Solutions to Durrett's Probability: Theory and Examples

Lumiso

1 Martingales

1.1 Martingales, Almost Sure Convergence

Problem 1.1.1 *X_n is a martingale w.r.t. $\mathcal{G}_n$ and let $\mathcal{F}_n = \sigma(X_1, \cdots, X_n)$. Then $\mathcal{G}_n \supseteq \mathcal{F}_n$ and X_n is a martingale w.r.t. $\mathcal{F}_n$.*

Proof Note that $\sigma(X_m) \subseteq \mathcal{G}_m \subseteq \mathcal{G}_n$ if $m \leq n$. Thus:

$$\mathcal{F}_n = \sigma(X_1, \cdots, X_n) = \sigma(\bigcup_{k=1}^{n} \sigma(X_k)) \subseteq \mathcal{G}_n$$

Obviously $X_n \in \mathcal{F}_n$ and is integrable. Also, using the property of conditional expectation:

$$\mathbb{E}[X_{n+1}|\mathcal{F}_n] = \mathbb{E}[\mathbb{E}[X_{n+1}|\mathcal{G}_n]|\mathcal{F}_n] = \mathbb{E}[X_n|\mathcal{F}_n] = X_n, \ \forall n \geq 1$$

Thus $(X_n)_{n\geq 1}$ is a martingale w.r.t $\mathcal{F}_n$. □

Problem 1.1.2 *Give an example of a submartingale X_n so that X_n^2 is a supermartingale. Hint: X_n does not have to be random.*

Proof Let $X_n = -\frac{1}{n}$. □

Problem 1.1.3 *Generalize (i) of* **Theorem** *4.2.7 by showing that if X_n and Y_n are submartingales w.r.t. $\mathcal{F}_n$ then $X_n \vee Y_n$ is also.*

Proof Obviously $X_n \vee Y_n \in \mathcal{F}_n$ and is integrable. By the definition of submartingale:

$$\mathbb{E}[X_{n+1} \vee Y_{n+1}|\mathcal{F}_n] \geq \mathbb{E}[X_{n+1}|\mathcal{F}_n] \geq X_n$$

$$\mathbb{E}[X_{n+1} \vee Y_{n+1}|\mathcal{F}_n] \geq \mathbb{E}[Y_{n+1}|\mathcal{F}_n] \geq Y_n$$

Thus $\mathbb{E}[X_{n+1} \vee Y_{n+1}|\mathcal{F}_n] \geq X_n \vee Y_n$, which proves the result. □

Problem 1.1.4 *Let X_n, $n \geq 0$, be a submartingale with $\sup X_n < \infty$. Let $\xi_n = X_n - X_{n-1}$ and suppose $\mathbb{E}[\sup \xi_n^+] < +\infty$. Show that X_n converges a.s.*

Proof Consider the stopping time $N_M = \inf\{n \geq 0 : X_n \geq M\}$ for $M \in \mathbb{N}$. $X_{N_M \wedge n}$ is a submartingale. Notice that $X_{N_M \wedge n}^+ \leq M + \sup \xi_n^+$, we have:

$$\mathbb{E}[X_{N_M \wedge n}^+] \leq M + \mathbb{E}[\sup \xi_n^+] < +\infty$$

By **Theorem** 4.2.11, $X_{N_M \wedge n}$ converges to a limit a.s. Thus for each M, X_n converges a.s. to a limit on $\{N_M = \infty\}$. Since $\sup X_n < +\infty$, $\Omega = \bigcup_{M=1}^{\infty} \{N_M = \infty\}$, which means that X_n converges almost surely on the whole Ω. □

Problem 1.1.5 *Give an example of a martingale X_n with $X_n \to -\infty$ a.s. Hint: Let $X_n = \xi_1 + \cdots + \xi_n$, where the ξ_i are independent (but not identically distributed) with $\mathbb{E}[\xi_n] = 0$.*

Durrett Probability Theory And Examples Solutions Manual

Robert R. Redfield

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