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On Soft $\#\pi g$-continuous Function in Soft Topological Spaces

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Abstract: This paper focuses on soft $\#\pi g$-continuous function in soft topological spaces and compare its relationship with other soft continuous function.

Keywords: Soft $\#\pi g$-closed set, soft $\#\pi g$-continuous function,soft $\#\pi g$-irresolute,soft generalized closed, soft topological spaces.

1. Introduction

The concept of soft set theory was first introduced by D. Molodtsov [8], a Russian researcher in 1999 as a new approach to handle uncertainties. Shabir and Naz [10] introduced the notion of soft topological spaces along with its properties. Kannan [6] introduced soft generalized closed and open sets in soft topological spaces. C.Janaki and V. Jeyanthi [3] introduced soft-πgr-closed sets.Soft-πgb-closed sets was introduced by C.Janaki and D.Sreeja [5] in soft topological spaces. In this paper, a new class of function called soft $\#\pi g$-continuous function is defined and study the relationships with other soft continuous function.

2. Preliminaries

Let U be an initial universe set and E be a collection of all possible parameters with respect to U, where parameters are the characteristics or properties of objects in U. Let $P(U)$ denote the power set of U, and let $A \subseteq E$.

Definition 2.1 ([8]). *A pair (G, A) is called a soft set over U, where G is a mapping given by $G : A \to P(U)$. In other words, a soft set over U is a parametrized family of subsets of the universe U. For a particular $e \in A$, $G(e)$ may be considered the set of e-approximate elements of the soft set (G, A).*

Definition 2.2 ([2]). *For two soft sets (G,A) and (H,B) over a common universe U, we say that (G,A) is a soft subset of (H, B) if*

(1). $A \subseteq B$ and

(2). $\forall\ e \in A$, $G(e) \tilde{\subseteq} H(e)$.

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We write $(G,A)\widetilde{\subset}(H,B)$. (G,A) is said to be soft super set of (H, B), if (H, B) is soft subset of (G, A) and is denoted by (H, B) $\widetilde{\subset}$ (G, A).

Definition 2.3 ([7]). *A soft set (G, A) over U is said to be*

(1). null soft set denoted by ϕ if $\forall$ e $\in$ A, G(e) = ϕ.

(2). absolute soft set denoted by A, if $\forall$ e $\in$ A, G(e) = U.

Definition 2.4 ([7]). *For two soft sets (G, A) and (H, B) over a common universe U, union of two soft sets of (G, A) and (H, B) is the soft set (J, C), where $C = A \cup B$ and $\forall$ $e \in C$,*

$$J(e) = \begin{cases} G(e) & if\ e \in A - B \\ H(e) & if\ e \in B - A \\ G(e) \cup H(e) & if\ e \in A \cap B \end{cases}$$

We write (G,A) $\cup$ (H,B)=(J,C).

Definition 2.5 ([2]). *The Intersection (J, C) of two soft sets (G, A) and (H, B) over a common universe U denoted by $(G,A) \cap (H,B)$ is defined as $C = A \cap B$ and $J(e) = G(e) \cap H(e)$ for all $e \in C$.*

Definition 2.6 ([10]). *Let Y be a non-empty subset of X, then $\widetilde{Y}$ denotes the soft set (Y, E) over X for which $Y(e) = Y$, for all e $\in E$. In particular, (X, E) is denoted by $\widetilde{X}$.*

Definition 2.7 ([10]). *For a soft set (G, A) over the universe U, the relative complement of (G, A) is denoted by $(G,A)^{'}$ and is defined by $(G,A)^{'} = (G^{'}, A)$, where $G^{'} : A \rightarrow P(U)$ is a mapping defined by $G^{'}(e) = U - G(e)$ for all $e \in A$.*

Definition 2.8 ([10]). *Let τ be the collection of soft sets over X,then τ is called a soft topology on X if τ satisfies the following axioms:*

(1). ϕ,$\widetilde{X}$ belong to τ

(2). The union of any number of soft sets in τ belongs to τ.

(3). The intersection of any two soft sets in τ belongs to τ.

The triplet (X, τ, E) is called a soft topological space over X.

Definition 2.9 ([10]). *Let (X, τ, E) be soft space over X. A soft set (G, E) over X is said to be soft closed in X, if its relative complement $(G,E)^{'}$ belongs to τ. The relative complement is a mapping $G^{'} : E \rightarrow P(X)$ defined by $G^{'}(e) = X - G(e)$ for all $e \in A$.*

Definition 2.10 ([6]). *Let X be an initial universe set, E be the set of parameters and $\tau = \{\phi, \widetilde{X}\}$. Then τ is called the soft indiscrete topology on X and (X, τ, E) is said to be a soft indiscrete space over X. If τ is the collection of all soft sets which can be defined over X then τ is called the soft discrete topology on X and (X, τ, E) is said to be a soft discrete space over X.*

Definition 2.11 ([6]). *Let (X, τ, E) be a soft topological space over X and the soft interior of (G, E) denoted by $int(G, E)$ is the union of all soft open subsets of (G, E). Clearly, (G, E) is the largest soft open set over X which is contained in (G, E). The soft closure of (G, E) denoted by $cl(G, E)$ is the intersection of all closed sets containing (G, E). Clearly, (G, E) is the smallest soft closed set containing (G, E).*

$$int(G,E) = \cup\{(O,E) : (O,E)\ is\ soft\ open\ and\ (O,E)\ \widetilde{\subset}(G,E)\}$$
$$cl(G,E) = \cap\{(O,E) : (O,E)\ is\ soft\ closed\ and\ (G,E)\ \widetilde{\subset}(O,E)\}.$$

Definition 2.12 ([6]). *Let U be the common universe set and E be the set of all parameters. Let (G, A) and (H, B) be soft sets over the common universe set U and $A, B \tilde{\subseteq} E$. Then (G, A) is a subset of (H, B), denoted by $(G, A) \tilde{\subseteq} (H, B)$. (G, A) equals (H, B), denoted by $(G, A) = (H, B)$ if $(G, A) \tilde{\subseteq} (H, B)$ and $(H, B) \tilde{\subseteq} (G, A)$.*

Definition 2.13. *A soft subset (A, E) of X is called*

(1). a soft generalized closed (soft g-closed) [6] in a soft topological space (X, τ, E) if $cl(A, E) \tilde{\subseteq} (U, E)$ whenever $(A, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft open in X.

(2). a soft regular open [3] if $(A, E) = int(cl(A, E))$

(3). a soft semi-open [1] if $(A, E) \tilde{\subseteq} cl(int(A, E))$.

The complement of soft semi open, soft regular open are their soft semi closed, soft regular closed.

Definition 2.14 ([9]). *The finite union of soft regular open sets is said to be soft π- open. The complement of soft π- open is said to be soft π-closed.*

Definition 2.15 ([11]). *A soft subset (A, E) of a soft topological space X is called soft $\#\pi g$- closed set in X if $\tilde{s}\pi cl(A, E) \tilde{\subseteq} (U, E)$ whenever $(A, E) \tilde{\subseteq} (U, E)$ where (U, E) is soft open in X and its relative complement is soft $\#\pi g$ open set.*

Definition 2.16 ([4]). *Let (X, τ_1, A) and (Y, τ_2, B) be soft topological spaces and $f : X \to Y$ be a function. Then the function f is called Soft regular continuous if $f^{-1}((G, B))$ is soft regular closed in (X, τ_1, A) for every soft closed set (G, B) in (Y, τ_2, B).*

3. Soft $\#\pi g$-Continuous Functions

Definition 3.1. *Let (X, τ_1, A) and (Y, τ_2, B) be soft topological spaces and $f : X \to Y$ be a function. Then the function f is called*

(1). Soft $\#\pi g$-continuous if $f^{-1}((G, B))$ is soft $\#\pi g$-closed in (X, τ_1, A) for every soft closed set (G, B) in (Y, τ_2, B).

(2). Soft $\#\pi g$-irresolute if $f^{-1}((G, B))$ is soft $\#\pi g$-closed in (X, τ_1, A) for every soft $\#\pi g$ - closed set (G, B) in (Y, τ_2, B).

Remark 3.2. *Soft $\#\pi g$ - continuity and soft $\#\pi g$ - irresolute are independent.*

Example 3.3.

(1). Let $X = Y = \{a, b, c\}$, $E = \{e_1, e_2\}$. Let G_1, G_2, G_3 are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = X$, $G_1(e_2) = \{a\}$, $G_2(e_1) = \{a, c\}$, $G_2(e_2) = \{\phi\}$, $G_3(e_1) = \{b\}$, $G_3(e_2) = \{a\}$. Then $\tau_1 = \{\phi, \tilde{X}, (G_1, E), (G_2, E), (G_3, E)\}$, $\tau_2 = \{\phi, \tilde{Y}, (G_1, E), (G_2, E), (G_3, E)\}$ is a soft topology and elements in τ_1, τ_2 are soft open sets. Let $f : X \to Y$ be a function defined as $f(a) = c$, $f(b) = a$, $f(c) = b$. Here the inverse image of the soft open set in Y is soft $\#\pi g$ open in X, but the inverse image of soft $\#\pi g$ - open set $(H, E) = \{ X, \{a, b\}\}$ in Y is not soft $\#\pi g$ - open in X. Hence soft $\#\pi g$ - continuous function need not be soft $\#\pi g$ - irresolute.

(2). Let $X = Y = \{a, b, c\}$, $E = \{e_1, e_2\}$. Let $G_1, G_2, \cdots G_9$ are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = \{b\}$, $G_2(e_2) = \{a\}$, $G_2(e_1) = \{b\}$, $G_2(e_2) = \{a, b\}$, $G_3(e_1) = \{b\}$, $G_3(e_2) = \{a, c\}$, $G_4(e_1) = \{b\}$, $G_4(e_2) = X$, $G_5(e_1) = \{a, b\}$, $G_5(e_2) = \{a, b\}$, $G_6(e_1) = \{a, b\}$, $G_6(e_2) = X$, $G_7(e_1) = \{b, c\}$, $G_7(e_2) = \{a, b\}$, $G_8(e_1) = \{b, c\}$, $G_8(e_2) = X$, $G_9(e_1) = X$, $G_9(e_2) = \{a, b\}$. Then $\tau_1 = \{\phi, \tilde{X}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$, $\tau_2 = \{\phi, \tilde{Y}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$

is a soft topology and elements in τ_1, τ_2 are soft open sets. Let $f : X \to Y$ be an identity function. Here the inverse image of the soft $\#\pi g$ - open set in Y are soft $\#\pi g$- open in X, but the inverse image of soft open set $(G_7, E) = \{\{b, c\}, \{a, b\}\}$ is not $\#\pi g$ - open set in X. Hence soft $\#\pi g$ - irresoluteness need not be soft $\#\pi g$ - continuous.

Remark 3.4. *Soft $\#\pi g$ - continuity and soft continuity are independent.*

Example 3.5.

(1). Let $X = Y = \{h_1, h_2, h_3\}$, $E = \{e_1, e_2\}$. Let G_1, G_2, G_3 are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = X$, $G_1(e_2) = \{h_1\}$, $G_2(e_1) = \{h_1, h_3\}$, $G_2(e_2) = \{\phi\}$, $G_3(e_1) = \{h_2\}$, $G_3(e_2) = \{h_1\}$. Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E), (G_3, E)\}$, $\tau_2 = \{\phi, \widetilde{Y}, (G_1, E), (G_2, E), (G_3, E)\}$ be a soft topology on X and Y respectively. Let $f : X \to Y$ be a function defined as $f(h_1) = h_2$, $f(h_2) = h_1$, $f(h_3) = h_3$. Here the inverse image of the soft open set $(G_2, E) = \{\{h_1, h_3\}, \{\phi\}\}$ in Y is soft $\#\pi g$ - open in X but not soft open in X. Hence soft $\#\pi g$ - continuity need not be soft continuity.

(2). Let $X = Y = \{a, b, c\}$, $E = \{e_1, e_2\}$. Let $G_1, G_2, \cdots G_9$ are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = \{b\}, G_1(e_2) = \{a\}$, $G_2(e_1) = \{b\}, G_2(e_2) = \{a, b\}$, $G_3(e_1) = \{b\}, G_3(e_2) = \{a, c\}$, $G_4(e_1) = \{b\}, G_4(e_2) = X$, $G_5(e_1) = \{a, b\}, G_5(e_2) = \{a, b\}$, $G_6(e_1) = \{a, b\}, G_6(e_2) = X$, $G_7(e_1) = \{b, c\}, G_7(e_2) = \{a, b\}$, $G_8(e_1) = \{b, c\}, G_8(e_2) = X$, $G_9(e_1) = X, G_9(e_2) = \{a, b\}$. Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$, $\tau_2 = \{\phi, \widetilde{Y}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$ is a soft topology on X and Y respectively. Let $f : X \to Y$ be an identity function. Here the inverse image of the soft open set $(G_3, E) = \{\{b\}, \{a, c\}\}$ in Y is not soft $\#\pi g$ - open in X but soft open in X. Hence soft continuous function need not be soft $\#\pi g$- continuous.

Theorem 3.6. *For a function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ the following hold*

(1). Every soft π-continuous function is soft $\#\pi g$- continuous.

(2). Every soft $\#\pi g$- continous function is soft πg- continuous.

(3). Every soft $\#\pi g$- continous function is soft g continuous.

Proof. Obvious. □

The converse of the above is not true.

Example 3.7. *Let $X = Y = \{h_1, h_2, h_3\}, E = \{e_1, e_2\}$. Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E), (G_3, E)\}$ is a soft topological space over X and $\tau_2 = \{\phi, \widetilde{Y}, (G_1, E), (G_2, E), (G_3, E)\}$ is a soft topological space over Y and are defined as follows: $G_1(e_1) = X, G_1(e_2) = \{h_1\}$, $G_2(e_1) = \{h_1, h_3\}, G_2(e_2) = \{\phi\}$, $G_3(e_1) = \{h_2\}, G_3(e_2) = \{h_1\}$. If the function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be defined as follows, $f(h_1) = h_2$, $f(h_2) = h_1$, $f(h_3) = h_3$, then f is soft $\#\pi g$-continuous but not soft π-continuous, since the inverse image of soft open set $(G_2, E) = \{\{h_1, h_3\}, \{\phi\}\}$ in Y is not a soft π- open set in X.*

Example 3.8. *Let $X = Y = \{a, b, c\}$, $E = \{e_1, e_2\}$. Let G_1, G_2 are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = \{a\}$, $G_1(e_2) = \{a\}$, $G_2(e_1) = \{a\}$, $G_2(e_2) = X$. Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E)\}$, $\tau_2 = \{\phi, \widetilde{Y}, (G_1, E), (G_2, E)\}$ is a soft topology. Let $f : X \to Y$ be defined as $f(a) = c, f(b) = f(c) = a$,then f is soft πg-continuous but not soft $\#\pi g$-continuous,since the inverse image of the soft open set $(G_2, E) = \{\{a\}, X\}$ in Y is soft πg-open in X but not soft $\#\pi g$-open in X.*

Example 3.9. *Let $X = Y = \{a, b, c\}$, $E = \{e_1, e_2\}$. Let $G_1, G_2, \cdots G_9$ are functions from E to $P(X)$ and defined as follows. $G_1(e_1) = \{b\}$, $G_1(e_2) = \{a\}$, $G_2(e_1) = \{b\}$, $G_2(e_2) = \{a, b\}$, $G_3(e_1) = \{b\}$, $G_3(e_2) = \{a, c\}$, $G_4(e_1) = \{b\}$, $G_4(e_2) = X$, $G_5(e_1) = \{a, b\}$, $G_5(e_2) = \{a, b\}$, $G_6(e_1) = \{a, b\}$, $G_6(e_2) = X$, $G_7(e_1) = \{b, c\}$, $G_7(e_2) = \{a, b\}$, $G_8(e_1) = \{b, c\}$, $G_8(e_2) = X$, $G_9(e_1) = X$, $G_9(e_2) = \{a, b\}$ Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$, $\tau_2 = \{\phi, \widetilde{Y}, (G_1, E), (G_2, E), \cdots (G_9, E)\}$ is a soft topology. Let $f : X \to Y$ be an identity function then f is g-continuous but not soft $\#\pi g$-continuous, since the inverse image of soft open set $(G_4, E) = \{\{b\}, X\}$ in Y is not soft $\#\pi g$ open set in X.*

Theorem 3.10. *If a function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$- continuous then $f(\tilde{s}\#\pi gcl(G, E))\widetilde{\subset}\tilde{s}cl(f(G, E))$ for every soft closed set (G, E) of X.*

Proof. Let $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be soft $\#\pi g$- continuous and $(G, E)\widetilde{\subset}X$. Then $\tilde{s}cl(f(G, E))$ is soft closed in Y. Since f is soft $\#\pi g$- continuous, $f^{-1}(\tilde{s}cl(f(G, E)))$ is soft $\#\pi g$- closed in X and $(G, E)\widetilde{\subset}f^{-1}(f(G, E))\widetilde{\subset}f^{-1}(\tilde{s}cl(f(G, E)))$. As $\tilde{s}\#\pi gcl(G, E)$ is the smallest soft $\#\pi g$- closed set containing (G, E), $\tilde{s}\#\pi gcl(G, E)\widetilde{\subset}f^{-1}(\tilde{s}cl(f(G, E)))$. Hence $f(\tilde{s}\#\pi gcl(G, E))\widetilde{\subset}\tilde{s}cl(f(G, E))$. □

Theorem 3.11. *If a function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$- continuous then $f^{-1}(\tilde{s}int(G, E))\widetilde{\subset}\tilde{s}\#\pi gint(f^{-1}(G, E))$ for every soft open set (G, E) of X.*

Proof. Let $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be soft $\#\pi g$- continuous and $\tilde{s}int(f(G, E))$ is soft open set in Y. Then by the soft $\#\pi g$- continuity of f, $f^{-1}(\tilde{s}int(f(G, E)))$ is soft $\#\pi g$- open in X and $f^{-1}(\tilde{s}int(f(G, E)))\widetilde{\subset}(G, E)$. As $\tilde{s}\#\pi gint(G, E)$ is the largest soft $\#\pi g$- open set contained in (G, E), $f^{-1}(\tilde{s}int(G, E))\widetilde{\subset}\tilde{s}\#\pi gint(f^{-1}(G, E))$. □

Remark 3.12. *Composition of two soft $\#\pi g$- continuous need not be soft $\#\pi g$- continuous and is shown in the following example.*

Example 3.13. *Let $X = Y = Z = \{a, b, c\}, E = \{e_1, e_2\}$. Let G_1, G_2, G_3, G_4, are open sets in X and H_1, H_2 are open sets in Y and Z. $G_1(e_1) = \{\phi\}$, $G_1(e_2) = \{c\}$, $G_2(e_1) = \{c\}$, $G_2(e_2) = \{a, c\}$, $G_3(e_1) = \{c\}$, $G_3(e_2) = \{c\}$, $G_4(e_1) = \{\phi\}$, $G_4(e_2) = \{a, c\}$, $H_1(e_1) = \{a\}$, $H_1(e_2) = \{a\}$, $H_2(e_1) = \{a\}$, $H_2(e_2) = X$. Then $\tau_1 = \{\phi, \widetilde{X}, (G_1, E), (G_2, E), (G_3, E), (G_4, E)\}$ $\tau_2 = \{\phi, \widetilde{Y}, (H_1, E), (H_2, E)\}$ and $\tau_3 = \{\phi, \widetilde{Z}, (H_1, E), (H_2, E)\}$ are soft topology. Let $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be an identity funtion and let $g : (Y, \tau_2, E) \to (Z, \tau_3, E)$ be a function defined by $g(a) = a = g(b), g(c) = c$, here f and g are soft $\#\pi g$- continuous and the inverse image of open set $(H_1, E) = \{\{a\}, \{a\}\}$ in Z under gof is not soft $\#\pi g$- open set. Thus composition of two soft $\#\pi g$ continuous need not be soft $\#\pi g$- continuous*

Definition 3.14. *A function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$ - open function, if the image of every soft open set in X is soft $\#\pi g$-open in Y.*

Definition 3.15. *A function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$ - closed function, if the image of every soft closed set in X is soft $\#\pi g$ - closed in Y.*

Theorem 3.16. *A function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$ - open if $f(\tilde{s}int(G, E))\widetilde{\subset}\tilde{s}\#\pi gintf((G, E))$ for every soft set (G, E) of X.*

Proof. Let $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be soft $\#\pi g$ - open. Then $f(\tilde{s}int(G, E)) = \tilde{s}\ \#\pi gint(f(int(G, E)))\widetilde{\subset}\tilde{s}$ $\#\pi gintf((G, E))$. □

Theorem 3.17. *A function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ is soft $\#\pi g$ - closed if $\tilde{s}\#\pi gcl(f(G, E))\widetilde{\subset}f(\tilde{s}cl(G, E))$ for every soft set (G, E) of X.*

Proof. Let $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be soft $\#\pi g$ - closed. Then $\tilde{s}\#\pi gcl(f(\tilde{s}cl(G, E))) = \tilde{s}\#\pi gclf((G, E))\tilde{\subseteq} f(\tilde{s}cl(G, E))$. □

Theorem 3.18. *A function $f : (X, \tau_1, E) \to (Y, \tau_2, E)$ be a bijection. Then the following are equivalent.*

(1). f is soft $\#\pi g$ open;

(2). f is soft $\#\pi g$ closed;

(3). f^{-1} is soft $\#\pi g$ continuous.

Proof. (1) $\Rightarrow$ (2): Let (G, E) be soft closed set in X and f be a soft $\#\pi g$ - open. Then $X - (G, E)$ is soft open in X. Since f is soft $\#\pi g$ - open, $f(X - (G, E))$ is soft $\#\pi g$ - open set in Y. Then $Y - f(X - (G, E)) = f(G, E)$ is soft $\#\pi g$ - closed in Y.

(2) $\Rightarrow$ (3): Let (G, E) be soft closed set in X and f be a soft $\#\pi g$ - closed. Then $f(G, E)$ is soft $\#\pi g$ - closed in Y. If $f(G, E) = (f^{-1})^{-1}(G, E)$ then f^{-1} is soft $\#\pi g$ - continuous. (3) $\Rightarrow$ (1): Suppose f^{-1} is soft $\#\pi g$ - continuous. Let (G, E) be soft open in X. Since f^{-1} is soft $\#\pi g$ - continuous, $(f^{-1})^{-1} = f(G, E)$ is soft $\#\pi g$ - open in Y. Hence f is soft $\#\pi g$ - open. □

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