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Workflow scheduling in cloud environment – Challenges, tools, limitations & methodologies: A review

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A R T I C L E I N F O

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A B S T R A C T

Workflow scheduling is a framework that simulates major domain applications like gaming, Natural language processing, data science etc., for which the task order automation and demand consistency to be maintained. This increases the complexities for CSPs based on various QoS parameters like cloud deployment models, service types, VM templates, migration process, energy dissipation etc., The recent research survey analysis and marketing perspective parameters include unknown demands, task requirements failure, cost incurs access delay, feasible deadlines, system capability, cache latency, scheduler types and policies, VMs, platform support, fault-tolerant and virtualization types and their limitations. The various survey papers considered were supporting QoS parameters of cloud environment towards industry task automation wherein the researchers will find their way to identify problem definitions with measured approaches and solutions. The analysis would pave way to incorporate machine learning approaches to derive workflows for business, healthcare, Speech recognition, Text recognition; drowsiness detection, road sign detection, metal part identification etc., The analysis done in this paper leads to various challenges and issues found in workflow scheduling approaches. The survey paper is summarized with introduction in chapter 1 followed by comparative conclusions of various research papers and concluded with summary of the findings based on the survey. This survey work can be extended considering each task in workflow and data migration types & issues which incurs budget, legal issues & policies and technical methodologies to find feasible solution for task automation.

1. Introduction

Cloud Computing [24] along with virtualization technology provide a large research scope towards all major domain and applications. The platforms support given by various vendors maintains the consistency towards the growth of the demand with feasible cost that maps directly the end user requirements with the process of automation. The survey analysis done from various research focus includes scheduling types, comparison between methodologies, execution environment, objectives and the conclusions derived, QoS parameters considered etc.,

1.1. Benefits & applications

The workflow is applicable to any domain in order to align the sequence of tasks and enhance process automation considering energy dissipation, VM types, workflow types, number of tasks enforced, deadline constraints, cloud billing cost, acquisition and termination delays etc. Any workflow systems [22] includes the processing sequence from problem identification, collection of datasets, load & summarize datasets, data segregation, model evaluation, feature scaling, algorithm or technique to be applied for the model, training the model, model validation and prediction. The benefits and applications [19] of workflow scheduling are listed below.

- ➢ Face detection workflow process
- ➢ Natural Language Processing
- ➢ Sheet Metal Part Identification systems
- ➢ Scientific workflows
- ➢ Object detection systems
- ➢ Leaf disease detection system
- ➢ License plate recognitions
- ➢ Fake news detection systems
- ➢ Gaming
- ➢ Speech Emotion Analysis
- ➢ Recommendation Systems
- ➢ Title formation for paragraphs

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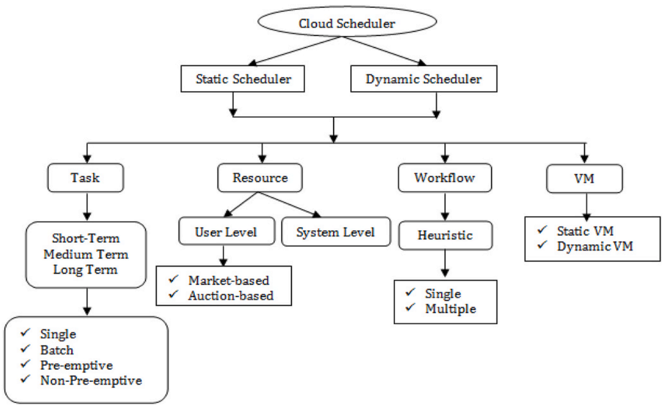

Fig. 1. Cloud scheduling levels.

- ➢ Traffic prediction systems
- ➢ Data intensive workflows
- ➢ Data science applications

1.2. Automation of workflow scheduling

The process or task automation in workflow scheduling is similar to resource allocation graph to one or multiple jobs [12] that depends on the domain and execution requirements in the cloud environment. To automate applications the static and dynamic scheduling [45] support by the cloud vendor that maps the continuous modifications in the VM instance given by service providers. This VM should meet all the objectives and challenges of tasks. The cloud scheduling levels [22] is shown below in Fig. 1 and research analysis with input and output mapping parameters, tools are shown in Table 1 below. The input and output representation decides the workflow scheduling levels [38] as depicted in Fig. 1 below. The scheduler type either static or dynamic will have an impact over the categorization of subsequent levels of cloud

Table 1
Comparative analysis of workflow scheduling strategies.

Ref. No.	Algorithm	Strategies	Results	Future Scope	Tools	Params
[1] Qin-zhe Xiao, 2022	Co-operative co evolution genetic programming	Task and Resource selection rule	High performance & Prediction of Heterogeneous earliest finish time	Optimize accuracy and heuristic interpretability	Montage, Epigenomics, Guassian Elimination, Fast Fourier Transform	Scheduling length ratio, speedup and efficiency
[2] Xiaoyong Tang, 2022	Cost-efficient task scheduling strategy	Task initialization, greedy workflow scheduling, task adjusting method	Minimum execution financial costs, save total workflow execution cost	VM Types and I/O capacity to be increased	Epigenomics, Cybershake, LIGO	Schedule length, deadline constrained tasks, cloud billing period
[3] Ya Zhou, 2022	Knowledge driven multi objective evolutionary workflow scheduling algorithm	Mined workflow structural knowledge, objective space normalization	Population diversity (15/20)	To increase number of workflow instances	Montage, Epigenomics, Cybershake, Sipht, Inspiral	Makespan, Monetary cost
[4] Huifang Li, 2022	Multi swarm co-evolution based hybrid intelligent optimization	Multi swarm co-evolutionary mechanism, update process of particle swarm optimizer, Genetic Algorithm	Minimize total makespan and cost	To consider hybrid clouds with various resource provisioning models	Montage, Epigenomics, Cybershake, LIGO	Application scheduling with different QoS
[5] Sebastian Braun, 2022	Multi agent systems	Skill based production based on real time demand	Flexible to correct errors, reconfiguration of the material flow	To introduce more agent types to improve prediction accuracy	Python 3.8	production cost & time
[6] Amelie Chi Zhou, 2022	Probabilistic approach	Pruning techniques to reduce computation overhead	Performance improved 65%	To improve reliability	Montage, Cybershake	Optimization, time, reliability
[7] Haihua Gu, 2021	Spark task scheduling	Stage sequencing, task scheduling, scheduling adjustment	Minimize rental cost,	To analyze heuristic algorithm with more practical characteristics	Montage, Epigenomics, Cybershake, LIGO	Data skew, deadline constraints
[8] Fuguang Yao, 2021	Task duplication based scheduling algorithm	Dynamic sub-budget allocation system & duplication based task scheduling mechanism	Optimize make span, improved resource utilization	To deal with uncertainties in workflows	Montage, Inspiral, Cybershake, Sipht, Epigenomics	Number of tasks, execution time, ratio of transmission to computing time, task out-degree
[9] Zulfiqar Ahmad, 2021	Workflow performance evaluation platforms	Resource scheduling, fault-tolerant, energy efficient approaches	Online workflow management	To consider big data management in fog and edge computing	Cloudsim, Workfloesim, Grounsim, IFogsim, IoTsim	Scheduling policies
[10] Yun Wang, 2021	Hybrid Particle swarm optimization	PSO and repair method for idle slots	Reduce execution cost, increased success rate	To implement prototype to test HPSO and predict execution times	Montage, Inspiral, Cybershake, Sipht, Epigenomics	VM types with deadline constraint
[11] Maria Carla Calzarossa, 2021	Multi objective constrained optimization	Scheduling plan with Monte Carlo and Genetic Algorithm	Efficient cloud resource provisioning	To consider edge technologies in uncertain cloud environment	Montage Cybershake, Epigenomics	Cloud infrastructure, VMs and processing capacity
[12] Jiagang Liu, 2021	Online Multi Workflow Scheduling Framework & Heuristic algorithm	Schedule workflows with random arrival time and uncertain/ unknown execution time	Reduce cost of VM rent and deadline violation probability	To consider optimization for VM rental costs in IaaS cloud	Montage, LIGO, Cybershake, Sipht, Epigenomics	Resource utilization
[13] Junlong Zhou, 2021	Dependable Scheduling	Lifetime reliability model	Lower PoF, Higher soft error reliability	To extend model to heterogeneous servers in	Montage, Inspiral, Cybershake, Sipht	Reliability, Security & real time constraints

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Table 1 (*continued*)

Ref. No.	Algorithm	Strategies	Results	Future Scope	Tools	Params
				cyber physical cloud systems		
[14] Xiaojin Ma, 2021	Real time multiple workflow scheduling	Model for workflow initialization, task allocation and feedback	Reduce cost under deadline constraints	To optimize algorithm performance when task fails due to hardware faults	Montage, LIGO, Cybershake, Sipht	Rental cost, resource utilization, success rate, deadline deviation
[15] Hongda Wang, 2020	Slicing algorithm	Prioritization method for regression test cases	Improved error detection	To consider large scale service oriented workflow applications	BPEL workflow applications in SOA	Error rate, Fault tolerance
[16] Ruey-Kai Sheu, 2020	Identification System for Process automation using Deep Learning Algorithm	Multi filtering approach	High performance	To apply in different types of production industries	CAD model database	Performance and accuracy
[17] Zheyi Chen, 2020	Online workflow scheduling algorithm	Adaptive resource allocation & consolidation	Reduce total cost of executing multiple scientific workflows	Data transmission between tasks	Cybershake, Epigenomic	High Resource utilization, Lower execution costs
[18] Omed Hassan Ahmed, 2020	Particle swarm optimization & Salp swarm algorithm	Markov models in fog environment	Reduce deadline missed workflows	Dynamic fog environments	Montage	Network bandwidths, VMs
[19] Wei Hu, 2020	Spark application framework with privacy protection	Task sequencing rules	High Performance, Shorter execution time	Spark scheduling with data affinity	Cybershake, Montage, Genome, SIPHT, LIGO	Deadline and privacy constraints
[20] Longxin Zhang, 2020	Reducing energy consumption using remapping of critical tasks	Task allocated to VMs with low energy consumption	Lower energy consumption without compromising budget constraints	Failed task recovery on edge computing	Epigenomic	Critical task path, budget factor
[21] Jie Zhu, 2020	Fuzzy task scheduling	Tight and relaxed deadline setting	Robust and Effective	Processing time and data size are uncertain	Java with simulated clusters	Minimize rental costs and maximize user satisfaction
[22] J. Angela Jennifa Sujana, 2019	Smart Particle swarm optimization bases secure scheduling	Assign task to best VMs	Make span with security	Efficient load balancing methods	Workflowsim	Minimum make span and cost
[23] Shahbaz Afzal, 2019	Load balancing techniques	Load balancing	Proactive & reactive algorithms	Efficient load balancing with QoS metrics & complexity evaluation	CloudSim, VMWare, Eucalyptus, Cloud Analyst, Matlab	Taxonomy based classification
[24] Yehia Kotb, 2019	Workflow net based framework	Convert workflow net to algebraic representations	Increase number of achieved tasks	Different fog computing sites to cooperate	Raspberry Pi	Performance 7 times faster
[25] Xin Ye, 2019	Fragmentation based genetic algorithm	Task priority dispatching rules	Minimize execution time for all workflow instances	To consider large number of VMs, workflow model, different objectives and constraints	Matlab R2010b	Execution time
[26] Somayeh Mohammadi, 2019	Multi objective model	Weighted-sum, Benson's scalarization, weighted min-max	Performs well than method wrt hypervolume	Heuristic approach	Montage, Epigenomic, Cybershake, Ligo	Minimization of cost, makespan
[27] Naqin Zhou, 2018	Multi workflow heterogeneous budget and deadline constrained scheduling	Uniform ranking, task priority	Performs in both consistent and inconsistent environments	Consider reliability and energy	SimGrid	Adaptability
[28] Khawar Hasham, 2018	Cloud aware provenance	Workflow structure, execution infrastructure, workflow outputs	Trace changes in provenance and workflow outputs	To consider different graph nodes or edges and weights prioritized by critical nature	Montage, Condor, Pegasus	Workflow reproducibility
[29] Huangke Chen, 2018	Cost effective reactive scheduling algorithm	Mltiple workflows in hybrid way	Monetary cost, resource efficiency	To improve resource utilization stability >78%	Montage, SIPHT, Cybershake, Ligo	Idle time slots & resource efficiency
[30] Guangshun Yao [2017]	Imbalance characteristic fault-tolerant workflow scheduling(ICFWS)	Resubmission & replication of tasks	Resource utilization, Task completion time	VM performance fluctuation, Elastic resource provisioning not done	WorkflowSim toolkit, Montage, CyberShake, Epigenomics, Inspiral	Fault – tolerance & Performance evaluation
[31] Bin Xiang [2017]	Greedy ANT	Task priority, Forward/ Backward dependency	Reduce total execution time	More QoS constraints, hybrid heuristic	Matlab R2013a platform	Computation Cost
[32] Quanwang Wu [2017]	L-ACO and ProLis	Rank tasks & service allocation to task with deadline	Minimize execution cost, Improved performance	Clustering & replication techniques to improve performance	Montage, CyberShake, Epigenomics, LIGO	Computation Cost & Performance evaluation
[33] Huangke Chen [2017]	SOLID (Scheduling apprOach with seLectIve tasks Duplication)	Task duplication and intermediate data encryption	Reduced cost & makespan with resource efficiency	Robust task scheduling & resource management	Montage, CyberShake, Epigenomics, Inspiral & SIPHT	Security & Performance evaluation
[34] Shuibing He [2017]	MinMax Memory Claim (MMC)	Banker's algorithm, Improved Banker's algorithm, Deadlock	maximize the concurrency with minimum memory resources	Constrained in-memory caching	–	Performance evaluation, Deadlock resolution

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Table 1 (*continued*)

Ref. No.	Algorithm	Strategies	Results	Future Scope	Tools	Params
		detection-based scheduling(DDS)				
[35] Bhaskar Prasad Rimal [2017]	Cloud-based workflow scheduling (CWSA) policy	Performance metrics & policies	minimize workflow completion time, tardiness, execution cost & resource utilization	Not considered resource failures & complex reservation scenarios for scaling multi-tier applications.	SIPHT and CyberShake, CloudSim framework	Performance, Resource utilization
[36] Seong-Hwan Kim [2017]	Cost adaptive resource management scheme	Division policy & science gateway, VM types	Minimize resource management cost with performance improvement	Not considered the resource unavailability failures	OpenStack, CloudStack	Cost, Performance
[37] Xiaoping Li [2017]	Multirule-based heuristic	deadline division and task scheduling	Improved performance	Different pricing interval lengths on resource provisioning	Montage, CyberShake, Epigenomics, SIPHT	Cost, Performance
[38] Mateusz [2016]	Minimum Dependencies Energy-efficient DAG (MinD + ED)	Dynamic task allocation to servers which are less dependant	Energy efficient approach & satisfiable level of tardiness	Consider multiple data centers or mobile app scenarios	GreenCloud simulator, Montage, Epigenomics & Layer-by-Layer	SaaS scheduling in data center
[39] Alexander A. Visheratin [2016]	Cloud Deadline Coevolutional Genetic Algorithm (CDCGA)	Various compute services with time periods of charge	High efficiency compared to heuristic algorithm	Improved heuristic algorithm	Montage, CyberShake, Epigenomics, Inspiral & SIPHT	Computational services
[40] Mohammad Masdari [2016]	Analysis of heuristic, metaheuristic and hybrid algorithms	pros and cons of scheduling approaches	Analysis of various security attacks	Secure scheduling	Cloudsim, IBM RC2, Amazon EC2, MATLAB	Cost, Type, Makespan, Load balancing
[41] Bing Lin [2016]	Multi-Clouds with Partial Critical Paths Pretreatment (MCPCPP)	Partial Critical Path	Minimize execution cost & satisfy deadline constraint	Consider execution time & data transfer time in multicloud & private & hybrid cloud types.	Montage, CyberShake, Epigenomics, SIPHT	Cost, Deadline
[42] Xiaomin Zhu [2016]	FASTER algorithm	Backward shifting. Horizontal/vertical scaling up and vertical scaling down	resource utilization and schedulability even in the presence of node failures	Communication faults & improve scheduling accuracy	CloudSim toolkit	Fault – tolerance
[43] Zhaomeng Zhu [2016]	Evolutionary Multi-objective Optimization (EMO)	IaaS platform scheduling	Minimize cost	Monetary cost & time overheads of communication and storage to be considered	Amazon EC2, Montage, CyberShake, Epigenomics, Inspiral & SIPHT	Cost
[44] Xiaolong Xu [2016]	EnReal Method	Dynamic deployment of VMs	VM allocation to support scientific workflow executions	Consider real cloud platform & scheduling issues	CloudSim toolkit	Energy consumption, Performance
[45] Amelie Chi Zhou [2016]	Dyna scheduling system	A^* based instance configuration method	minimize the expected monetary cost with deadlines met	Improved scheduling approach	Amazon EC2, Montage, LIGO, Epigenomics	Cost, Performance
[46] Zhicheng Cai [2016]	List based heuristic (LHCM) concerning the task processing cost and task-slot matching	Task mode mapping, critical path generation methods	Minimize service renting cost	software setup times should be explicitly considered	Montage, CyberShake, Epigenomics, LIGO, SIPHT	Services
[47] Yang Wang [2015]	Workflow-Aware File System(WaFS)	Dependency solver algorithm, Inserting dependencies to JobSpace	High performance, storage utilization	Centralized architecture – single point of failure, load balancing	Master host - AMD Athlon XP 2.2 GHz, 1 GB/512K Execution host - AMD Athlon 2.4 GHz, 1 GB/512K	Performance, Resource utilization
[48] Rodrigo N. Calheiros [2014]	Enhanced IC-PCP with Replication(EIPR) algorithm	Task scheduling, data transfer & task replication	Reduce total execution time and deadlines met	Task replication across multiple clouds	Montage, CyberShake, LIGO, SIPHT	Time, scalability, availability
[49] Maria A. Rodriguez [2014]	Particle Swarm Optimization (PSO)	Schedule generation & performance evaluation	Reduce total execution cost and deadlines met	Ignore performance variation, VM start up time and delay	CloudSim, Montage, CyberShake, LIGO, SIPHT	Cost, Performance

scheduling. The cloud architecture design for any application development should incorporate greater availability, scalability, security, optimized cost, migration types and issues etc., The approaches discussed in this work considers a wide variety of input/output parameters that proves results to be QoS centric. The schedulers are of different types listed as short, medium, long which helps in achieving task priority and reduced turnaround time. The cloud vendors provide strong interfacing and open source support for the end users in various packages considering requirements mapped with application size, count of VM instances, VM migration strategy, cost etc,.

2. Summary & future scope

The approaches used in the research articles were supporting static as well as dynamic cloud environment considering execution time, delays and cost as the major research factors. The implementation environments considered were simulators, scientific workflows like Montage, Cybershake, SIPHT, LIGO, Epigenomics, Inspiral, Amazon EC2 etc., The results of various papers compared above in Table I illustrate the inputs are of evolutionary algorithms or improved type which includes any of the QoS factors for deriving the conclusions. Based on the analysis done in this review paper, it is found that the challenge relies on workflows to be executed in some sequence and its priority and the identification of dependency between them. This complexity could be drastically reduced, when we consider the workflows in a graphical representation like DAGs (Directed Acyclic Graphs) and find a feasible cloud service and type in order to improve the QoS parameters. The future research scope can be analyzed for data size migration issues and a standard methodology could be implemented for enhanced task process flow execution. Further, we can focus on automating execution platform of VM efficiently with parameters like VM types, delays, cost along with parameters like cloud characteristics, cloud vendors, services support duration, maintenance, architecture, system capability, open source environment provision.

CRediT authorship contribution statement

M. Menaka: Conceptualization, Methodology, Validation. **K.S. Sendhil Kumar:** Comments evaluated, Training and testing, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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