Assignment and Prioritization of Tasks with Uncertain Durations for Satisfying Makespans in Decentralized Execution

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Motivation

Existing Planning & Scheduling(P&S) approaches are not compatible with human teams in office settings.

- Task preemption (context-switching) costs on execution time are not considered
- Constant central control is required vs decentralized execution

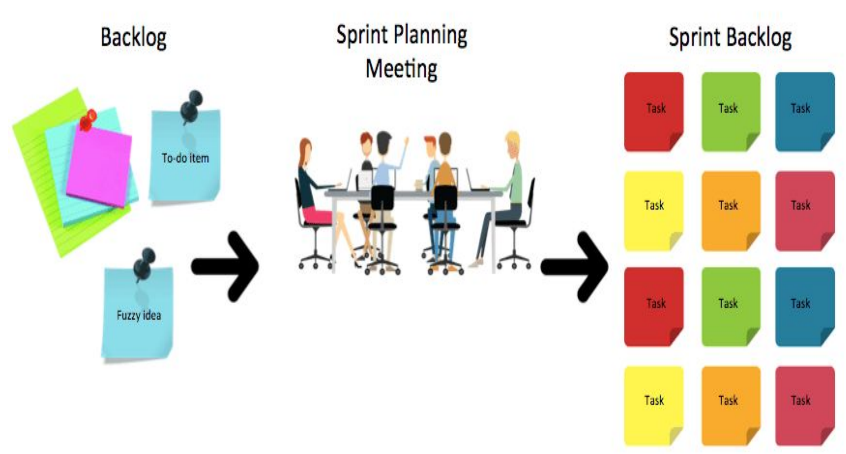
Assignment and Prioritization of Tasks **(APT)** that considers team member qualifications, availability, and tasks dependencies can help give better plans and outcome estimates.

Motivating Application

Sprint Planning(Agile Methodology) for software development

Teams plan for 2-week "sprints". Tasks difficulties are determined and assigned to team members. Team members then do their tasks independently.

We can improve outcomes by considering task dependencies, goal priorities, and task-switching costs.



Sprint Planning Process Overview[1]

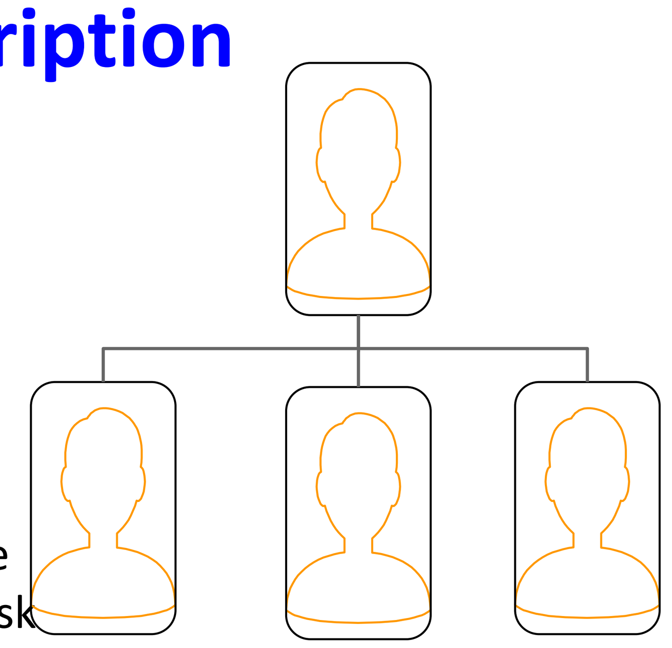
Problem Description

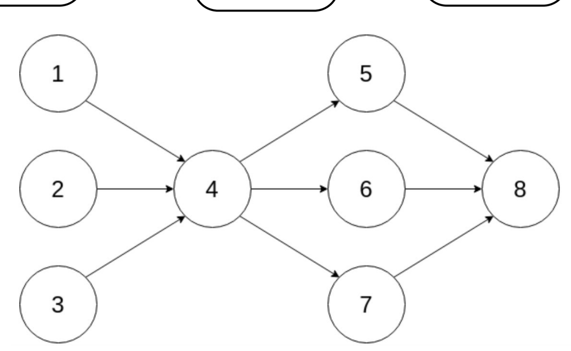
The plans (partial-order) are input, along with the action(task) qualifications and estimates on time required.

Employee availability and qualifications are also input.

Goals are completed when their associated tasks are finished. Goals priorities are input; separate from task priorities used to control preemption. Makespan is specified for goal completion.

The objective is to assign tasks and priorities to agents. Priorities are used by agents to switch tasks. Solutions are evaluated in a simulator





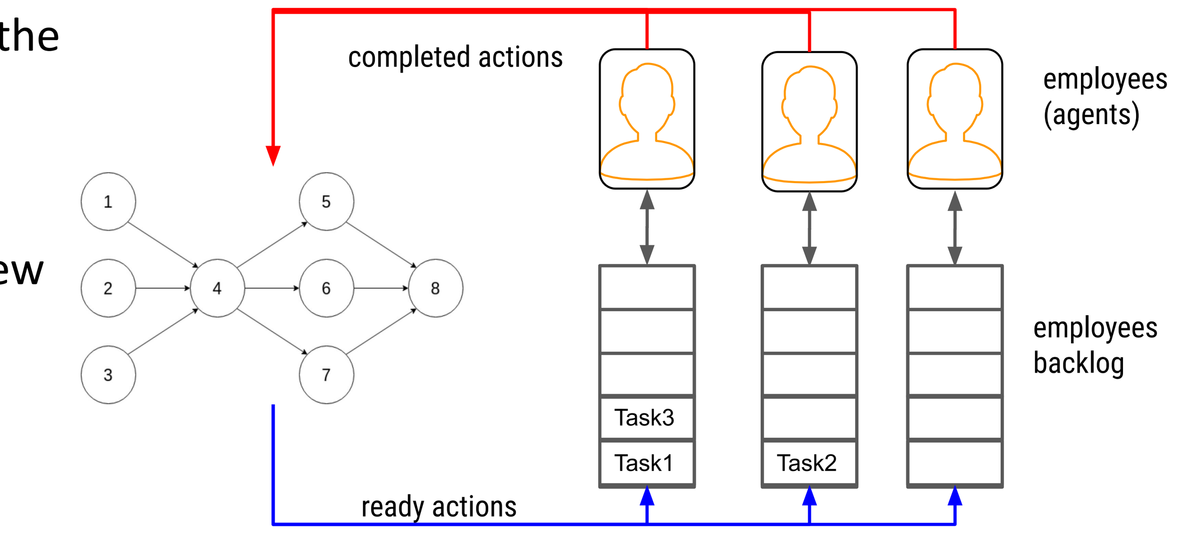
Simulator

The main process places tasks on the backlog of agent processes with a task-time.

Agent processes complete tasks after the associated task time and inform the main process.

The main process determines if any new tasks have had their dependencies satisfied and then places them on the assigned agent's backlog

When an agent process preempts the current task for a higher priority one, additional time is placed on the preempted task (context-switch cost)



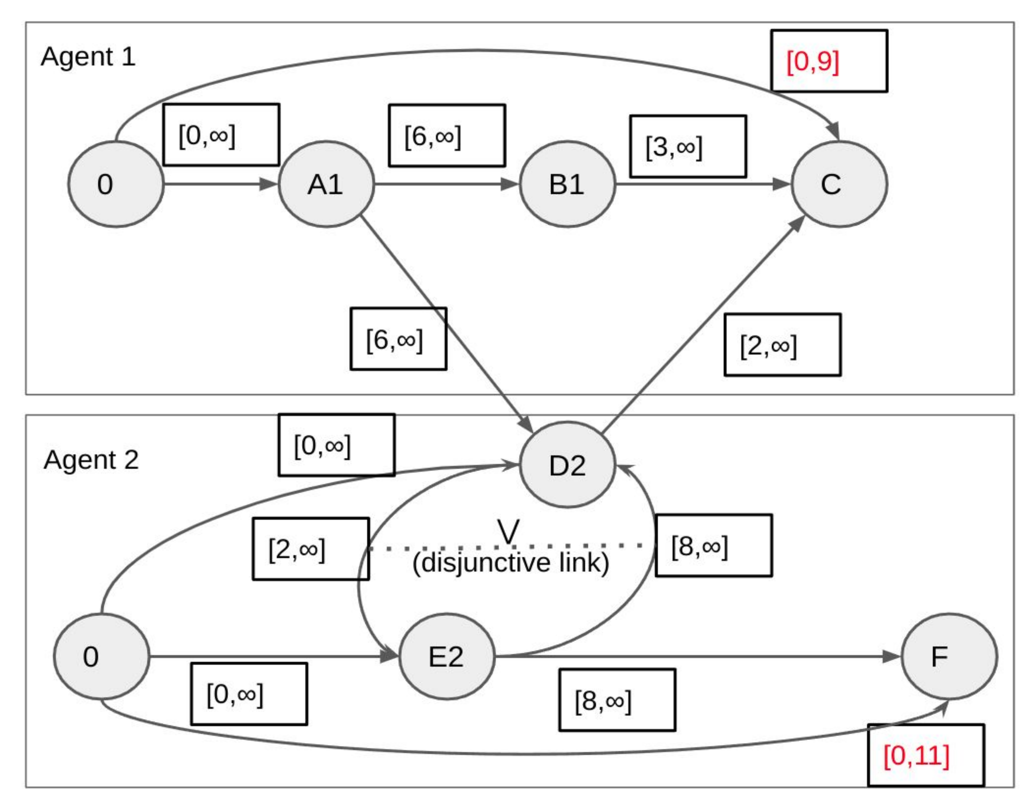
How Preemption Helps

Tasks may require qualifications that force assignment to specific subset of agents

Dependencies between tasks determine order of execution

In example on the right, the tasks are assigned to the two agents based on their qualifications, and the makespans cannot be satisfied without preemption by Agent 2

Preemption is also helpful for decentralized execution where there is no central control/dispatch to tell agents to start or stop tasks



Example of Multi Agent Simple Temporal Network in which preemption is needed to satisfy makespans

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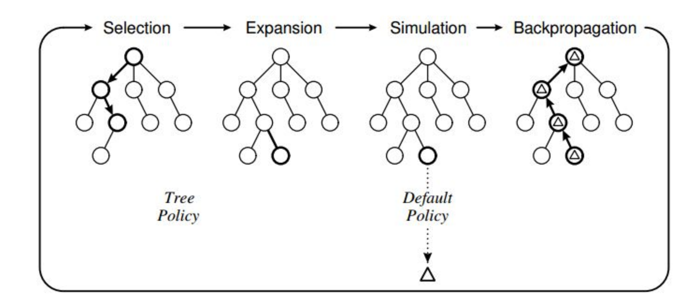
[1] Image Credit: Sprint planning process image source: https://www.techagilist.com/agile/scrum/sprint-planning/

Methodology

Tabu Search:
Tabu list comprises of prior solutions
Each step considers all single-task changes (assignment x priority)
Search based on weighted likelihood of goal-completion (weighted by goal priority)



Monte Carlo Tree Search :
Actions = Assignment X Priorities.
Default Policy = random rollout
Reward = Weighted likelihood of goal completion; averaged from 30 simulated executions of a plan (assignment and prioritization)

Actions are ordered by topology in the graph associated to the partial-order plan. They are also ordered based on the highest goal-priority of the goals associated to the actions

Experiments & Results

We procedurally generated partial-order plans with 30 tasks
The depth of the partial-order plan affects dependencies and is varied. The topological depth is set to 3 and 6.

Agent qualifications and task requirements are randomly assigned; All tasks have at least one agent with the necessary qualifications.

Task duration is uncertain, time taken is defined by a uniform distribution between a lower and an upper bound. Bounds are sampled from Normal(μ = 8,σ = 3)

Goals are associated to a subset of tasks goal priorities are randomly assigned

We compared Tabu search and Monte Carlo Tree Search (MCTS)

Increasing the priority levels available from 1 to 3 improves outcomes as expected

In the table to the right, each group of 4 results correspond to the same partial order plan; the number of agents, goals and priority levels are changed

				Goals						
H	a	p	m	g_0	g_1	g_2	g_3	g_4	MCTS	Tabu
3	4	1	163	1	1	2	1	1	0.86	0.83
3	4	3	163	1	1	2	1	1	0.99	0.93
3	6	1	163	2	2	1	3	3	0.99	1.0
3	6	3	163	2	2	1	3	3	1.0	1.0
3	4	1	156	2	3	1			0.04	0.0
3	4	3	156	2	3	1			0.48	0.4
3	6	1	156	1	2	1	2	2	1.0	1.0
3	6	3	156	1	2	1	2	2	1.0	1.0
3	4	1	165	3	3	3	1	3	1.0	1.0
3	4	3	165	3	3	3	1	3	0.93	0.99
3	6	1	165	3	3	2			1.0	1.0
3	6	3	165	3	3	2			1.0	1.0
6	4	1	169	2	1	3			0.32	0.33
6	4	3	169	2	1	3			0.34	0.33
6	6	1	169	1	3	3			1.0	1.0
6	6	3	169	1	3	3			1.0	1.0
6	4	1	174	2	1	1			1.0	1.0
6	4	3	174	2	1	1			1.0	0.99
6	6	1	174	3	1	2			1.0	1.0
6	6	3	174	3	1	2			1.0	1.0
6	4	1	154	1	2	3	3		0.51	0.59
6	4	3	154	1	2	3	3		0.7	0.76
6	6	1	154	3	2	3	3		1.0	0.84
6	6	3	154	3	2	3	3		1.0	1.0

Table : Likelihood of finishing execution by maximum makespan for MCTS and Tabu search given different configurations of topological depth (H), number of agents ($a = |A|$), priority levels ($p = |P|$)) and maximum makespan (m).