

# Real Analysis - Homework solutions

Chris Monico, May 2, 2013

1.1 (a) Rings (resp.  $\sigma$ -rings) are closed under finite (resp. countable) intersections.

(b) If  $\mathcal{R}$  is a ring (resp.  $\sigma$ -ring) then  $\mathcal{R}$  is an algebra (resp.  $\sigma$ -algebra) iff  $X \in \mathcal{R}$ .

(c) If  $\mathcal{R}$  is a (nonempty)  $\sigma$ -ring then  $\{E \subset X : E \in \mathcal{R} \text{ or } E^c \in \mathcal{R}\}$  is a  $\sigma$ -algebra.

(d) If  $\mathcal{R}$  is a  $\sigma$ -ring, then  $\{E \subset X : E \cap F \in \mathcal{R} \text{ for all } F \in \mathcal{R}\}$  is a  $\sigma$ -algebra.

Solution:

(a) If  $\mathcal{R}$  is a ring and  $E_1, E_2 \in \mathcal{R}$ , then since  $\mathcal{R}$  is closed under differences,  $E_1 - (E_1 - E_2) \in \mathcal{R}$ . But

$$E_1 - (E_1 - E_2) = E_1 - (E_1 \cap E_2^c) = E_1 \cap (E_1^c \cup E_2) = E_1 \cap E_2.$$

It follows inductively that  $\mathcal{R}$  is closed under finite intersections. Suppose now that  $\mathcal{R}$  is a  $\sigma$ -ring and  $\{E_n\} \subset \mathcal{R}$ . Let  $A = \bigcup E_j$  and  $\widetilde{E}_n = A - E_n$ . Then  $\widetilde{E}_n \in \mathcal{R}$  for all  $n \geq 1$  and so  $F = E_1 - \bigcup_{j=2}^{\infty} \widetilde{E}_j$  is also in  $\mathcal{R}$ . But

$$F = E_1 \cap \left( \bigcap_{j=2}^{\infty} \widetilde{E}_j^c \right) = E_1 \cap \left( \bigcap_{j=2}^{\infty} (A^c \cup E_j) \right) = \bigcap_{j=2}^{\infty} ((E_1 \cap A^c) \cup (E_1 \cap E_j)) = \bigcap_{j=2}^{\infty} (E_1 \cap E_j) = \bigcap_{j=1}^{\infty} E_j.$$

(b) If  $\mathcal{R}$  is a ring (resp.  $\sigma$ -ring) and  $X \in \mathcal{R}$ , then for all  $E \in \mathcal{R}$  we have  $E^c = X - E \in \mathcal{R}$  so  $\mathcal{R}$  is closed under complements and therefore an algebra (resp.  $\sigma$ -algebra). On the other hand if  $\mathcal{R}$  is an algebra (resp.  $\sigma$ -algebra), then it's nonempty so there exists  $E \in \mathcal{R}$  and hence  $X = E \cup E^c \in \mathcal{R}$ .

(c) Suppose  $\mathcal{R}$  is a nonempty  $\sigma$ -ring and  $\mathcal{M} = \{E \subset X : E \in \mathcal{R} \text{ or } E^c \in \mathcal{R}\}$ . Clearly  $\mathcal{M}$  is closed under complements. Suppose that  $\{E_n\} \subset \mathcal{M}$ . By part (a),  $\mathcal{R}$  is closed under countable intersections so  $A = \bigcap_{j \geq 1} E_j^c \in \mathcal{R}$ . Since  $\mathcal{R}$  is closed under countable unions,  $B = \bigcup_{j \geq 1} E_j \in \mathcal{R}$ . Now

$$\begin{aligned} \bigcup_{j \geq 1} E_j &= \left( \bigcup_{\substack{j \geq 1 \\ E_j^c \in \mathcal{R}}} E_j \right) \cup \left( \bigcup_{\substack{j \geq 1 \\ E_j \in \mathcal{R}}} E_j \right) \\ &= \left( \left( \bigcap_{\substack{j \geq 1 \\ E_j^c \in \mathcal{R}}} E_j^c \right) \cap \left( \bigcup_{\substack{j \geq 1 \\ E_j \in \mathcal{R}}} E_j \right) \right)^c \\ &= (A - B)^c. \end{aligned}$$

Since  $A, B \in \mathcal{R}$  and  $\mathcal{R}$  is closed under differences,  $A - B \in \mathcal{R}$ , hence  $\bigcup E_j = (A - B)^c \in \mathcal{M}$ . Therefore  $\mathcal{M}$  is also closed under countable unions, hence it's a  $\sigma$ -algebra.

(d) Suppose  $\mathcal{R}$  is a  $\sigma$ -ring and  $\mathcal{A} = \{E \subset X : E \cap F \in \mathcal{R} \text{ for all } F \in \mathcal{R}\}$ . Suppose  $E \in \mathcal{A}$  and let  $F \in \mathcal{R}$ . Then  $E \cap F \in \mathcal{R}$  and since  $\mathcal{R}$  is closed under differences,  $E^c \cap F = F - E = F - (E \cap F) \in \mathcal{R}$ , and therefore  $\mathcal{A}$  is closed under complements. If  $\{E_n\} \subset \mathcal{A}$  and  $F \in \mathcal{R}$  then  $E_n \cap F \in \mathcal{R}$  and so  $(\bigcup E_n) \cap F = \bigcup (E_n \cap F) \in \mathcal{R}$  for all  $n$ , so  $\mathcal{A}$  is closed under countable unions as well and therefore is a  $\sigma$ -algebra.

# Real Analysis Solution

**Masayoshi Hata**



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Stephen Abbott,2012-12-06 Understanding Analysis outlines an elementary one semester course designed to expose students to the rich rewards inherent in taking a mathematically rigorous approach to the study of functions of a real variable The aim of a course in real analysis should be to challenge and improve mathematical intuition rather than to verify it The philosophy of this book is to focus attention on the questions that give analysis its inherent fascination Does the Cantor set contain any irrational numbers Can the set of points where a function is discontinuous be arbitrary Are derivatives continuous Are derivatives integrable Is an infinitely differentiable function necessarily the limit of its Taylor series In giving these topics center stage the hard work of a rigorous study is justified by the fact that they are inaccessible without it

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