

**General rules for solving exercises**

- When handing in your solutions, please write your exercise group on the front sheet:

**Group A:** Wed 13–15 CAB G 56

**Group C:** Wed 16–18 CAB G 52

- This is a theory course, which means: if an exercise does not explicitly say “you do not need to prove your answer”, then a formal proof is **always** required.
- 

The following exercises will be discussed in the exercise class on November 14, 2018. Please hand in your solutions not later than November 13.

**Exercise 1**

Suppose that we have an oracle that, given a system of linear inequalities, decides its feasibility (outputs YES or NO). Design an algorithm that computes a solution of a given system of linear equations and inequalities, provided that one exists, in polynomial time and with polynomially many calls of the oracle.

- (a) How can we proceed if there are only equations in the system?
- (b) If there is at least one inequality, use the oracle to check if there is a solution satisfying that inequality with equality, and take appropriate actions depending on the outcome.

## Exercise 2

Recall the definition of the Subtour LP:

$$\begin{aligned} \text{minimize } c^T x \text{ subject to } & \sum_{e \in \delta(v)} x_e = 2 \text{ for all } v \in V \\ & \sum_{e \in \delta(S)} x_e \geq 2 \text{ for all } S \subseteq V \text{ with } \emptyset \neq S \neq V \\ & 1 \geq x_e \geq 0 \text{ for all } e \in E. \end{aligned}$$

- (i) Show that a graph  $G = (V, E)$  is connected if and only if  $\delta(S) \neq \emptyset$  for all  $S \subseteq V$ ,  $\emptyset \neq S \neq V$ . Prove this using the most basic definition of connectedness: A graph is connected if for any two vertices  $v, w \in V$  there is a path from  $v$  to  $w$ .
- (ii) Give a graph  $G$  where the subtour LP is feasible but there is no feasible integer solution.
- (iii) Assume  $|V| \geq 3$ . Show that the constraints " $1 \geq x_e$ " are redundant in the Subtour LP, i. e. every point  $x \in \mathbb{R}^E$  that is feasible w.r.t. all other constraints also satisfies  $1 \geq x_e$  for all  $e \in E$ .

## Exercise 3

Show that every feasible point of the Tight Spanning Tree LP is feasible in the Loose Spanning Tree LP – without using theorem 4.11.

## Exercise 4

Let  $m \in \mathbb{N}$ ,  $c \in \mathbb{R}^m$ ,  $S \subseteq \mathbb{R}^m$  finite and  $P := \text{conv}(S)$ . Show that we have

$$\min_{x \in P} c^T x = \min_{x \in S} c^T x.$$

## Exercise 5

Consider the following linear program, almost the Tight Spanning Tree LP, it seems:

$$\begin{aligned} \text{Some LP for graph } G = (V, E), c \in \mathbb{R}^E \\ \text{min } c^T x \\ \text{subject to } & \sum_{e \in E} x_e = n \\ & \sum_{e \in E \cap \binom{S}{2}} x_e \leq |S| - 1, \text{ for all } S \subseteq V, \emptyset \neq S \neq V, \text{ and} \\ & 1 \geq x_e \geq 0, \text{ for all } e \in E. \end{aligned}$$

What are the edge sets corresponding to vectors  $x \in \{0, 1\}^E$  feasible in Some LP?