Math. & Comput. Sci., 7(3) (2026), 97–104

Online: ISSN 2717-2708

Mathematics and computational Scinces

Journal Homepage: http://mcs.qut.ac.ir/mcs

Algorithm for data filling of an incomplete Turiyam soft set based on parameter association

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Abstract

In real world scenarios, data is often missing or unavailable due to various reasons. This incomplete or missing data can affect the reliability of decision-making models. In this paper, we defined the concept of an Incomplete Turiyam Soft Set, which is a Turiyam Soft Set with missing or unavailable data. To understand the relationships between the parameters of the Incomplete Turiyam Soft Set, we introduced the concepts of Consistent and Inconsistent Association between the parameters. We defined new terms such as Consistent Association Number, Consistent Association Degree, Inconsistent Association Number, and Inconsistent Association Degree to measure these associations. Finally, we presented a Data Filling Algorithm to estimate the missing values based on the parameter associations. Furthermore, a real-life example was included to show how the proposed method could be applied in decision-making situations.

Keywords: Turiyam Soft Set, Incomplete Turiyam Soft Set, Parameter Association, Consistent Association Number, Consistent Association Degree, Inconsistent Association Number, Inconsistent Association Degree

2020 MSC: 03E72, 94D05, 03E75

1. Introduction

In many real-world problems, especially those involving human behavior, decisions, or vague environments, we dont always get clear answers. In such cases, Neutrosophic Sets [7] introduced by Smarandache talks about truth, falsehood, and indeterminacy all at once. While Fuzzy Set [8] provide only truth membership, and Intuitionistic Fuzzy Set [1] extend this by including both truth and falsity memberships, Neutrosophic Set gave space for Indeterminacy along with Truth and Falsity memberships.

But there are cases where even indeterminacy itself isn't enough. We needed a framework that could capture not only what we know and what we dont but also something beyond, a sort of fourth-dimensional awareness. Prem Kumar Singh defined Turiyam Set [4, 5, 6] as a generalisation of Neutrosophic Set - which helps us to express what lies beyond the known, the unknown, and even the unknowable. Turiyam Set involves Liberalisation values along with Truth, Indeterminacy and Falsity membership

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doi: doi.org/10.30511/mcs.2026.2077693.1616

Received: 14 November 2025 Accepted: 02 June 2026

values. We incorporated this Turiyam Set into Soft Set and had defined Turiyam Soft Set [2] and studied their properties.

While previous works in Neutrosophic Soft Sets have proposed Data Filling Algorithm [3] to handle missing or incomplete information, they did not address situations where a single parameter might have a Consistent Association with some parameters and an Inconsistent Association with others. Recognizing this limitation, we extended the data filling approach to the Turiyam Soft Set framework by defining an improved data filling algorithm that considers these mixed associations, allowing us to effectively identify and fill in missing data. This enhancement strengthens the applicability of Turiyam Soft Sets in handling complex, uncertain missing data.

2. Preliminaries

Definition 2.1. [5] A Turiyam set A on U has the form,

$$A = \{< u, t_A(u), i_A(u), f_A(u), l_A(u) >: u \in U\}$$

where $t_A(u) : U \to [0,1], i_A(u) : U \to [0,1], f_A(u) : U \to [0,1] and l_A(u) : U \to [0,1]$ denote the truth value, the indeterminacy value, the falsity value and the Turiyam state (or liberal) value for each $u \in U$, correspondingly by which $t_A(u), i_A(u), f_A(u) and l_A(u)$ satisfies the condition $0 \leqslant t_A(u) + i_A(u) + f_A(u) + l_A(u) \leqslant 4, \ \forall \ u \in U$.

Definition 2.2. [2] A Turiyam Soft Set $(F, A)_L$ on the universe U over the set of parameters E is defined as,

$$(F, A)_L = \{(e, F(e)) : e \in A, F(e) \in T(U)\}$$

Where, $T(U)$ denotes the set of all Turiyam Sets of U and F is a mapping from $F : A \to T(U); \ A \subset E$.

3. Incomplete Turiyam Soft Set

Definition 3.1. A Turiyam Soft Set $(F, A)_L$ over U,

$$(F, A)_L = (e_j, F(e_j)) : e_j \in A, F(e_j) \in T(U)$$

is called an Incomplete Turiyam Soft Set if there exists $(e_j, F(e_j))$ is unknown for some $u_i \in U$. When one of the values of the 4-tuple $(t_{F(e_j)}(u_i), i_{F(e_j)}(u_i), f_{F(e_j)}(u_i), \ell_{F(e_j)}(u_i))$, is missing we consider it all as unknown values and denote it by $(*, *, *, *)$.
where, $T(U)$ denotes the set of Turiyam Sets of U, F is a mapping from $F : A \to T(U), \ \ A \subset E, \ \ i = 1, 2, ..., n$ and $j = 1, 2, ..., m$.

Example 3.2. Let U be the set of candidates. $U = \{u_1, u_2, u_3, u_4\}$ and the parameter set be $E = \{e_1, e_2, e_3\}$ where e_1= Qualified, e_2= Experienced and e_3= Team Player.

A hiring panel rates candidates on these criteria, but for some candidates, the data is incomplete. The Tabular representation of the Incomplete Turiyam Soft Set $(F, E)_L$ over U can be represented as Table 1.

Where the liberalisation value is whether this specific parameter has positively impacted the candidate's career, such as earned him a reward or salary hike. We explore the parameter associations in the context of Turiyam Soft Set. In the above example, we can see that between the parameters e_1 and e_2, theres a consistent association. Between the parameters e_1 and e_3, theres an inconsistent association.

Definition 3.3. Using these associations between the parameters e_k and e_l, when the data for $F(e_k)$ is missing, we can fill the missing data from the corresponding values of $F(e_l)$. Let,

$$\begin{aligned} U_{kl} = \big\{u \in U \,\big|\, &\big(t_{F(e_k)}(u), i_{F(e_k)}(u), f_{F(e_k)}(u), \ell_{F(e_k)}(u)\big) \neq (*, *, *, *), \\ \text{and} \quad &\big(t_{F(e_l)}(u), i_{F(e_l)}(u), f_{F(e_l)}(u), \ell_{F(e_l)}(u)\big) \neq (*, *, *, *), \quad \forall \quad e_k, e_l \in E\big\} \end{aligned}$$

That is, U_{kl} the collection of objects that have known values for both parameters e_k and e_l.

Table 1: Incomplete Turiyam Soft Set $(F, E)_L$

U/E	e_1	e_2	e_3
u_1	(0.4,0.5,0.3,0.6)	(0.2,0.4,0.6,0.8)	(0.3,0.6,0.2,0.8)
u_2	(0.6,0.3,0.1,0.5)	$(*,*,*,*)$	(0.7,0.3,0.2,0.4)
u_3	$(*,*,*,*)$	(0.3,0.5,0.1,0.9)	(0.3,0.2,0.5,0.8)
u_4	(0.3,0.6,0.7,0.2)	(0.4,0.5,0.8,0.2)	$(*,*,*,*)$

Example 3.4. Consider Example 3.2, for the parameter e_2,

$$U_{31} = \{u_1, u_2\}$$

$$U_{32} = \{u_1, u_3\}$$

Definition 3.5. The Consistent Association Number between the parameters e_k and e_l is denoted by CaN_{kl} and is defined by,

$$CaN_{kl} = \Big\{u \in U \,\Big|\, (t_{F(e_k)}(u) = t_{F(e_l)}(u), i_{F(e_k)}(u) = i_{F(e_l)}(u), \\ f_{F(e_k)}(u) = f_{F(e_l)}(u), \ell_{F(e_k)}(u) = \ell_{F(e_l)}(u)), \quad \forall \quad e_k, e_l \in E\Big\}$$

where $|\cdot|$ denotes the cardinality of a set.

Definition 3.6. The Consistent Association Degree between the parameters e_k and e_l is denoted by CaD_{kl} and is defined as,

$$CaD = \frac{CaN}{|U_{kl}|}$$

where, $|U_{kl}|$ denotes the cardinality of a set U_{kl} and $U_{kl} > 0$. It is clear that, the value of CaD_{kl} is in [0,1].

Example 3.7. From Examples 3.2 and 3.4,

$$CaN_{31} = |\{\ \}| = 0 \quad \text{and} \quad CaN_{32} = |\{\ \}| = 0$$

$$CaD_{31} = \frac{CaN_{31}}{|U_{31}|} = \frac{0}{2} = 0 \quad \text{and} \quad CaD_{32} = \frac{CaN_{32}}{|U_{32}|} = \frac{0}{2} = 0$$

Definition 3.8. The Inconsistent Association Number between the parameters e_k and e_l is denoted by $ICaN_{kl}$ and is defined by,

$$ICaN_{kl} = \Big\{u \in U \,\Big|\, (t_{F(e_k)}(u) \neq t_{F(e_l)}(u) \text{ or } i_{F(e_k)}(u) \neq i_{F(e_l)}(u) \text{ or} \\ f_{F(e_k)}(u) \neq f_{F(e_l)}(u) \text{ or } \ell_{F(e_k)}(u) \neq \ell_{F(e_l)}(u)), \quad \forall \quad e_k, e_l \in E\Big\}$$

where $|\cdot|$ denotes the cardinality of a set.

Definition 3.9. The Inconsistent Association Degree between the parameters e_k and e_l is denoted by $ICaD_{kl}$ and is defined as,

$$ICaD = \frac{ICaN}{|U_{kl}|}$$

where, $|U_{kl}|$ denotes the cardinality of a set U_{kl} and $U_{kl} > 0$. It is clear that, the value of $ICaD_{kl}$ is in [0,1].

Example 3.10. From Examples 3.2 and 3.4,

$$ICaN_{31} = |\{u_1, u_2\}| = 2 \quad \text{and} \quad ICaN_{32} = |\{u_1, u_3\}| = 2$$

$$ICaD_{31} = \frac{ICaN_{31}}{|U_{31}|} = \frac{2}{2} = 1 \quad \text{and} \quad ICaD_{32} = \frac{ICaN_{32}}{|U_{32}|} = \frac{2}{2} = 1$$

Definition 3.11. The Association Degree between the parameters e_k and e_l is denoted by D_{kl} and is defined by,

$$D_{kl} = max\{CaD_{kl}, ICaD_{kl}\}$$

Example 3.12. From Examples 3.7 and 3.10,

$$D_{31} = max\{CaD_{31}, ICaD_{31}\} = max\{0, 1\} = 1$$

$$D_{32} = max\{CaD_{32}, ICaD_{32}\} = max\{0, 1\} = 1$$

Remark 3.13. If $CaD_{kl} > ICaD_{kl}$, then $D_{kl} = CaD_{kl}$, indicating that most objects in U_{kl} show consistent values between the parameters e_k and e_l. On the other hand, if $CaD_{kl} < ICaD_{kl}$, then $D_{kl} = ICaD_{kl}$, suggesting that inconsistency dominates between the two parameters.
If both values are equal, that is, $CAD_{kl} = ICAD_{kl}$ this reflects the weakest level of association between the parameters e_k and e_l.

Theorem 3.14. *For the parameters* e_k *and* e_l, $D_{kl} \geqslant 0.5, \quad \forall \quad k, l$.

Proof. For any parameters e_k and e_l, from the definitions of CaD_{kl} and $ICaD_{kl}$, we have,

$$CaD_{kl} + ICaD_{kl} = 1$$

Therefore, at least one of CaD_{kl} and $ICaD_{kl}$ is more than 0.5, namely,

$$D_{kl} = max\{CaD_{kl}, ICaD_{kl}\} \geqslant 0.5$$

□

Definition 3.15. Let E be the set of parameters and $e_k \in E$. Then, the Maximal Association Degree of parameter e_k is denoted by MD_k and is defined by max

$$MD_k = \max_{l} D_{kl}$$

4. Algorithm for Data Filling of Incomplete Turiyam Soft Set

Step 1: Input the Incomplete Turiyam Soft Set in Tabular form with the missing data represented by $(*, *, *, *)$.
Step 2: Find all the parameters e_k for which data is missing.
Step 3: For all the parameters e_k for which data is missing, compute D_{kl} for $j = 1, 2, ..., m$ and $k \neq l$.
Step 4: Compute Maximal Association Degree MD_k for all the parameters e_k for which data is missing.
Step 5: Find those parameters e_l which has the maximal association degree MD_k with the parameter e_k.
Step 6: In case of Consistent Association between the parameter e_k and e_ls $(k, l = 1, 2, ..., m)$,

$$\left((t_{F(e_k)}(u))_C, (i_{F(e_k)}(u))_C, (f_{F(e_k)}(u))_C, (\ell_{F(e_k)}(u))_C\right)$$

$$= \left(\max_{l} t_{F(e_l)}(u), \max_{l} i_{F(e_l)}(u), \max_{l} f_{F(e_l)}(u), \max_{l} \ell_{F(e_l)}(u)\right)$$

In case of Inconsistent Association between the parameter e_k and e_ls $(k, l = 1, 2, ..., m)$,

$$\left((t_{F(e_k)}(u))_I, (i_{F(e_k)}(u))_I, (f_{F(e_k)}(u))_I, (\ell_{F(e_k)}(u))_I\right)$$

$$= \left(1-\max_l t_{F(e_k)}(u), 1-\max_l i_{F(e_k)}(u), 1-\max_l f_{F(e_k)}(u), 1-\max_l \ell_{F(e_k)}(u)\right)$$

Step 7:

Case (i): If the parameter e_k has only Consistent Association between e_ls for $k, l = 1, 2, ..., m$ then,

$$\left((t_{F(e_k)}(u))_C, (i_{F(e_k)}(u))_C, (f_{F(e_k)}(u))_C, (\ell_{F(e_k)}(u))_C\right)$$
$$= \left(t_{F(e_k)}(u), i_{F(e_k)}, f_{F(e_k)}(u), \ell_{F(e_k)}(u)\right)$$

Case (ii): If the parameter e_k has only Inconsistent Association between e_ls for $k, l = 1, 2, ..., m$ then,

$$\left((t_{F(e_k)}(u))_I, (i_{F(e_k)}(u))_I, (f_{F(e_k)}(u))_I, (\ell_{F(e_k)}(u))_I\right)$$

$$= \left(t_{F(e_k)}(u), i_{F(e_k)}, f_{F(e_k)}(u), \ell_{F(e_k)}(u)\right)$$

Case (iii): If the parameter e_k, has Consistent Association with some e_ls and has Inconsistent Association with other e_ls then,

$$\left(t_{F(e_k)}(u), i_{F(e_k)}(u), f_{F(e_k)}(u), \ell_{F(e_k)}(u)\right)$$
$$= \Big(\frac{(t_{F(e_k)}(u))_C + (t_{F(e_l)}(u))_I}{2}, \frac{(i_{F(e_k)}(u))_C + (i_{F(e_l)}(u))_I}{2},$$
$$\frac{(f_{F(e_k)}(u))_C + (f_{F(e_l)}(u))_I}{2}, \frac{(\ell_{F(e_k)}(u))_C + (\ell_{F(e_l)}(u))_I}{2}\Big)$$

Example 4.1. Consider $U = \{u_1, u_2, u_3, u_4, u_5\}$ be the five hostels under consideration and $E = \{e_1, e_2, e_3, e_4, e_5, e_6\}$ be the set of parameters under consideration, where e_1=Affordable, e_2=Clean, e_3=Near College, e_4=Good food, e_5=Wi-fi facility and e_6=Peaceful environment.
Were taking a students considerations for choosing the hostel. The degree to which the parameter helps her focus better on studies and overall academic success is taken as the Liberalisation value. It is represented as a table,

Table 2: Student's Consideration as Incomplete Turiyam Soft Set

U/E	e_1	e_2	e_3	e_4	e_5	e_6
u_1	(0.9,0.1,0.1,0.8)	(0.8,0.1,0.1,0.7)	(0.9,0.1,0.1,0.9)	(0.7,0.2,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.6,0.1,0.3,0.6)
u_2	(0.7,0.2,0.1,0.7)	**(*, *, *, *)**	(0.8,0.1,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.7,0.2,0.1,0.7)	(0.5,0.3,0.2,0.6)
u_3	(0.5,0.3,0.2,0.5)	(0.4,0.3,0.3,0.4)	(0.8,0.1,0.1,0.9)	**(*, *, *, *)**	(0.8,0.1,0.1,0.9)	(0.7,0.2,0.1,0.7)
u_4	(0.6,0.2,0.2,0.6)	(0.3,0.2,0.4,0.3)	(0.6,0.3,0.1,0.6)	(0.5,0.4,0.1,0.6)	(0.7,0.1,0.2,0.8)	**(*, *, *, *)**
u_5	(0.8,0.1,0.1,0.8)	(0.7,0.1,0.2,0.7)	**(*, *, *, *)**	(0.8,0.1,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.6,0.2,0.2,0.7)

a) For the parameter e_2:

$U_{21} = \{u_1, u_3, u_4, u_5\}$
$U_{23} = \{u_1, u_3, u_4\}$
$U_{24} = \{u_1, u_4, u_5\}$
$U_{25} = \{u_1, u_3, u_4, u_5\}$
$U_{26} = \{u_1, u_3, u_5\}$

$CaN_{21} = |\{\ \}| = 0$ and $CaD_{21} = 0$

$$ICaN_{21} = |\{u_1, u_3, u_4, u_5\}| = 4 \quad \text{and} \quad ICaD_{21} = \frac{ICaN_{21}}{|U_{21}|} = \frac{4}{4} = 1$$

$$D_{21} = max\{CaD_{21}, ICaD_{21}\} = max\{0, 1\} = 1$$

Similarly, $D_{23} = 1, D_{24} = 1, D_{25} = 1, D_{26} = 1$
The Maximal Association Degree of the parameter e_2 is,

$$MD_2 = \max_{l} D_{2l} = max\{D_{21}, D_{23}, D_{24}, D_{25}, D_{26}\}$$

$$MD_2 = \{1, 1, 1, 1, 1\} = 1$$

In the similar way, $MD_3 = 1, MD_4 = 1, MD_6 = 1$.
The Association Degree table of the Incomplete Turiyam Soft Set is,

Table 3: Association Degree table

	e_1	e_2	e_3	e_4	e_5	e_6
e_2	1	-	1	1	1	1
e_3	1	1	-	1	0.75	1
e_4	0.75	1	1	-	0.75	1
e_6	1	1	1	1	1	-

- The parameters e_1, e_3, e_4, e_5 and e_6 have Maximal Association Degree D_{21}, D_{23}, D_{24}, D_{25} and D_{26} respectively with e_2.
- The parameters e_1, e_2, e_4 and e_6 have the Maximal Association Degree D_{31}, D_{32}, D_{34} and D_{36} respectively with the parameter e_3.
- The parameters e_2, e_3 and e_6 have the Maximal Association Degree D_{42}, D_{43} and D_{46} respectively with the parameter e_4.
- The parameters e_1, e_2, e_3, e_4 and e_5 have the Maximal Association Degree D_{42}, D_{43} and D_{46} respectively with the parameter e_6.

For the parameter e_2, there is a Consistent Association with the parameter e_6 and there is an Inconsistent Association with the parameters e_1, e_3, e_4 and e_5. For Consistent Association,

$$\Big((t_{F(e_2)}(u_2))_C, (i_{F(e_2)}(u_2))_C, (f_{F(e_2)}(u_2))_C, (\ell_{F(e_2)}(u_2))_C\Big)$$

$$= \Big(max(t_{F(e_6)}(u_2)), max(i_{F(e_6)}(u_2)), max(f_{F(e_6)}(u_2)), max(\ell_{F(e_6)}(u_2))\Big)$$

$$= \Big(t_{F(e_6)}(u_2), i_{F(e_6)}(u_2), f_{F(e_6)}(u_2), \ell_{F(e_6)}(u_2)\Big)$$

$$= (0.5, 0.3, 0.2, 0.6)$$

For Inconsistent Association,

$$((t_{F(e_2)}(u_2))_I, (i_{F(e_2)}(u_2))_I, (f_{F(e_2)}(u_2))_I (\ell_{F(e_2)}(u_2))_I)$$

$$= \Big(1-\max(t_{F(e_1)}(u_2), t_{F(e_3)}(u_2), t_{F(e_4)}(u_2), t_{F(e_5)}(u_2)),$$
$$1-\max(\iota_{F(e_1)}(u_2), \iota_{F(e_3)}(u_2), \iota_{F(e_4)}(u_2), \iota_{F(e_5)}(u_2)),$$
$$1-\max(f_{F(e_1)}(u_2), f_{F(e_3)}(u_2), f_{F(e_4)}(u_2), f_{F(e_5)}(u_2)),$$
$$1-\max(\ell_{F(e_1)}(u_2), \ell_{F(e_3)}(u_2), \ell_{F(e_4)}(u_2), \ell_{F(e_5)}(u_2))\Big)$$
$$= \Big(1-\max(0.7, 0.8, 0.7, 0.7), 1-\max(0.2, 0.1, 0.2, 0.2), 1-\max(0.1, 0.1, 0.1, 0.1), 1-\max(0.7, 0.8, 0.8, 0.7)\Big)$$
$$= (1-0.8, 1-0.2, 1-0.1, 1-0.8)$$
$$= (0.2, 0.8, 0.9, 0.2)$$

Since the parameter e_2, has a Consistent Association with the parameter e_6 and Inconsistent Association with the parameters e_1, e_3, e_4 and e_5, the missing data is filled by,

$$(t_{F(e_2)}(u_2), \iota_{F(e_2)}(u_2), f_{F(e_2)}(u_2), \ell_{F(e_2)}(u_2))$$
$$= \Big(\frac{(t_{F(e_2)}(u_2))_C + (t_{F(e_2)}(u_2))_I}{2}, \frac{(\iota_{F(e_2)}(u_2))_C + (\iota_{F(e_2)}(u_2))_I}{2},$$
$$\frac{(f_{F(e_2)}(u_2))_C + (f_{F(e_2)}(u_2))_I}{2}, \frac{(\ell_{F(e_2)}(u_2))_C + (\ell_{F(e_2)}(u_2))_I}{2}\Big)$$
$$= \left(\frac{0.5+0.2}{2}, \frac{0.3+0.8}{2}, \frac{0.2+0.9}{2}, \frac{0.6+0.2}{2}\right)$$
$$= \left(\frac{0.7}{2}, \frac{1.1}{2}, \frac{1.1}{2}, \frac{0.8}{2}\right)$$
$$= (0.3, 0.5, 0.5, 0.4)$$

We can find all other missing values in the similar way. The tabular representation of the Complete Turiyam Soft Set or simply the Turiyam Soft Set is:

Table 4: Complete Turiyam Soft Set

U/E	e_1	e_2	e_3	e_4	e_5	e_6
u_1	(0.9,0.1,0.1,0.8)	(0.8,0.1,0.1,0.7)	(0.9,0.1,0.1,0.9)	(0.7,0.2,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.6,0.1,0.3,0.6)
u_2	(0.7,0.2,0.1,0.7)	**(0.3,0.5,0.5,0.4)**	(0.8,0.1,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.7,0.2,0.1,0.7)	(0.5,0.3,0.2,0.6)
u_3	(0.5,0.3,0.2,0.5)	(0.4,0.3,0.3,0.4)	(0.8,0.1,0.1,0.9)	**(0.4,0.4,0.4,0.4)**	(0.8,0.1,0.1,0.9)	(0.7,0.2,0.1,0.7)
u_4	(0.6,0.2,0.2,0.6)	(0.3,0.2,0.4,0.3)	(0.6,0.3,0.1,0.6)	(0.5,0.4,0.1,0.6)	(0.7,0.1,0.2,0.8)	**(0.5,0.5,0.6,0.6)**
u_5	(0.8,0.1,0.1,0.8)	(0.7,0.1,0.2,0.7)	**(0.5,0.4,0.4,0.5)**	(0.8,0.1,0.1,0.8)	(0.7,0.2,0.1,0.8)	(0.6,0.2,0.2,0.7)

5. Conclusion

Incomplete information, missing or unavailable data in a Turiyam Soft Set restricts its effective use in real-world applications. To enhance the usefulness of the Turiyam Soft Set in such situations, we proposed a data filling approach where the missing values are estimated using the association degree between the parameters. The proposed algorithm was explained with an example of a real-life situation, and the results showed that the relationship between the parameters can be effectively used to fill missing data.

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