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THE SCHWARZIAN DERIVATIVE AND STARLIKENESS

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ABSTRACT. In this paper, we obtain sufficient conditions for starlikeness by applying the Schwarzian derivative.

1. Introduction

Let $A$ be the class of the functions of the form

$$f(z) = z + \sum_{n=2}^{\infty} a_n z^n,$$

which are analytic in the unit disk $\mathcal{U} = \{z : |z| < 1\}$.

2. Preliminaries

In [1, p.304], Miller and Mocanu obtained the following result:

Theorem A. Let $f(z) \in A$ and suppose that

$$\text{Re} \left[ \frac{zf'(z)}{f(z)} \left( 1 + \frac{zf''(z)}{f'(z)} + z^2 \{f, z\} \right) \right] > 0 \quad \text{in} \quad \mathcal{U}$$

or

$$\text{Re} \left[ \frac{zf'(z)}{f(z)} (1 + z^2 \{f, z\}) \right] > 0 \quad \text{in} \quad \mathcal{U}$$

where $\{f, z\}$ is the Schwarzian derivative

$$\{f, z\} = \left( \frac{f''(z)}{f'(z)} \right)' - \frac{1}{2} \left( \frac{f''(z)}{f'(z)} \right)^2.$$

Then it follows that

$$\text{Re} \left[ \frac{zf'(z)}{f(z)} \right] > 0 \quad \text{in} \quad \mathcal{U}$$

or $f(z)$ is starlike in $\mathcal{U}$.

We will improve Theorem A.

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3. Main result

Theorem 1. Let \( f(z) \in A \) and suppose that

\[
\text{Re} \left[ \frac{zf'(z)}{f(z)} \left( 1 + \frac{zf''(z)}{f'(z)} + z^2 \{f, z\} \right) \right] \geq -\frac{1}{2} \quad \text{in} \quad \mathcal{U}.
\]

Then \( f(z) \) is starlike in \( \mathcal{U} \).

Proof. Let us put \( p(z) = \frac{zf'(z)}{f(z)} \), \( p(0) = 1 \).

Then it follows that

\[
1 + \frac{zf''(z)}{f'(z)} = p(z) + \frac{zp'(z)}{p(z)},
\]

and

\[
z^2 \{f, z\} = \frac{zp'(z)}{p(z)} + \frac{z^2 p''(z)}{p(z)} - \frac{3}{2} \left( \frac{zp'(z)}{p(z)} \right)^2 + \frac{1}{2} (1 - p(z)^2).
\]

Applying the same method as the proof of [2, Lemma 1], we have

\( f'(z) \neq 0 \quad \text{in} \quad \mathcal{U}, \)

because if \( f'(z) \) has zero in \( \mathcal{U} \), then it contradicts (1). Therefore we have

\( p(z) \neq 0 \quad \text{in} \quad \mathcal{U}. \)

On the other hand, if there exists a point \( z_0 \in \mathcal{U} \) such that

\[
\text{Re} p(z) > 0 \quad \text{for} \quad |z| < |z_0|
\]

and

\[
\text{Re} p(z_0) = 0 \quad (p(z_0) \neq 0).
\]

Then, from [3], we have

\[
\frac{z_0 p'(z_0)}{p(z_0)} = ik
\]

where

\[
k \geq \frac{1}{2} \left( a + \frac{1}{a} \right) \quad \text{when} \quad p(z_0) = ia, \quad a > 0
\]

and

\[
k \leq \frac{1}{2} \left( a + \frac{1}{a} \right) \quad \text{when} \quad p(z_0) = ia, \quad a < 0.
\]

This shows that

\( p'(z_0) \neq 0. \)
Therefore we have
\[
\frac{z_0^2 p''(z_0)}{p(z_0)} = \frac{z_0 p''(z_0)}{p'(z_0)} \frac{z_0 p'(z_0)}{p(z_0)} = ik \left( 1 + \frac{z^2 p''(z_0)}{p'(z_0)} - 1 \right)
\]
and it follows
\[
(2) \quad \text{Re} \left[ \frac{z_0 f'(z_0)}{f(z_0)} \left( 1 + \frac{z_0 p''(z_0)}{p'(z_0)} + z_0^2 \{f, z_0\} \right) \right]
\]
\[
= \text{Re} \left[ ia \left( ia + ik + ik \left( 1 + \frac{z_0 p''(z_0)}{p'(z_0)} - 1 \right) + \frac{1}{2} (3k^2 + a^2 + 1) \right) \right]
\]
\[
= -a^2 - ak - ak \text{Re} \left( 1 + \frac{z_0 p''(z_0)}{p'(z_0)} \right)
\]

From [1, Theorem 4, (ii)] or [4, p.3], we have
\[
(3) \quad 1 + \text{Re} \frac{z_0 p''(z_0)}{p'(z_0)} \geq 0.
\]

On the other hand, we have
\[
(4) \quad -ak \leq \frac{1}{2} (1 + a^2) < -\frac{1}{2}
\]
where \( p(z_0) = ia \) and
\[
\frac{z_0 p'(z_0)}{p(z_0)} = ik.
\]

From (2), (3) and (4), we have
\[
\text{Re} \left[ \frac{z_0 f'(z_0)}{f(z_0)} \left( 1 + \frac{z_0 p''(z_0)}{p'(z_0)} + z_0^2 \{f, z_0\} \right) \right] < -\frac{1}{2}.
\]
This contradicts (1). Therefore we have
\[
\text{Re} p(z) = \text{Re} \frac{zf'(z)}{f(z)} > 0 \quad \text{in} \quad \mathcal{U}.
\]

This completes the proof and improves Theorem A. Applying the same method as the proof of Theorem 1, we have the following theorem.

**Theorem 2.** Let \( f(z) \in A \) and suppose that
\[
\text{Re} \left[ \frac{zf'(z)}{f(z)} z^2 \{f, z\} \right] \geq 0 \quad \text{in} \quad \mathcal{U}.
\]

Then \( f(z) \) is starlike in \( \mathcal{U} \).
REFERENCES


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