# Total Causal Effect Calculation for Fuzzy Cognitive Maps (TCEC-FCM) - Pseudocodes

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In this document, we present the pseudocode for two variants of the TCEC-FCM algorithm, as proposed in our recent research: **'Tyrovolas, M., Kallimanis, N. D., & Stylios, C. (2024). Causal Effect Analysis in Large-Scale Fuzzy Cognitive Maps for Explainable Artificial Intelligence (XAI).'** Specifically, we detail the implementation of the TCEC-FCM algorithm employing a linear search approach (TCEC-FCM-LS) and a binary search strategy (TCEC-FCM-BS).

**Algorithm 1:** *"Total Causal Effect Calculation for Fuzzy Cognitive Maps"* Algorithm with Linear Search (TCEC-FCM-LS)

**Input:** $n$, number of concepts; $\mathbf{W_{n\times n}}$, weight matrix.
**Output:** $\mathbf{T}_{\text{eff}}$, vector of total causal effects.

/* Extract and sort non-zero weights and their indices */
$\mathcal{W}_{nz} \leftarrow \{(i, j, w_{ij}) \mid w_{ij} \in W, w_{ij} \neq 0\}$
$\mathcal{W}_{sorted} \leftarrow \text{sortDescending}(\{w_{ij} \mid (i, j, w_{ij}) \in \mathcal{W}_{nz}\})$ // $\mathcal{W}_{sorted} \in \mathbb{R}^{e\times 1}$ where $e$ is the number of non-zero weights
/* Initialize $\mathbf{T}_{\text{eff}}$ */
$\mathbf{T}_{\text{eff}} \leftarrow [0]_{n\times 1}$
**for** $C_i \leftarrow 1$ **to** $n-1$ **do**
    /* Initialize a copy of the FCM with isolated concepts */
    $\mathbf{W}_{\text{copy}} \leftarrow [0]_{n\times n}$
    **foreach** $(i, j, w_{ij}) \in \mathcal{W}_{sorted}$ **do**
        /* Update $\mathbf{W}_{\text{copy}}$ for the current weight */
        $\mathbf{W}_{\text{copy}}[i][j] \leftarrow w_{ij}$
        /* BFS for reachability to $C_n$ */
        reachableConcepts $\leftarrow \text{BFS}(\mathbf{W}_{\text{copy}}, C_i, C_n)$
        **if** $C_n \in$ *reachableConcepts* **then**
            $\mathbf{T}_{\text{eff}}[C_i] \leftarrow w_{ij}$
            **break**
    **if** $\mathbf{T}_{eff}[C_i] = 0$ **then**
        $\mathbf{T}_{\text{eff}}[C_i] \leftarrow 0$ // No path found
**return** $\mathbf{T}_{\text{eff}}$

**Algorithm 2:** *"Total Causal Effect Calculation for Fuzzy Cognitive Maps"* Algorithm with Binary Search (TCEC-FCM-BS)

**Input:** $n$, number of concepts; $\mathbf{W_{n\times n}}$, weight matrix.
**Output:** $\mathbf{T}_{\text{eff}}$, vector of total causal effects.

`// Extract and sort non-zero weights and their indices`
$\mathcal{W}_{nz} \leftarrow \{(i, j, w_{ij}) \mid w_{ij} \in W, w_{ij} \neq 0\}$
$\mathcal{W}_{sorted} \leftarrow \text{sortDescending}(\{w_{ij} \mid (i, j, w_{ij}) \in \mathcal{W}_{nz}\})$ `//` $\mathcal{W}_{sorted} \in \mathbb{R}^{e\times 1}$ `where` $e$ `is the number of non-zero weights`
`// Initialize` $\mathbf{T}_{\text{eff}}$
$\mathbf{T}_{\text{eff}} \leftarrow [0]_{n\times 1}$
**for** $C_i \leftarrow 1$ **to** $n-1$ **do**
    `/* Init binary search vars */`
    exIdxs $\leftarrow \emptyset$, pathFound $\leftarrow$ false
    upperIndex $\leftarrow 1$, midIndex $\leftarrow 1$
    lowerIndex $\leftarrow$ length($\mathcal{W}_{\text{sorted}}$)
    **while** $upperIndex - lowerIndex \geq 1$ **do**
        exIdxs $\leftarrow$ exIdxs $\cup$ {midIndex}
        `/* FCM copy for weights subset */`
        $\mathbf{W}_{\text{copy}} \leftarrow [0]_{n\times n}$
        **for** $idx \leftarrow 1$ **to** $midIndex$ **do**
            $(i, j, w_{ij}) \leftarrow \mathcal{W}_{\text{sorted}}[idx]$
            $\mathbf{W}_{\text{copy}}[i][j] \leftarrow w_{ij}$
        `/* BFS for reachability to` $C_n$ `*/`
        reachableConcepts $\leftarrow$ BFS($\mathbf{W}_{\text{copy}}, C_i, C_n$)
        **if** $C_n \in reachableConcepts$ **then**
            $\mathbf{T}_{\text{eff}}[C_i] \leftarrow \mathcal{W}_{\text{sorted}}$[midIndex]
            lowerIndex $\leftarrow$ midIndex
            pathFound $\leftarrow$ true
        **else**
            upperIndex $\leftarrow$ midIndex
        midIndex $\leftarrow$ Round $\left(\frac{\text{upperIndex}+\text{lowerIndex}}{2}\right)$
        `/* Check for convergence */`
        **if** $(upperIndex - lowerIndex) = 1$ ***and*** $midIndex \in examinedIndices$ **then**
            **break**
    **if** ***not*** *pathFound* **then**
        $\mathbf{T}_{\text{eff}}[C_i] \leftarrow 0$ `// No path found`
**return** $\mathbf{T}_{\text{eff}}$