

**fullsvd()** — Full singular value decomposition

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## Description

`fullsvd(A, U, s, Vt)` calculates the singular value decomposition of  $m \times n$  matrix *A*, returning the result in *U*, *s*, and *Vt*. Singular values in *s* are sorted from largest to smallest.

`fullsdiag(s, k)` converts column vector *s* returned by `fullsvd()` into matrix *S*. In all cases, the appropriate call for this function is

$$S = \text{fullsdiag}(s, \text{rows}(A) - \text{cols}(A))$$

`_fullsvd(A, U, s, Vt)` does the same as `fullsvd()`, except that, in the process, it destroys *A*. Use of `_fullsvd()` in place of `fullsvd()` conserves memory.

`_svd_la()` is the interface into the [M-1] **LAPACK** SVD routines and is used in the implementation of the previous functions. There is no reason you should want to use it. `_svd_la()` is similar to `_fullsvd()`. It differs in that it returns a real scalar equal to 1 if the numerical routines fail to converge, and it returns 0 otherwise. The previous SVD routines set *s* to contain missing values in this unlikely case.

## Syntax

<i>void</i>	<code>fullsvd(numeric matrix <i>A</i>, <i>U</i>, <i>s</i>, <i>Vt</i>)</code>
<i>numeric matrix</i>	<code>fullsdiag(numeric colvector <i>s</i>, real scalar <i>k</i>)</code>
<i>void</i>	<code>_fullsvd(numeric matrix <i>A</i>, <i>U</i>, <i>s</i>, <i>Vt</i>)</code>
<i>real scalar</i>	<code>_svd_la(numeric matrix <i>A</i>, <i>U</i>, <i>s</i>, <i>Vt</i>)</code>

## Remarks and examples

Remarks are presented under the following headings:

- [Introduction](#)
- [Relationship between the full and thin SVDs](#)
- [The contents of \*s\*](#)
- [Possibility of convergence problems](#)

Documented here is the full SVD, appropriate in all cases, but of interest mainly when *A*:  $m \times n$ ,  $m < n$ . There is a thin SVD that conserves memory when  $m \geq n$ ; see [M-5] `svd()`. The relationship between the two is discussed in [Relationship between the full and thin SVDs](#) below.

## Introduction

The SVD is used to compute accurate solutions to linear systems and least-squares problems, to compute the 2-norm, and to determine the numerical rank of a matrix.

The singular value decomposition (SVD) of  $A: m \times n$  is given by

$$A = USV'$$

where

$$\begin{aligned} U: & \quad m \times m \text{ and orthogonal (unitary)} \\ S: & \quad m \times n \text{ and diagonal} \\ V: & \quad n \times n \text{ and orthogonal (unitary)} \end{aligned}$$

When  $A$  is complex, the transpose operator  $'$  is understood to mean the conjugate transpose operator.

Diagonal matrix  $S$  contains the singular values and those singular values are real even when  $A$  is complex. It is usual (but not required) that  $S$  is arranged so that the largest singular value appears first, then the next largest, and so on. The SVD routines documented here do this.

The full SVD routines return  $U$  and  $Vt = V'$ .  $S$  is returned as a column vector  $s$ , and  $S$  can be obtained by

$$S = \text{fullsdiag}(s, \text{rows}(A) - \text{cols}(A))$$

so we will write the SVD as

$$A = U * \text{fullsdiag}(s, \text{rows}(A) - \text{cols}(A)) * Vt$$

Function `fullsvd(A, U, s, Vt)` returns the  $U$ ,  $s$ , and  $Vt$  corresponding to  $A$ .

## Relationship between the full and thin SVDs

A popular variant of the SVD is known as the thin SVD and is suitable for use when  $m \geq n$ . Both SVDs have the same formula,

$$A = USV'$$

but  $U$  and  $S$  have reduced dimensions in the thin version:

Matrix	Full SVD	Thin SVD
$U:$	$m \times m$	$m \times n$
$S:$	$m \times n$	$n \times n$
$V:$	$n \times n$	$n \times n$

When  $m = n$ , the two variants are identical.

The thin SVD is of use when  $m > n$ , because then only the first  $m$  diagonal elements of  $S$  are nonzero, and therefore only the first  $m$  columns of  $U$  are relevant in  $A = USV'$ . There are considerable memory savings to be had in calculating the thin SVD when  $m \gg n$ .

As a result, many people call the thin SVD the SVD and ignore the full SVD altogether. If the matrices you deal with have  $m \geq n$ , you will want to do the same. To obtain the thin SVD, see [\[M-5\] svd\(\)](#).

Regardless of the dimension of your matrix, you may wish to obtain only the singular values. In this case, see `svdsv()` documented in [\[M-5\] svd\(\)](#). That function is appropriate in all cases.

## The contents of $s$

Given  $A: m \times n$ , the singular values are returned in  $s: \min(m, n) \times 1$ .

Let's consider the  $m = n$  case first.  $A$  is  $m \times m$  and the  $m$  singular values are returned in  $s$ , an  $m \times 1$  column vector. If  $A$  were  $3 \times 3$ , perhaps we would get back

```
: s
      1
  1  13.47
  2   5.8
  3   2.63
```

If we needed it, we could obtain  $S$  from  $s$  simply by creating a diagonal matrix from  $s$

```
: S = diag(s)
: S
[symmetric]
      1      2      3
  1  13.47
  2    0   5.8
  3    0    0   2.63
```

although the official way we are supposed to do this is

```
: S = fullsdiag(s, rows(A)-cols(A))
```

and that will return the same result.

Now let's consider  $m < n$ . Let's pretend that  $A$  is  $3 \times 4$ . The singular values will be returned in  $3 \times 1$  vector  $s$ . For instance,  $s$  might still contain

```
: s
      1
  1  13.47
  2   5.8
  3   2.63
```

The  $S$  matrix here needs to be  $3 \times 4$ , and `fullsdiag()` will form it:

```
: fullsdiag(s, rows(A)-cols(A))
      1      2      3      4
  1  13.47    0    0    0
  2    0   5.8    0    0
  3    0    0   2.63    0
```

The final case is  $m > n$ . We will pretend that  $A$  is  $4 \times 3$ . The  $s$  vector we get back will look the same

```

: s
      1
1  13.47
2   5.8
3   2.63
    
```

but this time, we need a  $4 \times 3$  rather than a  $3 \times 4$  matrix formed from it.

```

: fullsdiag(s, rows(A)-cols(A))
      1      2      3
1  13.47      0      0
2      0    5.8      0
3      0      0    2.63
4      0      0      0
    
```

## Possibility of convergence problems

See *Possibility of convergence problems* in [M-5] `svd()`; what is said there applies equally here.

## Conformability

`fullsvd(A, U, s, Vt)`:

*input:*

*A:*  $m \times n$

*output:*

*U:*  $m \times m$

*s:*  $\min(m, n) \times 1$

*Vt:*  $n \times n$

*result:* *void*

`fullsdiag(s, k)`:

*input:*

*s:*  $r \times 1$

*k:*  $1 \times 1$

*output:*

*result:*  $r + k \times r$ , if  $k \geq 0$

$r \times r - k$ , otherwise

`_fullsvd(A, U, s, Vt)`:

*input:*

*A:*  $m \times n$

*output:*

*A:*  $0 \times 0$

*U:*  $m \times m$

*s:*  $\min(m, n) \times 1$

*Vt:*  $n \times n$

*result:* *void*

`_svd_la(A, U, s, Vt)`:

*input:*

$A$ :  $m \times n$

*output:*

$A$ :  $m \times n$ , but contents changed

$U$ :  $m \times m$

$s$ :  $\min(m, n) \times 1$

$Vt$ :  $n \times n$

*result:*  $1 \times 1$

## Diagnostics

`fullsvd(A, U, s, Vt)` and `_fullsvd(A, s, Vt)` return missing results if  $A$  contains missing. In all other cases, the routines should work, but there is the unlikely possibility of convergence problems, in which case missing results will also be returned; see [Possibility of convergence problems](#) in [M-5] `svd()`.

`_fullsvd()` aborts with error if  $A$  is a view.

Direct use of `_svd_la()` is not recommended.

## Also see

[M-5] `svd()` — Singular value decomposition

[M-5] `svsolve()` — Solve  $AX=B$  for  $X$  using singular value decomposition

[M-5] `pinv()` — Moore–Penrose pseudoinverse

[M-5] `norm()` — Matrix and vector norms

[M-5] `rank()` — Rank of matrix

[M-4] `matrix` — Matrix functions