

Homework problem set 5

Your homework must be handed in **electronically via Moodle before Friday December 9th, 20:00h**. This deadline is strict and late submissions are graded with a 0. At the end of the course, the lowest of your 6 weekly homework grades will be dropped. You are strongly encouraged to work together on the exercises, including the homework. However, after this discussion phase, you have to write down and submit your own individual solution. Numbers alone are never sufficient, always motivate your answers.

Problem 1: Channel capacities (6pt)

Find the capacity and optimal input distribution of the following channels:

- (a) (2pt) The ternary channel with transition matrix

$$P_{Y|X} = \begin{bmatrix} \frac{2}{3} & \frac{1}{3} & 0 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ 0 & \frac{1}{3} & \frac{2}{3} \end{bmatrix}.$$

- (b) (4pt) The Z-channel with transition matrix

$$P_{Y|X} = \begin{bmatrix} 1 & 0 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$

Problem 2: Shannon capacity of the complete graph (6pt)

A graph G with n vertices $V(G) = \{1, 2, \dots, n\}$ is called complete if it has edges between any two vertices, i.e. $\forall i \neq j : (i, j) \in E(G)$.

- (a) (2pt) Compute $\alpha(K_n)$, the independence number of the complete graph of size n .

- (b) (2pt) Show that $K_n \boxtimes K_n = K_{n^2}$.

Hint: the \LaTeX command for \boxtimes is `\boxtimes` (in the `amssymb` package). See also [Detexify](#).

- (c) (2pt) Use (a) and (b) to prove that the Shannon capacity of K_n is 0. Note that this result formally confirms the intuition that channels whose confusability graphs are complete are useless for zero-error communication, because all symbols can possibly be confused with each other.

Problem 3: Disjoint graphs (5 + 2 pt)

For two graphs G and H , the graph $G + H$ is defined as the disjoint union of the two graphs. Formally, assuming without loss of generality that $V(G) \cap V(H) = \emptyset$, then $V(G + H) = V(G) \cup V(H)$ and $E(G + H) = E(G) \cup E(H)$. (You can think of $G + H$ as G and H “next to each other”.)

- (a) (2pt) Prove that $\alpha(G + H) = \alpha(G) + \alpha(H)$.

- ★ (2 bonus points) Prove that for any three graphs G, H, L , it holds that

$$(G + H) \boxtimes L = (G \boxtimes L) + (H \boxtimes L)$$

and for the same reason, it also holds that

$$G \boxtimes (H + L) = (G \boxtimes H) + (G \boxtimes L).$$

- (b) (3pt) Use ★ to derive that for any natural number $k \in \mathbb{N}$, $(G + G)^{\boxtimes k} = (G^{\boxtimes k})^{+2^k}$.

Problem 4: Same-parity channel (6pt)

Let $\mathcal{X} = \mathcal{Y} = \{1, 2, 3, 4, 5, 6\}$. In this exercise, you will compute the zero-error Shannon capacity of the noisy channel with transition probabilities $P_{Y|X}(y|x) = 1/3$ if and only if x and y have the same parity (i.e. $x \equiv y \pmod{2}$).

- (a) (2pt) Give the confusability graph G of the noisy channel $P_{Y|X}$ described above.
- (b) (4pt) Compute the Shannon capacity of G .
Hint: use several results from the previous two exercises.