

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 work: '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 original TCEC-FCM algorithm and a simplified variant, termed TCEC-FCM-LS, that uses linear search.

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}_{eff} , vector of total causal effects.

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/* Extract and sort non-zero weights and their indices */
1  $\mathcal{W}_{nz} \leftarrow \{(i, j, w_{ij}) \mid w_{ij} \in W, w_{ij} \neq 0\}$ 
2  $\mathcal{W}_{sorted} \leftarrow \text{sortDescending}(\{w_{ij} \mid (i, j, w_{ij}) \in \mathcal{W}_{nz}\})$  //  $\mathcal{W}_{sorted} \in \mathbb{R}^{e \times 1}$ 
   where  $e$  is the number of non-zero weights

/* Initialize  $\mathbf{T}_{\text{eff}}$  */
3  $\mathbf{T}_{\text{eff}} \leftarrow [0]_{n \times 1}$ 

4 for  $C_i \leftarrow 1$  to  $n - 1$  do
    /* Initialize a copy of the FCM with isolated concepts */
    5  $\mathbf{W}_{\text{copy}} \leftarrow [0]_{n \times n}$ 
    6 foreach  $(i, j, w_{ij}) \in \mathcal{W}_{sorted}$  do
        /* Update  $\mathbf{W}_{\text{copy}}$  for the current weight */
        7  $\mathbf{W}_{\text{copy}}[i][j] \leftarrow w_{ij}$ 
        /* BFS for reachability to  $C_n$  */
        8  $\text{reachableConcepts} \leftarrow \text{BFS}(\mathbf{W}_{\text{copy}}, C_i, C_n)$ 
        9 if  $C_n \in \text{reachableConcepts}$  then
            10  $\mathbf{T}_{\text{eff}}[C_i] \leftarrow w_{ij}$ 
            11 break
    12 if  $\mathbf{T}_{\text{eff}}[C_i] = 0$  then
        13  $\mathbf{T}_{\text{eff}}[C_i] \leftarrow 0$  // No path found

14 return  $\mathbf{T}_{\text{eff}}$ 

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Algorithm 2: Total Causal Effect Calculation for Fuzzy Cognitive Maps (TCEC-FCM)

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

// Extract and sort non-zero weights and their indices

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1  $\mathcal{W}_{nz} \leftarrow \{(i, j, w_{ij}) \mid w_{ij} \in W, w_{ij} \neq 0\}$ 
2  $\mathcal{W}_{sorted} \leftarrow \text{sortDescending}(\{w_{ij} \mid (i, j, w_{ij}) \in \mathcal{W}_{nz}\})$  //  $\mathcal{W}_{sorted} \in \mathbb{R}^{e \times 1}$ 
   where  $e$  is the number of non-zero weights
// Initialize  $\mathbf{T}_{\text{eff}}$ 
3  $\mathbf{T}_{\text{eff}} \leftarrow [0]_{n \times 1}$ 
4 for  $C_i \leftarrow 1$  to  $n - 1$  do
    /* Init binary search vars */
    5  $\text{exIdxs} \leftarrow \emptyset, \text{pathFound} \leftarrow \text{false}$ 
    6  $\text{upperIndex} \leftarrow 1, \text{midIndex} \leftarrow 1$ 
    7  $\text{lowerIndex} \leftarrow \text{length}(\mathcal{W}_{sorted})$ 
    8 while  $\text{upperIndex} - \text{lowerIndex} \geq 1$  do
    9      $\text{exIdxs} \leftarrow \text{exIdxs} \cup \{\text{midIndex}\}$ 
        /* FCM copy for weights subset */
        10  $\mathbf{W}_{\text{copy}} \leftarrow [0]_{n \times n}$ 
        11 for  $idx \leftarrow 1$  to  $\text{midIndex}$  do
        12      $(i, j, w_{ij}) \leftarrow \mathcal{W}_{sorted}[idx]$ 
        13      $\mathbf{W}_{\text{copy}}[i][j] \leftarrow w_{ij}$ 

        /* BFS for reachability to  $C_n$  */
        14  $\text{reachableConcepts} \leftarrow \text{BFS}(\mathbf{W}_{\text{copy}}, C_i, C_n)$ 
        15 if  $C_n \in \text{reachableConcepts}$  then
        16      $\mathbf{T}_{\text{eff}}[C_i] \leftarrow \mathcal{W}_{sorted}[\text{midIndex}]$ 
        17      $\text{lowerIndex} \leftarrow \text{midIndex}$ 
        18      $\text{pathFound} \leftarrow \text{true}$ 
        19 else
        20      $\text{upperIndex} \leftarrow \text{midIndex}$ 
        21  $\text{midIndex} \leftarrow \text{Round}(\frac{\text{upperIndex} + \text{lowerIndex}}{2})$ 
        /* Check for convergence */
        22 if  $(\text{upperIndex} - \text{lowerIndex}) = 1$  and  $\text{midIndex} \in \text{exIdxs}$  then
        23     break
    24 if not  $\text{pathFound}$  then
    25      $\mathbf{T}_{\text{eff}}[C_i] \leftarrow 0$  // No path found
26 return  $\mathbf{T}_{\text{eff}}$ 

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