

Duality

How do we get an upper bound to a maximization LP?

$$\begin{array}{llll} \max & 13a & + & 23b \\ \text{s.t.} & 5a & + & 15b \leq 480 \\ & 4a & + & 4b \leq 160 \\ & 35a & + & 20b \leq 1190 \\ & & & a, b \geq 0 \end{array}$$

Note that a lower bound is easy to derive. Every choice of $a, b \geq 0$ gives us a lower bound (e.g. $a = 12, b = 28$ gives us a lower bound of 800).

If you take a conic combination of the rows (multiply the i -th row with $y_i \geq 0$) such that $\sum_i y_i a_{ij} \geq c_j$ then $\sum_i y_i b_i$ will be an upper bound.

Definition 2

Let $z = \max\{c^T x \mid Ax \leq b, x \geq 0\}$ be a linear program P (called the primal linear program).

The linear program D defined by

$$w = \min\{b^T y \mid A^T y \geq c, y \geq 0\}$$

is called the **dual problem**.

Lemma 3

The dual of the dual problem is the primal problem.

Proof:

- ▶ $w = \min\{b^T y \mid A^T y \geq c, y \geq 0\}$
- ▶ $w = -\max\{-b^T y \mid -A^T y \leq -c, y \geq 0\}$

The dual problem is

- ▶ $z = -\min\{-c^T x \mid -Ax \geq -b, x \geq 0\}$
- ▶ $z = \max\{c^T x \mid Ax \leq b, x \geq 0\}$

Weak Duality

Let $z = \max\{c^T x \mid Ax \leq b, x \geq 0\}$ and
 $w = \min\{b^T y \mid A^T y \geq c, y \geq 0\}$ be a primal dual pair.

x is primal feasible iff $x \in \{x \mid Ax \leq b, x \geq 0\}$

y is dual feasible, iff $y \in \{y \mid A^T y \geq c, y \geq 0\}$.

Theorem 4 (Weak Duality)

Let $\hat{x}$ be primal feasible and let $\hat{y}$ be dual feasible. Then

$$c^T \hat{x} \leq z \leq w \leq b^T \hat{y} .$$

Weak Duality

$$A^T \hat{y} \geq c \Rightarrow \hat{x}^T A^T \hat{y} \geq \hat{x}^T c \quad (\hat{x} \geq 0)$$

$$A\hat{x} \leq b \Rightarrow y^T A\hat{x} \leq \hat{y}^T b \quad (\hat{y} \geq 0)$$

This gives

$$c^T \hat{x} \leq \hat{y}^T A\hat{x} \leq b^T \hat{y} .$$

Since, there exists primal feasible $\hat{x}$ with $c^T \hat{x} = z$, and dual feasible $\hat{y}$ with $b^T \hat{y} = w$ we get $z \leq w$.

If P is unbounded then D is infeasible.