Discrete Valuations and Discrete Pseudo-Valuations

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The Sage Development Team

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CHAPTER

ONE

HIGH-LEVEL INTERFACE

Valuations can be defined conveniently on some Sage rings such as p-adic rings and function fields.

1.1 p-adic valuations

Valuations on number fields can be easily specified if they uniquely extend the valuation of a rational prime:

```
sage: v = QQ.valuation(2)
sage: v(1024)
10
```

They are normalized such that the rational prime has valuation 1:

```
sage: K.<a> = NumberField(x^2 + x + 1)
sage: v = K.valuation(2)
sage: v(1024)
10
```

If there are multiple valuations over a prime, they can be obtained by extending a valuation from a smaller ring:

```
sage: K.<a> = NumberField(x^2 + x + 1)
sage: K.valuation(7)
Traceback (most recent call last):
...
ValueError: The valuation Gauss valuation induced by 7-adic valuation does not␣
↪approximate a unique extension of 7-adic valuation with respect to x^2 + x + 1
sage: w,ww = QQ.valuation(7).extensions(K)
sage: w(a + 3), ww(a + 3)
(1, 0)
sage: w(a + 5), ww(a + 5)
(0, 1)
```

1.2 Valuations on Function Fields

Similarly, valuations can be defined on function fields:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x)
sage: v(1/x)
-1

sage: v = K.valuation(1/x)
sage: v(1/x)
1
```

On extensions of function fields, valuations can be created by providing a prime on the underlying rational function field when the extension is unique:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
sage: v = L.valuation(x)
sage: v(x)
1
```

Valuations can also be extended from smaller function fields:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x - 4)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
sage: v.extensions(L)
[[ (x - 4)-adic valuation, v(y + 2) = 1 ]-adic valuation,
 [ (x - 4)-adic valuation, v(y - 2) = 1 ]-adic valuation]
```

CHAPTER

TWO

LOW-LEVEL INTERFACE

2.1 Mac Lane valuations

Internally, all the above is backed by the algorithms described in [Mac1936I] and [Mac1936II]. Let us consider the extensions of `K.valuation(x - 4)` to the field L above to outline how this works internally.

First, the valuation on K is induced by a valuation on $\mathbf{Q}[x]$. To construct this valuation, we start from the trivial valuation on
Q and consider its induced Gauss valuation on
$Q[x]$, i.e., the valuation that assigns to a polynomial the minimum of the coefficient valuations:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
```

The Gauss valuation can be augmented by specifying that $x - 4$ has valuation 1:

```
sage: v = v.augmentation(x - 4, 1); v
[ Gauss valuation induced by Trivial valuation on Rational Field, v(x - 4) = 1 ]
```

This valuation then extends uniquely to the fraction field:

```
sage: K.<x> = FunctionField(QQ)
sage: v = v.extension(K); v
(x - 4)-adic valuation
```

Over the function field we repeat the above process, i.e., we define the Gauss valuation induced by it and augment it to approximate an extension to L:

```
sage: R.<y> = K[]
sage: w = GaussValuation(R, v)
sage: w = w.augmentation(y - 2, 1); w
[ Gauss valuation induced by (x - 4)-adic valuation, v(y - 2) = 1 ]
sage: L.<y> = K.extension(y^2 - x)
sage: ww = w.extension(L); ww
[ (x - 4)-adic valuation, v(y - 2) = 1 ]-adic valuation
```

2.2 Limit valuations

In the previous example the final valuation `ww` is not merely given by evaluating `w` on the ring $K[y]$:

```
sage: ww(y^2 - x)
+Infinity
sage: y = R.gen()
sage: w(y^2 - x)
1
```

Instead `ww` is given by a limit, i.e., an infinite sequence of augmentations of valuations:

```
sage: ww._base_valuation
[ Gauss valuation induced by (x - 4)-adic valuation, v(y - 2) = 1 , ... ]
```

The terms of this infinite sequence are computed on demand:

```
sage: ww._base_valuation._approximation
[ Gauss valuation induced by (x - 4)-adic valuation, v(y - 2) = 1 ]
sage: ww(y - 1/4*x - 1)
2
sage: ww._base_valuation._approximation
[ Gauss valuation induced by (x - 4)-adic valuation, v(y + 1/64*x^2 - 3/8*x - 3/4) = 3 ]
```

2.3 Non-classical valuations

Using the low-level interface we are not limited to classical valuations on function fields that correspond to points on the corresponding projective curves. Instead we can start with a non-trivial valuation on the field of constants:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: w = GaussValuation(R, v) # v is not trivial
sage: K.<x> = FunctionField(QQ)
sage: w = w.extension(K)
sage: w.residue_field()
Rational function field in x over Finite Field of size 2
```

CHAPTER

THREE

MAC LANE APPROXIMANTS

The main tool underlying this package is an algorithm by Mac Lane to compute, starting from a Gauss valuation on a polynomial ring and a monic squarefree polynomial G, approximations to the limit valuation which send G to infinity:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: f = x^5 + 3*x^4 + 5*x^3 + 8*x^2 + 6*x + 12
sage: v.mac_lane_approximants(f) # random output (order may vary)
[[ Gauss valuation induced by 2-adic valuation, v(x^2 + x + 1) = 3 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 1/2 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 1 ]]
```

From these approximants one can already see the residual degrees and ramification indices of the corresponding extensions. The approximants can be pushed to arbitrary precision, corresponding to a factorization of `f`:

```
sage: v.mac_lane_approximants(f, required_precision=10) # random output
[[ Gauss valuation induced by 2-adic valuation, v(x^2 + 193*x + 13/21) = 10 ],
 [ Gauss valuation induced by 2-adic valuation, v(x + 86) = 10 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 1/2, v(x^2 + 36/11*x + 2/17) = 11␣
↪]]
```

CHAPTER

FOUR

REFERENCES

The theory was originally described in [Mac1936I] and [Mac1936II]. A summary and some algorithmic details can also be found in Chapter 4 of [Rüt2014].

CHAPTER

FIVE

MORE DETAILS

5.1 Value groups of discrete valuations

This file defines additive sub(semi-)groups of $\mathbf{Q}$ and related structures.

AUTHORS:

- Julian Rüth (2013-09-06): initial version

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.value_group()
Additive Abelian Group generated by 1
sage: v.value_semigroup()
Additive Abelian Semigroup generated by 1
```

class sage.rings.valuation.value_group.**DiscreteValuationCodomain**

Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.parent.Parent

The codomain of discrete valuations, the rational numbers extended by $\pm\infty$.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValuationCodomain
sage: C = DiscreteValuationCodomain(); C
Codomain of Discrete Valuations
```

class sage.rings.valuation.value_group.**DiscreteValueGroup**(*generator*)

Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.parent.Parent

The value group of a discrete valuation, an additive subgroup of $\mathbf{Q}$ generated by `generator`.

INPUT:

- `generator` – a rational number

Note: We do not rely on the functionality provided by additive abelian groups in Sage since these require the underlying set to be the integers. Therefore, we roll our own Z-module here. We could have used `AdditiveAbelianGroupWrapper` here, but it seems to be somewhat outdated. In particular, generic group functionality should now come from the category and not from the super-class. A facade of Q appeared to be the better approach.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: D1 = DiscreteValueGroup(0); D1
Trivial Additive Abelian Group
sage: D2 = DiscreteValueGroup(4/3); D2
Additive Abelian Group generated by 4/3
sage: D3 = DiscreteValueGroup(-1/3); D3
Additive Abelian Group generated by 1/3
```

denominator()

Return the denominator of a generator of this group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(3/8).denominator()
8
```

gen()

Return a generator of this group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(-3/8).gen()
3/8
```

index(*other*)

Return the index of `other` in this group.

INPUT:

- `other` – a subgroup of this group

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(3/8).index(DiscreteValueGroup(3))
8
sage: DiscreteValueGroup(3).index(DiscreteValueGroup(3/8))
Traceback (most recent call last):
...
ValueError: other must be a subgroup of this group
sage: DiscreteValueGroup(3).index(DiscreteValueGroup(0))
Traceback (most recent call last):
...
ValueError: other must have finite index in this group
sage: DiscreteValueGroup(0).index(DiscreteValueGroup(0))
1
sage: DiscreteValueGroup(0).index(DiscreteValueGroup(3))
Traceback (most recent call last):
...
ValueError: other must be a subgroup of this group
```

is_trivial()

Return whether this is the trivial additive abelian group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(-3/8).is_trivial()
False
sage: DiscreteValueGroup(0).is_trivial()
True
```

numerator()

Return the numerator of a generator of this group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(3/8).numerator()
3
```

some_elements()

Return some typical elements in this group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueGroup
sage: DiscreteValueGroup(-3/8).some_elements()
[3/8, -3/8, 0, 42, 3/2, -3/2, 9/8, -9/8]
```

class sage.rings.valuation.value_group.**DiscreteValueSemigroup**(*generators*)

Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.parent.Parent

The value semigroup of a discrete valuation, an additive subsemigroup of $\mathbb{Q}$ generated by `generators`.

INPUT:

- `generators` – rational numbers

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueSemigroup
sage: D1 = DiscreteValueSemigroup(0); D1
Trivial Additive Abelian Semigroup
sage: D2 = DiscreteValueSemigroup(4/3); D2
Additive Abelian Semigroup generated by 4/3
sage: D3 = DiscreteValueSemigroup([-1/3, 1/2]); D3
Additive Abelian Semigroup generated by -1/3, 1/2
```

gens()

Return the generators of this semigroup.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueSemigroup
sage: DiscreteValueSemigroup(-3/8).gens()
(-3/8,)
```

is_group()

Return whether this semigroup is a group.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueSemigroup
sage: DiscreteValueSemigroup(1).is_group()
False
sage: D = DiscreteValueSemigroup([-1, 1])
sage: D.is_group()
True
```

Invoking this method also changes the category of this semigroup if it is a group:

```
sage: D in AdditiveMagmas().AdditiveAssociative().AdditiveUnital().
↪AdditiveInverse()
True
```

is_trivial()

Return whether this is the trivial additive abelian semigroup.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueSemigroup
sage: DiscreteValueSemigroup(-3/8).is_trivial()
False
sage: DiscreteValueSemigroup([]).is_trivial()
True
```

some_elements()

Return some typical elements in this semigroup.

EXAMPLES:

```
sage: from sage.rings.valuation.value_group import DiscreteValueSemigroup
sage: list(DiscreteValueSemigroup([-3/8,1/2]).some_elements())
[0, -3/8, 1/2, ...]
```

5.2 Discrete valuations

This file defines abstract base classes for discrete (pseudo-)valuations.

AUTHORS:

- Julian Rüth (2013-03-16): initial version

EXAMPLES:

Discrete valuations can be created on a variety of rings:

```
sage: ZZ.valuation(2)
2-adic valuation
sage: GaussianIntegers().valuation(3)
3-adic valuation
sage: QQ.valuation(5)
5-adic valuation
sage: Zp(7).valuation()
7-adic valuation
```

```
sage: K.<x> = FunctionField(QQ)
sage: K.valuation(x)
(x)-adic valuation
sage: K.valuation(x^2 + 1)
(x^2 + 1)-adic valuation
sage: K.valuation(1/x)
Valuation at the infinite place
```

```
sage: R.<x> = QQ[]
sage: v = QQ.valuation(2)
sage: w = GaussValuation(R, v)
sage: w.augmentation(x, 3)
[ Gauss valuation induced by 2-adic valuation, v(x) = 3 ]
```

We can also define discrete pseudo-valuations, i.e., discrete valuations that send more than just zero to infinity:

```
sage: w.augmentation(x, infinity)
[ Gauss valuation induced by 2-adic valuation, v(x) = +Infinity ]
```

class sage.rings.valuation.valuation.**DiscretePseudoValuation**(*parent*)

Bases: sage.categories.morphism.Morphism

Abstract base class for discrete pseudo-valuations, i.e., discrete valuations which might send more that just zero to infinity.

INPUT:

- domain – an integral domain

EXAMPLES:

```
sage: v = ZZ.valuation(2); v # indirect doctest
2-adic valuation
```

is_equivalent(*f*, *g*)

Return whether f and g are equivalent.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: v.is_equivalent(2, 1)
False
sage: v.is_equivalent(2, -2)
True
sage: v.is_equivalent(2, 0)
False
sage: v.is_equivalent(0, 0)
True
```

class sage.rings.valuation.valuation.**DiscreteValuation**(*parent*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Abstract base class for discrete valuations.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, v)
sage: w = v.augmentation(x, 1337); w # indirect doctest
[ Gauss valuation induced by 2-adic valuation, v(x) = 1337 ]
```

is_discrete_valuation()

Return whether this valuation is a discrete valuation.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(ZZ)
sage: v.is_discrete_valuation()
True
```

mac_lane_approximant(*G*, *valuation*, *approximants=None*)

Return the approximant from *mac_lane_approximants()* for `G` which is approximated by or approximates `valuation`.

INPUT:

- `G` – a monic squarefree integral polynomial in a univariate polynomial ring over the domain of this valuation
- `valuation` – a valuation on the parent of `G`
- `approximants` – the output of *mac_lane_approximants()*. If not given, it is computed.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: G = x^2 + 1
```

We can select an approximant by approximating it:

```
sage: w = GaussValuation(R, v).augmentation(x + 1, 1/2)
sage: v.mac_lane_approximant(G, w)
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 ]
```

As long as this is the only matching approximant, the approximation can be very coarse:

```
sage: w = GaussValuation(R, v)
sage: v.mac_lane_approximant(G, w)
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 ]
```

Or it can be very specific:

```
sage: w = GaussValuation(R, v).augmentation(x + 1, 1/2).augmentation(G,␣
↪infinity)
sage: v.mac_lane_approximant(G, w)
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 ]
```

But it must be an approximation of an approximant:

```
sage: w = GaussValuation(R, v).augmentation(x, 1/2)
sage: v.mac_lane_approximant(G, w)
```

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```
Traceback (most recent call last):
...
ValueError: The valuation [ Gauss valuation induced by 2-adic valuation, v(x) =␣
↪1/2 ] is not an approximant for a valuation which extends 2-adic valuation␣
↪with respect to x^2 + 1 since the valuation of x^2 + 1 does not increase in␣
↪every step
```

The `valuation` must single out one approximant:

```
sage: G = x^2 - 1
sage: w = GaussValuation(R, v)
sage: v.mac_lane_approximant(G, w)
Traceback (most recent call last):
...
ValueError: The valuation Gauss valuation induced by 2-adic valuation does not␣
↪approximate a unique extension of 2-adic valuation with respect to x^2 - 1

sage: w = GaussValuation(R, v).augmentation(x + 1, 1)
sage: v.mac_lane_approximant(G, w)
Traceback (most recent call last):
...
ValueError: The valuation [ Gauss valuation induced by 2-adic valuation, v(x +␣
↪1) = 1 ] does not approximate a unique extension of 2-adic valuation with␣
↪respect to x^2 - 1

sage: w = GaussValuation(R, v).augmentation(x + 1, 2)
sage: v.mac_lane_approximant(G, w)
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = +Infinity ]

sage: w = GaussValuation(R, v).augmentation(x + 3, 2)
sage: v.mac_lane_approximant(G, w)
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1 ]
```

mac_lane_approximants(*G*, *assume_squarefree=False*, *require_final_EF=True*, *required_precision=- 1*, *require_incomparability=False*, *require_maximal_degree=False*, *algorithm='serial'*)

Return approximants on $K[x]$ for the extensions of this valuation to $L = K[x]/(G)$.

If G is an irreducible polynomial, then this corresponds to extensions of this valuation to the completion of L.

INPUT:

- `G` – a monic squarefree integral polynomial in a univariate polynomial ring over the domain of this valuation
- `assume_squarefree` – a boolean (default: `False`), whether to assume that `G` is squarefree. If `True`, the squafreeness of `G` is not verified though it is necessary when `require_final_EF` is set for the algorithm to terminate.
- `require_final_EF` – a boolean (default: `True`); whether to require the returned key polynomials to be in one-to-one correspondance to the extensions of this valuation to `L` and require them to have the ramification index and residue degree of the valuations they correspond to.
- `required_precision` – a number or infinity (default: -1); whether to require the last key polynomial of the returned valuations to have at least that valuation.

- `require_incomparability` – a boolean (default: `False`); whether to require the returned valuations to be incomparable (with respect to the partial order on valuations defined by comparing them pointwise.)
- `require_maximal_degree` – a boolean (default: `False`); whether to require the last key polynomial of the returned valuation to have maximal degree. This is most relevant when using this algorithm to compute approximate factorizations of `G`, when set to `True`, the last key polynomial has the same degree as the corresponding factor.
- `algorithm` – one of `"serial"` or `"parallel"` (default: `"serial"`); whether or not to parallelize the algorithm

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: v.mac_lane_approximants(x^2 + 1)
[[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 ]]
sage: v.mac_lane_approximants(x^2 + 1, required_precision=infinity)
[[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2, v(x^2 + 1) =␣
↪+Infinity ]]
sage: v.mac_lane_approximants(x^2 + x + 1)
[[ Gauss valuation induced by 2-adic valuation, v(x^2 + x + 1) = +Infinity ]]
```

Note that `G` does not need to be irreducible. Here, we detect a factor $x+1$ and an approximate factor $x+1$ (which is an approximation to $x-1$):

```
sage: v.mac_lane_approximants(x^2 - 1)
[[ Gauss valuation induced by 2-adic valuation, v(x + 1) = +Infinity ],
 [ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1 ]]
```

However, it needs to be squarefree:

```
sage: v.mac_lane_approximants(x^2)
Traceback (most recent call last):
...
ValueError: G must be squarefree
```

montes_factorization(*G*, *assume_squarefree=False*, *required_precision=None*)

Factor `G` over the completion of the domain of this valuation.

INPUT:

- `G` – a monic polynomial over the domain of this valuation
- `assume_squarefree` – a boolean (default: `False`), whether to assume `G` to be squarefree
- `required_precision` – a number or infinity (default: infinity); if `infinity`, the returned polynomials are actual factors of `G`, otherwise they are only factors with precision at least `required_precision`.

ALGORITHM:

We compute *mac_lane_approximants()* with `required_precision`. The key polynomials approximate factors of `G`. This can be very slow unless `required_precision` is set to zero. Single factor lifting could improve this significantly.

EXAMPLES:

```
sage: k=Qp(5,4)
sage: v = k.valuation()
sage: R.<x>=k[]
sage: G = x^2 + 1
sage: v.montes_factorization(G)
((1 + O(5^4))*x + 2 + 5 + 2*5^2 + 5^3 + O(5^4)) * ((1 + O(5^4))*x + 3 + 3*5 +␣
↪2*5^2 + 3*5^3 + O(5^4))
```

The computation might not terminate over incomplete fields (in particular because the factors can not be represented there):

```
sage: R.<x> = QQ[]
sage: v = QQ.valuation(2)
sage: v.montes_factorization(x^6 - 1)
(x - 1) * (x + 1) * (x^2 - x + 1) * (x^2 + x + 1)

sage: v.montes_factorization(x^7 - 1) # not tested, does not terminate

sage: v.montes_factorization(x^7 - 1, required_precision=5)
(x - 1) * (x^3 - 5*x^2 - 6*x - 1) * (x^3 + 6*x^2 + 5*x - 1)
```

REFERENCES:

The underlying algorithm is described in [Mac1936II] and thoroughly analyzed in [GMN2008].

class sage.rings.valuation.valuation.**InfiniteDiscretePseudoValuation**(*parent*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Abstract base class for infinite discrete pseudo-valuations, i.e., discrete pseudo-valuations which are not discrete valuations.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, v)
sage: w = v.augmentation(x, infinity); w # indirect doctest
[ Gauss valuation induced by 2-adic valuation, v(x) = +Infinity ]
```

is_discrete_valuation()

Return whether this valuation is a discrete valuation.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, v)
sage: v.is_discrete_valuation()
True
sage: w = v.augmentation(x, infinity)
sage: w.is_discrete_valuation()
False
```

class sage.rings.valuation.valuation.**MacLaneApproximantNode**(*valuation*, *parent*, *ef*, *principal_part_bound*, *coefficients*, *valuations*)

Bases: `object`

A node in the tree computed by *DiscreteValuation.mac_lane_approximants()*

Leaves in the computation of the tree of approximants *mac_lane_approximants()*. Each vertex consists of a tuple `(v,ef,p,coeffs,vals)` where `v` is an approximant, i.e., a valuation, ef is a boolean, `p` is the parent of this vertex, and `coeffs` and `vals` are cached values. (Only `v` and `ef` are relevant, everything else are caches/debug info.) The boolean `ef` denotes whether `v` already has the final ramification index E and residue degree F of this approximant. An edge V – P represents the relation `P.v` $\leq$ `V.v` (pointwise on the polynomial ring K[x]) between the valuations.

class sage.rings.valuation.valuation.**NegativeInfiniteDiscretePseudoValuation**(*parent*)

Bases: *sage.rings.valuation.valuation.InfiniteDiscretePseudoValuation*

Abstract base class for pseudo-valuations which attain the value ∞ and $-\infty$, i.e., whose domain contains an element of valuation ∞ and its inverse.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ)).augmentation(x,␣
↪infinity)
sage: K.<x> = FunctionField(QQ)
sage: w = K.valuation(v)
```

is_negative_pseudo_valuation()

Return whether this valuation attains the value $-\infty$.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ)).augmentation(x,␣
↪infinity)
sage: v.is_negative_pseudo_valuation()
False
sage: K.<x> = FunctionField(QQ)
sage: w = K.valuation(v)
sage: w.is_negative_pseudo_valuation()
True
```

5.3 Spaces of valuations

This module provides spaces of exponential pseudo-valuations on integral domains. It currently only provides support for such valuations if they are discrete, i.e., their image is a discrete additive subgroup of the rational numbers extended by ∞.

AUTHORS:

- Julian Rüth (2016-10-14): initial version

EXAMPLES:

```
sage: QQ.valuation(2).parent()
Discrete pseudo-valuations on Rational Field
```

Note: Note that many tests not only in this module do not create instances of valuations directly since this gives the wrong inheritance structure on the resulting objects:

```
sage: from sage.rings.valuation.valuation_space import DiscretePseudoValuationSpace
sage: from sage.rings.valuation.trivial_valuation import TrivialDiscretePseudoValuation
sage: H = DiscretePseudoValuationSpace(QQ)
sage: v = TrivialDiscretePseudoValuation(H)
sage: v._test_category()
Traceback (most recent call last):
...
AssertionError: False is not true
```

Instead, the valuations need to be created through the `__make_element_class__` of the containing space:

```
sage: from sage.rings.valuation.trivial_valuation import TrivialDiscretePseudoValuation
sage: v = H.__make_element_class__(TrivialDiscretePseudoValuation)(H)
sage: v._test_category()
```

The factories such as `TrivialPseudoValuation` provide the right inheritance structure:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v._test_category()
```

---

class sage.rings.valuation.valuation_space.**DiscretePseudoValuationSpace**(*domain*)

Bases: sage.structure.unique_representation.UniqueRepresentation, sage.categories.homset.Homset

The space of discrete pseudo-valuations on `domain`.

EXAMPLES:

```
sage: from sage.rings.valuation.valuation_space import DiscretePseudoValuationSpace
sage: H = DiscretePseudoValuationSpace(QQ)
sage: QQ.valuation(2) in H
True
```

Note: We do not distinguish between the space of discrete valuations and the space of discrete pseudo-valuations. This is entirely for practical reasons: We would like to model the fact that every discrete valuation is also a discrete pseudo-valuation. At first, it seems to be sufficient to make sure that the `in` operator works which can essentially be achieved by overriding `_element_constructor_` of the space of discrete pseudo-valuations to accept discrete valuations by just returning them. Currently, however, if one does not change the parent of an element in `_element_constructor_` to `self`, then one cannot register that conversion as a coercion. Consequently, the operators <= and >= cannot be made to work between discrete valuations and discrete pseudo-valuations on the same domain (because the implementation only calls `_richcmp` if both operands have the same parent.) Of course, we could override `__ge__` and `__le__` but then we would likely run into other surprises. So in the end, we went for a single homspace for all discrete valuations (pseudo or not) as this makes the implementation much easier.

Todo: The comparison problem might be fixed by trac ticket #22029 or similar.

---

class ElementMethods

Bases: `object`

Provides methods for discrete pseudo-valuations that are added automatically to valuations in this space.

EXAMPLES:

Here is an example of a method that is automagically added to a discrete valuation:

```
sage: from sage.rings.valuation.valuation_space import␣
↪DiscretePseudoValuationSpace
sage: H = DiscretePseudoValuationSpace(QQ)
sage: QQ.valuation(2).is_discrete_pseudo_valuation() # indirect doctest
True
```

The methods will be provided even if the concrete type is not created with `__make_element_class__`:

```
sage: from sage.rings.valuation.valuation import DiscretePseudoValuation
sage: m = DiscretePseudoValuation(H)
sage: m.parent() is H
True
sage: m.is_discrete_pseudo_valuation()
True
```

However, the category framework advises you to use inheritance:

```
sage: m._test_category()
Traceback (most recent call last):
...
AssertionError: False is not true
```

Using `__make_element_class__`, makes your concrete valuation inherit from this class:

```
sage: m = H.__make_element_class__(DiscretePseudoValuation)(H)
sage: m._test_category()
```

change_domain(*ring*)

Return this valuation over `ring`.

Unlike *extension()* or *restriction()*, this might not be completely sane mathematically. It is essentially a conversion of this valuation into another space of valuations.

EXAMPLES:

```
sage: v = QQ.valuation(3)
sage: v.change_domain(ZZ)
3-adic valuation
```

element_with_valuation(*s*)

Return an element in the domain of this valuation with valuation `s`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.element_with_valuation(10)
1024
```

extension(*ring*)

Return the unique extension of this valuation to `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: w = v.extension(QQ)
sage: w.domain()
Rational Field
```

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.extensions(QQ)
[2-adic valuation]
```

inverse(*x*, *precision*)

Return an approximate inverse of `x`.

The element returned is such that the product differs from 1 by an element of valuation at least `precision`.

INPUT:

- `x` – an element in the domain of this valuation
- `precision` – a rational or infinity

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: x = 3
sage: y = v.inverse(3, 2); y
3
sage: x*y - 1
8
```

This might not be possible for elements of positive valuation:

```
sage: v.inverse(2, 2)
Traceback (most recent call last):
...
ValueError: element has no approximate inverse in this ring
```

Of course this always works over fields:

```
sage: v = QQ.valuation(2)
sage: v.inverse(2, 2)
1/2
```

is_discrete_pseudo_valuation()

Return whether this valuation is a discrete pseudo-valuation.

EXAMPLES:

```
sage: QQ.valuation(2).is_discrete_pseudo_valuation()
True
```

is_discrete_valuation()

Return whether this valuation is a discrete valuation, i.e., whether it is a *discrete pseudo valuation* that only sends zero to ∞.

EXAMPLES:

```
sage: QQ.valuation(2).is_discrete_valuation()
True
```

is_negative_pseudo_valuation()

Return whether this valuation is a discrete pseudo-valuation that does attain $-\infty$, i.e., it is non-trivial and its domain contains an element with valuation ∞ that has an inverse.

EXAMPLES:

```
sage: QQ.valuation(2).is_negative_pseudo_valuation()
False
```

is_trivial()

Return whether this valuation is trivial, i.e., whether it is constant ∞ or constant zero for everything but the zero element.

Subclasses need to override this method if they do not implement *uniformizer()*.

EXAMPLES:

```
sage: QQ.valuation(7).is_trivial()
False
```

lift(X)

Return a lift of `X` in the domain which reduces down to `X` again via *reduce()*.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: v.lift(v.residue_ring().one())
1
```

lower_bound(x)

Return a lower bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.lower_bound(2^10)
10
```

reduce(x)

Return the image of `x` in the *residue_ring()* of this valuation.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: v.reduce(2)
0
sage: v.reduce(1)
1
sage: v.reduce(1/3)
1
```

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```
sage: v.reduce(1/2)
Traceback (most recent call last):
...
ValueError: reduction is only defined for elements of non-negative valuation
```

residue_field()

Return the residue field of this valuation, i.e., the field of fractions of the *residue_ring()*, the elements of non-negative valuation modulo the elements of positive valuation.

EXAMPLES:

```
sage: QQ.valuation(2).residue_field()
Finite Field of size 2
sage: valuations.TrivialValuation(QQ).residue_field()
Rational Field

sage: valuations.TrivialValuation(ZZ).residue_field()
Rational Field
sage: GaussValuation(ZZ['x'], ZZ.valuation(2)).residue_field()
Rational function field in x over Finite Field of size 2
```

residue_ring()

Return the residue ring of this valuation, i.e., the elements of non-negative valuation modulo the elements of positive valuation. EXAMPLES:

```
sage: QQ.valuation(2).residue_ring()
Finite Field of size 2
sage: valuations.TrivialValuation(QQ).residue_ring()
Rational Field
```

Note that a residue ring always exists, even when a residue field may not:

```
sage: valuations.TrivialPseudoValuation(QQ).residue_ring()
Quotient of Rational Field by the ideal (1)
sage: valuations.TrivialValuation(ZZ).residue_ring()
Integer Ring
sage: GaussValuation(ZZ['x'], ZZ.valuation(2)).residue_ring()
Univariate Polynomial Ring in x over Finite Field of size 2 (using ...)
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: v = QQ.valuation(2)
sage: w = v.restriction(ZZ)
sage: w.domain()
Integer Ring
```

scale(*scalar*)

Return this valuation scaled by `scalar`.

INPUT:

- `scalar` – a non-negative rational number or infinity

EXAMPLES:

```
sage: v = ZZ.valuation(3)
sage: w = v.scale(3)
sage: w(3)
3
```

Scaling can also be done through multiplication with a scalar:

```
sage: w/3 == v
True
```

Multiplication by zero produces the trivial discrete valuation:

```
sage: w = 0*v
sage: w(3)
0
sage: w(0)
+Infinity
```

Multiplication by infinity produces the trivial discrete pseudo-valuation:

```
sage: w = infinity*v
sage: w(3)
+Infinity
sage: w(0)
+Infinity
```

separating_element(*others*)

Return an element in the domain of this valuation which has positive valuation with respect to this valuation but negative valuation with respect to the valuations in `others`.

EXAMPLES:

```
sage: v2 = QQ.valuation(2)
sage: v3 = QQ.valuation(3)
sage: v5 = QQ.valuation(5)
sage: v2.separating_element([v3,v5])
4/15
```

shift(*x*, *s*)

Shift `x` in its expansion with respect to *uniformizer()* by `s` "digits".

For non-negative `s`, this just returns `x` multiplied by a power of the uniformizer π.

For negative `s`, it does the same but when not over a field, it drops coefficients in the π-adic expansion which have negative valuation.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.shift(1, 10)
1024
sage: v.shift(11, -1)
5
```

For some rings, there is no clear π-adic expansion. In this case, this method performs negative shifts by iterated division by the uniformizer and substraction of a lift of the reduction:

```
sage: R.<x> = ZZ[]
sage: v = ZZ.valuation(2)
sage: w = GaussValuation(R, v)
sage: w.shift(x, 1)
2*x
sage: w.shift(2*x, -1)
x
sage: w.shift(x + 2*x^2, -1)
x^2
```

simplify(*x*, *error=None*, *force=False*)

Return a simplified version of `x`.

Produce an element which differs from `x` by an element of valuation strictly greater than the valuation of `x` (or strictly greater than `error` if set.)

If `force` is not set, then expensive simplifications may be avoided.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.simplify(6, force=True)
2
sage: v.simplify(6, error=0, force=True)
0
```

uniformizer()

Return an element in the domain which has positive valuation and generates the value group of this valuation.

EXAMPLES:

```
sage: QQ.valuation(11).uniformizer()
11
```

Trivial valuations have no uniformizer:

```
sage: from sage.rings.valuation.valuation_space import␣
↪DiscretePseudoValuationSpace
sage: v = DiscretePseudoValuationSpace(QQ).an_element()
sage: v.is_trivial()
True
sage: v.uniformizer()
Traceback (most recent call last):
...
ValueError: Trivial valuations do not define a uniformizing element
```

upper_bound(*x*)

Return an upper bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.upper_bound(2^10)
10
```

value_group()

Return the value group of this discrete pseudo-valuation, the discrete additive subgroup of the rational numbers which is generated by the valuation of the *uniformizer()*.

EXAMPLES:

```
sage: QQ.valuation(2).value_group()
Additive Abelian Group generated by 1
```

A pseudo-valuation that is ∞ everywhere, does not have a value group:

```
sage: from sage.rings.valuation.valuation_space import␣
↪DiscretePseudoValuationSpace
sage: v = DiscretePseudoValuationSpace(QQ).an_element()
sage: v.value_group()
Traceback (most recent call last):
...
ValueError: The trivial pseudo-valuation that is infinity everywhere does␣
↪not have a value group.
```

value_semigroup()

Return the value semigroup of this discrete pseudo-valuation, the additive subsemigroup of the rational numbers which is generated by the valuations of the elements in the domain.

EXAMPLES:

Most commonly, in particular over fields, the semigroup is the group generated by the valuation of the uniformizer:

```
sage: G = QQ.valuation(2).value_semigroup(); G
Additive Abelian Semigroup generated by -1, 1
sage: G in AdditiveMagmas().AdditiveAssociative().AdditiveUnital().
↪AdditiveInverse()
True
```

If the domain is a discrete valuation ring, then the semigroup consists of the positive elements of the *value_group()*:

```
sage: Zp(2).valuation().value_semigroup()
Additive Abelian Semigroup generated by 1
```

The semigroup can have a more complicated structure when the uniformizer is not in the domain:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: w = GaussValuation(R, v)
sage: u = w.augmentation(x, 5/3)
sage: u.value_semigroup()
Additive Abelian Semigroup generated by 1, 5/3
```

class sage.rings.valuation.valuation_space.**ScaleAction**

Bases: sage.categories.action.Action

Action of integers, rationals and the infinity ring on valuations by scaling it.

EXAMPLES:

```
sage: v = QQ.valuation(5)
sage: from operator import mul
sage: v.parent().get_action(ZZ, mul, self_on_left=False)
Left action by Integer Ring on Discrete pseudo-valuations on Rational Field
```

5.4 Trivial valuations

AUTHORS:

- Julian Rüth (2016-10-14): initial version

EXAMPLES:

```
sage: v = valuations.TrivialValuation(QQ); v
Trivial valuation on Rational Field
sage: v(1)
0
```

class sage.rings.valuation.trivial_valuation.**TrivialDiscretePseudoValuation**(*parent*)

Bases: *sage.rings.valuation.trivial_valuation.TrivialDiscretePseudoValuation_base*, *sage.rings.valuation.valuation.InfiniteDiscretePseudoValuation*

The trivial pseudo-valuation that is ∞ everywhere.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(QQ); v
Trivial pseudo-valuation on Rational Field
```

lift(*X*)

Return a lift of `X` to the domain of this valuation.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v.lift(v.residue_ring().zero())
0
```

reduce(*x*)

Reduce `x` modulo the positive elements of this valuation.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v.reduce(1)
0
```

residue_ring()

Return the residue ring of this valuation.

EXAMPLES:

```
sage: valuations.TrivialPseudoValuation(QQ).residue_ring()
Quotient of Rational Field by the ideal (1)
```

value_group()

Return the value group of this valuation.

EXAMPLES:

A trivial discrete pseudo-valuation has no value group:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v.value_group()
Traceback (most recent call last):
...
ValueError: The trivial pseudo-valuation that is infinity everywhere does not␣
↪have a value group.
```

class sage.rings.valuation.trivial_valuation.**TrivialDiscretePseudoValuation_base**(*parent*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Base class for code shared by trivial valuations.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(ZZ); v
Trivial pseudo-valuation on Integer Ring
```

is_negative_pseudo_valuation()

Return whether this valuation attains the value $-\infty$.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v.is_negative_pseudo_valuation()
False
```

is_trivial()

Return whether this valuation is trivial.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(QQ)
sage: v.is_trivial()
True
```

uniformizer()

Return a uniformizing element for this valuation.

EXAMPLES:

```
sage: v = valuations.TrivialPseudoValuation(ZZ)
sage: v.uniformizer()
Traceback (most recent call last):
...
ValueError: Trivial valuations do not define a uniformizing element
```

class sage.rings.valuation.trivial_valuation.**TrivialDiscreteValuation**(*parent*)

Bases: *sage.rings.valuation.trivial_valuation.TrivialDiscretePseudoValuation_base*, *sage.rings.valuation.valuation.DiscreteValuation*

The trivial valuation that is zero on non-zero elements.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(QQ); v
Trivial valuation on Rational Field
```

extensions(*ring*)

Return the unique extension of this valuation to `ring`.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(ZZ)
sage: v.extensions(QQ)
[Trivial valuation on Rational Field]
```

lift(*X*)

Return a lift of `X` to the domain of this valuation.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(QQ)
sage: v.lift(v.residue_ring().zero())
0
```

reduce(*x*)

Reduce `x` modulo the positive elements of this valuation.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(QQ)
sage: v.reduce(1)
1
```

residue_ring()

Return the residue ring of this valuation.

EXAMPLES:

```
sage: valuations.TrivialValuation(QQ).residue_ring()
Rational Field
```

value_group()

Return the value group of this valuation.

EXAMPLES:

A trivial discrete valuation has a trivial value group:

```
sage: v = valuations.TrivialValuation(QQ)
sage: v.value_group()
Trivial Additive Abelian Group
```

class sage.rings.valuation.trivial_valuation.**TrivialValuationFactory**(*clazz*, *parent*, **args*, ***kwargs*)

Bases: sage.structure.factory.UniqueFactory

Create a trivial valuation on `domain`.

EXAMPLES:

```
sage: v = valuations.TrivialValuation(QQ); v
Trivial valuation on Rational Field
sage: v(1)
0
```

create_key(*domain*)

Create a key that identifies this valuation.

EXAMPLES:

```
sage: valuations.TrivialValuation(QQ) is valuations.TrivialValuation(QQ) #␣
↪indirect doctest
True
```

create_object(*version*, *key*, ***extra_args*)

Create a trivial valuation from `key`.

EXAMPLES:

```
sage: valuations.TrivialValuation(QQ) # indirect doctest
Trivial valuation on Rational Field
```

5.5 Gauss valuations on polynomial rings

This file implements Gauss valuations for polynomial rings, i.e. discrete valuations which assign to a polynomial the minimal valuation of its coefficients.

AUTHORS:

- Julian Rüth (2013-04-15): initial version

EXAMPLES:

A Gauss valuation maps a polynomial to the minimal valuation of any of its coefficients:

```
sage: R.<x> = QQ[]
sage: v0 = QQ.valuation(2)
sage: v = GaussValuation(R, v0); v
Gauss valuation induced by 2-adic valuation
sage: v(2*x + 2)
1
```

Gauss valuations can also be defined iteratively based on valuations over polynomial rings:

```
sage: v = v.augmentation(x, 1/4); v
[ Gauss valuation induced by 2-adic valuation, v(x) = 1/4 ]
sage: v = v.augmentation(x^4+2*x^3+2*x^2+2*x+2, 4/3); v
[ Gauss valuation induced by 2-adic valuation, v(x) = 1/4, v(x^4 + 2*x^3 + 2*x^2 + 2*x +␣
↪2) = 4/3 ]
```

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```
sage: S.<T> = R[]
sage: w = GaussValuation(S, v); w
Gauss valuation induced by [ Gauss valuation induced by 2-adic valuation, v(x) = 1/4,␣
↪v(x^4 + 2*x^3 + 2*x^2 + 2*x + 2) = 4/3 ]
sage: w(2*T + 1)
0
```

class sage.rings.valuation.gauss_valuation.**GaussValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Create a Gauss valuation on `domain`.

INPUT:

- `domain` – a univariate polynomial ring
- `v` – a valuation on the base ring of `domain`, the underlying valuation on the constants of the polynomial ring (if unspecified take the natural valuation on the valued ring `domain`.)

EXAMPLES:

The Gauss valuation is the minimum of the valuation of the coefficients:

```
sage: v = QQ.valuation(2)
sage: R.<x> = QQ[]
sage: w = GaussValuation(R, v)
sage: w(2)
1
sage: w(x)
0
sage: w(x + 2)
0
```

create_key(*domain*, *v=None*)

Normalize and check the parameters to create a Gauss valuation.

create_object(*version*, *key*, ***extra_args*)

Create a Gauss valuation from normalized parameters.

class sage.rings.valuation.gauss_valuation.**GaussValuation_generic**(*parent*, *v*)

Bases: *sage.rings.valuation.inductive_valuation.NonFinalInductiveValuation*

A Gauss valuation on a polynomial ring `domain`.

INPUT:

- `domain` – a univariate polynomial ring over a valued ring R
- `v` – a discrete valuation on R

EXAMPLES:

```
sage: R = Zp(3,5)
sage: S.<x> = R[]
sage: v0 = R.valuation()
sage: v = GaussValuation(S, v0); v
Gauss valuation induced by 3-adic valuation

sage: S.<x> = QQ[]
```

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```
sage: v = GaussValuation(S, QQ.valuation(5)); v
Gauss valuation induced by 5-adic valuation
```

E()

Return the ramification index of this valuation over its underlying Gauss valuation, i.e., 1.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.E()
1
```

F()

Return the degree of the residue field extension of this valuation over the Gauss valuation, i.e., 1.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.F()
1
```

augmentation_chain()

Return a list with the chain of augmentations down to the underlying Gauss valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.augmentation_chain()
[Gauss valuation induced by 2-adic valuation]
```

change_domain(*ring*)

Return this valuation as a valuation over `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: w = GaussValuation(R, v)
sage: w.change_domain(QQ['x'])
Gauss valuation induced by 2-adic valuation
```

element_with_valuation(*s*)

Return a polynomial of minimal degree with valuation `s`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: v.element_with_valuation(-2)
1/4
```

equivalence_unit(*s*, *reciprocal=False*)

Return an equivalence unit of valuation `s`.

INPUT:

- `s` – an element of the *value_group()*
- `reciprocal` – a boolean (default: `False`); whether or not to return the equivalence unit as the *equivalence_reciprocal()* of the equivalence unit of valuation `-s`

EXAMPLES:

```
sage: S.<x> = Qp(3,5)[]
sage: v = GaussValuation(S)
sage: v.equivalence_unit(2)
3^2 + O(3^7)
sage: v.equivalence_unit(-2)
3^-2 + O(3^3)
```

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: w = GaussValuation(R, v)
sage: w.extensions(GaussianIntegers()['x'])
[Gauss valuation induced by 2-adic valuation]
```

is_gauss_valuation()

Return whether this valuation is a Gauss valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_gauss_valuation()
True
```

is_trivial()

Return whether this is a trivial valuation (sending everything but zero to zero.)

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
sage: v.is_trivial()
True
```

lift(*F*)

Return a lift of `F`.

INPUT:

- `F` – a polynomial over the *residue_ring()* of this valuation

OUTPUT:

a (possibly non-monic) polynomial in the domain of this valuation which reduces to F

EXAMPLES:

```
sage: S.<x> = Qp(3,5)[]
sage: v = GaussValuation(S)
sage: f = x^2 + 2*x + 16
sage: F = v.reduce(f); F
x^2 + 2*x + 1
sage: g = v.lift(F); g
(1 + O(3^5))*x^2 + (2 + O(3^5))*x + 1 + O(3^5)
sage: v.is_equivalent(f,g)
True
sage: g.parent() is v.domain()
True
```

See also:

reduce()

lift_to_key(*F*)

Lift the irreducible polynomial F from the *residue_ring()* to a key polynomial over this valuation.

INPUT:

- F – an irreducible non-constant monic polynomial in *residue_ring()* of this valuation

OUTPUT:

A polynomial f in the domain of this valuation which is a key polynomial for this valuation and which, for a suitable equivalence unit R, satisfies that the reduction of Rf is F

EXAMPLES:

```
sage: R.<u> = QQ
sage: S.<x> = R[]
sage: v = GaussValuation(S, QQ.valuation(2))
sage: y = v.residue_ring().gen()
sage: f = v.lift_to_key(y^2 + y + 1); f
x^2 + x + 1
```

lower_bound(*f*)

Return an lower bound of this valuation at f.

Use this method to get an approximation of the valuation of f when speed is more important than accuracy.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.lower_bound(1024*x + 2)
1
sage: v(1024*x + 2)
1
```

monic_integral_model(*G*)

Return a monic integral irreducible polynomial which defines the same extension of the base ring of the domain as the irreducible polynomial G together with maps between the old and the new polynomial.

EXAMPLES:

```
sage: R.<x> = Qp(2, 5)[]
sage: v = GaussValuation(R)
sage: v.monic_integral_model(5*x^2 + 1/2*x + 1/4)
(Ring endomorphism of Univariate Polynomial Ring in x over 2-adic Field with␣
↪capped relative precision 5
  Defn: (1 + O(2^5))*x |--> (2^-1 + O(2^4))*x,
 Ring endomorphism of Univariate Polynomial Ring in x over 2-adic Field with␣
↪capped relative precision 5
  Defn: (1 + O(2^5))*x |--> (2 + O(2^6))*x,
 (1 + O(2^5))*x^2 + (1 + 2^2 + 2^3 + O(2^5))*x + 1 + 2^2 + 2^3 + O(2^5))
```

reduce(*f*, *check=True*, *degree_bound=None*, *coefficients=None*, *valuations=None*)

Return the reduction of `f` modulo this valuation.

INPUT:

- `f` – an integral element of the domain of this valuation
- `check` – whether or not to check whether `f` has non-negative valuation (default: `True`)
- `degree_bound` – an a-priori known bound on the degree of the result which can speed up the computation (default: not set)
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); ignored
- `valuations` – the valuations of `coefficients` or `None` (default: `None`); ignored

OUTPUT:

A polynomial in the *residue_ring()* of this valuation.

EXAMPLES:

```
sage: S.<x> = Qp(2,5)[]
sage: v = GaussValuation(S)
sage: f = x^2 + 2*x + 16
sage: v.reduce(f)
x^2
sage: v.reduce(f).parent() is v.residue_ring()
True
```

The reduction is only defined for integral elements:

```
sage: f = x^2/2
sage: v.reduce(f)
Traceback (most recent call last):
...
ValueError: reduction not defined for non-integral elements and (2^-1 + O(2^
↪4))*x^2 is not integral over Gauss valuation induced by 2-adic valuation
```

See also:

lift()

residue_ring()

Return the residue ring of this valuation, i.e., the elements of valuation zero module the elements of positive valuation.

EXAMPLES:

```
sage: S.<x> = Qp(2,5)[]
sage: v = GaussValuation(S)
sage: v.residue_ring()
Univariate Polynomial Ring in x over Finite Field of size 2 (using ...)
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: w = GaussValuation(R, v)
sage: w.restriction(ZZ)
2-adic valuation
```

scale(*scalar*)

Return this valuation scaled by `scalar`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: 3*v # indirect doctest
Gauss valuation induced by 3 * 2-adic valuation
```

simplify(*f*, *error=None*, *force=False*, *size_heuristic_bound=32*, *effective_degree=None*, *phiadic=True*)

Return a simplified version of `f`.

Produce an element which differs from `f` by an element of valuation strictly greater than the valuation of `f` (or strictly greater than `error` if set.)

INPUT:

- `f` – an element in the domain of this valuation
- `error` – a rational, infinity, or `None` (default: `None`), the error allowed to introduce through the simplification
- `force` – whether or not to simplify `f` even if there is heuristically no change in the coefficient size of `f` expected (default: `False`)
- `effective_degree` – when set, assume that coefficients beyond `effective_degree` can be safely dropped (default: `None`)
- `size_heuristic_bound` – when `force` is not set, the expected factor by which the coefficients need to shrink to perform an actual simplification (default: 32)
- `phiadic` – whether to simplify in the x-adic expansion; the parameter is ignored as no other simplification is implemented

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: f = x^10/2 + 1
```

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```
sage: v.simplify(f)
(2^-1 + O(2^4))*x^10 + 1 + O(2^5)
```

uniformizer()

Return a uniformizer of this valuation, i.e., a uniformizer of the valuation of the base ring.

EXAMPLES:

```
sage: S.<x> = QQ[]
sage: v = GaussValuation(S, QQ.valuation(5))
sage: v.uniformizer()
5
sage: v.uniformizer().parent() is S
True
```

upper_bound(*f*)

Return an upper bound of this valuation at `f`.

Use this method to get an approximation of the valuation of `f` when speed is more important than accuracy.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.upper_bound(1024*x + 1)
10
sage: v(1024*x + 1)
0
```

valuations(*f*, *coefficients=None*, *call_error=False*)

Return the valuations of the $f_i\phi^i$ in the expansion $f = \sum f_i\phi^i$.

INPUT:

- `f` – a polynomial in the domain of this valuation
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); this can be used to speed up the computation when the expansion of `f` is already known from a previous computation.
- `call_error` – whether or not to speed up the computation by assuming that the result is only used to compute the valuation of `f` (default: `False`)

OUTPUT:

A list, each entry a rational numbers or infinity, the valuations of $f_0, f_1\phi, \ldots$

EXAMPLES:

```
sage: R = ZZ
sage: S.<x> = R[]
sage: v = GaussValuation(S, R.valuation(2))
sage: f = x^2 + 2*x + 16
sage: list(v.valuations(f))
[4, 1, 0]
```

value_group()
Return the value group of this valuation.

EXAMPLES:

```
sage: S.<x> = QQ[]
sage: v = GaussValuation(S, QQ.valuation(5))
sage: v.value_group()
Additive Abelian Group generated by 1
```

value_semigroup()
Return the value semigroup of this valuation.

EXAMPLES:

```
sage: S.<x> = QQ[]
sage: v = GaussValuation(S, QQ.valuation(5))
sage: v.value_semigroup()
Additive Abelian Semigroup generated by -1, 1
```

5.6 Valuations on polynomial rings based on ϕ-adic expansions

This file implements a base class for discrete valuations on polynomial rings, defined by a ϕ-adic expansion.

AUTHORS:

- Julian Rüth (2013-04-15): initial version

EXAMPLES:

The *Gauss valuation* is a simple example of a valuation that relies on ϕ-adic expansions:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
```

In this case, $\phi = x$, so the expansion simply lists the coefficients of the polynomial:

```
sage: f = x^2 + 2*x + 2
sage: list(v.coefficients(f))
[2, 2, 1]
```

Often only the first few coefficients are necessary in computations, so for performance reasons, coefficients are computed lazily:

```
sage: v.coefficients(f)
<generator object ...coefficients at 0x...>
```

Another example of a *DevelopingValuation* is an *augmented valuation*:

```
sage: w = v.augmentation(x^2 + x + 1, 3)
```

Here, the expansion lists the remainders of repeated division by $x^2 + x + 1$:

```
sage: list(w.coefficients(f))
[x + 1, 1]
```

class sage.rings.valuation.developing_valuation.**DevelopingValuation**(*parent*, *phi*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Abstract base class for a discrete valuation of polynomials defined over the polynomial ring `domain` by the ϕ-adic development.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(7))
```

coefficients(*f*)

Return the ϕ-adic expansion of `f`.

INPUT:

- `f` – a monic polynomial in the domain of this valuation

OUTPUT:

An iterator $f_0, f_1, \ldots, f_n$ of polynomials in the domain of this valuation such that $f = \sum_i f_i \phi^i$

EXAMPLES:

```
sage: R = Qp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: f = x^2 + 2*x + 3
sage: list(v.coefficients(f)) # note that these constants are in the polynomial␣
↪ring
[1 + 2 + O(2^5), 2 + O(2^6), 1 + O(2^5)]
sage: v = v.augmentation( x^2 + x + 1, 1)
sage: list(v.coefficients(f))
[(1 + O(2^5))*x + 2 + O(2^5), 1 + O(2^5)]
```

effective_degree(*f*, *valuations=None*)

Return the effective degree of `f` with respect to this valuation.

The effective degree of f is the largest i such that the valuation of f and the valuation of $f_i\phi^i$ in the development $f = \sum_j f_j \phi^j$ coincide (see [Mac1936II] p.497.)

INPUT:

- `f` – a non-zero polynomial in the domain of this valuation

EXAMPLES:

```
sage: R = Zp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.effective_degree(x)
1
sage: v.effective_degree(2*x + 1)
0
```

newton_polygon(*f*, *valuations=None*)

Return the Newton polygon of the ϕ-adic development of `f`.

INPUT:

- `f` – a polynomial in the domain of this valuation

EXAMPLES:

```
sage: R = Qp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: f = x^2 + 2*x + 3
sage: v.newton_polygon(f)
Finite Newton polygon with 2 vertices: (0, 0), (2, 0)

sage: v = v.augmentation( x^2 + x + 1, 1)
sage: v.newton_polygon(f)
Finite Newton polygon with 2 vertices: (0, 0), (1, 1)
sage: v.newton_polygon( f * v.phi()^3 )
Finite Newton polygon with 2 vertices: (3, 3), (4, 4)
```

phi()

Return the polynomial ϕ, the key polynomial of this valuation.

EXAMPLES:

```
sage: R = Zp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.phi()
(1 + O(2^5))*x
```

valuations(f)

Return the valuations of the $f_i\phi^i$ in the expansion $f = \sum f_i\phi^i$.

INPUT:

- `f` – a polynomial in the domain of this valuation

OUTPUT:

A list, each entry a rational numbers or infinity, the valuations of $f_0, f_1\phi, \ldots$

EXAMPLES:

```
sage: R = Qp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S, R.valuation())
sage: f = x^2 + 2*x + 16
sage: list(v.valuations(f))
[4, 1, 0]
```

5.7 Inductive valuations on polynomial rings

This module provides functionality for inductive valuations, i.e., finite chains of *augmented valuations* on top of a *Gauss valuation*.

AUTHORS:

- Julian Rüth (2016-11-01): initial version

EXAMPLES:

A *Gauss valuation* is an example of an inductive valuation:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
```

Generally, an inductive valuation is an augmentation of an inductive valuation, i.e., a valuation that was created from a Gauss valuation in a finite number of augmentation steps:

```
sage: w = v.augmentation(x, 1)
sage: w = w.augmentation(x^2 + 2*x + 4, 3)
```

REFERENCES:

Inductive valuations are originally discussed in [Mac1936I] and [Mac1936II]. An introduction is also given in Chapter 4 of [Rüt2014].

class sage.rings.valuation.inductive_valuation.**FinalInductiveValuation**(*parent*, *phi*)

Bases: *sage.rings.valuation.inductive_valuation.InductiveValuation*

Abstract base class for an inductive valuation which cannot be augmented further.

class sage.rings.valuation.inductive_valuation.**FiniteInductiveValuation**(*parent*, *phi*)

Bases: *sage.rings.valuation.inductive_valuation.InductiveValuation*, *sage.rings.valuation.valuation.DiscreteValuation*

Abstract base class for iterated *augmented valuations* on top of a *Gauss valuation* which is a discrete valuation, i.e., the last key polynomial has finite valuation.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
```

extensions(*other*)

Return the extensions of this valuation to `other`.

EXAMPLES:

```
sage: R.<x> = ZZ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(ZZ))
sage: K.<x> = FunctionField(QQ)
sage: v.extensions(K)
[Trivial valuation on Rational Field]
```

class sage.rings.valuation.inductive_valuation.**InductiveValuation**(*parent*, *phi*)

Bases: *sage.rings.valuation.developing_valuation.DevelopingValuation*

Abstract base class for iterated *augmented valuations* on top of a *Gauss valuation*.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(5))
```

E()

Return the ramification index of this valuation over its underlying Gauss valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.E()
1
```

F()

Return the residual degree of this valuation over its Gauss extension.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.F()
1
```

augmentation_chain()

Return a list with the chain of augmentations down to the underlying *Gauss valuation*.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.augmentation_chain()
[Gauss valuation induced by 2-adic valuation]
```

element_with_valuation(*s*)

Return a polynomial of minimal degree with valuation `s`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: v.element_with_valuation(-2)
1/4
```

Depending on the base ring, an element of valuation `s` might not exist:

```
sage: R.<x> = ZZ[]
sage: v = GaussValuation(R, ZZ.valuation(2))
sage: v.element_with_valuation(-2)
Traceback (most recent call last):
...
ValueError: s must be in the value semigroup of this valuation but -2 is not in␣
↪Additive Abelian Semigroup generated by 1
```

equivalence_reciprocal(*f*, *coefficients=None*, *valuations=None*, *check=True*)

Return an equivalence reciprocal of `f`.

An equivalence reciprocal of f is a polynomial h such that $f \cdot h$ is equivalent to 1 modulo this valuation (see [Mac1936II] p.497.)

INPUT:

- `f` – a polynomial in the domain of this valuation which is an *equivalence_unit()*

- `coefficients` – the coefficients of `f` in the *phi()*-adic expansion if known (default: `None`)
- `valuations` – the valuations of `coefficients` if known (default: `None`)
- `check` – whether or not to check the validity of `f` (default: `True`)

Warning: This method may not work over p-adic rings due to problems with the xgcd implementation there.

EXAMPLES:

```
sage: R = Zp(3,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: f = 3*x + 2
sage: h = v.equivalence_reciprocal(f); h
2 + O(3^5)
sage: v.is_equivalent(f*h, 1)
True
```

In an extended valuation over an extension field:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v = v.augmentation(x^2 + x + u, 1)
sage: f = 2*x + u
sage: h = v.equivalence_reciprocal(f); h
(u + 1) + O(2^5)
sage: v.is_equivalent(f*h, 1)
True
```

Extending the valuation once more:

```
sage: v = v.augmentation((x^2 + x + u)^2 + 2*x*(x^2 + x + u) + 4*x, 3)
sage: h = v.equivalence_reciprocal(f); h
(u + 1) + O(2^5)
sage: v.is_equivalent(f*h, 1)
True
```

equivalence_unit(*s*, *reciprocal=False*)

Return an equivalence unit of valuation `s`.

INPUT:

- `s` – an element of the *value_group()*
- `reciprocal` – a boolean (default: `False`); whether or not to return the equivalence unit as the *equivalence_reciprocal()* of the equivalence unit of valuation `-s`.

EXAMPLES:

```
sage: S.<x> = Qp(3,5)[]
sage: v = GaussValuation(S)
sage: v.equivalence_unit(2)
3^2 + O(3^7)
```

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```
sage: v.equivalence_unit(-2)
3^-2 + O(3^3)
```

Note that this might fail for negative `s` if the domain is not defined over a field:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: w = GaussValuation(R, v)
sage: w.equivalence_unit(1)
2
sage: w.equivalence_unit(-1)
Traceback (most recent call last):
...
ValueError: s must be in the value semigroup of this valuation but -1 is not in␣
↪Additive Abelian Semigroup generated by 1
```

is_equivalence_unit(*f*, *valuations=None*)

Return whether the polynomial `f` is an equivalence unit, i.e., an element of *effective_degree()* zero (see [Mac1936II] p.497.)

INPUT:

- `f` – a polynomial in the domain of this valuation

EXAMPLES:

```
sage: R = Zp(2,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_equivalence_unit(x)
False
sage: v.is_equivalence_unit(S.zero())
False
sage: v.is_equivalence_unit(2*x + 1)
True
```

is_gauss_valuation()

Return whether this valuation is a Gauss valuation over the domain.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_gauss_valuation()
True
```

monic_integral_model(*G*)

Return a monic integral irreducible polynomial which defines the same extension of the base ring of the domain as the irreducible polynomial `G` together with maps between the old and the new polynomial.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
```

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```
sage: v.monic_integral_model(5*x^2 + 1/2*x + 1/4)
(Ring endomorphism of Univariate Polynomial Ring in x over Rational Field
   Defn: x |--> 1/2*x,
 Ring endomorphism of Univariate Polynomial Ring in x over Rational Field
   Defn: x |--> 2*x,
x^2 + 1/5*x + 1/5)
```

mu()

Return the valuation of *phi()*.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: v.mu()
0
```

class sage.rings.valuation.inductive_valuation.**InfiniteInductiveValuation**(*parent*, *base_valuation*)

Bases: *sage.rings.valuation.inductive_valuation.FinalInductiveValuation*, *sage.rings.valuation.valuation.InfiniteDiscretePseudoValuation*

Abstract base class for an inductive valuation which is not discrete, i.e., which assigns infinite valuation to its last key polynomial.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, infinity)
```

change_domain(*ring*)

Return this valuation over `ring`.

EXAMPLES:

We can turn an infinite valuation into a valuation on the quotient:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, infinity)
sage: w.change_domain(R.quo(x^2 + x + 1))
2-adic valuation
```

class sage.rings.valuation.inductive_valuation.**NonFinalInductiveValuation**(*parent*, *phi*)

Bases: *sage.rings.valuation.inductive_valuation.FiniteInductiveValuation*, *sage.rings.valuation.valuation.DiscreteValuation*

Abstract base class for iterated *augmented valuations* on top of a *Gauss valuation* which can be extended further through *augmentation()*.

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v = v.augmentation(x^2 + x + u, 1)
```

augmentation(*phi*, *mu*, *check=True*)

Return the inductive valuation which extends this valuation by mapping `phi` to `mu`.

INPUT:

- `phi` – a polynomial in the domain of this valuation; this must be a key polynomial, see *is_key()* for properties of key polynomials.
- `mu` – a rational number or infinity, the valuation of `phi` in the extended valuation
- `check` – a boolean (default: `True`), whether or not to check the correctness of the parameters

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v = v.augmentation(x^2 + x + u, 1)
sage: v = v.augmentation((x^2 + x + u)^2 + 2*x*(x^2 + x + u) + 4*x, 3)
sage: v
[ Gauss valuation induced by 2-adic valuation,
  v((1 + O(2^5))*x^2 + (1 + O(2^5))*x + u + O(2^5)) = 1,
  v((1 + O(2^5))*x^4 + (2^2 + O(2^6))*x^3 + (1 + (u + 1)*2 + O(2^5))*x^2 + ((u␣
↪+ 1)*2^2 + O(2^6))*x + (u + 1) + (u + 1)*2 + (u + 1)*2^2 + (u + 1)*2^3 + (u +␣
↪1)*2^4 + O(2^5)) = 3 ]
```

See also:

augmented_valuation

equivalence_decomposition(*f*, *assume_not_equivalence_unit=False*, *coefficients=None*, *valuations=None*, *compute_unit=True*, *degree_bound=None*)

Return an equivalence decomposition of `f`, i.e., a polynomial $g(x) = e(x)\prod_i \phi_i(x)$ with $e(x)$ an *equivalence unit* and the ϕ_i *key polynomials* such that `f` *is_equivalent()* to g.

INPUT:

- `f` – a non-zero polynomial in the domain of this valuation
- `assume_not_equivalence_unit` – whether or not to assume that `f` is not an *equivalence unit* (default: `False`)
- `coefficients` – the coefficients of `f` in the *phi()*-adic expansion if known (default: `None`)
- `valuations` – the valuations of `coefficients` if known (default: `None`)
- `compute_unit` – whether or not to compute the unit part of the decomposition (default: `True`)
- `degree_bound` – a bound on the degree of the `_equivalence_reduction()` of `f` (default: `None`)

ALGORITHM:

We use the algorithm described in Theorem 4.4 of [Mac1936II]. After removing all factors ϕ from a polynomial f, there is an equivalence unit R such that Rf has valuation zero. Now Rf can be factored as $\prod_i \alpha_i$ over the *residue_field()*. Lifting all α_i to key polynomials ϕ_i gives $Rf = \prod_i R_i f_i$ for suitable equivalence units R_i (see *lift_to_key()*). Taking R' an *equivalence_reciprocal()* of R, we have f equivalent to $(R' \prod_i R_i) \prod_i \phi_i$.

EXAMPLES:

```
sage: R.<u> = Qq(4,10)
sage: S.<x> = R[]
```

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```
sage: v = GaussValuation(S)
sage: v.equivalence_decomposition(S.zero())
Traceback (most recent call last):
...
ValueError: equivalence decomposition of zero is not defined
sage: v.equivalence_decomposition(S.one())
1 + O(2^10)
sage: v.equivalence_decomposition(x^2+2)
((1 + O(2^10))*x)^2
sage: v.equivalence_decomposition(x^2+1)
((1 + O(2^10))*x + 1 + O(2^10))^2
```

A polynomial that is an equivalence unit, is returned as the unit part of a `Factorization`, leading to a unit non-minimal degree:

```
sage: w = v.augmentation(x, 1)
sage: F = w.equivalence_decomposition(x^2+1); F
(1 + O(2^10))*x^2 + 1 + O(2^10)
sage: F.unit()
(1 + O(2^10))*x^2 + 1 + O(2^10)
```

However, if the polynomial has a non-unit factor, then the unit might be replaced by a factor of lower degree:

```
sage: f = x * (x^2 + 1)
sage: F = w.equivalence_decomposition(f); F
(1 + O(2^10))*x
sage: F.unit()
1 + O(2^10)
```

Examples over an iterated unramified extension:

```
sage: v = v.augmentation(x^2 + x + u, 1)
sage: v = v.augmentation((x^2 + x + u)^2 + 2*x*(x^2 + x + u) + 4*x, 3)

sage: v.equivalence_decomposition(x)
(1 + O(2^10))*x
sage: F = v.equivalence_decomposition( v.phi() )
sage: len(F)
1
sage: F = v.equivalence_decomposition( v.phi() * (x^4 + 4*x^3 + (7 + 2*u)*x^2 +␣
↪(8 + 4*u)*x + 1023 + 3*u) )
sage: len(F)
2
```

is_equivalence_irreducible(*f*, *coefficients=None*, *valuations=None*)

Return whether the polynomial `f` is equivalence-irreducible, i.e., whether its *equivalence_decomposition()* is trivial.

ALGORITHM:

We use the same algorithm as in *equivalence_decomposition()* we just do not lift the result to key polynomials.

INPUT:

- `f` – a non-constant polynomial in the domain of this valuation

EXAMPLES:

```
sage: R.<u> = Qq(4,5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_equivalence_irreducible(x)
True
sage: v.is_equivalence_irreducible(x^2)
False
sage: v.is_equivalence_irreducible(x^2 + 2)
False
```

is_key(*phi*, *explain=False*, *assume_equivalence_irreducible=False*)

Return whether `phi` is a key polynomial for this valuation, i.e., whether it is monic, whether it *is_equivalence_irreducible()*, and whether it is *is_minimal()*.

INPUT:

- `phi` – a polynomial in the domain of this valuation
- `explain` – a boolean (default: `False`), if `True`, return a string explaining why `phi` is not a key polynomial

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_key(x)
True
sage: v.is_key(2*x, explain = True)
(False, 'phi must be monic')
sage: v.is_key(x^2, explain = True)
(False, 'phi must be equivalence irreducible')

sage: w = v.augmentation(x, 1)
sage: w.is_key(x + 1, explain = True)
(False, 'phi must be minimal')
```

is_minimal(*f*, *assume_equivalence_irreducible=False*)

Return whether the polynomial `f` is minimal with respect to this valuation.

A polynomial f is minimal with respect to v if it is not a constant and any non-zero polynomial h which is v-divisible by f has at least the degree of f.

A polynomial h is v-divisible by f if there is a polynomial c such that fc *is_equivalent()* to h.

ALGORITHM:

Based on Theorem 9.4 of [Mac1936II].

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.is_minimal(x + 1)
```

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```
True
sage: w = v.augmentation(x, 1)
sage: w.is_minimal(x + 1)
False
```

lift_to_key(*F*)

Lift the irreducible polynomial `F` from the *residue_ring()* to a key polynomial over this valuation.

INPUT:

- `F` – an irreducible non-constant monic polynomial in *residue_ring()* of this valuation

OUTPUT:

A polynomial f in the domain of this valuation which is a key polynomial for this valuation and which is such that an *augmentation()* with this polynomial adjoins a root of `F` to the resulting *residue_ring()*.

More specifically, if `F` is not the generator of the residue ring, then multiplying `f` with the *equivalence_reciprocal()* of the *equivalence_unit()* of the valuation of `f`, produces a unit which reduces to `F`.

EXAMPLES:

```
sage: R.<u> = Qq(4,10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: y = v.residue_ring().gen()
sage: u0 = v.residue_ring().base_ring().gen()
sage: f = v.lift_to_key(y^2 + y + u0); f
(1 + O(2^10))*x^2 + (1 + O(2^10))*x + u + O(2^10)
```

mac_lane_step(*G*, *principal_part_bound=None*, *assume_squarefree=False*, *assume_equivalence_irreducible=False*, *report_degree_bounds_and_caches=False*, *coefficients=None*, *valuations=None*, *check=True*, *allow_equivalent_key=True*)

Perform an approximation step towards the squarefree monic non-constant integral polynomial `G` which is not an *equivalence unit*.

This performs the individual steps that are used in *mac_lane_approximants()*.

INPUT:

- `G` – a squarefree monic non-constant integral polynomial `G` which is not an *equivalence unit*
- `principal_part_bound` – an integer or `None` (default: `None`), a bound on the length of the principal part, i.e., the section of negative slope, of the Newton polygon of `G`
- `assume_squarefree` – whether or not to assume that `G` is squarefree (default: `False`)
- `assume_equivalence_irreducible` – whether or not to assume that `G` is equivalence irreducible (default: `False`)
- `report_degree_bounds_and_caches` – whether or not to include internal state with the returned value (used by *mac_lane_approximants()* to speed up sequential calls)
- `coefficients` – the coefficients of `G` in the *phi()*-adic expansion if known (default: `None`)
- `valuations` – the valuations of `coefficients` if known (default: `None`)
- `check` – whether to check that `G` is a squarefree monic non-constant integral polynomial and not an *equivalence unit* (default: `True`)

- `allow_equivalent_key` – whether to return valuations which end in essentially the same key polynomial as this valuation but have a higher valuation assigned to that key polynomial (default: `True`)

EXAMPLES:

We can use this method to perform the individual steps of *mac_lane_approximants()*:

```
sage: R.<x> = QQ[]
sage: v = QQ.valuation(2)
sage: f = x^36 + 1160/81*x^31 + 9920/27*x^30 + 1040/81*x^26 + 52480/81*x^25 +␣
↪220160/81*x^24 - 5120/81*x^21 - 143360/81*x^20 - 573440/81*x^19 + 12451840/
↪81*x^18 - 266240/567*x^16 - 20316160/567*x^15 - 198737920/189*x^14 -␣
↪1129840640/81*x^13 - 1907359744/27*x^12 + 8192/81*x^11 + 655360/81*x^10 +␣
↪5242880/21*x^9 + 2118123520/567*x^8 + 15460204544/567*x^7 + 6509559808/81*x^6␣
↪- 16777216/567*x^2 - 268435456/567*x - 1073741824/567
sage: v.mac_lane_approximants(f)
[[ Gauss valuation induced by 2-adic valuation, v(x + 2056) = 23/2 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 11/9 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 2/5, v(x^5 + 4) = 7/2 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^10 + 8*x^5 +␣
↪64) = 7 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^5 + 8) = 5 ]]
```

Starting from the Gauss valuation, a MacLane step branches off with some linear key polynomials in the above example:

```
sage: v0 = GaussValuation(R, v)
sage: V1 = sorted(v0.mac_lane_step(f)); V1
[[ Gauss valuation induced by 2-adic valuation, v(x) = 2/5 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3/5 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 11/9 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3 ]]
```

The computation of MacLane approximants would now perform a MacLane step on each of these branches, note however, that a direct call to this method might produce some unexpected results:

```
sage: V1[1].mac_lane_step(f)
[[ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^5 + 8) = 5 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^10 + 8*x^5 +␣
↪64) = 7 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 11/9 ]]
```

Note how this detected the two augmentations of `V1[1]` but also two other valuations that we had seen in the previous step and that are greater than `V1[1]`. To ignore such trivial augmentations, we can set `allow_equivalent_key`:

```
sage: V1[1].mac_lane_step(f, allow_equivalent_key=False)
[[ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^5 + 8) = 5 ],
 [ Gauss valuation induced by 2-adic valuation, v(x) = 3/5, v(x^10 + 8*x^5 +␣
↪64) = 7 ]]
```

minimal_representative(f)

Return a minimal representative for `f`, i.e., a pair e, a such that `f` *is_equivalent()* to ea, e is an *equivalence unit*, and a *is_minimal()* and monic.

INPUT:

- `f` – a non-zero polynomial which is not an equivalence unit

OUTPUT:

A factorization which has e as its unit and a as its unique factor.

ALGORITHM:

We use the algorithm described in the proof of Lemma 4.1 of [Mac1936II]. In the expansion $f = \sum_i f_i\phi^i$ take $e = f_i$ for the largest i with $f_i\phi^i$ minimal (see *effective_degree()*). Let h be the *equivalence_reciprocal()* of e and take a given by the terms of minimal valuation in the expansion of ef.

EXAMPLES:

```
sage: R.<u> = Qq(4,10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.minimal_representative(x + 2)
(1 + O(2^10))*x

sage: v = v.augmentation(x, 1)
sage: v.minimal_representative(x + 2)
(1 + O(2^10))*x + 2 + O(2^11)
sage: f = x^3 + 6*x + 4
sage: F = v.minimal_representative(f); F
(2 + 2^2 + O(2^11)) * ((1 + O(2^10))*x + 2 + O(2^11))
sage: v.is_minimal(F[0][0])
True
sage: v.is_equivalent(F.prod(), f)
True
```

5.8 Augmented valuations on polynomial rings

Implements augmentations of (inductive) valuations.

AUTHORS:

- Julian Rüth (2013-04-15): initial version

EXAMPLES:

Starting from a *Gauss valuation*, we can create augmented valuations on polynomial rings:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x, 1); w
[ Gauss valuation induced by 2-adic valuation, v(x) = 1 ]
sage: w(x)
1
```

This also works for polynomial rings over base rings which are not fields. However, much of the functionality is only available over fields:

```
sage: R.<x> = ZZ[]
sage: v = GaussValuation(R, ZZ.valuation(2))
sage: w = v.augmentation(x, 1); w
[ Gauss valuation induced by 2-adic valuation, v(x) = 1 ]
sage: w(x)
1
```

REFERENCES:

Augmentations are described originally in [Mac1936I] and [Mac1936II]. An overview can also be found in Chapter 4 of [Rüt2014].

class sage.rings.valuation.augmented_valuation.**AugmentedValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Factory for augmented valuations.

EXAMPLES:

This factory is not meant to be called directly. Instead, *augmentation()* of a valuation should be called:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x, 1) # indirect doctest
```

Note that trivial parts of the augmented valuation might be dropped, so you should not rely on `_base_valuation` to be the valuation you started with:

```
sage: ww = w.augmentation(x, 2)
sage: ww._base_valuation is v
True
```

create_key(*base_valuation*, *phi*, *mu*, *check=True*)

Create a key which uniquely identifies the valuation over `base_valuation` which sends `phi` to `mu`.

Note: The uniqueness that this factory provides is not why we chose to use a factory. However, it makes pickling and equality checks much easier. At the same time, going through a factory makes it easier to enforce that all instances correctly inherit methods from the parent Hom space.

---

create_object(*version*, *key*)

Create the augmented valuation represented by `key`.

class sage.rings.valuation.augmented_valuation.**AugmentedValuation_base**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.inductive_valuation.InductiveValuation*

An augmented valuation is a discrete valuation on a polynomial ring. It extends another discrete valuation v by setting the valuation of a polynomial f to the minimum of $v(f_i)i\mu$ when writing $f = \sum_i f_i\phi^i$.

INPUT:

- `v` – a *InductiveValuation* on a polynomial ring
- `phi` – a *key polynomial* over `v`
- `mu` – a rational number such that `mu > v(phi)` or `infinity`

EXAMPLES:

```
sage: K.<u> = CyclotomicField(5)
sage: R.<x> = K[]
sage: v = GaussValuation(R, K.valuation(2))
sage: w = v.augmentation(x, 1/2); w # indirect doctest
[ Gauss valuation induced by 2-adic valuation, v(x) = 1/2 ]
sage: ww = w.augmentation(x^4 + 2*x^2 + 4*u, 3); ww
[ Gauss valuation induced by 2-adic valuation, v(x) = 1/2, v(x^4 + 2*x^2 + 4*u) = 3␣
↪]
```

E()

Return the ramification index of this valuation over its underlying Gauss valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1)
sage: w.E()
1

sage: w = v.augmentation(x, 1/2)
sage: w.E()
2
```

F()

Return the degree of the residue field extension of this valuation over the underlying Gauss valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1)
sage: w.F()
2

sage: w = v.augmentation(x, 1/2)
sage: w.F()
1
```

augmentation_chain()

Return a list with the chain of augmentations down to the underlying *Gauss valuation*.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x, 1)
sage: w.augmentation_chain()
[[ Gauss valuation induced by 2-adic valuation, v(x) = 1 ],
     Gauss valuation induced by 2-adic valuation]
```

For performance reasons, (and to simplify the underlying implementation,) trivial augmentations might get dropped. You should not rely on *augmentation_chain()* to contain all the steps that you specified to create the current valuation:

```
sage: ww = w.augmentation(x, 2)
sage: ww.augmentation_chain()
[[ Gauss valuation induced by 2-adic valuation, v(x) = 2 ],
     Gauss valuation induced by 2-adic valuation]
```

change_domain(*ring*)

Return this valuation over `ring`.

EXAMPLES:

We can change the domain of an augmented valuation even if there is no coercion between rings:

```
sage: R.<x> = GaussianIntegers()[]
sage: v = GaussValuation(R, GaussianIntegers().valuation(2))
sage: v = v.augmentation(x, 1)
sage: v.change_domain(QQ['x'])
[ Gauss valuation induced by 2-adic valuation, v(x) = 1 ]
```

element_with_valuation(*s*)

Create an element of minimal degree and of valuation `s`.

INPUT:

- `s` – a rational number in the value group of this valuation

OUTPUT:

An element in the domain of this valuation

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.element_with_valuation(0)
1 + O(2^5)
sage: w.element_with_valuation(1/2)
(1 + O(2^5))*x^2 + (1 + O(2^5))*x + u + O(2^5)
sage: w.element_with_valuation(1)
2 + O(2^6)
sage: c = w.element_with_valuation(-1/2); c
(2^-1 + O(2^4))*x^2 + (2^-1 + O(2^4))*x + u*2^-1 + O(2^4)
sage: w(c)
-1/2
sage: w.element_with_valuation(1/3)
Traceback (most recent call last):
...
ValueError: s must be in the value group of the valuation but 1/3 is not in␣
↪Additive Abelian Group generated by 1/2.
```

equivalence_unit(*s*, *reciprocal=False*)

Return an equivalence unit of minimal degree and valuation `s`.

INPUT:

- `s` – a rational number
- `reciprocal` – a boolean (default: `False`); whether or not to return the equivalence unit as the *equivalence_reciprocal()* of the equivalence unit of valuation `-s`.

OUTPUT:

A polynomial in the domain of this valuation which *is_equivalence_unit()* for this valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1)

sage: w.equivalence_unit(0)
1 + O(2^5)
sage: w.equivalence_unit(-4)
2^-4 + O(2)
```

Since an equivalence unit is of effective degree zero, ϕ must not divide it. Therefore, its valuation is in the value group of the base valuation:

```
sage: w = v.augmentation(x, 1/2)

sage: w.equivalence_unit(3/2)
Traceback (most recent call last):
...
ValueError: 3/2 is not in the value semigroup of 2-adic valuation
sage: w.equivalence_unit(1)
2 + O(2^6)
```

An equivalence unit might not be integral, even if `s >= 0`:

```
sage: w = v.augmentation(x, 3/4)
sage: ww = w.augmentation(x^4 + 8, 5)

sage: ww.equivalence_unit(1/2)
(2^-1 + O(2^4))*x^2
```

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)

sage: w.extensions(GaussianIntegers().fraction_field()['x'])
[[ Gauss valuation induced by 2-adic valuation, v(x^2 + x + 1) = 1 ]]
```

is_gauss_valuation()

Return whether this valuation is a Gauss valuation.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)

sage: w.is_gauss_valuation()
False
```

is_negative_pseudo_valuation()

Return whether this valuation attains $-\infty$.

EXAMPLES:

No element in the domain of an augmented valuation can have valuation $-\infty$, so this method always returns `False`:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
sage: w = v.augmentation(x, infinity)
sage: w.is_negative_pseudo_valuation()
False
```

is_trivial()

Return whether this valuation is trivial, i.e., zero outside of zero.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)
sage: w.is_trivial()
False
```

monic_integral_model(*G*)

Return a monic integral irreducible polynomial which defines the same extension of the base ring of the domain as the irreducible polynomial `G` together with maps between the old and the new polynomial.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)

sage: w.monic_integral_model(5*x^2 + 1/2*x + 1/4)
(Ring endomorphism of Univariate Polynomial Ring in x over Rational Field
   Defn: x |--> 1/2*x,
 Ring endomorphism of Univariate Polynomial Ring in x over Rational Field
   Defn: x |--> 2*x,
x^2 + 1/5*x + 1/5)
```

psi()

Return the minimal polynomial of the residue field extension of this valuation.

OUTPUT:

A polynomial in the residue ring of the base valuation

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.psi()
x^2 + x + u0

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: ww.psi()
x + 1
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K = GaussianIntegers().fraction_field()
sage: R.<x> = K[]
sage: v = GaussValuation(R, K.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)

sage: w.restriction(QQ['x'])
[ Gauss valuation induced by 2-adic valuation, v(x^2 + x + 1) = 1 ]
```

scale(*scalar*)

Return this valuation scaled by `scalar`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)
sage: 3*w # indirect doctest
[ Gauss valuation induced by 3 * 2-adic valuation, v(x^2 + x + 1) = 3 ]
```

uniformizer()

Return a uniformizing element for this valuation.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)

sage: w.uniformizer()
2
```

class sage.rings.valuation.augmented_valuation.**FinalAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.AugmentedValuation_base*, *sage.rings.valuation.inductive_valuation.FinalInductiveValuation*

An augmented valuation which can not be augmented anymore, either because it augments a trivial valuation or because it is infinite.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
sage: w = v.augmentation(x, 1)
```

lift(*F*)

Return a polynomial which reduces to `F`.

INPUT:

- `F` – an element of the *residue_ring()*

ALGORITHM:

We simply undo the steps performed in *reduce()*.

OUTPUT:

A polynomial in the domain of the valuation with reduction `F`

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))

sage: w = v.augmentation(x, 1)
sage: w.lift(1/2)
1/2

sage: w = v.augmentation(x^2 + x + 1, infinity)
sage: w.lift(w.residue_ring().gen())
x
```

A case with non-trivial base valuation:

```
sage: R.<u> = Qq(4, 10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, infinity)
sage: w.lift(w.residue_ring().gen())
(1 + O(2^10))*x
```

reduce(*f*, *check=True*, *degree_bound=None*, *coefficients=None*, *valuations=None*)

Reduce `f` module this valuation.

INPUT:

- `f` – an element in the domain of this valuation
- `check` – whether or not to check whether `f` has non-negative valuation (default: `True`)
- `degree_bound` – an a-priori known bound on the degree of the result which can speed up the computation (default: not set)
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); this can be used to speed up the computation when the expansion of `f` is already known from a previous computation.
- `valuations` – the valuations of `coefficients` or `None` (default: `None`); ignored

OUTPUT:

an element of the *residue_ring()* of this valuation, the reduction modulo the ideal of elements of positive valuation

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))

sage: w = v.augmentation(x, 1)
sage: w.reduce(x^2 + x + 1)
1

sage: w = v.augmentation(x^2 + x + 1, infinity)
sage: w.reduce(x)
u1
```

residue_ring()

Return the residue ring of this valuation, i.e., the elements of non-negative valuation modulo the elements of positive valuation.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))

sage: w = v.augmentation(x, 1)
sage: w.residue_ring()
Rational Field

sage: w = v.augmentation(x^2 + x + 1, infinity)
sage: w.residue_ring()
Number Field in u1 with defining polynomial x^2 + x + 1
```

An example with a non-trivial base valuation:

```
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, infinity)
sage: w.residue_ring()
Finite Field in u1 of size 2^2
```

Since trivial extensions of finite fields are not implemented, the resulting ring might be identical to the residue ring of the underlying valuation:

```
sage: w = v.augmentation(x, infinity)
sage: w.residue_ring()
Finite Field of size 2
```

class sage.rings.valuation.augmented_valuation.**FinalFiniteAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.FiniteAugmentedValuation*, *sage.rings.valuation.augmented_valuation.FinalAugmentedValuation*

An augmented valuation which is discrete, i.e., which assigns a finite valuation to its last key polynomial, but which can not be further augmented.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, valuations.TrivialValuation(QQ))
sage: w = v.augmentation(x, 1)
```

class sage.rings.valuation.augmented_valuation.**FiniteAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.AugmentedValuation_base*, *sage.rings.valuation.inductive_valuation.FiniteInductiveValuation*

A finite augmented valuation, i.e., an augmented valuation which is discrete, or equivalently an augmented valuation which assigns to its last key polynomial a finite valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1/2)
```

lower_bound(*f*)

Return a lower bound of this valuation at `f`.

Use this method to get an approximation of the valuation of `f` when speed is more important than accuracy.

ALGORITHM:

The main cost of evaluation is the computation of the *coefficients()* of the *phi()*-adic expansion of `f` (which often leads to coefficient bloat.) So unless *phi()* is trivial, we fall back to valuation which this valuation augments since it is guaranteed to be smaller everywhere.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.lower_bound(x^2 + x + u)
0
```

simplify(*f*, *error=None*, *force=False*, *effective_degree=None*, *size_heuristic_bound=32*, *phiadic=False*)

Return a simplified version of `f`.

Produce an element which differs from `f` by an element of valuation strictly greater than the valuation of `f` (or strictly greater than `error` if set.)

INPUT:

- `f` – an element in the domain of this valuation
- `error` – a rational, infinity, or `None` (default: `None`), the error allowed to introduce through the simplification
- `force` – whether or not to simplify `f` even if there is heuristically no change in the coefficient size of `f` expected (default: `False`)
- `effective_degree` – when set, assume that coefficients beyond `effective_degree` in the *phi()*-adic development can be safely dropped (default: `None`)
- `size_heuristic_bound` – when `force` is not set, the expected factor by which the coefficients need to shrink to perform an actual simplification (default: 32)

- `phiadic` – whether to simplify the coefficients in the ϕ-adic expansion recursively. This often times leads to huge coefficients in the x-adic expansion (default: `False`, i.e., use an x-adic expansion.)

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.simplify(x^10/2 + 1, force=True)
(u + 1)*2^-1 + O(2^4)
```

Check that trac ticket #25607 has been resolved, i.e., the coefficients in the following example are small::`

sage: R.<x> = QQ[] sage: K.<a> = NumberField(x^3 + 6) sage: R.<x> = K[] sage: v = GaussValuation(R, K.valuation(2)) sage: v = v.augmentation(x, 3/2) sage: v = v.augmentation(x^2 + 8, 13/4) sage: v = v.augmentation(x^4 + 16*x^2 + 32*x + 64, 20/3) sage: F.<x> = FunctionField(K) sage: S.<y> = F[] sage: v = F.valuation(v) sage: G = y^2 - 2*x^5 + 8*x^3 + 80*x^2 + 128*x + 192 sage: v.mac_lane_approximants(G) [[Gauss valuation induced by Valuation on rational function field induced by [Gauss valuation induced by 2-adic valuation, v(x) = 3/2, v(x^2 + 8) = 13/4, v(x^4 + 16*x^2 + 32*x + 64) = 20/3], v(y + 4*x + 8) = 31/8]]

upper_bound(*f*)

Return an upper bound of this valuation at `f`.

Use this method to get an approximation of the valuation of `f` when speed is more important than accuracy.

ALGORITHM:

Any entry of *valuations()* serves as an upper bound. However, computation of the *phi()*-adic expansion of `f` is quite costly. Therefore, we produce an upper bound on the last entry of *valuations()*, namely the valuation of the leading coefficient of `f` plus the valuation of the appropriate power of *phi()*.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.upper_bound(x^2 + x + u)
1/2
```

valuations(*f*, *coefficients=None*, *call_error=False*)

Return the valuations of the $f_i\phi^i$ in the expansion $f = \sum_i f_i\phi^i$.

INPUT:

- `f` – a polynomial in the domain of this valuation
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); this can be used to speed up the computation when the expansion of `f` is already known from a previous computation.
- `call_error` – whether or not to speed up the computation by assuming that the result is only used to compute the valuation of `f` (default: `False`)

OUTPUT:

An iterator over rational numbers (or infinity) $[v(f_0), v(f_1\phi), \dots]$

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: list(w.valuations( x^2 + 1 ))
[0, 1/2]

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: list(ww.valuations( ((x^2 + x + u)^2 + 2)^3 ))
[+Infinity, +Infinity, +Infinity, 5]
```

value_group()

Return the value group of this valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.value_group()
Additive Abelian Group generated by 1/2

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: ww.value_group()
Additive Abelian Group generated by 1/6
```

value_semigroup()

Return the value semigroup of this valuation.

EXAMPLES:

```
sage: R.<u> = Zq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.value_semigroup()
Additive Abelian Semigroup generated by 1/2

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: ww.value_semigroup()
Additive Abelian Semigroup generated by 1/2, 5/3
```

class sage.rings.valuation.augmented_valuation.**InfiniteAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.FinalAugmentedValuation*, *sage.rings.valuation.inductive_valuation.InfiniteInductiveValuation*

An augmented valuation which is infinite, i.e., which assigns valuation infinity to its last key polynomial (and which can therefore not be augmented further.)

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x, infinity)
```

lower_bound(*f*)

Return a lower bound of this valuation at `f`.

Use this method to get an approximation of the valuation of `f` when speed is more important than accuracy.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, infinity)
sage: w.lower_bound(x^2 + x + u)
+Infinity
```

simplify(*f*, *error=None*, *force=False*, *effective_degree=None*)

Return a simplified version of `f`.

Produce an element which differs from `f` by an element of valuation strictly greater than the valuation of `f` (or strictly greater than `error` if set.)

INPUT:

- `f` – an element in the domain of this valuation
- `error` – a rational, infinity, or `None` (default: `None`), the error allowed to introduce through the simplification
- `force` – whether or not to simplify `f` even if there is heuristically no change in the coefficient size of `f` expected (default: `False`)
- `effective_degree` – ignored; for compatibility with other `simplify` methods

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, infinity)
sage: w.simplify(x^10/2 + 1, force=True)
(u + 1)*2^-1 + O(2^4)
```

upper_bound(*f*)

Return an upper bound of this valuation at `f`.

Use this method to get an approximation of the valuation of `f` when speed is more important than accuracy.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, infinity)
sage: w.upper_bound(x^2 + x + u)
+Infinity
```

valuations(*f*, *coefficients=None*, *call_error=False*)

Return the valuations of the $f_i\phi^i$ in the expansion $f = \sum_i f_i\phi^i$.

INPUT:

- `f` – a polynomial in the domain of this valuation
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); this can be used to speed up the computation when the expansion of `f` is already known from a previous computation.
- `call_error` – whether or not to speed up the computation by assuming that the result is only used to compute the valuation of `f` (default: `False`)

OUTPUT:

An iterator over rational numbers (or infinity) $[v(f_0), v(f_1\phi), \dots]$

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x, infinity)
sage: list(w.valuations(x^2 + 1))
[0, +Infinity, +Infinity]
```

value_group()

Return the value group of this valuation.

EXAMPLES:

```
sage: R.<u> = Qq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x, infinity)
sage: w.value_group()
Additive Abelian Group generated by 1
```

value_semigroup()

Return the value semigroup of this valuation.

EXAMPLES:

```
sage: R.<u> = Zq(4, 5)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: w = v.augmentation(x, infinity)
sage: w.value_semigroup()
Additive Abelian Semigroup generated by 1
```

class sage.rings.valuation.augmented_valuation.**NonFinalAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.AugmentedValuation_base*, *sage.rings.valuation.inductive_valuation.NonFinalInductiveValuation*

An augmented valuation which can be augmented further.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x^2 + x + 1, 1)
```

lift(*F*, *report_coefficients=False*)

Return a polynomial which reduces to `F`.

INPUT:

- `F` – an element of the *residue_ring()*
- `report_coefficients` – whether to return the coefficients of the *phi()*-adic expansion or the actual polynomial (default: `False`, i.e., return the polynomial)

OUTPUT:

A polynomial in the domain of the valuation with reduction `F`, monic if `F` is monic.

ALGORITHM:

Since this is the inverse of *reduce()*, we only have to go backwards through the algorithm described there.

EXAMPLES:

```
sage: R.<u> = Qq(4, 10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: y = w.residue_ring().gen()
sage: u1 = w.residue_ring().base().gen()

sage: w.lift(1)
1 + O(2^10)
sage: w.lift(0)
0
sage: w.lift(u1)
(1 + O(2^10))*x
sage: w.reduce(w.lift(y)) == y
True
sage: w.reduce(w.lift(y + u1 + 1)) == y + u1 + 1
True

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: y = ww.residue_ring().gen()
sage: u2 = ww.residue_ring().base().gen()

sage: ww.reduce(ww.lift(y)) == y
True
sage: ww.reduce(ww.lift(1)) == 1
True
sage: ww.reduce(ww.lift(y + 1)) == y +  1
True
```

A more complicated example:

```
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1)
sage: ww = w.augmentation((x^2 + x + u)^2 + 2*x*(x^2 + x + u) + 4*x, 3)
sage: u = ww.residue_ring().base().gen()

sage: F = ww.residue_ring()(u); F
u2
sage: f = ww.lift(F); f
(2^-1 + O(2^9))*x^2 + (2^-1 + O(2^9))*x + u*2^-1 + O(2^9)
sage: F == ww.reduce(f)
True
```

lift_to_key(*F*, *check=True*)

Lift the irreducible polynomial `F` to a key polynomial.

INPUT:

- `F` – an irreducible non-constant polynomial in the *residue_ring()* of this valuation
- `check` – whether or not to check correctness of `F` (default: `True`)

OUTPUT:

A polynomial f in the domain of this valuation which is a key polynomial for this valuation and which, for a suitable equivalence unit R, satisfies that the reduction of Rf is `F`

ALGORITHM:

We follow the algorithm described in Theorem 13.1 [Mac1936I] which, after a *lift()* of `F`, essentially shifts the valuations of all terms in the ϕ-adic expansion up and then kills the leading coefficient.

EXAMPLES:

```
sage: R.<u> = Qq(4, 10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: y = w.residue_ring().gen()
sage: f = w.lift_to_key(y + 1); f
(1 + O(2^10))*x^4 + (2 + O(2^11))*x^3 + (1 + u*2 + O(2^10))*x^2 + (u*2 + O(2^
↪11))*x + (u + 1) + u*2 + O(2^10)
sage: w.is_key(f)
True
```

A more complicated example:

```
sage: v = GaussValuation(S)
sage: w = v.augmentation(x^2 + x + u, 1)
sage: ww = w.augmentation((x^2 + x + u)^2 + 2*x*(x^2 + x + u) + 4*x, 3)

sage: u = ww.residue_ring().base().gen()
sage: y = ww.residue_ring().gen()
sage: f = ww.lift_to_key(y^3+y+u)
sage: f.degree()
12
```

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```
sage: ww.is_key(f)
True
```

reduce(*f*, *check=True*, *degree_bound=None*, *coefficients=None*, *valuations=None*)

Reduce `f` module this valuation.

INPUT:

- `f` – an element in the domain of this valuation
- `check` – whether or not to check whether `f` has non-negative valuation (default: `True`)
- `degree_bound` – an a-priori known bound on the degree of the result which can speed up the computation (default: not set)
- `coefficients` – the coefficients of `f` as produced by *coefficients()* or `None` (default: `None`); this can be used to speed up the computation when the expansion of `f` is already known from a previous computation.
- `valuations` – the valuations of `coefficients` or `None` (default: `None`)

OUTPUT:

an element of the *residue_ring()* of this valuation, the reduction modulo the ideal of elements of positive valuation

ALGORITHM:

We follow the algorithm given in the proof of Theorem 12.1 of [Mac1936I]: If `f` has positive valuation, the reduction is simply zero. Otherwise, let $f = \sum f_i\phi^i$ be the expansion of f, as computed by *coefficients()*. Since the valuation is zero, the exponents i must all be multiples of τ, the index the value group of the base valuation in the value group of this valuation. Hence, there is an *equivalence_unit()* Q with the same valuation as ϕ^τ. Let Q' be its *equivalence_reciprocal()*. Now, rewrite each term $f_i\phi^{i\tau} = (f_iQ^i)(\phi^\tau Q^{-1})^i$; it turns out that the second factor in this expression is a lift of the generator of the *residue_field()*. The reduction of the first factor can be computed recursively.

EXAMPLES:

```
sage: R.<u> = Qq(4, 10)
sage: S.<x> = R[]
sage: v = GaussValuation(S)
sage: v.reduce(x)
x
sage: v.reduce(S(u))
u0

sage: w = v.augmentation(x^2 + x + u, 1/2)
sage: w.reduce(S.one())
1
sage: w.reduce(S(2))
0
sage: w.reduce(S(u))
u0
sage: w.reduce(x) # this gives the generator of the residue field extension of␣
↪w over v
u1
sage: f = (x^2 + x + u)^2 / 2
sage: w.reduce(f)
```

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```
x
sage: w.reduce(f + x + 1)
x + u1 + 1

sage: ww = w.augmentation((x^2 + x + u)^2 + 2, 5/3)
sage: g = ((x^2 + x + u)^2 + 2)^3 / 2^5
sage: ww.reduce(g)
x
sage: ww.reduce(f)
1
sage: ww.is_equivalent(f, 1)
True
sage: ww.reduce(f * g)
x
sage: ww.reduce(f + g)
x + 1
```

residue_ring()

Return the residue ring of this valuation, i.e., the elements of non-negative valuation modulo the elements of positive valuation.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))

sage: w = v.augmentation(x^2 + x + 1, 1)
sage: w.residue_ring()
Univariate Polynomial Ring in x over Finite Field in u1 of size 2^2
```

Since trivial valuations of finite fields are not implemented, the resulting ring might be identical to the residue ring of the underlying valuation:

```
sage: w = v.augmentation(x, 1)
sage: w.residue_ring()
Univariate Polynomial Ring in x over Finite Field of size 2 (using ...)
```

class sage.rings.valuation.augmented_valuation.**NonFinalFiniteAugmentedValuation**(*parent*, *v*, *phi*, *mu*)

Bases: *sage.rings.valuation.augmented_valuation.FiniteAugmentedValuation*, *sage.rings.valuation.augmented_valuation.NonFinalAugmentedValuation*

An augmented valuation which is discrete, i.e., which assigns a finite valuation to its last key polynomial, and which can be augmented further.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = v.augmentation(x, 1)
```

5.9 Valuations which are defined as limits of valuations.

The discrete valuation of a complete field extends uniquely to a finite field extension. This is not the case anymore for fields which are not complete with respect to their discrete valuation. In this case, the extensions essentially correspond to the factors of the defining polynomial of the extension over the completion. However, these factors only exist over the completion and this makes it difficult to write down such valuations with a representation of finite length.

More specifically, let v be a discrete valuation on K and let $L = K[x]/(G)$ a finite extension thereof. An extension of v to L can be represented as a discrete pseudo-valuation w' on $K[x]$ which sends G to infinity. However, such w' might not be described by an *augmented valuation* over a *Gauss valuation* anymore. Instead, we may need to write is as a limit of augmented valuations.

The classes in this module provide the means of writing down such limits and resulting valuations on quotients.

AUTHORS:

- Julian Rüth (2016-10-19): initial version

EXAMPLES:

In this function field, the unique place of `K` which corresponds to the zero point has two extensions to `L`. The valuations corresponding to these extensions can only be approximated:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(1)
sage: w = v.extensions(L); w
[[ (x - 1)-adic valuation, v(y + 1) = 1 ]-adic valuation,
 [ (x - 1)-adic valuation, v(y - 1) = 1 ]-adic valuation]
```

The same phenomenon can be observed for valuations on number fields:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(5)
sage: w = v.extensions(L); w
[[ 5-adic valuation, v(t + 2) = 1 ]-adic valuation,
 [ 5-adic valuation, v(t + 3) = 1 ]-adic valuation]
```

Note: We often rely on approximations of valuations even if we could represent the valuation without using a limit. This is done to improve performance as many computations already can be done correctly with an approximation:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(1/x)
sage: w = v.extension(L); w
Valuation at the infinite place
sage: w._base_valuation._base_valuation._improve_approximation()
sage: w._base_valuation._base_valuation._approximation
[ Gauss valuation induced by Valuation at the infinite place, v(y) = 1/2, v(y^2 - 1/x) =␣
↪+Infinity ]
```

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REFERENCES:

Limits of inductive valuations are discussed in [Mac1936I] and [Mac1936II]. An overview can also be found in Section 4.6 of [Rüt2014].

class sage.rings.valuation.limit_valuation.**LimitValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Return a limit valuation which sends the polynomial `G` to infinity and is greater than or equal than `base_valuation`.

INPUT:

- `base_valuation` – a discrete (pseudo-)valuation on a polynomial ring which is a discrete valuation on the coefficient ring which can be uniquely augmented (possibly only in the limit) to a pseudo-valuation that sends `G` to infinity.
- `G` – a squarefree polynomial in the domain of `base_valuation`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = valuations.LimitValuation(v, x)
sage: w(x)
+Infinity
```

create_key(*base_valuation*, *G*)

Create a key from the parameters of this valuation.

EXAMPLES:

Note that this does not normalize `base_valuation` in any way. It is easily possible to create the same limit in two different ways:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = valuations.LimitValuation(v, x) # indirect doctest
sage: v = v.augmentation(x, infinity)
sage: u = valuations.LimitValuation(v, x)
sage: u == w
False
```

The point here is that this is not meant to be invoked from user code. But mostly from other factories which have made sure that the parameters are normalized already.

create_object(*version*, *key*)

Create an object from `key`.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: v = GaussValuation(R, QQ.valuation(2))
sage: w = valuations.LimitValuation(v, x^2 + 1) # indirect doctest
```

class sage.rings.valuation.limit_valuation.**LimitValuation_generic**(*parent*, *approximation*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Base class for limit valuations.

A limit valuation is realized as an approximation of a valuation and means to improve that approximation when necessary.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(0)
sage: w = v.extension(L)
sage: w._base_valuation
[ Gauss valuation induced by (x)-adic valuation, v(y) = 1/2 , ... ]
```

The currently used approximation can be found in the `_approximation` field:

```
sage: w._base_valuation._approximation
[ Gauss valuation induced by (x)-adic valuation, v(y) = 1/2 ]
```

reduce(*f*, *check=True*)

Return the reduction of `f` as an element of the *residue_ring()*.

INPUT:

- `f` – an element in the domain of this valuation of non-negative valuation
- `check` – whether or not to check that `f` has non-negative valuation (default: `True`)

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - (x - 1))

sage: v = K.valuation(0)
sage: w = v.extension(L)
sage: w.reduce(y) # indirect doctest
u1
```

class sage.rings.valuation.limit_valuation.**MacLaneLimitValuation**(*parent*, *approximation*, *G*)

Bases: *sage.rings.valuation.limit_valuation.LimitValuation_generic*, *sage.rings.valuation.valuation.InfiniteDiscretePseudoValuation*

A limit valuation that is a pseudo-valuation on polynomial ring $K[x]$ which sends a square-free polynomial G to infinity.

This uses the MacLane algorithm to compute the next element in the limit.

It starts from a first valuation `approximation` which has a unique augmentation that sends G to infinity and whose uniformizer must be a uniformizer of the limit and whose residue field must contain the residue field of the limit.

EXAMPLES:

```
sage: R.<x> = QQ[]
sage: K.<i> = QQ.extension(x^2 + 1)

sage: v = K.valuation(2)
sage: u = v._base_valuation; u
[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 , ... ]
```

element_with_valuation(*s*)

Return an element with valuation `s`.

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = GaussianIntegers().valuation(2)
sage: u = v._base_valuation
sage: u.extensions(QQ['x'])
[[ Gauss valuation induced by 2-adic valuation, v(x + 1) = 1/2 , ... ]]
```

is_negative_pseudo_valuation()

Return whether this valuation attains $-\infty$.

EXAMPLES:

For a Mac Lane limit valuation, this is never the case, so this method always returns `False`:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: u = v.extension(L)
sage: u.is_negative_pseudo_valuation()
False
```

lift(*F*)

Return a lift of `F` from the *residue_ring()* to the domain of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^4 - x^2 - 2*x - 1)

sage: v = K.valuation(1)
sage: w = v.extensions(L)[1]; w
[ (x - 1)-adic valuation, v(y^2 - 2) = 1 ]-adic valuation
sage: s = w.reduce(y); s
u1
sage: w.lift(s) # indirect doctest
y
```

lower_bound(*f*)

Return a lower bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: u = v.extension(L)
sage: u.lower_bound(1024*t + 1024)
10
sage: u(1024*t + 1024)
21/2
```

residue_ring()

Return the residue ring of this valuation, which is always a field.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: w = v.extension(L)
sage: w.residue_ring()
Finite Field of size 2
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: w = v.extension(L)
sage: w._base_valuation.restriction(K)
2-adic valuation
```

simplify(*f*, *error=None*, *force=False*)

Return a simplified version of `f`.

Produce an element which differs from `f` by an element of valuation strictly greater than the valuation of `f` (or strictly greater than `error` if set.)

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: u = v.extension(L)
sage: u.simplify(t + 1024, force=True)
t
```

uniformizer()

Return a uniformizing element for this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(0)
sage: w = v.extension(L)
sage: w.uniformizer() # indirect doctest
y
```

upper_bound(*f*)

Return an upper bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = QQ.valuation(2)
sage: u = v.extension(L)
sage: u.upper_bound(1024*t + 1024)
21/2
sage: u(1024*t + 1024)
21/2
```

value_semigroup()

Return the value semigroup of this valuation.

5.10 Valuations which are implemented through a map to another valuation

EXAMPLES:

Extensions of valuations over finite field extensions $L = K[x]/(G)$ are realized through an infinite valuation on $K[x]$ which maps G to infinity:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(0)
sage: w = v.extension(L); w
(x)-adic valuation

sage: w._base_valuation
[ Gauss valuation induced by (x)-adic valuation, v(y) = 1/2 , ... ]
```

AUTHORS:

- Julian Rüth (2016-11-10): initial version

class sage.rings.valuation.mapped_valuation.**FiniteExtensionFromInfiniteValuation**(*parent*, *base_valuation*)

Bases: *sage.rings.valuation.mapped_valuation.MappedValuation_base*, *sage.rings.valuation.valuation.DiscreteValuation*

A valuation on a quotient of the form $L = K[x]/(G)$ with an irreducible G which is internally backed by a pseudo-valuations on $K[x]$ which sends G to infinity.

INPUT:

- `parent` – the containing valuation space (usually the space of discrete valuations on L)
- `base_valuation` – an infinite valuation on $K[x]$ which takes G to infinity

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(0)
sage: w = v.extension(L); w
(x)-adic valuation
```

lower_bound(*x*)

Return an lower bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 5)
sage: u,uu = v.extensions(L)
sage: u.lower_bound(t + 2)
0
sage: u(t + 2)
1
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 2)
sage: w = v.extension(L)
sage: w.restriction(K) is v
True
```

simplify(*x*, *error=None*, *force=False*)

Return a simplified version of `x`.

Produce an element which differs from `x` by an element of valuation strictly greater than the valuation of `x` (or strictly greater than `error` if set.)

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 5)
sage: u,uu = v.extensions(L)
sage: f = 125*t + 1
sage: u.simplify(f, error=u(f), force=True)
1
```

upper_bound(x)

Return an upper bound of this valuation at `x`.

Use this method to get an approximation of the valuation of `x` when speed is more important than accuracy.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 5)
sage: u,uu = v.extensions(L)
sage: u.upper_bound(t + 2) >= 1
True
sage: u(t + 2)
1
```

class sage.rings.valuation.mapped_valuation.**FiniteExtensionFromLimitValuation**(*parent*, *approximant*, *G*, *approximants*)

Bases: *sage.rings.valuation.mapped_valuation.FiniteExtensionFromInfiniteValuation*

An extension of a valuation on a finite field extensions $L = K[x]/(G)$ which is induced by an infinite limit valuation on $K[x]$.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
sage: v = K.valuation(1)
sage: w = v.extensions(L); w
[[ (x - 1)-adic valuation, v(y + 1) = 1 ]-adic valuation,
 [ (x - 1)-adic valuation, v(y - 1) = 1 ]-adic valuation]
```

class sage.rings.valuation.mapped_valuation.**MappedValuation_base**(*parent*, *base_valuation*)

Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

A valuation which is implemented through another proxy "base" valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
```

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```
sage: v = K.valuation(0)
sage: w = v.extension(L); w
(x)-adic valuation
```

element_with_valuation(*s*)

Return an element with valuation `s`.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 5)
sage: u,uu = v.extensions(L)
sage: u.element_with_valuation(1)
5
```

lift(*F*)

Lift `F` from the *residue_field()* of this valuation into its domain.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(2)
sage: w = v.extension(L)
sage: w.lift(w.residue_field().gen())
y
```

reduce(*f*)

Return the reduction of `f` in the *residue_field()* of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - (x - 2))

sage: v = K.valuation(0)
sage: w = v.extension(L)
sage: w.reduce(y)
u1
```

residue_ring()

Return the residue ring of this valuation.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 2)
```

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```
sage: v.extension(L).residue_ring()
Finite Field of size 2
```

simplify(*x*, *error=None*, *force=False*)

Return a simplified version of `x`.

Produce an element which differs from `x` by an element of valuation strictly greater than the valuation of `x` (or strictly greater than `error` if set.)

If `force` is not set, then expensive simplifications may be avoided.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)

sage: v = K.valuation(0)
sage: w = v.extensions(L)[0]
```

As `_relative_size()` misses the bloated term `x^32`, the following term does not get simplified:

```
sage: w.simplify(y + x^32)
y + x^32
```

In this case the simplification can be forced but this should not happen as a default as the recursive simplification can be quite costly:

```
sage: w.simplify(y + x^32, force=True)
y
```

uniformizer()

Return a uniformizing element of this valuation.

EXAMPLES:

```
sage: K = QQ
sage: R.<t> = K[]
sage: L.<t> = K.extension(t^2 + 1)
sage: v = valuations.pAdicValuation(QQ, 2)
sage: v.extension(L).uniformizer()
t + 1
```

5.11 Valuations which are scaled versions of another valuation

EXAMPLES:

```
sage: 3*ZZ.valuation(3)
3 * 3-adic valuation
```

AUTHORS:

- Julian Rüth (2016-11-10): initial version

class sage.rings.valuation.scaled_valuation.**ScaledValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Return a valuation which scales the valuation `base` by the factor `s`.

EXAMPLES:

```
sage: 3*ZZ.valuation(2) # indirect doctest
3 * 2-adic valuation
```

create_key(*base*, *s*)

Create a key which uniquely identifies a valuation.

create_object(*version*, *key*)

Create a valuation from `key`.

class sage.rings.valuation.scaled_valuation.**ScaledValuation_generic**(*parent*, *base_valuation*, *s*)

Bases: *sage.rings.valuation.valuation.DiscreteValuation*

A valuation which scales another `base_valuation` by a finite positive factor `s`.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(3); v
3 * 3-adic valuation
```

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(5)
sage: v.extensions(GaussianIntegers().fraction_field())
[3 * [ 5-adic valuation, v(x + 2) = 1 ]-adic valuation,
 3 * [ 5-adic valuation, v(x + 3) = 1 ]-adic valuation]
```

lift(*F*)

Lift `F` from the *residue_field()* of this valuation into its domain.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(2)
sage: v.lift(1)
1
```

reduce(*f*)

Return the reduction of `f` in the *residue_field()* of this valuation.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(2)
sage: v.reduce(1)
1
```

residue_ring()

Return the residue field of this valuation.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(2)
sage: v.residue_ring()
Finite Field of size 2
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: v = 3*QQ.valuation(5)
sage: v.restriction(ZZ)
3 * 5-adic valuation
```

uniformizer()

Return a uniformizing element of this valuation.

EXAMPLES:

```
sage: v = 3*ZZ.valuation(2)
sage: v.uniformizer()
2
```

value_semigroup()

Return the value semigroup of this valuation.

EXAMPLES:

```
sage: v2 = QQ.valuation(2)
sage: (2*v2).value_semigroup()
Additive Abelian Semigroup generated by -2, 2
```

5.12 Discrete valuations on function fields

AUTHORS:

- Julian Rüth (2016-10-16): initial version

EXAMPLES:

We can create classical valuations that correspond to finite and infinite places on a rational function field:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(1); v
(x - 1)-adic valuation
sage: v = K.valuation(x^2 + 1); v
(x^2 + 1)-adic valuation
sage: v = K.valuation(1/x); v
Valuation at the infinite place
```

Note that we can also specify valuations which do not correspond to a place of the function field:

```
sage: R.<x> = QQ[]
sage: w = valuations.GaussValuation(R, QQ.valuation(2))
sage: v = K.valuation(w); v
2-adic valuation
```

Valuations on a rational function field can then be extended to finite extensions:

```
sage: v = K.valuation(x - 1); v
(x - 1)-adic valuation
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
sage: w = v.extensions(L); w
[[ (x - 1)-adic valuation, v(y + 1) = 1 ]-adic valuation,
 [ (x - 1)-adic valuation, v(y - 1) = 1 ]-adic valuation]
```

REFERENCES:

An overview of some computational tools relating to valuations on function fields can be found in Section 4.6 of [Rüt2014]. Most of this was originally developed for number fields in [Mac1936I] and [Mac1936II].

class sage.rings.function_field.function_field_valuation.**ClassicalFunctionFieldValuation_base**(*parent*)

Bases: *sage.rings.function_field.function_field_valuation.DiscreteFunctionFieldValuation_base*

Base class for discrete valuations on rational function fields that come from points on the projective line.

class sage.rings.function_field.function_field_valuation.**DiscreteFunctionFieldValuation_base**(*parent*)

Bases: *sage.rings.valuation.valuation.DiscreteValuation*

Base class for discrete valuations on function fields.

extensions(*L*)

Return the extensions of this valuation to L.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x)
sage: v.extensions(L)
[(x)-adic valuation]
```

class sage.rings.function_field.function_field_valuation.**FiniteRationalFunctionFieldValuation**(*parent*, *base_valuat*

Bases: *sage.rings.function_field.function_field_valuation.InducedRationalFunctionFieldValuation_base*, *sage.rings.function_field.function_field_valuation.ClassicalFunctionFieldValuation_base*, *sage.rings.function_field.function_field_valuation.RationalFunctionFieldValuation_base*

Valuation of a finite place of a function field.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x + 1); v # indirect doctest
(x + 1)-adic valuation
```

A finite place with residual degree:

```
sage: w = K.valuation(x^2 + 1); w
(x^2 + 1)-adic valuation
```

A finite place with ramification:

```
sage: K.<t> = FunctionField(GF(3))
sage: L.<x> = FunctionField(K)
sage: u = L.valuation(x^3 - t); u
(x^3 + 2*t)-adic valuation
```

A finite place with residual degree and ramification:

```
sage: q = L.valuation(x^6 - t); q
(x^6 + 2*t)-adic valuation
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldExtensionMappedValuation**(*parent*, *base_valua*, *to_base_va*, *from_base_*)

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldMappedValuationRelative_base*

A valuation on a finite extensions of function fields $L = K[y]/(G)$ where K is another function field which redirects to another `base_valuation` on an isomorphism function field $M = K[y]/(H)$.

The isomorphisms must be trivial on `K`.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 + y + x^3)
sage: v = K.valuation(1/x)
sage: w = v.extension(L)

sage: w(x)
-1
sage: w(y)
-3/2
sage: w.uniformizer()
1/x^2*y
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 + y + x^3)
sage: v = K.valuation(1/x)
sage: w = v.extension(L)
sage: w.restriction(K) is v
True
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldFromLimitValuation**(*parent*, *approximant*, *G*, *approximants*)

Bases: *sage.rings.valuation.mapped_valuation.FiniteExtensionFromLimitValuation*, *sage.rings.function_field.function_field_valuation.DiscreteFunctionFieldValuation_base*

A valuation on a finite extensions of function fields $L = K[y]/(G)$ where K is another function field.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - (x^2 + x + 1))
sage: v = K.valuation(x - 1) # indirect doctest
sage: w = v.extension(L); w
(x - 1)-adic valuation
```

scale(*scalar*)

Return this valuation scaled by `scalar`.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - (x^2 + x + 1))
sage: v = K.valuation(x - 1) # indirect doctest
sage: w = v.extension(L)
sage: 3*w
3 * (x - 1)-adic valuation
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldMappedValuationRelative_base**(*paren*, *base_*, *to_ba*, *from_*

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldMappedValuation_base*

A valuation on a function field which relies on a `base_valuation` on an isomorphic function field and which is such that the map from and to the other function field is the identity on the constant field.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: v = K.valuation(1/x); v
Valuation at the infinite place
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: K.valuation(1/x).restriction(GF(2))
Trivial valuation on Finite Field of size 2
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldMappedValuation_base**(*parent*, *base_valuation*, *to_base_valuati*
from_base_valu

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldValuation_base*, *sage.rings.valuation.mapped_valuation.MappedValuation_base*

A valuation on a function field which relies on a `base_valuation` on an isomorphic function field.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: v = K.valuation(1/x); v
Valuation at the infinite place
```

is_discrete_valuation()

Return whether this is a discrete valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 - x^4 - 1)
sage: v = K.valuation(1/x)
sage: w0,w1 = v.extensions(L)
sage: w0.is_discrete_valuation()
True
```

scale(*scalar*)

Return this valuation scaled by `scalar`.

EXAMPLES:

```
sage: K.<x> = FunctionField(GF(2))
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 + y + x^3)
sage: v = K.valuation(1/x)
sage: w = v.extension(L)
sage: 3*w
3 * (x)-adic valuation (in Rational function field in x over Finite Field of␣
↪size 2 after x |--> 1/x)
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Create a valuation on `domain` corresponding to `prime`.

INPUT:

- `domain` – a function field
- `prime` – a place of the function field, a valuation on a subring, or a valuation on another function field together with information for isomorphisms to and from that function field

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(1); v # indirect doctest
(x - 1)-adic valuation
sage: v(x)
0
sage: v(x - 1)
1
```

See sage.rings.function_field.function_field.FunctionField.valuation() for further examples.

create_key_and_extra_args(*domain*, *prime*)
Create a unique key which identifies the valuation given by `prime` on `domain`.

create_key_and_extra_args_from_place(*domain*, *generator*)
Create a unique key which identifies the valuation at the place specified by `generator`.

create_key_and_extra_args_from_valuation(*domain*, *valuation*)
Create a unique key which identifies the valuation which extends `valuation`.

create_key_and_extra_args_from_valuation_on_isomorphic_field(*domain*, *valuation*, *to_valuation_domain*, *from_valuation_domain*)
Create a unique key which identifies the valuation which is `valuation` after mapping through `to_valuation_domain`.

create_object(*version*, *key*, ***extra_args*)
Create the valuation specified by `key`.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<x> = QQ[]
sage: w = valuations.GaussValuation(R, QQ.valuation(2))
sage: v = K.valuation(w); v # indirect doctest
2-adic valuation
```

class sage.rings.function_field.function_field_valuation.**FunctionFieldValuation_base**(*parent*)
Bases: *sage.rings.valuation.valuation.DiscretePseudoValuation*

Abstract base class for any discrete (pseudo-)valuation on a function field.

class sage.rings.function_field.function_field_valuation.**InducedRationalFunctionFieldValuation_base**(*parent*, *base*)
Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldValuation_base*

Base class for function field valuation induced by a valuation on the underlying polynomial ring.

extensions(*L*)
Return all extensions of this valuation to `L` which has a larger constant field than the domain of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x^2 + 1)
sage: L.<x> = FunctionField(GaussianIntegers().fraction_field())
sage: v.extensions(L) # indirect doctest
[(x - I)-adic valuation, (x + I)-adic valuation]
```

lift(*F*)

Return a lift of `F` to the domain of this valuation such that *reduce()* returns the original element.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x)
sage: v.lift(0)
0
sage: v.lift(1)
1
```

reduce(*f*)

Return the reduction of `f` in *residue_ring()*.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(x^2 + 1)
sage: v.reduce(x)
u1
```

residue_ring()

Return the residue field of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: K.valuation(x).residue_ring()
Rational Field
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: K.valuation(x).restriction(QQ)
Trivial valuation on Rational Field
```

simplify(*f*, *error=None*, *force=False*)

Return a simplified version of `f`.

Produce an element which differs from `f` by an element of valuation strictly greater than the valuation of `f` (or strictly greater than `error` if set.)

If `force` is not set, then expensive simplifications may be avoided.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(2)
sage: f = (x + 1)/(x - 1)
```

As the coefficients of this fraction are small, we do not simplify as this could be very costly in some cases:

```
sage: v.simplify(f)
(x + 1)/(x - 1)
```

However, simplification can be forced:

```
sage: v.simplify(f, force=True)
3
```

uniformizer()

Return a uniformizing element for this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: K.valuation(x).uniformizer()
x
```

value_group()

Return the value group of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: K.valuation(x).value_group()
Additive Abelian Group generated by 1
```

class sage.rings.function_field.function_field_valuation.**InfiniteRationalFunctionFieldValuation**(*parent*)

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldMappedValuationRelative_base*, *sage.rings.function_field.function_field_valuation.RationalFunctionFieldValuation_base*, *sage.rings.function_field.function_field_valuation.ClassicalFunctionFieldValuation_base*

Valuation of the infinite place of a function field.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = K.valuation(1/x) # indirect doctest
```

class sage.rings.function_field.function_field_valuation.**NonClassicalRationalFunctionFieldValuation**(*parent*, *base*)

Bases: *sage.rings.function_field.function_field_valuation.InducedRationalFunctionFieldValuation_base*, *sage.rings.function_field.function_field_valuation.RationalFunctionFieldValuation_base*

Valuation induced by a valuation on the underlying polynomial ring which is non-classical.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = GaussValuation(QQ['x'], QQ.valuation(2))
sage: w = K.valuation(v); w # indirect doctest
2-adic valuation
```

residue_ring()

Return the residue field of this valuation.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: v = valuations.GaussValuation(QQ['x'], QQ.valuation(2))
sage: w = K.valuation(v)
sage: w.residue_ring()
```

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```
Rational function field in x over Finite Field of size 2

sage: R.<x> = QQ[]
sage: vv = v.augmentation(x, 1)
sage: w = K.valuation(vv)
sage: w.residue_ring()
Rational function field in x over Finite Field of size 2

sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 + 2*x)
sage: w.extension(L).residue_ring()
Function field in u2 defined by u2^2 + x
```

class sage.rings.function_field.function_field_valuation.**RationalFunctionFieldMappedValuation**(*parent*, *base_valuat*, *to_base_val*, *from_base_v*)

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldMappedValuationRelative_base*, *sage.rings.function_field.function_field_valuation.RationalFunctionFieldValuation_base*

Valuation on a rational function field that is implemented after a map to an isomorphic rational function field.

EXAMPLES:

```
sage: K.<x> = FunctionField(QQ)
sage: R.<x> = QQ[]
sage: w = GaussValuation(R, QQ.valuation(2)).augmentation(x, 1)
sage: w = K.valuation(w)
sage: v = K.valuation((w, K.hom([~K.gen()]), K.hom([~K.gen()]))); v
Valuation on rational function field induced by [ Gauss valuation induced by 2-adic␣
↪valuation, v(x) = 1 ] (in Rational function field in x over Rational Field after␣
↪x |--> 1/x)
```

class sage.rings.function_field.function_field_valuation.**RationalFunctionFieldValuation_base**(*parent*)

Bases: *sage.rings.function_field.function_field_valuation.FunctionFieldValuation_base*

Base class for valuations on rational function fields.

element_with_valuation(*s*)

Return an element with valuation `s`.

EXAMPLES:

```
sage: K.<a> = NumberField(x^3+6)
sage: v = K.valuation(2)
sage: R.<x> = K[]
sage: w = GaussValuation(R, v).augmentation(x, 1/123)
sage: K.<x> = FunctionField(K)
sage: w = w.extension(K)
sage: w.element_with_valuation(122/123)
2/x
sage: w.element_with_valuation(1)
2
```

5.13 p-adic Valuations on Number Fields and Their Subrings and Completions

EXAMPLES:

```
sage: ZZ.valuation(2)
2-adic valuation
sage: QQ.valuation(3)
3-adic valuation
sage: CyclotomicField(5).valuation(5)
5-adic valuation
sage: GaussianIntegers().valuation(7)
7-adic valuation
sage: Zp(11).valuation()
11-adic valuation
```

These valuations can then, e.g., be used to compute approximate factorizations in the completion of a ring:

```
sage: v = ZZ.valuation(2)
sage: R.<x> = ZZ[]
sage: f = x^5 + x^4 + x^3 + x^2 + x - 1
sage: v.montes_factorization(f, required_precision=20)
(x + 676027) * (x^4 + 372550*x^3 + 464863*x^2 + 385052*x + 297869)
```

AUTHORS:

- Julian Rüth (2013-03-16): initial version

REFERENCES:

The theory used here was originally developed in [Mac1936I] and [Mac1936II]. An overview can also be found in Chapter 4 of [Rüt2014].

class sage.rings.padics.padic_valuation.**PadicValuationFactory**

Bases: sage.structure.factory.UniqueFactory

Create a `prime`-adic valuation on `R`.

INPUT:

- `R` – a subring of a number field or a subring of a local field in characteristic zero
- `prime` – a prime that does not split, a discrete (pseudo-)valuation, a fractional ideal, or `None` (default: `None`)

EXAMPLES:

For integers and rational numbers, `prime` is just a prime of the integers:

```
sage: valuations.pAdicValuation(ZZ, 3)
3-adic valuation

sage: valuations.pAdicValuation(QQ, 3)
3-adic valuation
```

`prime` may be `None` for local rings:

```
sage: valuations.pAdicValuation(Qp(2))
2-adic valuation

sage: valuations.pAdicValuation(Zp(2))
2-adic valuation
```

But it must be specified in all other cases:

```
sage: valuations.pAdicValuation(ZZ)
Traceback (most recent call last):
...
ValueError: prime must be specified for this ring
```

It can sometimes be beneficial to define a number field extension as a quotient of a polynomial ring (since number field extensions always compute an absolute polynomial defining the extension which can be very costly):

```
sage: R.<x> = QQ[]
sage: K.<a> = NumberField(x^2 + 1)
sage: R.<x> = K[]
sage: L.<b> = R.quo(x^2 + a)
sage: valuations.pAdicValuation(L, 2)
2-adic valuation
```

See also:

NumberField_generic.valuation(), Order.valuation(), pAdicGeneric.valuation(), RationalField.valuation(), IntegerRing_class.valuation().

create_key_and_extra_args(*R*, *prime=None*, *approximants=None*)

Create a unique key identifying the valuation of `R` with respect to `prime`.

EXAMPLES:

```
sage: QQ.valuation(2) # indirect doctest
2-adic valuation
```

create_key_and_extra_args_for_number_field(*R*, *prime*, *approximants*)

Create a unique key identifying the valuation of `R` with respect to `prime`.

EXAMPLES:

```
sage: GaussianIntegers().valuation(2) # indirect doctest
2-adic valuation
```

create_key_and_extra_args_for_number_field_from_ideal(*R*, *I*, *prime*)

Create a unique key identifying the valuation of `R` with respect to `I`.

Note: `prime`, the original parameter that was passed to *create_key_and_extra_args()*, is only used to provide more meaningful error messages

---

EXAMPLES:

```
sage: GaussianIntegers().valuation(GaussianIntegers().ideal(2)) # indirect␣
↪doctest
2-adic valuation
```

create_key_and_extra_args_for_number_field_from_valuation(*R*, *v*, *prime*, *approximants*)
Create a unique key identifying the valuation of `R` with respect to `v`.

Note: `prime`, the original parameter that was passed to *create_key_and_extra_args()*, is only used to provide more meaningful error messages

---

EXAMPLES:

```
sage: GaussianIntegers().valuation(ZZ.valuation(2)) # indirect doctest
2-adic valuation
```

create_key_for_integers(*R*, *prime*)
Create a unique key identifying the valuation of `R` with respect to `prime`.

EXAMPLES:

```
sage: QQ.valuation(2) # indirect doctest
2-adic valuation
```

create_key_for_local_ring(*R*, *prime*)
Create a unique key identifying the valuation of `R` with respect to `prime`.

EXAMPLES:

```
sage: Qp(2).valuation() # indirect doctest
2-adic valuation
```

create_object(*version*, *key*, ***extra_args*)
Create a p-adic valuation from `key`.

EXAMPLES:

```
sage: ZZ.valuation(5) # indirect doctest
5-adic valuation
```

class sage.rings.padics.padic_valuation.**pAdicFromLimitValuation**(*parent*, *approximant*, *G*, *approximants*)
Bases: *sage.rings.valuation.mapped_valuation.FiniteExtensionFromLimitValuation*, *sage.rings.padics.padic_valuation.pAdicValuation_base*

A p-adic valuation on a number field or a subring thereof, i.e., a valuation that extends the p-adic valuation on the integers.

EXAMPLES:

```
sage: v = GaussianIntegers().valuation(3); v
3-adic valuation
```

extensions(*ring*)
Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = GaussianIntegers().valuation(3)
sage: v.extensions(v.domain().fraction_field())
[3-adic valuation]
```

class sage.rings.padics.padic_valuation.**pAdicValuation_base**(*parent*, *p*)

Bases: *sage.rings.valuation.valuation.DiscreteValuation*

Abstract base class for p-adic valuations.

INPUT:

- `ring` – an integral domain
- `p` – a rational prime over which this valuation lies, not necessarily a uniformizer for the valuation

EXAMPLES:

```
   sage: ZZ.valuation(3)
   3-adic valuation

   sage: QQ.valuation(5)
   5-adic valuation

For `p`-adic rings, ``p`` has to match the `p` of the ring.

   sage: v = valuations.pAdicValuation(Zp(3), 2); v
   Traceback (most recent call last):
   ...
   ValueError: prime must be an element of positive valuation
```

change_domain(*ring*)

Change the domain of this valuation to `ring` if possible.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.change_domain(QQ).domain()
Rational Field
```

extensions(*ring*)

Return the extensions of this valuation to `ring`.

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.extensions(GaussianIntegers())
[2-adic valuation]
```

is_totally_ramified(*G*, *include_steps=False*, *assume_squarefree=False*)

Return whether `G` defines a single totally ramified extension of the completion of the domain of this valuation.

INPUT:

- `G` – a monic squarefree polynomial over the domain of this valuation
- `include_steps` – a boolean (default: `False`); where to include the valuations produced during the process of checking whether `G` is totally ramified in the return value
- `assume_squarefree` – a boolean (default: `False`); whether to assume that `G` is square-free over the completion of the domain of this valuation. Setting this to `True` can significantly improve the performance.

ALGORITHM:

This is a simplified version of *sage.rings.valuation.valuation.DiscreteValuation.mac_lane_approximants()*.

EXAMPLES:

```
sage: k = Qp(5,4)
sage: v = k.valuation()
sage: R.<x> = k[]
sage: G = x^2 + 1
sage: v.is_totally_ramified(G)
False
sage: G = x + 1
sage: v.is_totally_ramified(G)
True
sage: G = x^2 + 2
sage: v.is_totally_ramified(G)
False
sage: G = x^2 + 5
sage: v.is_totally_ramified(G)
True
sage: v.is_totally_ramified(G, include_steps=True)
(True, [Gauss valuation induced by 5-adic valuation, [ Gauss valuation induced␣
↪by 5-adic valuation, v((1 + O(5^4))*x) = 1/2 ]])
```

We consider an extension as totally ramified if its ramification index matches the degree. Hence, a trivial extension is totally ramified:

```
sage: R.<x> = QQ[]
sage: v = QQ.valuation(2)
sage: v.is_totally_ramified(x)
True
```

is_unramified(*G*, *include_steps=False*, *assume_squarefree=False*)

Return whether `G` defines a single unramified extension of the completion of the domain of this valuation.

INPUT:

- `G` – a monic squarefree polynomial over the domain of this valuation
- `include_steps` – a boolean (default: `False`); whether to include the approximate valuations that were used to determine the result in the return value.
- `assume_squarefree` – a boolean (default: `False`); whether to assume that `G` is square-free over the completion of the domain of this valuation. Setting this to `True` can significantly improve the performance.

EXAMPLES:

We consider an extension as unramified if its ramification index is 1. Hence, a trivial extension is unramified:

```
sage: R.<x> = QQ[]
sage: v = QQ.valuation(2)
sage: v.is_unramified(x)
True
```

If `G` remains irreducible in reduction, then it defines an unramified extension:

```
sage: v.is_unramified(x^2 + x + 1)
True
```

However, even if `G` factors, it might define an unramified extension:

```
sage: v.is_unramified(x^2 + 2*x + 4)
True
```

lift(*x*)

Lift `x` from the residue field to the domain of this valuation.

INPUT:

- `x` – an element of the *residue_field()*

EXAMPLES:

```
sage: v = ZZ.valuation(3)
sage: xbar = v.reduce(4)
sage: v.lift(xbar)
1
```

p()

Return the p of this p-adic valuation.

EXAMPLES:

```
sage: GaussianIntegers().valuation(2).p()
2
```

reduce(*x*)

Reduce `x` modulo the ideal of elements of positive valuation.

INPUT:

- `x` – an element in the domain of this valuation

OUTPUT:

An element of the *residue_field()*.

EXAMPLES:

```
sage: v = ZZ.valuation(3)
sage: v.reduce(4)
1
```

restriction(*ring*)

Return the restriction of this valuation to `ring`.

EXAMPLES:

```
sage: v = GaussianIntegers().valuation(2)
sage: v.restriction(ZZ)
2-adic valuation
```

value_semigroup()

Return the value semigroup of this valuation.

EXAMPLES:

```
sage: v = GaussianIntegers().valuation(2)
sage: v.value_semigroup()
Additive Abelian Semigroup generated by 1/2
```

class sage.rings.padics.padic_valuation.**pAdicValuation_int**(*parent*, *p*)

Bases: *sage.rings.padics.padic_valuation.pAdicValuation_base*

A p-adic valuation on the integers or the rationals.

EXAMPLES:

```
sage: v = ZZ.valuation(3); v
3-adic valuation
```

inverse(*x*, *precision*)

Return an approximate inverse of `x`.

The element returned is such that the product differs from 1 by an element of valuation at least `precision`.

INPUT:

- `x` – an element in the domain of this valuation
- `precision` – a rational or infinity

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: x = 3
sage: y = v.inverse(3, 2); y
3
sage: x*y - 1
8
```

This might not be possible for elements of positive valuation:

```
sage: v.inverse(2, 2)
Traceback (most recent call last):
...
ValueError: element has no approximate inverse in this ring
```

Unless the precision is very small:

```
sage: v.inverse(2, 0)
1
```

residue_ring()

Return the residue field of this valuation.

EXAMPLES:

```
sage: v = ZZ.valuation(3)
sage: v.residue_ring()
Finite Field of size 3
```

simplify(*x*, *error=None*, *force=False*, *size_heuristic_bound=32*)

Return a simplified version of `x`.

Produce an element which differs from `x` by an element of valuation strictly greater than the valuation of `x` (or strictly greater than `error` if set.)

INPUT:

- `x` – an element in the domain of this valuation
- `error` – a rational, infinity, or `None` (default: `None`), the error allowed to introduce through the simplification
- `force` – ignored
- `size_heuristic_bound` – when `force` is not set, the expected factor by which the `x` need to shrink to perform an actual simplification (default: 32)

EXAMPLES:

```
sage: v = ZZ.valuation(2)
sage: v.simplify(6, force=True)
2
sage: v.simplify(6, error=0, force=True)
0
```

In this example, the usual rational reconstruction misses a good answer for some moduli (because the absolute value of the numerator is not bounded by the square root of the modulus):

```
sage: v = QQ.valuation(2)
sage: v.simplify(110406, error=16, force=True)
562/19
sage: Qp(2, 16)(110406).rational_reconstruction()
Traceback (most recent call last):
...
ArithmeticError: rational reconstruction of 55203 (mod 65536) does not exist
```

uniformizer()

Return a uniformizer of this p-adic valuation, i.e., p as an element of the domain.

EXAMPLES:

```
sage: v = ZZ.valuation(3)
sage: v.uniformizer()
3
```

class sage.rings.padics.padic_valuation.**pAdicValuation_padic**(*parent*)

Bases: *sage.rings.padics.padic_valuation.pAdicValuation_base*

The p-adic valuation of a complete p-adic ring.

INPUT:

- `R` – a p-adic ring

EXAMPLES:

```
sage: v = Qp(2).valuation(); v #indirect doctest
2-adic valuation
```

element_with_valuation(*v*)

Return an element of valuation `v`.

INPUT:

- v – an element of the *pAdicValuation_base.value_semigroup()* of this valuation

EXAMPLES:

```
sage: R = Zp(3)
sage: v = R.valuation()
sage: v.element_with_valuation(3)
3^3 + O(3^23)

sage: K = Qp(3)
sage: R.<y> = K[]
sage: L.<y> = K.extension(y^2 + 3*y + 3)
sage: L.valuation().element_with_valuation(3/2)
y^3 + O(y^43)
```

lift(*x*)

Lift x from the *residue_field()* to the domain of this valuation.

INPUT:

- x – an element of the residue field of this valuation

EXAMPLES:

```
sage: R = Zp(3)
sage: v = R.valuation()
sage: xbar = v.reduce(R(4))
sage: v.lift(xbar)
1 + O(3^20)
```

reduce(*x*)

Reduce x modulo the ideal of elements of positive valuation.

INPUT:

- x – an element of the domain of this valuation

OUTPUT:

An element of the *residue_field()*.

EXAMPLES:

```
sage: R = Zp(3)
sage: Zp(3).valuation().reduce(R(4))
1
```

residue_ring()

Return the residue field of this valuation.

EXAMPLES:

```
sage: Qq(9, names='a').valuation().residue_ring()
Finite Field in a0 of size 3^2
```

shift(*x*, *s*)

Shift x in its expansion with respect to *uniformizer()* by s "digits".

For non-negative s, this just returns x multiplied by a power of the uniformizer π.

For negative `s`, it does the same but when not over a field, it drops coefficients in the π-adic expansion which have negative valuation.

EXAMPLES:

```
sage: R = ZpCA(2)
sage: v = R.valuation()
sage: v.shift(R.one(), 1)
2 + O(2^20)
sage: v.shift(R.one(), -1)
O(2^19)

sage: S.<y> = R[]
sage: S.<y> = R.extension(y^3 - 2)
sage: v = S.valuation()
sage: v.shift(1, 5)
y^5 + O(y^60)
```

simplify(*x*, *error=None*, *force=False*)

Return a simplified version of `x`.

Produce an element which differs from `x` by an element of valuation strictly greater than the valuation of `x` (or strictly greater than `error` if set.)

INPUT:

- `x` – an element in the domain of this valuation
- `error` – a rational, infinity, or `None` (default: `None`), the error allowed to introduce through the simplification
- `force` – ignored

EXAMPLES:

```
sage: R = Zp(2)
sage: v = R.valuation()
sage: v.simplify(6)
2 + O(2^21)
sage: v.simplify(6, error=0)
0
```

uniformizer()

Return a uniformizer of this valuation.

EXAMPLES:

```
sage: v = Zp(3).valuation()
sage: v.uniformizer()
3 + O(3^21)
```

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