CONTINUITY PROPERTIES OF DERIVATIVES OF SEQUENCES OF FUNCTIONS

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In a recent paper Dvoretzky [1] discusses an interesting generalization of a theorem of Walsh [2]. A striking supplement to Dvoretzky's theorem is the following one.

**Theorem.** There exists a sequence of functions

\[ \{f_n\}_{n=1}^{\infty}, \quad f_n \in C^1(-\infty, \infty), \]

with \( \lim_{n \to \infty} f_n(x) = 0 \), such that: if \( N_1 \) is any subsequence of the natural numbers with the property that there exists a sequence \( x_{n_1}, \quad n_1 \in N_1 \), satisfying

\[ f'_{n_1}(x_{n_1}) = 0, \quad \text{and} \quad \lim_{n_1 \to \infty} x_{n_1} = 0, \]

then the sequence \( N_2 \) complementary to \( N_1 \) (i.e., \( N_2 \) contains exactly those natural numbers omitted by \( N_1 \)) is infinite and

\[ \limsup_{n_2 \to \infty} \int_0^h |f'_{n_2}(x)| \, dx = \infty \]

for every \( h > 0 \).

**Proof.** Let \( \epsilon_n \downarrow 0 \) and let \( \{\lambda_n\} \) be the sequence 1, 2, 1, 2, 3, 1, 2, 3, 4, 1, \ldots. Let \( \{\mu_n\} \) be a sequence of positive numbers such that

\[ \epsilon_n \mu_n / \lambda_n \to \infty, \quad n \to \infty. \]

The functions \( f_n(x) \) shall be odd and

Received by the editors September 4, 1956.

1 This research was supported by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under contract No. AF 18(600)-1135.
\[ f_n(x) = \begin{cases} \varepsilon_n \sin \lambda_n x, & |x| \leq \pi/2\lambda_n, \\ \varepsilon_n \cos \mu_n \left( x - \frac{\pi}{2\lambda_n} \right), & x > \pi/2\lambda_n. \end{cases} \]

It is easily verified that \( f_n \in C^1 \) and \( f_n(x) \to 0 \). The smallest zeros of \( f_n'(x) \) are \( \pm \pi/(2\lambda_n) \). Because of (1) and the nature of \( \lambda_n \), any possible \( N_2 \) will contain infinitely many \( n_2 \) associated with each possible value of \( \lambda \). Thus \( N_2 \) splits into disjoint infinite sequences \( M_p, p \geq 1 \), such that

\[ \lambda_{m_p} = p, \quad m_p \subseteq M_p. \]

For a given \( h > 0 \), choose \( p \) such that \( \pi/p \leq h \). Then

\[
\int_0^h |f'_{m_p}(x)| \, dx > \int_{\pi/(2p)}^{\pi/p} |f'_{m_p}(x)| \, dx \\
= \varepsilon_{m_p} \mu_{m_p} \int_{\pi/(2p)}^{\pi/p} \left| \sin \mu_{m_p} \left( x - \frac{\pi}{2p} \right) \right| \, dx \\
= \varepsilon_{m_p} \int_0^{\pi/(2p)} \left| \sin \frac{\mu_{m_p}}{p} \right| \, dt \geq \varepsilon_{m_p} \left[ \frac{\mu_m}{p} \right],
\]

and (2) follows from this inequality and (3).

Finally we note that Dvoretzky’s use of the word “clearly” in the third line after equation (6) is dubious.

References


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