STRUCTURAL IDENTIFICATION AND COMPARISON OF INTELLIGENT MOBILE LEARNING ENVIRONMENT

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Abstract: *This paper proposes a methodology using graph theory, matrix algebra and permanent function to compare different architecture (structure) design of intelligent mobile learning environment. The current work deals with the development/selection of optimum architecture (structural) model of iMLE. This can be done using the criterion as discussed in the paper.*

Key words: *intelligent mobile learning environment; system structure; graph theory; matrix approach; variable permanent function (VPF)*

1. Introduction

An ***iMLE*** system architecture is represented as a system consisting of five subsystems, which affect properties and performance of finished ***iMLE*** product. This five-subsystem ***iMLE*** is modeled as a multinomial, a permanent function **[Upadhyay and Agarwal, 2007]**. Different ***iMLE*** systems developed using different subsystems and technologies will result in structure and interaction changes. This leads to different number of terms in different groups and subgroups of their permanent.

A variable permanent system structure matrix (**VPSSM-** ***iMLE***) '**Vp**' of ***SSG*** of ***iMLE*** with $\mathbf{e_{ij}} = \mathbf{e_{ji}}$ in Figure 1 is written as:

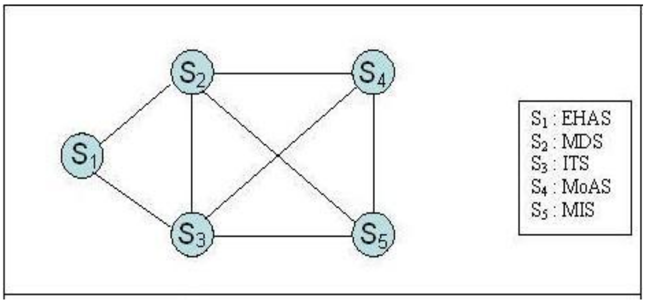

Figure 1. System Structure Graph of ***iMLE***

$$\begin{array}{ccccccl} & 1 & 2 & 3 & 4 & 5 & \text{Subsystems} \end{array}$$

$$V_p = \begin{bmatrix} S_1 & e_{12} & e_{13} & 0 & 0 \\ e_{12} & S_2 & e_{23} & e_{24} & e_{25} \\ e_{13} & e_{23} & S_3 & e_{34} & e_{35} \\ 0 & e_{24} & e_{34} & S_4 & e_{45} \\ 0 & e_{25} & e_{35} & e_{45} & S_5 \end{bmatrix} \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \qquad (1)$$

The VPF- ***iMLE*** for matrix is written as:

Per(**Vp**) =

$$S_1S_2S_3S_4S_5 + [e_{12}^2S_3S_4S_5 + e_{13}^2S_2S_4S_5 + e_{23}^2S_1S_4S_5 + e_{24}^2S_1S_3S_5 + e_{25}^2S_1S_3S_4 + e_{34}^2S_1S_2S_5 + e_{35}^2S_1S_2S_4 + e_{45}^2S_1S_2S_3]$$
$$+[2e_{12}e_{23}e_{31}S_4S_5 + 2e_{23}e_{34}e_{42}S_1S_5 + 2e_{23}e_{35}e_{52}S_1S_4 + 2e_{24}e_{45}e_{52}S_1S_3 + 2e_{34}e_{45}e_{53}S_1S_2]$$
$$+\{[2e_{23}e_{34}e_{45}e_{52}S_1 + 2e_{23}e_{35}e_{54}e_{42}S_1 + 2e_{24}e_{43}e_{35}e_{52}S_1 + 2e_{12}e_{24}e_{43}e_{31}S_5 + 2e_{12}e_{25}e_{53}e_{31}S_4] + [e_{13}^2e_{45}^2S_2 + e_{24}^2e_{35}^2S_1$$
$$+e_{25}^2e_{13}^2S_4 + e_{24}^2e_{13}^2S_5 + e_{23}^2e_{45}^2S_1 + e_{25}^2e_{34}^2S_1 + e_{12}^2e_{45}^2S_3 + e_{12}^2e_{34}^2S_5 + e_{12}^2e_{35}^2S_4]\}$$
$$+\{[2e_{12}^2e_{34}e_{45}e_{53} + 2e_{45}^2e_{12}e_{23}e_{31} + 2e_{13}^2e_{24}e_{45}e_{52}] + [2e_{12}e_{24}e_{45}e_{53}e_{31} + 2e_{12}e_{25}e_{54}e_{43}e_{31}]\} \qquad (2)$$

The physical /graphical representation of permanent expression for ***iMLE*** is shown in Figure 2.

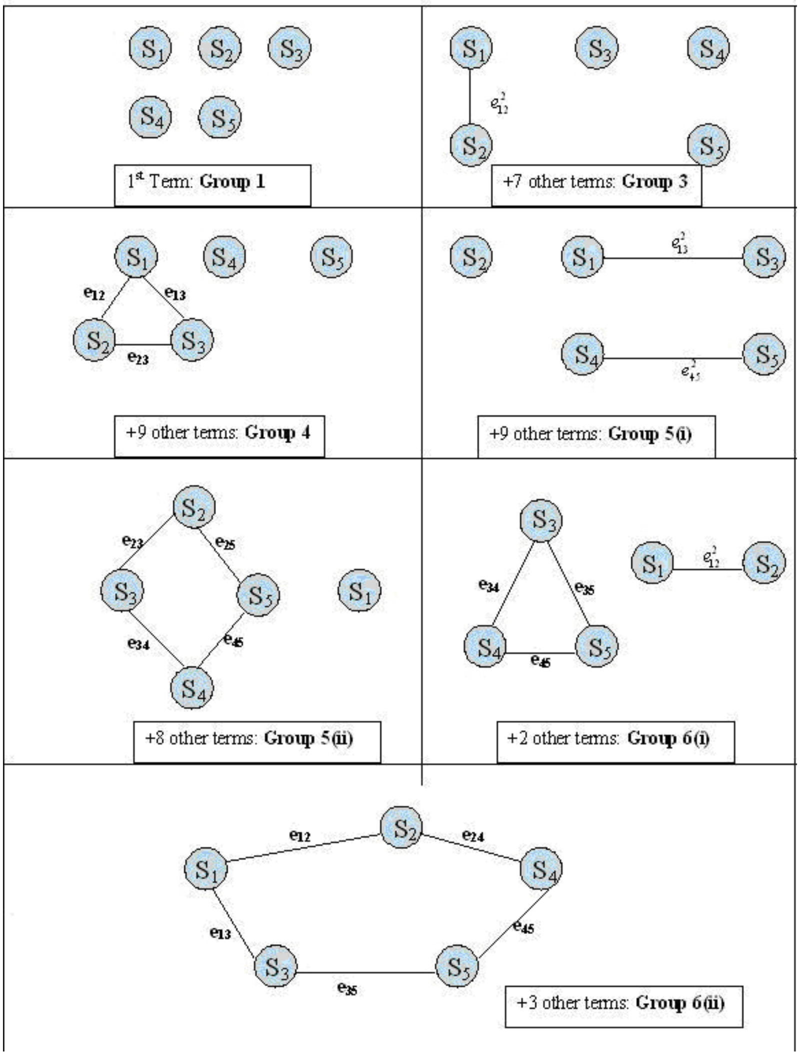

Figure 2. Graphical/Physical representation of Permanent Function Expression for ***iMLE***

2. Structural identification and comparison of systems

An ***iMLE*** system architecture is represented as a system consisting of five subsystems, which affect properties and performance of finished ***iMLE*** product. This five-subsystem ***iMLE*** is modeled as a multinomial, a permanent function. The similarity or dissimilarity in the structure between two ***iMLE*** systems is obtained by comparing their permanents. Using the proposed methodology, the identification of ***iMLE*** system architecture and its comparison with other ***iMLE*** system architecture is based on the analysis carried out with the help of **VPF- *iMLE***. Two ***iMLE*** system architectures are similar from subsystems and its interactions viewpoint only if their digraphs are isomorphic. Two ***iMLE*** system architecture digraphs are isomorphic if they have identical **VPF- *iMLE***. This means that the set of number of terms in each grouping/sub-grouping of two ***iMLE*** systems is the same. Based on this, an ***iMLE*** identification set for any product is written as:

$$\left[\left(M_1/M_2/M_3/M_4/M_{51}+M_{52}/M_{61}+M_{62}/...\right)\right] \quad (3)$$

Where M_i represents the structural property of a system. It can be interpreted as the total number of terms in i^th^ grouping, M_{ij} represents the total number of terms in the j^th^ subgroup of i ^th^ grouping. In case there is no sub-grouping, the M_{ij} is the same as M_i ; the sub-groupings are arranged in decreasing order of size (i.e., number of elements in a loop). In general, two ***iMLE*** products may not be isomorphic from the viewpoint of architecture of subsystems and interactions among subsystems. A comparison is also carried out on the basis of the coefficient of similarity. The coefficient is derived from the structure, i.e., VPF-***iMLE*** and it compares two ***iMLE*** products or a set of ***iMLE*** products on the basis of similarity or dissimilarity. If the value of distinct terms in the j ^th^ sub-grouping of the i ^th^ grouping of **VPF- *iMLE*** of two ***iMLE*** products under consideration are denoted by M_{ij} and M'_{ij}, then two criteria are proposed as follows [**Liu et al., 2004**]: The coefficient of similarity and dissimilarity are calculated using number of terms only.

Criterion 1: The coefficient of dissimilarity C_{d-1} based on criterion 1 is proposed as:

$$C_{d-1} = \frac{1}{Y_1}\sum_i\sum_j \psi_{ij} \quad (4)$$

where $Y_1 = \max\left[\sum_i\sum_i\left|M_{ij}\right| and \sum_i\sum_i\left|M'_{ij}\right|\right]$

When sub-groupings are absent $M_{ij} = M_i \; and \quad M'_{ij} = M'_i \; and$ $\psi_{ij} = \left|M_{ij} - M'_{ij}\right|$ when the sub-groupings exists and $\psi_{ij} = \left|M_i - M'_i\right|$, when the sub-groupings are absent. Criterion 1 is based on the sum of the difference in number of terms in different subgroups and groups of **VPF- *iMLE*** of two structurally distinct iMLE architecture. There may be a case when some $\sum_i\sum_j \psi_{ij}$ is zero though two systems are structurally different. This situation may arise when some of the differences are positive while some other differences are negative such that $\sum_i \sum_j \psi_{ij}$ become zero. To improve the differentiating power, another criterion is proposed.

Criterion 2: The coefficient of dissimilarity C_{d-2} is proposed as:

$$C_{d-2} = \frac{1}{Y_2} \sum_i \sum_j \psi'_{ij} \tag{5}$$

Where $Y_2 = \max\left[\sum_i \sum_i \left(M_{ij}\right)^2 and \sum_i \sum_i \left(M'_{ij}\right)^2 \right]$

When sub-groupings are absent $M_{ij} = M_i \; and \; M'_{ij} = M'_i \; and$ $\psi'_{ij} = \left|M_{ij}^2 - M'^2_{ij}\right|$ when the sub-groupings exists and $\psi'_{ij} = \left|M_i^2 - M'^2_i\right|$, when the sub-groupings are absent.

Criterion 2 is based on the sum of the squares of the difference in number of terms in different sub-groups and groups of **VPF-** ***iMLE*** of two structurally distinct ***iMLE*** architecture. It shows that ψ'_{ij} (criterion 2) is much larger than ψ_{ij} (criterion 1). To increase further the differentiating power another criterion 3 is proposed.

Criterion 3: The coefficient of dissimilarity C_{d-3} based on criterion one is proposed

$$C_{d-3} = \left[\frac{1}{Y_3} \sqrt{\sum_i \sum_j \psi_{ij}} \right] \tag{6}$$

Where ψ_{ij} the same as is described in criterion 1 and

$$Y_3 = \max\left[\sqrt{\sum_i \sum_i \left|M_{ij}\right|} and \sqrt{\sum_i \sum_i \left|M'_{ij}\right|} \right]$$

When sub-groupings are absent $M_{ij} = M_i \; and \; M'_{ij} = M'_i$. Criterion 3 is derived from criterion 1.

Criterion 4: The coefficient of dissimilarity C_{d-4} based on criterion two is proposed

$$C_{d-4} = \left[\frac{1}{Y_3} \sqrt{\sum_i \sum_j \psi'^2_{ij}} \right] \tag{7}$$

Where ψ'_{ij} is the same as is described in criterion 2 and

$$Y_4 = \max\left[\sqrt{\sum_i \sum_i \left(M_{ij}\right)^2} and \sqrt{\sum_i \sum_i \left(M'_{ij}\right)^2} \right]$$

When sub-groupings are absent $M_{ij} = M_i \; and \; M'_{ij} = M'_i$. Criterion 4 is derived from criterion 2. This can further increase the differentiating power. Using above equations the coefficient of similarity is given as

$$C_{m-1} = 1 - C_{d-1}; C_{m-2} = 1 - C_{d-2}; C_{m-3} = 1 - C_{d-3}; C_{m-4} = 1 - C_{d-4} \tag{8}$$

Where C_{m-1}, C_{m-2}, C_{m-3} and C_{m-4} are the coefficient of similarity between two *iMLE* architectures under consideration based on criterion 1, criterion 2, criterion 3 and criterion 4.

Using above-mentioned criteria, comparison of two or family of ***iMLE*** system architectures is carried out. Two ***iMLE*** architectures are isomorphic or completely similar from a structural point of view, if structural identification set for the two systems are exactly the same. This means the number of terms/ items in each grouping/ sub-grouping are exactly the same. The structural identification set equation (3) for the system shown in Figure 8 is obtained by considering its structure graph and **VPF-** ***iMLE*** as **/1/8/(2*5)/(2*5+9)/(2*3+2*2)/.**

It may be noted that the coefficient of similarity and dissimilarity lies in the range between 0 and 1. If two ***iMLE*** architectures are isomorphic or completely similar, their coefficient of similarity is 1 and the coefficient of dissimilarity is 0. Similarly, if two ***iMLE*** architectures are completely dissimilar, their coefficient of similarity is 0 and the coefficient of dissimilarity is 1.

3. Illustrative example

Two given intelligent mobile learning environment systems can be compared using the coefficient of similarity/dissimilarity. To illustrate this, another possible permanent function is considered. This illustrative permanent function is obtained after substituting the terms containing element $\mathbf{e_{12}}$ equals to zero. This implies no connection between subsystems 1 and 2. Because, it can be considered that mobile dimension system is not dependent on environment and human aspect system. A variable permanent system structure matrix (**VPSSM-** ***iMLE***) '**Vp**'' of ***SSG*** of ***iMLE*** after substituting $\mathbf{e_{12}}$ to zero with $\mathbf{e_{ij}} = \mathbf{e_{ji}}$ in Figure 1 is written as:

$$
\begin{array}{c} \\ V_p = \end{array}
\begin{array}{c}
\begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \text{ Subsystems} \\
\left[\begin{array}{ccccc}
S_1 & 0 & e_{13} & 0 & 0 \\
0 & S_2 & e_{23} & e_{24} & e_{25} \\
e_{13} & e_{23} & S_3 & e_{34} & e_{35} \\
0 & e_{24} & e_{34} & S_4 & e_{45} \\
0 & e_{25} & e_{35} & e_{45} & S_5
\end{array}\right]
\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array}
\end{array}
\quad (9)
$$

The VPF- ***iMLE*** for matrix is written as:

Per(Vp') =

$$
\begin{aligned}
& S_1S_2S_3S_4S_5 + [e_{13}^2S_2S_4S_5 + e_{23}^2S_1S_4S_5 + e_{24}^2S_1S_3S_5 + e_{25}^2S_1S_3S_4 + e_{34}^2S_1S_2S_5 + e_{35}^2S_1S_2S_4 + e_{45}^2S_1S_2S_3] \\
& +[2e_{23}e_{34}e_{42}S_1S_5 + 2e_{23}e_{35}e_{52}S_1S_4 + 2e_{24}e_{45}e_{52}S_1S_3 + 2e_{34}e_{45}e_{53}S_1S_2] \\
& +\{[2e_{23}e_{34}e_{45}e_{52}S_1 + 2e_{23}e_{35}e_{54}e_{42}S_1 + 2e_{24}e_{43}e_{35}e_{52}S_1] + [e_{13}^2e_{45}^2S_2 + e_{24}^2e_{35}^2S_1 \\
& +e_{25}^2e_{13}^2S_4 + e_{24}^2e_{13}^2S_5 + e_{23}^2e_{45}^2S_1 + e_{25}^2e_{34}^2S_1]\} \\
& +\{[2e_{13}^2e_{24}e_{45}e_{52}]\}
\end{aligned}
\quad (10)
$$

The physical /graphical representation of permanent expression for ***iMLE*** is shown in Figure 3.

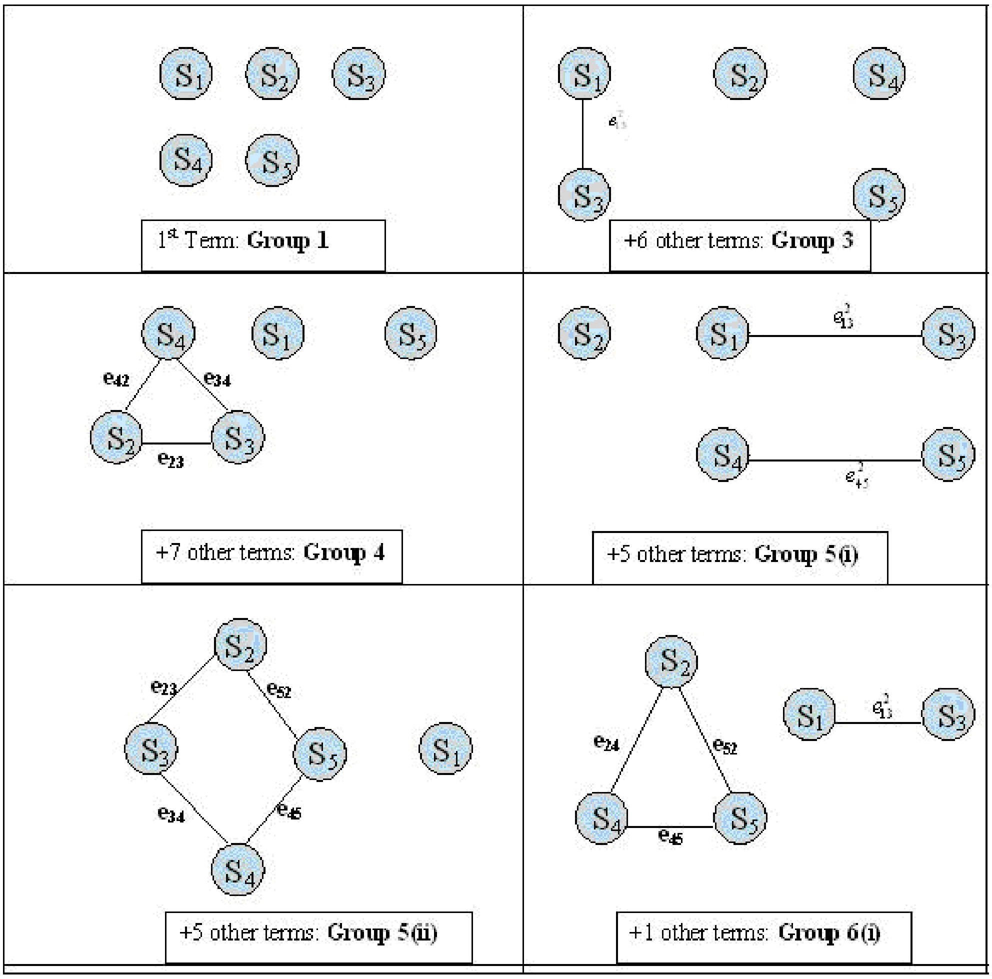

Figure 3. Graphical/ Physical representation of Permanent Function Expression for ***iMLE***

The number of terms of various grouping and sub groupings for both the system is shown below:

The coefficients of similarity/dissimilarity for these two systems are calculated by using four different criteria and are given below:

Group No.	1st ***iMLE*** Architecture	2nd ***iMLE*** Architecture
1	1	1
2	0	0
3	8	7
4	2 * 5 = 10	2 * 4 = 8
5	2 * 5 + 9 = 19	2 * 3 + 6 = 12
6	2 * 3 + 2 * 2 = 10	2 * 1 = 2
Total	48	30

The structure identification set for 2nd ***iMLE*** Architecture can be written as **/1/2/(2*4)/(2*3+6)/(2*1)/**. Similarly the matrices and graph of the new 2nd ***iMLE*** architecture can be developed.

The coefficients of similarity/dissimilarity for these two systems are calculated by using three different criteria and are given below:

Criterion 1:

$$\sum_i \sum_j |M_{ij}| = 1 + 0 + 8 + 10 + (10 + 9) + (6 + 4) = 48$$

$$\sum_i \sum_j |M'_{ij}| = 1 + 0 + 7 + 8 + (6 + 6) + 2 = 30$$

$$\sum_i \sum_j \psi_{ij} = (1-1) + (0-0) + (8-7) + (10-8) + (10-6) + (9-6) + (6-2) + 4 = 18$$

$$Y_1 = 48$$

$$C_{d-1} = \frac{18}{48} = 0.375$$

Criterion 2:

$$\sum_i \sum_j \left(M_{ij}\right)^2 = 1^2 + 0^2 + 8^2 + 10^2 + (10^2 + 9^2) + (6^2 + 4^2) = 398$$

$$\sum_i \sum_j \left(M'_{ij}\right)^2 = 1^2 + 0^2 + 7^2 + 8^2 + (6^2 + 6^2) + 2^2 = 190$$

$$\sum_i \sum_j \psi'_{ij} = (1^2 - 1^2) + (0^2 - 0^2) + (8^2 - 7^2) + (10^2 - 8^2) + (10^2 - 6^2) + (9^2 - 6^2) + (6^2 - 2^2) + 4^2 = 196$$

$$Y_2 = 398$$

$$C_{d-2} = \frac{196}{398} = 0.492$$

Criterion 3:

$$\sqrt{\sum_i \sum_j |M_{ij}|} = \sqrt{(1 + 0 + 8 + 10 + (10 + 9) + (6 + 4))} = \sqrt{48} = 6.928$$

$$\sqrt{\sum_i \sum_j |M'_{ij}|} = \sqrt{(1 + 0 + 7 + 8 + (6 + 6) + 2)} = \sqrt{30} = 5.477$$

$$\sqrt{\sum_i \sum_j \psi_{ij}} = \sqrt{((1-1) + (0-0) + (8-7) + (10-8) + (10-6) + (9-6) + (6-2) + 4)}$$

$$\sqrt{\sum_i \sum_j \psi_{ij}} = \sqrt{18} = 4.242$$

$$Y_3 = 6.928$$

$$C_{d-3} = \left[\frac{4.242}{6.928}\right] = 0.612$$

Criterion 4:

$$\sqrt{\sum_i \sum_j \left(M_{ij}\right)^2} = \sqrt{\left(1^2 + 0^2 + 8^2 + 10^2 + (10^2 + 9^2) + (6^2 + 4^2)\right)} = \sqrt{398} = 19.949$$

$$\sqrt{\sum_i \sum_j \left(M'_{ij}\right)^2} = \sqrt{\left(1^2 + 0^2 + 7^2 + 8^2 + (6^2 + 6^2) + 2^2\right)} = \sqrt{190} = 13.78$$

$$\sqrt{\sum_i \sum_j \psi'^2_{ij}} = \sqrt{\left((1^2 - 1^2) + (0^2 - 0^2) + (8^2 - 7^2) + (10^2 - 8^2) + (10^2 - 6^2) + (9^2 - 6^2) + (6^2 - 2^2) + 4^2\right)}$$

$$\sqrt{\sum_i \sum_j \psi'^2_{ij}} = \sqrt{196} = 14$$

$$Y_4 = 19.949$$

$$C_{d-4} = \left[\frac{14}{19.949}\right] = 0.701$$

This shows that criterion 4 has much larger value as compared to criterion 1, 2 and 3. This demonstrates larger differentiating capacity of criterion 4 over criterion 1, 2 and 3.

$$C_{m-1} = 1 - C_{d-1}$$
$$C_{m-1} = 1 - 0.375$$
$$C_{m-1} = 0.625$$
$$C_{m-2} = 1 - C_{d-2}$$
$$C_{m-2} = 1 - 0.492$$
$$C_{m-2} = 0.508$$
$$C_{m-3} = 1 - C_{d-3}$$
$$C_{m-3} = 1 - 0.612$$
$$C_{m-3} = 0.388$$
$$C_{m-4} = 1 - C_{d-4}$$
$$C_{m-4} = 1 - 0.701$$
$$C_{m-4} = 0.299$$

If we compare these two system graph, it is found that both have the same number of nodes, but the new system has only one edge less. This deleted edge causes a large change in the structural complexity, which is directly reflected in the similarity/dissimilarity coefficient as calculated.

It may be noted that the coefficient of similarity and dissimilarity lies in the range between 0 and 1. If two ***iMLE*** architectures are isomorphic or completely similar, their coefficient of similarity is 1 and the coefficient of dissimilarity is 0. Likewise, if two ***iMLE*** architectures are completely dissimilar, their coefficient of similarity is 0 and the coefficient of dissimilarity is 1.

4. Architecture and performance of *iMLE* products

It has been shown by a number of researchers that performance of any system is dependent on its architecture/structure consisting of its structural components and interactions between them. Structurally similar or closely similar architectures will likely perform nearly the same. Availability of a number of alternative architecturally similar ***iMLE*** modules provides a large amount of design flexibility in the hands of designer to develop highly efficient, effective and consumer friendly ***iMLE*** products at less cost and less time. This provides a competitive edge in the hands of different stakeholders.

5. Step-by-step procedure

The step-by-step methodology is proposed which will help in identifying various choices of available designs depending upon interaction/interdependencies or information flow between systems and their sub-systems (modules) and so on. A generalized procedure for the identification and comparison of ***iMLE*** system architecture which is extension of the procedure specified in **[Upadhyay and Agarwal, 2007]** is summarized below:

Step 1: Consider the desired ***iMLE*** product. Study the complete ***iMLE*** system and its subsystems, and also their interactions.
Step 2: Develop a block diagram of the ***iMLE*** system, considering its sub-systems and interactions along with assumptions, if any.
Step 3: Develop a systems graph of the ***iMLE*** system Figure 1 with sub-systems as nodes and edges for interconnection between the nodes.
Step 4: Develop the matrix equation (1) and multinomial representations equation (2) of ***iMLE*** system.
Step 5: Evaluate functions/values of diagonal elements from the permanent functions of distinct sub-systems of the composite and repeat Steps 2 – 4 for each sub-system.
Step 6: Identify the functions/values of off-diagonal elements/interconnections at different levels of hierarchy of the ***iMLE*** amongst systems, sub-systems, sub-sub-systems, etc.
Step 7: Calculate ***iMLE*** identification set. Carry out architectural similarity and dissimilarity with potential candidates to take appropriate decisions.
Step 8: Carry out modular design and analysis of ***iMLE*** products while purchasing off the shelf from the global market.

The visualization model for the comparison of two ***iMLE*** system/product is shown in Figure 4.

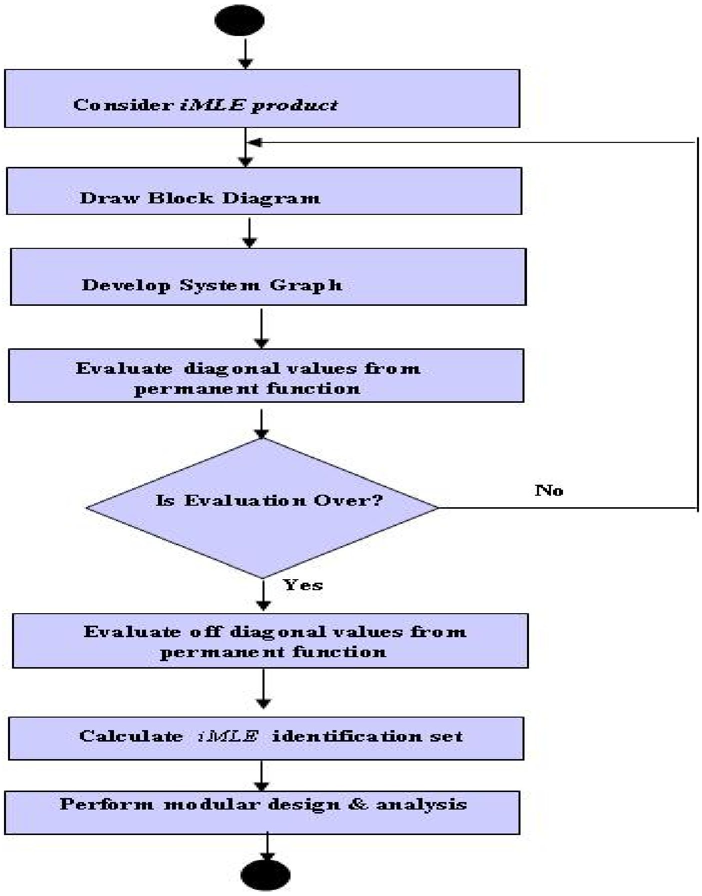

Figure 4. Visualization model

6. Usefulness of the proposed methodology

Different stakeholders in ***iMLE*** e.g. students, universities, ***iMLE*** module developers, designers and consultants are benefited by the proposed methodology as:

1. The methodology is dynamic in nature as sub-systems/components and interactions, which appear as variables in different models may be changed without any difficulty.
2. It also helps to develop a variety of ***iMLE*** systems providing optimum performance characteristics under different industrial/organizational learning applications.
3. Thus, the approach helps to express the ***iMLE*** system in quantitative terms, which has more often been expressed in qualitative terms.
4. The procedure helps to compare different ***iMLE*** systems in terms of its characteristics and rate them for particular applications.
5. It is hoped that this methodology will provide a new direction in the research attempts towards global projects of quantitative structure activity relationship (**QSAR**) and quantitative structure properties relationship (**QSPR**)[**Liu et al., 2004; Katritzky et al., 1997**].
6. The present work is an attempt towards the development of complete methodology for virtual integration [**Choi and Chan, 2004**] of ***iMLE*** components/sub-system as well as virtual design of complete iMLE system

architecture consisting of Mobile Dimension System (**MDS**), Mobile Agent System (**MoAS**), Multiagent Intelligent System (**MIS**), Intelligent Tutoring System (**ITS**), Environment and Human Aspect System (**EHAS**).

7. The proposed methodology is a powerful tool in the hands of the system analyst, designer, decision makers and developers.
8. Using this and morphological chart/tree, the system analyst, decision makers and designer can generate alternative design solutions and select the optimum one.
9. Similarly, this method can be exploited to improve quality and reduce cost and time-to-market in learning industry.
10. It is also possible to exploit the methodology to extend the useful product life in the learning industry market by making strategic changes in the ***iMLE*** systems architecture. This methodology gives a comprehensive knowledge to the user about ***iMLE*** systems architecture and helps in the selection of right systems architecture at the right time and at right cost from the global market.

7. Conclusion

1. Proposed structural coefficients of similarity and dissimilarity and identification sets are useful models to select optimum set of subsystems up to component level to finally achieve high quality ***iMLE*** system architecture in less cost and time by comparing their structures.
2. As proposed systems model gives complete information of the existing system, **SWOT** (Strength-Weakness-Opportunities-Threats) analysis and cause and effect analysis (Fishbone diagram/Ishikawa diagram) can be carried out effectively and efficiently. This permits cutting edge over its competitors.
3. This study gives a criterion how to compare two ***iMLE*** system architectures with the help of permanent function on structure basis.
4. Research is in progress to correlate quantitatively the structure of the system with different performance parameters of ***iMLE*** e.g. quality, reliability, etc.
5. Current undergoing research deals with correlation of structural models with the desired performance parameters (quality, reliability, responsiveness, flexibility etc), design and development of new systems as an improvement of existing systems and critical analysis of failed system. The outcome will be reported in future publications.

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