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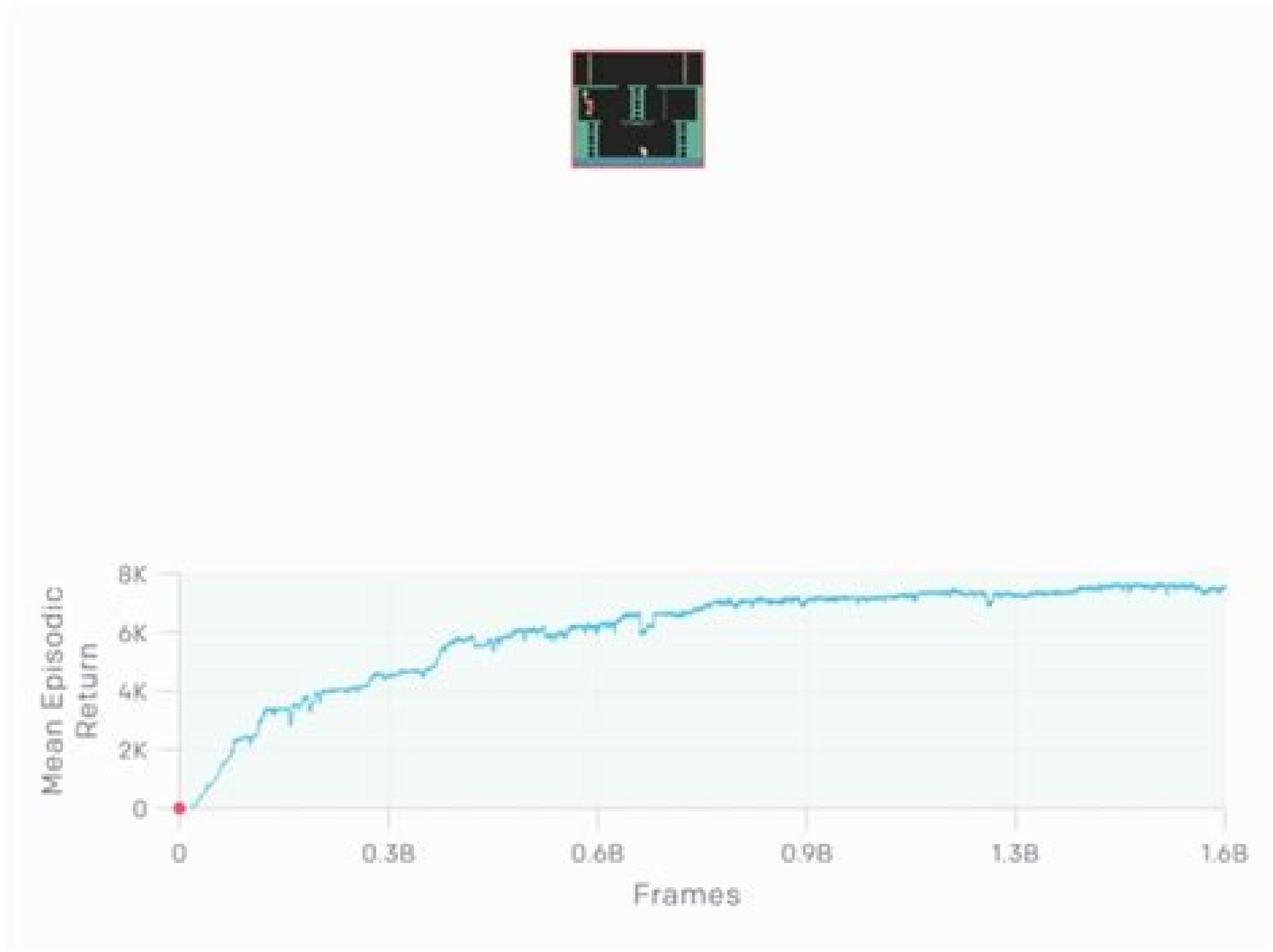

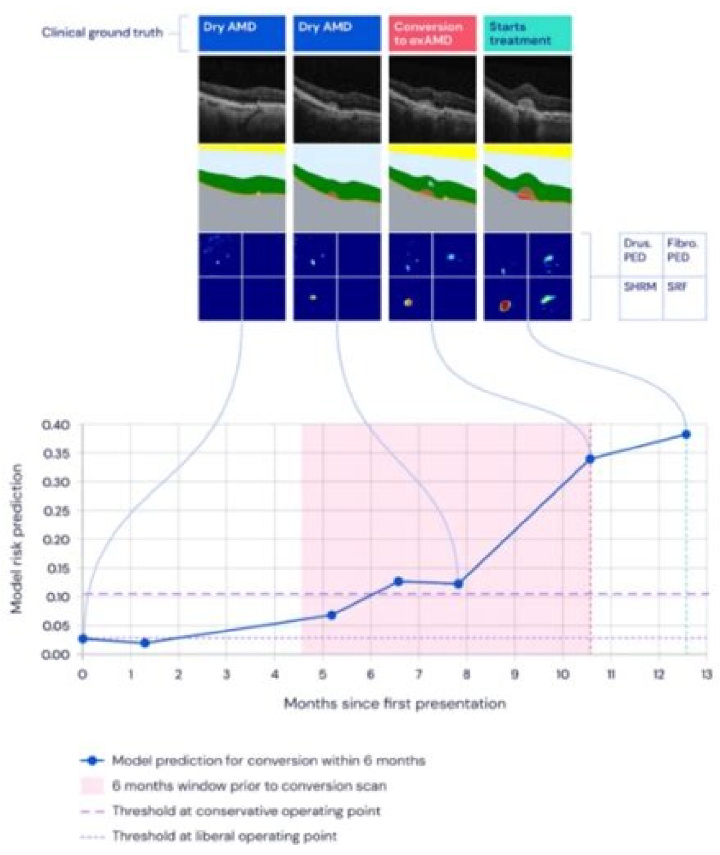

By Lemma 8.1.8, (fn) converges uniformly to f (x) 0 on A.Now let A [0,]. If (xn) I converges to xo I, show that lim(fn (xn)) lim f (x0).Solution: By Theorem 8.2.2, f is continuous on I, so limx x0 f (x) f (x0). We theninfer that lim fn (x) 0.We will now prove that (fn) is does not converge uniformly on [0, 2]. Therefore, 0 sup{ sin(nx)/(1 nx) 0 : x A} 1/(1 an) 1/an. Note that g 0 is discontinuous at x 0.Now let be given where 0 1/2. Let gn (x) : nx(1 x)n for x [0, 1], n N. From Exercise 8.1.9, (fn) (x2 e nx) converges pointwise to f (x) 0. We then have for all k N:fn2 f 2 12xk1 2 2 2 1.kkkFor positive where 1, we have fn2 f 2 . However, by Theorem 3.1.4, the limit function f is uniquelydetermined, so we have a contradiction if f 0 6 f . From Exercise 8.1.2, (fn) converges pointwise to f (x) 0 on A. Weconclude that (g fn) uniformly converges to g f on A.Section 8.2Problem 8.2-2. Accordingly, if (fn) does not convergeuniformly to f on A, it does not converge uniformly to any function on A.Problem 8.1-12. Therefore, (gn0) converges to g 0 (0) 1 and g 0 (x) 0for x (0,). We then have: gnk (xk) nk xk (1 xk)nk 11 k k 1 ,ewhere we have used the result from Exercise 3.3.12(d). Therefore, f (x) 1.If x R\Z, then 0 cos2 (πx) 1, so by Example 3.1.11(b), lim[cos2 (πx)]n 0. Let (xk) be a sequence on [0, 1] where xk 1/k and nk k for all k N. (Note that the limit above holdstrue even though b may be a function of n. Problem 8.1-3. For x 0, observe that 0 e x 1.From Example 3.1.11(b), it follows that lim(x2 e nx) x2 lim(e x)n 0. Bartle - Introduction to Real Analysis - Chapter 8 SolutionsSection 8.1Problem 8.1-2. For the sake of brevity, I cavalierly omitted this point in applying the SqueezeTheorem.)Now suppose A [0,). Therefore: 0 for x Zf (x) 1 for x R\Z.Problem 8.1-10. Show that (fn) is a decreasing sequenceof discontinuous functions that converge to a continuous limit function, but the convergence is not uniform on [0, 1]Solution: Clearly fn is discontinuous at x 0 and x 1/n for all n N.Let x [0, 1] and n N. If x [0, 2], then let 0 and K(, x) 2/x. By Theorem 3.1.9, lim(gn 0) 0, so (gn) convergesto g(x) 0 on x [0, 1].We see that gn0 (x) n(1 x)n 1 [1 (n 1)x]. If (fn) does not uniformly converge to f on A, then (fn)does not uniformly converge to any function on A.Proof. 1/kk1 1/21 (2)By Lemma 8.1.5, (fn) does not uniformly converge on [0, 1].Problem 8.1-15. As shown in Theorem 1 below, if (fn) is uniformly convergent on A, then it must convergeuniformly to f (x) 0 because this sequence is pointwise convergent to that function on A. Clearly lim kxn /(1 xn) 0kA (lim bn)/(1 lim bn) 0since n (0, 1). Now let t1 sup{ ψ(x) : x A} andt2 sup{ ψ(x) : x A}. We see that if x0 1/ n, then fn0 (x0) 0. Suppose (fn) converges uniformly to f on [a, b]. Therefore, (fn) uniformly converges to f (x) 1 on [a,).Page 2(1)Now let A [0,). ByLemma 8.1.5, (fn) does not converge uniformly on [0, 2].Problem 8.2-4. To keep our site running, we need your help to cover our server cost (about $400/m), a small donation will help us a lot. (Thus the product of uniformly convergent sequences of functions may not convergeuniformly.)Solution: Note that in contrast to the functions in Exercise 8.1-23, fn is not bounded on R.For (fn), we have lim kx 1/n xkA lim k1/nkA lim 1/n 0. If x A, then t1 t2 φ(x) ψ(x) φ(x) ψ(x) . Let gn (x) : e nx /n for x 0, n N. Observe thatfn0 (x) n(1 n2 x2)/(1 n2 x2)2 . By Lemma8.1.5, (gn0) does not uniformly converge on [0,).Problem 8.2-11. We see that kfn 0kA sup{ x/(x n) : x 0} 1. Show that if a 0, then the convergence of the sequence in Exercise 1 is uniform on the interval [0, a], butis not uniform on the interval [0,).Solution: Let a 0 and A [0, a]. INSTRUCTOR'S MANUAL TO ACCOMPANYINTRODUCTION TO REALANALYSISFourth EditionRobert G. Then kfn 0kA sup{x/(x n) : x A} a/(a n) because fn is increasing on A. Because each fn0 is continuous on I, by the Lebesque Cirterion fn R[a, x].Applying Theorem 8.2.4 and the fact that (fn0) converges to g by hypothesis, we have:Z xZ xZ x0g limfn f 0,aaaand g R[a, x].Since f 0 exists on all of I, f 0 is continuous on I. It follows from the continuity of g that: (g fn)(x) (g f)(x) g(fn (x)) g(f (x) /2.Because this is true for all x A, we have established /2 as an upper bound of kg fn g f kA for n K(δ).Consequently, kg fn g f kA 0 /2 for n K(δ), from which it follows that lim kg fn g f kA 0. Setting gn (x0) 0, we see that gn is at an absolute maximum atx0 1/(n 1). Show that lim(nx/(1 n2 x2)) 0 for all x R.Solution: For x 0, we have lim(nx/(1 n2 x2)) lim(0/1) 0, so f (0) 0. Show that if (fn), (gn) converge uniformly on the set A to f , g, respectively, then (fn gn) convergesuniformly on A to f g.Solution: For 0, there are K 0 (/2), K 00 (/2) 0 such that if n K 0 (/2), then kfn f kA /2, and if n K 00 (/2), then kgn gkA /2. SherbertUniversity of IllinoisJOHN WILEY & SONS, INC.New York •Chichester •Weinheim •Brisbane •Singapore •Toronto Thank you for interesting in our services. Let (fn) be a sequence of functions that converges uniformly to f on A and that satisfies fn (x) M forall n N and for all x A. Therefore, 0 gn (x) 1 for all x [0, 1], from which itfollows that kgn k[0,1] 1 for all n N. Therefore:Page 5kfn f kR sup{ fn (x) f (x) : x R} .Since is arbitrary, lim kfn f kR 0, and (fn) uniformly converges to f on R.Problem 8.2-7. This is because 0 x/(x n) 1, and for 0 δ 2, if x n(2/δ 1), then1 δ x/(x n) 1 δ/2 1. For any positive where 1/(1 π/2):sin π/2sin(k(π/(2k)))1 0 .1 k(π/(2k))1 π/21 π/2It follows that (fn) does not uniformly converge on [0,).Problem 8.1-19. From Exercise 8, we know that (fn) converges pointwise to f (x) 0 on A. Let I : [a, b] and let (fn) be a sequence of functions on I R that converges on I to f . Therefore, (fn) converges uniformly to f on R.Note that lim fn2 lim(x2 2x/n 1/n2) x2 lim(2x/n 1/n2) x2 . We will let fn and f take the place of y and c to establish our result. Accordingly, if x [0,), then (n2 x2 e nx) converges to f (x) 0.limProblem 8.1-10. (That is, for each n there is a constant Mn such that fn (x) Mn for all x A.) Show that the function f is boundedon A.Solution: For any 0, there is a K N such that if n K, then sup{ fn (x) f (x) : x A} . Then e kxk eln 2 2 for all k N. For x 2Rnf0g, observe that 0 nx (nx2) 1 (nx). A simple calculation shows that fn (2/n) 4/(en)2 fn (0) 0. Prove that f (x) f (a) a g(t)dtand that f 0 (x) g(x) for all x I.Solution: Because (fn) converges to f on the bounded interval I and (fn0) exists for n N and converges uniformly to g,it follows from Theorem 8.2.3 that (fn) converges uniformly to some function. Applying the Fundamental Theorem of Calculus, we get:Z xZ xg f 0 f (x) f (a).aaTheorem 3. Let g(m) m2 x2 e mx m2 x2 /emx . Suppose 0 1/e. If x (0,), then because 0 e x 1, it followsfrom the Squeeze Theorem that lim[e nx] lim(e x)n) 0. Theorem 3.2.2 then requires that, (gn) be bounded.We may now establish boundaries on kfn gn f gkA sup{ fn gn f g : x A}. ApplyingR1R1Theorem 8.2.5, we infer that 0 g 0 lim 0 gn .Note, however, that (gn) does not uniformly converge on [0, 1] (hence the power of Theorem 8.2.5). If x [1/(n 1), 1/n), then fn (x) 1 fn 1 (x) 0. If x (0, 1/(n 1)), then fn (x) fn 1 (x) 1. By Lemma 8.1.5, (fn2) does not uniformly converge on R.Problem 8.1-23. Therefore, lim e nx /n 0 for x [0,).Because gn is bounded above by 1/n, it follows from the Squeeze Theorem that lim ke nx /n 0kR 0 0. Therefore, f(x) 0 for all x2R. As a result, f (x) 0 for x 0.Part (ii): We can establish limit of (fn) (n2 x2 e nx) using L'Hopital's Rule and the Sequential Criterion for limitsof functions. Suppose (xk) is a sequence on [0,) where xk ln(2)/k (note that theallowed range of ensures xk 0 for all k N) and nk k. Therefore, (fn) converges uniformly to f (x) 0 on A.Problem 8.1-21. Therefore, 1 is the supremum of { x/(x n) : x 0}. Show that the sequence (x2 e nx) converges uniformly on [0,).Solution: Let A [0,). Suppose K( ) 2/x. Therefore,(gn) converges uniformly to g(x) 0 on [0,).We then have gn0 (x) e nx . Observe that: nx 111kfn (x) 1)kA sup 1 :x A .1 nx1 nx1 nx1 anIt follows that lim kfn f kA 0. It follows that (fn) converges pointwise to f (x) 0 on [0, 1].The sequBartle - Introduction to Real Analysis - Chapter 8 Solutions Section 8.1 Problem 8.1-2. Since is arbitrary, fn (x) f (x) for n K. Show that lim(nx (1 n2x2)) 0 for all x2R. Therefore, (fn) converges uniformly to f (x) 0 on x [0, b].Now let A [0, 1]. Let fn (x) : 1 for x (0, 1/n) and fn (x) : 0 elsewhere on [0, 1]. If g is continuous on the interval [M, M], show that the sequence (g fn) converges uniformlyto (g f) on A.Page 4 Solution: Let 0 be given. If yn n for all n N, then (g(yn)) (n2 x2 e nx), which is equal to (fn). Prove that the sequence in Example 8.2.1(c) is an example of a sequence of continuous functions that convergesnonuniformly to a continuous limit.Solution: If x 0, then lim fn (x) lim 0 0. We are a non-profit group that run this website to share documents. Let (fn), (gn) be sequences of bounded functions on A that converge uniformly on A to f , g, respectively.Show that (fn gn) converges uniformly on A to f g.Solution: In order to show the uniform convergence of (fn gn) on A, we can rewrite the limit we seek under Lemma 8.1.8as:lim kfn gn f gkA lim k(fn gn f gn) (f g f gn)kA lim kgn (fn f) f (gn g)kA .Since fn is bounded on A, it must be that f is bounded on A by some M1 0. We then have: kfn (x) f (x)kA sup nxn·0 1. Let (xk) be a sequence on R such that xk k andnk k. We need your help to maintenance this website. Show that if a 0, then the convergence of the sequence in Exercise 2 is uniform on the interval [a,], butis not uniform on the interval [0,).Solution: Let a 0 and A [a,). Observe that 0 kfn f k[a,γ] kfn f k[a,b] for all n N. By Theorem 6.2.8, the maximum of fn on [0,) is at x0 . By the Squeeze Theorem, lim(nx/(1 n2 x2)) 0. Since g is continuous on [M, M], there is a δ 0 such that if y [M, M] and y c δ, then g(y) g(c) /2. By Lemma 8.1.8, (fn) uniformly converges to f (x) 0 on [a,). By the Squeeze Theorem, lim(nx (1 n 2x)) 0. Therefore, (fn)is a decreasing sequence of discontinuous functions.Let x [0, 1] and 0 be given. This function must be f because the limitof (fn) is unique. Accordingly, (fn2) converges pointwise tof 2 on R.We will now show that (fn2) does not uniformly converge on R. Since t1 t2 kφkA kψkA , we haveshown the desired inequality.Problem 8.1-22. The function f is therefore bounded on A.Problem 8.2-10. What is its limit?Solution: If x Z, then cos(πx)2n (1)2n 1, so lim(cos(πx)2n) 1. If γ [a, b], then (fn) also converges uniformly to f on[a, γ].Proof. Therefore, lim(1/xn) 0.Problem 8.1-9. We have from the Triangle Inequality: fn gn f g gn (fn f) f (gn g) M2 fn f M1 gn g .It follows that:0 sup{ fn gn f g : x A} M2 kfn f kA M1 kgn gkA .By hypothesis:lim (M2 kfn f kA M1 kgn gkA) M2 lim kfn f kA M1 lim kgn gkA M2 · 0 M1 · 0 0.By the Squeeze Theorem, lim kfn gn f gkA 0. Therefore, (fn gn) converges uniformly to f g on A.Problem 8.1-24. Evaluate lim(nx/(1 nx)) for x R, x 0.Solution: For x 0, we have lim(nx/(1 nx)) lim(0/1) 0, so f (0) 0.For x (0,), we have: nx11lim lim 1,1 nx1/nx 11/x lim(1/n) 1from which it follows that f (x) 1 for x (0,). We can prove this by contradiction.If we assume this were not true, then for some x A, it would follow that fn (x) f (x) is unbounded, resulting in thecontradiction that the supremum of { fn (x) f (x) : x A} does not exist.It must also be that (gn) is bounded by some M2 0 for all x A. BecausefK is bounded on A, it follows that f (x) MK for all x inA. By the Triangle Inequality and Theorem 2 below,for n K( ):Page 3k(fn gn) (f g)kA 0 kfn f kA kgn gkA /2 /2 .It follows that lim k(fn gn) (f g)kA 0, so (fn gn) converges uniformly on A to f g.Theorem 2. For x R\{0}, observe that0 nx/(1 n2 x2) nx/(n2 x2) 1/(nx). Since gn is continuous on [0, 1], each gn R[0, 1]; further, g R[0, 1]. Show that if 0 b 1, then the convergence of the sequence in Exercise 4 is uniform on the interval [0, b],but is not uniform on the interval [0, 1].Solution: Let b (0, 1) be given and A [0, b]. It follows that for any 0 where 1/3: fnk (xk) f (xk) 1/2(2 1/k)k 1/3 . Show that lim(x2 e nx) 0 and that lim(n2 x2 e nx) 0 for x R, x 0.Solution: Part (i): For x 0, we have lim(x2 e nx) lim(0·1n) 0, so f (0) 0. This follows from the fact that lim gn must existbecause (gn) must pointwise converge to g on A. We then have: nxbnnx sup 0:x A ,2 x21 n2 x21 n1 n2 b2ASince 0 bn/(1 n2 b2) bn/(n2 b2) 1/(nb) and lim 1/(nb) 0, it follows from the Squeeze Theorem thatlim kfn f kA 0. Note that fn0 (x) e nx (2x nx2). Solution: For x 0, we have lim(nx (1 n2x2)) lim(0 1) 0, so f(0) 0. By Lemma 8.1.5, (gn) does not uniformly converge on [0, 1].Problem 8.2-17. You're Reading a Free Preview Pages 5 to 8 are not shown in this preview. Therefore, f (x) 0 forall x R.Problem 8.1-3. We then have gn (x0) (n/(n 1))n 1 1. For a given 0, there is a K 0 (/2) N such thatif n K 0 (/2), then: .2Because (fn) converges uniformly on I, there is also a K 00 (/2) N such that if n K 00 (/2), then for x xn forany n N: f (xn) f (x0) fn (xn) f (xn) .2Let K( ) sup{K 0 (/2), K 00 (/2)}, We then have for n K( ): fn (xn) f (x0) (fn (xn) f (xn)) (f (xn) f (x0) fn (xn) f (xn) f (xn) f (x0) 2 2Therefore, lim fn (xn) f (x0).Problem 8.2-5. We then have: xnxnbn sup 0:xinA ,1 xn1 xn1 bnAbecause fn is increasing on A (since fn0 0 on that interval). 1 : x (0,) 01 nx1 n·0(2)Consequently, lim kfn f kA 1, so by Lemma 8.1.7 (fn) does not converge uniformly on A.Problem 8.1-14. If x 0, then lim[e nx] 1. For a given 0 1, we have fnk (xk) 0 k 2 (1/k) k 1 . There is a y 0 such that 1 x 1/(1 y).By the Binomial Theorem:Page 6(1 y)n nnn 2n n11 y y ··· y n(n 1)y 2 .012n2It follows that for n 2:0 nx(1 x)n nx2xnx 2.(1 y)n(1/2)n(n 1)y 2y (n 1)By the Squeeze Theorem, the 2-tail of (gn) converges to zero. For x (0,), the limit as m is in / indeterminate form,so we apply L'Hopital's Rule twice:m 2 x22mx22m22 lim lim lim mx 0.mxmx2mxn em xem m em eBy the Sequential Criterion for limits of functions (Theorem 4.1.8), the limit of g above implies that for any sequence(yn) on (0,) that converges to infinity, the sequence (g(yn)) converges to 0. The roots of fn0 are at 0 and 2/n. Applying the Sequential Criterion (Theorem5.1.3), since (xn) converges to x0 , it follows that lim f (xn) f (x0). For x 1, we havelim(xn /(1 xn)) 1/2, so f (1) 1/2. Consequently, isan upper bound on this set, so fn (x) f (x) for all x A. Let s kφ ψkA , in which case s sup{ φ(x) ψ(x) : x A}. It follows that the maximum of fn on A is b sup{1/ n, a}. Suppose (fn) is a sequence of continuous functions on an interval I that converges uniformly on I to a functionf . Suppose (fn) converges pointwise to f on A R. If n K( ), then 1/n x/2 x, so fn (x) 0. Given any φ, ψ : A R on A R, kφ ψkA kφkA kψkA .Proof. Let (xk) be a sequence on A where xk 1/k and nk k. By the SqueezeTheorem, lim kfn f k[a,γ] 0. Because (fn)uniformly converges to f on A, there is a K(δ) 0 such that if n K(δ), then:0 kfn f kA sup{ fn (x) f (x) : x A} δ.Accordingly, if n K(δ) and x A, then fn (x) f (x) δ. Evaluate lim(xn /(1 xn)) for x R, x 0.Solution: For 0 x 1, we have lim(xn /(1 xn)) 0/1 0 by Example 3.1.11(b), so f (x) 0. Let K( ) sup{K 0 (/2), K 00 (/2)}. Let (xk) be a sequence on A where xk π/(2k) and nk k. Note that 1/(n 1) 1/n. Because fn is continuous, it is bounded on A by Theorem 5.3.2. Suppose f (x) 0for x A. Consequently, lim kfn 0kA 1.By Lemma 8.1.8, (fn) does not uniformly converge to any f on [0,).Theorem 1. Show that lim(cos(πx)2n) exists for all x R. BartleEastern Michigan UniversityDonald R. Therefore, 0 forf (x) 1 forx 0x 0.Problem 8.1-4. Because lim(4/n) 0, it follows from the Squeeze Theoremthat lim kfn f kA 0. Let (xk) be a sequence on [0, 2] where xk 1/kand let nk k, in each case for all k N. Show that (fn)converges uniformly on R to f .Solution: Because f is uniformly continuous on R, for any given 0, there is a δ( ) 0 such that for any x, y R, if x u δ( ), then f (x) f (u) . Examine the relationship between lim(gn) and lim(gn0).Solution: Observe that 0 e nx 1 for all x [0,), so 0 e nx /n 1/n. On either side of this point, fn0 (x) 0for x x0 and fn0 (x) 0 for x x0 . Moreover, it is clear thatfn0 decreases on (x0 ,). Show that if a 0, then the convergence of the sequence in Exercise 3 is uniform on the interval [a,), butis not uniform on the interval [0,).Solution: Let a 0 and A [a,). For 1/4: fnk (xk) f (xk) k(1/k)1 .1 k 2 (1/k 2)2From Lemma 8.1.5, it follows that (fn) does not converge uniformly on [0,).Problem 8.1-13. Suppose the sequence (fn) converges uniformly to f on the set A, and suppose that each fn is bounded onA. It follows that t1 t2 is an upperbound of { φ(x) ψ(x) : x A} and therefore is greater than or equal to s. Evaluate lim(nx (1 nx . Given that (fn0) converges uniformly on I, it must converge uniformly on [a, x] (since this result hasnot yet been proven, see Theorem 3 below). Let (xk) be a sequence in A where xk 2 1/k and nk k. Now let x (0, 1). Ifx [0, 1]\(0, 1/n), then fn (x) fn 1 (x) 0. Let f : R R be uniformly continuous on R and let fn (x) : f (x 1/n) for x R. For n K(, x), we have fn (x) 0 n2 (x 2/n) 0 . The sequence (fn) therefore uniformly converges to f on [a, γ].Problem 8.2-15. By Theorem 6.2.8, fn is at an absolute maximum atx 4/n.As a result, 0 kfn f kA fn (2/n) 4/(en)2 4/n. By hypothesis, lim kfn f k[a,b] 0. Let K( ) 2/δ( ). Therefore, it must be that f f 0 . It further follows from Theorem 8.2.3 that f 0 (x) g(x) for all x I.Now let x [a, b]. Suppose there is a function f 0 : A R to which (fn) converges uniformly on A. Inaddition, fn0 (x) 0 for 0 x 4/n and fn0 (x) 0 for x 4/n. It follows that if x 0, then lim n2 x2 e nx 0.For x 0, clearly lim n2 x2 e nx lim 0 0. Suppose that eachRbderivative fn0 is continuous on I and that the sequence (fn0) is uniformly convergent to g on I. If n K( ), then (x 1/n) x δ( )/2 δ( ), in whichcase fn (x) f (x) f (x 1/n) f (x) . For x 1, we have lim(xn /(1 xn)) lim(1/(1 1/xn) 1, so f (x) 1.*Accordingly, 0 for 0 x 11for x 1f (x) 21 for x 1.* Note that for 1/xn with fixed x, given 0, if K( ) logx (2/), then for n K( ), we have 1/xn 1/xn 1/(2/) /2 . Discuss the convergence of (gn) and (i nt10 gn dx.Solution: Observe that gn (0) gn (1) 0 for all n N. We know that (fn) converges pointwise to f (x) 1 on A. Now assume that f 0 6 f .It follows that (fn) must converges pointwise to f 0 on A. By Lemma 8.1.8, (fn) converges uniformly to f (x) 0.Now let A [0,). Show that if a 0, then the convergence of the sequence in Exercise 5 is uniform on the interval [a,), butis not uniform on the interval [0,).Solution: Suppose a 0 and A [a,). Since lim 1/an 0,it follows from the Squeeze Theorem that lim kfn f kA 0. It isclear that sin(nx) 1. Therefore,lim kfn 0kA lim a/(a n) 0. Therefore, fn (x) 0 0 for all x [0, 1]. If n K(, x), then fn (x) 0, from which follows that fn (x) 0 . Show that if fn (x) : x 1/n and f (x) : x, then (fn) converges uniformly on R to f , but the sequence(fn2) does not converge uniformly on R. Please help us to share our service with your friends.

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