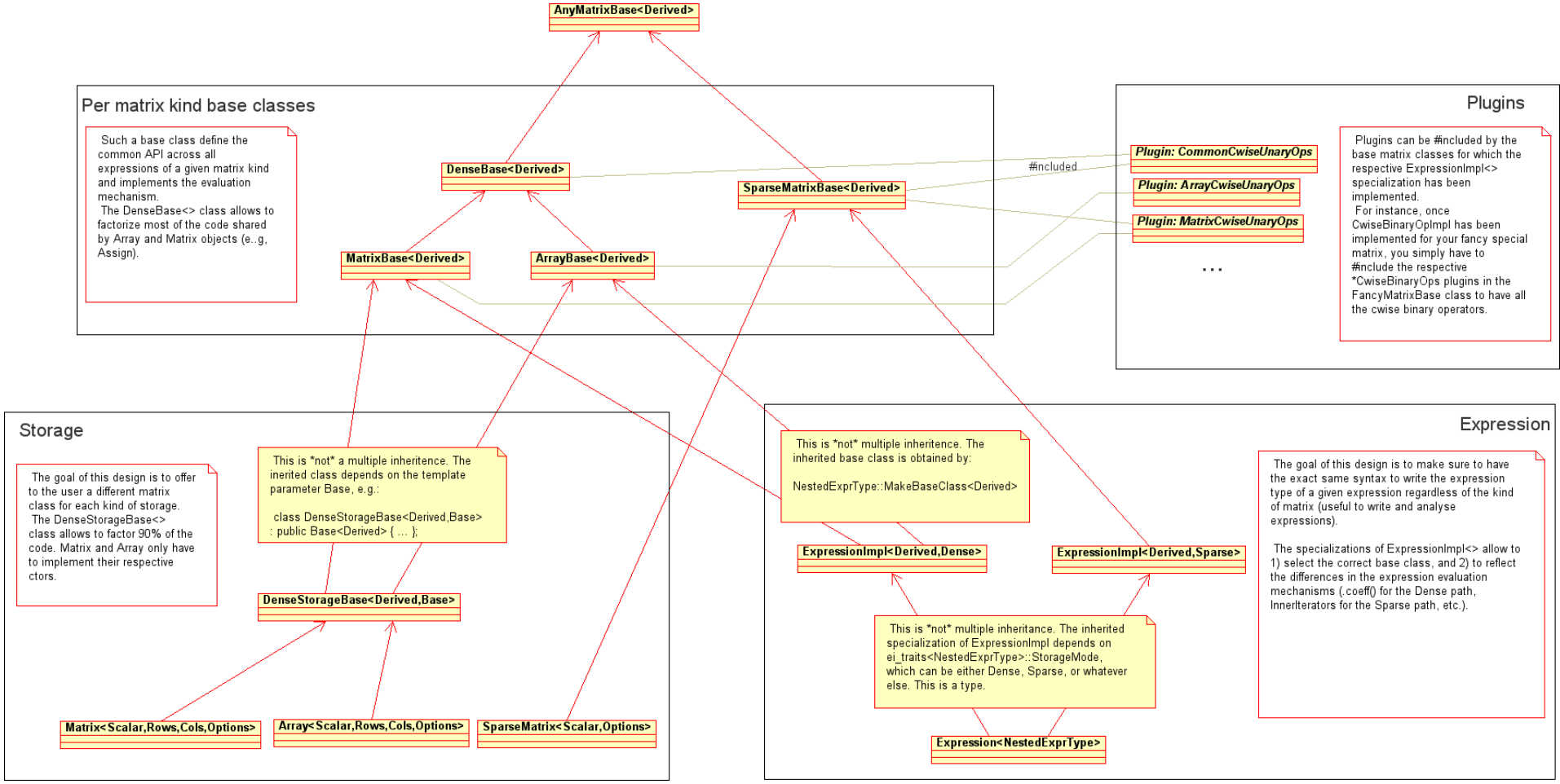
Eigen's class hierarchy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Expression templates

- Example:

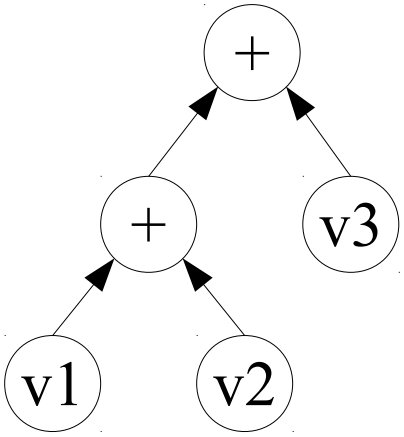
```
v3 = v1 + v2 + v3;
```

- Expression templates:
  - "+" returns an expression

    Sum<typeof(v1),typeof(v2)>

  - expression tree

    Sum<Sum<typeof(v1),typeof(v2),
    typeof(v3)>



  - evaluation entirely performed in the "="

```
for(i=0; i<v3.size(); ++i)
    v3[i] = v1[i] + v2[i] + v3[i];
```

E.T. in Eigen 2.0

- v1 + v2 returns a Sum expression:
  - *Sum<typeof(v1),typeof(v2)>*
- with:
  - *template<Lhs,Rhs> class Sum {*
    const Lhs& m_lhs;
    const Rhs& m_rhs;

    Sum(const Lhs& l, const Rhs& r) : m_lhs(l), m_rhs(r) {}

    *Scalar **coeff**(int i, int j) { return m_lhs.coeff(i,j) + m_rhs.coeff(i,j); }*

    int rows() {…}
    int cols() {...}
    };
- What about: (v1 + v2) + v3 ?

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- v1 + v2 returns a Sum expression:
  - *Sum<typeof(v1),typeof(v2)>*
- with:
  - *template<Lhs,Rhs> class Sum* ***: MatrixBase<Sum<Lhs,Rhs>>*** *{*

```
const Lhs& m_lhs;
const Rhs& m_rhs;

Sum(const Lhs& l, const Rhs& r) : m_lhs(l), m_rhs(r) {}

Scalar coeff(int i, int j) { return m_lhs.coeff(i,j) + m_rhs.coeff(i,j); }

int rows() {…}
int cols() {...}
};
```

- What about: (v1 + v2) + v3 ?
  - > common base class: MatrixBase

The base class

```
template<Derived> class MatrixBase {
  /* … */

  template<OtherDerived> Sum<Derived,OtherDerived>
  operator+(const MatrixBase<OtherDerived>& other)
  { return Sum<Derived,OtherDerived>(*this, other); }

  template<Src> Derived& operator=(const MatrixBase<Src>& src) {
    foreach coeffs i,j do
      *this.coeff(i,j) = other.coeff(i,j);
    }

};
```

The ei_traits class

```
template<Lhs,Rhs> class Sum : MatrixBase<Sum<Lhs,Rhs>> {
  /* … */
  typedef typename Lhs::Scalar Scalar;
};

template<Derived> class MatrixBase {
  /* … */
  typedef typename Derived::Scalar Scalar;
};
```

! circular dependency !

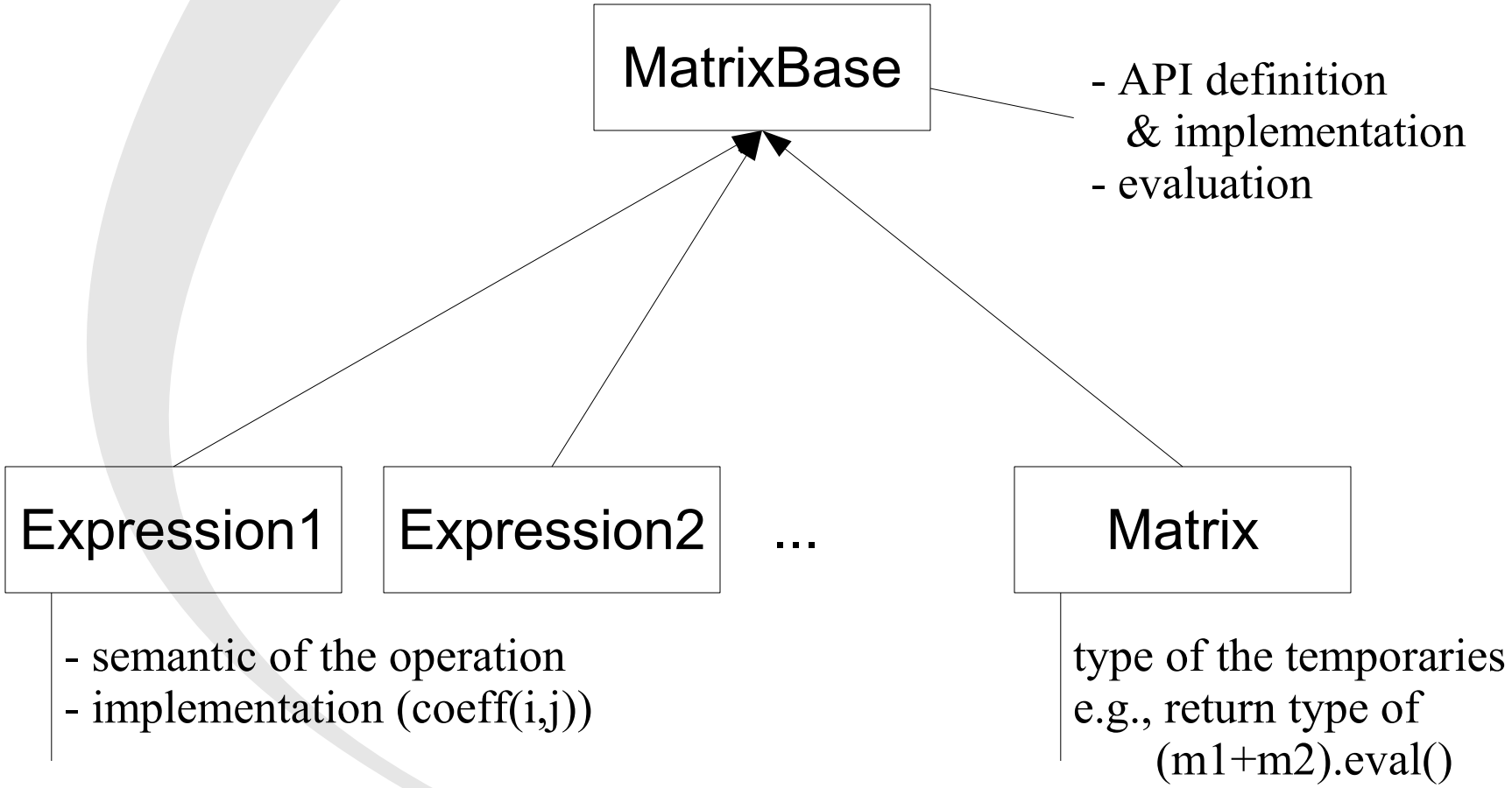
The ei_traits class

```
template<Lhs,Rhs> struct ei_traits<Sum<Lhs,Rhs>> {
  /* .. */
  typedef typename Lhs::Scalar Scalar;
};


template<Lhs,Rhs> class Sum : MatrixBase<Sum<Lhs,Rhs>> {
  /* … */
  typedef typename ei_traits<Sum>::Scalar Scalar;
};

template<Derived> class MatrixBase {
  /* … */
  typedef typename ei_traits<Derived>::Scalar Scalar;
};
```

Eigen 2.0: Class hierarchy

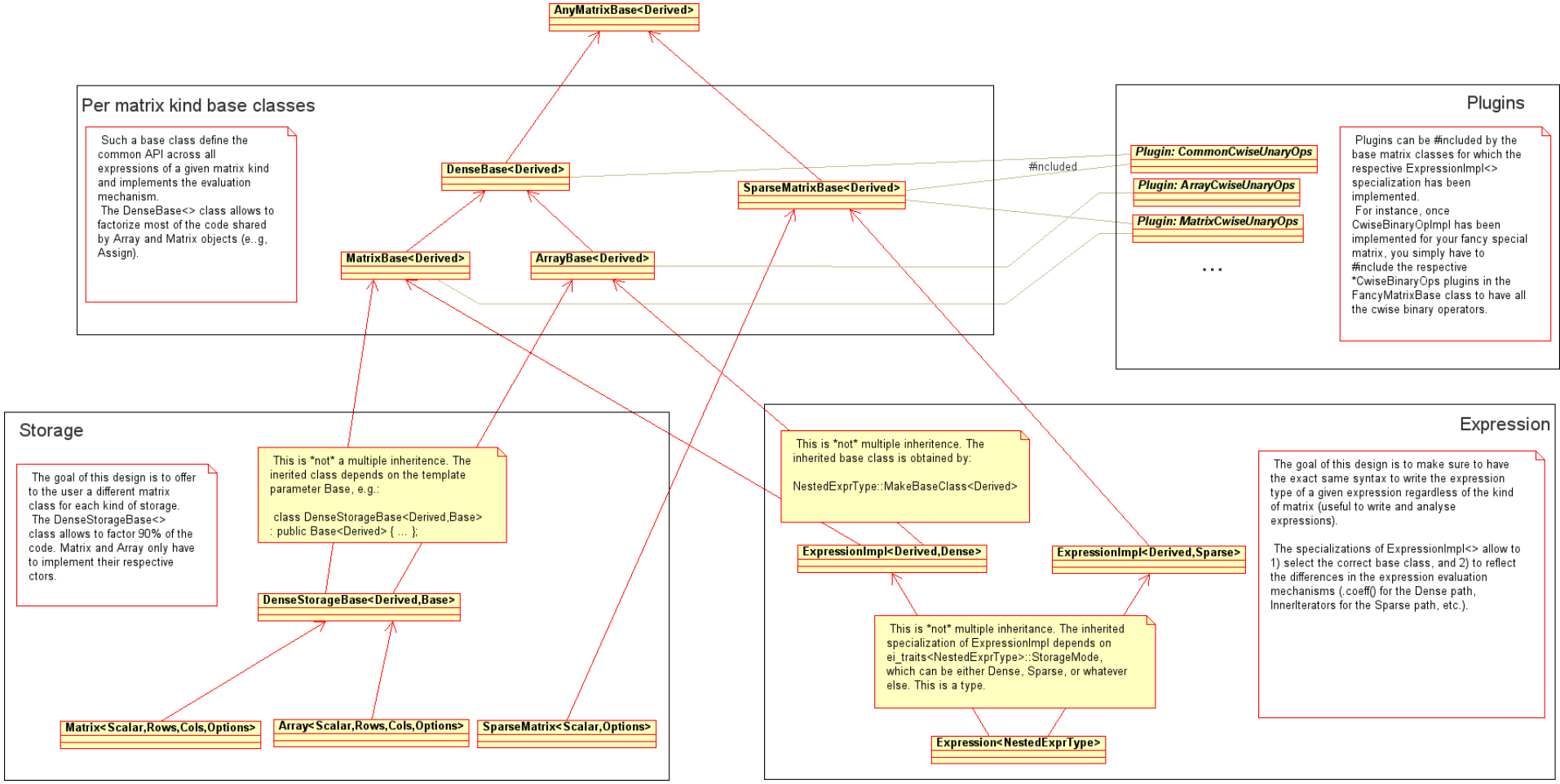


Motivations for 3.0

- Eigen 2.0: limited to a single type of Matrix
  - we want E.T. for all kind of objects
  - different storages
    - dense, sparse matrices, triangular matrices, etc.
      - require different evaluation mechanisms
      - coeffs based, interators, etc.
  - different semantics
    - matrix, array, transform, etc.
      - slightly different API

Additional goals / constraints

- zero code duplication
  - operator+ declared, documented, implemented only once!
- uniform expression tree
  - typeof(v1+v2) == Sum<typeof(v1),typeof(v2)>
- decouple the semantic and the implementation of the expressions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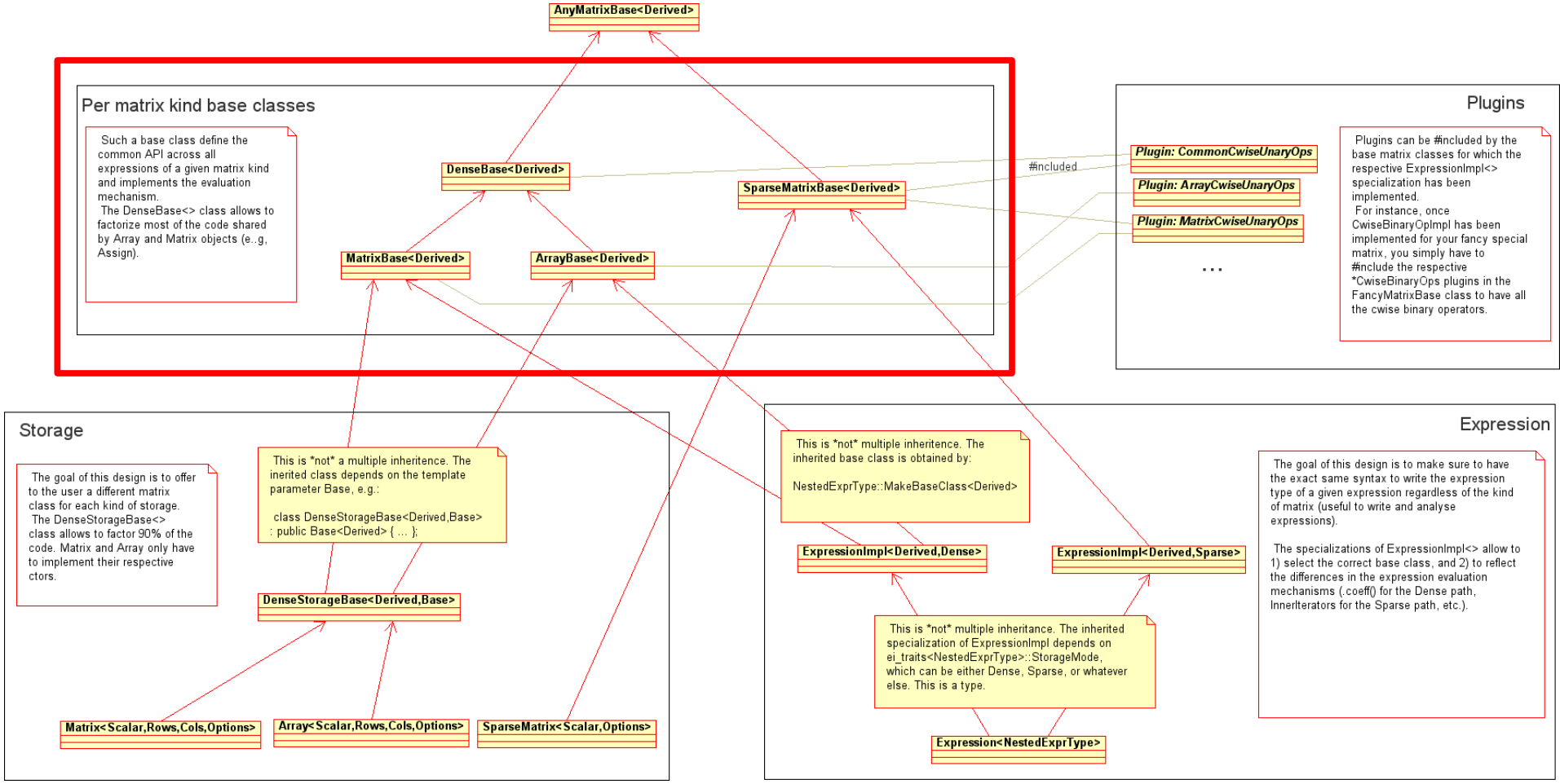
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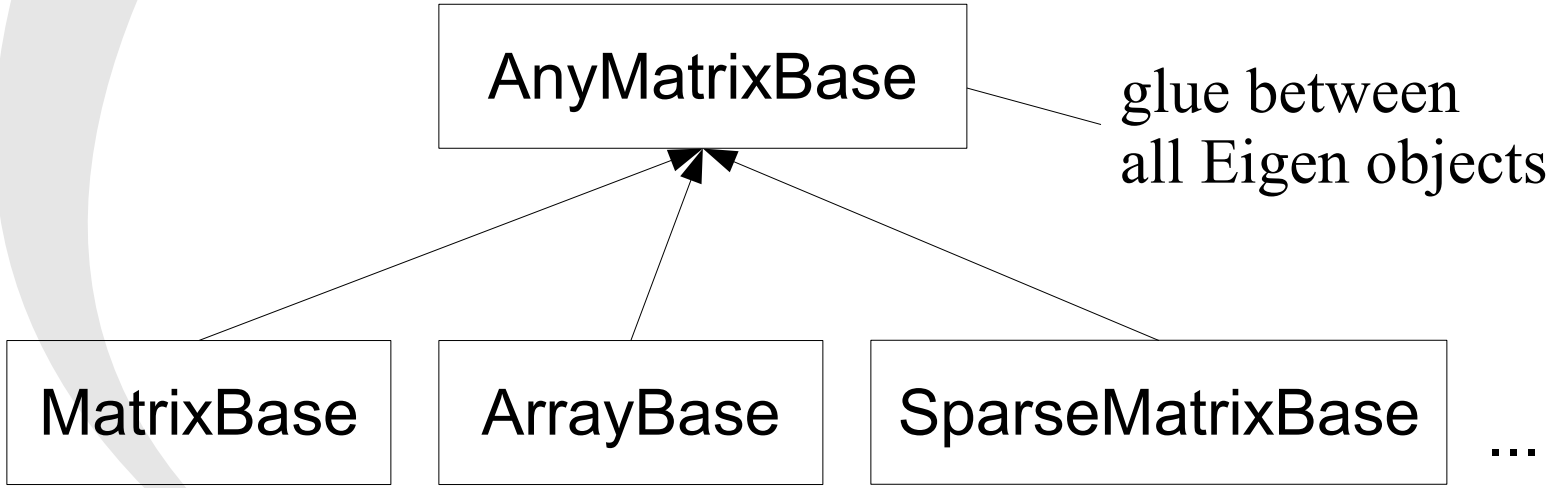
One base class per kind of matrix

- Why?
  - slightly different API
  - different evaluation mechanisms (coeff, iterators, etc.)



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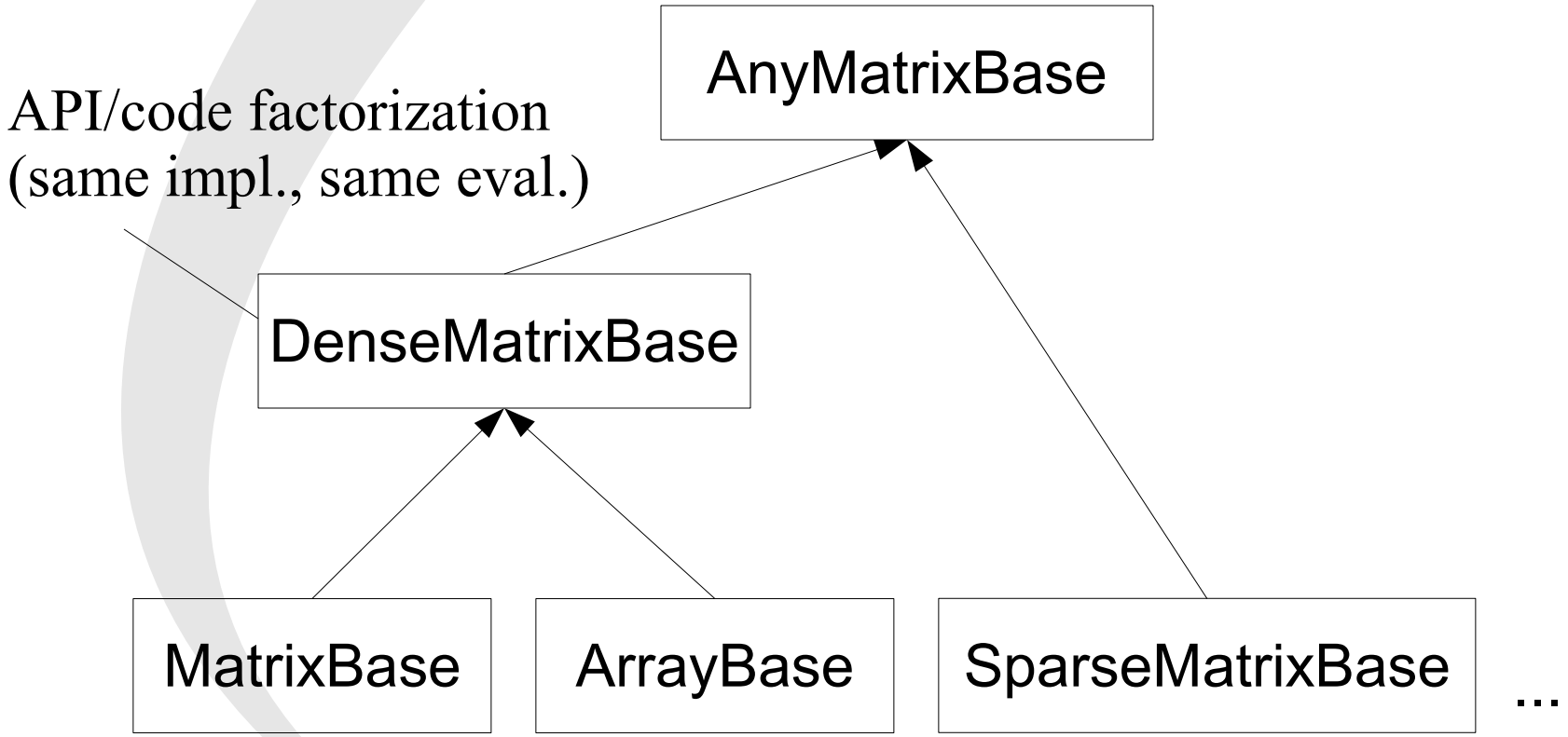

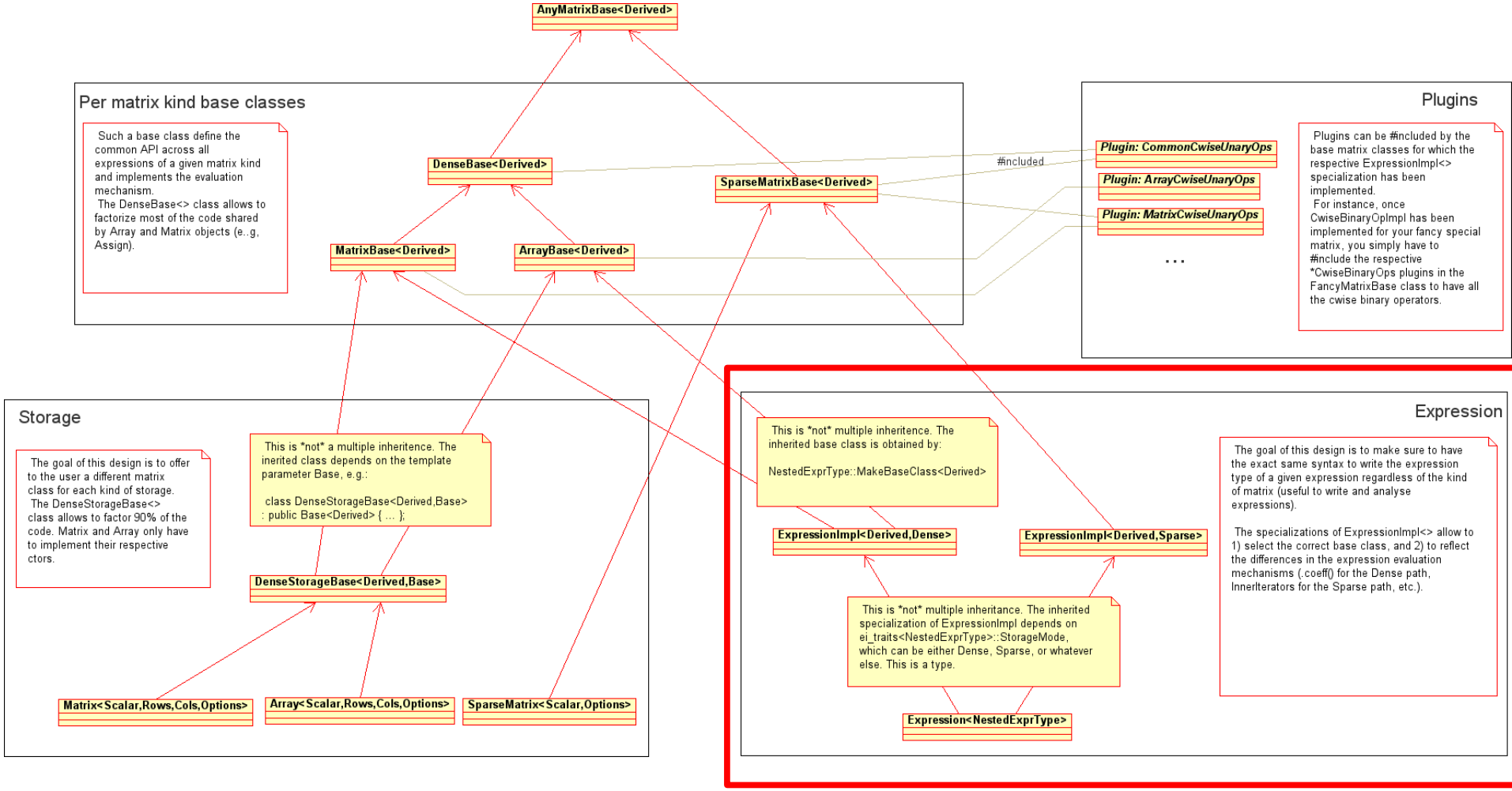
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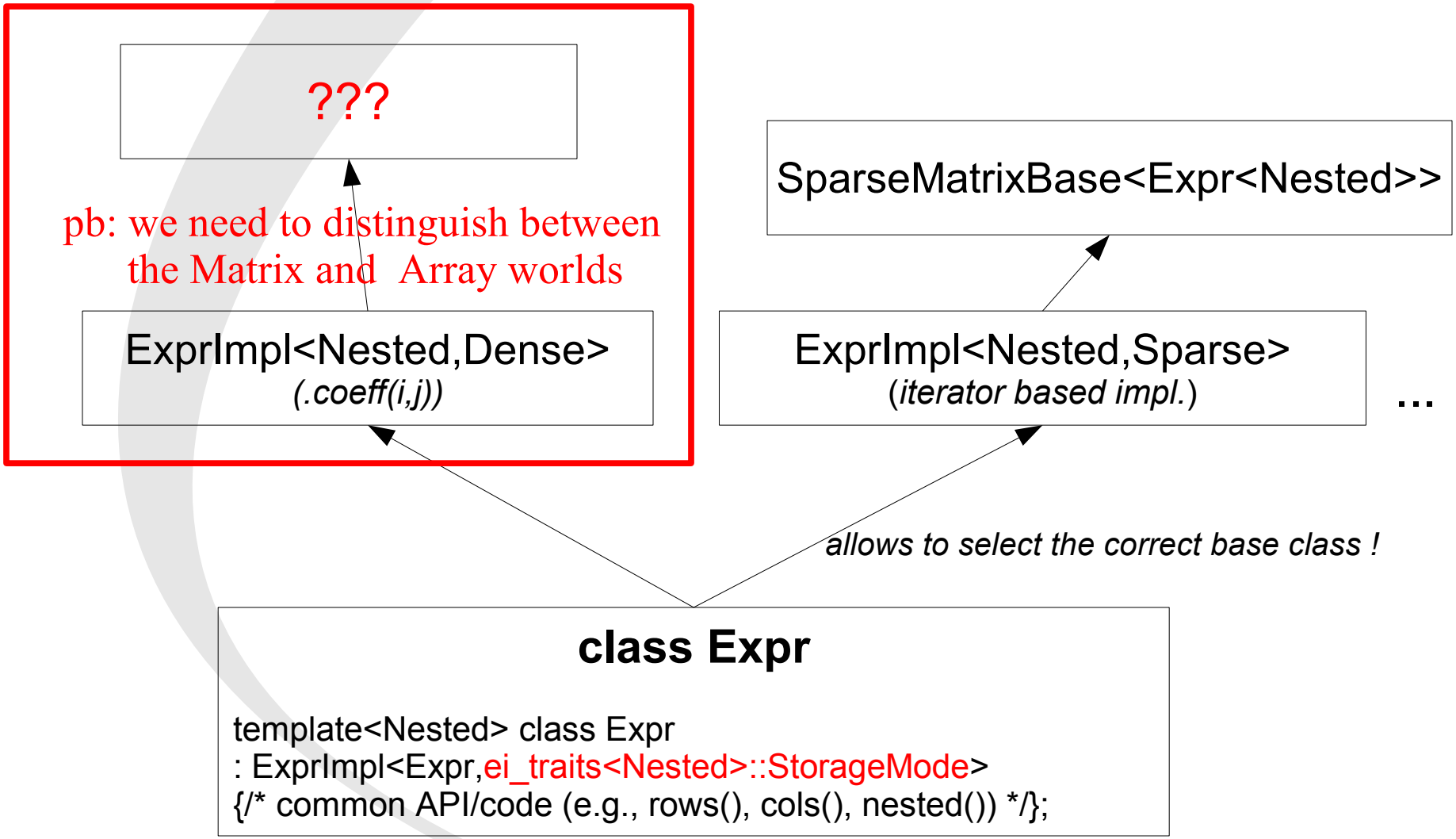
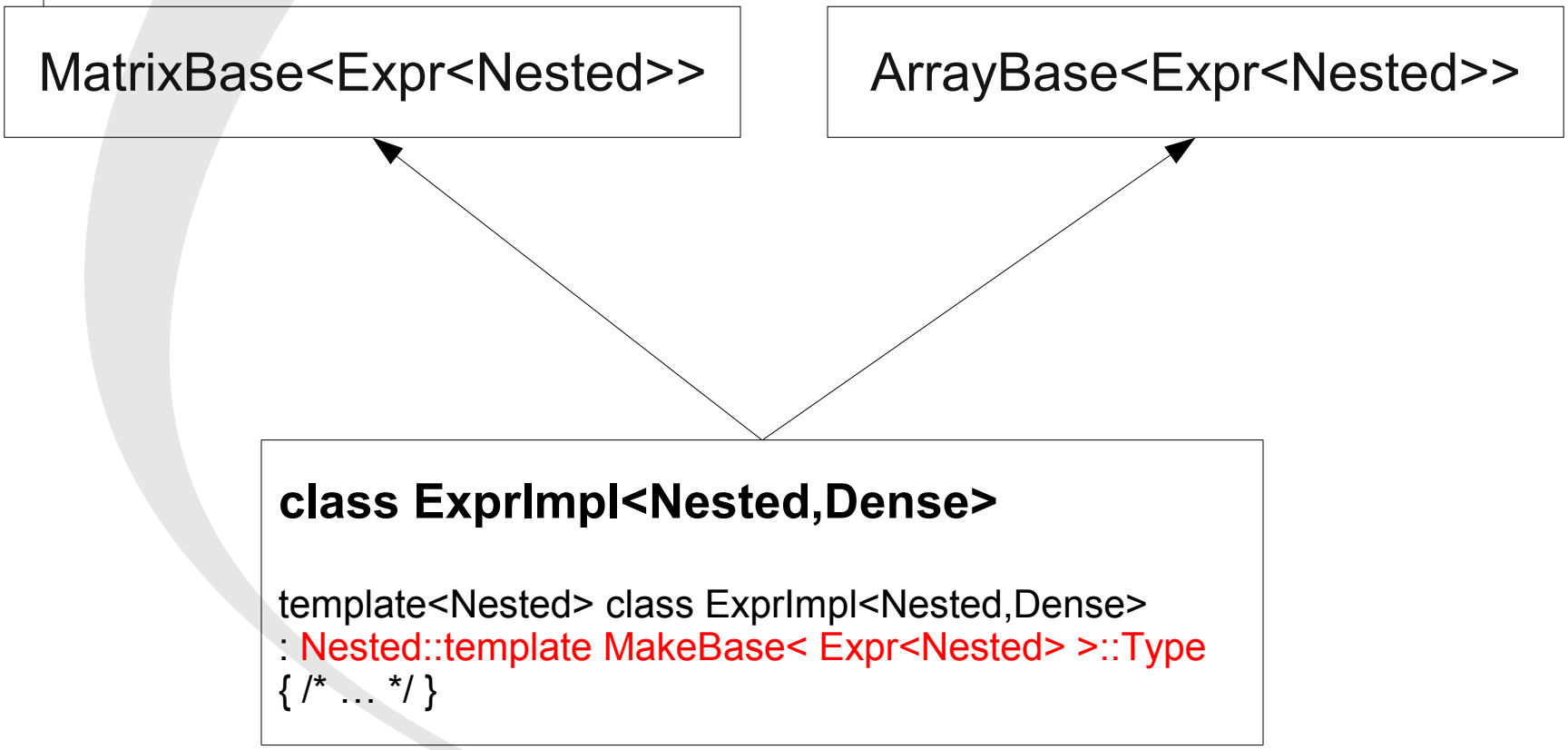
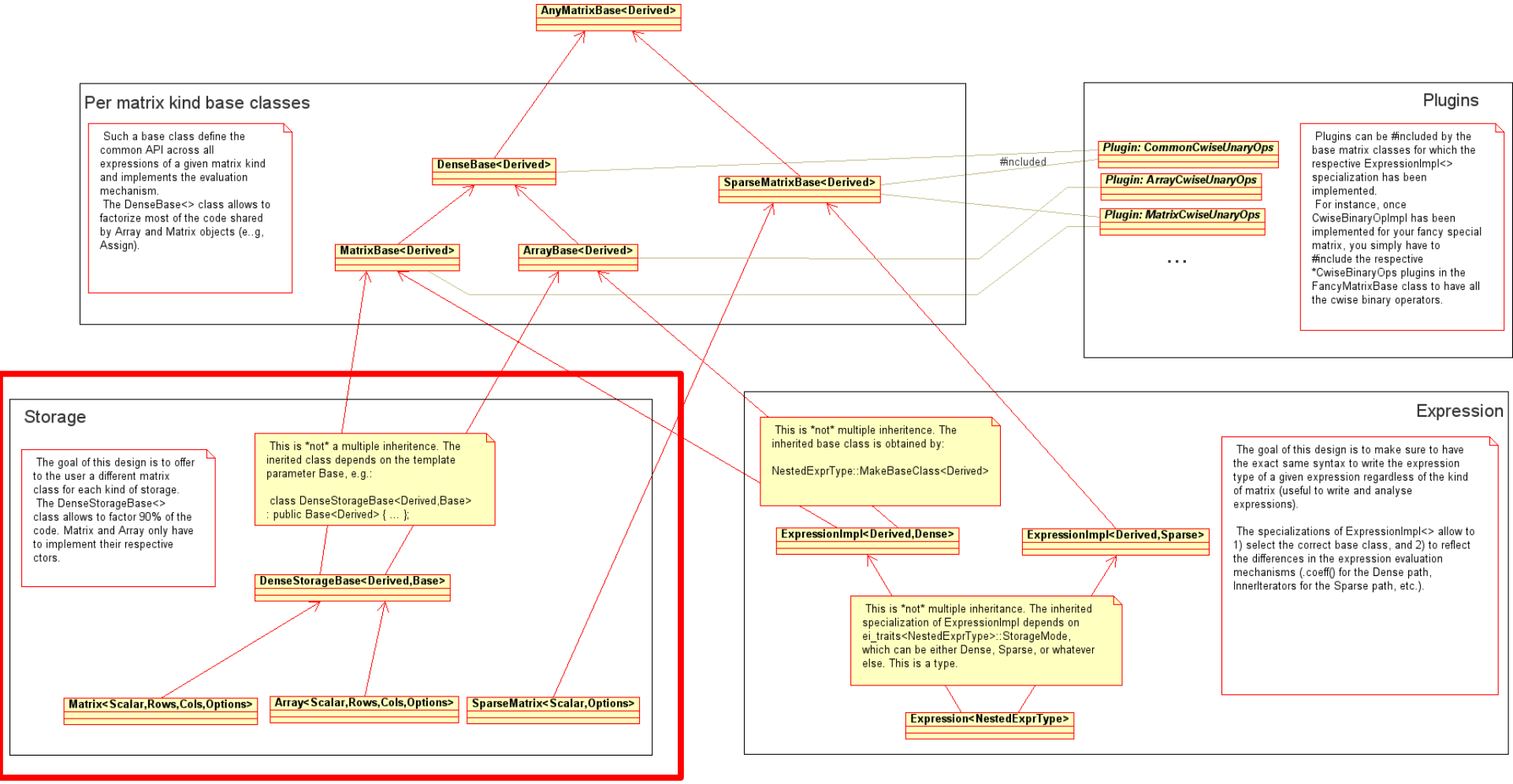
Semantic/implementation decoupling



Semantic/implementation decoupling

template <typename OtherDerived>
struct MakeBase { typedef MatrixBase<OtherDerived> Type; };

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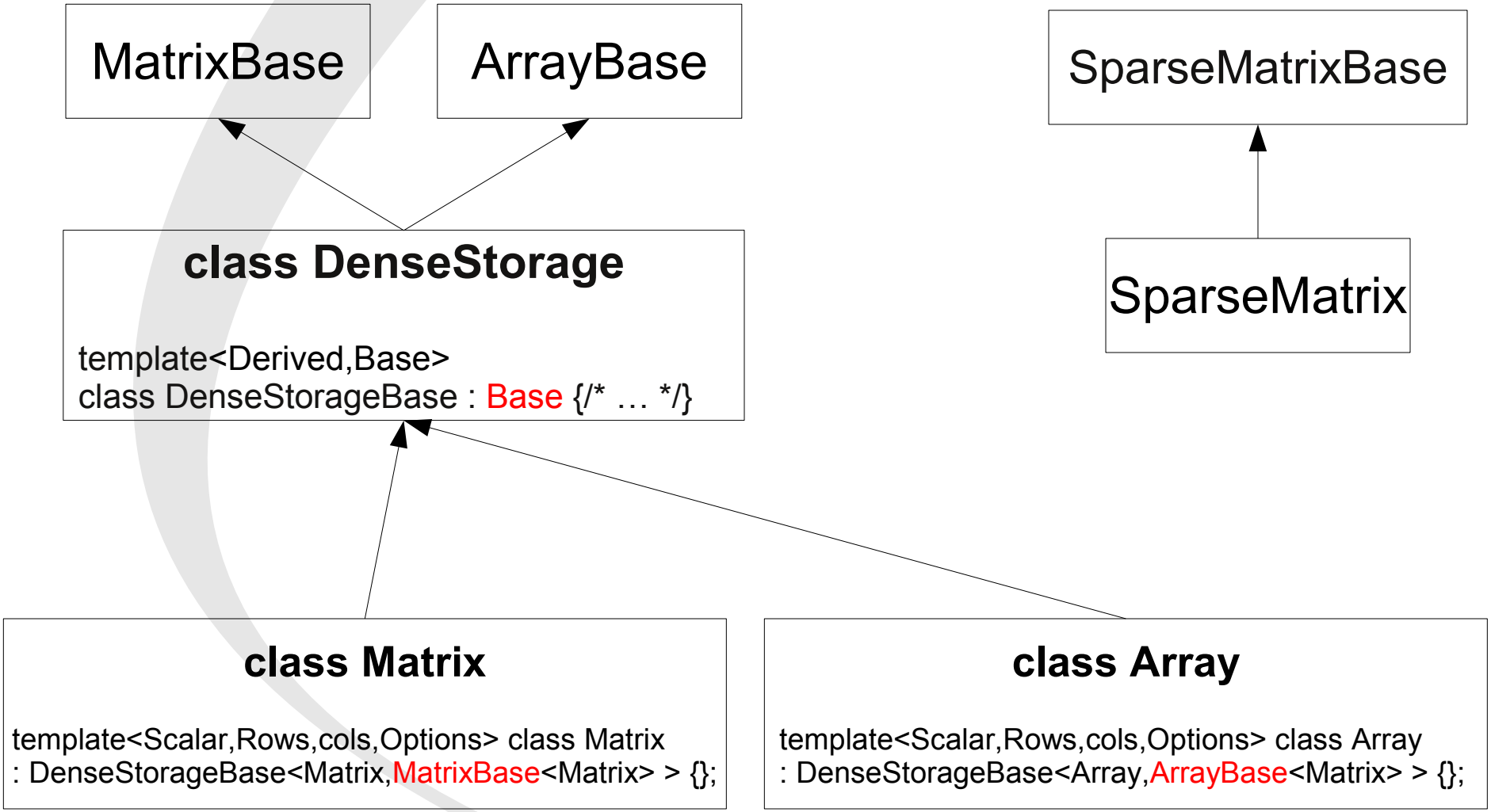

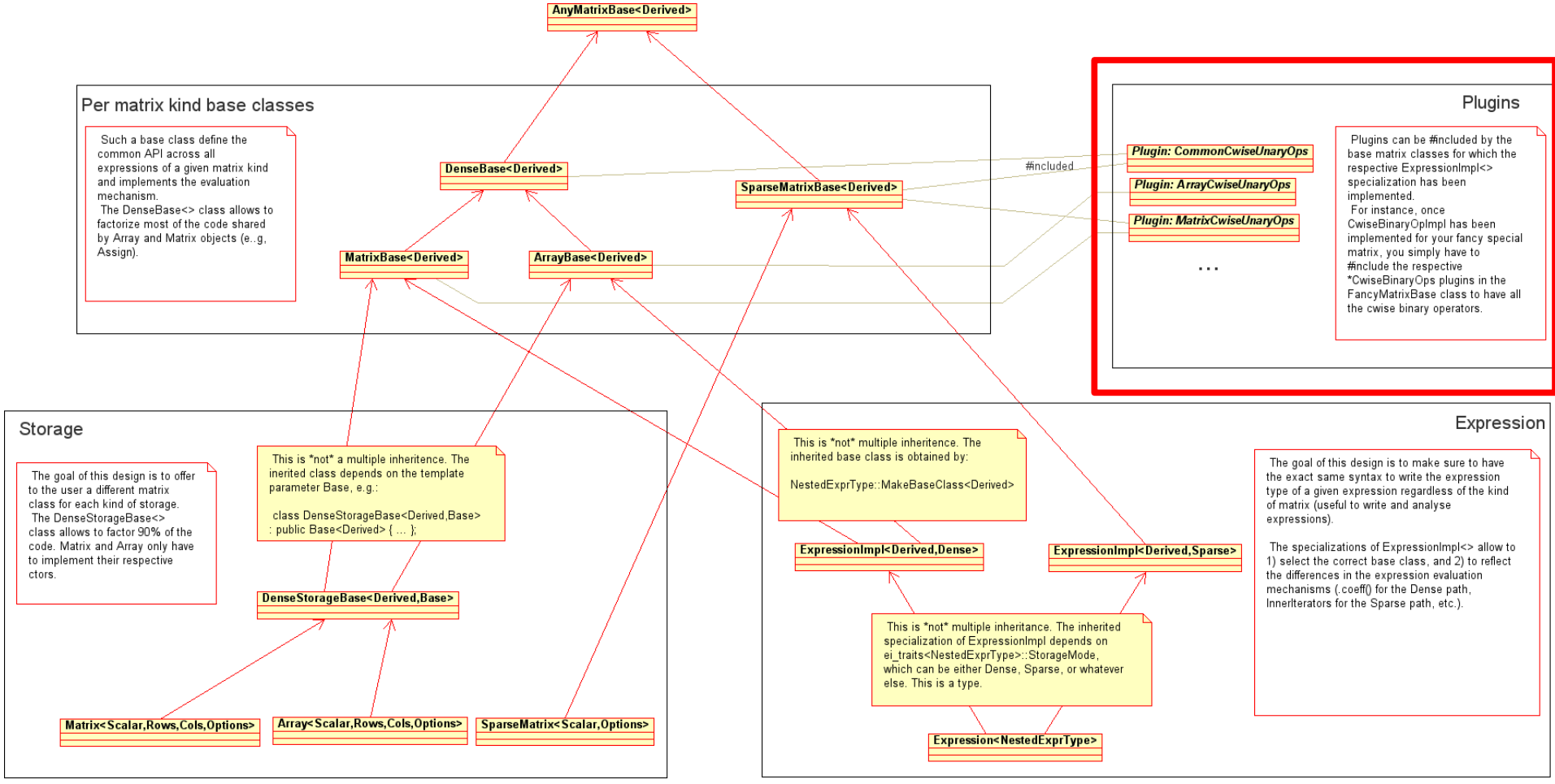
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Objective Zero Code Duplication

- How to factor common API between, e.g., Dense and Sparse objects ?
  - Notion of set of “features”:
    - one feature set per kind of expression (unary, binary, etc.)
    - split feature set wrt matrix/array world
  - create one “plugin” per feature set
    - 1 plugin = 1 header file
    - plugins are #included in the body of the base classes
  - examples:
    - common unary operators (e.g., minCoeff)
    - matrix specific binary operators (matrix product)
    - array specific binary operators (<,>,&,|,etc.)
    - etc.

Objective Zero Code Duplication

plugins/MatrixCwiseUnaryOps.h:

```
/** nice documentation here */
const CwiseUnaryOp<ei_scalar_abs_op<Scalar>,Derived> cwiseAbs() const { return derived(); }
/* … */
```

Core/MatrixBase.h

```
class MatrixBase {
#define EIGEN_CURRENT_STORAGE_BASE_CLASS Eigen::MatrixBase
#   include "../plugins/CommonCwiseUnaryOps.h"
#   include "../plugins/CommonCwiseBinaryOps.h"
#   include "../plugins/MatrixCwiseUnaryOps.h"
#   include "../plugins/MatrixCwiseBinaryOps.h"
#undef EIGEN_CURRENT_STORAGE_BASE_CLASS
};
```

plugins/MatrixCwiseBinaryOps.h:

```
template<typename OtherDerived>
const CwiseBinaryOp<max<Scalar>, Derived, OtherDerived>
cwiseMax(const EIGEN_CURRENT_STORAGE_BASE_CLASS<OtherDerived> &other) const
{
  return CwiseBinaryOp<max<Scalar>, Derived, OtherDerived>(derived(), other.derived());
}
```

Matrix products