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**ANALYTIC MAPS OF THE OPEN UNIT DISK ONTO A
GLEASON PART**

KAZUO KISHI

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The purpose of this paper is to show that in certain uniform algebras all analytic maps (for the definition see §2) of the open unit disk onto a nontrivial Gleason part are mutually closely related (Theorem 2), and that these maps are isometries of the open unit disk with pseudo-hyperbolic metric onto a nontrivial Gleason part with part metric (Theorem 3).

The results of this paper are contained in §2. Some necessary preliminaries are given in §1.

1. Preliminaries. A uniform algebra A on a compact Hausdorff space X is a uniformly closed subalgebra of the algebra $C(X)$ of complex valued continuous functions on X which contains the constants and separates the points of X . Let $\mathcal{M}(A)$ denote the maximal ideal space of A which has the Gelfand topology. Let \hat{f} be the Gelfand transform of f in A and let $\hat{A} = \{\hat{f}: f \in A\}$.

For φ and θ in $\mathcal{M}(A)$ we define

$$(1.1) \quad G: G(\varphi, \theta) = \sup \{|\varphi(f) - \theta(f)|: f \in A, \|f\| \leq 1\},$$

$$(1.2) \quad \sigma: \sigma(\varphi, \theta) = \sup \{|\varphi(f)|: f \in A, \|f\| \leq 1, \theta(f) = 0\},$$

where $\|f\| = \sup \{|f(x)|: x \in X\}$, and we write $\varphi \sim \theta$ when $G(\varphi, \theta) < 2$ (or, equivalently, $\sigma(\varphi, \theta) < 1$). Then \sim is an equivalence relation in $\mathcal{M}(A)$, and an equivalence class $P(m) = \{\varphi: \varphi \in \mathcal{M}(A), \varphi \sim m\} (\cong \{m\})$ is called the (*nontrivial*) *Gleason part* of $m \in \mathcal{M}(A)$ (cf. Gleason [2]). $G(\varphi, \theta)$ and $\sigma(\varphi, \theta)$ are metrics on $P(m)$ (cf. König [5]).

If $m \in \mathcal{M}(A)$ has a unique representing measure μ_m , i.e., if m has a unique probability measure μ_m on X such that $m(f) = \int f d\mu_m$ for every $f \in A$, then every φ in $P(m)$ also has a unique representing measure μ_φ . It is also known that φ in M_A belongs to $P(m)$ if and only if there exist mutually absolutely continuous representing measures μ_φ, μ_m for φ, m respectively; indeed, there exists a constant c ($0 < c < 1$) such that $c\mu_\varphi \leq \mu_m$ and $c\mu_m \leq \mu_\varphi$.

For example, let $A(D)$ denote the disk algebra of all continuous functions on the closed unit disk $\bar{D} = \{s: |s| \leq 1\}$ in the plane which are analytic in the open unit disk D . Then $\mathcal{M}(A(D))$ can be identified with \bar{D} , and the open unit disk D is one part. For $t, s \in D$, we see that

$$(1.3) \quad G(t, s) = \sup \{ |f(t) - f(s)| : f \in A(D), \|f\| \leq 1 \},$$

$$(1.4) \quad \sigma(t, s) = \sup \{ |f(t)| : f \in A(D), \|f\| \leq 1, f(s) = 0 \} \\ = \left| \frac{t - s}{1 - \bar{s}t} \right| \quad (\text{pseudo-hyperbolic metric}).$$

Throughout the rest of this paper, we do not distinguish in notations $\varphi \in \mathcal{M}(A)$ from its representing measure when φ has a unique representing measure, and we suppose that $m \in \mathcal{M}(A)$ has a unique representing measure m . Let $A_m = \{f \in A; m(f) = 0\}$, the kernel of a complex homomorphism m . Let $H^\infty(m)$, H_m^∞ be the weak-star closures of A , A_m in $L^\infty(m)$ respectively, and for $1 \leq p < \infty$ let $H^p(m)$, H_m^p be the closures of A , A_m in $L^p(m)$ norm respectively. If φ belongs to $P(m)(\supseteq \{m\})$, then for $1 \leq p < \infty$ the spaces $H^p(m)$ and $H^p(\varphi)$ are identical as sets of (equivalence classes of) functions; as Banach spaces, they have distinct but equivalent norms. Under the same hypothesis, the Banach algebras $H^\infty(m)$ and $H^\infty(\varphi)$ are identical.

For a Dirichlet algebra Wermer [7] showed the following theorem, and Hoffman [3] generalized Wermer's result to a logmodular algebra (cf. Browder [1], Chap. IV). Functions in $H^\infty(m)$ of unit modulus are called *inner functions*.

THEOREM 1 (WERMER'S EMBEDDING THEOREM). *Let A be a uniform algebra on a compact space X . Suppose that $m \in \mathcal{M}(A)$ has a unique representing measure m on X , and that the part P of m consists of more than one point. Then we have the following.*

(1) *There is an inner function Z (= Wermer's embedding function) such that $ZH^\infty(m) = H_m^\infty$.*

(2) *If $\varphi \in P$, define $\hat{Z}(\varphi) = \int Z d\varphi$. Then \hat{Z} is a one-one map of the part P onto the open unit disk D in the plane. The inverse map τ of \hat{Z} is a one-one continuous map of D onto P (with the Gelfand topology).*

(3) *For every f in A the composed function $\hat{f} \circ \tau$ is analytic on D .*

Let φ be an element of the Gleason part $P(m)$ of m in $\mathcal{M}(A)$. Then there is a function h in $L^\infty(m)$ such that $\varphi(f) = \int f d\varphi = \int f h dm$ for all $f \in A$, so φ has a unique extension to a linear functional $\tilde{\varphi}$ on $H^\infty(m)$ which is both multiplicative and weak-star continuous. For any $f \in H^\infty(m)$ $\tilde{\varphi}$ has the form

$$\tilde{\varphi}(f) = \int f d\varphi = \int f h dm.$$

We call $\tilde{\varphi}$ the *measure extension* of φ in $P(m)$.

PROPOSITION. *Let $A, m, P(m)$ and Z be as in Wermer's embedding theorem. Let $\mathcal{P} = \mathcal{P}(m)$ be the set of measure extension $\tilde{\varphi}$ of φ in $P(m)$. Then we have the following.*

(1) \mathcal{P} is the nontrivial Gleason part of \tilde{m} in $\mathcal{M}(H^\infty(m))$.

(2) The map $\hat{Z}|_{\mathcal{P}}$ is a one-one continuous map of the part \mathcal{P} (with the Gelfand topology) onto the open unit disk D , and thus the inverse map $\tilde{\tau}$ of $\hat{Z}|_{\mathcal{P}}$ is a homeomorphism of D onto \mathcal{P} .

Proof. If the Gelfand transform $\hat{H}^\infty(m) = \hat{H}^\infty$ of $H^\infty(m)$ is restricted to the maximal ideal space Y of $L^\infty(m)$, then \hat{H}^∞ is a logmodular algebra on Y (see Hoffman [3], Theorem 6.4, corollary), and therefore every complex homomorphism φ of $H^\infty(m)$ has a unique representing measure on Y (see [3], Theorem 4.2). In particular, $\tilde{m} \in \mathcal{M}(H^\infty(m))$ has a unique representing (normal) measure \tilde{m} on the hyperstonean space Y . Then for every f in $L^\infty(m)$ we have

$$\int_X f dm = \int_Y \hat{f} d\tilde{m}.$$

And we can identify $L^\infty(\tilde{m})$ with $C(Y) = \hat{L}^\infty(m)$ (cf. Srinivasan-Wang [6], pp. 221-223).

Now let Σ be the Gleason part of \tilde{m} . For $\tilde{\varphi}$ in \mathcal{P} , we have

$$(1.5) \quad \tilde{\varphi}(f) = \int_X f d\varphi = \int_X f h dm = \int_Y \hat{f} \hat{h} d\tilde{m} \quad (f \in H^\infty(m)),$$

where h is a function in $L^\infty(m)$ with $a < h < b$ for some positive constants a and b . From this we see that $\tilde{\varphi}$ is in Σ .

Conversely if λ is an element of Σ , then λ has a unique representing measure $\tilde{\lambda}$ on Y , and we have for every $f \in H^\infty(m)$

$$\lambda(f) = \int_Y \hat{f} d\tilde{\lambda} = \int_Y \hat{f} \frac{d\tilde{\lambda}}{d\tilde{m}} d\tilde{m}.$$

Since $d\tilde{\lambda}/d\tilde{m}$ is an element of $L^\infty(\tilde{m})$, there is a function h in $L^\infty(m)$ such that $d\tilde{\lambda}/d\tilde{m} = \hat{h}$ a.e. ($d\tilde{m}$). Hence we have

$$\lambda(f) = \int_Y \hat{f} \hat{h} d\tilde{m} = \int_X f h dm$$

and thus $\lambda \in \mathcal{P}$. So we get $\mathcal{P} = \Sigma$. Then the rest part (2) of the proposition follows from Theorem 1.

2. Results.

DEFINITION. Let $P(m)$ be the nontrivial Gleason part of m in

the maximal ideal space $\mathcal{M}(A)$ of a uniform algebra A . A one-one continuous map $\rho(t)$ of the open unit disk D onto $P(m)$ (with the Gelfand topology) is called an *analytic map* if the composition $\hat{f}(\rho(t))$ is analytic on D , for every f in A .

Now we are in a position to prove the following theorem.

THEOREM 2. *Let A be a uniform algebra on a compact space X . Suppose that $m \in \mathcal{M}(A)$ has a unique representing measure m on X , and that the part P of m consists of more than one point. Let $\tau(t)$ be an analytic map of the open unit disk D onto P which is obtained in Theorem 1. If $\rho(t)$ is an analytic map of D onto P such that $\rho(\alpha) = m$, then we have*

$$(2.1) \quad \rho(t) = \tau\left(\beta \frac{t - \alpha}{1 - \bar{\alpha}t}\right),$$

where β is a constant of modulus 1. Furthermore, $\tau(t)$ is a homeomorphism if and only if $\rho(t)$ is a homeomorphism.

Proof. Let \mathcal{S} , Z , and $\tilde{\tau}$ be as in Theorem 1 and proposition. For any $t \in D$, $\rho(t)$ has a unique representing measure $h_t dm$, where h_t is an element of $L^\infty(m)$. Let $\tilde{\rho}(t)$ be the measure extension of $\rho(t)$ i.e., $\tilde{\rho}(t)(f) = \int f h_t dm$ for all $f \in H^\infty(m)$. For each $f \in H^\infty(m)$ there exists a sequence $\{f_n\}$ in A such that $\|f_n\| \leq \|f\|$ for all n and $f_n \rightarrow f$ a.e. (dm) (Hoffman-Wermer theorem, see [1], Theorem 4.2.5). Then, by Lebesgue's dominant convergence theorem, $\rho(t)(f_n) = \int f_n h_t dm \rightarrow \tilde{\rho}(t)(f)$ for every t in D . Since $\rho(t)(f_n)$ ($n = 1, 2, \dots$) are analytic in D and $|\rho(t)(f_n)| \leq \|f_n\| \leq \|f\|$, we see that, for every f in $H^\infty(m)$, $\tilde{\rho}(t)(f)$ is analytic in D (Vitali's theorem). Hence we see that $\tilde{\rho}(t)$ is an analytic map of D onto \mathcal{S} . If we set $g(t) = (\tilde{\tau}^{-1} \circ \tilde{\rho})(t) = \hat{Z}(\tilde{\rho}(t))$, then $g(t)$ is a one-one holomorphic map of D onto D , and $g(\alpha) = 0$. Hence we see

$$g(t) = \beta \frac{t - \alpha}{1 - \bar{\alpha}t},$$

where β is a constant of modulus 1, and thus we have

$$\tilde{\tau}\left(\beta \frac{t - \alpha}{1 - \bar{\alpha}t}\right) = \tilde{\rho}(t).$$

Since $\tilde{\tau}(t)|_A = \tau(t)$ and $\tilde{\rho}(t)|_A = \rho(t)$ we have

$$\tau\left(\beta \frac{t - \alpha}{1 - \bar{\alpha}t}\right) = \rho(t).$$

Next we prove that $\tau(t)$ is a homeomorphism if and only if $\rho(t) = \tau(\beta(t-\alpha)/(1-\bar{\alpha}t))$ is a homeomorphism. We put $L_\alpha(t) = (t+\alpha)/(1+\bar{\alpha}t)$ and $\beta = e^{i\theta}$. Then $\tau(t)$ is a homeomorphism of D onto P if and only if $\hat{Z}(\varphi) (= \int Z d\varphi)$ is a continuous map of P onto D if and only if $L_\alpha \circ e^{-i\theta} \circ \hat{Z}$ is a continuous map of P onto D if and only if

$$(L_\alpha \circ e^{-i\theta} \circ \hat{Z})^{-1}(t) = \tau(e^{i\theta} L_{-\alpha}(t)) = \tau\left(e^{i\theta} \frac{t-\alpha}{1-\bar{\alpha}t}\right) = \rho(t)$$

is a homeomorphism, and the theorem is proved.

Next we shall prove the following theorem which generalizes a formula (6.12) in Hoffman [4], p. 105.

THEOREM 3. *Let A be a uniform algebra on X . Suppose that $m \in \mathcal{M}(A)$ has a unique representing measure m on X , and that the part P of m consists of more than one point. If $\rho(t)$ is an analytic map of the open unit disk D onto $P(m)$, then we have*

$$\begin{aligned} \sigma(\rho(t), \rho(s)) &= \sigma(t, s), \\ G(\rho(t), \rho(s)) &= G(t, s). \end{aligned}$$

For the definitions of σ, G see (1.1) ~ (1.4).

Proof. Let Z, \mathcal{S}, τ and $\tilde{\tau}$ be as Theorem 1 and proposition. Let $\tilde{\tau}(t) = \tilde{\varphi}, \tilde{\tau}(s) = \tilde{\theta}, \tau(t) = \varphi$ and $\tau(s) = \theta$. From Lemma 4.4.4 in Browder [1], we see that

$$f \in H_{\tilde{\theta}}^\infty = \left\{ f : f \in H^\infty(m) = H^\infty(\theta), \int f d\theta = 0 \right\}$$

if and only if $f \in (Z-s)H^\infty(m)$, and from this we easily get $H_{\tilde{\theta}}^\infty = \{(Z-s)/(1-\bar{s}Z)\}H^\infty(m)$. So we have

$$\begin{aligned} \sigma(\tilde{\varphi}, \tilde{\theta}) &= \sup \{ |\tilde{\varphi}(f)|; f \in H^\infty(m), \|f\| \leq 1, \int f d\theta = 0 \} \\ &= \sup \left\{ |\tilde{\varphi}(f)| : f \in \frac{Z-s}{1-\bar{s}Z} H^\infty(m), \|f\| \leq 1 \right\} \\ &= \sup \left\{ \left| \tilde{\varphi}\left(\frac{Z-s}{1-\bar{s}Z}\right) \tilde{\varphi}(g) \right| : g \in H^\infty(m), \|g\| \leq 1 \right\} \\ &= \left| \frac{t-s}{1-\bar{s}t} \right| = \sigma(t, s). \end{aligned}$$

Since the closures of A_θ and $H_{\tilde{\theta}}^\infty$ in $L^2(m)$ are the same $H_\theta^2 = \left\{ f : f \in H^2(m) = H^2(\theta), \int f d\theta = 0 \right\}$, we have the following equalities from the result which is stated as “the perhaps surprising equality” in

Browder [1], p. 134. (Note that $\tilde{\varphi}(f) = \int_Y \hat{f} \hat{h} d\tilde{m} = \int_Y \hat{f} d\tilde{\varphi}$ (see (1.5)) and $\int_X |f|^2 d\varphi = \int_Y |\hat{f}|^2 d\tilde{\varphi}$, for any $f \in H_\theta^\infty$.)

$$\begin{aligned} \sigma(\varphi, \theta) &= \sup \{ |\varphi(f)| : f \in A_\theta, \|f\| \leq 1 \} \\ &= \sup \left\{ |\varphi(f)| : f \in A_\theta, \int |f|^2 d\varphi \leq 1 \right\} \\ &= \sup \left\{ |\varphi(f)| : f \in H_\theta^2, \int |f|^2 d\varphi \leq 1 \right\} \\ &= \sup \left\{ |\tilde{\varphi}(f)| : f \in H_\theta^\infty, \int |f|^2 d\varphi \leq 1 \right\} \\ &= \sup \{ |\tilde{\varphi}(f)| : f \in H_\theta^\infty, \|f\| \leq 1 \} \\ &= \sigma(\tilde{\varphi}, \tilde{\theta}). \end{aligned}$$

Hence we have

$$\sigma(\tau(t), \tau(s)) = \sigma(\tilde{\tau}(t), \tilde{\tau}(s)) = \sigma(t, s).$$

If $\rho(t)$ is an analytic map of D onto $P(m)$, then by Theorem 2 we have $\rho(t) = \tau(\beta(t - \alpha)/(1 - \bar{\alpha}t))$, where β is a constant of modulus 1. Therefore we have

$$\sigma(\rho(t), \rho(s)) = \sigma\left(\beta \frac{t - \alpha}{1 - \bar{\alpha}t}, \beta \frac{s - \alpha}{1 - \bar{\alpha}s}\right) = \sigma(t, s).$$

The following equality is proved by König [5], which holds for φ, θ in the maximal ideal space $\mathcal{M}(A)$ of any uniform algebra A .

$$2 \log \frac{2 + G(\varphi, \theta)}{2 - G(\varphi, \theta)} = \log \frac{1 + \sigma(\varphi, \theta)}{1 - \sigma(\varphi, \theta)}.$$

Using this we get

$$G(\rho(t), \rho(s)) = G(t, s).$$

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