

Exercise 1

a) We have

$$\begin{array}{c|c|c|c}
r & x & y & q \\
\hline
135 & 1 & 0 & \\
54 & 0 & 1 & 2 \\
27 & 1 & -2 & 2 \\
0 & -2 & 5 &
\end{array}$$

and thus $\gcd(135, 54) = 27$. Since $27 \mid 0$, there is a solution.

From the last row we know that $125 \cdot -2 + 54 \cdot 5 = 0$, thus $(-2, 5) \in L$. We can now describe L as $L = \{(-2k, 5k) \mid k \in \mathbb{Z}\}$.

b) We have (note that x and y are reversed)

$$\begin{array}{c|c|c|c}
r & y & x & q \\
\hline
105 & 1 & 0 & \\
99 & 0 & 1 & 1 \\
6 & 1 & -1 & 16 \\
3 & -16 & 17 & 2 \\
0 & 33 & -35 &
\end{array}$$

and thus $\gcd(105, 99) = 3$. Since $3 \mid 12$, there is a solution.

From the second to last row we know

$$\begin{aligned}
3 &= (17 \cdot 99) + (-16 \cdot 105) \quad \text{and, after multiplying by 4} \\
12 &= (68 \cdot 99) + (-64 \cdot 105).
\end{aligned}$$

Thus we have that $(68, -64) \in L$ and further $L = \{(68 - 35k, -64 + 33k) \mid k \in \mathbb{Z}\}$.

c) We have

$$\begin{array}{c|c|c|c}
q & x & y & r \\
\hline
38 & 1 & 0 & \\
19 & 0 & 1 & 2 \\
0 & 1 & -2 &
\end{array}$$

and thus $\gcd(38, 19) = \gcd(19, -38) = 19$. Since $19 \nmid 5$ this equation does not have a solution.

Exercise 2 We are looking for solutions to

$$35x + 45y = 1000$$

where x is the number of linear Algebra books and y is the number of Analysis books. We have (note that x and y are reversed)

| r | y | x | q |
|-----|-----|-----|-----|
| 45 | 1 | 0 | |
| 35 | 0 | 1 | 1 |
| 10 | 1 | -1 | 3 |
| 5 | -3 | 4 | 2 |
| 0 | 7 | -9 | |

and thus $\gcd(45, 35) = 5$. Since $5 \mid 1000$, there is a solution.

From the second to last row we know

$$5 = (4 \cdot 35) + (-3 \cdot 45) \quad \text{and, after multiplying by 200}$$

$$1000 = (800 \cdot 35) + (-600 \cdot 45)$$

and thus $(800, -600) \in L$, allowing us to state $L = \{(800 \cdot -9k, -600 \cdot 7k) \mid k \in \mathbb{Z}\}$. For $86 \leq k \leq 88$ neither of the values in the pairs $\in L$ are negative. Thus we can either buy

| Lineare Algebra | Analysis |
|-----------------|----------|
| 26 | 2 |
| 17 | 9 |
| 8 | 16 |

books.

If the total available money were 1001 then we would have $5 \nmid 1001$, thus we would not be able to spend all of our budget.

Exercise 3 Idk.

Exercise 4 Interpreting the polynomials as being in \mathbb{Z}_5 .

$$\begin{array}{cccccc}
 x^5 & x^4 & x^3 & x^2 & x^1 & x^0 \\
 3 & 1 & 4 & 1 & 0 & 4 \\
 3 & 3 & 4 & 2 & &
 \end{array}
 :
 \begin{array}{cccccc}
 x^3 & x^2 & x^1 & x^0 & & \\
 2 & 2 & 1 & 3 & &
 \end{array}
 =
 \begin{array}{cccccc}
 x^2 & x^1 & x^0 & & & \\
 4 & 4 & 1 & & &
 \end{array}$$

$$\begin{array}{cccccc}
 & 3 & 0 & 4 & 0 & 4 \\
 & 3 & 3 & 4 & 2 & \\
 & 2 & 0 & 3 & 4 & \\
 & 2 & 2 & 1 & 3 & \\
 & 3 & 2 & 1 & &
 \end{array}$$

Interpreting the polynomials as being in \mathbb{Q} .

$$\begin{array}{cccccc}
 x^5 & x^4 & x^3 & x^2 & x^1 & x^0 \\
 3 & 1 & 4 & 1 & 5 & 9 \\
 3 & 10.5 & 1.5 & 12 & &
 \end{array}
 :
 \begin{array}{cccccc}
 x^3 & x^2 & x^1 & x^0 & & \\
 2 & 7 & 1 & 8 & &
 \end{array}
 =
 \begin{array}{cccccc}
 x^2 & x^1 & x^0 & & & \\
 1.5 & -4.75 & 17.875 & & &
 \end{array}$$

$$\begin{array}{cccccc}
 -9.5 & 3.5 & -11 & 5 & 9 & \\
 -9.5 & -33.25 & -4.75 & -38 & & \\
 35.75 & -6.25 & 43 & 9 & & \\
 35.75 & 125.12 & 17.975 & 143 & & \\
 -132.37 & 25.125 & -134 & & &
 \end{array}$$

Exercise 5

a) Consider that a general table for the GCD is

| r | u | v | q |
|-------|-------|-------|-------|
| P_1 | 1 | 0 | |
| P_2 | 0 | 1 | q_1 |
| r_1 | 1 | v_1 | q_2 |
| r_2 | u_2 | v_2 | q_3 |
| r_3 | u_3 | v_3 | q_4 |

We begin by calculating q_1 and r_1 .

$$\begin{array}{ccccccccc}
 x^5 & x^4 & x^3 & x^2 & x^1 & x^0 & & x^4 & x^3 & x^2 & x^1 & x^0 & & x^1 & x^0 \\
 1 & 6 & 9 & -6 & -22 & -12 & : & 1 & 1 & -4 & -2 & 4 & = & 1 & 5 \\
 1 & 1 & -4 & -2 & 4 & & & & & & & & & & \\
 \hline
 & 5 & 13 & -4 & -26 & -12 & & & & & & & & & \\
 & 5 & 5 & -20 & -10 & 20 & & & & & & & & & \\
 \hline
 & & 8 & 16 & -16 & -32 & & & & & & & & &
 \end{array}$$

Thus $q_1 = x + 5$, $r_1 = 8x^3 + 16x^2 - 16x - 32$ and $v_1 = 0 - q_1 = -x - 5$.

We continue by calculating q_2 and r_2 .

$$\begin{array}{ccccccccc}
 x^4 & x^3 & x^2 & x^1 & x^0 & & x^3 & x^2 & x^1 & x^0 & & x^1 & x^0 \\
 1 & 1 & -4 & -2 & 4 & : & 8 & 16 & -16 & -32 & = & \frac{1}{8} & -\frac{1}{8} \\
 1 & 2 & -2 & -4 & & & & & & & & & \\
 \hline
 & -1 & -2 & 2 & 4 & & & & & & & & \\
 & -1 & -2 & 2 & 4 & & & & & & & & \\
 \hline
 & & 0 & 0 & 0 & 0 & & & & & & &
 \end{array}$$

Thus $q_2 = \frac{1}{8}x - \frac{1}{8}$ and $r_2 = 0$. We have $\gcd(P_1, P_2) = r_1 = 8x^3 + 16x^2 - 16x - 32$.

b) If $\frac{a}{b}$ is a root of $\gcd(P_1, P_2)$ then a must be a divisor of 32 and b must be a divisor of 8. The candidates are thus

$$\pm 1 \quad \boxed{-2} \quad \pm 4 \quad \pm 8 \quad \pm 16 \quad \pm 32 \quad \pm \frac{1}{2} \quad \pm \frac{1}{4} \quad \pm \frac{1}{8}$$

where boxed numbers are actual roots. We can thus factor out $x + 2$ by division.

$$\begin{array}{ccccccccc}
 x^3 & x^2 & x^1 & x^0 & & x^1 & x^0 & & x^2 & x^1 & x^0 \\
 8 & 16 & -16 & -32 & : & 1 & 2 & = & 8 & 0 & -16 \\
 8 & 16 & & & & & & & & & \\
 \hline
 & & -16 & -32 & & & & & & & \\
 & & -16 & -32 & & & & & & &
 \end{array}$$

We can now solve $8x^2 - 16 = 0$ through

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \pm \frac{\sqrt{-4 \cdot 8 \cdot -16}}{2 \cdot 8} = \pm \frac{\sqrt{512}}{16} = \pm \frac{16\sqrt{2}}{16} = \pm \sqrt{2}.$$

The roots are thus -2 , $-\sqrt{2}$ and $\sqrt{2}$.

Exercise 6 We are looking for the rational roots of

$$P(x) = 18x^6 - 51x^5 - 7x^4 + 106x^3 - 62x^2 - 8x + 8$$

Using the fact that, if $\frac{a}{b}$ is a root of a polynomial then $a \mid a_0$ and $b \mid a_n$, we get

$$\pm 1 \quad \boxed{2} \quad \pm 4 \quad \pm 8 \quad \boxed{\frac{1}{2}} \quad \boxed{-\frac{1}{3}} \quad \pm \frac{1}{6} \quad \pm \frac{1}{9} \quad \pm \frac{1}{18} \quad \boxed{\frac{2}{3}} \quad \pm \frac{2}{9} \quad \pm \frac{2}{18} \quad \pm \frac{4}{3} \quad \pm \frac{4}{9} \quad \pm \frac{8}{3} \quad \pm \frac{8}{9}$$

as potential roots. Boxed numbers are actual roots.

We can thus factor out

$$\left(x + \frac{1}{3}\right) \left(x - \frac{1}{2}\right) \left(x - \frac{2}{3}\right) (x - 2) = x^4 - \frac{17}{6}x^3 + \frac{29}{18}x^2 + \frac{2}{9}x - \frac{2}{9}$$

by division.

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|----|-------|-----------------|-----------------|---------------|----------------|---|-------|-------|-------|
| x^6 | x^5 | x^4 | x^3 | x^2 | x^1 | x^0 | | x^4 | x^3 | x^2 | x^1 | x^0 | | x^2 | x^1 | x^0 |
| 18 | -51 | -7 | 106 | -62 | -8 | 8 | : | 1 | $-\frac{17}{6}$ | $\frac{29}{18}$ | $\frac{2}{9}$ | $-\frac{2}{9}$ | = | 18 | 0 | -36 |
| 18 | -51 | 29 | 4 | -4 | | | | | | | | | | | | |
| | | | | -36 | 102 | -58 | -8 | 8 | | | | | | | | |
| | | | | -36 | 102 | -58 | -8 | 8 | | | | | | | | |

We can now solve $18x^2 - 36 = 0$ through

$$x_1, x_2 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \pm \frac{\sqrt{-4 \cdot 18 \cdot -36}}{2 \cdot 18} = \pm \frac{\sqrt{2592}}{36} = \pm \frac{36\sqrt{2}}{36} = \pm\sqrt{2},$$

yielding no rational roots. The rational roots are thus these obtained previously.

Exercise 7 We have

$$p(x) = x^7 - 6x^6 + 10x^5 - 6x^4 + 9x^3$$

$$p'(x) = 7x^6 - 36x^5 + 50x^4 - 24x^3 + 27x^2$$

and we are looking for a square-free factorisation of p . Calculating the GCD of p and p' we first divide p by p'

| | | | | | | | | | | | | | | |
|-------|-----------------|------------------|-------------------|------------------|-------------------|-----|-------|-------|-------|-------|-------|-----|---------------|-----------------|
| x^7 | x^6 | x^5 | x^4 | x^3 | x^2 | $:$ | x^6 | x^5 | x^4 | x^3 | x^2 | $=$ | x^1 | x^0 |
| 1 | -6 | 10 | -6 | 9 | 0 | | 7 | -36 | 50 | -24 | 27 | | $\frac{1}{7}$ | $-\frac{6}{49}$ |
| 1 | $-\frac{36}{7}$ | $\frac{50}{7}$ | $-\frac{24}{7}$ | $\frac{27}{7}$ | | | | | | | | | | |
| | $-\frac{6}{7}$ | $\frac{20}{7}$ | $-\frac{17}{7}$ | $\frac{36}{7}$ | 0 | | | | | | | | | |
| | $-\frac{6}{7}$ | $\frac{216}{49}$ | $-\frac{300}{49}$ | $\frac{144}{49}$ | $-\frac{162}{49}$ | | | | | | | | | |
| | | $-\frac{76}{49}$ | $\frac{174}{49}$ | $\frac{108}{49}$ | $\frac{162}{49}$ | | | | | | | | | |

and get $r_1 = -\frac{76x^5}{49} + \frac{174x^4}{49} + \frac{108x^3}{49} + \frac{162x^2}{49}$ and $q_1 = \frac{x}{7} - \frac{6}{49}$. We can simplify $r_1 = -38x^5 + 87x^4 + 54x^3 + 81x^2$.

Now we divide p' by r_1

| | | | | | | | | | | | | |
|-------|-------------------|-------------------------|-------------------------|--------------------------|-----|-------|-------|-------|-------|-----|-----------------|--------------------|
| x^6 | x^5 | x^4 | x^3 | x^2 | $:$ | x^5 | x^4 | x^3 | x^2 | $=$ | x^1 | x^0 |
| 7 | -36 | 50 | -24 | 27 | | -38 | 87 | 54 | 81 | | $-\frac{7}{38}$ | $\frac{759}{1444}$ |
| 7 | $\frac{126}{19}$ | $\frac{175}{19}$ | $\frac{84}{19}$ | $-\frac{189}{38}$ | | | | | | | | |
| | $-\frac{810}{19}$ | $\frac{775}{19}$ | $-\frac{540}{19}$ | $\frac{1215}{38}$ | | | | | | | | |
| | $-\frac{810}{19}$ | $\frac{66033}{1444}$ | $\frac{20493}{722}$ | $\frac{61479}{1444}$ | | | | | | | | |
| | | $\frac{20531x^4}{1444}$ | $-\frac{13524x^3}{361}$ | $-\frac{22491x^2}{1444}$ | | | | | | | | |

and get $r_2 = \frac{20531x^4}{1444} - \frac{13524x^3}{361} - \frac{22491x^2}{1444}$. We then divide r_1 by r_2 and get $r_3 = \frac{11696400x^2}{175561} - \frac{3898800x^3}{175561}$. We then divide r_2 by r_3 and get $r_4 = 0$.

Thus r_3 , which can be simplified to $x^3 - 3x^2$, is the GCD we are looking for.

We now divide p by this result which yields $x^4 - 3x^3 + x^2 - 3x$ with no remainder.

Exercise 8 To show that $p \mid \binom{p}{k}$ note that

$$\binom{p}{k} = \frac{p!}{k!(p-k)!}$$

$$p! = \binom{p}{k} (k!(p-k)!).$$

Since the left hand side of the equation is clearly divisible by p , the right hand side must also be divisible by it. The expression $k!(p-k)!$ is not divisible by p since it is a product of numbers smaller than p and p is prime. Thus the binomial coefficient must be the part which is divisible by p .

Now consider that, by the binomial theorem

$$(x+y)^p = \sum_{k=0}^p \binom{p}{k} x^{p-k} y^k$$

$$(x+y)^p = \binom{p}{0} x^p y^0 + \binom{p}{1} x^{p-1} y^1 + \cdots + \binom{p}{p-1} x^1 y^{p-1} + \binom{p}{p} x^0 y^p$$

$$(x+y)^p = x^p + \binom{p}{1} x^{p-1} y^1 + \cdots + \binom{p}{p-1} x^1 y^{p-1} + y^p$$

$$(x+y)^p \equiv_6 x^p + y^p$$