6 The Smith Canonical Form

6.1 Equivalence of Polynomial Matrices

DEFINITION 6.1

A matrix $P \in M_{n\times n}(F[x])$ is called a **unit** *in $M_{n\times n}(F[x])$ if $\exists\ Q \in M_{n\times n}(F[x])$ such that*

$$PQ = I_n.$$

Clearly if P and Q are units, so is PQ.

THEOREM 6.1

A matrix $P \in M_{n\times n}(F[x])$ is a unit in $M_{n\times n}(F[x])$ if and only if $\det P = c$, where $c \in F$ and $c \neq 0$.

proof

"only if". Suppose P is a unit. Then $PQ = I_n$ and

$$\det PQ = \det P \det Q = \det I_n = 1.$$

However $\det P$ and $\det Q$ belong to $F[x]$, so both are in fact non–zero elements of F.

"if". Suppose $P \in M_{n\times n}(F[x])$ satisfies $\det P = c$, where $c \in F$ and $c \neq 0$. Then

$$P \operatorname{adj} P = (\det P) I_n = cI_n.$$

Hence $PQ = I_n$, where $Q = c^{-1} \operatorname{adj} P \in M_{n\times n}(F[x])$. Hence P is a unit in $M_{n\times n}(F[x])$.

EXAMPLE 6.1

$P = \begin{bmatrix} 1+x & -x \\ x & 1-x \end{bmatrix} \in M_{2\times 2}(F[x])$ is a unit, as $\det P = 1$.

THEOREM 6.2

Elementary row matrices in $M_{n\times n}(F[x])$ are units:

(i) E_{ij}: interchange rows i and j of I_n;

(ii) $E_i(t)$: multiply row i of I_n by $t \in F$, $t \neq 0$;

(iii) $E_{ij}(f)$: add f times row j of I_n to row i, $f \in F[x]$.

In fact $\det E_{ij} = -1$; $\det E_i(t) = t$; $\det E_{ij}(f) = 1$.

Similarly for elementary column matrices in $M_{n\times n}(F[x])$:

$$F_{ij},\ F_i(t),\ F_{ij}(f).$$

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