Fuzzy Mean *e*-Open and *e*-Closed Sets

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Abstract

The notions of fuzzy mean *e* -open and *e* -closed sets is established. Moreover, some comparative study of these with other fuzzy mappings are investigated. Finally, we extend fuzzy mean *e* -open to fuzzy para *e* -open sets in fuzzy topology.

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1. Introduction

Fuzzy sets were established by Zadeh [10] and the perception of fuzzy topology instigated by Chang [2] in 1968. The ideas of fuzzy minimal (resp. maximal open) [3] sets explored in [3]. Subsequently the concepts of fuzzy mean open set investigated by Swaminathan [9]. On combining fuzzy mean open [9] and fuzzy paraopen open [4] sets, we extend the perception of fuzzy mean open (resp. closed) sets and from which we investigate some results.

The following terminologies "fuzzy *e*-open (resp.closed), fuzzy *e*-mean open(resp.closed), fuzzy minimal *e*-open(resp.maximal), fuzzyminimal *e*-closed set, (resp.maximal), fuzzy *e*-paraopen(resp.paraclosed) and fuzzy *e*-connected topological space respectively abbreviated as F*e*-O, F*e*-C, FME*e*-O, FME*e*-C, FMI*e*-O, FMA*e*-O, FMI*e*-C, FMA*e*-C, F*e*-PO, F*e*-PC and F*e*-CTS. Entire paper *F* stands for fuzzy topology (*F*, τ)".

2. Preliminaries

Definition 2.1. *A fuzzy subset* $\beta \in F$ *is said to be fuzzy regular open [1] if* $\beta = Int\,[Cl(\beta)]$

The union of all fuzzy regular open sets contained in fuzzy subset $\beta \in F$ is F *e* -interior of β .If $\beta = Int\delta(\beta)$ then fuzzy subset β is called F *e* -O [8] such that its complement is called F *e* -C (i.e, $\beta = Cl\delta(\beta)$).

Definition 2.2. [5] *A proper nonzero F e -O set* $\beta \in F$ *is called (i) FMI e -O if only F e -O sets contained in* β. *are* β *and* 0 *(ii)FMA e -O if only F e -O sets containing* β *are* 1 *and* β .

Definition 2.3. *A FO set* $\mu \in F$ *is said to be a FPO [4]set if it is neither FMIO nor FMAO set.*

3. Fuzzy *e*-Paraopen and *e*-Paraclosed Sets

Definition 3.1. *A F e -O set* $\zeta \subset F$ *which is neither FMI e -O nor FMA e -O set is said to be F e -PO set .*

Definition 3.2. *A F e -C set* $\alpha \subset F$ *is said to be a F e -PC set iff its complement* $1 - \alpha$ *is F e -PO set.*

Remark 3.1. The converse of the statement: Every F *e* -PO set (resp.F *e* -PC) is a FO set(resp.FC set). Need not to be true proven by following example.

Example 3.2.

Remark 3.3. Union (resp.intersection) of F *e* -PO (resp. F *e* -PC) sets need not be F *e* -PO

(resp. F *e* -PC) set.

Theorem 3.4. Let F be a FTS and α be a nonempty proper F *e* -PO subset of F , then ∃a FMI *e* -O set ζ with $\zeta < \alpha$.

Proof. Clearly $\zeta < \alpha$ as per the FMI *e* -O set definition.

Theorem 3.5. Let α be a nonempty proper F *e* -PO subset of a FTS F, then ∃ a ψ FMA *e* -O set with $\alpha < \psi$.

Proof. Clearly $\alpha < \psi$ as per the FMA *e* -O set definition.

Theorem 3.6. Suppose that $\digamma$ is a FTS, then

(i) $\varsigma \wedge \zeta = 0$ or $\zeta < \varsigma$ for any F *e* -PO ς and a FMI *e* -O set ζ . (ii) $\varsigma \vee \lambda = 1$ or $\varsigma < \lambda$ for any F *e* -PO ς and a FMA *e* -O set λ . (iii)Intersection of F *e* -PO sets is either F *e* -PO or FMI *e* -O set.

Proof. (i) For any F *e* -PO set ς and a FMI *e* -O open set ζ in $\digamma$. Then $\varsigma \wedge \zeta = 0$ or $\varsigma \wedge \zeta \neq 0$. If $\varsigma \wedge \zeta = 0$, then proof could be over. Assume $\varsigma \wedge \zeta \neq 0$. Then we write $\varsigma \wedge \zeta$ is a FO set and $\varsigma \wedge \zeta < \zeta$. Hence $\zeta < \varsigma$.

(ii) For any F *e* -PO set ς and a FMA *e* -O set ξ in $\digamma$. Then $\varsigma \vee \xi = 1$ or $\varsigma \vee \xi \neq 1$. If $\varsigma \vee \xi = 1$, then proof could be over. Assume $\varsigma \vee \xi \neq 1$. Clearly, $\varsigma \vee \gamma$ is a FO set and $\gamma < \varsigma \vee \gamma$. Hence γ is a FMA *e* -O set, $\varsigma \vee \gamma = \gamma$ implies $\varsigma < \gamma$.

(iii)Let ς and ξ be a F *e* -PO sets in $\digamma$. If $\varsigma \wedge \xi$ is a F *e* -PO set, then proof could be over. Suppose $\varsigma \wedge \xi$ is not a F *e* -PO set. By definition, $\varsigma \wedge \xi$ is a FMI *e* -O or FMA *e* -O set. If $\varsigma \wedge \xi$ is a FMI *e* -O set, then proof could be over. Suppose $\varsigma \wedge \xi$ is a FMA *e* -O set. Now $\varsigma \wedge \xi < \varsigma$ and $\varsigma \wedge \xi < \xi$ contradicting the fact that ς and ξ are F *e* -PO sets. Hence, $\varsigma \wedge \xi$ is not a FMA *e* -O set. (i.e.) $\varsigma \wedge \xi$ is a FMI *e* -O set.

Theorem 3.7. A subset λ of a FTS $\digamma$ is F *e* -PC iff it is neither FMA *e* -C nor FMI *e* –C set.

Proof. The complement of FMI *e* -O set and FMA *e* -O set are FMA *e* -C set and FMI *e* -C set respectively.

Theorem 3.8. Let λ be a nonempty F *e* -PC subset of a FTS $\digamma$. Then $\exists$ a FMI *e* -C set ψ with $\psi < \lambda$.

Proof. Clearly by FMI *e* -C set definition , it follows that $\psi < \lambda$.

Theorem 3.9. Suppose that λ is a nonempty F *e* -PC subset of FTS $\digamma$ then $\exists$ a FMA *e* -C set κ such that $\lambda < \kappa$.

Proof. Clearly by FMA *e* -C set definition, it follows that $\lambda < \kappa$.

Theorem 3.10. Suppose that $\digamma$ is a FTS then

(i) $\kappa \wedge \eta = 0$ or $\eta < \kappa$ for any F *e* -PC set κ and FMI *e* -C set η . (ii) $\kappa \vee \zeta = 1$ or $\kappa < \zeta$ for any F *e* -PC set κ and FMA *e* -C set ζ .

(iii) Intersection of F *e* -PC sets is either F *e* -PC or FMI *e* -C set.

Proof. (i) Suppose that κ is a F *e* -PC and η is a FMI *e* -C set in $\digamma$. Then $(1-\kappa)$ is F *e* -PO and $(1-\eta)$ is FMA *e* -O set in $\digamma$. Then by Theorem 3.6 (ii) $(1-\kappa) \vee (1-\eta) = \digamma$ or $(1-\kappa) < (1-\eta)$ implying $1-(\kappa \wedge \eta) = 1$ or $\eta < \kappa$. Hence, $\kappa \wedge \eta = 0$ or $\eta < \kappa$.

(ii) Suppose that κ is a F *e* -PC and ζ is a FMA *e* -C set in $\digamma$. Then $(1-\kappa)$ is F *e* -PO and $(1-\zeta)$ is FMI *e* -O sets in $\digamma$. Then by Theorem 3.6(i) $(1-\kappa) \wedge (1-\zeta) = 0$ or $1-\zeta < 1-\kappa$ implying $1-(\kappa \vee \zeta) = 0$ or $\kappa < \zeta$. Hence, $\kappa \vee \zeta = 1$ or $\kappa < \zeta$.

(iii)Suppose that κ and ξ is a F *e* -PC sets in $\digamma$. If $\kappa \wedge \xi$ is a F *e* -PC set, then proof could be over. Suppose $\kappa \wedge \xi$ is not a F *e* -PC set. Then clearly, $\kappa \wedge \xi$ is FMI *e* -C or FMA *e* -C set. Suppose $\kappa \wedge \xi$ is a FMI *e* -C set, then proof could be over. Suppose $\kappa \wedge \xi$ is a FMA *e* -C set. Now $\kappa < \kappa \wedge \xi$ and $\xi < \kappa \wedge \xi$ a contradiction for κ and ξ are F *e* -PC sets. Hence, $\kappa \wedge \xi$ is not a FMA *e* -C set. (i.e.) $\kappa \wedge \xi$ is a FMI *e* -C set.

4. Fuzzy Mean *e*-Open and *e*-Closed Sets

Definition 4.1. *A F e -O set* $\psi \subset \digamma$ *is said to be a FME e -O set if* $\exists$ $\omega 1$, $\omega 1 (\neq \psi)$ *two distinct proper F e -O sets such that* $\omega 1 < \psi < \omega 2$.

Remark 4.1. It could be understood from the succeding example that the union and intersection of FME *e* -O need not be FME *e* -O sets.

Example 4.2. Let $\digamma = \{x, y, z, w\}$. Then fuzzy sets

$\omega 1 = \{(0.5, x), (0.4, y), (0.4, z), (0.5, w)\}$;
$\omega 2 = \{(0.5, x), (0.4, y), (0.6, z), (0.5, w)\}$;
$\omega 3 = \{(0.5, x), (0.6, y), (0.4, z), (0.5, w)\}$

and $\omega 4 = \{(0.5, x), (0.6, y), (0.6, z), (0.5, w)\}$ of the fuzzy topology $\tau = \{0, \omega 1, \omega 2, \omega 3, \omega 4, 1\}$. Hence $\omega 2$ and $\omega 3$ are FME *e* -O sets but their union $\omega 2 \vee \omega 3 = \omega 4$ and intersection $\omega 2 \wedge \omega 3 = \omega 1$ are not FME *e* -O sets.

Definition 4.2. *A F e -C set* $\upsilon \subset \mathrm{F}$ *is said to be a FME e -C set if two F e -C sets* $\xi 1 \neq \xi 1 (\neq \upsilon)$ *such that* $\xi 1 < \upsilon < \xi 2$.

Definition 4.3. *A F e -O set* $\zeta \subset \mathrm{F}$ *which is neither FMI e -O nor FMA e -O set is said to be F e -PO set where its complement is known to be F e -PC set.*

Theorem 4.3. A F *e* -O set of a fts is a FME *e* -O set iff its complement is a FME *e* -C set.

Proof. By deploying definition 4.1 for any FME *e* -O set ψ in F we have $\omega 1 < \psi < \omega 2$

implying that $1 - \omega 2 < 1 - \psi < 1 - \omega 1$. Clearly $1 - \omega 2 \neq 0, 1 - \psi$ and $1 - \omega 1 \neq 1 - \psi, 1$. Hence $1 - \psi$ is a FME *e* -C set.

Conversly, Let $1 - \psi$ is a FME *e* -C set for any FME *e* -O set ψ in F . By definition 4.2, F *e* -C sets $\xi 1 \neq \neq 0, 1 - \psi$ and $\xi_2 \neq 1, 1 - \psi$ such that $\xi 1 < 1 - \psi < \xi 2$ implying that $1 - \xi 2 < \psi < 1 - \xi 1$. As $\xi 2 \neq 0$, ψ and $1 - \xi 1 \neq \psi, 1$; ψ is a FME *e* -O set.

Theorem 4.4. A proper F *e* -PO set is a FME *e* -O set and vice-e-versa.

Proof. The proof of necessary part is obvious by theorem 1.7 [9].

Conversely, let ψ be a proper FME *e* -O set in F . Then two F *e* -O sets $\zeta 1 \neq \zeta 2$ such that $\zeta 1 < \psi < \zeta 2$. Clearly ψ is neither FMI *e* -O nor FMA *e* -O set as $\zeta 1 \neq 0, \psi$ and $\zeta 2 \neq \psi, 1$. As $\psi \neq 0, 1$, ψ is a proper F *e* -PO set.

Theorem 4.5. A proper F *e* -PC set is a FME *e* -C set and vice-e-versa.

Proof. The proof of necessary part is obvious by theorem 1.10 [9].

Conversely, let ϑ be a proper FME *e* -C set in F . Then two F *e* -C sets $\upsilon 1 \neq \upsilon 2 \neq \vartheta$ such that $\upsilon 1 < \vartheta < \upsilon 2$. Clearly ϑ is neither a FMI *e* -C nor a FMA *e* -C set as $\upsilon 1 \neq 0, \vartheta$ and $\upsilon 2 \neq 1, \vartheta$. As $\vartheta \neq 0, 1$, ϑ is a proper F *e* -PC set.

Theorem 4.6. ([5]) Let F be a fts.

(i) If ζ is a FMI *e* -O and ξ is a F *e* -O sets in F , then $\zeta \wedge \xi = 0$ or $\zeta < \xi$. (ii)If ζ and κ are FMI *e* -O sets, then $\zeta \wedge \xi = 0$ or $\zeta = \xi$.

Theorem 4.7. ([5]) Let F be a fts.

(i) If ζ is a FMA *e* -O and ξ is a F *e* -O sets in F , then $\zeta \vee \xi = 1$ or $\xi < \zeta$. (ii)If ζ and κ are FMA *e* -O set, then $\zeta \vee \kappa = 1$ or $\zeta = \kappa$.

Theorem 4.8. If $\xi 1$ is a FMA *e* -O set and $\xi 2$ is a FMI *e* -O set of a fts F , then either $\xi 2 < \xi 1$ or F is fuzzy *e* – disconnected.

Theorem 4.9. Let a F *e* -CTS F contain a FMA *e* -O set $\zeta 2$, a FMI *e* -O set $\zeta 1 \neq \zeta 2$ and a proper F *e* -O set $\xi \neq \zeta 1, \zeta 2$. Then exactly one of the succeeding could be true on F :

(i) ξ is a FME *e* -O set with $\zeta 1 < \xi < \zeta 2$.

(ii) $\zeta 1 < 1 - \xi < \zeta 2$.

(iii) $\zeta 1 < \xi, \zeta 1 \vee \xi = 1$ and $\zeta 2 \wedge \xi \neq 0$.
(iv) $\xi < \zeta 2, \zeta 1 \wedge \zeta 2 = 0$ and $\zeta 1 \vee \zeta 2 \neq 1$.

Proof. By deploying theorem 4.8, a FMI *e* -O set $\zeta 1 < \zeta 2$ a FMA *e* -O set. This implies either $\zeta 1 < \xi$ or $\zeta 1 \wedge \xi = 0$ and $\xi < \zeta 2$ or $\zeta 2 \vee \xi = 1$. Hence the feasible combinations are (i) $\zeta 1 < \xi < \zeta 2$, (ii) $\zeta 1 \wedge \xi = 0$; $\zeta 2 \vee \xi = 1$, (iii) $\zeta 1 < \xi$; $\zeta 2 \vee \xi = 1$, (iv) $\zeta 1 \wedge \xi = 0$ and $\xi < \zeta 2$.

Clearly $\zeta 1 < 1 - \xi < \zeta 2$ if (ii) is true. Also, $0 \neq \zeta 1 < \zeta 1 \wedge \xi$ as $\zeta 1 < \zeta 2$ and (iii) is true. Again $\zeta 1 \vee \xi < \zeta 2 \neq 1$ as $\zeta 1 < \zeta 2$ and (iv) is true.

Case(I): As (i) and (ii) are true, then $\zeta 1 < \xi \vee (1 - \xi) < \zeta 2$ and $\zeta 1 < \xi \wedge (1 - \xi) < \zeta 2$. As $\zeta 1 < \xi \vee (1 - \xi) < \zeta 2$ $\zeta 1 < 1 < \zeta 2$ then $\zeta 2 = 1$, an absurd result.
Similarly, for $\zeta 1 < \xi \wedge (1 - \xi) < \zeta 2$ we get $\zeta 1 = 0$, an absurd result.

Case(II): As both (i),(iii) are true, then $\xi < \zeta2$ and $\zeta2 \vee \xi = 1$ gives $\zeta2 = 1$, an absurd result.

Case(III): As both (i),(iv) are true, then $\zeta1 < \xi$ and $\zeta1 \wedge \xi = 0$ gives $\zeta1 = 0$, an absurd result.

Case(IV): As both (ii),(iii) are true, then $\zeta1 < 1 - \xi$ and $\zeta1 < \xi$ gives $\zeta1 = 0$, an absurd result.

Case(V): As both (ii),(iv) are true, then $1 - \xi < \zeta2$ and $\xi < \zeta2$ gives $\zeta2 = 1$, an absurd result.

Case(VI): As both (iii),(iv) are true, then $\zeta1 < \xi < \zeta2$, $\zeta2 \vee \xi = 1$ and $\zeta1 \wedge \xi = 0$. Clearly $\zeta2 = 1$ as $\xi < \zeta2$ and $\zeta2 \vee \xi = 1$ a contradiction. Simlilarly, we get $\zeta1 = 0$ as $\zeta1 < \xi$ and $\zeta1 \wedge \xi = 0$ a contradiction.

Theorem 4.10. Let a F *e* -CTS $\digamma$ contain a FMA *e* -C set $\upsilon2$, a FMI *e* -C set $\upsilon1$ with $\upsilon1 \neq \upsilon2$ and a proper F *e* -C set $\beta \neq \upsilon1, \upsilon2$ .Then any one of them could be true on $\digamma$:

(i) β is a FME *e* -C set such that $\upsilon1 < \beta < \upsilon2$.

(ii) $\upsilon1 < 1 - \beta < \upsilon2$.

(iii) $\beta < \upsilon2$, $\upsilon1 \wedge \beta = 0$ and $\upsilon1 \vee \beta \neq 1$

(iv) $\upsilon1 < \beta$, $\upsilon2 \vee \beta = 1$ and $\upsilon2 \wedge \beta \neq 0$.

Proof. Let $\digamma$ be a F *e* -CTS containing $1 - \upsilon1$, a FMA *e* -O set; $1 - \upsilon2$ a FMI *e* -O set and $1 - \beta$ a proper F *e* -O set such that $1 - \upsilon1 \neq 1 - \upsilon2$ and $1 - \beta \neq 1 - \upsilon1, 1 - \upsilon2$. By deploying Theorem 4.9, any one of them could be true:

(i) For any FME *e* -O set $1-\beta$ we get $\upsilon1 < \beta < \upsilon2$ as $1-\upsilon2 < 1-\beta < 1-\upsilon1$, Hence, β is a FME *e* -C set.
(ii) Clearly, $\upsilon1 < 1 - \beta < \upsilon2$. as $1 - \upsilon2 < 1 - (1 - \beta) < 1 - \upsilon1$
(iii) If $1-\upsilon2 < 1-\beta$; $(1-\upsilon1) \vee (1-\beta) = 1$ and $(1-\upsilon1) \wedge (1-\beta) \neq 0$ then $\beta < \upsilon2$; $\upsilon1\wedge\beta = 0$ and $\upsilon1 \vee \beta \neq 1$.
(iv) If $1-\beta < 1-\upsilon1$; $(1-\upsilon2)\wedge(1-\beta) = 0$ and $(1-\upsilon2) \vee (1-\beta) \neq 1$ then $\upsilon1 < \beta$; $\upsilon2\vee\beta = 1$ and $\upsilon2 \wedge \beta \neq 0$.

Theorem 4.11. Let two distinct FMA *e* -O and FME *e* -O sets in $\digamma$. Then intersection of

the two FMA *e* -O sets is nonzero.

Proof. By deploying theorem 4.7, $\kappa1 \vee \kappa2 = 1$ for any two distinct FMA *e* -O sets $\kappa1$ and $\kappa1$ in $\digamma$. Let σ be a FME *e* -O set in a fts $\digamma$ then σ is neither FMA *e* -O nor FMI *e* –O such that, $\sigma \neq \kappa1, \kappa2$ and $\sigma \neq 1$. By Theorem 4.7, we get $\sigma \gneqq \kappa1$ or $\sigma \vee \kappa1 = 1$ and $\sigma \gneqq \kappa2$ or $\sigma \vee \kappa2 = 1$. The feasible combinations are (i) $\sigma \gneqq \kappa1$ and $\sigma \gneqq \kappa2$, (ii) $\sigma \gneqq \kappa1$ and $\sigma \vee \kappa2 = 1$, (iii) $\sigma \gneqq \kappa2$ and $\sigma \vee \kappa1 = 1$ and (iv) $\sigma \vee \kappa1 = 1$ and $\sigma \vee \kappa2 = 1$. Case (I): Obviously true.

Case (II): By assuming $\sigma \wedge \kappa2 \neq 0$,we have to prove that $\kappa1 \wedge \kappa2 \neq 0$. As $\sigma \wedge \kappa2 \neq 0$ and $\sigma \gneqq \kappa1$, then *there exists* $x\alpha \in \kappa1$ such that $x\alpha \neq \kappa2$. Since $\sigma \vee \kappa2 = 1$, $x\alpha \in \kappa2$. So, $\kappa1 \wedge \kappa2 \neq 0$.

Case (III): Similar to previous case.

Case (IV): As $\sigma \vee \kappa1 = 1$; $\sigma \vee \kappa2 = 1$ imply that $\sigma \vee (\kappa1 \wedge \kappa2) = 1$ then $\sigma = 1$ if $\kappa1 \wedge \kappa2 = 0$. Again $\kappa1 \wedge \kappa2 \neq 0$ as $\sigma \neq 1$.

Theorem 4.12. Let two distinct FMI *e* -O and FME *e* -O sets in $\digamma$. Then union of the two

FMI *e* -O sets is not equal to 1.

Proof. By deploying theorem 4.6,we have $\kappa1 \vee \kappa2 = 0$ for any two distinct FMI *e* -O sets $\kappa1$, $\kappa2$ in a fts $\digamma$. Let σ being a FME *e* -O set in $\digamma$, then it is neither FMA *e* -O nor FMI *e* -O. Hence, $\sigma \neq \kappa1, \kappa2$ and $\sigma \neq 0, 1$. By theorem 4.6, we get $\kappa1 \gneqq \sigma$ or $\sigma \wedge \kappa1 = 0$ and $\kappa2 \gneqq \sigma$ or $\sigma \wedge \kappa2 = 0$. The possible combinations are (I) $\kappa1 \gneqq \sigma$ and $\kappa2 \gneqq \sigma$, (II) $\kappa1 \gneqq \sigma$ and $\sigma \wedge \kappa2 = 0$, (III) $\kappa2 \gneqq \sigma$ and $\sigma \wedge \kappa1 = 0$ and (IV) $\sigma \wedge \kappa1 = 0$ and $\sigma \wedge \kappa2 = 0$ as $\sigma \neq 1$.

Case I: Obviously, if $\kappa1 \gneqq \sigma$ and $\kappa2 \gneqq \sigma$ then $\kappa1 \vee \kappa2 \neq 1$.

Case II: Suppose that $\sigma \vee \kappa2 \neq 1$. Since $\kappa1 \gneqq \sigma$, then there exists $x\alpha \in \sigma$ such that $x\alpha \neq \kappa1$.

As $\sigma \wedge \kappa2 = 0$; clearly $x\alpha \neq \kappa2$. Hence, $x\alpha \neq \kappa1, \kappa2$ imply that $\kappa1 \vee \kappa2 \neq 1$.
Case III: Similar to previous case.

Case IV: As $\sigma \wedge \kappa1 = 0$; $\sigma \wedge \kappa2 = 0$ imply that $\sigma \wedge (\kappa1 \vee \kappa2) = 0$ then $\sigma = 0$ if $\kappa1 \vee \kappa2 =$.

Clearly κ1 ∨ κ2 ≠ 1 as σ ≠ 0 .

"On combining theorems 4.11 and 4.12, we get theorems 4.13 and 4.14 and the proofs succeeded by theorems 4.11 and 4.12."

Theorem 4.13. Let κ and ϱ be distinct FMA *e* -C and FME *e* -C sets in a FTS respectively. Then the intersection of two FMA *e* -O sets is nonzero.

Theorem 4.14. Let ζ and ξ be distinct FMI *e* -C and FME *e* -C sets in a FTS respectively. Then the union of two FMI *e* -C sets is not equal to 1.

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