On-Demand Pilot Job Scheduling for Adaptive Execution of HEP Workflows on HPC Systems

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Background and Motivation

HEP workflows often consist of complex DAGs with streaming job arrivals that challenge traditional static scheduling approaches. We introduce a dynamic pilot job scheduling model that allocates HPC resources on demand when queued DAG jobs reach a configurable threshold. The simulation framework models interactions between the trace parser, DAG manager, pilot job manager, and HPC resources. The system improves scheduling responsiveness and resource utilization by reserving nodes as needed and scheduling jobs in batches based on DAG dependencies.







BatchSystem FNAL Log Analysis

1.0 -	1208170	2555261	1312002	4469674	2213051	2834864	633991
2.0 -	700325	891633	592976	1509367	531661	597188	49237
3.0 -	168552	164523	85881	475619	124705	82776	14131
4.0 -	105247	197175	55976	215740	112228	74889	4713
5.0 -	19976	12320	1710	20980	23485	33526	144
6.0 -	10844	7628	2790	11531	13588	16896	291
7.0 -	3529	3243	607	5122	14619	43363	1
8.0	513	275	131	26194	27700	14544	96
0.0 -	1620	11610	420	20194	27700	1429	30
9.0 -	1030	2018	420	3423	4047	1420	30
10.0 -	603	3018	3577	7956	3180	24409	272
11.0 -	94	2403	169	4633	533	/21	59
12.0 -	1940	510	90	63	2	44	4
15.0 -	475	328	27	4468	142	478	11
16.0 -	1	8	10	169	228	603	93
17.0 -	0	1	0	0	0	0	7
20.0 -	23	2	55	3610	473	154	108
22.0 -	0	0	0	5	5	13	0
25.0 -	4	505	2	9	24	33	0
28.0 -	2	71	13	134	555	146	0
30.0 -	0	1	0	8	4	0	0
33.0 -	1	0	18	3	0	0	4
35.0 -	0	0	0	1	0	1	0
40.0 -	0	0	0	2	0	1	0
50.0 -	11	1	0	0	1	1	0
110.0 -	0	0	0	7	2	0	0
			1	1			Folk
	0-100s	100-500s	500-1000s	1k-5k Runtime (binned)	5k-10k	10k-50k	JUK+
	0-100s	100-500s	500-1000s Heatmap:	1k-5k Runtime (binned) RequestSlots vs	5k-10k s. Runtime	10k-50k	50K+
1 -	0-100s 1126139	100-500s 1568572	500-1000s Heatmap: 1067943	1k-5k Runtime (binned) RequestSlots vs 3530245	5k-10k 5. Runtime 1357762	10k-50k 1464872	50K+ 412936
1 - 2 -	0-100s 1126139 380177	100-500s 1568572 495532	500-1000s Heatmap: 1067943 348231	1k-5k Runtime (binned) RequestSlots vs 3530245 1043010	5k-10k 5. Runtime 1357762 470104	10k-50k 1464872 746458	412936 25157
1 - 2 - 3 -	0-100s 1126139 380177 126805	100-500s 1568572 495532 85196	500-1000s Heatmap: 1067943 348231 85939	1k-5k Runtime (binned) RequestSlots vs 3530245 1043010 415353	5k-10k 5. Runtime 1357762 470104 109883	10k-50k 1464872 746458 108513	412936 25157 13348
1 - 2 - 3 - 4 -	0-100s	100-500s 1568572 495532 85196 199852	500-1000s Heatmap: 1067943 348231 85939 67875	1k-5k Runtime (binned) RequestSlots vs 3530245 1043010 415353 330040	5k-10k 5. Runtime 1357762 470104 109883 105195	10k-50k 1464872 746458 108513 112530	412936 25157 13348 5602
1 - 2 - 3 - 4 - 5 -	0-100s 1126139 380177 126805 100061 48648	100-500s 1568572 495532 85196 199852 115915	500-1000s Heatmap: 1067943 348231 85939 67875 40340	1k-5k Runtime (binned) RequestSlots vs 3530245 1043010 415353 330040 80834	5k-10k 5. Runtime 1357762 470104 109883 105195 7676	10k-50k 1464872 746458 108513 112530 4340	412936 25157 13348 5602 926
1 - 2 - 3 - 4 - 5 - 6 -	0-100s 1126139 380177 126805 100061 48648 2176	100-500s 1568572 495532 85196 199852 115915 925	500-1000s Heatmap: 1067943 348231 85939 67875 40340 1297	1k-5k Runtime (binned) RequestSlots vs 3530245 1043010 415353 330040 80834 27015	5k-10k 5. Runtime 1357762 470104 109883 105195 7676 14938	10k-50k 1464872 746458 108513 112530 4340 15281	412936 25157 13348 5602 926 389
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- Jobs parsed into DAG (tuple format: <task_id>, <level>, job_id)
- Two queues: Parent jobs \rightarrow Ready-To-Run Q, Child jobs \rightarrow Wait Q,
- Schedule RTR jobs via pilot jobs when threshold reached
- If > 2× threshold \rightarrow send multiple pilot batches
- On job completion, unlock dependent child jobs, Wait \rightarrow RTR



- Multi-resource scheduling for HEP Workflow Jobs
- Resource matching to schedule RTRQ,
- Simulate job dependency and running on each resource
- Calculate most optimal decision and send back decision to HTC

• Receive resource state information after each scheduling cycle

- Assumes static threshold values, work needed for dynamic or learning-based thresholds
- No failure modeling yet, resilience and retry mechanisms are out of scope for the initial design
- Simulates job scheduling behavior, performance metrics are indicative, not empirical
- Octopus: Use GNN and DRL for scheduling decisions
- GRAPHENE: Prioritize troublesome tasks in an offline phase, enforce the order online.
- Pegasus: Task clustering for efficient workflow mapping.
- DAGMap: Prioritization, grouping, heuristic scheduling for grid
- LAPS: Round-robin strategy for scalable online DAG scheduling, SJF to greedily schedule DAG jobs

