cs473 Algorithms

Problem Set #6

Prof. Michael A. Forbes — Due: *Fri., 2026-04-03 17:00*

All problems are of equal value.

1. Shapley value. Kleinberg-Tardos Chapter 13, Problem #5.

2. Online auction. Kleinberg-Tardos Chapter 13, Problem #10.

3. In lecture it was shown that the family of hash functions $\mathcal{H}_{k,p}$,

$$\mathcal{H}_{k,p} = \left\{ h : \mathbb{Z}_p^k \to \mathbb{Z}_p, h(x) = \sum_{i=1}^{k} x_i b_i, b \in \mathbb{Z}_p^k \right\} ,$$

   is *universal* for any prime p and integer $k \geq 1$, in that for any $x \neq y \in \mathbb{Z}_p^k$,

$$\Pr_{h \in \mathcal{H}_{k,p}} [h(x) = h(y)] = \frac{1}{p} ,$$

   where h is taken uniformly from $\mathcal{H}_{k,p}$. A stronger requirement is that of *ℓ-wise independence*, which means that for any distinct $x_1, \ldots, x_\ell \in \mathbb{Z}_p$ and (not necessarily distinct) $y_1, \ldots, y_\ell \in \mathbb{Z}_p$,

$$\Pr_{h \in \mathcal{H}_{k,p}} [h(x_1) = y_1 \wedge \cdots \wedge h(x_\ell) = y_\ell] = \frac{1}{p^\ell} .$$

   When $\ell = 2$, this is called *pairwise independence*.

   (a) Show that any family of hash functions that is pairwise independent is also universal.

   (b) Show that $\mathcal{H}_{k,p}$ is <u>not</u> pairwise independent, for every k and p.

   (c) Show that hash family $\mathcal{H}'_{k,p} = \{h : \mathbb{Z}_p^k \to \mathbb{Z}_p, h(x) = c + \sum_{i=1}^{k} x_i b_i, b \in \mathbb{Z}_p^k, c \in \mathbb{Z}_p\}$ <u>is</u> pairwise independent.

   (d) Show that $\mathcal{H}'_{k,p}$ is <u>not</u> 3-wise independent, for every k and p with $p > 3$.