springer.com/article/10.1007/s10208-016-9329-5 arxiv link: https://arxiv.org/abs/1606.06613

[3] D. Nuyens, *The Magic Point Shop of QMC point generators and generating vectors.* MATLAB and Python software, 2018. Available from https://people.cs.kuleuven.be/~dirk.nuyens/

[4] Constructing embedded lattice rules for multivariate integration R Cools, FY Kuo, D Nuyens - SIAM J. Sci. Comput., 28(6), 2162-2188.

[5] L'Ecuyer, Pierre & Munger, David. (2015). LatticeBuilder: A General Software Tool for Constructing Rank-1 Lattice Rules. ACM Transactions on Mathematical Software. 42. 10.1145/2754929.

__init__(*dimension=1*, *randomize=True*, *order='natural'*, *seed=None*, *generating_vector='lattice_vec.3600.20.npy'*, *d_max=None*, *m_max=None*)

Parameters

- **dimension** (*int or ndarray*) – dimension of the generator. If an int is passed in, use sequence dimensions [0,…,dimensions-1]. If a ndarray is passed in, use these dimension indices in the sequence.
- **randomize** (*bool*) – If True, apply shift to generated samples. Note: Non-randomized lattice sequence includes the origin.
- **order** (*str*) – 'linear', 'natural', or 'mps' ordering.
- **seed** (*None or int or numpy.random.SeedSeq*) – seed the random number generator for reproducibility
- **generating_vector** (*ndarray or str*) – generating matrix or path to generating matrices. ndarray should have shape (d_max). a string generating_vector should be formatted like 'lattice_vec.3600.20.npy' where 'name.d_max.m_max.npy'
- **d_max** (*int*) – maximum dimension
- **m_max** (*int*) – 2^m_max is the max number of supported samples

---

Note: d_max and m_max are required if generating_vector is a ndarray. If generating_vector is an string (path), d_max and m_max can be taken from the file name if None

---

gen_samples(*n=None*, *n_min=0*, *n_max=8*, *warn=True*, *return_unrandomized=False*)

Generate lattice samples

Parameters

- **n** (*int*) – if n is supplied, generate from n_min=0 to n_max=n samples. Otherwise use the n_min and n_max explicitly supplied as the following 2 arguments
- **n_min** (*int*) – Starting index of sequence.
- **n_max** (*int*) – Final index of sequence.

- **return_unrandomized** (*bool*) – return samples without randomization as 2nd return value. Will not be returned if randomize=False.

Returns
(n_max-n_min) x d (dimension) array of samples

Return type
ndarray

Note: Lattice generates in blocks from 2**m to 2**(m+1) so generating n_min=3 to n_max=9 requires necessarily produces samples from n_min=2 to n_max=16 and automatically subsets. May be inefficient for non-powers-of-2 samples sizes.

---

pdf(*x*)

pdf of a standard uniform

3.1.4 Halton

3.1.5 IID Standard Uniform

class qmcpy.discrete_distribution.iid_std_uniform.**IIDStdUniform**(*dimension=1*, *seed=None*)

A wrapper around NumPy's IID Standard Uniform generator *numpy.random.rand*.

```
>>> dd = IIDStdUniform(dimension=2,seed=7)
>>> dd.gen_samples(4)
array([[0.04386058, 0.58727432],
       [0.3691824 , 0.65212985],
       [0.69669968, 0.10605352],
       [0.63025643, 0.13630282]])
>>> dd
IIDStdUniform (DiscreteDistribution Object)
    d               2^(1)
    entropy         7
    spawn_key       ()
```

__init__(*dimension=1*, *seed=None*)

Parameters

- **dimension** (*int*) – dimension of samples
- **seed** (*None or int or numpy.random.SeedSeq*) – seed the random number generator for reproducibility

gen_samples(*n*)

Generate samples

Parameters
n (*int*) – Number of observations to generate

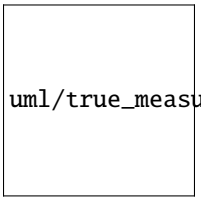
Returns
n x self.d array of samples

Return type
ndarray

pdf(*x*)

ABSTRACT METHOD to evaluate pdf of distribution the samples mimic at locations of x.

3.2 True Measure Class



3.2.1 Abstract Measure Class

3.2.2 Uniform

3.2.3 Gaussian

3.2.4 Brownian Motion

3.2.5 Lebesgue

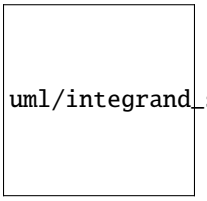
3.2.6 Continuous Bernoulli

3.2.7 Johnson's SU

3.2.8 Kumaraswamy

3.2.9 SciPy Wrapper

3.3 Integrand Class



3.3.1 Abstract Integrand Class

3.3.2 Custom Function

3.3.3 Keister Function

3.3.4 Box Integral

3.3.5 European Option

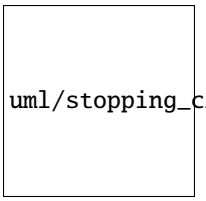
3.3.6 Asian Option

3.3.7 Multilevel Call Options with Milstein Discretization

3.3.8 Linear Function

3.3.9 Sobol' Indices

3.4 Stopping Criterion Algorithms



3.4.1 Abstract Stopping Criterion Class

3.4.2 Guaranteed Digital Net Cubature (QMC)

3.4.3 Guaranteed Lattice Cubature (QMC)

3.4.4 Bayesian Lattice Cubature (QMC)

3.4.5 Bayesian Digital Net Cubature (QMC)

3.4.6 CLT QMC Cubature (with Replications)

3.4.7 Guaranteed MC Cubature

3.4.8 CLT MC Cubature

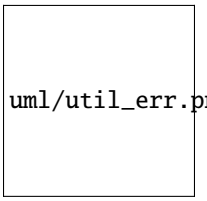
3.4.9 Continuation Multilevel QMC Cubature

3.4.10 Multilevel QMC Cubature

3.4.11 Continuation Multilevel MC Cubature

3.4.12 Multilevel MC Cubature

3.5 Utilities



qmcpy.util.latnetbuilder_linker.**latnetbuilder_linker**(*lnb_dir='./'*, *out_dir='./'*, *fout_prefix='lnb4qmcpy'*)

Parameters

- **lnb_dir** (*str*) – relative path to directory where *outputMachine.txt* is stored e.g. 'my_lnb/poly_lat/'
- **out_dir** (*str*) – relative path to directory where output should be stored e.g. 'my_lnb/poly_lat_qmcpy/'
- **fout_prefix** (*str*) – start of output file name. e.g. 'my_poly_lat_vec'

Returns

path to file which can be passed into QMCPy's Lattice or Sobol' in order to use
the linked latnetbuilder generating vector/matrix e.g. 'my_poly_lat_vec.10.16.npy'

Return type
str

Adapted from latnetbuilder parser:
https://github.com/umontreal-simul/latnetbuilder/blob/master/python-wrapper/latnetbuilder/parse_output.py#L74

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