

**Problem 2:**

- (a) Prove that  $x$  is in the Cantor set iff  $x$  has a ternary expansion that uses only 0's and 2's.
- (b) The Cantor-Lebesgue function is defined on the Cantor set by writing  $x$ 's ternary expansion in 0's and 2's, switching 2's to 1's, and re-interpreting as a binary expansion. Show that this is well-defined and continuous,  $F(0) = 0$ , and  $F(1) = 1$ .
- (c) Prove that  $F$  is surjective onto  $[0, 1]$ .
- (d) Show how to extend  $F$  to a continuous function on  $[0, 1]$ .

*Solution.*

- (a) The  $n$ th iteration of the Cantor set removes the open segment(s) consisting of all numbers with a 1 in the  $n$ th place of the ternary expansion. Thus, the numbers remaining after  $n$  iterations will have only 0's and 2's in the first  $n$  places. So the numbers remaining at the end are precisely those with only 0's and 2's in all places. (Note: Some numbers have a non-unique ternary representation, namely those that have a representation that terminates. For these, we choose the infinitely repeating representation instead; if it consists of all 0's and 2's, it is in the Cantor set. This works because we remove an *open* interval each time, and numbers with terminating representations are the endpoints of one of the intervals removed.)
- (b) First, we show that this is well-defined. The only possible problem is that some numbers have more than one ternary representation. However, such numbers can have only one representation that consists of all 0's and 2's. This is because the only problems arise when one representation terminates and another doesn't. Now if a representation terminates, it must end in a 2 if it contains all 0's and 2's. But then the other representation ends with 12222... and therefore contains a 1.

Next we show  $F$  is continuous on the Cantor set; given  $\epsilon > 0$ , choose  $k$  such that  $\frac{1}{2^k} < \epsilon$ . Then if we let  $\delta = \frac{1}{3^k}$ , any numbers within  $\delta$  will agree in their first  $k$  places, which means that the first  $k$  places of their images will also agree, so that their images are within  $\frac{1}{2^k} < \epsilon$  of each other.

The equalities  $F(0) = 0$  and  $F(1) = 1$  are obvious; for the latter,  $1 = 0.2222\dots$  so  $F(1) = 0.1111\dots = 1$ .

- (c) Let  $x \in [0, 1]$ . Choose any binary expansion of  $x$ , replace the 0's with 2's, and re-interpret as a ternary expansion. By part (a), this will produce a member of the Cantor set whose image is  $x$ . (Note: Their may be more than one preimage of  $x$ , e.g.  $F(\frac{1}{3}) = F(\frac{2}{3}) = \frac{1}{2}$ .)
- (d) First, note that  $F$  is increasing on the Cantor set  $C$ . Now let

$$G(x) = \sup\{F(y) : y \leq x, y \in C\}.$$

Note that  $G(x) = F(x)$  for  $x \in C$  because  $F$  is increasing.  $G$  is continuous at points not in  $C$ , because  $\bar{C}$  is open, so if  $x \in \bar{C}$ , there is a neighborhood of  $x$  on which  $G$  is constant. To show that  $G$  is continuous on  $C$ , let  $x \in C$  and use the continuity of  $F$  (part b) to

# Real Analysis Solutions Manual Stein

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