

## Abstract

A workflow depicts how a set of tasks of any business process get executed within the associated business constraints, when it is triggered by a business event. A workflow generally cuts across various functional divisions of any organization (or a set of organizations) thus mapping all the tasks that are to be performed for achieving a given objective. Workflow Management Systems (WfMSs) deal with automating such workflows. A complete workflow process definition comprises task definitions, resource requirements, execution dependencies between tasks, temporal constraints in executing tasks, data flows across various tasks, and application mapping of tasks. Workflows can be represented in one of the many representations available, including UML diagrams, workflow graphs and Petri nets.

Workflow verification is an area of increasing concern in workflow management. It deals with verifying structural correctness of the workflows. Currently, workflow verification algorithms exist for Petri nets, workflow graphs, UML diagrams, and propositional logic representations. Of these, algorithms based on Petri nets and workflow graphs are popular. This dissertation discusses various existing algorithms for workflow verification and their limitations, and then proposes two algorithms for verifying workflow graphs, one for verifying acyclic workflow graphs, and the other one for verifying both acyclic and cyclic workflow graphs. Theoretical worst-case time complexity of the proposed algorithms are  $O(E^2)$ , where  $E$  is the number of the edges in the workflow graph. These algorithms are described through various illustrative business examples and toy problems.

Main contributions of this dissertation are, (a) Mahanti-Sinnakrishnan (MS) algorithm for verifying acyclic workflow graphs, (b) Mahanti-Sinnakrishnan Cyclic Workflow Verification (MSCWV) algorithm for verifying cyclic and acyclic workflow graphs, and (c) Workflow Hyperpath Generation (WHG) algorithm for generating workflow hyperpaths. A short summary of the work on these algorithms are given in the following paragraphs.

Structural conflicts that could be present in acyclic workflow graphs are deadlock and lack of synchronization. Mahanti-Sinnakrishnan algorithm for verifying acyclic workflow graphs is based on graph search techniques like AO\* and Depth-First Search, thus making it simple and efficient. It could be noted that Mahanti-Sinnakrishnan algorithm is the first algorithm in the workflow literature to use graph search techniques for workflow verification. This algorithm is presented with a detailed theoretical proof, which also brings out various properties of acyclic workflow graphs. Finally, the implementation details of this algorithm are presented with various charts comparing performance of this algorithm with the Graph Reduction Method available in the literature. It could be noted that this is the first attempt in workflow literature to compare two workflow verification methods empirically. This algorithm has

several advantages over the existing algorithms such as, (a) it is much simpler to comprehend visually, (b) it consumes much lesser time compared to the existing algorithm, (c) it is easier to detect any errors that could be committed during the implementation of this algorithm, (d) it is based on well known graph analysis techniques, and (e) it does not disturb the original workflow graph structure while doing the verification.

In any workflow corresponding to a business process, especially those involving hundreds of tasks, chances are there that there is a cycle. This could be due to repetition of tasks for correction, for business rules adherence, etc. It is required to identify errors in workflows before deploying them in business environment. Otherwise, it could lead to various issues such as customer dissatisfaction, employees' frustration with the systems, reducing profits, etc. This problem is especially severe in workflows with cycles, due to the complexity involved in identifying errors in such workflows through human intervention. Some of the structural conflicts that could be present in cyclic workflow graphs are deadlock, lack of synchronization, and infinite loops. MSCWV algorithm proposed in this dissertation can be used for verifying both cyclic and acyclic workflow graphs. MSCWV algorithm uses many concepts from Mahanti-Sinnakrishnan algorithm, and also from various graph search techniques like AO\*, Depth-First Search and Breadth-First Search. Theoretical worst-case time complexity of this algorithm is  $O(E^2)$ , which is much lower than the theoretical worst-case time complexity of various existing algorithms in literature. Further, this dissertation brings out various issues in existing workflow verification methods such as Block Reduction Method and VERIFY\_WF. It could be noted that there are only few algorithms in literature for verifying cyclic workflow graphs, due to the complexity of this problem.

While executing a process, many decisions are taken at its various decision points for selecting paths. There is a need for understanding and analyzing on various paths that emanate from various decision points to ensure that right decision is taken at these moments. For this purpose, this dissertation presents the notion of hyperpaths in the context of workflows, its properties, and an algorithm (called WHG algorithm) to generate various hyperpaths from a node of a workflow graph. We term various multi-pronged process paths that emanate from a node of a workflow process and terminate in its end node as hyperpaths. It could be noted that this is the first attempt in the workflow literature to formally coin the term "workflow hyperpath", and define it. The algorithm for hyperpath generation is presented with detailed workouts using examples. Various similarities between hyperpaths and related concepts like instance subgraphs, instance flows, etc., are also discussed. Hyperpaths can have various applications in process mining, business process re-engineering, etc. Further, hyperpaths can be used in service-oriented

computing model for resource management, business activity monitoring (BAM), dynamic orchestration, and mission-critical service oriented systems.

Business processes undergo many changes due to change in regulations, business requirements, business rules, methods, technology, etc [1]. Dynamic workflows adapt to suit the business requirements from time to time using various methods, functionalities, and techniques. This dissertation presents a brief literature survey on dynamic workflows, and presents a simple application of Mahanti-Sinnakrishnan algorithm for dynamic workflows.

**Keywords:** Workflow Verification, Cyclic Workflow Graphs, Workflow Hyperpaths, Dynamic Workflows

**References:**

- [1] S. W. Sadiq, M. E. Orłowska, and W. Sadiq, "Specification and validation of process constraints for flexible workflows," *Information Systems*, vol. 30, pp. 349 - 378, 2005.