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Comparison of Desynchronization Methods for a Decentralized Swarm on a Logistical Resupply Problem

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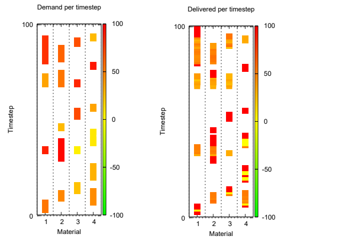
Abstract

Decentralized computational swarms have been used to simulate the workings of insect colonies or hives, often utilizing a response threshold model which underlies agent interaction with dynamic environmental stimuli. Here, we propose a logistics resupply problem in which agents must select from multiple incoming scheduled tasks that generate competing resource demands for workers. In this setting, agents should be judicious with their labor, and must be wary of overestimating the demands of any given task, at the expense of other, less urgent, tasks that may require the attention of some subsection of the collective personnel. Conversely, a sufficient pool of workers who react quickly to changing tasks may be necessary for schedules that require significant volumes of labor shifting rapidly across different tasks in the construction site. We examine the effects of two mechanism that can potentially improve swarm coordination by desynchronizing agent behaviors, variation in response threshold and response duration.

Problem Description

Each problem is represented as a schedule of material demands where the demand for each material is indicated as one or more sessions that extend over a period. *Sessions* within each *material* constitute dynamic task demands. Each agent can respond to any of M tasks. The *Original Schedule*, S_O, represents requested material demands, while the *Working Schedule*, S_W, signifies the actual amount of material delivered. S_O and S_W are depicted below [1], respectively. Sessions terminate once the demanded material amounts are met. Start times, subsequently, may be delayed – but not decreased. A schedule is completed once all sessions have terminated. Experimentally, we designate three schedule types: long, short and ushort, each with decreasing session lengths, but with identical aggregate task demands.

[1]



[2]

Algorithm 1 Task Selection(Agent i)

```
if random(0, 1) < prob_check then
    T ← Array[M] initialized to 0
    for j ← 1 to M do
        if σ_j > τ_j^i then
            T[j] ← σ_j
    if T[k] > 0 then
        current_task_i ← random d_k
    else
        current_task_i ← idle
else
    current_task_i ← prev_task_i
```

Multi-Agent System

A *response threshold* defines a minimum stimulus to trigger a possible response from an agent. Task selection involves the agent evaluation of current task demands – a selection of tasks to be addressed, or otherwise, to remain idle. An agent uniformly selects, at random, from *candidate tasks* which exceed its threshold. Scaling_factor adjusts thresholds by multiplying raw threshold values: τ ∈[0,1]. Init_thresh dictates the distribution type for heterogeneous response thresholds. The task selection algorithm [2] is shown above.

Response duration is a measure of how long an agent remains on one task before switching to another. In our model, response duration is probabilistic. Prob_check∈(0,1] defines the probability that an agent may switch tasks in a given timestep. Thus, lower Prob_check values indicate higher time on task.

Altogether, we include 3 benchmarks for measuring swarm performance: Timesteps to completion, sum of agent over-delivery, and average number of task switches per agent - all for a given schedule.

Experimental Study

Experiments are divided into response threshold and response duration segments, each with a separate ANOVA for each benchmark. 7 probability distributions are used to generate threshold values: constant, uniform, Gaussian (μ = 0.50, 0.25), and Poisson (λ = 3, 5, 7). For response duration, we test prob_check values from [0.1, 1.0] in increments of 0.1. Inputs contain 10 runs of distinct schedules. Measure stress_index is defined as agent resources relative to task demands, being directly proportional to Scaling_factor, and inversely proportional to Popsize.

- 8 experiments [3]

- [A,B,C] = Decreasing stress_index via decreased Scaling_factor
- [D,A,E,F,G] = Decreasing stress_index via increased Popsize
- All experiments are run on long and short schedules, for response duration, we include ushort, as well.
- The Two-Way ANOVA examines

1) Main effects:
- Threshold/Duration Level
- Schedule Type

2) Interaction effects between both factors

[3]

Expt	Popsize	Scaling_factor	Stress_index
A	100	100	1.00
B	100	50	0.50
C	100	25	0.25
D	50	100	2.00
E	150	100	0.67
F	200	100	0.50
G	400	100	0.25

Conclusion

Both desynchronization mechanisms impact swarm behavior to different outcomes. Variable response duration diversifies the frequency with which agents re-evaluate their actions and affects how quickly agents respond to changing task demands, and variable response thresholds allow agents to respond differently to the same material demands, effectively desynchronizing task acceptance for any given material. From our analysis, we broadly observe that interaction between threshold distribution and schedule variant diminishes under low-stress environments.

Results

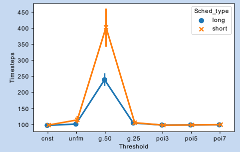
Two Way ANOVA: Experiments are motivated by an assessment of the main effects given by both categorical variables, and their interaction. Low p-values (p ≤ 0.05) signify rejection of null hypotheses, and thus, a statistically significant effect for the given parameter.

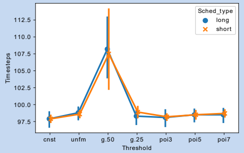
Response Threshold, Timesteps

Expt. A → B

Rejection of null hypothesis happens when scaling values are higher. Lower threshold scales cause us to accept null hyp. in experiment C, when stress is lower. Factors won't interact when scaling values are small.

Expt	Stress index	Main effect: Init_thresh	Main effect: Sched_type	Interaction effect
A	1.00	6.01E-108	7.93E-14	2.20E-08
B	0.50	4.46E-89	1.03E-26	5.03E-03
C	0.25	5.56E-60	8.06E-31	3.55E-01



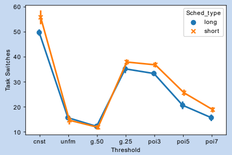


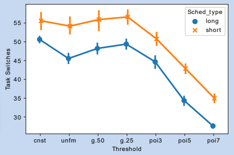
Response Threshold, Task Switching

Expt. A → C

Similar case as above. Lower threshold scales cause us to accept null hyp. in experiments B and C, when stress is lower. We also accept null hyp. for both main effects in C, for Sched_type in B.

Expt	Stress index	Main effect: Init_thresh	Main effect: Sched_type	Interaction effect
A	1.00	1.05E-58	3.67E-07	1.64E-18
B	0.50	5.60E-16	1.00E+00	9.99E-01
C	0.25	0.789445	0.589522	0.942792





Response Duration, Timesteps

Expt. A → G

Interaction lessens as stress decreases, via increasing Popsize. Null hyp. accepted for experiments F and G, implying no interaction between Prob_check and Sched_type.

Expt	Stress index	Main effect: Prob_check	Main effect: Sched_type	Interaction effect
D	2.00	8.66E-257	1.07E-121	1.08E-105
A	1.00	1.23E-168	6.84E-08	1.92E-13
E	0.67	3.15E-163	1.86E-05	4.61E-02
F	0.50	8.35E-144	1.03E-04	4.09E-01
G	0.25	2.89E-148	1.44E-15	7.73E-01