A SIMPLIFIED APPROACH TO SOFT SET THEORY

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Abstract

In this paper a new foundation for soft set theory is developed which is compact and encompassing extant theories dealing with soft sets. Essentially, new notions of parametric union, intersection, their negations and related properties are formulated which help redefining existing long-winded definitions of operations of soft sets and proving various identities involving them with utmost simplicity.

Keywords: Soft set, Parameter sets, Operations of parameter sets

1. Introduction

More often than not, real-life problems inherently involve uncertainties. In particular, such classes of problems arise in engineering, economics, environmental science, social sciences, management and medical sciences. To solve such problems mathematical theories such as probability theory, fuzzy set theory, rough set theory, game theory, interval mathematics and vague set theory have been found partially successful. The difficulties arising with all these methods are particularly due to their inadequate parameterization (see [7], for details).

In order to adequately deal with real-life problems, Molodtsov [7] developed *Soft Set Theory* (SST, for short) as a powerful mathematical tool entirely free from parametrization inadequacy like that of *setting membership function in each case* in fuzzy Set theory. Essentially, the initial description of the objects in SST is approximate and free from any restrictions. This seminal work, besides unfolding a rich potential for multitudinal application of soft set theory, included directions for further research, specifically for discovering new operations of soft sets and their properties. Not long after, some excellent papers by Maji *et al.* [5, 6] appeared which introduced several new operations, their properties and applications in decision making. In the sequel, a number of related works [1 – 4, 8, 9] have appeared, particularly modifying [5] and introducing thereby panoply of new definitions and their properties.

The objective of this paper is to develop a new foundation for soft set theory that would be compact and encompassing all extant theories.

2. The Structure of New Foundation for Soft Set Theory

Definition 2.1 Soft Set

Following Molodtsov [7] and other subsequent works, a soft set can be defined as follows:

Let U be an initial universe set and E a set of all possible parameters under consideration with respect to U. Let $P(U)$ denote the power set of U and $A \subseteq E$. A pair (F, A), also denoted by F_A ,is called a soft set over U, where F is a mapping given by

$$F : A \to P(U).$$

Likewise, the soft set (F, E) can be defined.

Also, $F(e) = \phi$ (null set) if and only if there is no object in U corresponding to each parameter $e \in E$. The sets $F(e)$, $e \in E$,may be empty, intersecting or disjoint.

Characteristically, F is a *set valued function of a set*. In other words, the set *(F, E) over* U is a parameterized family $\{F(e_k) : e_k \in E, k = 1,2,\cdots\}$ of the subsets of U and gives rise to a collection of approximate descriptions of objects in U. For each $e \in E$, $F(e)$ may be considered as the set *of e-Approximate* elements of the soft set (F, E), something like *J-open sets in a topological space (X, J)*. Schematically, the soft set *(F, E)* can be viewed as a collection of approximations viz.,

$$(F, E) = \{\ p_1 = v_1, p_2 = v_2, \cdots, p_n = v_n\ \}$$

where $p_1, p_2, \cdots, p_n$ are the *parameters* or *predicates* or *properties* characterizing the objects of U and $v_1, v_2, \cdots, v_n$ are the corresponding approximate value sets (see [5, 6], for example).

Cagman and Enginoglu [2] provide a relatively elegant alternative definition of a soft set as follows:

A soft set F_A over U is defined by the set of ordered pairs viz.,

$$F_A = \{(x, f_A(x)) : x \in E, f_A(x) \in P(U)\}$$

where $f_A : E \to P(U)$ such that $f_A(x) = \phi$ if $x \notin A.$ The function f_A is called *approximate function* of the soft set F_A and $f_A(x)$ the *approximate value set* or *e-approximate set* consisting of the related objects of U for all $x \in E$.

Henceforth, let $(F, A), (G, B), \cdots$ denote soft sets over a common universe U , $S(U)$ the class of all soft sets, and $A, B, C, \cdots$ the subsets of E .

Remark 2.1

It may be observed that each parameter $x \in E$ *specifies* an approximate value set $f_A(x) \subseteq U$. Thus $f_A(x)$ can be viewed as the *extension* of the predicate $x \in E$ and the soft set (f_A, E) as *predicated* family of subsets of U . In SST, unlike classical set theory, neither equivalent predicates necessarily give rise to the same extension nor does the converse hold. At this point, it seems natural to look for a fragment of SST in which the classical notion that equivalent predicates give rise to the same extension holds. We propose to call it a *Restricted Soft Set Theory* (RSST).

2.2 Fundamental Assumptions of SST

A1. Assumptions of Relevance

(i) $\forall (F, A) \in S(U)), \forall e \in A \subseteq E, F(e) \subseteq U.$

It says that every e-valued set is a subset of U , that is, $C_{(F,E)} \subseteq P(U)$ where $C_{(F,E)}$ the class of is all e-valued sets of (F, E) . In other words, parameters under consideration need to be *relevant* to the nature of objects that they intend to describe.

(ii) $\forall (F, A), (G, B) \in S(U),\ A \cap B \neq \phi$.

It forbids occurrence of degenerate cases.

A2. Assumption of Approximations Value set

$$\forall (F,A),\,(G,B) \in S(U), e \in A \cap B, F(e) \neq G(e), \text{ in general.}$$

It says that the two soft sets over a common universe may have distinct approximations value sets for the same parameter.

A2*. Assumption of Restricted Approximations Value set

$$\forall (F,A),\,(G,B) \in S(U), \forall e \in A \cap B, F(e) = G(e).$$

It says that the two soft sets over a common universe may have the same approximations value set for a common parameter.

We propose to call a theory of soft sets founded on {A1, A2*} a *Restricted Soft Set Theory* (RSST) and, in the same vein, that which is founded on { A1, A2 }, an *Extended Soft Set Theory* (ESST) or simply a *Soft Set Theory*. It may be noted that the counter examples provided (see [1], for example) to prove incorrectness of some results of [5] largely exploit the insufficiency of $(A2^*)$. Of course, there remain other discrepancies in [5] which will be discussed later.

2.3 Operations of Soft Sets

Definition 2.3.1 Soft Subset

(F,A) **is a** *soft subset* **of** (G,B), denoted by $(F,A) \,\tilde{\subseteq}\, (G,B)$, if

(i) $A \subseteq B$, and

(ii) $\forall\ e \in A,\ F(e) \subseteq G(e)$.

In RSST, $F(e) = G(e)$ for all $e \in A$ [5, 6].

It is not difficult to see that the notion of soft subsets is different from that of classical notion of subsets, since $(F,A) \,\tilde{\subseteq}\, (G,B)$ does not necessarily imply that every element of (F,A) is an element of (G,B) (see [2], for example).

(F,A) and (G,B) are called *soft equal* if $(F,A) \,\tilde{\subseteq}\, (G,B)$ and $(G,B) \,\tilde{\subseteq}\, (F,A)$.

Definition 2.3.2 *Not set* of a set of parameters [5, 6]

Let $E = \{e_1, e_2, \cdots, e_n\}$ be a universe set of parameters and $A, B, \cdots$ are subsets of E.

The *Not set* of E, denoted by $\neg E = \{\neg e_1, \neg e_2, \cdots, \neg e_n\}$ where $\neg e_k$ =not e_k, for all *k*. Note that $\neg$ operation used on parameter sets has no counterpart in classical set theory whereas $\neg$ used on parameters is standard set-theoretic negation. However, for convenience we have used the same notation for both. Clearly, $\forall A \subseteq E, A^C = (complement\ of\ A\ in\ E) = E - A.$

Definition 2.3.3 Complement of a Soft Set [1, 5]

The *complement* of a soft set (F, A), denoted by $(F, A)^c$, is defined by $(F, A)^c = (F^C, A) = (F, \neg A)$, where $F^C : A \to P(U)$ is a mapping given by $F^C(\alpha) = U - F(\alpha), \forall \alpha\ in\ A$. It is straightforward to see that $(F^C)^C = F$ and $((F, A)^C)^C = (F, A)$. Note that this definition is equivalent to the definition of *relative complement* of soft set in [1]. Unfortunately, the definition of complement soft set given in [5] Is confusing, since $\left[F^C(\neg e) = U - F(\neg e) \neq U - F(e) = F^C(e) = F(\neg e)\right]$.

The confusion arises because of not observing that the domain of any function constituting a soft set must be a subsets of *E*, and not of $\neg E$.

Definition 2.3.4 The Relative NULL and Whole Soft Set [1]

A soft set (F, A) is called a *relative* NULL soft set, denoted by $\overline{\phi_A}$, if $\forall e \in A,\ F(e) = \phi(null\ set)$. Note that $\overline{\phi_A}$, also denoted by ($\overline{\phi}$, A) [3], is a soft set parameterized by $A = \phi$ (null set). That is, $\overline{\phi_A}(e) = \phi, \forall e \in A.$

A soft set (F, A) is called a *relative whole soft set* with respect to U, denoted by $U_A\ or\ (U, A)$ [3], if $\forall e \in A$, $F^C(e) = U$.

It is easy to see that $\phi_A{}^C = U_A$, $U_A{}^C = \overline{\phi_A}$.

As described in [3], the notation $\overline{\phi}$, introduced in [5], is confusing since the parameter set for $\overline{\phi}$ is not well defined. For example, $(F, A) = \overline{\phi} = (F, B)$, but $A \neq B$, which is not in conformity with the definition of the union of two soft sets given in [5]. Nevertheless, as the notion of *Absolute* Soft Set $\overline{A}$ of [5] is parameterized by a particular parameter set *A,* no confusion arises.

2.4 Parameters, Parameter sets, Related Operations and their Properties

As has been emphasized in definition 2.1 for soft set and assumption of relevance A1 (I) in 2.2 above, consideration of a universe set E of all possible parameters *relevant* to the objects of a given universe set U is quite fundamental. As the parameters are not bald rather *predicates* or *properties* or *attributes* specific to the objects of U, operations of both parameters and those of the sets of parameters need to be viewed differently from that of the usual set theoretic notions. The actual import of parameters, negates of parameters, their union and intersection, etc., gets realized only when they appear as arguments of the function F in a given soft set (F, A). In other words, the import of a parameter is *relative* to a given function. This is why, for the same parameter e_k, $F(e_k)$ and $G(e_k)$ may be different. Note also that, unlike $F(e_j)$ and $F(e_k)$, $k \neq j$, the approximate value sets $F(e_k)$ and $F(\neg e_k)$, $\forall k$ are complementary to each other. In view of this, the same parameter $e_k \in E$ needs to be identified in respect of two subsets $A\ and\ B$ of E appearing in the soft sets (F, A) and (G, B). For example, given $E = \{e_1, e_2, e_3\}$, we write

$A = \{e_{1A}, e_{2A}\}$, $B = \{e_{1B}, e_{3B}\}$, etc. In what follows, we propose to introduce the following operations over parameters and parameter sets.

Proposition 2.4.1

$\forall k$, the following results hold:

(i) $F^c(e_k) = F(\neg e_k)$, $F^c(\neg e_k) = F(e_k)$.

(ii) $F(e_k \cup \neg e_k) = F(e_k) \cup F(\neg e_k) = U$; $F(e_k \cap \neg e_k) = F(e_k) \cap F(\neg e_k) = \phi$

(iii) $F^C(e_k \cup \neg e_k) = F(\neg(e_k \cup \neg e_k) = F(\neg e_k \cap \neg\neg e_k) = F(e_k \cap \neg e_k) = \phi$;

$$F^C(e_k \cap \neg e_k) = F(\neg(e_k \cap \neg e_k)) = F(\neg e_k \cup \neg\neg e_k) = F(\neg e_k \cup e_k) = U.$$

For an illustration,

Let $U = \{h_1, h_2, h_3, h_4, h_5, h_6\}$ be the set of houses, and $E = \{e_1, e_2, e_3, e_4, e_5\}$ the set of parameters, where e_1=expensive, e_2=beautiful, e_3=wooden, e_4=cheap, e_5=in green surroundings.

Let $F(e_1) = \{h_2, h_4\}$, $F(e_2) = \{h_1, h_3\}$, $F(e_3) = \{h_2, h_4, h_5\}$, $F(e_4) = \{h_1, h_3, h_5\}$, $F(e_5) = \{h_1\}$.

Then $F(\neg e_1) =$ set of not expensive houses with respect to U

$= U - F(e_1) = F^C(e_1) = \{h_1, h_3, h_5, h_6\}$.

Also $F^C(\neg e_1) = U - F(\neg e_1) = F(e_1) = \{h_2, h_4\}$.

Now, $F(e_1) \cup F(\neg e_1) = U, \quad F(e_1) \cap F(\neg e_1) = \phi,$ etc.

Definition 2.4.1 Parametric Union ($\bigcup$) and Parametric intersection ($\bigcap$) of Parameter Sets

Let e_{kA} *and* $e_{k\mathbf{B}}$ represent the same parameter $e_k \in E, \forall k$ while appearing in the parameter sets A *and* B, respectively. Besides, A *and* B contain all other e_{iA} and e_{jB}, respectively, where $i \neq j \;\; \forall i, j$ etc. That is, $A = \{e_{kA}, e_{iA}, \cdots\}, B = \{e_{kB}, e_{jB}, \cdots\}$

$A = \{e_{kA}, k = 1,2,3,\cdots\},\; B = \{e_{kB}, k = 1,2,3,\cdots\}.\; \forall k, i, j \cdots.$

1. The *Parametric Union*, denoted by $\bigcup$, of two parameter sets A *and* B is defined by

$A \bigcup B = \{e_{kA} \cup e_{k\mathbf{B}}, e_{iA}, e_{jB} \cdots\} \; \forall k, i, j \cdots.$

2. The *parametric intersection*, denoted by $\bigcap$, of two parameter sets A *and* B is defined as

$A \bigcap B = \{e_{kA} \cap e_{k\mathbf{B}}, k = 1,2,\cdots\}.$

Likewise $\neg A \bigcup \neg B$, $\neg A \bigcap \neg B$, etc., can be defined.

Note that $\bigcup$ and $\bigcap$ are specific to parameter sets and have no counterparts in classical set theory. As emphasized above, $\forall A, B; \forall i, k$ the terms such as $e_{iA} \cup e_{kB}$, $e_{iA} \cap e_{kB}$ or their negates are not eligible to appear as elements of $\bigcup$ and $\bigcap$, respectively, unless $i = k$. Besides, in union $\bigcup$, such terms appear if one of e_{iA} *and* e_{kB} does not exist but not in $\bigcap$. Note, however, that all ordered pairs of any two elements of the parameter set $\{e_{iA}, e_{kB}, \neg e_{iA}, \neg e_{kB}\}, \forall i, k$ are defined terms of $A \times B$, for all A, B. For example, let $E = \{e_1, e_2, e_3\}$, $A = \{e_{1A}, e_{2A}\}$ and $B = \{e_{1\mathbf{B}}, e_{3\mathbf{B}}\}$. Then

$A \bigcup B = \{e_{1A} \cup e_{1B}, e_{2A}, e_{3B}\},$

$A \bigcap B = \{e_{1A} \cap e_{1B}\},\; A \bigcup \neg A = \{e_{1A} \cup \neg e_{1A}, e_{2A} \cup \neg e_{2A}\}$

$\neg A \bigcup \neg B = \{\neg e_{1A} \cup \neg e_{1B}, \neg e_{2A}, \neg e_{3B}\},$

$\neg A \bigcap \neg B = \{\neg e_{1A} \cap \neg e_{1B}\}$, etc.

Semantically, the representation, for example $A\bigcup\neg A=\{e_{1A},e_{2A},\neg e_{1A},\neg e_{2A}\}$, legitimate in the classical set theory, is not legitimate in soft set context.

Proposition 2.4.2

(i) $\neg(\neg A)=A$

(ii) $\neg(A\bigcup B)=\neg A\bigcup\neg B$

(iii) $\neg(A\bigcap B)=\neg A\bigcap\neg B$

(iv) $A\bigcup A=A$; $A\bigcap A=A$

(v) $A\bigcup B=B\bigcup A$; $A\bigcap B=B\bigcap A$

(vi) $A\bigcup(B\bigcup C)=(A\bigcup B)\bigcup C$;
$A\bigcap(B\bigcap C)=(A\bigcap B)\bigcap C$

(vii) $A\bigcup(B\bigcap C)=(A\bigcup B)\bigcap(A\bigcup C$;
$A\bigcap(B\bigcup C)=(A\bigcap B)\bigcup(A\bigcap C$

(viii) $A\times(B\times C)=(A\times B)\times C$

Proofs follow by definitions given above.

Remark 2.4.1

As emphasized earlier,

$\neg(e_{kA}\cup e_{k\mathbf{B}})=\neg e_{kA}\cup\neg e_{kB}$ and $\neg e_{1A}\cap\neg e_{1B}=\neg e_{kA}\cap\neg e_{kB}$

need to hold when they appear in $\bigcup$ *and* $\bigcap$ of two parameter sets.

Definition 2.4.2 The Union of two Soft Sets

The *union* of two soft sets (F,A) *and* (G,B), denoted by $(F,A)\tilde{\bigcup}(G,B)$, is the soft set (H,C) where $C=A\bigcup B$, and $\forall e_k\in C$,

$H(e_k)=F(e_{kA})\cup G(e_{kB})$, $H(e_k)=F(e_{kA})$ *or* $G(e_{kB})$ according as $G(e_{kB})=\phi$ or $F(e_{kA})=\phi$ (see definition 2.4.1).

This is equivalent to the definition of *soft union* in the existing literature, but comparatively much elegant.

Definition 2.4.3 The Intersection of two Soft Sets

The Intersection of two soft sets (F,A) *and* (G,B), denoted by $(F,A)\tilde{\bigcap}(G,B)$, is the soft set (H,C) where $C=A\bigcap B\neq\phi$, and $\forall e_k\in C$, $H(e_k)=F(e_{kA})\cap G(e_{kB})$. This is equivalent to the *restricted intersection* $\tilde{\cap}_R$ of [1].

Definition 2.4.4 The Extended Intersection of two Soft Sets

The *extended intersection* of two soft sets (F,A) *and* (G,B), denoted by $(F,A)\tilde{\cap}_E\ (G,B)$, is the soft set (H,C) where $C = A \bigcup B$,
and $\forall e_k \in C$, $H(e_k) = F(e_{kA})$ *if* $G(e_{kB}) = \phi$,
$H(e_k) = G(e_{kB})$ *if* $F(e_{kA}) = \phi$, and
$H(e_k) = F(e_{kA}) \cap G(e_{kB})$ if both $F(e_{kA})$ *and* $G(e_{kB})$ are nonempty.
This is equivalent to the extended union of [1].

Definition 2.4.5 The Restricted Union of two Soft Sets

The *restricted union* of two soft sets (F,A) *and* (G,B), denoted by $(F,A)\tilde{\cup}_R\ (G,B)$, is the soft set (H,C) where $C = A \bigcap B \neq \phi$,
and $\forall e_k \in C$, $H(e_k) = F(e_{kA}) \cup G(e_{kB}), \forall k$.
This is equivalent to the definition the Definition of Restricted Union of [1].

Definition 2.4.6 The AND-Operation of two Soft Sets

The *AND-operation* of two soft sets (F,A) *and* (G,B), denoted by $(F,A) \wedge (G,B)$, is the soft set (H,C) where $C = A \times B$,
and $\forall e_{i,k} \in C$, $H(e_{i,k}) = F(e_{iA}) \cap G(e_{kB}), \forall i,k$. This is equivalent to the definition of *AND- Operation* of [1].

Definition 2.4.7 The OR-Operation of two Soft Sets

The *OR-operation* of two soft sets (F,A) *and* (G,B), denoted by $(F,A) \vee (G,B)$, is the soft set (H,C) where $C = A \times B$,
and $\forall e_{i,k} \in C$, $H(e_{i,k}) = F(e_{iA}) \cup G(e_{kB}), \forall i,k$. This is equivalent to the definition of *OR- Operation* of [1].

Definition 2.4.8 The Restricted Difference of two Soft Sets

The *restricted difference* of two soft sets (F,A) *and* (G,B), denoted by $(F,A) -_R (G,B)$, is the soft set (H,C) where $C = A \bigcap B \neq \phi$,
and $\forall e_k \in C$,
$H(e_k) = F(e_{kA}) \setminus G(e_{kB}), \forall k$.
This is equivalent to the definition of the *restricted difference* of soft sets of [1].

Proposition 2.4.3

(i) $(F,A)\,\tilde{\cup}\,(F,A)=(F,A)$

(ii) $(F,A)\,\tilde{\cap}\,(F,A)=(F,A)$

(iii) $(F,A)\,\tilde{\cup}\,(\bar{\phi},A)=(F,A)$

(iv) $(F,A)\,\tilde{\cap}\,(\bar{\phi},A)=\phi$

(v) $(F,A)\,\tilde{\cup}\,(U,A)=U_A$

(vi) $(F,A)\,\tilde{\cap}\,(U,A)=(F,A)$

(vii) $(F,A)\,\tilde{\cup}\,(F,A)^C=U_A$

(viii) $(F,A)\,\tilde{\cap}\,(F,A)^C=\phi_A$

(I x) $((F,A)\,\tilde{\cup}_R\,(G,B))^C=(F,A)^C\,\tilde{\cap}_R\,(G,B)^C$

(x) $((F,A)\,\tilde{\cap}_R\,(G,B))^C=(F,A)^C\,\tilde{\cup}_R\,(G,B)^C$

(xi) $((F,A)\,\tilde{\cup}\,(G,B))^C=(F,A)^C\,\tilde{\cap}_E\,(G,B)^C$

(xii) $((F,A)\,\tilde{\cap}_E\,(G,B))^C=(F,A)^C\,\tilde{\cup}\,(G,B)^C$

Proofs of some of these are straightforward. We shall outline proofs of specifically those results which have been found controversial in the literature of soft sets.

Proof of (iii)

$$(F,A)\,\tilde{\cup}\,(\bar{\phi},A)=(H,A\bigcup A)=(F,A),$$

Since

$$H(e_k)=F(e_k)\cup\bar{\phi}(e_k)\ ,\ \forall e_k\in A$$
$$=F(e_k)\,,\ \forall e_k\in A.$$

Note that the proposition (2.3) (iii) of [5] is counter-intuitive (see also [1, 10]).

Proof of (vii)

$$(F,A)\,\tilde{\cup}\,(F,A)^C=(F,A)\,\tilde{\cup}\,(F,\neg A)$$
$$=(F,A\bigcup\neg A)=U_A\text{, since}$$
$$F(e_k\cup\neg e_k)=F(e_k)\cup F(\neg e_k)=U_A\ ,\forall e_k\in A\,.$$

Proof of (ix)

$$((F,A)\,\tilde{\cup}_R\,(G,B))^C=(F,A)^C\,\tilde{\cap}_R\,(G,B)^C\,.$$

$LHS = (H, A \bigcap B)^C = (H, \neg(A \bigcap B)) = (H,\ \neg A \bigcap \neg B)$,

since $H(e_k) = F(\neg e_{kA}) \cap G(\neg e_{kB})$.

$RHS = (F, \neg A) \tilde{\cap}_R (G, \neg B) = (H,\ \neg A \bigcap \neg B).$

$Hence\ LHS = RHS$.

Note that $C = A \bigcap B \neq \phi$ for both $LHS\ and\ RHS$.

Proof of (x)

$((F, A) \tilde{\cap}_R (G, B))^C = (F, A)^C \tilde{\cup}_R (G, B)^C$.

$LHS = (H, A \bigcap B)^c = (H, \neg(A \bigcap B)) = (H,\ \neg A \bigcap \neg B).$

$RHS = (F, \neg A) \tilde{\cup}_R (G, \neg B) = (H, \neg A \bigcap \neg B).$

$Hence\ LHS = RHS$,

Note that $C = A \bigcap B \neq \phi$ for both $LHS\ and\ RHS$.

Proof of (xi)

$[(F, A) \tilde{\cup} (G, B)]^C = (F, A)^C \tilde{\cap}_E (G, B)^C$.

$LHS = [(F, A) \tilde{\cup} (G, B)]^C = [H, (A \bigcup B)]^C = [H, \neg(A \bigcup B)] = [H, (\neg A \bigcup \neg B)].$

$RHS = (F, A)^C \tilde{\cap}_E (G, B)^C = (F, \neg A) \tilde{\cap}_E (G, \neg B) = [(H, (\neg A \bigcup \neg B)].$

Hence $LHS = RHS$ and hence the proof.

Note that $C = A \bigcup B$ for both $LHS\ and\ RHS$.

Following the techniques developed in this paper it is not hard to see that all other results established in the literature [2, 9] can be similarly proved.

3. Concluding Remarks

The new foundation for soft sets developed in this paper is intuitively sound, perceptively compact, and encompassing extant theories of soft sets. In particular, since the proofs of various identities turn out to be extremely simple, it would be computationally efficient and hence better suited to applications.

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