

SHOW ALL NECESSARY WORK FOR EACH PROBLEM

(1) (10 Points) $A = \begin{bmatrix} 1 & 1 & -1 & 1 & 0 \\ 2 & 1 & 0 & -1 & 5 \\ 3 & 1 & 1 & 1 & 2 \\ 4 & 1 & 2 & -1 & 7 \end{bmatrix}$ row reduces to $C = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & -2 & 0 & 1 \\ 0 & 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$.

Let $L_A : \mathbb{F}^5 \rightarrow \mathbb{F}^4$ be the linear map $L_A(X) = AX$.

- (a) (2 Points) Find a **basis** for $Row(A)$, the row space of A .
 - (b) (2 Points) Find a **basis** for $Ker(L_A) = Nul(A)$, the kernel of L_A .
 - (c) (2 Points) Find a **basis** for $Range(L_A) = Col(A)$.
 - (d) (4 Points) For each free variable in $Ker(L_A)$, find a **dependence relation** among the columns of A and use it to write each **non-pivot** column of A as a linear combination of **previous pivot** columns of A .
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(2) (10 Pts) Answer each question **separately**. V and W are vector spaces over \mathbb{F} .

- (a) Find the elementary matrix E such that for any $A \in \mathbb{F}_n^3$, EA is the matrix obtained from A by multiplying row 3 of A by 7.
 - (b) If $S = \{v_1, v_2, \dots, v_n\}$ is an **independent** subset of V , and $L : V \rightarrow W$ is **injective**, what is the most you can be sure about $L(S) = \{L(v_1), L(v_2), \dots, L(v_n)\}$ in W ?
 - (c) If $S = \{v_1, v_2, \dots, v_m\}$ is **dependent** in V , and linear map $L : V \rightarrow W$ is **bijective**, what is the most you can be sure about $L(S) = \{L(v_1), \dots, L(v_m)\}$?
 - (d) In W let $T = \{w_1, w_2, \dots, w_{m-1}\}$ and $T' = \{w_1, w_2, \dots, w_{m-1}, w_m\}$ where the last vector $w_m \in \langle T \rangle$ is a linear combination of the previous vectors. What is the relationship between the spans $\langle T \rangle$ and $\langle T' \rangle$?
 - (e) If $S = \{v_1, v_2, \dots, v_n\}$ is **independent** in V and $v \notin \langle S \rangle$ and $T = \{v_1, v_2, \dots, v_n, v\}$, then what is the most you can be sure about $dim(\langle T \rangle)$?
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(3) (10 points) Answer each question separately.

- (a) If $L : \mathbb{F}_3^3 \rightarrow \mathbb{F}^9$ is **injective**, what is the most you can be sure about L ?
 - (b) If $L : \mathbb{F}^3 \rightarrow \mathbb{F}^8$ what are all the possibilities for $dim(Range(L))$?
 - (c) If $L : \mathbb{F}^7 \rightarrow \mathbb{F}^4$ what are all the possibilities for $dim(Ker(L))$?
 - (d) If $A \in \mathbb{F}_n^n$ and $X \in \mathbb{F}^n$ is a **non-zero** solution to $AX = 0_1^n$ then X is an eigenvector for A with what eigenvalue?
 - (e) Let $A \in \mathbb{F}_n^n$ be **invertible** and suppose a **non-zero** $X \in \mathbb{F}^n$ satisfies $AX = \lambda X$ for some $\lambda \in \mathbb{F}$. Why can you be sure that $\lambda \neq 0$?
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(4) (10 Pts) Answer each question **separately**.

- (a) (5 Pts) $S = \left\{ v_1 = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}, v_2 = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}, v_3 = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}, \right\}$ is a basis of \mathbb{F}^3 . For $v = \begin{bmatrix} a \\ b \\ c \end{bmatrix}$ find the coordinate vector $[v]_S$ with respect to S .
- (b) (5 Pts) $T = \{t^2, t^2 + t, t^2 + t + 1\}$ is a basis of \mathcal{P}_2 (polynomials of degree at most 2). For $p = at^2 + bt + c$ find the coordinate vector $[p]_T$ with respect to T .

(5) (10 Points) Answer each question separately.

- (a) Determine whether $A = \begin{bmatrix} 1 & 2 & 3 \\ 1 & 0 & 2 \\ 0 & 1 & 0 \end{bmatrix}$ is invertible, and find A^{-1} if it is.
- (b) Let $A \in \mathbb{F}_n^n$ with $\text{Rank}(A) < n$. What can you say about $\det(A)$?
- (c) For $A \in \mathbb{F}_n^n$ let $A_{\lambda_i} = \{X \in \mathbb{F}^n \mid AX = \lambda_i X\}$ be the λ_i eigenspace of A . What is the **geometric multiplicity** g_i of A ?
- (d) Suppose $A \in \mathbb{F}_n^n$ has r distinct eigenvalues $\lambda_1, \dots, \lambda_r$ in \mathbb{F} and let T_i be a basis of A_{λ_i} for $1 \leq i \leq r$. What is the most you can say about the union $T = T_1 \cup \dots \cup T_r$?
- (e) With notation as in part (d), what property of the set T means A is **diagonalizable**?
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(6) (10 Points) Let $L : \mathbb{F}^2 \rightarrow \mathbb{F}^3$ be given by $L \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} 2a + 3b \\ -a + b \\ 4a - 5b \end{bmatrix}$.

Let $S = \{v_1, v_2\}$ be the standard basis of \mathbb{F}^2 and let $T = \{w_1, w_2, w_3\}$ be the standard basis of \mathbb{F}^3 . Let other ordered bases be

$$S' = \left\{ v'_1 = \begin{bmatrix} 1 \\ 2 \end{bmatrix}, v'_2 = \begin{bmatrix} 1 \\ 3 \end{bmatrix} \right\} \quad \text{and} \quad T' = \left\{ w'_1 = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}, w'_2 = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}, w'_3 = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \right\}.$$

- (a) (2 pts) Find the matrix ${}_T[L]_S$ representing L from S to T .
- (b) (3 pts) Find the matrix ${}_{T'}[L]_{S'}$ representing L from S' to T' **without using transition matrices**. Do it directly by row reducing $[T' \mid L(S')]$.
- (c) (3 pts) Find the transition matrices ${}_S P_{S'}$, ${}_T Q_{T'}$ and ${}_{T'} Q_T = ({}_T Q_{T'})^{-1}$.
- (d) (2 pts) Using your answers from parts (a) and (c), explicitly multiply out ${}_{T'} Q_T {}_T [L]_S {}_S P_{S'}$ and compare it to your answer for ${}_{T'} [L]_{S'}$ from part (b). What was their relationship, and what should it have been?
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(7) (15 Points) Let $A = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix}$. Then $[A \mid 0_1^4]$ has solutions with two free variables,

which means $\lambda = 0$ is an eigenvalue of A .

- (a) (5 pts) Find the $\lambda_1 = 0$ **eigenspace** A_0 and a **basis** for it.
- (b) (5 pts) Find an eigenvalue $\lambda \neq 0$ of A by row reduction of $[A - \lambda I_4 \mid 0_1^4]$.
- (c) (3 pts) For that eigenvalue, $\lambda = \lambda_2$, find its **eigenspace** A_{λ_2} and a **basis** for it.
- (d) (2 pts) Use your answers to find invertible P and diagonal D so that $D = P^{-1}AP$.
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(1) (10 Points) (a) (2 Points)

$$A = \begin{bmatrix} 1 & 1 & -1 & 1 & 0 \\ 2 & 1 & 0 & -1 & 5 \\ 3 & 1 & 1 & 1 & 2 \\ 4 & 1 & 2 & -1 & 7 \end{bmatrix} \text{ row reduces to } C = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & -2 & 0 & 1 \\ 0 & 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ so}$$

$\{[1 \ 0 \ 1 \ 0 \ 1], [0 \ 1 \ -2 \ 0 \ 1], [0 \ 0 \ 0 \ 1 \ -2]\}$ is a basis for $Row(A)$.

(b) (2 Points) A basis for $Ker(L_A) = Nul(A)$ is found by row reducing $[A|\mathbf{0}_1^4]$ to $[C|\mathbf{0}_1^4]$, interpreting the solutions in \mathbb{F}^5 , and separating the free variables to get two independent vectors which span it:

$$\left\{ \begin{bmatrix} -r-s \\ 2r-s \\ r \\ 2s \\ s \end{bmatrix} = r \begin{bmatrix} -1 \\ 2 \\ 1 \\ 0 \\ 0 \end{bmatrix} + s \begin{bmatrix} -1 \\ -1 \\ 0 \\ 2 \\ 1 \end{bmatrix} \in \mathbb{F}^5 \mid r, s \in \mathbb{F} \right\} \text{ so } \left\{ \begin{bmatrix} -1 \\ 2 \\ 1 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} -1 \\ -1 \\ 0 \\ 2 \\ 1 \end{bmatrix} \right\}$$

is a basis for $Ker(L_A)$.

(c) (2 Points) A basis for $Col(A)$ consists of the three pivot columns of A , the columns with leading ones in the RREF C , that is, $\{Col_1(A), Col_2(A), Col_4(A)\}$. Other correct answers can be obtained by linear combinations of those three columns, for example,

$$\left\{ \begin{bmatrix} 1 \\ 0 \\ 0 \\ -1 \end{bmatrix}, \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix} \right\}$$

(d) (4 Points) Each basis vector in $Ker(L_A)$ gives a dependence relation among the columns of A . The two dependence relations obtained that way are:

$$-1Col_1(A) + 2Col_2(A) + Col_3(A) = \mathbf{0}_1^4$$

and

$$-1Col_1(A) - 1Col_2(A) + 2Col_4(A) + Col_5(A) = \mathbf{0}_1^4$$

so the two **non-pivot** columns are the linear combinations of **previous pivot** columns

$$Col_3(A) = Col_1(A) - 2Col_2(A) \quad \text{and} \quad Col_5(A) = Col_1(A) + Col_2(A) - 2Col_4(A).$$

(2) (10 Points, 2 points each)

(a) For elementary matrix $E = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 7 \end{bmatrix}$, obtained by doing the row operation to I_3 ,

EA is the matrix obtained from A by multiplying row 3 of A by 7.

(b) If $S = \{v_1, v_2, \dots, v_n\}$ is **independent** in V , and $L : V \rightarrow W$ is **injective**, then you be sure that $L(S) = \{L(v_1), L(v_2), \dots, L(v_n)\}$ is an **independent** subset of $Range(L)$.

(c) If $S = \{v_1, v_2, \dots, v_m\}$ is **dependent** in V , and linear map $L : V \rightarrow W$ is **bijective**, you can be sure that $L(S) = \{L(v_1), \dots, L(v_m)\}$ is **dependent**.

(d) In W let $T = \{w_1, w_2, \dots, w_{m-1}\}$ and $T' = \{w_1, w_2, \dots, w_{m-1}, w_m\}$ where the last vector $w_m \in \langle T \rangle$ is a linear combination of the previous vectors. The relationship is $\langle T \rangle = \langle T' \rangle$ since w_m is redundant in T' .

(e) If $S = \{v_1, v_2, \dots, v_n\}$ is **independent** in V and $v \notin \langle S \rangle$, then $T = \{v_1, v_2, \dots, v_n, v\}$ is **independent** since v is not redundant, so $\langle T \rangle$ has basis T so $dim(\langle T \rangle) = n + 1$.

(3) (10 Points, 2 points each)

(a) Use $dim(V) = dim(Ker(L)) + dim(Range(L))$. L injective means $dim(Ker(L)) = 0$ so $dim(V) = dim(\mathbb{F}_3^3) = 9 = dim(Range(L)) = dim(\mathbb{F}^9)$, so $Range(L) = \mathbb{F}^9$ so L is **surjective**. L is thus **bijective, invertible** and an **isomorphism**.

(b) $L : \mathbb{F}^3 \rightarrow \mathbb{F}^8$ so $3 = dim(Ker(L)) + dim(Range(L))$ and $0 \leq dim(Ker(L)) \leq 3$ so $0 \leq dim(Range(L)) \leq 3$.

(c) $L : \mathbb{F}^7 \rightarrow \mathbb{F}^4$ so $7 = dim(\mathbb{F}^7) = dim(Ker(L)) + dim(Range(L))$ and $0 \leq dim(Range(L)) \leq 4$ so $3 \leq dim(Ker(L)) \leq 7$.

(d) If $A \in \mathbb{F}_n^n$ and $X \in \mathbb{F}^n$ is a **non-zero** solution to $AX = 0_1^n$ then X is an eigenvector for A with eigenvalue 0 since $AX = 0X$.

(e) Let $A \in \mathbb{F}_n^n$ be **invertible** and suppose a **non-zero** $X \in \mathbb{F}^n$ satisfies $AX = \lambda X$ for some $\lambda \in \mathbb{F}$. Then $\lambda \neq 0$ because otherwise $AX = 0_1^n$ has a **non-trivial** solution so $Rank(A) < n$ so A could not be invertible.

(4) (10 Points) (a) (5 Pts) To solve $x_1v_1 + x_2v_2 + x_3v_3 = v$ row reduce

$$\left[\begin{array}{ccc|c} 1 & 1 & 0 & a \\ 1 & 2 & 1 & b \\ 1 & 3 & 1 & c \\ \hline & S & & v \end{array} \right] \quad \text{to} \quad \left[\begin{array}{ccc|c} 1 & 0 & 0 & a+b-c \\ 0 & 1 & 0 & -b+c \\ 0 & 0 & 1 & -a+2b-c \\ \hline & I_3 & & X \end{array} \right] \quad \text{so } [v]_S = \begin{bmatrix} a+b-c \\ -b+c \\ -a+2b-c \end{bmatrix}.$$

(b) (5 Pts) To write p as a linear combination from T , solve the equation

$$x_1(t^2) + x_2(t^2 + t) + x_3(t^2 + t + 1) = at^2 + bt + b.$$

Compare coefficients of each power of t on both sides to get the linear system

$$x_1 + x_2 + x_3 = a, \quad x_2 + x_3 = b, \quad x_3 = c. \quad \text{To solve that, row reduce}$$

$$\left[\begin{array}{ccc|c} 1 & 1 & 1 & a \\ 0 & 1 & 1 & b \\ 0 & 0 & 1 & c \\ \hline & T & & p \end{array} \right] \quad \text{to} \quad \left[\begin{array}{ccc|c} 1 & 0 & 0 & a-b \\ 0 & 1 & 0 & b-c \\ 0 & 0 & 1 & c \\ \hline & I_3 & & X \end{array} \right]. \quad \text{So } [p]_T = \begin{bmatrix} a-b \\ b-c \\ c \end{bmatrix}. \quad \text{We can check that}$$

$$(a-b)t^2 + (b-c)(t^2 + t) + c(t^2 + t + 1) = at^2 + bt + c.$$

(5) (10 Points, 2 points each) Answer each question separately.

(a) $A = \begin{bmatrix} 1 & 2 & 3 \\ 1 & 0 & 2 \\ 0 & 1 & 0 \end{bmatrix}$ is invertible and $A^{-1} = \begin{bmatrix} -2 & 3 & 4 \\ 0 & 0 & 1 \\ 1 & -1 & -2 \end{bmatrix}$ because

$$\left[\begin{array}{ccc|ccc} 1 & 2 & 3 & 1 & 0 & 0 \\ 1 & 0 & 2 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \end{array} \right] \text{ reduces to } \left[\begin{array}{ccc|ccc} 1 & 0 & 0 & -2 & 3 & 4 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 & -1 & -2 \end{array} \right].$$

$A \qquad I_3 \qquad I_3 \qquad A^{-1}$

(b) Let $A \in \mathbb{F}_n^n$ with $\text{Rank}(A) < n$. Then $\det(A) = 0$.

(c) For $A \in \mathbb{F}_n^n$ let $A_{\lambda_i} = \{X \in \mathbb{F}^n \mid AX = \lambda_i X\}$ be the λ_i eigenspace of A . Then $g_i = \dim(A_{\lambda_i})$ is the **geometric multiplicity** of A for λ_i .

(d) Suppose $A \in \mathbb{F}_n^n$ has r distinct eigenvalues $\lambda_1, \dots, \lambda_r$ in \mathbb{F} and let T_i be a basis of A_{λ_i} for $1 \leq i \leq r$. The most you can say about the union $T = T_1 \cup \dots \cup T_r$ is that it is **independent**.

(e) With notation as in part (d), A is **diagonalizable** when the set T spans \mathbb{F}^n , which means T is a basis for \mathbb{F}^n , which means T contains n vectors. (All are correct answers.)

(6) (10 Points)

(a) (2 Pts) $L(S)$: $L(v_1) = \begin{bmatrix} 2 \\ -1 \\ 4 \end{bmatrix}$, $L(v_2) = \begin{bmatrix} 3 \\ 1 \\ -5 \end{bmatrix}$. Then $[T \mid L(S)] = \left[\begin{array}{ccc|cc} 1 & 0 & 0 & 2 & 3 \\ 0 & 1 & 0 & -1 & 1 \\ 0 & 0 & 1 & 4 & -5 \\ \hline & T & & & L(S) \end{array} \right]$

so ${}_T[L]_S = \begin{bmatrix} 2 & 3 \\ -1 & 1 \\ 4 & -5 \end{bmatrix}$.

(b) (3 Pts) Find $L(S')$: $L(v'_1) = \begin{bmatrix} 8 \\ 1 \\ -6 \end{bmatrix}$, $L(v'_2) = \begin{bmatrix} 11 \\ 2 \\ -11 \end{bmatrix}$. Row reduce

$$\left[\begin{array}{ccc|cc} 1 & 0 & 1 & 8 & 11 \\ 1 & 1 & 1 & 1 & 2 \\ 0 & 1 & 1 & -6 & -11 \\ \hline & T' & & & L(S') \end{array} \right] \text{ to } \left[\begin{array}{ccc|cc} 1 & 0 & 0 & 7 & 13 \\ 0 & 1 & 0 & -7 & -9 \\ 0 & 0 & 1 & 1 & -2 \\ \hline & I_3 & & & {}_{T'}[L]_{S'} \end{array} \right] \text{ so } {}_{T'}[L]_{S'} = \begin{bmatrix} 7 & 13 \\ -7 & -9 \\ 1 & -2 \end{bmatrix}.$$

(c) (3 Pts) ${}_S P_{S'} = \begin{bmatrix} 1 & 1 \\ 2 & 3 \end{bmatrix}$ and ${}_T Q_{T'} = \begin{bmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix}$ since S and T are standard bases.

To get ${}_{T'} Q_T = ({}_T Q_{T'})^{-1}$, row reduce

$$\left[\begin{array}{ccc|ccc} 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ \hline & T' & & T & & \end{array} \right] \text{ to } \left[\begin{array}{ccc|ccc} 1 & 0 & 0 & 0 & 1 & -1 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & 1 & -1 & 1 \\ \hline & I_3 & & & & {}_{T'} Q_T \end{array} \right] \text{ so } {}_{T'} Q_T = \begin{bmatrix} 0 & 1 & -1 \\ -1 & 1 & 0 \\ 1 & -1 & 1 \end{bmatrix}.$$

(d) (2 Pts) $({}_{T'} Q_T)({}_T [L]_S)({}_S P_{S'}) =$

$$\begin{bmatrix} 0 & 1 & -1 \\ -1 & 1 & 0 \\ 1 & -1 & 1 \end{bmatrix} \begin{bmatrix} 2 & 3 \\ -1 & 1 \\ 4 & -5 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 2 & 3 \end{bmatrix} = \begin{bmatrix} -5 & 6 \\ -3 & -2 \\ 7 & -3 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 2 & 3 \end{bmatrix} = \begin{bmatrix} 7 & 13 \\ -7 & -9 \\ 1 & -2 \end{bmatrix} =$$

${}_{T'} [L]_{S'}$ is the relationship, as it should be according to a theorem we proved in class.

(7) (15 Points) Let $A = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix}$. Then $[A|0_1^4]$ has solutions with two free variables,

which means $\lambda = 0$ is an eigenvalue of A .

(a) (5 pts) Find the $\lambda_1 = 0$ **eigenspace** A_0 and a **basis** for it. For $\lambda_1 = 0$, row reduce $[A|0_1^4] =$

$$\begin{bmatrix} 1 & 0 & 1 & 0 & | & 0 \\ 0 & 1 & 0 & 1 & | & 0 \\ 1 & 0 & 1 & 0 & | & 0 \\ 0 & 1 & 0 & 1 & | & 0 \end{bmatrix} \text{ to } \begin{bmatrix} 1 & 0 & 1 & 0 & | & 0 \\ 0 & 1 & 0 & 1 & | & 0 \\ 0 & 0 & 0 & 0 & | & 0 \\ 0 & 0 & 0 & 0 & | & 0 \end{bmatrix} \text{ so } \begin{matrix} x_1 = -r \\ x_2 = -s \\ x_3 = r \in \mathbb{F}, \text{ then} \\ x_4 = s \in \mathbb{F} \end{matrix}$$

$$A_{\lambda_1} = \left\{ \begin{bmatrix} -r \\ -s \\ r \\ s \end{bmatrix} \in \mathbb{F}^4 \mid r, s \in \mathbb{F} \right\} \text{ has basis } T_1 = \left\{ \begin{bmatrix} -1 \\ 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -1 \\ 0 \\ 1 \end{bmatrix} \right\}.$$

(b) (5 pts) Find an eigenvalue $\lambda \neq 0$ of A by row reduction of $[A - \lambda I_4|0_1^4]$. For $\lambda \neq 0$, row reduce $[A - \lambda I_4|0_1^4] =$

$$\begin{bmatrix} 1-\lambda & 0 & 1 & 0 & | & 0 \\ 0 & 1-\lambda & 0 & 1 & | & 0 \\ 1 & 0 & 1-\lambda & 0 & | & 0 \\ 0 & 1 & 0 & 1-\lambda & | & 0 \end{bmatrix} \text{ to } \begin{bmatrix} 1 & 0 & -1 & 0 & | & 0 \\ 0 & 1 & 0 & -1 & | & 0 \\ 0 & 0 & 2-\lambda & 0 & | & 0 \\ 0 & 0 & 0 & 2-\lambda & | & 0 \end{bmatrix} \text{ so for } \lambda = 2 \begin{matrix} x_1 = r \\ x_2 = s \\ x_3 = r \in \mathbb{F} \\ x_4 = s \in \mathbb{F} \end{matrix}$$

(c) (3 pts) For that eigenvalue, $\lambda = \lambda_2$, find its **eigenspace** A_{λ_2} and a **basis** for it.

$$A_{\lambda_2} = \left\{ \begin{bmatrix} r \\ s \\ r \\ s \end{bmatrix} \in \mathbb{F}^4 \mid r, s \in \mathbb{F} \right\} \text{ has basis } T_2 = \left\{ \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix} \right\}.$$

(d) (2 pts) Use your answers to find invertible P and diagonal D so that $D = P^{-1}AP$.

$$D = \text{Diag}(\lambda_1, \lambda_1, \lambda_2, \lambda_2) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 2 \end{bmatrix} = P^{-1}AP =$$

$$\frac{1}{2} \begin{bmatrix} -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix}.$$
