

Homework 5 of Introduction to Analysis(II)

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1. (a) If $x \in A$, $d(x, A) = \|x - x\| = 0$ and $d(x, B) = k > 0$, $\phi(x) = \frac{0}{0+k} = 0$. If $x \in B$, $d(x, A) = l > 0$ and $d(x, B) = 0$, $\phi(x) = \frac{l}{l+0} = 1$. If $x \notin A \wedge x \notin B$, $d(x, A) = l$ and $d(x, B) = k$, $\phi(x) = \frac{l}{l+k} < 1$ and is positive.

And for $x, y \in A$ and $\|x - y\| < \delta$, $\phi(x)$ Thus, $0 \leq \phi(x) \leq 1$ for all $x \in \mathbb{R}^n$.

- (b) Let $\phi(x) = (b - a) \frac{d(x, A)}{d(x, A) + d(x, B)} + a$. From (a), we can get $\phi(x \in A) = (b - a) \cdot 0 + a = a$, $\phi(x \in B) = (b - a) \cdot 1 + a = b$, and $a \leq \phi(x) \leq b$ for all $x \in A$.

2. If f has more than one fixed point, there exists $x, y \in S$ s.t. $d(f^n(x), f^n(y)) = d(x, y)$ for all $n \in \mathbb{N}$ (contradiction to $a_n \rightarrow 0$). Then, we want to show that f has fixed point. For any $x_0 \in S$, we let $x_k = f^k(x)$ and we can find a $N \in \mathbb{N}$ s.t. $a_n < \varepsilon$ for all $n > N$. Then, $d(x_{n+k}, x_n) \leq a_n d(x_k, x_0) < \varepsilon \cdot d(x_k, x_0)$ for any k and $n > N$. Thus, $x_n \rightarrow x^* \in S$ by S is complete, and x^* is a fixed point of f .

3. Since $T(u)(t) = \int_a^t u(s) ds$, assume $T^m(u)(t) = \int_a^t \frac{(t-s)^{m-1}}{(m-1)!} u(s) ds$. Then,

$$\begin{aligned} T^{m+1}(u)(t) &= T(T^m(u))(t) \\ &= \int_a^t T^m(u)(s) ds \\ &= \int_a^t \frac{1}{(m-1)!} \int_a^s (s-\tau)^{m-1} u(\tau) d\tau ds \\ &= \int_a^t \frac{1}{(m-1)!} \int_a^\tau (s-\tau)^{m-1} u(\tau) ds d\tau \\ &= \int_a^t \frac{1}{m!} (t-\tau)^m u(\tau) d\tau \end{aligned}$$

Thus, by M.I., $T^m(u) = \frac{1}{(m-1)!} \int_a^t (t-s)^m u(s) ds \leq \int_a^t \frac{(t-s)^m}{(m-1)!} M ds$ for M is upper bound of u .

Thus, T has unique fixed point by 2., and $T(0) = 0$ trivially.

4.