

# Sage and Linear Algebra Worksheet

FCLA Section SD

Robert Beezer

Department of Mathematics and Computer Science

University of Puget Sound

Spring 2020

## 1 Similarity

We manufacture two matrices that are similar, and use Sage to check. A “unimodular” matrix is one with determinant 1. A unimodular matrix with integer entries will have an inverse with integer entries (that is a theorem, and Exercise PDM.M20).

```
A = random_matrix(ZZ, 10, x = -9, y = 9).change_ring(QQ)
S = random_matrix(QQ, 10, algorithm='unimodular',
    upper_bound=9)
B = S.inverse()*A*S
A, B
```

This next command might be broken, and might even just hang. My fault. It will be fixed, using rational canonical form, for Sage 7.6. See [Trac ticket #18505](#) for the details.

```
A.is_similar(B)
```

## 2 Diagonalization

These two matrices are from the earlier demo for Section EE. First is diagonalizable, second is not. The easiest way to see the difference is with the `eigenmatrix` commands.

**Demonstration 1** Diagonalize the matrix  $A$ .

```
A = matrix(QQ, [
    [-31, -23, -16, 12, 120, -17],
    [-3, 7, 0, -12, 60, -21],
    [-28, -14, -9, -4, 152, -30],
    [-36, -20, -16, -1, 192, -32],
    [-9, -5, -4, 0, 47, -8],
    [-1, 1, 0, -4, 20, -3]
])
A
```

$S$ , the matrix whose columns are eigenvectors, will “diagonalize”  $A$ .

```
D, S = A.eigenmatrix_right()
D, S
```

```
S.inverse()*A*S == D
```

Here is an equivalent formulation.

```
A*S == S*D
```

**Demonstration 2** Now, in contrast, a matrix that is not diagonalizable. Try to diagonalize the matrix  $C$ .

```
C = matrix(QQ, [
    [128, 20, 44, -50, 236, -18, -330, -565],
    [-23, -16, -5, 6, -40, 27, 62, 128],
    [-44, -12, -15, 16, -78, 20, 110, 207],
    [-2, 10, -4, 3, -10, -23, 20, -9],
    [-61, 5, -25, 27, -116, -26, 153, 225],
    [-12, -12, -1, 2, -20, 24, 34, 82],
    [-23, -3, -8, 9, -42, 2, 57, 99],
    [13, 6, 3, -4, 23, -12, -35, -72]
])
C
```

```
D, S = C.eigenmatrix_right()
D, S
```

The zero columns in  $S$  tell us that at least one eigenvalue has a geometric multiplicity strictly less than the algebraic multiplicity of the eigenvalue. So by Theorem DMFE the matrix  $C$  is not diagonalizable.

A second consequence of the zero columns of  $S$  is that it will not be an invertible matrix. But the output from Sage still obeys a fundamental relationship.

```
C*S == S*D
```

Perhaps simpler is the built-in function `.is_diagonalizable()`.

```
A.is_diagonalizable()
```

```
C.is_diagonalizable()
```

### 3 Nearly Diagonalizable

A matrix that is not diagonalizable will always be similar to a matrix that is *almost* diagonalizable. The “nearly diagonal” matrix is called the **Jordan canonical form** of the matrix.

**Demonstration 3** While beyond the scope of this course, use Sage to compute the Jordan canonical form for the matrix  $C$ . Notice the eigenvalues of  $C$  on the diagonal and the 1’s on the **super-diagonal**.

Peculiarly, the similarity matrix need not be computed to get the form, and it is a significant computational expense. So we ask for it explicitly.

```
J, T = C.jordan_form(transformation=True)
J, T
```

The transformation matrix,  $T$ , is invertible and will “almost diagonalize”  $C$ .

```
T.inverse()*C*T == J
```

**Demonstration 4 Rational canonical form** is another interesting version of this idea, try `.rational_form()` on  $C$ . And if you do, then execute the following two cells and see if the coefficients look familiar. Learn more about **companion matrices** if this makes you curious.

```
C.rational_form()
```

```
C.fcp()
```

```
((x-1)^3*(x+2)^3).expand()
```

This work is Copyright 2016–2019 by Robert A. Beezer. It is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/).