scikit-allel Documentation

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This package provides utilities for exploratory analysis of large scale genetic variation data. It is based on numpy, scipy and other established Python scientific libraries.

- Source: https://github.com/cggh/scikit-allel

- Documentation: http://scikit-allel.readthedocs.org/

- Download: https://pypi.python.org/pypi/scikit-allel

- Gitter: https://gitter.im/cggh/pygenomics

Please feel free to ask questions via cggh/pygenomics on Gitter. Release announcements are posted to the cggh/pygenomics Gitter channel and the biovalidation mailing list. If you find a bug or would like to suggest a feature, please raise an issue on GitHub.

This site provides reference documentation for *scikit-allel*. For worked examples with real data, see the following articles:

- Introducing scikit-allel

- A tour of scikit-allel

-

- Fast PCA

If you would like to cite *scikit-allel* please use the DOI below.

Why "scikit-allel"?

"SciKits" (short for SciPy Toolkits) are add-on packages for SciPy, hosted and developed separately and independently from the main SciPy distribution.

"Allel" (Greek $\lambda\lambda\lambda$) is the root of the word "allele" short for "allelomorph", a word coined by William Bateson to mean variant forms of a gene. Today we use "allele" to mean any of the variant forms found at a site of genetic variation, such as the different nucleotides observed at a single nucleotide polymorphism (SNP).

Installation

This package requires [numpy](), [scipy](), [matplotlib](), [seaborn](), [pandas](), [scikit-learn](), [h5py](), [numexpr](), [bcolz](), [zarr](), [dask]() and [petl](). Please install these dependencies first, then use pip to install scikit-allel:

```
$ pip install -U scikit-allel
```

Contents

3.1 Data structures

3.1.1 In-memory data structures

This module defines NumPy array classes for variant call data.

Please note, functions and command line utilities for converting variant call data from the VCF file format into NumPy arrays and HDF5 files are available from the vcfnp package.

GenotypeArray

class `allel.model.ndarray.`**`GenotypeArray`**

Array of discrete genotype calls.

> **Parameters** **data** : array_like, int, shape (n_variants, n_samples, ploidy)
>
> > Genotype data.
>
> > ****kwargs** : keyword arguments
>
> > > All keyword arguments are passed through to `numpy.array()`.

Notes

This class represents data on discrete genotype calls as a 3-dimensional numpy array of integers. By convention the first dimension corresponds to the variants genotyped, the second dimension corresponds to the samples genotyped, and the third dimension corresponds to the ploidy of the samples.

Each integer within the array corresponds to an **allele index**, where 0 is the reference allele, 1 is the first alternate allele, 2 is the second alternate allele, ... and -1 (or any other negative integer) is a missing allele call. A single byte integer dtype (int8) can represent up to 127 distinct alleles, which is usually sufficient. The actual alleles (i.e., the alternate nucleotide sequences) and the physical positions of the variants within the genome of an organism are stored in separate arrays, discussed elsewhere.

Arrays of this class can store either **phased or unphased** genotype calls. If the genotypes are phased (i.e., haplotypes have been resolved) then individual haplotypes can be extracted by converting to a *HaplotypeArray* then indexing the second dimension. If the genotype calls are unphased then the ordering of alleles along the third (ploidy) dimension is arbitrary. N.B., this means that an unphased diploid heterozygous call could be stored as (0, 1) or equivalently as (1, 0).

A genotype array can store genotype calls with any ploidy > 1. For haploid calls, use a *HaplotypeArray*. Note that genotype arrays are not capable of storing calls for samples with differing or variable ploidy.

With genotype data on large numbers of variants and/or samples, storing the genotype calls in memory as an uncompressed numpy array if integers may be impractical. For working with large arrays of genotype data, see the *allel.model.chunked.GenotypeChunkedArray* class, which provides an alternative implementation of this interface using chunked compressed arrays.

Examples

Instantiate a genotype array:

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]], dtype='i1')
>>> g.dtype
dtype('int8')
>>> g.ndim
3
>>> g.shape
(3, 2, 2)
>>> g.n_variants
3
>>> g.n_samples
2
>>> g.ploidy
2
```

Genotype calls for a single variant at all samples can be obtained by indexing the first dimension, e.g.:

```
>>> g[1]
array([[0, 1],
       [1, 1]], dtype=int8)
```

Genotype calls for a single sample at all variants can be obtained by indexing the second dimension, e.g.:

```
>>> g[:, 1]
array([[ 0,  1],
       [ 1,  1],
       [-1, -1]], dtype=int8)
```

A genotype call for a single sample at a single variant can be obtained by indexing the first and second dimensions, e.g.:

```
>>> g[1, 0]
array([0, 1], dtype=int8)
```

A genotype array can store polyploid calls, e.g.:

```
>>> g = allel.GenotypeArray([[[0, 0, 0], [0, 0, 1]],
...                          [[0, 1, 1], [1, 1, 1]],
...                          [[0, 1, 2], [-1, -1, -1]]],
...                          dtype='i1')
>>> g.ploidy
3
```

n_variants
    Number of variants (length of first array dimension).

n_samples
  Number of samples (length of second array dimension).

ploidy
  Sample ploidy (length of third array dimension).

mask
  A boolean mask associated with this genotype array, indicating genotype calls that should be filtered (i.e., excluded) from genotype and allele counting operations.

Notes

This is a lightweight genotype call mask and **not** a mask in the sense of a numpy masked array. This means that the mask will only be taken into account by the genotype and allele counting methods of this class, and is ignored by any of the generic methods on the ndarray class or by any numpy ufuncs.

Note also that the mask may not survive any slicing, indexing or other subsetting procedures (e.g., call to `numpy.compress()` or `numpy.take()`). I.e., the mask will have to be similarly indexed then reapplied. The only exceptions are simple slicing operations that preserve the dimensionality and ploidy of the array, and the subset() method, both of which **will** preserve the mask if present.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]], dtype='i1')
>>> g.count_called()
5
>>> g.count_alleles()
AlleleCountsArray((3, 3), dtype=int32)
[[3 1 0]
 [1 3 0]
 [1 0 1]]
>>> mask = [[True, False], [False, True], [False, False]]
>>> g.mask = mask
>>> g.count_called()
3
>>> g.count_alleles()
AlleleCountsArray((3, 3), dtype=int32)
[[1 1 0]
 [1 1 0]
 [1 0 1]]
```

fill_masked(*value=-1*, *mask=None*, *copy=True*)
  Fill masked genotype calls with a given value.

> **Parameters value** : int, optional
>
>> The fill value.
>
> **mask** : array_like, bool, shape (n_variants, n_samples), optional
>
>> A boolean array where True elements indicate genotype calls to be filled. If not provided, value of the *mask* property will be used.
>
> **copy** : bool, optional

If False, modify the array in place.

> **Returns g** : GenotypeArray

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]], dtype='i1')
>>> mask = [[True, False], [False, True], [False, False]]
>>> g.mask = mask
>>> g.fill_masked()
GenotypeArray((3, 2, 2), dtype=int8)
[[[-1 -1]
  [ 0  1]]
 [[ 0  1]
  [-1 -1]]
 [[ 0  2]
  [-1 -1]]]
```

subset (*sel0=None*, *sel1=None*)

Make a sub-selection of variants and samples.

> **Parameters sel0** : array_like
>
> > Boolean array or list of indices selecting variants.
>
> **sel0** : array_like
>
> > Boolean array or list of indices selecting samples.
>
> **Returns out** : GenotypeArray

See also:

`numpy.take`, `numpy.compress`

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1], [1, 1]],
...                          [[0, 1], [1, 1], [1, 2]],
...                          [[0, 2], [-1, -1], [-1, -1]]])
>>> g.subset([0, 1], [0, 2])
GenotypeArray((2, 2, 2), dtype=int64)
[[[0 0]
  [1 1]]
 [[0 1]
  [1 2]]]
```

is_called ()

Find non-missing genotype calls.

> **Returns out** : ndarray, bool, shape (n_variants, n_samples)
>
> > Array where elements are True if the genotype call matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.is_called()
array([[ True,  True],
       [ True,  True],
       [ True, False]], dtype=bool)
```

is_missing()
> Find missing genotype calls.

> > **Returns** **out** : ndarray, bool, shape (n_variants, n_samples)

> > > Array where elements are True if the genotype call matches the condition.

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.is_missing()
array([[False, False],
       [False, False],
       [False,  True]], dtype=bool)
```

is_hom(*allele=None*)
> Find genotype calls that are homozygous.

> > **Parameters** **allele** : int, optional

> > > Allele index.

> > **Returns** **out** : ndarray, bool, shape (n_variants, n_samples)

> > > Array where elements are True if the genotype call matches the condition.

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.is_hom()
array([[ True, False],
       [False,  True],
       [ True, False]], dtype=bool)
>>> g.is_hom(allele=1)
array([[False, False],
       [False,  True],
       [False, False]], dtype=bool)
```

is_hom_ref()
> Find genotype calls that are homozygous for the reference allele.

3.1. Data structures 11

Returns **out** : ndarray, bool, shape (n_variants, n_samples)

Array where elements are True if the genotype call matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.is_hom_ref()
array([[ True, False],
       [False, False],
       [False, False]], dtype=bool)
```

is_hom_alt()
Find genotype calls that are homozygous for any alternate (i.e., non-reference) allele.

Returns **out** : ndarray, bool, shape (n_variants, n_samples)

Array where elements are True if the genotype call matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.is_hom_alt()
array([[False, False],
       [False,  True],
       [ True, False]], dtype=bool)
```

is_het(*allele=None*)
Find genotype calls that are heterozygous.

Returns **out** : ndarray, bool, shape (n_variants, n_samples)

Array where elements are True if the genotype call matches the condition.

allele : int, optional

Heterozygous allele.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.is_het()
array([[False,  True],
       [ True, False],
       [ True, False]], dtype=bool)
>>> g.is_het(2)
array([[False, False],
```

```
            [False, False],
            [ True, False]], dtype=bool)
```

is_call(*call*)

> Find genotypes with a given call.

>> **Parameters call** : array_like, int, shape (ploidy,)

>>> The genotype call to find.

>> **Returns out** : ndarray, bool, shape (n_variants, n_samples)

>>> Array where elements are True if the genotype is *call*.

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.is_call((0, 2))
array([[False, False],
       [False, False],
       [ True, False]], dtype=bool)
```

count_called(*axis=None*)

count_missing(*axis=None*)

count_hom(*allele=None*, *axis=None*)

count_hom_ref(*axis=None*)

count_hom_alt(*axis=None*)

count_het(*allele=None*, *axis=None*)

count_call(*call*, *axis=None*)

count_alleles(*max_allele=None*, *subpop=None*)

> Count the number of calls of each allele per variant.

>> **Parameters max_allele** : int, optional

>>> The highest allele index to count. Alleles above this will be ignored.

>> **subpop** : sequence of ints, optional

>>> Indices of samples to include in count.

>> **Returns ac** : AlleleCountsArray

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.count_alleles()
AlleleCountsArray((3, 3), dtype=int32)
[[3 1 0]
```

```
       [1 2 1]
       [0 0 2]]
>>> g.count_alleles(max_allele=1)
AlleleCountsArray((3, 2), dtype=int32)
[[3 1]
 [1 2]
 [0 0]]
```

count_alleles_subpops(*subpops*, *max_allele=None*)
  Count alleles for multiple subpopulations simultaneously.

> **Parameters subpops** : dict (string -> sequence of ints)
>
>> Mapping of subpopulation names to sample indices.
>
>> **max_allele** : int, optional
>
>> The highest allele index to count. Alleles above this will be ignored.
>
> **Returns out** : dict (string -> AlleleCountsArray)
>
>> A mapping of subpopulation names to allele counts arrays.

map_alleles(*mapping*, *copy=True*)
  Transform alleles via a mapping.

> **Parameters mapping** : ndarray, int8, shape (n_variants, max_allele)
>
>> An array defining the allele mapping for each variant.
>
>> **copy** : bool, optional
>
>> If True, return a new array; if False, apply mapping in place (only applies for arrays with dtype int8; all other dtypes require a copy).
>
> **Returns gm** : GenotypeArray

See also:

create_allele_mapping

Notes

For arrays with dtype int8 an optimised implementation is used which is faster and uses far less memory. It is recommended to convert arrays to dtype int8 where possible before calling this method.

Examples

```
>>> import allel
>>> import numpy as np
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[1, 2], [2, 1]],
...                          [[2, 2], [-1, -1]]], dtype='i1')
>>> mapping = np.array([[1, 2, 0],
...                     [2, 0, 1],
...                     [2, 1, 0],
...                     [0, 2, 1]], dtype='i1')
>>> g.map_alleles(mapping)
GenotypeArray((4, 2, 2), dtype=int8)
```

```
      [[[ 1  1]
       [ 1  2]]
      [[ 2  1]
       [ 0  0]]
      [[ 1  0]
       [ 0  1]]
      [[ 1  1]
       [-1 -1]]]
```

to_haplotypes(*copy=False*)

Reshape a genotype array to view it as haplotypes by dropping the ploidy dimension.

> **Returns h** : HaplotypeArray, shape (n_variants, n_samples * ploidy)
>
> > Haplotype array.
>
> **copy** : bool, optional
>
> > If True, make a copy of the data.

Notes

If genotype calls are unphased, the haplotypes returned by this function will bear no resemblance to the true haplotypes.

Examples

```python
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]])
>>> g.to_haplotypes()
HaplotypeArray((3, 4), dtype=int64)
[[ 0  0  0  1]
 [ 0  1  1  1]
 [ 0  2 -1 -1]]
```

to_n_ref(*fill=0, dtype='i1'*)

Transform each genotype call into the number of reference alleles.

> **Parameters fill** : int, optional
>
> > Use this value to represent missing calls.
>
> **Returns out** : ndarray, int, shape (n_variants, n_samples)
>
> > Array of ref alleles per genotype call.

Notes

By default this function returns 0 for missing genotype calls **and** for homozygous non-reference genotype calls. Use the *fill* argument to change how missing calls are represented.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.to_n_ref()
array([[2, 1],
       [1, 0],
       [0, 0]], dtype=int8)
>>> g.to_n_ref(fill=-1)
array([[ 2,  1],
       [ 1,  0],
       [ 0, -1]], dtype=int8)
```

to_n_alt (*fill=0*, *dtype='i1'*)

Transform each genotype call into the number of non-reference alleles.

> **Parameters fill** : int, optional
>
>> Use this value to represent missing calls.
>
> **Returns out** : ndarray, int, shape (n_variants, n_samples)
>
>> Array of non-ref alleles per genotype call.

Notes

This function simply counts the number of non-reference alleles, it makes no distinction between different alternate alleles.

By default this function returns 0 for missing genotype calls **and** for homozygous reference genotype calls. Use the *fill* argument to change how missing calls are represented.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.to_n_alt()
array([[0, 1],
       [1, 2],
       [2, 0]], dtype=int8)
>>> g.to_n_alt(fill=-1)
array([[ 0,  1],
       [ 1,  2],
       [ 2, -1]], dtype=int8)
```

to_allele_counts (*alleles=None*)

Transform genotype calls into allele counts per call.

> **Parameters alleles** : sequence of ints, optional
>
>> If not None, count only the given alleles. (By default, count all alleles.)
>
> **Returns out** : ndarray, uint8, shape (n_variants, n_samples, len(alleles))

Array of allele counts per call.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.to_allele_counts()
array([[[2, 0, 0],
        [1, 1, 0]],
       [[1, 0, 1],
        [0, 2, 0]],
       [[0, 0, 2],
        [0, 0, 0]]], dtype=uint8)
>>> g.to_allele_counts(alleles=(0, 1))
array([[[2, 0],
        [1, 1]],
       [[1, 0],
        [0, 2]],
       [[0, 0],
        [0, 0]]], dtype=uint8)
```

to_packed(*boundscheck=True*)

Pack diploid genotypes into a single byte for each genotype, using the left-most 4 bits for the first allele and the right-most 4 bits for the second allele. Allows single byte encoding of diploid genotypes for variants with up to 15 alleles.

> **Parameters boundscheck** : bool, optional
>
> > If False, do not check that minimum and maximum alleles are compatible with bit-packing.
>
> **Returns packed** : ndarray, uint8, shape (n_variants, n_samples)
>
> > Bit-packed genotype array.

Notes

If a mask has been set, it is ignored by this function.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]], dtype='i1')
>>> g.to_packed()
array([[  0,   1],
       [  2,  17],
       [ 34, 239]], dtype=uint8)
```

static **from_packed**(*packed*)

Unpack diploid genotypes that have been bit-packed into single bytes.

> **Parameters packed** : ndarray, uint8, shape (n_variants, n_samples)

Bit-packed diploid genotype array.

Returns **g** : GenotypeArray, shape (n_variants, n_samples, 2)

Genotype array.

Examples

```
>>> import allel
>>> import numpy as np
>>> packed = np.array([[0, 1],
...                     [2, 17],
...                     [34, 239]], dtype='u1')
>>> allel.GenotypeArray.from_packed(packed)
GenotypeArray((3, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  1]]
 [[ 0  2]
  [ 1  1]]
 [[ 2  2]
  [-1 -1]]]
```

to_sparse (*format='csr'*, ***kwargs*)
   Convert into a sparse matrix.

   Parameters **format** : {'coo', 'csc', 'csr', 'dia', 'dok', 'lil'}

   Sparse matrix format.

   kwargs : keyword arguments

   Passed through to sparse matrix constructor.

   Returns **m** : scipy.sparse.spmatrix

   Sparse matrix

Notes

If a mask has been set, it is ignored by this function.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 1], [0, 1]],
...                          [[1, 1], [0, 0]],
...                          [[0, 0], [-1, -1]]], dtype='i1')
>>> m = g.to_sparse(format='csr')
>>> m
<4x4 sparse matrix of type '<class 'numpy.int8'>'
    with 6 stored elements in Compressed Sparse Row format>
>>> m.data
array([ 1,  1,  1,  1, -1, -1], dtype=int8)
>>> m.indices
array([1, 3, 0, 1, 2, 3], dtype=int32)
```

```
>>> m.indptr
array([0, 0, 2, 4, 6], dtype=int32)
```

static from_sparse(*m*, *ploidy*, *order=None*, *out=None*)

Construct a genotype array from a sparse matrix.

> **Parameters m** : scipy.sparse.spmatrix
>
> > Sparse matrix
>
> **ploidy** : int
>
> > The sample ploidy.
>
> **order** : {'C', 'F'}, optional
>
> > Whether to store data in C (row-major) or Fortran (column-major) order in memory.
>
> **out** : ndarray, shape (n_variants, n_samples), optional
>
> > Use this array as the output buffer.
>
> **Returns g** : GenotypeArray, shape (n_variants, n_samples, ploidy)
>
> > Genotype array.

Examples

```
>>> import allel
>>> import numpy as np
>>> import scipy.sparse
>>> data = np.array([ 1,  1,  1,  1, -1, -1], dtype=np.int8)
>>> indices = np.array([1, 3, 0, 1, 2, 3], dtype=np.int32)
>>> indptr = np.array([0, 0, 2, 4, 6], dtype=np.int32)
>>> m = scipy.sparse.csr_matrix((data, indices, indptr))
>>> g = allel.GenotypeArray.from_sparse(m, ploidy=2)
>>> g
GenotypeArray((4, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  0]]
 [[ 0  1]
  [ 0  1]]
 [[ 1  1]
  [ 0  0]]
 [[ 0  0]
  [-1 -1]]]
```

to_gt(*phased=False*, *max_allele=None*)

Convert genotype calls to VCF-style string representation.

> **Parameters phased** : bool, optional
>
> > Determines separator.
>
> **max_allele** : int, optional
>
> > Manually specify max allele index.
>
> **Returns gt** : ndarray, string, shape (n_variants, n_samples)

Notes

If a mask has been set, it is ignored by this function.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[1, 2], [2, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.to_gt()
chararray([[b'0/0', b'0/1'],
        [b'0/2', b'1/1'],
        [b'1/2', b'2/1'],
        [b'2/2', b'./.']],
       dtype='|S3')
>>> g.to_gt(phased=True)
chararray([[b'0|0', b'0|1'],
        [b'0|2', b'1|1'],
        [b'1|2', b'2|1'],
        [b'2|2', b'.|.']],
       dtype='|S3')
```

haploidify_samples()
    Construct a pseudo-haplotype for each sample by randomly selecting an allele from each genotype call.

    Returns **h** : HaplotypeArray

Notes

If a mask has been set, it is ignored by this function.

Examples

```
>>> import allel
>>> import numpy as np
>>> np.random.seed(42)
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[1, 2], [2, 1]],
...                          [[2, 2], [-1, -1]]])
>>> g.haploidify_samples()
HaplotypeArray((4, 2), dtype=int64)
[[ 0  1]
 [ 0  1]
 [ 1  1]
 [ 2 -1]]
>>> g = allel.GenotypeArray([[[0, 0, 0], [0, 0, 1]],
...                          [[0, 1, 1], [1, 1, 1]],
...                          [[0, 1, 2], [-1, -1, -1]]])
>>> g.haploidify_samples()
HaplotypeArray((3, 2), dtype=int64)
[[ 0  0]
```

```
        [ 1  1]
        [ 2 -1]]
```

vstack(**others*)
> Stack arrays in sequence vertically (row wise).

hstack(**others*)
> Stack arrays in sequence horizontally (column wise).

HaplotypeArray

class `allel.model.ndarray.`**HaplotypeArray**
> Array of haplotypes.

> > **Parameters data** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype data.
> >
> > ****kwargs** : keyword arguments
> >
> > > All keyword arguments are passed through to `numpy.array()`.

> ### Notes

> This class represents haplotype data as a 2-dimensional numpy array of integers. By convention the first dimension corresponds to the variants genotyped, the second dimension corresponds to the haplotypes.

> Each integer within the array corresponds to an **allele index**, where 0 is the reference allele, 1 is the first alternate allele, 2 is the second alternate allele, ... and -1 (or any other negative integer) is a missing allele call.

> If adjacent haplotypes originate from the same sample, then a haplotype array can also be viewed as a genotype array. However, this is not a requirement.

> With data on large numbers of variants and/or haplotypes, storing the data in memory as an uncompressed numpy array if integers may be impractical. For working with large arrays of haplotype data, see the *allel.model.chunked.HaplotypeChunkedArray* class, which provides an alternative implementation of this interface using chunked compressed arrays.

> ### Examples

> Instantiate a haplotype array:

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 1],
...                           [0, 1, 1, 1],
...                           [0, 2, -1, -1]], dtype='i1')
>>> h.dtype
dtype('int8')
>>> h.ndim
2
>>> h.shape
(3, 4)
>>> h.n_variants
3
>>> h.n_haplotypes
4
```

Allele calls for a single variant at all haplotypes can be obtained by indexing the first dimension, e.g.:

```
>>> h[1]
array([0, 1, 1, 1], dtype=int8)
```

A single haplotype can be obtained by indexing the second dimension, e.g.:

```
>>> h[:, 1]
array([0, 1, 2], dtype=int8)
```

An allele call for a single haplotype at a single variant can be obtained by indexing the first and second dimensions, e.g.:

```
>>> h[1, 0]
0
```

View haplotypes as diploid genotypes:

```
>>> h.to_genotypes(ploidy=2)
GenotypeArray((3, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

n_variants
> Number of variants (length of first dimension).

n_haplotypes
> Number of haplotypes (length of second dimension).

subset(*sel0=None*, *sel1=None*)
> Make a sub-selection of variants and haplotypes.

> > **Parameters** **sel0** : array_like
> >
> > > Boolean array or list of indices selecting variants.
> >
> > **sel1** : array_like
> >
> > > Boolean array or list of indices selecting haplotypes.
> >
> > **Returns** **out** : HaplotypeArray

> **See also:**

> `numpy.take`, `numpy.compress`

is_called()

is_missing()

is_ref()

is_alt(*allele=None*)

is_call(*allele*)

count_called(*axis=None*)

count_missing(*axis=None*)

count_ref(*axis=None*)

---

count_alt (*axis=None*)

count_call (*allele*, *axis=None*)

count_alleles (*max_allele=None*, *subpop=None*)
Count the number of calls of each allele per variant.

> **Parameters max_allele** : int, optional
>
>> The highest allele index to count. Alleles greater than this index will be ignored.
>
> **subpop** : array_like, int, optional
>
>> Indices of haplotypes to include.
>
> **Returns ac** : AlleleCountsArray, int, shape (n_variants, n_alleles)

Examples

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 1],
...                           [0, 1, 1, 1],
...                           [0, 2, -1, -1]], dtype='i1')
>>> ac = h.count_alleles()
>>> ac
AlleleCountsArray((3, 3), dtype=int32)
[[3 1 0]
 [1 3 0]
 [1 0 1]]
```

count_alleles_subpops (*subpops*, *max_allele=None*)
Count alleles for multiple subpopulations simultaneously.

> **Parameters subpops** : dict (string -> sequence of ints)
>
>> Mapping of subpopulation names to sample indices.
>
> **max_allele** : int, optional
>
>> The highest allele index to count. Alleles above this will be ignored.
>
> **Returns out** : dict (string -> AlleleCountsArray)
>
>> A mapping of subpopulation names to allele counts arrays.

map_alleles (*mapping*, *copy=True*)
Transform alleles via a mapping.

> **Parameters mapping** : ndarray, int8, shape (n_variants, max_allele)
>
>> An array defining the allele mapping for each variant.
>
> **copy** : bool, optional
>
>> If True, return a new array; if False, apply mapping in place (only applies for arrays with dtype int8; all other dtypes require a copy).
>
> **Returns hm** : HaplotypeArray

See also:

create_allele_mapping

Notes

For arrays with dtype int8 an optimised implementation is used which is faster and uses far less memory. It is recommended to convert arrays to dtype int8 where possible before calling this method.

Examples

```
>>> import allel
>>> import numpy as np
>>> h = allel.HaplotypeArray([[0, 0, 0, 1],
...                           [0, 1, 1, 1],
...                           [0, 2, -1, -1]], dtype='i1')
>>> mapping = np.array([[1, 2, 0],
...                     [2, 0, 1],
...                     [2, 1, 0]], dtype='i1')
>>> h.map_alleles(mapping)
HaplotypeArray((3, 4), dtype=int8)
[[ 1  1  1  2]
 [ 2  0  0  0]
 [ 2  0 -1 -1]]
```

to_genotypes (*ploidy*, *copy=False*)
    Reshape a haplotype array to view it as genotypes by restoring the ploidy dimension.

> **Parameters ploidy** : int
>
> > The sample ploidy.
>
> **Returns g** : ndarray, int, shape (n_variants, n_samples, ploidy)
>
> > Genotype array (sharing same underlying buffer).
>
> > **copy** : bool, optional
>
> > If True, copy the data.

Examples

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 1],
...                           [0, 1, 1, 1],
...                           [0, 2, -1, -1]], dtype='i1')
>>> h.to_genotypes(ploidy=2)
GenotypeArray((3, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

to_sparse (*format='csr'*, ***kwargs*)
    Convert into a sparse matrix.

> **Parameters format** : {'coo', 'csc', 'csr', 'dia', 'dok', 'lil'}
>
> > Sparse matrix format.

kwargs : keyword arguments

    Passed through to sparse matrix constructor.

Returns m : scipy.sparse.spmatrix

    Sparse matrix

Examples

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 0],
...                           [0, 1, 0, 1],
...                           [1, 1, 0, 0],
...                           [0, 0, -1, -1]], dtype='i1')
>>> m = h.to_sparse(format='csr')
>>> m
<4x4 sparse matrix of type '<class 'numpy.int8'>'
    with 6 stored elements in Compressed Sparse Row format>
>>> m.data
array([ 1,  1,  1,  1, -1, -1], dtype=int8)
>>> m.indices
array([1, 3, 0, 1, 2, 3], dtype=int32)
>>> m.indptr
array([0, 0, 2, 4, 6], dtype=int32)
```

static **from_sparse**(*m*, *order=None*, *out=None*)

    Construct a haplotype array from a sparse matrix.

Parameters m : scipy.sparse.spmatrix

    Sparse matrix

order : {'C', 'F'}, optional

    Whether to store data in C (row-major) or Fortran (column-major) order in memory.

out : ndarray, shape (n_variants, n_samples), optional

    Use this array as the output buffer.

Returns h : HaplotypeArray, shape (n_variants, n_haplotypes)

    Haplotype array.

Examples

```
>>> import allel
>>> import numpy as np
>>> import scipy.sparse
>>> data = np.array([ 1,  1,  1,  1, -1, -1], dtype=np.int8)
>>> indices = np.array([1, 3, 0, 1, 2, 3], dtype=np.int32)
>>> indptr = np.array([0, 0, 2, 4, 6], dtype=np.int32)
>>> m = scipy.sparse.csr_matrix((data, indices, indptr))
>>> h = allel.HaplotypeArray.from_sparse(m)
>>> h
HaplotypeArray((4, 4), dtype=int8)
[[ 0  0  0  0]
 [ 0  1  0  1]
```

```
        [ 1  1  0  0]
        [ 0  0 -1 -1]]
```

prefix_argsort()
>   Return indices that would sort the haplotypes by prefix.

distinct()
>   Return sets of indices for each distinct haplotype.

distinct_counts()
>   Return counts for each distinct haplotype.

distinct_frequencies()
>   Return frequencies for each distinct haplotype.

vstack(**others*)
>   Stack arrays in sequence vertically (row wise).

hstack(**others*)
>   Stack arrays in sequence horizontally (column wise).

AlleleCountsArray

class `allel.model.ndarray.`**AlleleCountsArray**
>   Array of allele counts.

>>   Parameters **data** : array_like, int, shape (n_variants, n_alleles)

>>>   Allele counts data.

>>   ****kwargs** : keyword arguments

>>>   All keyword arguments are passed through to `numpy.array()`.

Notes

This class represents allele counts as a 2-dimensional numpy array of integers. By convention the first dimension corresponds to the variants genotyped, the second dimension corresponds to the alleles counted.

Examples

Obtain allele counts from a genotype array:

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 1], [1, 1]],
...                          [[0, 2], [-1, -1]]], dtype='i1')
>>> ac = g.count_alleles()
>>> ac
AlleleCountsArray((3, 3), dtype=int32)
[[3 1 0]
 [1 3 0]
 [1 0 1]]
>>> ac.dtype
dtype('int32')
>>> ac.shape
(3, 3)
```

```
>>> ac.n_variants
3
>>> ac.n_alleles
3
```

Allele counts for a single variant can be obtained by indexing the first dimension, e.g.:

```
>>> ac[1]
array([1, 3, 0], dtype=int32)
```

Allele counts for a specific allele can be obtained by indexing the second dimension, e.g., reference allele counts:

```
>>> ac[:, 0]
array([3, 1, 1], dtype=int32)
```

Calculate the total number of alleles called for each variant:

```
>>> import numpy as np
>>> n = np.sum(ac, axis=1)
>>> n
array([4, 4, 2])
```

n_variants
> Number of variants (length of first array dimension).

n_alleles
> Number of alleles (length of second array dimension).

max_allele()
> Return the highest allele index for each variant.

> > **Returns n** : ndarray, int, shape (n_variants,)

> > > Allele index array.

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.max_allele()
array([1, 2, 2], dtype=int8)
```

allelism()
> Determine the number of distinct alleles observed for each variant.

> > **Returns n** : ndarray, int, shape (n_variants,)

> > > Allelism array.

> **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
```

```
>>> ac = g.count_alleles()
>>> ac.allelism()
array([2, 3, 1])
```

is_variant()
>   Find variants with at least one non-reference allele call.

>   > **Returns** **out** : ndarray, bool, shape (n_variants,)
>   >
>   > > Boolean array where elements are True if variant matches the condition.

>   **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.is_variant()
array([False,  True,  True,  True], dtype=bool)
```

is_non_variant()
>   Find variants with no non-reference allele calls.

>   > **Returns** **out** : ndarray, bool, shape (n_variants,)
>   >
>   > > Boolean array where elements are True if variant matches the condition.

>   **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.is_non_variant()
array([ True, False, False, False], dtype=bool)
```

is_segregating()
>   Find segregating variants (where more than one allele is observed).

>   > **Returns** **out** : ndarray, bool, shape (n_variants,)
>   >
>   > > Boolean array where elements are True if variant matches the condition.

>   **Examples**

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
```

```
>>> ac.is_segregating()
array([False,  True,  True, False], dtype=bool)
```

is_non_segregating(*allele=None*)

Find non-segregating variants (where at most one allele is observed).

> **Parameters allele** : int, optional
>
> > Allele index.
>
> **Returns out** : ndarray, bool, shape (n_variants,)
>
> > Boolean array where elements are True if variant matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.is_non_segregating()
array([ True, False, False,  True], dtype=bool)
>>> ac.is_non_segregating(allele=2)
array([False, False, False,  True], dtype=bool)
```

is_singleton(*allele*)

Find variants with a single call for the given allele.

> **Parameters allele** : int, optional
>
> > Allele index.
>
> **Returns out** : ndarray, bool, shape (n_variants,)
>
> > Boolean array where elements are True if variant matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[1, 1], [1, 2]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.is_singleton(allele=1)
array([False,  True, False, False], dtype=bool)
>>> ac.is_singleton(allele=2)
array([False, False,  True, False], dtype=bool)
```

is_doubleton(*allele*)

Find variants with exactly two calls for the given allele.

> **Parameters allele** : int, optional
>
> > Allele index.
>
> **Returns out** : ndarray, bool, shape (n_variants,)

Boolean array where elements are True if variant matches the condition.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [1, 1]],
...                          [[1, 1], [1, 2]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.is_doubleton(allele=1)
array([False,  True, False, False], dtype=bool)
>>> ac.is_doubleton(allele=2)
array([False, False, False,  True], dtype=bool)
```

is_biallelic()
    Find biallelic variants.

> **Returns out** : ndarray, bool, shape (n_variants,)
>
> > Boolean array where elements are True if variant matches the condition.

is_biallelic_01(*min_mac=None*)
    Find variants biallelic for the reference (0) and first alternate (1) allele.

> **Parameters min_mac** : int, optional
>
> > Minimum minor allele count.
>
> **Returns out** : ndarray, bool, shape (n_variants,)
>
> > Boolean array where elements are True if variant matches the condition.

count_variant()

count_non_variant()

count_segregating()

count_non_segregating(*allele=None*)

count_singleton(*allele=1*)

count_doubleton(*allele=1*)

to_frequencies(*fill=nan*)
    Compute allele frequencies.

> **Parameters fill** : float, optional
>
> > Value to use when number of allele calls is 0.
>
> **Returns af** : ndarray, float, shape (n_variants, n_alleles)

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac.to_frequencies()
```

```
array([[ 0.75,  0.25,  0.  ],
       [ 0.25,  0.5 ,  0.25],
       [ 0.  ,  0.  ,  1.  ]])
```

map_alleles(*mapping*)

Transform alleles via a mapping.

> **Parameters** **mapping** : ndarray, int8, shape (n_variants, max_allele)
>
> > An array defining the allele mapping for each variant.
>
> **Returns** **ac** : AlleleCountsArray

See also:

create_allele_mapping

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 2], [1, 1]],
...                          [[2, 2], [-1, -1]]])
>>> ac = g.count_alleles()
>>> ac
AlleleCountsArray((4, 3), dtype=int32)
[[4 0 0]
 [3 1 0]
 [1 2 1]
 [0 0 2]]
>>> mapping = [[1, 0, 2],
...            [1, 0, 2],
...            [2, 1, 0],
...            [1, 2, 0]]
>>> ac.map_alleles(mapping)
AlleleCountsArray((4, 3), dtype=int64)
[[0 4 0]
 [1 3 0]
 [1 2 1]
 [2 0 0]]
```

vstack(**others*)

Stack arrays in sequence vertically (row wise).

hstack(**others*)

Stack arrays in sequence horizontally (column wise).

VariantTable

class allel.model.ndarray.**VariantTable**

Table (catalogue) of variants.

> **Parameters** **data** : array_like, structured, shape (n_variants,)
>
> > Variant records.
>
> **index** : string or pair of strings, optional

Names of columns to use for positional index, e.g., 'POS' if table contains a 'POS' column and records from a single chromosome/contig, or ('CHROM', 'POS') if table contains records from multiple chromosomes/contigs.

**kwargs : keyword arguments, optional

Further keyword arguments are passed through to `numpy.rec.array()`.

Examples

Instantiate a table from existing data:

```
>>> import allel
>>> records = [[b'chr1', 2, 35, 4.5, (1, 2)],
...            [b'chr1', 7, 12, 6.7, (3, 4)],
...            [b'chr2', 3, 78, 1.2, (5, 6)],
...            [b'chr2', 9, 22, 4.4, (7, 8)],
...            [b'chr3', 6, 99, 2.8, (9, 10)]]
>>> dtype = [('CHROM', 'S4'),
...          ('POS', 'u4'),
...          ('DP', int),
...          ('QD', float),
...          ('AC', (int, 2))]
>>> vt = allel.VariantTable(records, dtype=dtype,
...                         index=('CHROM', 'POS'))
>>> vt.names
('CHROM', 'POS', 'DP', 'QD', 'AC')
>>> vt.n_variants
5
```

Access a column:

```
>>> vt['DP']
array([35, 12, 78, 22, 99])
```

Access multiple columns:

```
>>> vt[['DP', 'QD']]
VariantTable((5,), dtype=(numpy.record, [('DP', '<i8'), ('QD', '<f8...
[(35, 4.5) (12, 6.7) (78, 1.2) (22, 4.4) (99, 2.8)]
```

Access a row:

```
>>> vt[2]
(b'chr2', 3, 78, 1.2, array([5, 6]))
```

Access multiple rows:

```
>>> vt[2:4]
VariantTable((2,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '...
[(b'chr2', 3, 78, 1.2, array([5, 6])) (b'chr2', 9, 22, 4.4, array([...
```

Evaluate expressions against the table:

```
>>> vt.eval('DP > 30')
array([ True, False,  True, False,  True], dtype=bool)
>>> vt.eval('(DP > 30) & (QD > 4)')
array([ True, False, False, False, False], dtype=bool)
>>> vt.eval('DP * 2')
array([ 70,  24, 156,  44, 198])
```

Query the table:

```
>>> vt.query('DP > 30')
VariantTable((3,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '...
[(b'chr1', 2, 35, 4.5, array([1, 2])) (b'chr2', 3, 78, 1.2, array([...
 (b'chr3', 6, 99, 2.8, array([ 9, 10]))]
>>> vt.query('(DP > 30) & (QD > 4)')
VariantTable((1,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '...
[(b'chr1', 2, 35, 4.5, array([1, 2]))]
```

Use the index to query variants:

```
>>> vt.query_region(b'chr2', 1, 10)
VariantTable((2,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '...
[(b'chr2', 3, 78, 1.2, array([5, 6])) (b'chr2', 9, 22, 4.4, array([...
```

n_variants
    Number of variants (length of first dimension).

names
    Column names.

eval (*expression*, *vm='python'*)
    Evaluate an expression against the table columns.

>   **Parameters expression** : string
>
>>   Expression to evaluate.
>
>   **vm** : {'numexpr', 'python'}
>
>>   Virtual machine to use.
>
>   **Returns result** : ndarray

query (*expression*, *vm='python'*)
    Evaluate expression and then use it to extract rows from the table.

>   **Parameters expression** : string
>
>>   Expression to evaluate.
>
>   **vm** : {'numexpr', 'python'}
>
>>   Virtual machine to use.
>
>   **Returns result** : structured array

query_position (*chrom=None*, *position=None*)
    Query the table, returning row or rows matching the given genomic position.

>   **Parameters chrom** : string, optional
>
>>   Chromosome/contig.
>
>   **position** : int, optional
>
>>   Position (1-based).
>
>   **Returns result** : row or VariantTable

query_region (*chrom=None*, *start=None*, *stop=None*)
    Query the table, returning row or rows within the given genomic region.

>   **Parameters chrom** : string, optional
>
>>   Chromosome/contig.

> **start** : int, optional
>
>> Region start position (1-based).
>
> **stop** : int, optional
>
>> Region stop position (1-based).
>
> **Returns result** : VariantTable

to_vcf (*path*, *rename=None*, *number=None*, *description=None*, *fill=None*, *write_header=True*)
    Write to a variant call format (VCF) file.

> **Parameters path** : string
>
>> File path.
>
> **rename** : dict, optional
>
>> Rename these columns in the VCF.
>
> **number** : dict, optional
>
>> Override the number specified in INFO headers.
>
> **description** : dict, optional
>
>> Descriptions for the INFO and FILTER headers.
>
> **fill** : dict, optional
>
>> Fill values used for missing data in the table.

Examples

Setup a variant table to write out:

```
>>> import allel
>>> chrom = [b'chr1', b'chr1', b'chr2', b'chr2', b'chr3']
>>> pos = [2, 6, 3, 8, 1]
>>> id = ['a', 'b', 'c', 'd', 'e']
>>> ref = [b'A', b'C', b'T', b'G', b'N']
>>> alt = [(b'T', b'.'),
...        (b'G', b'.'),
...        (b'A', b'C'),
...        (b'C', b'A'),
...        (b'X', b'.')]
>>> qual = [1.2, 2.3, 3.4, 4.5, 5.6]
>>> filter_qd = [True, True, True, False, False]
>>> filter_dp = [True, False, True, False, False]
>>> dp = [12, 23, 34, 45, 56]
>>> qd = [12.3, 23.4, 34.5, 45.6, 56.7]
>>> flg = [True, False, True, False, True]
>>> ac = [(1, -1), (3, -1), (5, 6), (7, 8), (9, -1)]
>>> xx = [(1.2, 2.3), (3.4, 4.5), (5.6, 6.7), (7.8, 8.9),
...       (9.0, 9.9)]
>>> columns = [chrom, pos, id, ref, alt, qual, filter_dp,
...            filter_qd, dp, qd, flg, ac, xx]
>>> records = list(zip(*columns))
>>> dtype = [('chrom', 'S4'),
...          ('pos', 'u4'),
...          ('ID', 'S1'),
...          ('ref', 'S1'),
```

```
...                 ('alt', ('S1', 2)),
...                 ('qual', 'f4'),
...                 ('filter_dp', bool),
...                 ('filter_qd', bool),
...                 ('dp', int),
...                 ('qd', float),
...                 ('flg', bool),
...                 ('ac', (int, 2)),
...                 ('xx', (float, 2))]
>>> vt = allel.VariantTable(records, dtype=dtype)
```

Now write out to VCF and inspect the result:

```
>>> rename = {'dp': 'DP', 'qd': 'QD', 'filter_qd': 'QD'}
>>> fill = {'ALT': b'.', 'ac': -1}
>>> number = {'ac': 'A'}
>>> description = {'ac': 'Allele counts', 'filter_dp': 'Low depth'}
>>> vt.to_vcf('example.vcf', rename=rename, fill=fill,
...           number=number, description=description)
>>> print(open('example.vcf').read())
##fileformat=VCFv4.1
##fileDate=...
##source=...
##INFO=<ID=DP,Number=1,Type=Integer,Description="">
##INFO=<ID=QD,Number=1,Type=Float,Description="">
##INFO=<ID=ac,Number=A,Type=Integer,Description="Allele counts">
##INFO=<ID=flg,Number=0,Type=Flag,Description="">
##INFO=<ID=xx,Number=2,Type=Float,Description="">
##FILTER=<ID=QD,Description="">
##FILTER=<ID=dp,Description="Low depth">
#CHROM    POS    ID    REF    ALT    QUAL    FILTER    INFO
chr1      2      a     A      T      1.2     QD;dp     DP=12;QD=12.3;ac=1;flg;xx=...
chr1      6      b     C      G      2.3     QD        DP=23;QD=23.4;ac=3;xx=3.4,4.5
chr2      3      c     T      A,C    3.4     QD;dp     DP=34;QD=34.5;ac=5,6;flg;x...
chr2      8      d     G      C,A    4.5     PASS      DP=45;QD=45.6;ac=7,8;xx=7...
chr3      1      e     N      X      5.6     PASS      DP=56;QD=56.7;ac=9;flg;xx=...
```

FeatureTable

class allel.model.ndarray.**FeatureTable**

Table of genomic features (e.g., genes, exons, etc.).

> **Parameters** **data** : array_like, structured, shape (n_variants,)
>
> > Variant records.
>
> **index** : pair or triplet of strings, optional
>
> > Names of columns to use for positional index, e.g., ('start', 'stop') if table contains 'start' and 'stop' columns and records from a single chromosome/contig, or ('seqid', 'start', 'end') if table contains records from multiple chromosomes/contigs.
>
> ****kwargs** : keyword arguments, optional
>
> > Further keyword arguments are passed through to numpy.rec.array().

n_features

Number of features (length of first dimension).

names
> Column names.

eval (*expression*, *vm='python'*)
> Evaluate an expression against the table columns.

>> **Parameters** **expression** : string

>>> Expression to evaluate.

>> **vm** : {'numexpr', 'python'}

>>> Virtual machine to use.

>> **Returns** **result** : ndarray

query (*expression*, *vm='python'*)
> Evaluate expression and then use it to extract rows from the table.

>> **Parameters** **expression** : string

>>> Expression to evaluate.

>> **vm** : {'numexpr', 'python'}

>>> Virtual machine to use.

>> **Returns** **result** : structured array

static **from_gff3** (*path*, *attributes=None*, *region=None*, *score_fill=-1*, *phase_fill=-1*, *attributes_fill='.'*, *dtype=None*)
> Read a feature table from a GFF3 format file.

>> **Parameters** **path** : string

>>> File path.

>> **attributes** : list of strings, optional

>>> List of columns to extract from the "attributes" field.

>> **region** : string, optional

>>> Genome region to extract. If given, file must be position sorted, bgzipped and tabix indexed. Tabix must also be installed and on the system path.

>> **score_fill** : object, optional

>>> Value to use where score field has a missing value.

>> **phase_fill** : object, optional

>>> Value to use where phase field has a missing value.

>> **attributes_fill** : object or list of objects, optional

>>> Value(s) to use where attribute field(s) have a missing value.

>> **dtype** : numpy dtype, optional

>>> Manually specify a dtype.

>> **Returns** **ft** : FeatureTable

to_mask (*size*, *start_name='start'*, *stop_name='end'*)
> Construct a mask array where elements are True if the fall within features in the table.

>> **Parameters** **size** : int

>>> Size of chromosome/contig.

> **start_name** : string, optional
>
>> Name of column with start coordinates.
>
> **stop_name** : string, optional
>
>> Name of column with stop coordinates.
>
> **Returns mask** : ndarray, bool

SortedIndex

class `allel.model.ndarray.`**`SortedIndex`**

Index of sorted values, e.g., positions from a single chromosome or contig.

> **Parameters data** : array_like
>
>> Values in ascending order.
>
> ****kwargs** : keyword arguments
>
>> All keyword arguments are passed through to `numpy.array()`.

Notes

Values must be given in ascending order, although duplicate values may be present (i.e., values must be monotonically increasing).

Examples

```
>>> import allel
>>> idx = allel.SortedIndex([2, 5, 14, 15, 42, 42, 77], dtype='i4')
>>> idx.dtype
dtype('int32')
>>> idx.ndim
1
>>> idx.shape
(7,)
>>> idx.is_unique
False
```

`is_unique`
>   True if no duplicate entries.

`locate_key`(*key*)
>   Get index location for the requested key.
>
> > **Parameters key** : int
> >
> > > Value to locate.
> >
> > **Returns loc** : int or slice
> >
> > > Location of *key* (will be slice if there are duplicate entries).

Examples

```
>>> import allel
>>> idx = allel.SortedIndex([3, 6, 6, 11])
>>> idx.locate_key(3)
0
>>> idx.locate_key(11)
3
>>> idx.locate_key(6)
slice(1, 3, None)
>>> try:
...     idx.locate_key(2)
... except KeyError as e:
...     print(e)
...
2
```

locate_keys(*keys*, *strict=True*)

Get index locations for the requested keys.

> **Parameters keys** : array_like, int
>
> > Array of keys to locate.
>
> > **strict** : bool, optional
> >
> > > If True, raise KeyError if any keys are not found in the index.
>
> **Returns loc** : ndarray, bool
>
> > Boolean array with location of values.

Examples

```
>>> import allel
>>> idx1 = allel.SortedIndex([3, 6, 11, 20, 35])
>>> idx2 = allel.SortedIndex([4, 6, 20, 39])
>>> loc = idx1.locate_keys(idx2, strict=False)
>>> loc
array([False,  True, False,  True, False], dtype=bool)
>>> idx1[loc]
SortedIndex((2,), dtype=int64)
[ 6 20]
```

locate_intersection(*other*)

Locate the intersection with another array.

> **Parameters other** : array_like, int
>
> > Array of values to intersect.
>
> **Returns loc** : ndarray, bool
>
> > Boolean array with location of intersection.
>
> > **loc_other** : ndarray, bool
> >
> > > Boolean array with location in *other* of intersection.

Examples

```
>>> import allel
>>> idx1 = allel.SortedIndex([3, 6, 11, 20, 35])
>>> idx2 = allel.SortedIndex([4, 6, 20, 39])
>>> loc1, loc2 = idx1.locate_intersection(idx2)
>>> loc1
array([False,  True, False,  True, False], dtype=bool)
>>> loc2
array([False,  True,  True, False], dtype=bool)
>>> idx1[loc1]
SortedIndex((2,), dtype=int64)
[ 6 20]
>>> idx2[loc2]
SortedIndex((2,), dtype=int64)
[ 6 20]
```

intersect(*other*)

Intersect with *other* sorted index.

> **Parameters other** : array_like, int
>
> > Array of values to intersect with.
>
> **Returns out** : SortedIndex
>
> > Values in common.

Examples

```
>>> import allel
>>> idx1 = allel.SortedIndex([3, 6, 11, 20, 35])
>>> idx2 = allel.SortedIndex([4, 6, 20, 39])
>>> idx1.intersect(idx2)
SortedIndex((2,), dtype=int64)
[ 6 20]
```

locate_range(*start=None*, *stop=None*)

Locate slice of index containing all entries within *start* and *stop* values **inclusive**.

> **Parameters start** : int, optional
>
> > Start value.
>
> > **stop** : int, optional
>
> > Stop value.
>
> **Returns loc** : slice
>
> > Slice object.

Examples

```
>>> import allel
>>> idx = allel.SortedIndex([3, 6, 11, 20, 35])
>>> loc = idx.locate_range(4, 32)
>>> loc
slice(1, 4, None)
```

```
>>> idx[loc]
SortedIndex((3,), dtype=int64)
[ 6 11 20]
```

intersect_range(*start=None*, *stop=None*)

Intersect with range defined by *start* and *stop* values **inclusive**.

    Parameters start : int, optional

        Start value.

        stop : int, optional

        Stop value.

    Returns idx : SortedIndex

Examples

```
>>> import allel
>>> idx = allel.SortedIndex([3, 6, 11, 20, 35])
>>> idx.intersect_range(4, 32)
SortedIndex((3,), dtype=int64)
[ 6 11 20]
```

locate_ranges(*starts*, *stops*, *strict=True*)

Locate items within the given ranges.

    Parameters starts : array_like, int

        Range start values.

        stops : array_like, int

        Range stop values.

        strict : bool, optional

        If True, raise KeyError if any ranges contain no entries.

    Returns loc : ndarray, bool

        Boolean array with location of entries found.

Examples

```
>>> import allel
>>> import numpy as np
>>> idx = allel.SortedIndex([3, 6, 11, 20, 35])
>>> ranges = np.array([[0, 2], [6, 17], [12, 15], [31, 35],
...                     [100, 120]])
>>> starts = ranges[:, 0]
>>> stops = ranges[:, 1]
>>> loc = idx.locate_ranges(starts, stops, strict=False)
>>> loc
array([False,  True,  True, False,  True], dtype=bool)
>>> idx[loc]
SortedIndex((3,), dtype=int64)
[ 6 11 35]
```

locate_intersection_ranges(*starts*, *stops*)
    Locate the intersection with a set of ranges.

        Parameters starts : array_like, int

            Range start values.

           stops : array_like, int

            Range stop values.

        Returns loc : ndarray, bool

            Boolean array with location of entries found.

           loc_ranges : ndarray, bool

            Boolean array with location of ranges containing one or more entries.

Examples

```
>>> import allel
>>> import numpy as np
>>> idx = allel.SortedIndex([3, 6, 11, 20, 35])
>>> ranges = np.array([[0, 2], [6, 17], [12, 15], [31, 35],
...                    [100, 120]])
>>> starts = ranges[:, 0]
>>> stops = ranges[:, 1]
>>> loc, loc_ranges = idx.locate_intersection_ranges(starts, stops)
>>> loc
array([False,  True,  True, False,  True], dtype=bool)
>>> loc_ranges
array([False,  True, False,  True, False], dtype=bool)
>>> idx[loc]
SortedIndex((3,), dtype=int64)
[ 6 11 35]
>>> ranges[loc_ranges]
array([[ 6, 17],
       [31, 35]])
```

intersect_ranges(*starts*, *stops*)
    Intersect with a set of ranges.

        Parameters starts : array_like, int

            Range start values.

           stops : array_like, int

            Range stop values.

        Returns idx : SortedIndex

Examples

```
>>> import allel
>>> import numpy as np
>>> idx = allel.SortedIndex([3, 6, 11, 20, 35])
>>> ranges = np.array([[0, 2], [6, 17], [12, 15], [31, 35],
...                    [100, 120]])
```

```
>>> starts = ranges[:, 0]
>>> stops = ranges[:, 1]
>>> idx.intersect_ranges(starts, stops)
SortedIndex((3,), dtype=int64)
[ 6 11 35]
```

UniqueIndex

class `allel.model.ndarray.`**`UniqueIndex`**
    Array of unique values (e.g., variant or sample identifiers).

> **Parameters data** : array_like
>
>> Values.
>
> ****kwargs** : keyword arguments
>
>> All keyword arguments are passed through to `numpy.array()`.

Notes

This class represents an arbitrary set of unique values, e.g., sample or variant identifiers.

There is no need for values to be sorted. However, all values must be unique within the array, and must be hashable objects.

Examples

```
>>> import allel
>>> idx = allel.UniqueIndex(['A', 'C', 'B', 'F'])
>>> idx.dtype
dtype('<U1')
>>> idx.ndim
1
>>> idx.shape
(4,)
```

`locate_key`(*key*)
    Get index location for the requested key.

> **Parameters key** : object
>
>> Key to locate.
>
> **Returns loc** : int
>
>> Location of *key*.

Examples

```
>>> import allel
>>> idx = allel.UniqueIndex(['A', 'C', 'B', 'F'])
>>> idx.locate_key('A')
0
>>> idx.locate_key('B')
```

```
      2
>>> try:
...       idx.locate_key('X')
... except KeyError as e:
...       print(e)
...
'X'
```

locate_keys(*keys*, *strict=True*)
Get index locations for the requested keys.

> **Parameters keys** : array_like
>
> > Array of keys to locate.
>
> **strict** : bool, optional
>
> > If True, raise KeyError if any keys are not found in the index.
>
> **Returns loc** : ndarray, bool
>
> > Boolean array with location of keys.

Examples

```
>>> import allel
>>> idx = allel.UniqueIndex(['A', 'C', 'B', 'F'])
>>> idx.locate_keys(['F', 'C'])
array([False,  True, False,  True], dtype=bool)
>>> idx.locate_keys(['X', 'F', 'G', 'C', 'Z'], strict=False)
array([False,  True, False,  True], dtype=bool)
```

locate_intersection(*other*)
Locate the intersection with another array.

> **Parameters other** : array_like
>
> > Array to intersect.
>
> **Returns loc** : ndarray, bool
>
> > Boolean array with location of intersection.
>
> **loc_other** : ndarray, bool
>
> > Boolean array with location in *other* of intersection.

Examples

```
>>> import allel
>>> idx1 = allel.UniqueIndex(['A', 'C', 'B', 'F'])
>>> idx2 = allel.UniqueIndex(['X', 'F', 'G', 'C', 'Z'])
>>> loc1, loc2 = idx1.locate_intersection(idx2)
>>> loc1
array([False,  True, False,  True], dtype=bool)
>>> loc2
array([False,  True, False,  True, False], dtype=bool)
>>> idx1[loc1]
UniqueIndex((2,), dtype=<U1)
['C' 'F']
```

```
>>> idx2[loc2]
UniqueIndex((2,), dtype=<U1)
['F' 'C']
```

intersect(*other*)

Intersect with *other*.

> **Parameters other** : array_like
>
>> Array to intersect.
>
> **Returns out** : UniqueIndex

Examples

```
>>> import allel
>>> idx1 = allel.UniqueIndex(['A', 'C', 'B', 'F'])
>>> idx2 = allel.UniqueIndex(['X', 'F', 'G', 'C', 'Z'])
>>> idx1.intersect(idx2)
UniqueIndex((2,), dtype=<U1)
['C' 'F']
>>> idx2.intersect(idx1)
UniqueIndex((2,), dtype=<U1)
['F' 'C']
```

SortedMultiIndex

class allel.model.ndarray.**SortedMultiIndex**(*l1*, *l2*, *copy=False*)

Two-level index of sorted values, e.g., variant positions from two or more chromosomes/contigs.

> **Parameters l1** : array_like
>
>> First level values in ascending order.
>
> **l2** : array_like
>
>> Second level values, in ascending order within each sub-level.
>
> **copy** : bool, optional
>
>> If True, inputs will be copied into new arrays.

Examples

```
>>> import allel
>>> chrom = ['chr1', 'chr1', 'chr2', 'chr2', 'chr2', 'chr3']
>>> pos = [1, 4, 2, 5, 5, 3]
>>> idx = allel.SortedMultiIndex(chrom, pos)
>>> len(idx)
6
```

locate_key(*k1*, *k2=None*)

Get index location for the requested key.

> **Parameters k1** : object
>
>> Level 1 key.

> **k2** : object, optional
>
>> Level 2 key.
>
> **Returns loc** : int or slice
>
>> Location of requested key (will be slice if there are duplicate entries).

Examples

```
>>> import allel
>>> chrom = ['chr1', 'chr1', 'chr2', 'chr2', 'chr2', 'chr3']
>>> pos = [1, 4, 2, 5, 5, 3]
>>> idx = allel.SortedMultiIndex(chrom, pos)
>>> idx.locate_key('chr1')
slice(0, 2, None)
>>> idx.locate_key('chr1', 4)
1
>>> idx.locate_key('chr2', 5)
slice(3, 5, None)
>>> try:
...     idx.locate_key('chr3', 4)
... except KeyError as e:
...     print(e)
...
('chr3', 4)
```

locate_range(*k1*, *start=None*, *stop=None*)
  Locate slice of index containing all entries within the range *key*:*start-stop* **inclusive**.

> **Parameters key** : object
>
>> Level 1 key value.
>
> **start** : object, optional
>
>> Level 2 start value.
>
> **stop** : object, optional
>
>> Level 2 stop value.
>
> **Returns loc** : slice
>
>> Slice object.

Examples

```
>>> import allel
>>> chrom = ['chr1', 'chr1', 'chr2', 'chr2', 'chr2', 'chr3']
>>> pos = [1, 4, 2, 5, 5, 3]
>>> idx = allel.SortedMultiIndex(chrom, pos)
>>> idx.locate_range('chr1')
slice(0, 2, None)
>>> idx.locate_range('chr1', 1, 4)
slice(0, 2, None)
>>> idx.locate_range('chr2', 3, 7)
slice(3, 5, None)
>>> try:
...     idx.locate_range('chr3', 4, 9)
```

```
    ... except KeyError as e:
    ...     print(e)
    ('chr3', 4, 9)
```

Utility functions

allel.model.ndarray.**create_allele_mapping**(*ref*, *alt*, *alleles*, *dtype='i1'*)

    Create an array mapping variant alleles into a different allele index system.

        Parameters ref : array_like, S1, shape (n_variants,)

            Reference alleles.

        alt : array_like, S1, shape (n_variants, n_alt_alleles)

            Alternate alleles.

        alleles : array_like, S1, shape (n_variants, n_alleles)

            Alleles defining the new allele indexing.

        Returns mapping : ndarray, int8, shape (n_variants, n_alt_alleles + 1)

    See also:

    GenotypeArray.map_alleles,   *HaplotypeArray.map_alleles*,
    AlleleCountsArray.map_alleles

Examples

Example with biallelic variants:

```
>>> import allel
>>> from allel.model.ndarray import create_allele_mapping
>>> ref = [b'A', b'C', b'T', b'G']
>>> alt = [b'T', b'G', b'C', b'A']
>>> alleles = [[b'A', b'T'],  # no transformation
...            [b'G', b'C'],  # swap
...            [b'T', b'A'],  # 1 missing
...            [b'A', b'C']]  # 1 missing
>>> mapping = create_allele_mapping(ref, alt, alleles)
>>> mapping
array([[ 0,  1],
       [ 1,  0],
       [ 0, -1],
       [-1,  0]], dtype=int8)
```

Example with multiallelic variants:

```
>>> ref = [b'A', b'C', b'T']
>>> alt = [[b'T', b'G'],
...        [b'A', b'T'],
...        [b'G', b'.']]
>>> alleles = [[b'A', b'T'],
...            [b'C', b'T'],
...            [b'G', b'A']]
>>> mapping = create_allele_mapping(ref, alt, alleles)
>>> mapping
array([[ 0,  1, -1],
```

```
        [ 0, -1,  1],
        [-1,  0, -1]], dtype=int8)
```

`allel.model.ndarray.`**`locate_fixed_differences`**(*ac1*, *ac2*)

　　Locate variants with no shared alleles between two populations.

> > **Parameters ac1** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the first population.
> >
> > **ac2** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the second population.
> >
> > **Returns loc** : ndarray, bool, shape (n_variants,)

> **See also:**
>
> *allel.stats.diversity.windowed_df*

> **Examples**

```
>>> import allel
>>> from allel.model.ndarray import locate_fixed_differences
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [1, 1], [1, 1]],
...                          [[0, 1], [0, 1], [0, 1], [0, 1]],
...                          [[0, 1], [0, 1], [1, 1], [1, 1]],
...                          [[0, 0], [0, 0], [1, 1], [2, 2]],
...                          [[0, 0], [-1, -1], [1, 1], [-1, -1]]])
>>> ac1 = g.count_alleles(subpop=[0, 1])
>>> ac2 = g.count_alleles(subpop=[2, 3])
>>> loc_df = locate_fixed_differences(ac1, ac2)
>>> loc_df
array([ True, False, False,  True,  True], dtype=bool)
```

`allel.model.ndarray.`**`locate_private_alleles`**(**acs*)

　　Locate alleles that are found only in a single population.

> > **Parameters *acs** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts arrays from each population.
> >
> > **Returns loc** : ndarray, bool, shape (n_variants, n_alleles)
> >
> > > Boolean array where elements are True if allele is private to a single population.

> **Examples**

```
>>> import allel
>>> from allel.model.ndarray import locate_private_alleles
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [1, 1], [1, 1]],
...                          [[0, 1], [0, 1], [0, 1], [0, 1]],
...                          [[0, 1], [0, 1], [1, 1], [1, 1]],
...                          [[0, 0], [0, 0], [1, 1], [2, 2]],
...                          [[0, 0], [-1, -1], [1, 1], [-1, -1]]])
>>> ac1 = g.count_alleles(subpop=[0, 1])
>>> ac2 = g.count_alleles(subpop=[2])
>>> ac3 = g.count_alleles(subpop=[3])
>>> loc_private_alleles = locate_private_alleles(ac1, ac2, ac3)
```

3.1. Data structures

```
>>> loc_private_alleles
array([[ True, False, False],
       [False, False, False],
       [ True, False, False],
       [ True,  True,  True],
       [ True,  True, False]], dtype=bool)
>>> loc_private_variants = np.any(loc_private_alleles, axis=1)
>>> loc_private_variants
array([ True, False,  True,  True,  True], dtype=bool)
```

allel.model.ndarray.**sample_to_haplotype_selection**(*indices*, *ploidy*)

3.1.2 Chunked arrays

This module provides alternative implementations of array and table classes defined in the *allel.model.ndarray* module, using chunked arrays for data storage. Chunked arrays can be compressed and optionally stored on disk, providing a means for working with data too large to fit uncompressed in main memory.

Either HDF5 (via h5py) or bcolz can be used as the underlying storage layer. Choice of storage layer can be made via the *storage* keyword argument which all class methods accept. This argument can either be a string identifying one of the predefined storage layer configurations, or an object implementing the chunked storage API. For more information about controlling storage see the *allel.chunked* module.

GenotypeChunkedArray

class allel.model.chunked.**GenotypeChunkedArray**(*data*)

Alternative implementation of the *allel.model.ndarray.GenotypeArray* class, wrapping a chunked array as the backing store.

> **Parameters data** : array_like, int, shape (n_variants, n_samples, ploidy)
>
> > Genotype data to be wrapped. May be a bcolz carray, h5py dataset, or anything providing a similar interface.

Examples

Wrap an HDF5 dataset:

```
>>> import h5py
>>> with h5py.File('callset.h5', mode='w') as h5f:
...     h5g = h5f.create_group('/3L/calldata')
...     h5g.create_dataset('genotype',
...                        data=[[[0, 0], [0, 1]],
...                              [[0, 1], [1, 1]],
...                              [[0, 2], [-1, -1]]],
...                        dtype='i1', chunks=(2, 2, 2),
...                        compression='gzip', compression_opts=1)
...
<HDF5 dataset "genotype": shape (3, 2, 2), type "|i1">
>>> import allel
>>> callset = h5py.File('callset.h5', mode='r')
>>> g = allel.GenotypeChunkedArray(callset['/3L/calldata/genotype'])
>>> g
GenotypeChunkedArray((3, 2, 2), int8, chunks=(2, 2, 2))
  nbytes: 12; cbytes: 30; cratio: 0.4;
```

```
    compression: gzip; compression_opts: 1;
    data: h5py._hl.dataset.Dataset
>>> g.data
<HDF5 dataset "genotype": shape (3, 2, 2), type "|i1">
```

Obtain a numpy array by slicing, e.g.:

```
>>> g[:]
GenotypeArray((3, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

Note that most methods will return a chunked array, using whatever chunked storage is set as default (bcolz carray) or specified directly via the *storage* keyword argument. E.g.:

```
>>> g.copy()
GenotypeChunkedArray((3, 2, 2), int8, chunks=(4096, 2, 2))
  nbytes: 12; cbytes: 16.0K; cratio: 0.0;
  compression: blosc; compression_opts: cparams(clevel=5, shuffle=1, cname='lz4', quantize=0);
  data: bcolz.carray_ext.carray
>>> g.copy(storage='zarrmem')
GenotypeChunkedArray((3, 2, 2), int8, chunks=(262144, 2, 2))
  nbytes: 12; cbytes: 4.9K; cratio: 0.0;
  compression: blosc; compression_opts: {'clevel': 5, 'cname': 'blosclz', 'shuffle': 1};
  data: zarr.core.Array
>>> g.copy(storage='hdf5mem_zlib1')
GenotypeChunkedArray((3, 2, 2), int8, chunks=(262144, 2, 2))
  nbytes: 12; cbytes: 4.5K; cratio: 0.0;
  compression: gzip; compression_opts: 1;
  data: h5py._hl.dataset.Dataset
```

HaplotypeChunkedArray

class allel.model.chunked.**HaplotypeChunkedArray**(*data*)

> Alternative implementation of the *allel.model.ndarray.HaplotypeArray* class, using a chunked array as the backing store.
>
> > **Parameters data** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype data to be wrapped. May be a bcolz carray, h5py dataset, or anything providing a similar interface.

AlleleCountsChunkedArray

class allel.model.chunked.**AlleleCountsChunkedArray**(*data*)

> Alternative implementation of the *allel.model.ndarray.AlleleCountsArray* class, using a chunked array as the backing store.
>
> > **Parameters data** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts data to be wrapped. May be a bcolz carray, h5py dataset, or anything providing a similar interface.

VariantChunkedTable

class allel.model.chunked.**VariantChunkedTable**(*data*, *names=None*, *index=None*)

  Alternative implementation of the *allel.model.ndarray.VariantTable* class, using a chunked table as the backing store.

    Parameters data: table_like

      Data to be wrapped. May be a tuple or list of columns (array-like), a dict mapping names to columns, a bcolz ctable, h5py group, numpy recarray, or anything providing a similar interface.

     names : sequence of strings

      Column names.

Examples

Wrap columns stored as datasets within an HDF5 group:

```
>>> import h5py
>>> chrom = [b'chr1', b'chr1', b'chr2', b'chr2', b'chr3']
>>> pos = [2, 7, 3, 9, 6]
>>> dp = [35, 12, 78, 22, 99]
>>> qd = [4.5, 6.7, 1.2, 4.4, 2.8]
>>> ac = [(1, 2), (3, 4), (5, 6), (7, 8), (9, 10)]
>>> with h5py.File('callset.h5', mode='w') as h5f:
...     h5g = h5f.create_group('/3L/variants')
...     h5g.create_dataset('CHROM', data=chrom, chunks=True)
...     h5g.create_dataset('POS', data=pos, chunks=True)
...     h5g.create_dataset('DP', data=dp, chunks=True)
...     h5g.create_dataset('QD', data=qd, chunks=True)
...     h5g.create_dataset('AC', data=ac, chunks=True)
...
<HDF5 dataset "CHROM": shape (5,), type "|S4">
<HDF5 dataset "POS": shape (5,), type "<i8">
<HDF5 dataset "DP": shape (5,), type "<i8">
<HDF5 dataset "QD": shape (5,), type "<f8">
<HDF5 dataset "AC": shape (5, 2), type "<i8">
>>> import allel
>>> callset = h5py.File('callset.h5', mode='r')
>>> vt = allel.VariantChunkedTable(callset['/3L/variants'],
...                                names=['CHROM', 'POS', 'AC', 'QD', 'DP'])
>>> vt
VariantChunkedTable(5)
  nbytes: 220; cbytes: 220; cratio: 1.0;
  data: h5py._hl.group.Group
```

Obtain a single row:

```
>>> vt[0]
row(CHROM=b'chr1', POS=2, AC=array([1, 2]), QD=4.5, DP=35)
```

Obtain a numpy array by slicing:

```
>>> vt[:]
VariantTable((5,), dtype=[('CHROM', 'S4'), ('POS', '<i8'), ('AC', ...
[(b'chr1', 2, [1, 2], 4.5, 35) (b'chr1', 7, [3, 4], 6.7, 12)
```

```
   (b'chr2', 3, [5, 6], 1.2, 78) (b'chr2', 9, [7, 8], 4.4, 22)
   (b'chr3', 6, [9, 10], 2.8, 99)]
```

Access a subset of columns:

```
>>> vt[['CHROM', 'POS']]
VariantChunkedTable(5)
  nbytes: 60; cbytes: 60; cratio: 1.0;
  data: builtins.list
```

Note that most methods will return a chunked table, using whatever chunked storage is set as default (bcolz ctable) or specified directly via the *storage* keyword argument. E.g.:

```
>>> vt.copy()
VariantChunkedTable(5)
  nbytes: 220; cbytes: 80.0K; cratio: 0.0;
  data: bcolz.ctable.ctable
>>> vt.copy(storage='zarr')
VariantChunkedTable(5)
  nbytes: 220; cbytes: 39.1K; cratio: 0.0;
  data: allel.chunked.storage_zarr.ZarrTable
>>> vt.copy(storage='hdf5mem_zlib1')
VariantChunkedTable(5)
  nbytes: 220; cbytes: 22.5K; cratio: 0.0;
  data: h5py._hl.files.File
```

FeatureChunkedTable

class allel.model.chunked.**FeatureChunkedTable**(*data*, *names=None*)

Alternative implementation of the *allel.model.ndarray.FeatureTable* class, using a chunked table as the backing store.

> **Parameters data: table_like**
>
>> Data to be wrapped. May be a tuple or list of columns (array-like), a dict mapping names to columns, a bcolz ctable, h5py group, numpy recarray, or anything providing a similar interface.
>
>> **names** : sequence of strings
>>
>>> Column names.

AlleleCountsChunkedTable

class allel.model.chunked.**FeatureChunkedTable**(*data*, *names=None*)

Alternative implementation of the *allel.model.ndarray.FeatureTable* class, using a chunked table as the backing store.

> **Parameters data: table_like**
>
>> Data to be wrapped. May be a tuple or list of columns (array-like), a dict mapping names to columns, a bcolz ctable, h5py group, numpy recarray, or anything providing a similar interface.
>
>> **names** : sequence of strings
>>
>>> Column names.

3.1.3 Dask arrays (experimental)

This module provides alternative implementations of array classes defined in the *allel.model.ndarray* module, using dask.array as the computational engine.

Dask uses blocked algorithms and task scheduling to break up work into smaller pieces, allowing computation over large datasets. It also uses lazy evaluation, meaning that multiple operations can be chained together into a task graph, reducing total memory requirements for intermediate results, and only the tasks required to generate the requested part of the final data set will be executed.

This module is experimental, if you find a bug please raise an issue on GitHub.

This module requires Dask >= 0.7.6.

GenotypeDaskArray

class `allel.model.dask.`**`GenotypeDaskArray`**(**args*, ***kwargs*)
Dask genotype array.

To instantiate from an existing array-like object, use `GenotypeDaskArray.from_array()`.

HaplotypeDaskArray

class `allel.model.dask.`**`HaplotypeDaskArray`**
Dask haplotype array.

To instantiate from an existing array-like object, use `HaplotypeDaskArray.from_array()`.

AlleleCountsDaskArray

class `allel.model.dask.`**`AlleleCountsDaskArray`**
Dask allele counts array.

To instantiate from an existing array-like object, use `AlleleCountsDaskArray.from_array()`.

3.1.4 bcolz arrays (deprecated)

This module provides alternative implementations of array classes defined in the *allel.model.ndarray* module, using bcolz compressed arrays instead of numpy arrays for data storage.

Note: Please note this module is now deprecated and will be removed in a future release. It has been superseded by the *allel.model.chunked* module which supports both bcolz and HDF5 as the underlying storage layer.

GenotypeCArray

class `allel.model.bcolz.`**`GenotypeCArray`**(*data=None*, *copy=False*, ***kwargs*)
Alternative implementation of the *allel.model.ndarray.GenotypeArray* class, using a
`bcolz.carray` as the backing store.

> **Parameters data** : array_like, int, shape (n_variants, n_samples, ploidy), optional

Data to initialise the array with. May be a bcolz carray, which will not be copied if copy=False. May also be None, in which case rootdir must be provided (disk-based array).

copy : bool, optional

If True, copy the input data into a new bcolz carray.

**kwargs : keyword arguments

Passed through to the bcolz carray constructor.

Examples

Instantiate a compressed genotype array from existing data:

```
>>> import allel
>>> g = allel.GenotypeCArray([[[0, 0], [0, 1]],
...                           [[0, 1], [1, 1]],
...                           [[0, 2], [-1, -1]]], dtype='i1')
>>> g
GenotypeCArray((3, 2, 2), int8)
  nbytes := 12; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 4096; chunksize: 16384; blocksize: 0
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

Obtain a numpy ndarray from a compressed array by slicing:

```
>>> g[:]
GenotypeArray((3, 2, 2), dtype=int8)
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

Build incrementally:

```
>>> import bcolz
>>> data = bcolz.zeros((0, 2, 2), dtype='i1')
>>> data.append([[0, 0], [0, 1]])
>>> data.append([[0, 1], [1, 1]])
>>> data.append([[0, 2], [-1, -1]])
>>> g = allel.GenotypeCArray(data)
>>> g
GenotypeCArray((3, 2, 2), int8)
  nbytes := 12; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 4096; chunksize: 16384; blocksize: 0
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
```

```
     [ 1  1]]
   [[ 0  2]
    [-1 -1]]]
```

Load from HDF5:

```python
>>> import h5py
>>> with h5py.File('test1.h5', mode='w') as h5f:
...     h5f.create_dataset('genotype',
...                        data=[[[0, 0], [0, 1]],
...                              [[0, 1], [1, 1]],
...                              [[0, 2], [-1, -1]]],
...                        dtype='i1',
...                        chunks=(2, 2, 2))
...
<HDF5 dataset "genotype": shape (3, 2, 2), type "|i1">
>>> g = allel.GenotypeCArray.from_hdf5('test1.h5', 'genotype')
>>> g
GenotypeCArray((3, 2, 2), int8)
  nbytes := 12; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 4096; chunksize: 16384; blocksize: 0
[[[ 0  0]
  [ 0  1]]
 [[ 0  1]
  [ 1  1]]
 [[ 0  2]
  [-1 -1]]]
```

Note that methods of this class will return bcolz carrays rather than numpy ndarrays where possible. E.g.:

```python
>>> g.take([0, 2], axis=0)
GenotypeCArray((2, 2, 2), int8)
  nbytes := 8; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 4096; chunksize: 16384; blocksize: 0
[[[ 0  0]
  [ 0  1]]
 [[ 0  2]
  [-1 -1]]]
>>> g.is_called()
CArrayWrapper((3, 2), bool)
  nbytes := 6; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 8192; chunksize: 16384; blocksize: 0
[[ True  True]
 [ True  True]
 [ True False]]
>>> g.to_haplotypes()
HaplotypeCArray((3, 4), int8)
  nbytes := 12; cbytes := 16.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 4096; chunksize: 16384; blocksize: 0
[[ 0  0  0  1]
 [ 0  1  1  1]
 [ 0  2 -1 -1]]
>>> g.count_alleles()
AlleleCountsCArray((3, 3), int32)
  nbytes := 36; cbytes := 16.00 KB; ratio: 0.00
```

```
    cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
    chunklen := 1365; chunksize: 16380; blocksize: 0
[[3 1 0]
 [1 3 0]
 [1 0 1]]
```

HaplotypeCArray

class allel.model.bcolz.**HaplotypeCArray**(*data=None*, *copy=False*, ***kwargs*)

Alternative implementation of the *allel.model.ndarray.HaplotypeArray* class, using a bcolz.carray as the backing store.

> **Parameters data** : array_like, int, shape (n_variants, n_haplotypes), optional
>
>> Data to initialise the array with. May be a bcolz carray, which will not be copied if copy=False. May also be None, in which case rootdir must be provided (disk-based array).
>
>> **copy** : bool, optional
>
>> If True, copy the input data into a new bcolz carray.
>
>> ****kwargs** : keyword arguments
>
>> Passed through to the bcolz carray constructor.

AlleleCountsCArray

class allel.model.bcolz.**AlleleCountsCArray**(*data=None*, *copy=False*, ***kwargs*)

Alternative implementation of the *allel.model.ndarray.AlleleCountsArray* class, using a bcolz.carray as the backing store.

> **Parameters data** : array_like, int, shape (n_variants, n_alleles), optional
>
>> Data to initialise the array with. May be a bcolz carray, which will not be copied if copy=False. May also be None, in which case rootdir must be provided (disk-based array).
>
>> **copy** : bool, optional
>
>> If True, copy the input data into a new bcolz carray.
>
>> ****kwargs** : keyword arguments
>
>> Passed through to the bcolz carray constructor.

VariantCTable

class allel.model.bcolz.**VariantCTable**(*data=None*, *copy=False*, *index=None*, ***kwargs*)

Alternative implementation of the *allel.model.ndarray.VariantTable* class, using a bcolz.ctable as the backing store.

> **Parameters data** : tuple or list of column objects, optional
>
>> The list of column data to build the ctable object. This can also be a pure NumPy structured array. May also be a bcolz ctable, which will not be copied if copy=False. May also be None, in which case rootdir must be provided (disk-based array).
>
>> **copy** : bool, optional

If True, copy the input data into a new bcolz ctable.

index : string or pair of strings, optional

If a single string, name of column to use for a sorted index. If a pair of strings, name of columns to use for a sorted multi-index.

**kwargs : keyword arguments

Passed through to the bcolz ctable constructor.

Examples

Instantiate from existing data:

```
>>> import allel
>>> chrom = [b'chr1', b'chr1', b'chr2', b'chr2', b'chr3']
>>> pos = [2, 7, 3, 9, 6]
>>> dp = [35, 12, 78, 22, 99]
>>> qd = [4.5, 6.7, 1.2, 4.4, 2.8]
>>> ac = [(1, 2), (3, 4), (5, 6), (7, 8), (9, 10)]
>>> vt = allel.VariantCTable([chrom, pos, dp, qd, ac],
...                          names=['CHROM', 'POS', 'DP', 'QD', 'AC'],
...                          index=('CHROM', 'POS'))
>>> vt
VariantCTable((5,), [('CHROM', 'S4'), ('POS', '<i8'), ('DP', '<i8'), ('QD', '<f8'), ('AC', '<i8'
  nbytes: 220; cbytes: 80.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
[(b'chr1', 2, 35, 4.5, [1, 2]) (b'chr1', 7, 12, 6.7, [3, 4])
 (b'chr2', 3, 78, 1.2, [5, 6]) (b'chr2', 9, 22, 4.4, [7, 8])
 (b'chr3', 6, 99, 2.8, [9, 10])]
```

Slicing rows returns *allel.model.ndarray.VariantTable*:

```
>>> vt[:2]
VariantTable((2,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '<i8'), ('DP', '<i8'), ('QD',
[(b'chr1', 2, 35, 4.5, array([1, 2])) (b'chr1', 7, 12, 6.7, array([3, 4]))]
```

Accessing columns returns *allel.model.bcolz.VariantCTable*:

```
>>> vt[['DP', 'QD']]
VariantCTable((5,), [('DP', '<i8'), ('QD', '<f8')])
  nbytes: 80; cbytes: 32.00 KB; ratio: 0.00
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
[(35, 4.5) (12, 6.7) (78, 1.2) (22, 4.4) (99, 2.8)]
```

Use the index to locate variants:

```
>>> loc = vt.index.locate_range(b'chr2', 1, 10)
>>> vt[loc]
VariantTable((2,), dtype=(numpy.record, [('CHROM', 'S4'), ('POS', '<i8'), ('DP', '<i8'), ('QD',
[(b'chr2', 3, 78, 1.2, array([5, 6])) (b'chr2', 9, 22, 4.4, array([7, 8]))]
```

FeatureCTable

class allel.model.bcolz.**FeatureCTable**(*data=None*, *copy=False*, ***kwargs*)

Alternative implementation of the *allel.model.ndarray.FeatureTable* class, using a bcolz.ctable as the backing store.

> **Parameters data** : tuple or list of column objects, optional
>
>> The list of column data to build the ctable object. This can also be a pure NumPy structured array. May also be a bcolz ctable, which will not be copied if copy=False. May also be None, in which case rootdir must be provided (disk-based array).
>
> **copy** : bool, optional
>
>> If True, copy the input data into a new bcolz ctable.
>
> **index** : pair or triplet of strings, optional
>
>> Names of columns to use for positional index, e.g., ('start', 'stop') if table contains 'start' and 'stop' columns and records from a single chromosome/contig, or ('seqid', 'start', 'end') if table contains records from multiple chromosomes/contigs.
>
> ****kwargs** : keyword arguments
>
>> Passed through to the bcolz ctable constructor.

Utility functions

allel.model.bcolz.**carray_block_map**(*domain*, *f*, *out=None*, *blen=None*, *wrap=None*, ***kwargs*)

allel.model.bcolz.**carray_block_sum**(*carr*, *axis=None*, *blen=None*, *transform=None*)

allel.model.bcolz.**carray_block_max**(*carr*, *axis=None*, *blen=None*)

allel.model.bcolz.**carray_block_min**(*carr*, *axis=None*, *blen=None*)

allel.model.bcolz.**carray_block_compress**(*carr*, *condition*, *axis*, *blen=None*, ***kwargs*)

allel.model.bcolz.**carray_block_take**(*carr*, *indices*, *axis*, *blen=None*, ***kwargs*)

allel.model.bcolz.**carray_block_vstack**(*tup*, *blen=None*, ***kwargs*)

allel.model.bcolz.**carray_block_hstack**(*tup*, *blen=None*, ***kwargs*)

allel.model.bcolz.**carray_from_hdf5**(**args*, ***kwargs*)
   Load a bcolz carray from an HDF5 dataset.

   Either provide an h5py dataset as a single positional argument, or provide two positional arguments giving the HDF5 file path and the dataset node path within the file.

   The following optional parameters may be given. Any other keyword arguments are passed through to the bcolz.carray constructor.

> **Parameters start** : int, optional
>
>> Index to start loading from.
>
> **stop** : int, optional
>
>> Index to finish loading at.
>
> **condition** : array_like, bool, optional
>
>> A 1-dimensional boolean array of the same length as the first dimension of the dataset to load, indicating a selection of rows to load.
>
> **blen** : int, optional
>
>> Block size to use when loading.

allel.model.bcolz.**carray_to_hdf5**(*carr*, *parent*, *name*, ***kwargs*)
   Write a bcolz carray to an HDF5 dataset.

>>> **Parameters carr** : bcolz.carray
>>>
>>>> Data to write.
>>>
>>> **parent** : string or h5py group
>>>
>>>> Parent HDF5 file or group. If a string, will be treated as HDF5 file name.
>>>
>>> **name** : string
>>>
>>>> Name or path of dataset to write data into.
>>>
>>> **kwargs** : keyword arguments
>>>
>>>> Passed through to h5py require_dataset() function.
>>>
>> **Returns h5d** : h5py dataset

allel.model.bcolz.**ctable_block_compress**(*ctbl*, *condition*, *blen=None*, ***kwargs*)

allel.model.bcolz.**ctable_block_take**(*ctbl*, *indices*, ***kwargs*)

allel.model.bcolz.**ctable_from_hdf5_group**(**args*, ***kwargs*)
> Load a bcolz ctable from columns stored as separate datasets with an HDF5 group.

> Either provide an h5py group as a single positional argument, or provide two positional arguments giving the HDF5 file path and the group node path within the file.

> The following optional parameters may be given. Any other keyword arguments are passed through to the bcolz.carray constructor.

>> **Parameters start** : int, optional
>>
>>> Index to start loading from.
>>
>> **stop** : int, optional
>>
>>> Index to finish loading at.
>>
>> **condition** : array_like, bool, optional
>>
>>> A 1-dimensional boolean array of the same length as the columns of the table to load, indicating a selection of rows to load.
>>
>> **blen** : int, optional
>>
>>> Block size to use when loading.

allel.model.bcolz.**ctable_to_hdf5_group**(*ctbl*, *parent*, *name*, ***kwargs*)
> Write each column in a bcolz ctable to a dataset in an HDF5 group.

>> **Parameters parent** : string or h5py group
>>
>>> Parent HDF5 file or group. If a string, will be treated as HDF5 file name.
>>
>> **name** : string
>>
>>> Name or path of group to write data into.
>>
>> **kwargs** : keyword arguments
>>
>>> Passed through to h5py require_dataset() function.
>>
> **Returns h5g** : h5py group

3.2 Statistics and plotting

3.2.1 Diversity & divergence

allel.stats.diversity.**mean_pairwise_difference**(*ac*, *an=None*, *fill=nan*)
> Calculate for each variant the mean number of pairwise differences between chromosomes sampled from within a single population.

>> **Parameters ac** : array_like, int, shape (n_variants, n_alleles)

>>> Allele counts array.

>> **an** : array_like, int, shape (n_variants,), optional

>>> Allele numbers. If not provided, will be calculated from *ac*.

>> **fill** : float

>>> Use this value where there are no pairs to compare (e.g., all allele calls are missing).

>> **Returns mpd** : ndarray, float, shape (n_variants,)

> **See also:**

> *sequence_diversity*, *windowed_diversity*

> ### Notes

> The values returned by this function can be summed over a genome region and divided by the number of accessible bases to estimate nucleotide diversity, a.k.a. *pi*.

> ### Examples

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 0],
...                           [0, 0, 0, 1],
...                           [0, 0, 1, 1],
...                           [0, 1, 1, 1],
...                           [1, 1, 1, 1],
...                           [0, 0, 1, 2],
...                           [0, 1, 1, 2],
...                           [0, 1, -1, -1]])
>>> ac = h.count_alleles()
>>> allel.stats.mean_pairwise_difference(ac)
array([ 0.        ,  0.5       ,  0.66666667,  0.5       ,  0.        ,
        0.83333333,  0.83333333,  1.        ])
```

allel.stats.diversity.**sequence_diversity**(*pos*, *ac*, *start=None*, *stop=None*, *is_accessible=None*)
> Estimate nucleotide diversity within a given region.

>> **Parameters pos** : array_like, int, shape (n_items,)

>>> Variant positions, using 1-based coordinates, in ascending order.

>> **ac** : array_like, int, shape (n_variants, n_alleles)

>>> Allele counts array.

>> **start** : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

Returns pi : ndarray, float, shape (n_windows,)

Nucleotide diversity.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> pi = allel.stats.sequence_diversity(pos, ac, start=1, stop=31)
>>> pi
0.13978494623655915
```

`allel.stats.diversity.`**`windowed_diversity`**(*pos*, *ac*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *is_accessible=None*, *fill=nan*)

Estimate nucleotide diversity in windows over a single chromosome/contig.

Parameters pos : array_like, int, shape (n_items,)

Variant positions, using 1-based coordinates, in ascending order.

ac : array_like, int, shape (n_variants, n_alleles)

Allele counts array.

size : int, optional

The window size (number of bases).

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

fill : object, optional

The value to use where a window is completely inaccessible.

Returns pi : ndarray, float, shape (n_windows,)

Nucleotide diversity in each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

n_bases : ndarray, int, shape (n_windows,)

Number of (accessible) bases in each window.

counts : ndarray, int, shape (n_windows,)

Number of variants in each window.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> pi, windows, n_bases, counts = allel.stats.windowed_diversity(
...     pos, ac, size=10, start=1, stop=31
... )
>>> pi
array([ 0.11666667,  0.21666667,  0.09090909])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 31]])
>>> n_bases
array([10, 10, 11])
>>> counts
array([3, 4, 2])
```

allel.stats.diversity.**mean_pairwise_difference_between**(*ac1*, *ac2*, *an1=None*, *an2=None*, *fill=nan*)

Calculate for each variant the mean number of pairwise differences between chromosomes sampled from two different populations.

Parameters ac1 : array_like, int, shape (n_variants, n_alleles)

Allele counts array from the first population.

ac2 : array_like, int, shape (n_variants, n_alleles)

Allele counts array from the second population.

an1 : array_like, int, shape (n_variants,), optional

Allele numbers for the first population. If not provided, will be calculated from *ac1*.

an2 : array_like, int, shape (n_variants,), optional

Allele numbers for the second population. If not provided, will be calculated from *ac2*.

fill : float

Use this value where there are no pairs to compare (e.g., all allele calls are missing).

Returns mpd : ndarray, float, shape (n_variants,)

See also:

sequence_divergence, *windowed_divergence*

Notes

The values returned by this function can be summed over a genome region and divided by the number of accessible bases to estimate nucleotide divergence between two populations, a.k.a. *Dxy*.

Examples

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 0],
...                           [0, 0, 0, 1],
...                           [0, 0, 1, 1],
...                           [0, 1, 1, 1],
...                           [1, 1, 1, 1],
...                           [0, 0, 1, 2],
...                           [0, 1, 1, 2],
...                           [0, 1, -1, -1]])
>>> ac1 = h.count_alleles(subpop=[0, 1])
>>> ac2 = h.count_alleles(subpop=[2, 3])
>>> allel.stats.mean_pairwise_difference_between(ac1, ac2)
array([ 0.  ,  0.5 ,  1.  ,  0.5 ,  0.  ,  1.  ,  0.75,   nan])
```

allel.stats.diversity.**sequence_divergence**(*pos,   ac1,   ac2,   an1=None,   an2=None,*
start=None, stop=None, is_accessible=None)

Estimate nucleotide divergence between two populations within a given region.

Parameters pos : array_like, int, shape (n_items,)

Variant positions, using 1-based coordinates, in ascending order.

ac1 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the first population.

ac2 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the second population.

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

Returns Dxy : ndarray, float, shape (n_windows,)

Nucleotide divergence.

Examples

Simplest case, two haplotypes in each population:

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 0],
...                           [0, 0, 0, 1],
...                           [0, 0, 1, 1],
...                           [0, 1, 1, 1],
...                           [1, 1, 1, 1],
...                           [0, 0, 1, 2],
...                           [0, 1, 1, 2],
...                           [0, 1, -1, -1],
...                           [-1, -1, -1, -1]])
>>> ac1 = h.count_alleles(subpop=[0, 1])
>>> ac2 = h.count_alleles(subpop=[2, 3])
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> dxy = sequence_divergence(pos, ac1, ac2, start=1, stop=31)
>>> dxy
0.12096774193548387
```

allel.stats.diversity.**windowed_divergence**(*pos*, *ac1*, *ac2*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *is_accessible=None*, *fill=nan*)

Estimate nucleotide divergence between two populations in windows over a single chromosome/contig.

Parameters pos : array_like, int, shape (n_items,)

Variant positions, using 1-based coordinates, in ascending order.

ac1 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the first population.

ac2 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the second population.

size : int, optional

The window size (number of bases).

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

> The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.
>
> **windows** : array_like, int, shape (n_windows, 2), optional
>
> Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.
>
> **is_accessible** : array_like, bool, shape (len(contig),), optional
>
> Boolean array indicating accessibility status for all positions in the chromosome/contig.
>
> **fill** : object, optional
>
> The value to use where a window is completely inaccessible.

Returns   Dxy : ndarray, float, shape (n_windows,)

> Nucleotide divergence in each window.
>
> **windows** : ndarray, int, shape (n_windows, 2)
>
> The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.
>
> **n_bases** : ndarray, int, shape (n_windows,)
>
> Number of (accessible) bases in each window.
>
> **counts** : ndarray, int, shape (n_windows,)
>
> Number of variants in each window.

Examples

Simplest case, two haplotypes in each population:

```
>>> import allel
>>> h = allel.HaplotypeArray([[0, 0, 0, 0],
...                           [0, 0, 0, 1],
...                           [0, 0, 1, 1],
...                           [0, 1, 1, 1],
...                           [1, 1, 1, 1],
...                           [0, 0, 1, 2],
...                           [0, 1, 1, 2],
...                           [0, 1, -1, -1],
...                           [-1, -1, -1, -1]])
>>> ac1 = h.count_alleles(subpop=[0, 1])
>>> ac2 = h.count_alleles(subpop=[2, 3])
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> dxy, windows, n_bases, counts = windowed_divergence(
...     pos, ac1, ac2, size=10, start=1, stop=31
... )
>>> dxy
array([ 0.15 ,  0.225,  0.   ])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 31]])
>>> n_bases
array([10, 10, 11])
```

```
>>> counts
array([3, 4, 2])
```

allel.stats.diversity.**watterson_theta**(*pos*, *ac*, *start=None*, *stop=None*, *is_accessible=None*)

Calculate the value of Watterson's estimator over a given region.

> **Parameters** **pos** : array_like, int, shape (n_items,)
>
>> Variant positions, using 1-based coordinates, in ascending order.
>
>> **ac** : array_like, int, shape (n_variants, n_alleles)
>
>> Allele counts array.
>
>> **start** : int, optional
>
>> The position at which to start (1-based).
>
>> **stop** : int, optional
>
>> The position at which to stop (1-based).
>
>> **is_accessible** : array_like, bool, shape (len(contig),), optional
>
>> Boolean array indicating accessibility status for all positions in the chromosome/contig.
>
> **Returns** **theta_hat_w** : float
>
>> Watterson's estimator (theta hat per base).

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> theta_hat_w = allel.stats.watterson_theta(pos, ac, start=1, stop=31)
>>> theta_hat_w
0.10557184750733138
```

allel.stats.diversity.**windowed_watterson_theta**(*pos*, *ac*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *is_accessible=None*, *fill=nan*)

Calculate the value of Watterson's estimator in windows over a single chromosome/contig.

> **Parameters** **pos** : array_like, int, shape (n_items,)
>
>> Variant positions, using 1-based coordinates, in ascending order.
>
>> **ac** : array_like, int, shape (n_variants, n_alleles)
>
>> Allele counts array.

size : int, optional

> The window size (number of bases).

start : int, optional

> The position at which to start (1-based).

stop : int, optional

> The position at which to stop (1-based).

step : int, optional

> The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

> Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

is_accessible : array_like, bool, shape (len(contig),), optional

> Boolean array indicating accessibility status for all positions in the chromosome/contig.

fill : object, optional

> The value to use where a window is completely inaccessible.

Returns theta_hat_w : ndarray, float, shape (n_windows,)

> Watterson's estimator (theta hat per base).

windows : ndarray, int, shape (n_windows, 2)

> The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

n_bases : ndarray, int, shape (n_windows,)

> Number of (accessible) bases in each window.

counts : ndarray, int, shape (n_windows,)

> Number of variants in each window.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> theta_hat_w, windows, n_bases, counts = allel.stats.windowed_watterson_theta(
...     pos, ac, size=10, start=1, stop=31
... )
```

```
>>> theta_hat_w
array([ 0.10909091,  0.16363636,  0.04958678])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 31]])
>>> n_bases
array([10, 10, 11])
>>> counts
array([3, 4, 2])
```

allel.stats.diversity.**tajima_d**(*ac*, *pos=None*, *start=None*, *stop=None*)

 Calculate the value of Tajima's D over a given region.

  Parameters **ac** : array_like, int, shape (n_variants, n_alleles)

    Allele counts array.

   pos : array_like, int, shape (n_items,), optional

    Variant positions, using 1-based coordinates, in ascending order.

   start : int, optional

    The position at which to start (1-based).

   stop : int, optional

    The position at which to stop (1-based).

  Returns **D** : float

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> allel.stats.tajima_d(ac)
3.1445848780213814
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> allel.stats.tajima_d(ac, pos=pos, start=7, stop=25)
3.8779735196179366
```

allel.stats.diversity.**windowed_tajima_d**(*pos*, *ac*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*)

 Calculate the value of Tajima's D in windows over a single chromosome/contig.

  Parameters **pos** : array_like, int, shape (n_items,)

    Variant positions, using 1-based coordinates, in ascending order.

   ac : array_like, int, shape (n_variants, n_alleles)

    Allele counts array.

> **size** : int, optional
>> The window size (number of bases).

> **start** : int, optional
>> The position at which to start (1-based).

> **stop** : int, optional
>> The position at which to stop (1-based).

> **step** : int, optional
>> The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

> **windows** : array_like, int, shape (n_windows, 2), optional
>> Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

> **fill** : object, optional
>> The value to use where a window is completely inaccessible.

Returns **D** : ndarray, float, shape (n_windows,)
> Tajima's D.

> **windows** : ndarray, int, shape (n_windows, 2)
>> The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

> **counts** : ndarray, int, shape (n_windows,)
>> Number of variants in each window.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> pos = [2, 4, 7, 14, 15, 18, 19, 25, 27]
>>> D, windows, counts = allel.stats.windowed_tajima_d(
...     pos, ac, size=10, start=1, stop=31
... )
>>> D
array([ 0.59158014,  2.93397641,  6.12372436])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 31]])
```

```
>>> counts
array([3, 4, 2])
```

`allel.stats.diversity.`**`moving_tajima_d`**(*ac*, *size*, *start=0*, *stop=None*, *step=None*)

    Calculate the value of Tajima's D in moving windows of *size* variants.

        Parameters ac : array_like, int, shape (n_variants, n_alleles)

            Allele counts array.

        size : int

            The window size (number of variants).

        start : int, optional

            The index at which to start.

        stop : int, optional

            The index at which to stop.

        step : int, optional

            The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

        Returns D : ndarray, float, shape (n_windows,)

            Tajima's D.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0]],
...                          [[0, 0], [0, 1]],
...                          [[0, 0], [1, 1]],
...                          [[0, 1], [1, 1]],
...                          [[1, 1], [1, 1]],
...                          [[0, 0], [1, 2]],
...                          [[0, 1], [1, 2]],
...                          [[0, 1], [-1, -1]],
...                          [[-1, -1], [-1, -1]]])
>>> ac = g.count_alleles()
>>> D = allel.stats.moving_tajima_d(ac, size=3)
>>> D
array([ 0.59158014,  1.89305645,  5.79748537])
```

`allel.stats.diversity.`**`windowed_df`**(*pos*, *ac1*, *ac2*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *is_accessible=None*, *fill=nan*)

    Calculate the density of fixed differences between two populations in windows over a single chromosome/contig.

        Parameters pos : array_like, int, shape (n_items,)

            Variant positions, using 1-based coordinates, in ascending order.

        ac1 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array for the first population.

        ac2 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array for the second population.

size : int, optional

The window size (number of bases).

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

fill : object, optional

The value to use where a window is completely inaccessible.

Returns **df** : ndarray, float, shape (n_windows,)

Per-base density of fixed differences in each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

n_bases : ndarray, int, shape (n_windows,)

Number of (accessible) bases in each window.

counts : ndarray, int, shape (n_windows,)

Number of variants in each window.

See also:

allel.model.locate_fixed_differences

3.2.2 F-statistics

allel.stats.fst.**weir_cockerham_fst**(*g*, *subpops*, *max_allele=None*, *blen=None*)
Compute the variance components from the analyses of variance of allele frequencies according to Weir and Cockerham (1984).

Parameters **g** : array_like, int, shape (n_variants, n_samples, ploidy)

Genotype array.

subpops : sequence of sequences of ints

Sample indices for each subpopulation.

max_allele : int, optional

The highest allele index to consider.

> **blen** : int, optional
>
> > Block length to use for chunked computation.
>
> **Returns a** : ndarray, float, shape (n_variants, n_alleles)
>
> > Component of variance between populations.
>
> **b** : ndarray, float, shape (n_variants, n_alleles)
>
> > Component of variance between individuals within populations.
>
> **c** : ndarray, float, shape (n_variants, n_alleles)
>
> > Component of variance between gametes within individuals.

Examples

Calculate variance components from some genotype data:

```
>>> import allel
>>> g = [[[0, 0], [0, 0], [1, 1], [1, 1]],
...      [[0, 1], [0, 1], [0, 1], [0, 1]],
...      [[0, 0], [0, 0], [0, 0], [0, 0]],
...      [[0, 1], [1, 2], [1, 1], [2, 2]],
...      [[0, 0], [1, 1], [0, 1], [-1, -1]]]
>>> subpops = [[0, 1], [2, 3]]
>>> a, b, c = allel.stats.weir_cockerham_fst(g, subpops)
>>> a
array([[ 0.5  ,   0.5  ,   0.   ],
       [ 0.   ,   0.   ,   0.   ],
       [ 0.   ,   0.   ,   0.   ],
       [ 0.   ,  -0.125,  -0.125],
       [-0.375,  -0.375,   0.   ]])
>>> b
array([[ 0.        ,   0.        ,   0.        ],
       [-0.25      ,  -0.25      ,   0.        ],
       [ 0.        ,   0.        ,   0.        ],
       [ 0.        ,   0.125     ,   0.25      ],
       [ 0.41666667,   0.41666667,   0.        ]])
>>> c
array([[ 0.        ,   0.        ,   0.        ],
       [ 0.5       ,   0.5       ,   0.        ],
       [ 0.        ,   0.        ,   0.        ],
       [ 0.125     ,   0.25      ,   0.125     ],
       [ 0.16666667,   0.16666667,   0.        ]])
```

Estimate the parameter theta (a.k.a., Fst) for each variant and each allele individually:

```
>>> fst = a / (a + b + c)
>>> fst
array([[ 1. ,   1. ,   nan],
       [ 0. ,   0. ,   nan],
       [ nan,  nan,   nan],
       [ 0. ,  -0.5,  -0.5],
       [-1.8,  -1.8,   nan]])
```

Estimate Fst for each variant individually (averaging over alleles):

```
>>> fst = (np.sum(a, axis=1) /
...        (np.sum(a, axis=1) + np.sum(b, axis=1) + np.sum(c, axis=1)))
>>> fst
array([ 1. ,  0. ,  nan, -0.4, -1.8])
```

Estimate Fst averaging over all variants and alleles:

```
>>> fst = np.sum(a) / (np.sum(a) + np.sum(b) + np.sum(c))
>>> fst
-4.3680905886891398e-17
```

Note that estimated Fst values may be negative.

allel.stats.fst.**hudson_fst**(*ac1*, *ac2*, *fill=nan*)

> Calculate the numerator and denominator for Fst estimation using the method of Hudson (1992) elaborated by Bhatia et al. (2013).
>
> > **Parameters ac1** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the first population.
> >
> > **ac2** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the second population.
> >
> > **fill** : float
> >
> > > Use this value where there are no pairs to compare (e.g., all allele calls are missing).
> >
> > **Returns num** : ndarray, float, shape (n_variants,)
> >
> > > Divergence between the two populations minus average of diversity within each population.
> >
> > **den** : ndarray, float, shape (n_variants,)
> >
> > > Divergence between the two populations.

Examples

Calculate numerator and denominator for Fst estimation:

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [1, 1], [1, 1]],
...                          [[0, 1], [0, 1], [0, 1], [0, 1]],
...                          [[0, 0], [0, 0], [0, 0], [0, 0]],
...                          [[0, 1], [1, 2], [1, 1], [2, 2]],
...                          [[0, 0], [1, 1], [0, 1], [-1, -1]]])
>>> subpops = [[0, 1], [2, 3]]
>>> ac1 = g.count_alleles(subpop=subpops[0])
>>> ac2 = g.count_alleles(subpop=subpops[1])
>>> num, den = allel.stats.hudson_fst(ac1, ac2)
>>> num
array([ 1.        , -0.16666667,  0.        , -0.125     , -0.33333333])
>>> den
array([ 1.   ,  0.5  ,  0.   ,  0.625,  0.5  ])
```

Estimate Fst for each variant individually:

```
>>> fst = num / den
>>> fst
array([ 1.        , -0.33333333,         nan, -0.2       , -0.66666667])
```

Estimate Fst averaging over variants:

```
>>> fst = np.sum(num) / np.sum(den)
>>> fst
0.1428571428571429
```

`allel.stats.fst.`**`patterson_fst`**(*aca*, *acb*)

    Estimator of differentiation between populations A and B based on the F2 parameter.

> **Parameters aca** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for population A.
>
> **acb** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for population B.
>
> **Returns num** : ndarray, shape (n_variants,), float
>
> > Numerator.
>
> **den** : ndarray, shape (n_variants,), float
>
> > Denominator.

> **Notes**

> See Patterson (2012), Appendix A.

> TODO check if this is numerically equivalent to Hudson's estimator.

`allel.stats.fst.`**`average_weir_cockerham_fst`**(*g*, *subpops*, *blen*, *max_allele=None*)

    Estimate average Fst and standard error using the block-jackknife.

> **Parameters g** : array_like, int, shape (n_variants, n_samples, ploidy)
>
> > Genotype array.
>
> **subpops** : sequence of sequences of ints
>
> > Sample indices for each subpopulation.
>
> **blen** : int
>
> > Block size (number of variants).
>
> **max_allele** : int, optional
>
> > The highest allele index to consider.
>
> **Returns fst** : float
>
> > Estimated value of the statistic using all data.
>
> **se** : float
>
> > Estimated standard error.
>
> **vb** : ndarray, float, shape (n_blocks,)
>
> > Value of the statistic in each block.
>
> **vj** : ndarray, float, shape (n_blocks,)
>
> > Values of the statistic from block-jackknife resampling.

allel.stats.fst.**average_hudson_fst**(*ac1*, *ac2*, *blen*)

    Estimate average Fst between two populations and standard error using the block-jackknife.

        Parameters ac1 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array from the first population.

        ac2 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array from the second population.

        blen : int

            Block size (number of variants).

        Returns fst : float

            Estimated value of the statistic using all data.

        se : float

            Estimated standard error.

        vb : ndarray, float, shape (n_blocks,)

            Value of the statistic in each block.

        vj : ndarray, float, shape (n_blocks,)

            Values of the statistic from block-jackknife resampling.

allel.stats.fst.**average_patterson_fst**(*ac1*, *ac2*, *blen*)

    Estimate average Fst between two populations and standard error using the block-jackknife.

        Parameters ac1 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array from the first population.

        ac2 : array_like, int, shape (n_variants, n_alleles)

            Allele counts array from the second population.

        blen : int

            Block size (number of variants).

        Returns fst : float

            Estimated value of the statistic using all data.

        se : float

            Estimated standard error.

        vb : ndarray, float, shape (n_blocks,)

            Value of the statistic in each block.

        vj : ndarray, float, shape (n_blocks,)

            Values of the statistic from block-jackknife resampling.

allel.stats.fst.**moving_weir_cockerham_fst**(*g*, *subpops*, *size*, *start=0*, *stop=None*, *step=None*, *max_allele=None*)

    Estimate average Fst in moving windows over a single chromosome/contig, following the method of Weir and Cockerham (1984).

        Parameters g : array_like, int, shape (n_variants, n_samples, ploidy)

            Genotype array.

>> **subpops** : sequence of sequences of ints

>>> Sample indices for each subpopulation.

>> **size** : int

>>> The window size (number of variants).

>> **start** : int, optional

>>> The index at which to start.

>> **stop** : int, optional

>>> The index at which to stop.

>> **step** : int, optional

>>> The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

>> **max_allele** : int, optional

>>> The highest allele index to consider.

> **Returns fst** : ndarray, float, shape (n_windows,)

>> Average Fst in each window.

`allel.stats.fst.`**`moving_hudson_fst`**(*ac1*, *ac2*, *size*, *start=0*, *stop=None*, *step=None*)

> Estimate average Fst in moving windows over a single chromosome/contig, following the method of Hudson (1992) elaborated by Bhatia et al. (2013).

>> **Parameters ac1** : array_like, int, shape (n_variants, n_alleles)

>>> Allele counts array from the first population.

>> **ac2** : array_like, int, shape (n_variants, n_alleles)

>>> Allele counts array from the second population.

>> **size** : int

>>> The window size (number of variants).

>> **start** : int, optional

>>> The index at which to start.

>> **stop** : int, optional

>>> The index at which to stop.

>> **step** : int, optional

>>> The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

>> **Returns fst** : ndarray, float, shape (n_windows,)

>>> Average Fst in each window.

`allel.stats.fst.`**`moving_patterson_fst`**(*ac1*, *ac2*, *size*, *start=0*, *stop=None*, *step=None*)

> Estimate average Fst in moving windows over a single chromosome/contig, following the method of Patterson (2012).

>> **Parameters ac1** : array_like, int, shape (n_variants, n_alleles)

>>> Allele counts array from the first population.

> **ac2** : array_like, int, shape (n_variants, n_alleles)
>
>> Allele counts array from the second population.
>
> **size** : int
>
>> The window size (number of variants).
>
> **start** : int, optional
>
>> The index at which to start.
>
> **stop** : int, optional
>
>> The index at which to stop.
>
> **step** : int, optional
>
>> The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.
>
> **Returns fst** : ndarray, float, shape (n_windows,)
>
>> Average Fst in each window.

allel.stats.fst.**windowed_weir_cockerham_fst**(*pos*, *g*, *subpops*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*, *max_allele=None*)

Estimate average Fst in windows over a single chromosome/contig, following the method of Weir and Cockerham (1984).

> **Parameters pos** : array_like, int, shape (n_items,)
>
>> Variant positions, using 1-based coordinates, in ascending order.
>
> **g** : array_like, int, shape (n_variants, n_samples, ploidy)
>
>> Genotype array.
>
> **subpops** : sequence of sequences of ints
>
>> Sample indices for each subpopulation.
>
> **size** : int
>
>> The window size (number of bases).
>
> **start** : int, optional
>
>> The position at which to start (1-based).
>
> **stop** : int, optional
>
>> The position at which to stop (1-based).
>
> **step** : int, optional
>
>> The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.
>
> **windows** : array_like, int, shape (n_windows, 2), optional
>
>> Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.
>
> **fill** : object, optional
>
>> The value to use where there are no variants within a window.
>
> **max_allele** : int, optional

The highest allele index to consider.

Returns fst : ndarray, float, shape (n_windows,)

Average Fst in each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

counts : ndarray, int, shape (n_windows,)

Number of variants in each window.

allel.stats.fst.**windowed_hudson_fst**(*pos*, *ac1*, *ac2*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*)

Estimate average Fst in windows over a single chromosome/contig, following the method of Hudson (1992) elaborated by Bhatia et al. (2013).

Parameters pos : array_like, int, shape (n_items,)

Variant positions, using 1-based coordinates, in ascending order.

ac1 : array_like, int, shape (n_variants, n_alleles)

Allele counts array from the first population.

ac2 : array_like, int, shape (n_variants, n_alleles)

Allele counts array from the second population.

size : int, optional

The window size (number of bases).

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

fill : object, optional

The value to use where there are no variants within a window.

Returns fst : ndarray, float, shape (n_windows,)

Average Fst in each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

counts : ndarray, int, shape (n_windows,)

Number of variants in each window.

3.2. Statistics and plotting 77

`allel.stats.fst.`**`windowed_patterson_fst`**(*pos*, *ac1*, *ac2*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*)

> Estimate average Fst in windows over a single chromosome/contig, following the method of Patterson (2012).

> > **Parameters** **pos** : array_like, int, shape (n_items,)
> >
> > > Variant positions, using 1-based coordinates, in ascending order.
> >
> > **ac1** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the first population.
> >
> > **ac2** : array_like, int, shape (n_variants, n_alleles)
> >
> > > Allele counts array from the second population.
> >
> > **size** : int, optional
> >
> > > The window size (number of bases).
> >
> > **start** : int, optional
> >
> > > The position at which to start (1-based).
> >
> > **stop** : int, optional
> >
> > > The position at which to stop (1-based).
> >
> > **step** : int, optional
> >
> > > The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.
> >
> > **windows** : array_like, int, shape (n_windows, 2), optional
> >
> > > Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.
> >
> > **fill** : object, optional
> >
> > > The value to use where there are no variants within a window.
> >
> > **Returns** **fst** : ndarray, float, shape (n_windows,)
> >
> > > Average Fst in each window.
> >
> > **windows** : ndarray, int, shape (n_windows, 2)
> >
> > > The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.
> >
> > **counts** : ndarray, int, shape (n_windows,)
> >
> > > Number of variants in each window.

3.2.3 Hardy-Weinberg equilibrium

`allel.stats.hw.`**`heterozygosity_observed`**(*g*, *fill=nan*)

> Calculate the rate of observed heterozygosity for each variant.

> > **Parameters** **g** : array_like, int, shape (n_variants, n_samples, ploidy)
> >
> > > Genotype array.
> >
> > **fill** : float, optional
> >
> > > Use this value for variants where all calls are missing.

Returns ho : ndarray, float, shape (n_variants,)

Observed heterozygosity

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [0, 0]],
...                          [[0, 0], [0, 1], [1, 1]],
...                          [[0, 0], [1, 1], [2, 2]],
...                          [[1, 1], [1, 2], [-1, -1]]])
>>> allel.stats.heterozygosity_observed(g)
array([ 0.        ,  0.33333333,  0.        ,  0.5       ])
```

allel.stats.hw.**heterozygosity_expected**(*af*, *ploidy*, *fill=nan*)

Calculate the expected rate of heterozygosity for each variant under Hardy-Weinberg equilibrium.

Parameters af : array_like, float, shape (n_variants, n_alleles)

Allele frequencies array.

fill : float, optional

Use this value for variants where allele frequencies do not sum to 1.

Returns he : ndarray, float, shape (n_variants,)

Expected heterozygosity

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [0, 0]],
...                          [[0, 0], [0, 1], [1, 1]],
...                          [[0, 0], [1, 1], [2, 2]],
...                          [[1, 1], [1, 2], [-1, -1]]])
>>> af = g.count_alleles().to_frequencies()
>>> allel.stats.heterozygosity_expected(af, ploidy=2)
array([ 0.        ,  0.5       ,  0.66666667,  0.375     ])
```

allel.stats.hw.**inbreeding_coefficient**(*g*, *fill=nan*)

Calculate the inbreeding coefficient for each variant.

Parameters g : array_like, int, shape (n_variants, n_samples, ploidy)

Genotype array.

fill : float, optional

Use this value for variants where the expected heterozygosity is zero.

Returns f : ndarray, float, shape (n_variants,)

Inbreeding coefficient.

Notes

The inbreeding coefficient is calculated as *1 - (Ho/He)* where *Ho* is the observed heterozygosity and *He* is the expected heterozygosity.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 0], [0, 0]],
...                          [[0, 0], [0, 1], [1, 1]],
...                          [[0, 0], [1, 1], [2, 2]],
...                          [[1, 1], [1, 2], [-1, -1]]])
>>> allel.stats.inbreeding_coefficient(g)
array([       nan,  0.33333333,  1.        , -0.33333333])
```

3.2.4 Linkage disequilibrium

allel.stats.ld.**rogers_huff_r**(*gn*, *fill=nan*)
    Estimate the linkage disequilibrium parameter *r* for each pair of variants using the method of Rogers and Huff (2008).

> **Parameters gn** : array_like, int8, shape (n_variants, n_samples)
>
> > Diploid genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).
>
> **Returns r** : ndarray, float, shape (n_variants * (n_variants - 1) // 2,)
>
> > Matrix in condensed form.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [1, 1], [0, 0]],
...                          [[0, 0], [1, 1], [0, 0]],
...                          [[1, 1], [0, 0], [1, 1]],
...                          [[0, 0], [0, 1], [-1, -1]]], dtype='i1')
>>> gn = g.to_n_alt(fill=-1)
>>> gn
array([[ 0,  2,  0],
       [ 0,  2,  0],
       [ 2,  0,  2],
       [ 0,  1, -1]], dtype=int8)
>>> r = allel.stats.rogers_huff_r(gn)
>>> r
array([ 1.        , -1.00000012,  1.        , -1.00000012,  1.        , -1.        ], dtype=floa
>>> r ** 2
array([ 1.        ,  1.00000024,  1.        ,  1.00000024,  1.        ,  1.        ], dtype=floa
>>> from scipy.spatial.distance import squareform
>>> squareform(r ** 2)
array([[ 0.        ,  1.        ,  1.00000024,  1.        ],
       [ 1.        ,  0.        ,  1.00000024,  1.        ],
       [ 1.00000024,  1.00000024,  0.        ,  1.        ],
       [ 1.        ,  1.        ,  1.        ,  0.        ]])
```

allel.stats.ld.**rogers_huff_r_between**(*gna*, *gnb*, *fill=nan*)
    Estimate the linkage disequilibrium parameter *r* for each pair of variants between the two input arrays, using the method of Rogers and Huff (2008).

> **Parameters gna, gnb** : array_like, int8, shape (n_variants, n_samples)

> > > Diploid genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).

> > **Returns r** : ndarray, float, shape (m_variants, n_variants)

> > > Matrix in rectangular form.

`allel.stats.ld.`**`windowed_r_squared`**(*pos*, *gn*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*, *percentile=50*)
Summarise linkage disequilibrium in windows over a single chromosome/contig.

> > **Parameters pos** : array_like, int, shape (n_items,)

> > > The item positions in ascending order, using 1-based coordinates..

> > **gn** : array_like, int8, shape (n_variants, n_samples)

> > > Diploid genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).

> > **size** : int, optional

> > > The window size (number of bases).

> > **start** : int, optional

> > > The position at which to start (1-based).

> > **stop** : int, optional

> > > The position at which to stop (1-based).

> > **step** : int, optional

> > > The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

> > **windows** : array_like, int, shape (n_windows, 2), optional

> > > Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

> > **fill** : object, optional

> > > The value to use where a window is empty, i.e., contains no items.

> > **percentile** : int or sequence of ints, optional

> > > The percentile or percentiles to calculate within each window.

> > **Returns out** : ndarray, shape (n_windows,)

> > > The value of the statistic for each window.

> > **windows** : ndarray, int, shape (n_windows, 2)

> > > The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

> > **counts** : ndarray, int, shape (n_windows,)

> > > The number of items in each window.

> **See also:**

> *allel.stats.window.windowed_statistic*

Notes

Linkage disequilibrium (r**2) is calculated using the method of Rogers and Huff (2008).

`allel.stats.ld.` **`locate_unlinked`** (*gn*, *size=100*, *step=20*, *threshold=0.1*, *chunked=False*, *blen=None*)
Locate variants in approximate linkage equilibrium, where r**2 is below the given *threshold*.

> **Parameters gn** : array_like, int8, shape (n_variants, n_samples)
>
> > Diploid genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).
>
> **size** : int
>
> > Window size (number of variants).
>
> **step** : int
>
> > Number of variants to advance to the next window.
>
> **threshold** : float
>
> > Maximum value of r**2 to include variants.
>
> **blen** : int, optional
>
> > Block length to use for chunked computation.
>
> **Returns loc** : ndarray, bool, shape (n_variants)
>
> > Boolean array where True items locate variants in approximate linkage equilibrium.

Notes

The value of r**2 between each pair of variants is calculated using the method of Rogers and Huff (2008).

`allel.stats.ld.` **`plot_pairwise_ld`** (*m*, *colorbar=True*, *ax=None*, *imshow_kwargs=None*)
Plot a matrix of genotype linkage disequilibrium values between all pairs of variants.

> **Parameters m** : array_like
>
> > Array of linkage disequilibrium values in condensed form.
>
> **colorbar** : bool, optional
>
> > If True, add a colorbar to the current figure.
>
> **ax** : axes, optional
>
> > The axes on which to draw. If not provided, a new figure will be created.
>
> **imshow_kwargs** : dict-like, optional
>
> > Additional keyword arguments passed through to `matplotlib.pyplot.imshow()`.
>
> **Returns ax** : axes
>
> > The axes on which the plot was drawn.

3.2.5 Site frequency spectra

`allel.stats.sf.`**`sfs`**(*dac*)

> Compute the site frequency spectrum given derived allele counts at a set of biallelic variants.
>
> > **Parameters dac** : array_like, int, shape (n_variants,)
> >
> > > Array of derived allele counts.
> >
> > **Returns sfs** : ndarray, int, shape (n_chromosomes,)
> >
> > > Array where the kth element is the number of variant sites with k derived alleles.

`allel.stats.sf.`**`sfs_folded`**(*ac*)

> Compute the folded site frequency spectrum given reference and alternate allele counts at a set of biallelic variants.
>
> > **Parameters ac** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts array.
> >
> > **Returns sfs_folded** : ndarray, int, shape (n_chromosomes//2,)
> >
> > > Array where the kth element is the number of variant sites with a minor allele count of k.

`allel.stats.sf.`**`sfs_scaled`**(*dac*)

> Compute the site frequency spectrum scaled such that a constant value is expected across the spectrum for neutral variation and constant population size.
>
> > **Parameters dac** : array_like, int, shape (n_variants,)
> >
> > > Array of derived allele counts.
> >
> > **Returns sfs_scaled** : ndarray, int, shape (n_chromosomes,)
> >
> > > An array where the value of the kth element is the number of variants with k derived alleles, multiplied by k.

`allel.stats.sf.`**`sfs_folded_scaled`**(*ac*, *n=None*)

> Compute the folded site frequency spectrum scaled such that a constant value is expected across the spectrum for neutral variation and constant population size.
>
> > **Parameters ac** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts array.
> >
> > **n** : int, optional
> >
> > > The total number of chromosomes called at each variant site. Equal to the number of samples multiplied by the ploidy. If not provided, will be inferred to be the maximum value of the sum of reference and alternate allele counts present in *ac*.
> >
> > **Returns sfs_folded_scaled** : ndarray, int, shape (n_chromosomes//2,)
> >
> > > An array where the value of the kth element is the number of variants with minor allele count k, multiplied by the scaling factor (k * (n - k) / n).

`allel.stats.sf.`**`joint_sfs`**(*dac1*, *dac2*)

> Compute the joint site frequency spectrum between two populations.
>
> > **Parameters dac1** : array_like, int, shape (n_variants,)
> >
> > > Derived allele counts for the first population.
> >
> > **dac2** : array_like, int, shape (n_variants,)

Derived allele counts for the second population.

Returns joint_sfs : ndarray, int, shape (m_chromosomes, n_chromosomes)

Array where the (i, j)th element is the number of variant sites with i derived alleles in the first population and j derived alleles in the second population.

allel.stats.sf.**joint_sfs_folded**(*ac1*, *ac2*)
    Compute the joint folded site frequency spectrum between two populations.

Parameters ac1 : array_like, int, shape (n_variants, 2)

Allele counts for the first population.

ac2 : array_like, int, shape (n_variants, 2)

Allele counts for the second population.

Returns joint_sfs_folded : ndarray, int, shape (m_chromosomes//2, n_chromosomes//2)

Array where the (i, j)th element is the number of variant sites with a minor allele count of i in the first population and j in the second population.

allel.stats.sf.**joint_sfs_scaled**(*dac1*, *dac2*)
    Compute the joint site frequency spectrum between two populations, scaled such that a constant value is expected across the spectrum for neutral variation, constant population size and unrelated populations.

Parameters dac1 : array_like, int, shape (n_variants,)

Derived allele counts for the first population.

dac2 : array_like, int, shape (n_variants,)

Derived allele counts for the second population.

Returns joint_sfs_scaled : ndarray, int, shape (m_chromosomes, n_chromosomes)

Array where the (i, j)th element is the scaled frequency of variant sites with i derived alleles in the first population and j derived alleles in the second population.

allel.stats.sf.**joint_sfs_folded_scaled**(*ac1*, *ac2*, *m=None*, *n=None*)
    Compute the joint folded site frequency spectrum between two populations, scaled such that a constant value is expected across the spectrum for neutral variation, constant population size and unrelated populations.

Parameters ac1 : array_like, int, shape (n_variants, 2)

Allele counts for the first population.

ac2 : array_like, int, shape (n_variants, 2)

Allele counts for the second population.

m : int, optional

Number of chromosomes called in the first population.

n : int, optional

Number of chromosomes called in the second population.

Returns joint_sfs_folded_scaled : ndarray, int, shape (m_chromosomes//2, n_chromosomes//2)

Array where the (i, j)th element is the scaled frequency of variant sites with a minor allele count of i in the first population and j in the second population.

allel.stats.sf.**fold_sfs**(*s*, *n*)
    Fold a site frequency spectrum.

Parameters **s** : array_like, int, shape (n_chromosomes,)

   Site frequency spectrum

n : int

   Total number of chromosomes called.

Returns **sfs_folded** : ndarray, int

   Folded site frequency spectrum

`allel.stats.sf.`**`fold_joint_sfs`**(*s*, *m*, *n*)

   Fold a joint site frequency spectrum.

Parameters **s** : array_like, int, shape (m_chromosomes, n_chromosomes)

   Joint site frequency spectrum.

m : int

   Number of chromosomes called in the first population.

n : int

   Number of chromosomes called in the second population.

Returns **joint_sfs_folded** : ndarray, int

   Folded joint site frequency spectrum.

`allel.stats.sf.`**`scale_sfs`**(*s*)

   Scale a site frequency spectrum.

Parameters **s** : array_like, int, shape (n_chromosomes,)

   Site frequency spectrum.

Returns **sfs_scaled** : ndarray, int, shape (n_chromosomes,)

   Scaled site frequency spectrum.

`allel.stats.sf.`**`scale_sfs_folded`**(*s*, *n*)

   Scale a folded site frequency spectrum.

Parameters **s** : array_like, int, shape (n_chromosomes//2,)

   Folded site frequency spectrum.

n : int

   Number of chromosomes called.

Returns **sfs_folded_scaled** : ndarray, int, shape (n_chromosomes//2,)

   Scaled folded site frequency spectrum.

`allel.stats.sf.`**`scale_joint_sfs`**(*s*)

   Scale a joint site frequency spectrum.

Parameters **s** : array_like, int, shape (m_chromosomes, n_chromosomes)

   Joint site frequency spectrum.

Returns **joint_sfs_scaled** : ndarray, int, shape (m_chromosomes, n_chromosomes)

   Scaled joint site frequency spectrum.

`allel.stats.sf.`**`scale_joint_sfs_folded`**(*s*, *m*, *n*)

   Scale a folded joint site frequency spectrum.

Parameters s : array_like, int, shape (m_chromosomes//2, n_chromosomes//2)

Folded joint site frequency spectrum.

m : int

Number of chromosomes called in the first population.

n : int

Number of chromosomes called in the second population.

Returns joint_sfs_folded_scaled : ndarray, int, shape (m_chromosomes//2, n_chromosomes//2)

Scaled folded joint site frequency spectrum.

allel.stats.sf.**plot_sfs**(*s*, *yscale='log'*, *bins=None*, *n=None*, *clip_endpoints=True*, *label=None*, *plot_kwargs=None*, *ax=None*)

Plot a site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes,)

Site frequency spectrum.

yscale : string, optional

Y axis scale.

bins : int or array_like, int, optional

Allele count bins.

n : int, optional

Number of chromosomes sampled. If provided, X axis will be plotted as allele frequency, otherwise as allele count.

clip_endpoints : bool, optional

If True, do not plot first and last values from frequency spectrum.

label : string, optional

Label for data series in plot.

plot_kwargs : dict-like

Additional keyword arguments, passed through to ax.plot().

ax : axes, optional

Axes on which to draw. If not provided, a new figure will be created.

Returns ax : axes

The axes on which the plot was drawn.

allel.stats.sf.**plot_sfs_folded**(**args*, ***kwargs*)

Plot a folded site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes/2,)

Site frequency spectrum.

yscale : string, optional

Y axis scale.

bins : int or array_like, int, optional

Allele count bins.

n : int, optional

> Number of chromosomes sampled. If provided, X axis will be plotted as allele frequency, otherwise as allele count.

clip_endpoints : bool, optional

> If True, do not plot first and last values from frequency spectrum.

label : string, optional

> Label for data series in plot.

plot_kwargs : dict-like

> Additional keyword arguments, passed through to ax.plot().

ax : axes, optional

> Axes on which to draw. If not provided, a new figure will be created.

Returns ax : axes

> The axes on which the plot was drawn.

allel.stats.sf.**plot_sfs_scaled**(*args*, ***kwargs*)
> Plot a scaled site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes,)

> Site frequency spectrum.

yscale : string, optional

> Y axis scale.

bins : int or array_like, int, optional

> Allele count bins.

n : int, optional

> Number of chromosomes sampled. If provided, X axis will be plotted as allele frequency, otherwise as allele count.

clip_endpoints : bool, optional

> If True, do not plot first and last values from frequency spectrum.

label : string, optional

> Label for data series in plot.

plot_kwargs : dict-like

> Additional keyword arguments, passed through to ax.plot().

ax : axes, optional

> Axes on which to draw. If not provided, a new figure will be created.

Returns ax : axes

> The axes on which the plot was drawn.

allel.stats.sf.**plot_sfs_folded_scaled**(*args*, ***kwargs*)
> Plot a folded scaled site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes/2,)

Site frequency spectrum.

yscale : string, optional

Y axis scale.

bins : int or array_like, int, optional

Allele count bins.

n : int, optional

Number of chromosomes sampled. If provided, X axis will be plotted as allele frequency, otherwise as allele count.

clip_endpoints : bool, optional

If True, do not plot first and last values from frequency spectrum.

label : string, optional

Label for data series in plot.

plot_kwargs : dict-like

Additional keyword arguments, passed through to ax.plot().

ax : axes, optional

Axes on which to draw. If not provided, a new figure will be created.

Returns ax : axes

The axes on which the plot was drawn.

allel.stats.sf.**plot_joint_sfs**(*s*, *ax=None*, *imshow_kwargs=None*)

Plot a joint site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes_pop1, n_chromosomes_pop2)

Joint site frequency spectrum.

ax : axes, optional

Axes on which to draw. If not provided, a new figure will be created.

imshow_kwargs : dict-like

Additional keyword arguments, passed through to ax.imshow().

Returns ax : axes

The axes on which the plot was drawn.

allel.stats.sf.**plot_joint_sfs_folded**(**args*, ***kwargs*)

Plot a joint site frequency spectrum.

Parameters s : array_like, int, shape (n_chromosomes_pop1/2, n_chromosomes_pop2/2)

Joint site frequency spectrum.

ax : axes, optional

Axes on which to draw. If not provided, a new figure will be created.

imshow_kwargs : dict-like

Additional keyword arguments, passed through to ax.imshow().

Returns ax : axes

The axes on which the plot was drawn.

`allel.stats.sf.`**`plot_joint_sfs_scaled`**(**args*, ***kwargs*)
   Plot a scaled joint site frequency spectrum.

    Parameters **s** : array_like, int, shape (n_chromosomes_pop1, n_chromosomes_pop2)

        Joint site frequency spectrum.

    ax : axes, optional

        Axes on which to draw. If not provided, a new figure will be created.

    imshow_kwargs : dict-like

        Additional keyword arguments, passed through to ax.imshow().

    Returns **ax** : axes

        The axes on which the plot was drawn.

`allel.stats.sf.`**`plot_joint_sfs_folded_scaled`**(**args*, ***kwargs*)
   Plot a scaled folded joint site frequency spectrum.

    Parameters **s** : array_like, int, shape (n_chromosomes_pop1/2, n_chromosomes_pop2/2)

        Joint site frequency spectrum.

    ax : axes, optional

        Axes on which to draw. If not provided, a new figure will be created.

    imshow_kwargs : dict-like

        Additional keyword arguments, passed through to ax.imshow().

    Returns **ax** : axes

        The axes on which the plot was drawn.

3.2.6 Pairwise distance and ordination

`allel.stats.distance.`**`pairwise_distance`**(*x*, *metric*, *chunked=False*, *blen=None*)
   Compute pairwise distance between individuals (e.g., samples or haplotypes).

    Parameters **x** : array_like, shape (n, m, ...)

        Array of m observations (e.g., samples or haplotypes) in a space with n dimensions (e.g., variants). Note that the order of the first two dimensions is **swapped** compared to what is expected by scipy.spatial.distance.pdist.

    metric : string or function

        Distance metric. See documentation for the function `scipy.spatial.distance.pdist()` for a list of built-in distance metrics.

    chunked : bool, optional

        If True, use a block-wise implementation to avoid loading the entire input array into memory. This means that a distance matrix will be calculated for each block of the input array, and the results will be summed to produce the final output. For some distance metrics this will return a different result from the standard implementation.

    blen : int, optional

        Block length to use for chunked implementation.

Returns dist : ndarray, shape (m * (m - 1) / 2,)

Distance matrix in condensed form.

Examples

```
>>> import allel
>>> g = allel.GenotypeArray([[[0, 0], [0, 1], [1, 1]],
...                          [[0, 1], [1, 1], [1, 2]],
...                          [[0, 2], [2, 2], [-1, -1]]])
>>> d = allel.stats.pairwise_distance(g.to_n_alt(), metric='cityblock')
>>> d
array([ 3.,  4.,  3.])
>>> import scipy.spatial
>>> scipy.spatial.distance.squareform(d)
array([[ 0.,  3.,  4.],
       [ 3.,  0.,  3.],
       [ 4.,  3.,  0.]])
```

`allel.stats.distance.`**`plot_pairwise_distance`**(*dist*, *labels=None*, *colorbar=True*, *ax=None*, *imshow_kwargs=None*)

Plot a pairwise distance matrix.

Parameters dist : array_like

The distance matrix in condensed form.

labels : sequence of strings, optional

Sample labels for the axes.

colorbar : bool, optional

If True, add a colorbar to the current figure.

ax : axes, optional

The axes on which to draw. If not provided, a new figure will be created.

imshow_kwargs : dict-like, optional

Additional keyword arguments passed through to `matplotlib.pyplot.imshow()`.

Returns ax : axes

The axes on which the plot was drawn

`allel.stats.distance.`**`pairwise_dxy`**(*pos*, *gac*, *start=None*, *stop=None*, *is_accessible=None*)

Convenience function to calculate a pairwise distance matrix using nucleotide divergence (a.k.a. Dxy) as the distance metric.

Parameters pos : array_like, int, shape (n_variants,)

Variant positions.

gac : array_like, int, shape (n_variants, n_samples, n_alleles)

Per-genotype allele counts.

start : int, optional

Start position of region to use.

stop : int, optional

Stop position of region to use.

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

Returns dist : ndarray

Distance matrix in condensed form.

See also:

allel.model.ndarray.GenotypeArray.to_allele_counts

allel.stats.distance.**pcoa**(*dist*)

Perform principal coordinate analysis of a distance matrix, a.k.a. classical multi-dimensional scaling.

Parameters dist : array_like

Distance matrix in condensed form.

Returns coords : ndarray, shape (n_samples, n_dimensions)

Transformed coordinates for the samples.

explained_ratio : ndarray, shape (n_dimensions)

Variance explained by each dimension.

allel.stats.distance.**condensed_coords**(*i, j, n*)

Transform square distance matrix coordinates to the corresponding index into a condensed, 1D form of the matrix.

Parameters i : int

Row index.

j : int

Column index.

n : int

Size of the square matrix (length of first or second dimension).

Returns ix : int

allel.stats.distance.**condensed_coords_within**(*pop, n*)

Return indices into a condensed distance matrix for all pairwise comparisons within the given population.

Parameters pop : array_like, int

Indices of samples or haplotypes within the population.

n : int

Size of the square matrix (length of first or second dimension).

Returns indices : ndarray, int

allel.stats.distance.**condensed_coords_between**(*pop1, pop2, n*)

Return indices into a condensed distance matrix for all pairwise comparisons between two populations.

Parameters pop1 : array_like, int

Indices of samples or haplotypes within the first population.

pop2 : array_like, int

Indices of samples or haplotypes within the second population.

> **n** : int
>
>> Size of the square matrix (length of first or second dimension).
>
> **Returns indices** : ndarray, int

3.2.7 Principal components analysis

allel.stats.decomposition.**pca**(*gn*, *n_components=10*, *copy=True*, *scaler='patterson'*, *ploidy=2*)

Perform principal components analysis of genotype data, via singular value decomposition.

> **Parameters gn** : array_like, float, shape (n_variants, n_samples)
>
>> Genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).
>
> **n_components** : int, optional
>
>> Number of components to keep.
>
> **copy** : bool, optional
>
>> If False, data passed to fit are overwritten.
>
> **scaler** : {'patterson', 'standard', None}
>
>> Scaling method; 'patterson' applies the method of Patterson et al 2006; 'standard' scales to unit variance; None centers the data only.
>
> **ploidy** : int, optional
>
>> Sample ploidy, only relevant if 'patterson' scaler is used.
>
> **Returns coords** : ndarray, float, shape (n_samples, n_components)
>
>> Transformed coordinates for the samples.
>
> **model** : GenotypePCA
>
>> Model instance containing the variance ratio explained and the stored components (a.k.a., loadings). Can be used to project further data into the same principal components space via the transform() method.

See also:

randomized_pca, *allel.stats.ld.locate_unlinked*

Notes

Genotype data should be filtered prior to using this function to remove variants in linkage disequilibrium.

allel.stats.decomposition.**randomized_pca**(*gn*, *n_components=10*, *copy=True*, *iterated_power=3*, *random_state=None*, *scaler='patterson'*, *ploidy=2*)

Perform principal components analysis of genotype data, via an approximate truncated singular value decomposition using randomization to speed up the computation.

> **Parameters gn** : array_like, float, shape (n_variants, n_samples)
>
>> Genotypes at biallelic variants, coded as the number of alternate alleles per call (i.e., 0 = hom ref, 1 = het, 2 = hom alt).

> > **n_components** : int, optional
>
> > > Number of components to keep.
> >
> > **copy** : bool, optional
> >
> > > If False, data passed to fit are overwritten.
> >
> > **iterated_power** : int, optional
> >
> > > Number of iterations for the power method.
> >
> > **random_state** : int or RandomState instance or None (default)
> >
> > > Pseudo Random Number generator seed control. If None, use the numpy.random singleton.
> >
> > **scaler** : {'patterson', 'standard', None}
> >
> > > Scaling method; 'patterson' applies the method of Patterson et al 2006; 'standard' scales to unit variance; None centers the data only.
> >
> > **ploidy** : int, optional
> >
> > > Sample ploidy, only relevant if 'patterson' scaler is used.
>
> **Returns coords** : ndarray, float, shape (n_samples, n_components)
>
> > > Transformed coordinates for the samples.
> >
> > **model** : GenotypeRandomizedPCA
> >
> > > Model instance containing the variance ratio explained and the stored components (a.k.a., loadings). Can be used to project further data into the same principal components space via the transform() method.

See also:

pca, *allel.stats.ld.locate_unlinked*

Notes

Genotype data should be filtered prior to using this function to remove variants in linkage disequilibrium.

Based on the `sklearn.decomposition.RandomizedPCA` implementation.

3.2.8 Admixture

allel.stats.admixture.**patterson_f2**(*aca*, *acb*)

> Unbiased estimator for F2(A, B), the branch length between populations A and B.
>
> > **Parameters aca** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for population A.
> >
> > **acb** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for population B.
> >
> > **Returns f2** : ndarray, float, shape (n_variants,)

Notes

See Patterson (2012), Appendix A.

`allel.stats.admixture.`**`patterson_f3`**(*acc*, *aca*, *acb*)

Unbiased estimator for F3(C; A, B), the three-population test for admixture in population C.

> **Parameters acc** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for the test population (C).
>
> **aca** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for the first source population (A).
>
> **acb** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for the second source population (B).
>
> **Returns T** : ndarray, float, shape (n_variants,)
>
> > Un-normalized f3 estimates per variant.
>
> **B** : ndarray, float, shape (n_variants,)
>
> > Estimates for heterozygosity in population C.

Notes

See Patterson (2012), main text and Appendix A.

For un-normalized f3 statistics, ignore the *B* return value.

To compute the f3* statistic, which is normalized by heterozygosity in population C to remove numerical dependence on the allele frequency spectrum, compute `np.sum(T) / np.sum(B)`.

`allel.stats.admixture.`**`patterson_d`**(*aca*, *acb*, *acc*, *acd*)

Unbiased estimator for D(A, B; C, D), the normalised four-population test for admixture between (A or B) and (C or D), also known as the "ABBA BABA" test.

> **Parameters aca** : array_like, int, shape (n_variants, 2),
>
> > Allele counts for population A.
>
> **acb** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for population B.
>
> **acc** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for population C.
>
> **acd** : array_like, int, shape (n_variants, 2)
>
> > Allele counts for population D.
>
> **Returns num** : ndarray, float, shape (n_variants,)
>
> > Numerator (un-normalised f4 estimates).
>
> **den** : ndarray, float, shape (n_variants,)
>
> > Denominator.

Notes

See Patterson (2012), main text and Appendix A.

For un-normalized f4 statistics, ignore the *den* return value.

allel.stats.admixture.**average_patterson_f3**(*acc*, *aca*, *acb*, *blen*, *normed=True*)
> Estimate F3(C; A, B) and standard error using the block-jackknife.

> > **Parameters acc** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for the test population (C).
> >
> > **aca** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for the first source population (A).
> >
> > **acb** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for the second source population (B).
> >
> > **blen** : int
> >
> > > Block size (number of variants).
> >
> > **normed** : bool, optional
> >
> > > If False, use un-normalised f3 values.
> >
> > **Returns f3** : float
> >
> > > Estimated value of the statistic using all data.
> >
> > **se** : float
> >
> > > Estimated standard error.
> >
> > **z** : float
> >
> > > Z-score (number of standard errors from zero).
> >
> > **vb** : ndarray, float, shape (n_blocks,)
> >
> > > Value of the statistic in each block.
> >
> > **vj** : ndarray, float, shape (n_blocks,)
> >
> > > Values of the statistic from block-jackknife resampling.

> **See also:**
>
> *allel.stats.admixture.patterson_f3*

Notes

See Patterson (2012), main text and Appendix A.

allel.stats.admixture.**average_patterson_d**(*aca*, *acb*, *acc*, *acd*, *blen*)
> Estimate D(A, B; C, D) and standard error using the block-jackknife.

> > **Parameters aca** : array_like, int, shape (n_variants, 2),
> >
> > > Allele counts for population A.
> >
> > **acb** : array_like, int, shape (n_variants, 2)
> >
> > > Allele counts for population B.

> **acc** : array_like, int, shape (n_variants, 2)
>
>> Allele counts for population C.
>
> **acd** : array_like, int, shape (n_variants, 2)
>
>> Allele counts for population D.
>
> **blen** : int
>
>> Block size (number of variants).
>
> **Returns d** : float
>
>> Estimated value of the statistic using all data.
>
> **se** : float
>
>> Estimated standard error.
>
> **z** : float
>
>> Z-score (number of standard errors from zero).
>
> **vb** : ndarray, float, shape (n_blocks,)
>
>> Value of the statistic in each block.
>
> **vj** : ndarray, float, shape (n_blocks,)
>
>> Values of the statistic from block-jackknife resampling.

See also:

allel.stats.admixture.patterson_d

Notes

See Patterson (2012), main text and Appendix A.

allel.stats.admixture.**moving_patterson_f3**(*acc*, *aca*, *acb*, *size*, *start=0*, *stop=None*, *step=None*, *normed=True*)

> Estimate F3(C; A, B) in moving windows.
>
> **Parameters acc** : array_like, int, shape (n_variants, 2)
>
>> Allele counts for the test population (C).
>
> **aca** : array_like, int, shape (n_variants, 2)
>
>> Allele counts for the first source population (A).
>
> **acb** : array_like, int, shape (n_variants, 2)
>
>> Allele counts for the second source population (B).
>
> **size** : int
>
>> The window size (number of variants).
>
> **start** : int, optional
>
>> The index at which to start.
>
> **stop** : int, optional
>
>> The index at which to stop.
>
> **step** : int, optional

The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

normed : bool, optional

If False, use un-normalised f3 values.

Returns f3 : ndarray, float, shape (n_windows,)

Estimated value of the statistic in each window.

allel.stats.admixture.**moving_patterson_d**(*aca*, *acb*, *acc*, *acd*, *size*, *start=0*, *stop=None*, *step=None*)

Estimate D(A, B; C, D) in moving windows.

Parameters aca : array_like, int, shape (n_variants, 2),

Allele counts for population A.

acb : array_like, int, shape (n_variants, 2)

Allele counts for population B.

acc : array_like, int, shape (n_variants, 2)

Allele counts for population C.

acd : array_like, int, shape (n_variants, 2)

Allele counts for population D.

size : int

The window size (number of variants).

start : int, optional

The index at which to start.

stop : int, optional

The index at which to stop.

step : int, optional

The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

Returns d : ndarray, float, shape (n_windows,)

Estimated value of the statistic in each window.

3.2.9 Selection

allel.stats.selection.**ihs**(*h*, *pos*, *map_pos=None*, *min_ehh=0.05*, *min_maf=0.05*, *include_edges=False*, *gap_scale=20000*, *max_gap=200000*, *is_accessible=None*, *use_threads=True*)

Compute the unstandardized integrated haplotype score (IHS) for each variant, comparing integrated haplotype homozygosity between the reference (0) and alternate (1) alleles.

Parameters h : array_like, int, shape (n_variants, n_haplotypes)

Haplotype array.

pos : array_like, int, shape (n_variants,)

Variant positions (physical distance).

map_pos : array_like, float, shape (n_variants,)

> Variant positions (genetic map distance).

min_ehh: float, optional

> Minimum EHH beyond which to truncate integrated haplotype homozygosity calculation.

min_maf : float, optional

> Do not compute integrated haplotype homozogysity for variants with minor allele frequency below this value.

include_edges : bool, optional

> If True, report scores even if EHH does not decay below *min_ehh* before reaching the edge of the data.

gap_scale : int, optional

> Rescale distance between variants if gap is larger than this value.

max_gap : int, optional

> Do not report scores if EHH spans a gap larger than this number of base pairs.

is_accessible : array_like, bool, optional

> Genome accessibility array. If provided, distance between variants will be computed as the number of accessible bases between them.

use_threads : bool, optional

> If True use multiple threads to compute.

Returns score : ndarray, float, shape (n_variants,)

> Unstandardized IHS scores.

See also:

standardize_by_allele_count

Notes

This function will calculate IHS for all variants. To exclude variants below a given minor allele frequency, filter the input haplotype array before passing to this function.

This function computes IHS comparing the reference and alternate alleles. These can be polarised by switching the sign for any variant where the reference allele is derived.

This function returns NaN for any IHS calculations where haplotype homozygosity does not decay below *min_ehh* before reaching the first or last variant. To disable this behaviour, set *include_edges* to True.

Note that the unstandardized score is returned. Usually these scores are then standardized in different allele frequency bins.

allel.stats.selection.**xpehh**(*h1*, *h2*, *pos*, *map_pos=None*, *min_ehh=0.05*, *include_edges=False*, *gap_scale=20000*, *max_gap=200000*, *is_accessible=None*, *use_threads=True*)
Compute the unstandardized cross-population extended haplotype homozygosity score (XPEHH) for each variant.

> **Parameters h1** : array_like, int, shape (n_variants, n_haplotypes)

Haplotype array for the first population.

h2 : array_like, int, shape (n_variants, n_haplotypes)

Haplotype array for the second population.

pos : array_like, int, shape (n_variants,)

Variant positions on physical or genetic map.

map_pos : array_like, float, shape (n_variants,)

Variant positions (genetic map distance).

min_ehh: float, optional

Minimum EHH beyond which to truncate integrated haplotype homozygosity calculation.

include_edges : bool, optional

If True, report scores even if EHH does not decay below *min_ehh* before reaching the edge of the data.

gap_scale : int, optional

Rescale distance between variants if gap is larger than this value.

max_gap : int, optional

Do not report scores if EHH spans a gap larger than this number of base pairs.

is_accessible : array_like, bool, optional

Genome accessibility array. If provided, distance between variants will be computed as the number of accessible bases between them.

use_threads : bool, optional

If True use multiple threads to compute.

Returns score : ndarray, float, shape (n_variants,)

Unstandardized XPEHH scores.

See also:

standardize

Notes

This function will calculate XPEHH for all variants. To exclude variants below a given minor allele frequency, filter the input haplotype arrays before passing to this function.

This function returns NaN for any EHH calculations where haplotype homozygosity does not decay below *min_ehh* before reaching the first or last variant. To disable this behaviour, set *include_edges* to True.

Note that the unstandardized score is returned. Usually these scores are then standardized genome-wide.

Haplotype arrays from the two populations may have different numbers of haplotypes.

allel.stats.selection.**nsl**(*h*, *use_threads=True*)
    Compute the unstandardized number of segregating sites by length (nSl) for each variant, comparing the reference and alternate alleles, after Ferrer-Admetlla et al. (2014).

Parameters h : array_like, int, shape (n_variants, n_haplotypes)

> > > Haplotype array.
>
> > **use_threads** : bool, optional
>
> > > If True use multiple threads to compute.
>
> > **Returns score** : ndarray, float, shape (n_variants,)
>
> **See also:**
>
> *standardize_by_allele_count*
>
> ### Notes
>
> This function will calculate nSl for all variants. To exclude variants below a given minor allele frequency, filter the input haplotype array before passing to this function.
>
> This function computes nSl by comparing the reference and alternate alleles. These can be polarised by switching the sign for any variant where the reference allele is derived.
>
> This function does nothing about nSl calculations where haplotype homozygosity extends up to the first or last variant. There may be edge effects.
>
> Note that the unstandardized score is returned. Usually these scores are then standardized in different allele frequency bins.

allel.stats.selection.**xpnsl**(*h1*, *h2*, *use_threads=True*)

> Cross-population version of the NSL statistic.
>
> > **Parameters h1** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array for the first population.
> >
> > **h2** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array for the second population.
> >
> > **use_threads** : bool, optional
> >
> > > If True use multiple threads to compute.
> >
> > **Returns score** : ndarray, float, shape (n_variants,)
> >
> > > Unstandardized XPNSL scores.

allel.stats.selection.**standardize**(*score*)

> Centre and scale to unit variance.

allel.stats.selection.**standardize_by_allele_count**(*score*, *aac*, *bins=None*, *n_bins=None*, *diagnostics=True*)

> Standardize *score* within allele frequency bins.
>
> > **Parameters score** : array_like, float
> >
> > > The score to be standardized, e.g., IHS or NSL.
> >
> > **aac** : array_like, int
> >
> > > An array of alternate allele counts.
> >
> > **bins** : array_like, int, optional
> >
> > > Allele count bins, overrides *n_bins*.
> >
> > **n_bins** : int, optional
> >
> > > Number of allele count bins to use.

> > **diagnostics** : bool, optional
> >
> > > If True, plot some diagnostic information about the standardization.
> >
> > **Returns score_standardized** : ndarray, float
> >
> > > Standardized scores.
> >
> > **bins** : ndarray, int
> >
> > > Allele count bins used for standardization.

allel.stats.selection.**ehh_decay**(*h*, *truncate=False*)

> Compute the decay of extended haplotype homozygosity (EHH) moving away from the first variant.
>
> > **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array.
> >
> > **truncate** : bool, optional
> >
> > > If True, the return array will exclude trailing zeros.
> >
> > **Returns ehh** : ndarray, float, shape (n_variants,)
> >
> > > EHH at successive variants from the first variant.

allel.stats.selection.**voight_painting**(*h*)

> Paint haplotypes, assigning a unique integer to each shared haplotype prefix.
>
> > **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array.
> >
> > **Returns painting** : ndarray, int, shape (n_variants, n_haplotypes)
> >
> > > Painting array.
> >
> > **indices** : ndarray, int, shape (n_hapotypes,)
> >
> > > Haplotype indices after sorting by prefix.

allel.stats.selection.**plot_voight_painting**(*painting*, *palette='colorblind'*, *flank='right'*, *ax=None*, *height_factor=0.01*)

> Plot a painting of shared haplotype prefixes.
>
> > **Parameters painting** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Painting array.
> >
> > **ax** : axes, optional
> >
> > > The axes on which to draw. If not provided, a new figure will be created.
> >
> > **palette** : string, optional
> >
> > > A Seaborn palette name.
> >
> > **flank** : {'right', 'left'}, optional
> >
> > > If left, painting will be reversed along first axis.
> >
> > **height_factor** : float, optional
> >
> > > If no axes provided, determine height of figure by multiplying height of painting array by this number.
> >
> > **Returns ax** : axes

allel.stats.selection.**fig_voight_painting**(*h*, *index=None*, *palette='colorblind'*, *height_factor=0.01*, *fig=None*)

> Make a figure of shared haplotype prefixes for both left and right flanks, centred on some variant of choice.

> > **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array.
> >
> > **index** : int, optional
> >
> > > Index of the variant within the haplotype array to centre on. If not provided, the middle variant will be used.
> >
> > **palette** : string, optional
> >
> > > A Seaborn palette name.
> >
> > **height_factor** : float, optional
> >
> > > If no axes provided, determine height of figure by multiplying height of painting array by this number.
> >
> > **fig** : figure
> >
> > > The figure on which to draw. If not provided, a new figure will be created.
> >
> > **Returns fig** : figure

Notes

N.B., the ordering of haplotypes on the left and right flanks will be different. This means that haplotypes on the right flank **will not** correspond to haplotypes on the left flank at the same vertical position.

allel.stats.selection.**haplotype_diversity**(*h*)

> Estimate haplotype diversity.

> > **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array.
> >
> > **Returns hd** : float
> >
> > > Haplotype diversity.

allel.stats.selection.**moving_haplotype_diversity**(*h*, *size*, *start=0*, *stop=None*, *step=None*)

> Estimate haplotype diversity in moving windows.

> > **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
> >
> > > Haplotype array.
> >
> > **size** : int
> >
> > > The window size (number of variants).
> >
> > **start** : int, optional
> >
> > > The index at which to start.
> >
> > **stop** : int, optional
> >
> > > The index at which to stop.
> >
> > **step** : int, optional

The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

Returns hd : ndarray, float, shape (n_windows,)

Haplotype diversity.

allel.stats.selection.**garud_h**(*h*)

Compute the H1, H12, H123 and H2/H1 statistics for detecting signatures of soft sweeps, as defined in Garud et al. (2015).

Parameters h : array_like, int, shape (n_variants, n_haplotypes)

Haplotype array.

Returns h1 : float

H1 statistic (sum of squares of haplotype frequencies).

h12 : float

H12 statistic (sum of squares of haplotype frequencies, combining the two most common haplotypes into a single frequency).

h123 : float

H123 statistic (sum of squares of haplotype frequencies, combining the three most common haplotypes into a single frequency).

h2_h1 : float

H2/H1 statistic, indicating the "softness" of a sweep.

allel.stats.selection.**moving_garud_h**(*h*, *size*, *start=0*, *stop=None*, *step=None*)

Compute the H1, H12, H123 and H2/H1 statistics for detecting signatures of soft sweeps, as defined in Garud et al. (2015), in moving windows,

Parameters h : array_like, int, shape (n_variants, n_haplotypes)

Haplotype array.

size : int

The window size (number of variants).

start : int, optional

The index at which to start.

stop : int, optional

The index at which to stop.

step : int, optional

The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

Returns h1 : ndarray, float, shape (n_windows,)

H1 statistics (sum of squares of haplotype frequencies).

h12 : ndarray, float, shape (n_windows,)

H12 statistics (sum of squares of haplotype frequencies, combining the two most common haplotypes into a single frequency).

h123 : ndarray, float, shape (n_windows,)

H123 statistics (sum of squares of haplotype frequencies, combining the three most common haplotypes into a single frequency).

h2_h1 : ndarray, float, shape (n_windows,)

H2/H1 statistics, indicating the "softness" of a sweep.

allel.stats.selection.**plot_haplotype_frequencies**(*h*, *palette='Paired'*, *singleton_color='w'*, *ax=None*)

Plot haplotype frequencies.

> **Parameters h** : array_like, int, shape (n_variants, n_haplotypes)
>
> > Haplotype array.
>
> **palette** : string, optional
>
> > A Seaborn palette name.
>
> **singleton_color** : string, optional
>
> > Color to paint singleton haplotypes.
>
> **ax** : axes, optional
>
> > The axes on which to draw. If not provided, a new figure will be created.
>
> **Returns ax** : axes

allel.stats.selection.**plot_moving_haplotype_frequencies**(*pos*, *h*, *size*, *start=0*, *stop=None*, *n=None*, *palette='Paired'*, *singleton_color='w'*, *ax=None*)

Plot haplotype frequencies in moving windows over the genome.

> **Parameters pos** : array_like, int, shape (n_items,)
>
> > Variant positions, using 1-based coordinates, in ascending order.
>
> **h** : array_like, int, shape (n_variants, n_haplotypes)
>
> > Haplotype array.
>
> **size** : int
>
> > The window size (number of variants).
>
> **start** : int, optional
>
> > The index at which to start.
>
> **stop** : int, optional
>
> > The index at which to stop.
>
> **n** : int, optional
>
> > Color only the *n* most frequent haplotypes (by default, all non-singleton haplotypes are colored).
>
> **palette** : string, optional
>
> > A Seaborn palette name.
>
> **singleton_color** : string, optional
>
> > Color to paint singleton haplotypes.
>
> **ax** : axes, optional

The axes on which to draw. If not provided, a new figure will be created.

Returns ax : axes

allel.stats.selection.**moving_delta_tajima_d**(*ac1*, *ac2*, *size*, *start=0*, *stop=None*, *step=None*)

Compute the difference in Tajima's D between two populations in moving windows.

Parameters ac1 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the first population.

ac2 : array_like, int, shape (n_variants, n_alleles)

Allele counts array for the second population.

size : int

The window size (number of variants).

start : int, optional

The index at which to start.

stop : int, optional

The index at which to stop.

step : int, optional

The number of variants between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

Returns delta_d : ndarray, float, shape (n_windows,)

Standardized delta Tajima's D.

See also:

allel.stats.diversity.moving_tajima_d

3.2.10 Window utilities

allel.stats.window.**moving_statistic**(*values*, *statistic*, *size*, *start=0*, *stop=None*, *step=None*)

Calculate a statistic in a moving window over *values*.

Parameters values : array_like

The data to summarise.

statistic : function

The statistic to compute within each window.

size : int

The window size (number of values).

start : int, optional

The index at which to start.

stop : int, optional

The index at which to stop.

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

Returns out : ndarray, shape (n_windows,)

Examples

```
>>> import allel
>>> values = [2, 5, 8, 16]
>>> allel.stats.moving_statistic(values, np.sum, size=2)
array([ 7, 24])
>>> allel.stats.moving_statistic(values, np.sum, size=2, step=1)
array([ 7, 13, 24])
```

allel.stats.window.**windowed_statistic**(*pos*, *values*, *statistic*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*, *fill=nan*)

Calculate a statistic from items in windows over a single chromosome/contig.

Parameters pos : array_like, int, shape (n_items,)

The item positions in ascending order, using 1-based coordinates..

values : array_like, int, shape (n_items,)

The values to summarise. May also be a tuple of values arrays, in which case each array will be sliced and passed through to the statistic function as separate arguments.

statistic : function

The statistic to compute.

size : int, optional

The window size (number of bases).

start : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

fill : object, optional

The value to use where a window is empty, i.e., contains no items.

Returns out : ndarray, shape (n_windows,)

The value of the statistic for each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

> **counts** : ndarray, int, shape (n_windows,)
>
> > The number of items in each window.

Notes

The window stop positions are included within a window.

The final window will be truncated to the specified stop position, and so may be smaller than the other windows.

Examples

Count non-zero (i.e., True) items in non-overlapping windows:

```
>>> import allel
>>> pos = [1, 7, 12, 15, 28]
>>> values = [True, False, True, False, False]
>>> nnz, windows, counts = allel.stats.windowed_statistic(
...     pos, values, statistic=np.count_nonzero, size=10
... )
>>> nnz
array([1, 1, 0])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 28]])
>>> counts
array([2, 2, 1])
```

Compute a sum over items in half-overlapping windows:

```
>>> values = [3, 4, 2, 6, 9]
>>> x, windows, counts = allel.stats.windowed_statistic(
...     pos, values, statistic=np.sum, size=10, step=5, fill=0
... )
>>> x
array([ 7, 12,  8,  0,  9])
>>> windows
array([[ 1, 10],
       [ 6, 15],
       [11, 20],
       [16, 25],
       [21, 28]])
>>> counts
array([2, 3, 2, 0, 1])
```

allel.stats.window.**windowed_count**(*pos*, *size=None*, *start=None*, *stop=None*, *step=None*, *windows=None*)
Count the number of items in windows over a single chromosome/contig.

> **Parameters** **pos** : array_like, int, shape (n_items,)
>
> > The item positions in ascending order, using 1-based coordinates..
>
> **size** : int, optional
>
> > The window size (number of bases).
>
> **start** : int, optional

The position at which to start (1-based).

stop : int, optional

The position at which to stop (1-based).

step : int, optional

The distance between start positions of windows. If not given, defaults to the window size, i.e., non-overlapping windows.

windows : array_like, int, shape (n_windows, 2), optional

Manually specify the windows to use as a sequence of (window_start, window_stop) positions, using 1-based coordinates. Overrides the size/start/stop/step parameters.

Returns counts : ndarray, int, shape (n_windows,)

The number of items in each window.

windows : ndarray, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions, using 1-based coordinates.

Notes

The window stop positions are included within a window.

The final window will be truncated to the specified stop position, and so may be smaller than the other windows.

Examples

Non-overlapping windows:

```
>>> import allel
>>> pos = [1, 7, 12, 15, 28]
>>> counts, windows = allel.stats.windowed_count(pos, size=10)
>>> counts
array([2, 2, 1])
>>> windows
array([[ 1, 10],
       [11, 20],
       [21, 28]])
```

Half-overlapping windows:

```
>>> counts, windows = allel.stats.windowed_count(pos, size=10, step=5)
>>> counts
array([2, 3, 2, 0, 1])
>>> windows
array([[ 1, 10],
       [ 6, 15],
       [11, 20],
       [16, 25],
       [21, 28]])
```

allel.stats.window.**per_base** (*x*, *windows*, *is_accessible=None*, *fill=nan*)
    Calculate the per-base value of a windowed statistic.

Parameters x : array_like, shape (n_windows,)

The statistic to average per-base.

windows : array_like, int, shape (n_windows, 2)

The windows used, as an array of (window_start, window_stop) positions using 1-based coordinates.

is_accessible : array_like, bool, shape (len(contig),), optional

Boolean array indicating accessibility status for all positions in the chromosome/contig.

fill : object, optional

Use this value where there are no accessible bases in a window.

Returns y : ndarray, float, shape (n_windows,)

The input array divided by the number of (accessible) bases in each window.

n_bases : ndarray, int, shape (n_windows,)

The number of (accessible) bases in each window

`allel.stats.window.`**`equally_accessible_windows`**(*is_accessible*, *size*)
Create windows each containing the same number of accessible bases.

Parameters is_accessible : array_like, bool, shape (n_bases,)

Array defining accessible status of all bases on a contig/chromosome.

size : int

Window size (number of accessible bases).

Returns windows : ndarray, int, shape (n_windows, 2)

Window start/stop positions (1-based).

3.2.11 Preprocessing utilities

`allel.stats.preprocessing.`**`get_scaler`**(*scaler*, *copy*, *ploidy*)

class `allel.stats.preprocessing.`**`CenterScaler`**(*copy=True*)

class `allel.stats.preprocessing.`**`StandardScaler`**(*copy=True*)

class `allel.stats.preprocessing.`**`PattersonScaler`**(*copy=True*, *ploidy=2*)

3.2.12 Miscellanea

`allel.stats.misc.`**`plot_variant_locator`**(*pos*, *step=None*, *ax=None*, *start=None*, *stop=None*,
                                                flip=False, *line_kwargs=None*)
Plot lines indicating the physical genome location of variants from a single chromosome/contig. By default the top x axis is in variant index space, and the bottom x axis is in genome position space.

Parameters pos : array_like

A sorted 1-dimensional array of genomic positions from a single chromosome/contig.

step : int, optional

Plot a line for every *step* variants.

ax : axes, optional

The axes on which to draw. If not provided, a new figure will be created.

start : int, optional

The start position for the region to draw.

stop : int, optional

The stop position for the region to draw.

flip : bool, optional

Flip the plot upside down.

line_kwargs : dict-like

Additional keyword arguments passed through to *plt.Line2D*.

Returns ax : axes

The axes on which the plot was drawn

3.3 Input/output utilities

allel.io.**write_vcf**(*path*, *variants*, *rename=None*, *number=None*, *description=None*, *fill=None*, *write_header=True*)

allel.io.**write_fasta**(*path*, *sequences*, *names*, *mode='w'*, *width=80*)
    Write nucleotide sequences stored as numpy arrays to a FASTA file.

Parameters path : string

File path.

sequences : sequence of arrays

One or more ndarrays of dtype 'S1' containing the sequences.

names : sequence of strings

Names of the sequences.

mode : string, optional

Use 'a' to append to an existing file.

width : int, optional

Maximum line width.

allel.io.**iter_gff3**(*path*, *attributes=None*, *region=None*, *score_fill=-1*, *phase_fill=-1*, *attributes_fill='.'*)

3.4 Chunked storage utilities

This module provides an abstraction layer over generic chunked array storage libraries. Currently HDF5 (via h5py), bcolz and zarr are supported storage layers.

Different storage configurations can be used with the functions and classes defined below. Wherever a function or method takes a *storage* keyword argument, the value of the argument will determine the storage used for the output.

If *storage* is a string, it will be used to look up one of several predefined storage configurations via the storage registry, which is a dictionary located at *allel.chunked.storage_registry*. The default storage can be changed globally by setting the value of the 'default' key in the storage registry.

Alternatively, *storage* may be an instance of one of the storage classes defined below, e.g., *allel.chunked.storage_bcolz.BcolzMemStorage* or *allel.chunked.storage_hdf5.HDF5TmpStorage*, which allows custom configuration of storage parameters such as compression type and level.

For example:

```
>>> from allel import chunked
>>> import numpy as np
>>> a = np.arange(10000000)
>>> chunked.copy(a)
carray((10000000,), int64)
  nbytes := 76.29 MB; cbytes := 1.80 MB; ratio: 42.41
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 65536; chunksize: 524288; blocksize: 32768
[      0       1       2 ..., 9999997 9999998 9999999]
>>> chunked.copy(a, storage='bcolztmp')
carray((10000000,), int64)
  nbytes := 76.29 MB; cbytes := 1.80 MB; ratio: 42.41
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 65536; chunksize: 524288; blocksize: 32768
  rootdir := '/tmp/scikit_allel_....bcolz'
  mode    := 'w'
[      0       1       2 ..., 9999997 9999998 9999999]
>>> chunked.copy(a, storage='zarrmem')
zarr.core.Array((10000000,), int64, chunks=(131072,), order=C)
  compression: blosc; compression_opts: {'clevel': 5, 'cname': 'blosclz', 'shuffle': 1}
  nbytes: 76.3M; nbytes_stored: 1.3M; ratio: 56.8; initialized: 77/77
  store: builtins.dict
>>> chunked.copy(a, storage='zarrtmp')
zarr.core.Array((10000000,), int64, chunks=(131072,), order=C)
  compression: blosc; compression_opts: {'clevel': 5, 'cname': 'blosclz', 'shuffle': 1}
  nbytes: 76.3M; nbytes_stored: 1.3M; ratio: 56.8; initialized: 77/77
  store: zarr.storage.DirectoryStore
>>> chunked.copy(a, storage=chunked.BcolzStorage(cparams=bcolz.cparams(cname='lz4')))
carray((10000000,), int64)
  nbytes := 76.29 MB; cbytes := 1.80 MB; ratio: 42.41
  cparams := cparams(clevel=5, shuffle=1, cname='lz4', quantize=0)
  chunklen := 65536; chunksize: 524288; blocksize: 32768
[      0       1       2 ..., 9999997 9999998 9999999]
>>> chunked.copy(a, storage='hdf5mem_zlib1')
<HDF5 dataset "data": shape (10000000,), type "<i8">
>>> chunked.copy(a, storage='hdf5tmp_zlib1')
<HDF5 dataset "data": shape (10000000,), type "<i8">
>>> import h5py
>>> h5f = h5py.File('example.h5', mode='w')
>>> h5g = h5f.create_group('test')
>>> chunked.copy(a, storage='hdf5', group=h5g, name='data')
<HDF5 dataset "data": shape (10000000,), type "<i8">
>>> h5f['test/data']
<HDF5 dataset "data": shape (10000000,), type "<i8">
```

3.4.1 Storage

bcolz

class `allel.chunked.storage_bcolz.`**`BcolzStorage`**(***kwargs*)
    Storage layer using bcolz carray and ctable.

class `allel.chunked.storage_bcolz.`**`BcolzMemStorage`**(***kwargs*)

class `allel.chunked.storage_bcolz.`**`BcolzTmpStorage`**(***kwargs*)

`allel.chunked.storage_bcolz.`**`bcolz_storage`** = 'bcolz'
    bcolz storage with default parameters

`allel.chunked.storage_bcolz.`**`bcolzmem_storage`** = 'bcolzmem'
    bcolz in-memory storage with default compression

`allel.chunked.storage_bcolz.`**`bcolztmp_storage`** = 'bcolztmp'
    bcolz temporary file storage with default compression

`allel.chunked.storage_bcolz.`**`bcolz_zlib1_storage`** = 'bcolz_zlib1'
    bcolz storage with zlib level 1 compression

`allel.chunked.storage_bcolz.`**`bcolzmem_zlib1_storage`** = 'bcolzmem_zlib1'
    bcolz in-memory storage with zlib level 1 compression

`allel.chunked.storage_bcolz.`**`bcolztmp_zlib1_storage`** = 'bcolztmp_zlib1'
    bcolz temporary file storage with zlib level 1 compression

HDF5 (h5py)

class `allel.chunked.storage_hdf5.`**`HDF5Storage`**(***kwargs*)
    Storage layer using HDF5 dataset and group.

class `allel.chunked.storage_hdf5.`**`HDF5MemStorage`**(***kwargs*)

class `allel.chunked.storage_hdf5.`**`HDF5TmpStorage`**(***kwargs*)

`allel.chunked.storage_hdf5.`**`hdf5_storage`** = 'hdf5'
    HDF5 storage with default parameters

`allel.chunked.storage_hdf5.`**`hdf5mem_storage`** = 'hdf5mem'
    HDF5 in-memory storage with default compression

`allel.chunked.storage_hdf5.`**`hdf5tmp_storage`** = 'hdf5tmp'
    HDF5 temporary file storage with default compression

`allel.chunked.storage_hdf5.`**`hdf5_zlib1_storage`** = 'hdf5_zlib1'
    HDF5 storage with zlib level 1 compression

`allel.chunked.storage_hdf5.`**`hdf5mem_zlib1_storage`** = 'hdf5mem_zlib1'
    HDF5 in-memory storage with zlib level 1 compression

`allel.chunked.storage_hdf5.`**`hdf5tmp_zlib1_storage`** = 'hdf5tmp_zlib1'
    HDF5 temporary file storage with zlib level 1 compression

`allel.chunked.storage_hdf5.`**`hdf5_lzf_storage`** = 'hdf5_lzf'
    HDF5 storage with LZF compression

`allel.chunked.storage_hdf5.`**`hdf5mem_lzf_storage`** = 'hdf5mem_lzf'
    HDF5 in-memory storage with LZF compression

`allel.chunked.storage_hdf5.`**`hdf5tmp_lzf_storage`** = 'hdf5tmp_lzf'
    HDF5 temporary file storage with LZF compression

`allel.chunked.storage_hdf5.`**`h5fmem`**(***kwargs*)
    Create an in-memory HDF5 file.

`allel.chunked.storage_hdf5.`**`h5ftmp`**(***kwargs*)
    Create an HDF5 file backed by a temporary file.

3.4.2 Functions

`allel.chunked.core.`**`store`**(*data*, *arr*, *start=0*, *stop=None*, *offset=0*, *blen=None*)
    Copy *data* block-wise into *arr*.

`allel.chunked.core.`**`copy`**(*data*, *start=0*, *stop=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Copy *data* block-wise into a new array.

`allel.chunked.core.`**`apply`**(*data*, *f*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Apply function *f* block-wise over *data*.

`allel.chunked.core.`**`reduce_axis`**(*data*, *reducer*, *block_reducer*, *mapper=None*, *axis=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Apply an operation to *data* that reduces over one or more axes.

`allel.chunked.core.`**`amax`**(*data*, *axis=None*, *mapper=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Compute the maximum value.

`allel.chunked.core.`**`amin`**(*data*, *axis=None*, *mapper=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Compute the minimum value.

`allel.chunked.core.`**`asum`**(*data*, *axis=None*, *mapper=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Compute the sum.

`allel.chunked.core.`**`count_nonzero`**(*data*, *mapper=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Count the number of non-zero elements.

`allel.chunked.core.`**`compress`**(*data*, *condition*, *axis=0*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Return selected slices of an array along given axis.

`allel.chunked.core.`**`take`**(*data*, *indices*, *axis=0*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Take elements from an array along an axis.

`allel.chunked.core.`**`subset`**(*data*, *sel0=None*, *sel1=None*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Return selected rows and columns of an array.

`allel.chunked.core.`**`hstack`**(*tup*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Stack arrays in sequence horizontally (column wise).

`allel.chunked.core.`**`vstack`**(*tup*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Stack arrays in sequence vertically (row wise).

`allel.chunked.core.`**`binary_op`**(*data*, *op*, *other*, *blen=None*, *storage=None*, *create='array'*, ***kwargs*)
    Compute a binary operation block-wise over *data*.

`allel.chunked.core.`**`copy_table`**(*tbl*, *start=0*, *stop=None*, *blen=None*, *storage=None*, *create='table'*, ***kwargs*)

Copy *tbl* block-wise into a new table.

`allel.chunked.core.`**`compress_table`**(*tbl*, *condition*, *blen=None*, *storage=None*, *create='table'*, ***kwargs*)

Return selected rows of a table.

`allel.chunked.core.`**`take_table`**(*tbl*, *indices*, *blen=None*, *storage=None*, *create='table'*, ***kwargs*)

Return selected rows of a table.

`allel.chunked.core.`**`vstack_table`**(*tup*, *blen=None*, *storage=None*, *create='table'*, ***kwargs*)

Stack tables in sequence vertically (row-wise).

`allel.chunked.core.`**`eval_table`**(*tbl*, *expression*, *vm='python'*, *blen=None*, *storage=None*, *create='array'*, *vm_kwargs=None*, ***kwargs*)

Evaluate *expression* against columns of a table.

3.4.3 Classes

class `allel.chunked.core.`**`ChunkedArray`**(*data*)

Wrapper class for chunked array-like data.

> **Parameters data** : array_like
>
> > Data to be wrapped. May be a bcolz carray, h5py dataset, or anything providing a similar interface.

class `allel.chunked.core.`**`ChunkedTable`**(*data*, *names=None*)

Wrapper class for chunked table-like data.

> **Parameters data: table_like**
>
> > Data to be wrapped. May be a tuple or list of columns (array-like), a dict mapping names to columns, a bcolz ctable, h5py group, numpy recarray, or anything providing a similar interface.
>
> **names** : sequence of strings
>
> > Column names.

3.5 Miscellaneous utilities

`allel.util.`**`hdf5_cache`**(*filepath=None*, *parent=None*, *group=None*, *names=None*, *typed=False*, *hashed_key=False*, ***h5dcreate_kwargs*)

HDF5 cache decorator.

> **Parameters filepath** : string, optional
>
> > Path to HDF5 file. If None a temporary file name will be used.
>
> **parent** : string, optional
>
> > Path to group within HDF5 file to use as parent. If None the root group will be used.
>
> **group** : string, optional
>
> > Path to group within HDF5 file, relative to parent, to use as container for cached data. If None the name of the wrapped function will be used.

names : sequence of strings, optional

> Name(s) of dataset(s). If None, default names will be 'f00', 'f01', etc.

typed : bool, optional

> If True, arguments of different types will be cached separately. For example, f(3.0) and f(3) will be treated as distinct calls with distinct results.

hashed_key : bool, optional

> If False (default) the key will not be hashed, which makes for readable cache group names. If True the key will be hashed, however note that on Python >= 3.3 the hash value will not be the same between sessions unless the environment variable PYTHON-HASHSEED has been set to the same value.

Returns decorator : function

Examples

Without any arguments, will cache using a temporary HDF5 file:

```
>>> import allel
>>> @allel.util.hdf5_cache()
... def foo(n):
...     print('executing foo')
...     return np.arange(n)
...
>>> foo(3)
executing foo
array([0, 1, 2])
>>> foo(3)
array([0, 1, 2])
>>> foo.cache_filepath
'/tmp/tmp_jwtwgjz'
```

Supports multiple return values, including scalars, e.g.:

```
>>> @allel.util.hdf5_cache()
... def bar(n):
...     print('executing bar')
...     a = np.arange(n)
...     return a, a**2, n**2
...
>>> bar(3)
executing bar
(array([0, 1, 2]), array([0, 1, 4]), 9)
>>> bar(3)
(array([0, 1, 2]), array([0, 1, 4]), 9)
```

Names can also be specified for the datasets, e.g.:

```
>>> @allel.util.hdf5_cache(names=['z', 'x', 'y'])
... def baz(n):
...     print('executing baz')
...     a = np.arange(n)
...     return a, a**2, n**2
...
>>> baz(3)
executing baz
```

```
    (array([0, 1, 2]), array([0, 1, 4]), 9)
>>> baz(3)
    (array([0, 1, 2]), array([0, 1, 4]), 9)
```

3.6 Release notes

3.6.1 v0.21.1

- Added parameter *min_maf* to `allel.stats.selection.ihs()` to skip IHS calculation for variants below a given minor allele frequency.

- Minor change to calculation of integrated haplotype homozygosity to enable values to be reported for first and last variants if *include_edges* is *True*.

- Minor change to `allel.stats.selection.standardize_by_allele_count()` to better handle missing values.

3.6.2 v0.21.0

In this release the implementations of `allel.stats.selection.ihs()` and `allel.stats.selection.xpehh()` selection statistics have been reworked to address a number of issues:

- Both functions can now integrate over either a genetic map (via the *map_pos* parameter) or a physical map.

- Both functions now accept *max_gap* and *gap_scale* parameters to perform adjustments to integrated haplotype homozygosity where there are large gaps between variants, following the standard approach. Alternatively, if a map of genome accessibility is available, it may be provided via the *is_accessible* parameter, in which case the distance between variants will be scaled by the fraction of accessible bases between them.

- Both functions are now faster and can make use of multiple threads to further accelerate computation.

- Several bugs in the previous implementations of these functions have been fixed (#91).

- New utility functions are provided for standardising selection scores, see `allel.stats.selection.standardize_by_allele_count()` (for use with IHS and NSL) and `allel.stats.selection.standardize()` (for use with XPEHH).

Other changes:

- Added functions `allel.stats.diversity.moving_tajima_d()` and `allel.stats.selection.moving_delta_tajima_d()` (#81, #70).

- Added functions `allel.stats.fst.moving_weir_cockerham_fst()`, `allel.stats.fst.moving_hudson_fst()`, `allel.stats.fst.moving_patterson_fst()`.

- Added functions `allel.stats.admixture.moving_patterson_f3()` and `allel.stats.admixture.moving_patterson_d()`.

- Renamed "blockwise" to "average" in function names in `allel.stats.fst` and `allel.stats.admixture` for clarity.

- Added convenience methods `allel.model.ndarray.AlleleCountsArray.is_biallelic()` and `allel.model.ndarray.AlleleCountsArray.is_biallelic_01()` for locating biallelic variants.

- Added support for zarr in the `allel.chunked` module (#101).

- Changed HDF5 default chunked storage to use gzip level 1 compression instead of no compression (#100).

- Fixed bug in `allel.stats.diversity.sequence_divergence()` (#75).

- Added workaround for chunked arrays if passed as arguments into numpy aggregation functions (#66).

- Protect against invalid coordinates when mapping from square to condensed coords (#83).

- Fixed bug in `allel.stats.sf.plot_sfs_folded()` and added docstrings for all plotting functions in `allel.stats.sf` (#80).

- Fixed bug related to taking views of genotype and haplotype arrays (#77).

3.6.3 v0.20.3

- Fixed a bug in the *count_alleles()* methods on genotype and haplotype array classes that manifested if the *max_allele* argument was provided (#59).

- Fixed a bug in Jupyter notebook *display* method for chunked tables (#57).

- Fixed a bug in site frequency spectrum scaling functions (#54).

- Changed behaviour of *subset* method on genotype and haplotype arrays to better infer argument types and handle None argument values (#55).

- Changed table *eval* and *query* methods to make python the default for expression evaluation, because it is more expressive than numexpr (#58).

3.6.4 v0.20.2

- Changed `allel.util.hdf5_cache()` to resolve issues with hashing and argument order (#51, #52).

3.6.5 v0.20.1

- Changed functions `allel.stats.fst.weir_cockerham_fst()` and `allel.stats.ld.locate_unlinked()` such that chunked implementations are now used by default, to avoid accidentally and unnecessarily loading very large arrays into memory (#50).

3.6.6 v0.20.0

- Added new `allel.model.dask` module, providing implementations of the genotype, haplotype and allele counts classes backed by dask.array (#32).

- Released the GIL where possible in Cython optimised functions (#43).

- Changed functions in `allel.stats.selection` that accept *min_ehh* argument, such that *min_ehh = None* should now be used to indicate that no minimum EHH threshold should be applied.

3.6.7 v0.19.0

The major change in v0.19.0 is the addition of the new `allel.model.chunked` module, which provides classes for variant call data backed by chunked array storage (#31). This is a generalisation of the previously available `allel.model.bcolz` to enable the use of both bcolz and HDF5 (via h5py) as backing storage. The `allel.model.bcolz` module is now deprecated but will be retained for backwargs compatibility until the next major release.

Other changes:

- Added function for computing the number of segregating sites by length (nSl), a summary statistic comparing haplotype homozygosity between different alleles (similar to IHS), see `allel.stats.selection.nsl()` (#40).

- Added functions for computing haplotype diversity, see `allel.stats.selection.haplotype_diversity()` and `allel.stats.selection.moving_haplotype_diversity()` (#29).

- Added function `allel.stats.selection.plot_moving_haplotype_frequencies()` for visualising haplotype frequency spectra in moving windows over the genome (#30).

- Added *vstack()* and *hstack()* methods to genotype and haplotype arrays to enable combining data from multiple arrays (#21).

- Added convenience function `allel.stats.window.equally_accessible_windows()` (#16).

- Added methods *from_hdf5_group()* and *to_hdf5_group()* to `allel.model.ndarray.VariantTable` (#26).

- Added `allel.util.hdf5_cache()` utility function.

- Modified functions in the `allel.stats.selection` module that depend on calculation of integrated haplotype homozygosity to return NaN when haplotypes do not decay below a specified threshold (#39).

- Fixed missing return value in `allel.stats.selection.plot_voight_painting()` (#23).

- Fixed return type from array reshape() (#34).

Contributors: alimanfoo, hardingnj

3.6.8 v0.18.1

- Minor change to the Garud H statistics to avoid raising an exception when the number of distinct haplotypes is very low (#20).

3.6.9 v0.18.0

- Added functions for computing H statistics for detecting signatures of soft sweeps, see `allel.stats.selection.garud_h()`, `allel.stats.selection.moving_garud_h()`, `allel.stats.selection.plot_haplotype_frequencies()` (#19).

- Added function `allel.stats.selection.fig_voight_painting()` to paint both flanks either side of some variant under selection in a single figure (#17).

- Changed return values from `allel.stats.selection.voight_painting()` to also return the indices used for sorting haplotypes by prefix (#18).

3.6.10 v0.17.0

- Added new module for computing and plotting site frequency spectra, see `allel.stats.sf` (#12).

- All plotting functions have been moved into the appropriate stats module that they naturally correspond to. The `allel.plot` module is deprecated (#13).

- Improved performance of carray and ctable loading from HDF5 with a condition (#11).

3.6.11 v0.16.2

- Fixed behaviour of take() method on compressed arrays when indices are not in increasing order (#6).

- Minor change to scaler argument to PCA functions in *allel.stats.decomposition* to avoid confusion about when to fall back to default scaler (#7).

3.6.12 v0.16.1

- Added block-wise implementation to *allel.stats.ld.locate_unlinked()* so it can be used with compressed arrays as input.

3.6.13 v0.16.0

- Added new selection module with functions for haplotype-based analyses of recent selection, see *allel.stats.selection*.

3.6.14 v0.15.2

- Improved performance of *allel.model.bcolz.carray_block_compress()*, *allel.model.bcolz.ctable_block_compress()* and allel.model.bcolz.carray_block_subset() for very sparse selections.

- Fix bug in IPython HTML table captions.

- Fix bug in addcol() method on bcolz ctable wrappers.

3.6.15 v0.15.1

- Fix missing package in setup.py.

3.6.16 v0.15

- Added functions to estimate Fst with standard error via a block-jackknife: allel.stats.fst.blockwise_weir_cockerham_fst(), allel.stats.fst.blockwise_hudson_fst(),allel.stats.fst.blockwise_patterson_fst().

- Fixed a serious bug in *allel.stats.fst.weir_cockerham_fst()* related to incorrect estimation of heterozygosity, which manifested if the subpopulations being compared were not a partition of the total population (i.e., there were one or more samples in the genotype array that were not included in the subpopulations to compare).

- Added method allel.model.AlleleCountsArray.max_allele() to determine highest allele index for each variant.

- Changed first return value from admixture functions allel.stats.admixture.blockwise_patterson_f3() and allel.stats.admixture.blockwise_patterson_d() to return the estimator from the whole dataset.

- Added utility functions to the *allel.stats.distance* module for transforming coordinates between condensed and uncondensed forms of a distance matrix.

- Classes previously available from the *allel.model* and *allel.bcolz* modules are now aliased from the root `allel` module for convenience. These modules have been reorganised into an `allel.model` package with sub-modules `allel.model.ndarray` and `allel.model.bcolz`.

- All functions in the `allel.model.bcolz` module use cparams from input carray as default for output carray (convenient if you, e.g., want to use zlib level 1 throughout).

- All classes in the `allel.model.ndarray` and `allel.model.bcolz` modules have changed the default value for the *copy* keyword argument to *False*. This means that **not** copying the input data, just wrapping it, is now the default behaviour.

- Fixed bug in `GenotypeArray.to_gt()` where maximum allele index is zero.

3.6.17 v0.14

- Added a new module `allel.stats.admixture` with statistical tests for admixture between populations, implementing the f2, f3 and D statistics from Patterson (2012). Functions include `allel.stats.admixture.blockwise_patterson_f3()` and `allel.stats.admixture.blockwise_patterson_d()` which compute the f3 and D statistics respectively in blocks of a given number of variants and perform a block-jackknife to estimate the standard error.

3.6.18 v0.12

- Added functions for principal components analysis of genotype data. Functions in the new module `allel.stats.decomposition` include `allel.stats.decomposition.pca()` to perform a PCA via full singular value decomposition, and `allel.stats.decomposition.randomized_pca()` which uses an approximate truncated singular value decomposition to speed up computation. In tests with real data the randomized PCA is around 5 times faster and uses half as much memory as the conventional PCA, producing highly similar results.

- Added function `allel.stats.distance.pcoa()` for principal coordinate analysis (a.k.a. classical multi-dimensional scaling) of a distance matrix.

- Added new utility module `allel.stats.preprocessing` with classes for scaling genotype data prior to use as input for PCA or PCoA. By default the scaling (i.e., normalization) of Patterson (2006) is used with principal components analysis functions in the `allel.stats.decomposition` module. Scaling functions can improve the ability to resolve population structure via PCA or PCoA.

- Added method `allel.model.GenotypeArray.to_n_ref()`. Also added `dtype` argument to `allel.model.GenotypeArray.to_n_ref()` and `allel.model.GenotypeArray.to_n_alt()` methods to enable direct output as float arrays, which can be convenient if these arrays are then going to be scaled for use in PCA or PCoA.

- Added `allel.model.GenotypeArray.mask` property which can be set with a Boolean mask to filter genotype calls from genotype and allele counting operations. A similar property is available on the `allel.bcolz.GenotypeCArray` class. Also added method `allel.model.GenotypeArray.fill_masked()` and similar method on the `allel.bcolz.GenotypeCArray` class to fill masked genotype calls with a value (e.g., -1).

3.6.19 v0.11

- Added functions for calculating Watterson's theta (proportional to the number of segregating variants): `allel.stats.diversity.watterson_theta()` for calculating over a given region, and

allel.stats.diversity.windowed_watterson_theta() for calculating in windows over a chromosome/contig.

- Added functions for calculating Tajima's D statistic (balance between nucleotide diversity and number of segregating sites): *allel.stats.diversity.tajima_d()* for calculating over a given region and *allel.stats.diversity.windowed_tajima_d()* for calculating in windows over a chromosome/contig.

- Added *allel.stats.diversity.windowed_df()* for calculating the rate of fixed differences between two populations.

- Added function `allel.model.locate_fixed_differences()` for locating variants that are fixed for different alleles in two different populations.

- Added function `allel.model.locate_private_alleles()` for locating alleles and variants that are private to a single population.

3.6.20 v0.10

- Added functions implementing the Weir and Cockerham (1984) estimators for F-statistics: *allel.stats.fst.weir_cockerham_fst()* and *allel.stats.fst.windowed_weir_cockerham_fst()*.

- Added functions implementing the Hudson (1992) estimator for Fst: *allel.stats.fst.hudson_fst()* and *allel.stats.fst.windowed_hudson_fst()*.

- Added new module *allel.stats.ld* with functions for calculating linkage disequilibrium estimators, including *allel.stats.ld.rogers_huff_r()* for pairwise variant LD calculation, *allel.stats.ld.windowed_r_squared()* for windowed LD calculations, and *allel.stats.ld.locate_unlinked()* for locating variants in approximate linkage equilibrium.

- Added function `allel.plot.pairwise_ld()` for visualising a matrix of linkage disequilbrium values between pairs of variants.

- Added function `allel.model.create_allele_mapping()` for creating a mapping of alleles into a different index system, i.e., if you want 0 and 1 to represent something other than REF and ALT, e.g., ancestral and derived. Also added methods `allel.model.GenotypeArray.map_alleles()`, `allel.model.HaplotypeArray.map_alleles()` and `allel.model.AlleleCountsArray.map_alleles()` which will perform an allele transformation given an allele mapping.

- Added function `allel.plot.variant_locator()` ported across from anhima.

- Refactored the `allel.stats` module into a package with sub-modules for easier maintenance.

3.6.21 v0.9

- Added documentation for the functions `allel.bcolz.carray_from_hdf5()`, `allel.bcolz.carray_to_hdf5()`, `allel.bcolz.ctable_from_hdf5_group()`, `allel.bcolz.ctable_to_hdf5_group()`.

- Refactoring of internals within the `allel.bcolz` module.

3.6.22 v0.8

- Added *subpop* argument to `allel.model.GenotypeArray.count_alleles()` and `allel.model.HaplotypeArray.count_alleles()` to enable count alleles within a sub-population without subsetting the array.

- Added functions `allel.model.GenotypeArray.count_alleles_subpops()` and `allel.model.HaplotypeArray.count_alleles_subpops()` to enable counting alleles in multiple sub-populations in a single pass over the array, without sub-setting.

- Added classes `allel.model.FeatureTable` and `allel.bcolz.FeatureCTable` for storing and querying data on genomic features (genes, etc.), with functions for parsing from a GFF3 file.

- Added convenience function *allel.stats.distance.pairwise_dxy()* for computing a distance matrix using Dxy as the metric.

3.6.23 v0.7

- Added function *allel.io.write_fasta()* for writing a nucleotide sequence stored as a NumPy array out to a FASTA format file.

3.6.24 v0.6

- Added method `allel.model.VariantTable.to_vcf()` for writing a variant table to a VCF format file.

Acknowledgments

Indices and tables

- genindex
- modindex
- search

a

A

B

C

H

I

J

L