

## Homework 1 Partial Solutions

### Homework 1 problems:

#### Section 1.1

8. Use elimination and back substitution to solve the given system:

$$x_1 + 2x_2 - 2x_3 = 1$$

$$2x_1 + 5x_2 + x_3 = 9$$

$$x_1 + 3x_2 + 4x_3 = 9$$

Elimination on the augmented system looks like:

$$\left[ \begin{array}{ccc|c} 1 & 2 & -2 & 1 \\ 2 & 5 & 1 & 9 \\ 1 & 3 & 4 & 9 \end{array} \right] \xrightarrow[r_3 - r_1 \rightarrow r_3]{r_2 - 2r_1 \rightarrow r_2} \left[ \begin{array}{ccc|c} 1 & 2 & -2 & 1 \\ 0 & 1 & 5 & 7 \\ 0 & 1 & 6 & 8 \end{array} \right] \xrightarrow{r_3 - r_2 \rightarrow r_3} \left[ \begin{array}{ccc|c} 1 & 2 & -2 & 1 \\ 0 & 1 & 5 & 7 \\ 0 & 0 & 1 & 1 \end{array} \right]$$

This gives the triangular system

$$x_1 + 2x_2 - 2x_3 = 1$$

$$x_2 + 5x_3 = 7$$

$$x_3 = 1$$

Back substitution gives:

$$x_2 = 7 - 5(1) = 2$$

$$x_1 = 1 + 2(1) - 2(2) = -1$$

So we have the solution  $(-1, 2, 1)$ . (Check this in the initial system!)

9.

(a) Suppose  $m_1 \neq m_2$ . Assume  $m_1 \neq 0$ . (If  $m_1 = 0$ , then  $m_2 \neq 0$  by our assumption so we could just swap the rolls below.) Multiply the first equation by  $-m_2/m_1$  add to the second

and replace the second. This yields the new system:

$$\begin{aligned} -m_1x_1 + x_2 &= b_1 \\ (1 - m_2/m_1)x_2 &= b_2 - (m_2/m_1)b_1 \end{aligned}$$

Now you can use back substitution:

$$\begin{aligned} x_2 &= \frac{b_2 - (m_2/m_1)b_1}{1 - m_2/m_1} = \frac{m_1b_2 - m_2b_1}{m_1 - m_2} && (\text{ok since } m_1 \neq m_2) \\ x_1 &= -\frac{b_1 - x_2}{m_1} = \frac{2m_2b_1 - m_1(b_1 + b_2)}{m_1(m_1 - m_2)} \end{aligned}$$

So we have a unique solution.

(b) If  $m_1 = m_2$ , then the system is just

$$\begin{aligned} -m_1x_1 + x_2 &= b_1 \\ -m_1x_1 + x_2 &= b_2 \end{aligned}$$

This is equivalent to the single equation  $-m_1x_1 + x_2 = b_1$  if  $b_1 = b_2$ , else you get  $0 = b_2 - b_1 \neq 0$  which cannot happen.

(c) For (a) saying  $m_1 \neq m_2$  is equivalent to saying that the two lines have different slopes and hence have a unique point of intersection. For (b), if  $m_1 = m_2$ , the lines are parallel, they are the same line if  $b_1 = b_2$ , else they are distinct parallel lines and hence never intersect.

## Section 1.2

5.

(c)

$$\begin{aligned} x_1 + x_2 &= 0 \\ 2x_1 + 3x_2 &= 0 \\ 3x_1 - 2x_2 &= 0 \end{aligned}$$

Gaussian Elimination looks like

$$\left[ \begin{array}{cc|c} 1 & 1 & 0 \\ 2 & 3 & 0 \\ 3 & -2 & 0 \end{array} \right] \xrightarrow[r_3 - 3r_1 \rightarrow r_3]{r_2 - 2r_1 \rightarrow r_2} \left[ \begin{array}{cc|c} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & -5 & 0 \end{array} \right] \xrightarrow{r_3 + 5r_2 \rightarrow r_3} \left[ \begin{array}{cc|c} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{array} \right]$$

This results in the triangular system

$$\begin{aligned} x_1 + x_2 &= 0 \\ x_2 &= 0 \end{aligned}$$

Which is solved by back substitution to give:  $x_2 = 0$ , and  $x_1 = -x_2 = 0$ .

(d)

$$\begin{aligned} 3x_1 + 2x_2 - x_3 &= 4 \\ x_1 - 2x_2 + 2x_3 &= 1 \\ 11x_1 + 2x_2 + x_3 &= 14 \end{aligned}$$

Gaussian Elimination looks like

$$\begin{aligned} \left[ \begin{array}{ccc|c} 3 & 2 & -1 & 4 \\ 1 & -2 & 2 & 1 \\ 11 & 2 & 1 & 14 \end{array} \right] &\xrightarrow{r_1 \leftrightarrow r_2} \left[ \begin{array}{ccc|c} 1 & -2 & 2 & 1 \\ 3 & 2 & -1 & 4 \\ 11 & 2 & 1 & 14 \end{array} \right] \xrightarrow{\substack{r_2 - 3r_1 \rightarrow r_2 \\ r_3 - 11r_1 \rightarrow r_3}} \\ \left[ \begin{array}{ccc|c} 1 & -2 & 2 & 1 \\ 0 & 8 & -7 & 1 \\ 0 & 24 & -21 & 3 \end{array} \right] &\xrightarrow{r_3 - 3r_2 \rightarrow r_3} \left[ \begin{array}{ccc|c} 1 & -2 & 2 & 1 \\ 0 & 8 & -7 & 1 \\ 0 & 0 & 0 & 0 \end{array} \right] \end{aligned}$$

This is equivalent to the "triangular system"

$$\begin{aligned} x_1 - 2x_2 + 2x_3 &= 1 \\ 8x_2 - 7x_3 &= 1 \end{aligned}$$

So  $x_1$  and  $x_2$  are the two "pivot variables" and  $x_3$  is the "free variable." Let  $x_3 = t$  be any value, then we use back substitution to get:

$$\begin{aligned} x_2 &= 1/8 + 7/8t \\ x_1 - 2(1/8 + 7/8t) + 2t &= 1 \\ x_1 &= 5/4 - 1/4t \end{aligned}$$

So

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 5/4 - 1/4t \\ 1/8 + 7/8t \\ t \end{bmatrix} = \begin{bmatrix} 5/4 \\ 1/8 \\ 0 \end{bmatrix} + t \begin{bmatrix} -1/4 \\ 7/8 \\ 1 \end{bmatrix}$$

(e)

$$\begin{aligned} 2x_1 + 3x_2 + x_3 &= 1 \\ x_1 + x_2 + x_3 &= 3 \\ 3x_1 + 4x_2 + 2x_3 &= 4 \end{aligned}$$

Elimination on the augmented system looks like:

$$\left[ \begin{array}{ccc|c} 2 & 3 & 1 & 1 \\ 1 & 1 & 1 & 3 \\ 3 & 4 & 2 & 4 \end{array} \right] \xrightarrow{r_1 \leftrightarrow r_2} \left[ \begin{array}{ccc|c} 1 & 1 & 1 & 3 \\ 2 & 3 & 1 & 1 \\ 3 & 4 & 2 & 4 \end{array} \right] \xrightarrow{\substack{r_2 - 2r_1 \rightarrow r_2 \\ r_3 - 3r_1 \rightarrow r_3}} \left[ \begin{array}{ccc|c} 1 & 1 & 1 & 3 \\ 0 & 1 & -1 & -5 \\ 0 & 1 & -1 & -5 \end{array} \right] \xrightarrow{r_3 - r_2 \rightarrow r_3} \left[ \begin{array}{ccc|c} 1 & 1 & 1 & 3 \\ 0 & 1 & -1 & -5 \\ 0 & 0 & 0 & 0 \end{array} \right]$$

The echelon form of the matrix coefficient matrix is now shown.

This system is consistent. if we let  $x_3 = t$ , then by back substitution get

$$\begin{aligned}x_3 &= t \\x_2 &= -5 + t \\x_1 &= 3 - t - (-5 + t) = 8 - 2t\end{aligned}$$

so the solution set is

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 8 \\ -5 \\ 0 \end{bmatrix} + t \begin{bmatrix} -2 \\ 1 \\ 1 \end{bmatrix}$$

8. For what values of  $a$  does the following have a unique solution?

$$\left[ \begin{array}{ccc|c} 1 & 2 & 1 & 1 \\ -1 & 4 & 3 & 2 \\ 2 & -2 & a & 3 \end{array} \right]$$

$$\begin{aligned} \left[ \begin{array}{ccc|c} 1 & 2 & 1 & 1 \\ -1 & 4 & 3 & 2 \\ 2 & -2 & a & 3 \end{array} \right] & \xrightarrow[r_3 - 2r_1 \rightarrow r_3]{r_2 + r_1 \rightarrow r_2} \left[ \begin{array}{ccc|c} 1 & 2 & 1 & 1 \\ 0 & 6 & 4 & 3 \\ 0 & -6 & a - 2 & 1 \end{array} \right] \\ & \xrightarrow{r_3 + r_2 \rightarrow r_3} \left[ \begin{array}{ccc|c} 1 & 2 & 1 & 3 \\ 0 & 6 & 4 & -5 \\ 0 & 0 & a + 2 & 4 \end{array} \right] \end{aligned}$$

All that is required to get a unique solution is that  $a + 2 \neq 0$  or  $a \neq -2$ .

11. Solve

$$\begin{aligned}x_1 + 2x_2 &= 2 & x_1 + 2x_2 &= 1 \\ 3x_1 + 7x_2 &= 8 & 3x_1 + 7x_2 &= 7\end{aligned}$$

Set this up as:

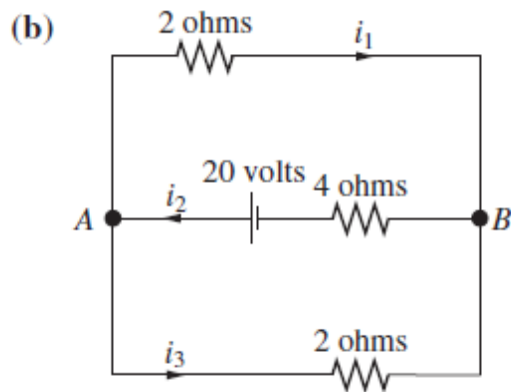
$$\left[ \begin{array}{cc|cc} 1 & 2 & 2 & 1 \\ 3 & 7 & 8 & 7 \end{array} \right] \xrightarrow{r_2 - 3r_1 \rightarrow r_2} \left[ \begin{array}{cc|cc} 1 & 2 & 2 & 1 \\ 0 & 1 & 2 & 4 \end{array} \right] \xrightarrow{r_1 - 2r_2 \rightarrow r_1} \left[ \begin{array}{cc|cc} 1 & 0 & -2 & -7 \\ 0 & 1 & 2 & 4 \end{array} \right]$$

So the solutions are

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} -2 \\ 2 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} -7 \\ 4 \end{bmatrix}$$

respectively. As usual, you should check this.

(b)



From this we have

$$\begin{aligned} i_1 - i_2 + i_3 &= 0 && \text{(node B)} \\ -i_1 + i_2 - i_3 &= 0 && \text{(node A)} \\ 2i_1 + 4i_2 &= 20 && \text{(top loop)} \\ 4i_2 + 2i_3 &= 20 && \text{(bottom loop)} \end{aligned}$$

This gives

$$\begin{aligned} \left[ \begin{array}{ccc|c} 1 & -1 & 1 & 0 \\ -1 & 1 & -1 & 0 \\ 2 & 4 & 0 & 20 \\ 0 & 4 & 2 & 20 \end{array} \right] &\xrightarrow{\substack{r_2 + r_1 \rightarrow r_2 \\ r_3 - 2r_1 \rightarrow r_3}} \left[ \begin{array}{ccc|c} 1 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 6 & -2 & 20 \\ 0 & 4 & 2 & 20 \end{array} \right] \\ &\xrightarrow{\substack{r_2 \leftrightarrow r_4 \\ 1/2r_2 \rightarrow r_2 \\ 1/2r_3 \rightarrow r_3}} \left[ \begin{array}{ccc|c} 1 & -1 & 1 & 0 \\ 0 & 2 & 1 & 10 \\ 0 & 3 & -1 & 10 \\ 0 & 0 & 0 & 0 \end{array} \right] \\ &\xrightarrow{r_3 - 3/2r_2 \rightarrow r_3} \left[ \begin{array}{ccc|c} 1 & -1 & 1 & 0 \\ 0 & 2 & 1 & 10 \\ 0 & 0 & -5/2 & -5 \\ 0 & 0 & 0 & 0 \end{array} \right] \end{aligned}$$

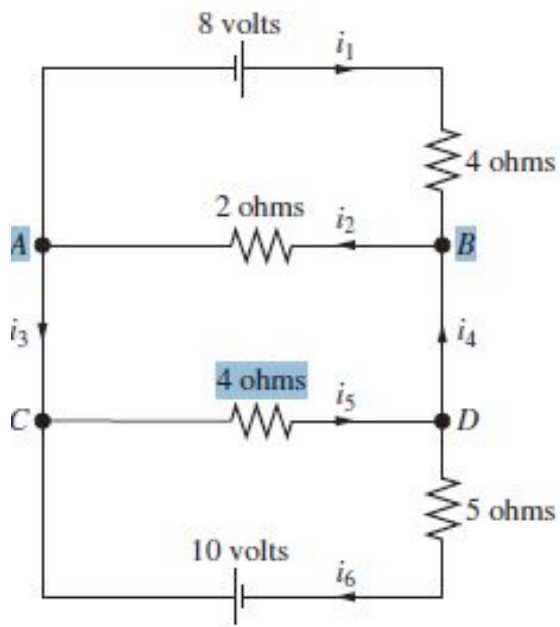
This gives the triangular system

$$\begin{aligned} i_1 - i_2 + i_3 &= 0 \\ 2i_2 + i_3 &= 10 \\ -5/2i_3 &= -5 \end{aligned}$$

So

$$\begin{aligned} i_3 = 2 &\implies i_3 = 2 \\ 2i_2 + 2 &= 10 \implies i_2 = 4 \\ i_1 - 4 + 2 &= 0 \implies i_1 = 2 \end{aligned}$$

(c)



The equations here are

$$-i_1 + i_2 - i_3 = 0 \quad (\text{Node A})$$

$$i_1 - i_2 + i_4 = 0 \quad (\text{Node B})$$

$$i_3 - i_5 + i_6 = 0 \quad (\text{Node C})$$

$$-i_4 + i_5 - i_6 = 0 \quad (\text{Node D})$$

$$4i_1 + 2i_2 = 8 \quad (\text{Top Loop})$$

$$4i_5 + 5i_6 = 10 \quad (\text{Bottom Node})$$

The augmented matrix is

$$\left[ \begin{array}{cccccc|c} -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & -1 & 1 & -1 & 0 \\ 4 & 2 & 0 & 0 & 0 & 0 & 8 \\ 0 & 0 & 0 & 0 & 4 & 5 & 10 \end{array} \right]$$

solving gives

$$\begin{bmatrix} 1/2 \\ 3 \\ 5/2 \\ 5/2 \\ 0 \end{bmatrix}$$

## Section 1.3

6. This is just computational. Do this by hand, but this is also good to verify in MATLAB.

7. This is just computational. Do this by hand, but this is also good to verify in MATLAB.

13.

(a) Say the variables are  $x_1, x_2, x_3, x_4, x_5$  the variables  $x_2, x_4$  and  $x_5$  will be independent since the columns 2, 4, and 5 do not contain pivot elements. The others can be solved in terms of those. Let  $s, t, u$  be arbitrary real numbers and set  $x_2 = s$ ,  $x_4 = t$ , and  $x_5 = u$ , then

$$x_1 = -2 - 2s - 3t - u$$

$$x_2 = s$$

$$x_3 = 5 - 2t - 4u$$

$$x_4 = t$$

$$x_5 = u$$

We can write this nicely as

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} -2 \\ 0 \\ 5 \\ 0 \\ 0 \end{bmatrix} + s \begin{bmatrix} -2 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} + t \begin{bmatrix} -3 \\ 0 \\ -2 \\ 1 \\ 0 \end{bmatrix} + u \begin{bmatrix} -1 \\ 0 \\ -4 \\ 0 \\ 1 \end{bmatrix} \quad (1)$$

(b)

We know

$$A\mathbf{x} = \mathbf{b} \iff \begin{bmatrix} 1 & 2 & 0 & 3 & 1 \\ 0 & 0 & 1 & 2 & 4 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \mathbf{x} = \begin{bmatrix} -2 \\ 5 \\ 0 \\ 0 \end{bmatrix}$$

We also know that

$$\mathbf{x} = \begin{bmatrix} -2 \\ 0 \\ 5 \\ 0 \\ 0 \end{bmatrix}$$

is a solution, namely the solution where  $s = t = u = 0$

$$\text{So } A\mathbf{x} = -2\mathbf{a}_1 + 5\mathbf{a}_3 = -2 \begin{bmatrix} 1 \\ 1 \\ 3 \\ 4 \end{bmatrix} + 5 \begin{bmatrix} 2 \\ -1 \\ 1 \\ 3 \end{bmatrix} = \begin{bmatrix} 8 \\ -7 \\ -1 \\ 7 \end{bmatrix} = \mathbf{b}$$

**16.**  $A^T = -A$  implies  $a_{ii} = -a_{ii}$  so  $a_{ii} = 0$ .

## Section 1.4

**8.** Check that  $A^2 = I$ , so  $A^{2n+1} = A$  and  $A^{2n} = I$ .

**1.4 #10** Assume  $A^T = A$  and  $B^T = B$ .

**(a)** Symmetric since:  $(A + B)^T = A^T + B^T = A + B$

**(b)** Symmetric since:  $(A^2)^T = A^T A^T = AA = A^2$

**(c)** Not necessarily transitive since:  $(AB)^T = B^T A^T = BA$ . Symmetry would only happen if  $AB = BA$ , i.e.,  $A$  and  $B$  commute.

Example: Let  $A = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$  and  $B = \begin{bmatrix} 1 & -1 \\ -1 & -1 \end{bmatrix}$ , notice both  $A$  and  $B$  are symmetric.  $AB = \begin{bmatrix} 0 & -2 \\ 0 & -2 \end{bmatrix}$  is not symmetric so  $(AB)^T \neq AB$ .

**(d)** Symmetric since:  $(ABA)^T = A^T B^T A^T = ABA$

**(e)** Symmetric since:  $(AB + BA)^T = (AB)^T + (BA)^T = B^T A^T + A^T B^T = BA + AB =$



$$AB + BA$$

(f) Not symmetric since:  $(AB - BA)^T = (AB)^T - (BA)^T = B^T A^T - A^T B^T = BA - AB = -(AB - BA)$ . So  $AB - BA$  is symmetric iff  $AB - BA = 0$ , that is iff  $A$  and  $B$  commute.

The same example as in (c) works here.

**22.**

$$\begin{aligned} RR^T &= \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \\ &= \begin{bmatrix} \cos^2(\theta) + \sin^2(\theta) & \cos(\theta)\sin(\theta) - \sin(\theta)\cos(\theta) \\ \sin(\theta)\cos(\theta) - \cos(\theta)\sin(\theta) & \sin^2(\theta) + \cos^2(\theta) \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \end{aligned}$$

**23.**  $H = I - 2\mathbf{u}\mathbf{u}^T$ , so

$$\begin{aligned} H^2 &= (I - 2\mathbf{u}\mathbf{u}^T)(I - 2\mathbf{u}\mathbf{u}^T) \\ &= I^2 - 2\mathbf{u}\mathbf{u}^T I - 2I\mathbf{u}\mathbf{u}^T + 4\mathbf{u}\mathbf{u}^T \mathbf{u}\mathbf{u}^T \\ &= I^2 - 4\mathbf{u}\mathbf{u}^T + 4\mathbf{u}\mathbf{u}^T \mathbf{u}\mathbf{u}^T \\ &= I^2 - 4\mathbf{u}\mathbf{u}^T + 4\mathbf{u}(1)\mathbf{u}^T \\ &= I^2 - 4\mathbf{u}\mathbf{u}^T + 4\mathbf{u}\mathbf{u}^T \\ &= I^2 \\ &= I \end{aligned}$$

**27.** Assume  $A^2 = I$  and let  $B = \frac{1}{2}(I + A)$  and  $C = \frac{1}{2}(I - A)$ . Note

$$B^2 = \frac{1}{4}(I^2 + IA + AI + A^2) = \frac{1}{4}(I + 2A + I) = \frac{1}{4}(2)(I + A) = B$$

Similarly,  $C^2 = C$ .

**30.**

$$(A + A^T)^T = A^T + (A^T)^T = A^T + A = A + A^T$$

So  $A + A^T$  is symmetric. Similarly,

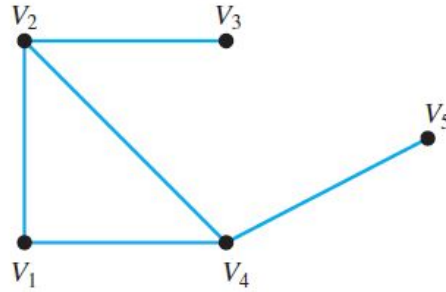
$$(A - A^T)^T = A^T - (A^T)^T = A^T - A = -(A - A^T)$$

So  $A - A^T$  is skew-symmetric.

Since  $A = \frac{1}{2}(A + A^T) + \frac{1}{2}(A - A^T)$  we see  $A$  can be written as symmetric + skew-symmetric.

**32.** This is false, for example let  $A = B = I$  and  $C = -I$ , then clearly  $A$  is row equivalent to  $B$  and  $C$ , but  $B + C = \mathbf{0}$  (the all 0 matrix). It is not true that  $A$  is row equivalent to  $\mathbf{0}$ , else  $I = \mathbf{0}$  (a version of  $1 = 0$ ).

**33.**



(a) Adjacency Matrix,  $A$ :

$$A = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

(b)

$$A^2 = \begin{bmatrix} 2 & 1 & 1 & 1 & 1 \\ 1 & 3 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 3 & 0 \\ 1 & 1 & 0 & 0 & 1 \end{bmatrix}$$

There are 6 walks starting at  $V_1$  and that is the sum of column 1 or row 1 (the matrix is symmetric).  $V_1V_2V_1$ ,  $V_1V_4V_1$ ,  $V_1, V_2V_3$ ,  $V_1V_2V_4$ ,  $V_1V_4V_2$ , and  $V_1V_4V_5$ .

(c)

$$A^2 = \begin{bmatrix} 2 & 4 & 1 & 4 & 1 \\ 4 & 2 & 3 & 5 & 1 \\ 1 & 3 & 0 & 1 & 1 \\ 4 & 5 & 1 & 2 & 3 \\ 1 & 1 & 1 & 3 & 0 \end{bmatrix}$$

There are 5 walks of length 3 from  $V_2$  to  $V_4$  and 1 of length 2 so 6 altogether.

## Section 1.5

8. find the  $LU$  decomposition of the following matrices:

(b)  $\begin{bmatrix} 2 & 4 \\ -2 & 1 \end{bmatrix}$

$$\begin{bmatrix} 2 & 4 \\ -2 & 1 \end{bmatrix} \xrightarrow{r_2 + (1)r_1 \rightarrow r_2; L_{2,1} = -1} \begin{bmatrix} 2 & 4 \\ 0 & 5 \end{bmatrix} = U$$

The  $(2, 1)$  position of  $L$  is  $-1$  so

$$L = \begin{bmatrix} 1 & 0 \\ -1 & 0 \end{bmatrix}$$

It is easy to see that

$$\begin{bmatrix} 1 & 0 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} 2 & 4 \\ 0 & 5 \end{bmatrix} = \begin{bmatrix} 2 & 4 \\ -2 & 1 \end{bmatrix}$$

(d)  $\begin{bmatrix} -2 & 1 & 2 \\ 4 & 1 & -2 \\ -6 & -3 & 4 \end{bmatrix}$

$$\begin{bmatrix} -2 & 1 & 2 \\ 4 & 1 & -2 \\ -6 & -3 & 4 \end{bmatrix} \xrightarrow[r_3 + (-3)r_1 \rightarrow r_3; L_{3,1} = 3]{r_2 + (2)r_1 \rightarrow r_2; L_{2,1} = -2} \begin{bmatrix} -2 & 1 & 2 \\ 0 & 3 & 2 \\ 0 & -6 & -2 \end{bmatrix} \xrightarrow{r_3 + (2)r_2 \rightarrow r_3; L_{3,2} = -2} \begin{bmatrix} -2 & 1 & 2 \\ 0 & 3 & 2 \\ 0 & 0 & 2 \end{bmatrix} = U$$

We see

$$L = \begin{bmatrix} 1 & 0 & 0 \\ -2 & 1 & 0 \\ 3 & -2 & 1 \end{bmatrix}$$

Again, it is easy to check that

$$LU = \begin{bmatrix} 1 & 0 & 0 \\ -2 & 1 & 0 \\ 3 & -2 & 1 \end{bmatrix} \begin{bmatrix} -2 & 1 & 2 \\ 0 & 3 & 2 \\ 0 & 0 & 2 \end{bmatrix} = \begin{bmatrix} -2 & 1 & 2 \\ 4 & 1 & -2 \\ -6 & -3 & 4 \end{bmatrix}$$

19. (a) If  $U$  is upper triangular with non-zero diagonal, then clearly  $U$  can be row reduced to  $I$ . Since  $U$  is row equivalent to  $I$ ,  $U$  is invertible. (Theorem 1.5.2).

(b) **Proof 1:** For this, essentially look into the proof of 1.5.2. Let  $E_n E_{n-1} \cdots E_1 U = I$  where  $E_i$  is an elementary matrix. Since  $U$  starts as upper-triangular (u.t.) it is clear that only type

II and III operations are needed and the type II here are of the form  $R_i - c \cdot R_j \rightarrow R_i$  where  $i < j$ , so  $c$  goes in the  $(i, j)^{\text{th}}$  spot and hence this matrix is u.t. So all the  $E_i$  are u.t. Thus  $E_n E_{n-1} \cdots E_1 = U^{-1}$  is u.t.

**Proof 2:** We can show that if  $AB = C$  with  $B$  and  $C$  u.t. and  $B$  invertible, then  $A$  is u.t. This will clearly imply what we want. Suppose  $A$  is not u.t. and let  $i$  be least such that there is  $j < i$  with  $A_{i,j} \neq 0$ . Let  $j$  be the least  $< i$  so that  $A_{i,j} \neq 0$ . Then  $0 = C_{i,j} = \sum_{k \leq n} A_{i,k} B_{k,j} = \sum_{k \leq j} A_{i,k} B_{k,j}$ , that is,

$$0 = A_{i,1} B_{1,j} + \cdots + A_{i,j} B_{j,j} = 0 + \cdots + A_{i,j} B_{j,j} = A_{i,j} B_{j,j} = 0$$

This is a contradiction to the choice of  $A_{i,j}$  and the fact that  $B$  is invertible, hence  $B_{j,j} \neq 0$ , since  $B$  is u.t.

**28.** (a) There is nothing to do except unpack matrix multiplication, which is done below for (b).

(b) For this

$$V\mathbf{c} = c_0 \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} + c_1 \begin{bmatrix} x_1 \\ \vdots \\ x_{n+1} \end{bmatrix} + \cdots + c_n \begin{bmatrix} x_i^n \\ \vdots \\ x_{n+1}^n \end{bmatrix} = \begin{bmatrix} p(x_1) \\ \vdots \\ p(x_{n+1}) \end{bmatrix} = \begin{bmatrix} 0 \\ \vdots \\ 0 \end{bmatrix}$$

But then we have  $n + 1$  distinct roots to a polynomial of degree  $n$ , which is a contradiction unless  $p(x) \equiv 0$ , i.e.,  $p$  is the constant 0 polynomial.