

## 18.218 PROBLEM SET

### Instructions:

- All submissions must be **typed in LaTeX** and submitted as PDF on [Stellar](#) (try [Overleaf](#) if you are looking for an online LaTeX editor without requiring installations). Please name your file `ps#_Lastname_Firstname.pdf` and remember to include your name in each file.
- At the top of each submission, you must **acknowledge all references and people consulted** (other than lectures and the textbook). Failure acknowledge sources will lead to an automatic 10% penalty. Examples include: names of people you discussed homework with, books, and online resources. If you consulted no additional sources, you should write **sources consulted: none**.
- Please turn in the problems marked `ps1` and `ps1*` for problem set 1, etc., by midnight of each due date (see course homepage for due dates). Do not submit the other problems—they are for you to practice. See [course homepage](#) for policies (20% per day late penalty; do not look up solutions; collaboration policy).
- **Bonus problems**, marked by  $\star$ , are more challenging. A grade of A- may be attained by only solving the non-starred problems. To attain a grade of A or A+, you should solve a substantial number of starred problems.
- Please **do not exceed one page** for each problem (standard 1-inch margins and 11pt font). If you cannot fit your solution within one page, then think about how to better distill your ideas. If necessary, you may skip details of routine calculations (we don't really want to read them either).
- This file will be updated constantly as the term progresses. Please check back regularly. It will be announced when each problem set is complete.
- You are encouraged to include figures whenever they are helpful. Here are some recommended ways to produce figures in decreasing order of learning curve difficulty:
  - (1) [TikZ](#) or other drawing script
  - (2) [IPE](#) (which supports LaTeX) or other drawing app
  - (3) photo/scan (I recommend the Dropbox app on your phone, which has a nice scanning feature that produces clear monochrome scans)

Problems begin on the next page

1. Verify the following asymptotic calculations used in Ramsey number lower bounds:
  - (a) For each  $k$ , the largest  $n$  satisfying  $\binom{n}{k} 2^{1-\binom{k}{2}} < 1$  has  $n = \left(\frac{1}{e\sqrt{2}} + o(1)\right) k 2^{k/2}$ .
  - (b) For each  $k$ , the maximum value of  $n - \binom{n}{k} 2^{1-\binom{k}{2}}$  as  $n$  ranges over positive integers is  $\left(\frac{1}{e} + o(1)\right) k 2^{k/2}$ .
  - (c) For each  $k$ , the largest  $n$  satisfying  $e \left(\binom{k}{2} \binom{n}{k-2} + 1\right) 2^{1-\binom{k}{2}} < 1$  satisfies  $n = \left(\frac{\sqrt{2}}{e} + o(1)\right) k 2^{k/2}$ .
2. Prove that, if there is a real  $p \in [0, 1]$  such that

$$\binom{n}{k} p^{\binom{k}{2}} + \binom{n}{t} (1-p)^{\binom{t}{2}} < 1$$

then the Ramsey number  $R(k, t)$  satisfies  $R(k, t) > n$ . Using this show that

$$R(4, t) \geq c \left( \frac{t}{\log t} \right)^{3/2}$$

for some constant  $c > 0$ .

3. (Extension of Sperner's theorem) Let  $\mathcal{F}$  be a collection of subset of  $[n]$  that does not contain  $k+1$  elements forming a chain:  $A_1 \subsetneq \cdots \subsetneq A_{k+1}$ . Prove that  $\mathcal{F}$  is no larger than taking the union of the  $k$  levels of the boolean lattice closest to the middle layer.
- ps1 4. Let  $A_1, \dots, A_m$  be  $r$ -element sets and  $B_1, \dots, B_m$  be  $s$ -element sets. Suppose  $A_i \cap B_i = \emptyset$  for each  $i$ , and for each  $i \neq j$ , either  $A_i \cap B_j \neq \emptyset$  or  $A_j \cap B_i \neq \emptyset$ . Prove that  $m \leq (r+s)^{r+s}/(r^r s^s)$ .
- ps1 5. Prove that for every positive integer  $r$ , there exists an integer  $K$  such that the following holds. Let  $S$  be a set of  $rk$  points evenly spaced on a circle. If we partition  $S = S_1 \cup \cdots \cup S_r$  so that  $|S_i| = k$  for each  $i$ , then, provided  $k \geq K$ , there exists  $r$  congruent triangles where the vertices of the  $i$ -th triangle lie in  $S_i$ , for each  $1 \leq i \leq r$ .
- ps1 6. Prove that every set of 10 points in the plane can be covered by a union of disjoint unit disks.
- ps1★ 7. Prove that  $[n]^d$  cannot be partitioned into fewer than  $2^d$  sets each of the form  $A_1 \times \cdots \times A_d$  where  $A_i \subsetneq [n]$ .