## Lecture 8 - UM 102 (Spring 2021)

Vamsi Pritham Pingali

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# Recap

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- Defined row space, column space, and stated that row rank=column rank=rank as a linear map.

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  - If the rank is *n*: The column space is all of  $\mathbb{F}^n$ . Hence  $T(e_1), T(e_2), \ldots T(e_n)$  form a basis.

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  - If the rank is n: The column space is all of 𝔽<sup>n</sup>. Hence
     T(e<sub>1</sub>), T(e<sub>2</sub>), ..., T(e<sub>n</sub>) form a basis. Therefore T is invertible.

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- By nullity-rank theorem,

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- We need to form *n* augmented matrices  $[A|e_1], [A|e_2], \dots, [A|e_n].$
- Unless the resulting equations are *inconsistent*, that is, A is not invertible, one can bring *all n* augmented matrices to their RREFs simultaneously, by the *same* row operations. (Indeed, the A part is the same for all *n* matrices.)
- So in practice, one applies row operations to [A|I] to get [I|A<sup>-1</sup>]. (After all, if the column rank is full, then the RREF *is* I.) Note that this procedue also lets us know whether A is invertible or not.
- On paper, if A is invertible, and we know the inverse A<sup>-1</sup>, any linear system Ax = b can be solved using x = A<sup>-1</sup>b. However, in practice, computing the inverse is inefficient and subject to rounding-off errors.

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$$\begin{bmatrix} 1 & 1 & 2 & 0 & 0 & 1 \\ 2 & 1 & 1 & 0 & 1 & 0 \\ 2 & 3 & 4 & 1 & 0 & 0 \end{bmatrix}.$$

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- Determine if  $A = \begin{bmatrix} 2 & 3 & 4 \\ 2 & 1 & 1 \\ -1 & 1 & 2 \end{bmatrix}$  is invertible. If so, find the inverse.
- We must row-reduce [A|I].  $R_1 \leftrightarrow R_3$  and  $R_1 \rightarrow -R_1$ :  $\begin{bmatrix} 1 & -1 & -2 & | & 0 & 0 & -1 \\ 2 & 1 & 1 & | & 0 & 1 & 0 \\ 2 & 3 & 4 & | & 1 & 0 & 0 \end{bmatrix}$ . • To clear the first column,  $R_2 \rightarrow R_2 - 2R_1, R_3 \rightarrow R_3 - 2R_1$ :  $\begin{bmatrix} 1 & -1 & -2 & | & 0 & 0 & -1 \\ 0 & 3 & 5 & | & 0 & 1 & 2 \\ 0 & 5 & 8 & | & 1 & 0 & 2 \end{bmatrix}$ .

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$$R_2 \to R_2/3$$
,  $R_3 \to R_3 - 5R_2$ ,

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$$R_2 \to R_2/3, R_3 \to R_3 - 5R_2,$$
  
 $R_1 \to R_1 + R_2: \begin{bmatrix} 1 & 0 & -\frac{1}{3} & 0 & \frac{1}{3} & -\frac{1}{3} \\ 0 & 1 & \frac{5}{3} & 0 & \frac{1}{3} & \frac{2}{3} \\ 0 & 0 & -\frac{1}{3} & 1 & -\frac{5}{3} & -\frac{4}{3} \end{bmatrix}.$ 

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 $\begin{bmatrix} 1 & 0 & 0 & -1 & 2 & 1 \\ 0 & 1 & 0 & 5 & -8 & -6 \\ 0 & 0 & 1 & -3 & 5 & 4 \end{bmatrix}.$ 

Lecture 8

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•  $R_3 \to -3R_3$ ,  $R_2 \to R_2 - \frac{5}{3}R_3$ ,  $R_1 \to R_1 + \frac{1}{3}R_3$ :  
 $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} -1 = 2 = 1$   
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#### Elementary row matrices

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## Elementary row matrices

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- *R<sub>i</sub>* → *cR<sub>i</sub>* (*c* ≠ 0): *B* = *E*<sub>2</sub>*A* where *E*<sub>2</sub> is again obtained the same way. Its *i<sup>th</sup>* row has *c* instead of 1.

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- $R_i \rightarrow cR_i \ (c \neq 0)$ :  $B = E_2A$  where  $E_2$  is again obtained the same way. Its *i*<sup>th</sup> row has *c* instead of 1. Its inverse has  $\frac{1}{c}$  instead of 1.
- $R_i \rightarrow R_i + cR_j$ :  $B = E_3A$  where  $E_3$  is obtained similarly. Its inverse is obtained by replacing c with -c.

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- $R_i \rightarrow R_i + cR_j$ :  $B = E_3A$  where  $E_3$  is obtained similarly. Its inverse is obtained by replacing c with -c.
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- $R_i \rightarrow R_i + cR_j$ :  $B = E_3A$  where  $E_3$  is obtained similarly. Its inverse is obtained by replacing c with -c.
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- *R<sub>i</sub>* ↔ *R<sub>j</sub>*: *B* = *E*<sub>1</sub>*A* where *E*<sub>1</sub> is the matrix obtained by interchanging the rows of *I<sub>m×m</sub>*. It is invertible with the inverse being itself.
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- So row-reduction is equivalent to left-multiplying with a product of elementary row matrices. So if row-reduction leads to *I*, , then *EA* = *I* and hence

- $R_i \leftrightarrow R_i$ :  $B = E_1 A$  where  $E_1$  is the matrix obtained by interchanging the rows of  $I_{m \times m}$ . It is invertible with the inverse being itself.
- $R_i \rightarrow cR_i$  ( $c \neq 0$ ):  $B = E_2A$  where  $E_2$  is again obtained the same way. Its *i*<sup>th</sup> row has c instead of 1. Its inverse has  $\frac{1}{2}$ instead of 1.
- $R_i \rightarrow R_i + cR_i$ :  $B = E_3A$  where  $E_3$  is obtained similarly. Its inverse is obtained by replacing c with -c.
- So row-reduction is equivalent to left-multiplying with a product of elementary row matrices. So if row-reduction leads to I, , then EA = I and hence  $A^{-1} = E$ .