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*Erratum*

# Erratum to "On Integral Inequalities of Hermite-Hadamard Type for *s*-Geometrically Convex Functions"

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In [1, Definition 1.9], the concept "$s$-geometrically convex function" was introduced.

Making use of [1, Lemma 2.1], Hölder's integral inequality, and other analytic techniques, some inequalities of Hermite-Hadamard type were established. However, there are some vital errors appeared in main results of the paper [1].

The aim of this paper is to correct these errors and we now start off to correct them.

*Correction to Theorem 3.1*. Let $f : I \subset \mathbb{R}_+ \to \mathbb{R}$ be a differentiable function on $I^\circ$ such that $f' \in L([a,b])$ for $0 < a < b < \infty$. If $|f'(x)|^q$ is $s$-geometrically convex and monotonically decreasing on $[a,b]$ for $q \geq 1$ and $s \in (0,1]$, then

$$\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q} G_1\left(s,q;g_1(\alpha),g_2(\alpha)\right), \tag{1}$$

$$\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q} G_1\left(s,q;g_2(\alpha),g_1(\alpha)\right), \tag{2}$$

where

$$g_1(\alpha) = \begin{cases} \dfrac{1}{2}, & \alpha = 1, \\ \dfrac{\alpha\ln\alpha-\alpha+1}{\ln^2\alpha}, & \alpha \neq 1, \end{cases} \qquad g_2(\alpha) = \begin{cases} \dfrac{1}{2}, & \alpha = 1, \\ \dfrac{\alpha-\ln\alpha-1}{\ln^2\alpha}, & \alpha \neq 1, \end{cases} \tag{3}$$

$$\alpha = \left|\frac{f'(b)}{f'(a)}\right|^{sq/2}, \tag{4}$$

$$G_1\left(s,q;g_1(\alpha),g_2(\alpha)\right) = \begin{cases} \left|f'(a)\right|^{s}\left[g_1(\alpha)\right]^{1/q}+\left|f'(a)f'(b)\right|^{s/2} \times\left[g_2(\alpha)\right]^{1/q}, & \left|f'(a)\right| \leq 1, \\ \left|f'(a)\right|\left[g_1(\alpha)\right]^{1/q}+\left|f'(a)\right|^{1-s/2} \times\left|f'(b)\right|^{s/2}\left[g_2(\alpha)\right]^{1/q}, & \left|f'(b)\right| \leq 1 \leq \left|f'(a)\right|, \\ \left|f'(a)\right|\left|f'(b)\right|^{1-s}\left[g_1(\alpha)\right]^{1/q}+\left|f'(a)f'(b)\right|^{1-s/2} \times\left[g_2(\alpha)\right]^{1/q}, & 1 \leq \left|f'(b)\right|. \end{cases} \tag{5}$$

*Proof.* Since $|f'|^q$ is $s$-geometrically convex and monotonically decreasing on $[a,b]$, using Lemma 2.1 and Hölder's inequality gives

$$\begin{aligned}
&\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \\
&\le \frac{b-a}{4}\int_0^1\left[t\left|f'\left((1-t)a+t\frac{a+b}{2}\right)\right| + (1-t)\left|f'\left((1-t)\frac{a+b}{2}+tb\right)\right|\right]dt \\
&\le \frac{b-a}{4}\left\{\left(\int_0^1 t\,dt\right)^{1-1/q}\times\left[\int_0^1 t\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\right]^{1/q}\right. \\
&\qquad\left.+\left(\int_0^1(1-t)\,dt\right)^{1-1/q}\times\left[\int_0^1(1-t)\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\right]^{1/q}\right\} \\
&= \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q}\left\{\left[\int_0^1 t\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\right]^{1/q}\right. \\
&\qquad\left.+\left[\int_0^1(1-t)\left|f'(a)\right|^{q((1-t)/2)^s}\times\left|f'(b)\right|^{q((1+t)/2)^s}dt\right]^{1/q}\right\}.
\end{aligned} \tag{6}$$

Let $0<\mu\le 1\le\eta$ and $0<s,t\le 1$. Then

$$\mu^{t^s}\le\mu^{st},\qquad \eta^{t^s}\le\eta^{st+1-s}. \tag{7}$$

When $|f'(a)|\le 1$, we have

$$\begin{aligned}
&\int_0^1 t\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \\
&\le \int_0^1 t\left|f'(a)\right|^{sq((2-t)/2)}\left|f'(b)\right|^{sq(t/2)}dt \\
&= \left|f'(a)\right|^{sq}g_1(\alpha),
\end{aligned} \tag{8}$$

$$\begin{aligned}
&\int_0^1(1-t)\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \\
&\le \int_0^1(1-t)\left|f'(a)\right|^{sq((1-t)/2)}\left|f'(b)\right|^{sq((1+t)/2)}dt \\
&= \left|f'(a)f'(b)\right|^{sq/2}g_2(\alpha).
\end{aligned} \tag{9}$$

When $|f'(b)|\le 1\le|f'(a)|$, by (7), we obtain

$$\begin{aligned}
&\int_0^1 t\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \\
&\le \int_0^1 t\left|f'(a)\right|^{q[s(2-t)/2+1-s]}\left|f'(b)\right|^{sqt/2}dt \\
&= \left|f'(a)\right|^{q}g_1(\alpha),
\end{aligned} \tag{10}$$

$$\begin{aligned}
&\int_0^1(1-t)\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \\
&\le \int_0^1(1-t)\left|f'(a)\right|^{q[s(1-t)/2+1-s]}\left|f'(b)\right|^{sq(1+t)/2}dt \\
&= \left|f'(a)\right|^{(1-s/2)q}\left|f'(b)\right|^{sq/2}g_2(\alpha).
\end{aligned} \tag{11}$$

When $1\le|f'(b)|$, by (7), we have

$$\begin{aligned}
&\int_0^1 t\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \\
&\le \left|f'(a)\right|^{q}\left|f'(b)\right|^{(1-s)q}g_1(\alpha),
\end{aligned} \tag{12}$$

$$\begin{aligned}
&\int_0^1(1-t)\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \\
&\le \left|f'(a)f'(b)\right|^{(1-s/2)q}g_2(\alpha).
\end{aligned} \tag{13}$$

Substituting (8) to (13) into (6) yields inequality (1).

Since $|f'|^q$ is $s$-geometrically convex and monotonically decreasing on $[a,b]$, by Lemma 2.1 and Hölder's inequality, we obtain

$$\begin{aligned}
&\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \\
&\le \frac{b-a}{4}\int_0^1\left[(1-t)\left|f'\left((1-t)a+t\frac{a+b}{2}\right)\right| + t\left|f'\left((1-t)\frac{a+b}{2}+tb\right)\right|\right]dt \\
&\le \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q}\left\{\left[\int_0^1(1-t)\left|f'(a)\right|^{q((2-t)/2)^s}\times\left|f'(b)\right|^{q(t/2)^s}dt\right]^{1/q}\right. \\
&\qquad\left.+\left[\int_0^1 t\left|f'(a)\right|^{q((1-t)/2)^s}\times\left|f'(b)\right|^{q((1+t)/2)^s}dt\right]^{1/q}\right\}.
\end{aligned} \tag{14}$$

When $|f'(a)| \leq 1$, we have

$$\int_0^1 (1-t)\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \leq \left|f'(a)\right|^{sq} g_2(\alpha), \quad (15)$$

$$\int_0^1 t\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \leq \left|f'(a)\,f'(b)\right|^{sq/2} g_1(\alpha). \quad (16)$$

When $|f'(b)| \leq 1 \leq |f'(a)|$, by (7), we obtain

$$\int_0^1 (1-t)\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \leq \left|f'(a)\right|^{q} g_2(\alpha), \quad (17)$$

$$\int_0^1 t\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \leq \left|f'(a)\right|^{(1-s/2)q}\left|f'(b)\right|^{sq/2} g_1(\alpha). \quad (18)$$

When $1 \leq |f'(b)|$, by (7), we have

$$\int_0^1 (1-t)\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt \leq \left|f'(a)\right|^{q}\left|f'(b)\right|^{(1-s)q} g_2(\alpha), \quad (19)$$

$$\int_0^1 t\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt \leq \left|f'(a)\,f'(b)\right|^{(1-s/2)q} g_1(\alpha). \quad (20)$$

Substituting (15) to (20) into (14) leads to inequality (2). Theorem 3.1 is thus proved. □

*Correction to Corollary 3.2* . Under the conditions of Theorem 3.1,

(1) when $q = 1$,

$$\begin{aligned}
&\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}G_1\left(s,1;g_1(\alpha),g_2(\alpha)\right),\\
&\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}G_1\left(s,1;g_2(\alpha),g_1(\alpha)\right);
\end{aligned} \quad (21)$$

(2) when $s = 1$,

$$\begin{aligned}
&\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q}G_1\left(1,q;g_1(\alpha),g_2(\alpha)\right),\\
&\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{1}{2}\right)^{1-1/q}G_1\left(1,q;g_2(\alpha),g_1(\alpha)\right).
\end{aligned} \quad (22)$$

*Correction to Theorem 3.3.* Let $f : I \subset \mathbb{R}_+ \to \mathbb{R}$ be a differentiable function on $I^\circ$ such that $f' \in L([a,b])$ for $0 < a < b < \infty$. If $|f'(x)|^q$ is $s$-geometrically convex and monotonically decreasing on $[a,b]$ for $q > 1$ and $s \in (0,1]$, then

$$\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}G_2\left(s,q;g_3(\alpha)\right), \quad (23)$$

$$\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right| \leq \frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}G_2\left(s,q;g_3(\alpha)\right), \quad (24)$$

where $\alpha$ is the same as in (4),

$$g_3(\alpha) = \begin{cases} 1, & \alpha = 1,\\ \dfrac{\alpha-1}{\ln\alpha}, & \alpha \neq 1, \end{cases}$$

$$G_2\left(s,q;g_3(\alpha)\right) = \begin{cases} \left[\left|f'(a)\right|^{s}+\left|f'(a)\,f'(b)\right|^{s/2}\right]\left[g_3(\alpha)\right]^{1/q}, & \left|f'(a)\right| \leq 1,\\ \left[\left|f'(a)\right|+\left|f'(a)\right|^{1-s/2}\left|f'(b)\right|^{s/2}\right]\times\left[g_3(\alpha)\right]^{1/q}, & \left|f'(b)\right| \leq 1 \leq \left|f'(a)\right|,\\ \left[\left|f'(a)\right|\left|f'(b)\right|^{1-s}+\left|f'(a)\,f'(b)\right|^{1-s/2}\right]\times\left[g_3(\alpha)\right]^{1/q}, & 1 \leq \left|f'(b)\right|. \end{cases} \quad (25)$$

*Proof.* Since $|f'|^q$ is $s$-geometrically convex and monotonically decreasing on $[a,b]$, by Lemma 2.1 and Hölder's inequality, we have

$$\begin{aligned}&\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right|\\&\le\frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}\\&\quad\times\left\{\left[\int_0^1\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\right]^{1/q}\right.\\&\quad\left.+\left[\int_0^1\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\right]^{1/q}\right\},\end{aligned}\tag{26}$$

$$\begin{aligned}&\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right|\\&\le\frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}\\&\quad\times\left\{\left[\int_0^1\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\right]^{1/q}\right.\\&\quad\left.+\left[\int_0^1\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\right]^{1/q}\right\}.\end{aligned}\tag{27}$$

When $|f'(a)|\le 1$, we have

$$\begin{aligned}&\int_0^1\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\\&\quad\le\left|f'(a)\right|^{sq}g_3(\alpha),\end{aligned}\tag{28}$$

$$\begin{aligned}&\int_0^1\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\\&\quad\le\left|f'(a)\,f'(b)\right|^{sq/2}g_3(\alpha).\end{aligned}\tag{29}$$

When $|f'(b)|\le 1\le|f'(a)|$, by (7), we obtain

$$\int_0^1\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\le\left|f'(a)\right|^{q}g_3(\alpha),\tag{30}$$

$$\begin{aligned}&\int_0^1\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\\&\quad\le\left|f'(a)\right|^{(1-s/2)q}\left|f'(b)\right|^{sq/2}g_3(\alpha).\end{aligned}\tag{31}$$

When $1\le|f'(b)|$, by (7), we have

$$\begin{aligned}&\int_0^1\left|f'(a)\right|^{q((2-t)/2)^s}\left|f'(b)\right|^{q(t/2)^s}dt\\&\quad\le\left|f'(a)\right|^{q}\left|f'(b)\right|^{(1-s)q}g_3(\alpha),\end{aligned}\tag{32}$$

$$\begin{aligned}&\int_0^1\left|f'(a)\right|^{q((1-t)/2)^s}\left|f'(b)\right|^{q((1+t)/2)^s}dt\\&\quad\le\left|f'(a)\,f'(b)\right|^{(1-s/2)q}g_3(\alpha).\end{aligned}\tag{33}$$

Substituting (28) to (33) into (26) and (27) results in inequalities (23) and (24). Theorem 3.3 is thus proved. □

*Correction to Corollary 3.4*. Under the conditions of Theorem 3.3, when $s=1$, we have

$$\begin{aligned}&\left|f\left(\frac{a+b}{2}\right)-\frac{1}{b-a}\int_a^b f(x)\,dx\right|\\&\quad\le\frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}G_2\left(1,q;g_3(\alpha)\right),\end{aligned}\tag{34}$$

$$\begin{aligned}&\left|\frac{f(a)+f(b)}{2}-\frac{1}{b-a}\int_a^b f(x)\,dx\right|\\&\quad\le\frac{b-a}{4}\left(\frac{q-1}{2q-1}\right)^{1-1/q}G_2\left(1,q;g_3(\alpha)\right).\end{aligned}\tag{35}$$

*Correction to Theorem 4.1*. Let $0<a<b\le 1$, $0<s<1$, and $q\ge 1$. Then

$$\begin{aligned}&0<[A(a,b)]^s-[L_s(a,b)]^s\\&\le\frac{(b-a)^{1-1/q}s}{8}\left[\frac{4}{s(1-s)q}L(a,b)\right]^{1/q}\\&\quad\times\left\{a^{s-1}b^{(s-1)(1-s/2)}\right.\\&\qquad\times\left[L\left(a^{s(1-s)q/2},b^{s(1-s)q/2}\right)-a^{s(1-s)q/2}\right]^{1/q}\\&\qquad+a^{(s-1)(1-s/2)}b^{s-1}\\&\qquad\left.\times\left[b^{s(1-s)q/2}-L\left(a^{s(1-s)q/2},b^{s(1-s)q/2}\right)\right]^{1/q}\right\},\end{aligned}\tag{36}$$

$$\begin{aligned}&0<[L_s(a,b)]^s-A\left(a^s,b^s\right)\\&\le\frac{(b-a)^{1-1/q}s}{8}\left[\frac{4}{s(1-s)q}L(a,b)\right]^{1/q}\\&\quad\times\left\{a^{s-1}b^{(s-1)(1-s/2)}\right.\end{aligned}$$

$$\times \left[b^{s(1-s)q/2} - L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right)\right]^{1/q} + a^{(s-1)(1-s/2)} b^{s-1} \times \left[L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right) - a^{s(1-s)q/2}\right]^{1/q}\Bigg\}, \quad (37)$$

where

$$A(a,b) = \frac{a+b}{2}, \qquad L(a,b) = \frac{b-a}{\ln b - \ln a}, \quad (38)$$

$$L_p(a,b) = \left[\frac{b^{p+1} - a^{p+1}}{(p+1)(b-a)}\right]^{1/p} \quad (39)$$

for $a \neq b$ and $p \in \mathbb{R}$ with $p \neq 0, -1$ are the arithmetic, logarithmic, and generalized logarithmic means, respectively.

If $q = 1$, then

$$0 < [A(a,b)]^s - [L_s(a,b)]^s \le \frac{L(a,b)}{2(1-s)} \times \Big\{a^{s-1} b^{(s-1)(1-s/2)} \times \left[L\left(a^{s(1-s)/2}, b^{s(1-s)/2}\right) - a^{s(1-s)/2}\right], + a^{(s-1)(1-s/2)} b^{s-1} \times \left[b^{s(1-s)/2} - L\left(a^{s(1-s)/2}, b^{s(1-s)/2}\right)\right]\Big\} \quad (40)$$

$$0 < [L_s(a,b)]^s - A(a^s, b^s) \le \frac{L(a,b)}{2(1-s)} \Big\{a^{s-1} b^{(s-1)(1-s/2)} \times \left[b^{s(1-s)/2} - L\left(a^{s(1-s)/2}, b^{s(1-s)/2}\right)\right] + a^{(s-1)(1-s/2)} b^{s-1} \times \left[L\left(\mathrm{a}^{s(1-s)/2}, b^{s(1-s)/2}\right) - a^{s(1-s)/2}\right]\Big\}. \quad (41)$$

*Proof.* Let $0 < s < 1$, $q \ge 1$, and $f(x) = x^s/s$ for $x \in (0,1]$. Then the function $|f'(x)|^q$ is $s$-geometrically convex on $(0,1]$ for $0 < s < 1$,

$$\left|f'(a)\right| = a^{s-1} > b^{s-1} = \left|f'(b)\right| \ge 1, \quad (42)$$

and $\alpha = (a/b)^{s(1-s)q/2}$. Therefore,

$$g_1(\alpha) = \frac{2}{s(1-s)qb^{s(1-s)q/2}(\ln b - \ln a)} \times \left[L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right) - a^{s(1-s)q/2}\right], \quad (43)$$

$$g_2(\alpha) = \frac{2}{s(1-s)qb^{s(1-s)q/2}(\ln b - \ln a)} \times \left[b^{s(1-s)q/2} - L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right)\right]. \quad (44)$$

By Theorem 3.1, Theorem  4.1 isthus proved. □

*Correction to Theorem* 4.2. Let $0 < a < b \le 1$, $0 < s < 1$, and $q > 1$. Then

$$0 < [A(a,b)]^s - [L_s(a,b)]^s \le \frac{(b-a)s}{4}\left(\frac{q-1}{2q-1}\right)^{1/q} \times \left[a^{s-1} b^{(s-1)(1-s/2)} + a^{(s-1)(1-s/2)} b^{s-1}\right] \times \left[L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right)\right]^{1/q}, \quad (45)$$

$$0 < [L_s(a,b)]^s - A(a^s, b^s) \le \frac{(b-a)s}{4}\left(\frac{q-1}{2q-1}\right)^{1/q} \times \left[a^{s-1} b^{(s-1)(1-s/2)} + a^{(s-1)(1-s/2)} b^{s-1}\right] \times \left[L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right)\right]^{1/q}. \quad (46)$$

*Proof.* It is easy to see that

$$g_3(\alpha) = \frac{1}{qb^{s(1-s)q/2}} L\left(a^{s(1-s)q/2}, b^{s(1-s)q/2}\right). \quad (47)$$

Hence, by Theorem 3.3, Theorem 4.2 is thus proved. □

*Remark.* By the way, all the powers $1-(3/q)$ which appeared four times in [2, Theorem 4.2 and Corollary 4.2] should be corrected as $3(1-(1/q))$, respectively.

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