

MATH 447 - Homework 6

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October 14, 2014

SECTION 3.3, EX. 3

Let $x_1 \geq 2$ and $x_{n+1} := 1 + \sqrt{x_n - 1}$ for $n \in \mathbb{N}$. Show that (x_n) is decreasing and bounded below by 2. Find the limit.

PROOF. We can demonstrate by induction that (x_n) is bounded below by 2. First note that $x_1 \geq 2$ by hypothesis. Thus,

$$\begin{aligned}x_1 &\geq 2 \\x_1 - 1 &\geq 1 \\\sqrt{x_1 - 1} &\geq 1 \\1 + \sqrt{x_1 - 1} &\geq 1 + 1 \\x_2 &\geq 2\end{aligned}$$

so we have a basis for induction. Assume now that $x_n \geq 2$, and we will use this to demonstrate that $x_{n+1} \geq 2$:

$$\begin{aligned}x_n &\geq 2 \\x_n - 1 &\geq 1 \\\sqrt{x_n - 1} &\geq 1 \\1 + \sqrt{x_n - 1} &\geq 1 + 1 \\x_{n+1} &\geq 2\end{aligned}$$

Thus we have confirmed that (x_n) is bounded below by 2.

We can also demonstrate by induction that (x_n) is decreasing. Begin by noting that $x_1 \geq 2$, which implies that $x_1 - 1 \geq 1$. This tells us that $\sqrt{x_1 - 1} \geq 1$. Taking the difference of the previous equations tells us that $(x_1 - 1) - (\sqrt{x_1 - 1}) \geq 0$, and thus that $x_1 \geq 1 + \sqrt{x_1 - 1} = x_2$. Since $x_1 \geq x_2$, we have established a basis for induction.

Now assume that $x_{n-1} \geq x_n$ and recall that since 2 is a lower bound, $x_n - 1 \geq 1$. We aim to show that this implies $x_n \geq x_{n+1}$.

$$\begin{aligned} x_{n-1} &\geq x_n \\ x_{n-1} - 1 &\geq x_n - 1 \\ \sqrt{x_{n-1} - 1} &\geq \sqrt{x_n - 1} \\ 1 + \sqrt{x_{n-1} - 1} &\geq 1 + \sqrt{x_n - 1} \\ x_n &\geq x_{n+1} \end{aligned}$$

Thus we have shown that (x_n) decreases.

Since (x_n) is decreasing, bounded below, and recursively defined, we may calculate its limit by acknowledging that $\lim(x_n) = \lim(x_{n+1})$, and for convenience we shall denote this x^* . Thus,

$$\begin{aligned} x^* &= 1 + \sqrt{x^* - 1} \\ x^* + 1 &= \sqrt{x^* - 1} \\ (x^* + 1)^2 &= x^* - 1 \\ x^{*2} - 3x^* + 2 &= 0 \end{aligned}$$

The solutions of the final quadratic equation are 1 and 2, however, since 2 is a lower bound for (x_n) , we know its limit may not be 1. Thus, $\lim(x_n) = 2$. ■

SECTION 3.3, EX. 4

Let $x_1 := 1$ and $x_{n+1} := \sqrt{2 + x_n}$ for $n \in \mathbb{N}$. Show that (x_n) converges and find the limit.

PROOF. $x_2 = \sqrt{3} < 2$, so we know that x_1 and x_2 are both less than 2. Assume $x_n < 2$, then

$$\begin{aligned} x_n &< 2 \\ x_n + 2 &< 2 + 2 \\ \sqrt{x_n + 2} &< \sqrt{4} \\ x_{n+1} &= \sqrt{x_n + 2} < 2 \end{aligned}$$

so by induction we have that (x_n) is increasing and bounded above by 2. Since it is recursively defined, we may acknowledge that $\lim(x_n) = \lim(x_{n+1})$ and call that value x^* .

$$\begin{aligned}x^* &= \sqrt{2 + x^*} \\(x^*)^2 &= 2 + x^* \\(x^*)^2 - x^* - 2 &= 0\end{aligned}$$

so that solving with the quadratic formula gives us $x^* = 2$. ■

SECTION 3.3., EX. 5

Let $y_1 := \sqrt{p}$, where $p > 0$, and $y_{n+1} := \sqrt{p + y_n}$ for $n \in \mathbb{N}$. Show that (y_n) converges and find the limit.

PROOF. The book tells us that $y_n \leq 1 + 2\sqrt{p} \ \forall n \in \mathbb{N}$, so (y_n) is bounded above. Since (y_n) is increasing, we know that $\lim(y_n) = \sup\{y_n : n \in \mathbb{N}\}$, and we call this value y^* . Since this sequence is recursively defined, $\lim(y_{n+1}) = y^*$. Thus,

$$\begin{aligned}y^* &= \sqrt{p + y^*} \\(y^*)^2 &= p + y^* \\(y^*) - y^* &= p \\(y^*)^2 - y^* - p &= 0\end{aligned}$$

so by the quadratic formula, $y^* \in \{\frac{1+\sqrt{1+4p}}{2}, \frac{1-\sqrt{1+4p}}{2}\}$. We can rule out the second element by noting that:

$$\begin{aligned}p &> 0 \\4p &> 0 \\1 + 4p &> 1 \\\sqrt{1 + 4p} &> 1 \\-\sqrt{1 + 4p} &< -1 \\1 - \sqrt{1 + 4p} &< 0\end{aligned}$$

and since $y_n > 0$, it is clear that $y^* = \frac{1+\sqrt{1+4p}}{2}$. ■

SECTION 3.3, EX. 9

Let A be an infinite subset of \mathbb{R} that is bounded above and let $u := \sup A$. Show there exists an increasing sequence (x_n) with $x_n \in A \forall n \in \mathbb{N}$ such that $u = \lim(x_n)$.

PROOF. By the Supremum Principle, for all $\epsilon > 0$, $\exists x_\epsilon \in A$ such that $u \geq x_\epsilon > u - \epsilon$. Pick some decreasing sequence of (ϵ_n) that converges to zero, and then $(x_n) = (x_{\epsilon_n})$. ■

SECTION 3.3, EX. 11

Let $x_n := 1/1^1 + 1/2^2 + \cdots + 1/n^2$ for each $n \in \mathbb{N}$. Prove that (x_n) is increasing and bounded, and hence converges.

PROOF. We want to show that (x_n) is increasing. First note that (x_n) is a sum of positive terms, it is positive. Thus, since $x_{n+1} = x_n + 1/(n+1)^2$, it is clear that (x_n) is increasing.

The book tells us that $1/k^2 \leq 1/k(k-1) = 1/(k-1) - 1/k$ when $k \geq 2$. Noting that $x_k - x_{k-1} = 1/k^2$ and also that $\lim(1/k^2) = 0$, we have that $\lim(x_k - x_{k-1}) = 0$. This tells us that for large enough k , we have $|x_k - x_{k-1}| < \epsilon$, so by the Cauchy Criterion (x_n) converges. This infers that it is bounded above. ■