Multi-model Maintenance Scheduling

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Introduction

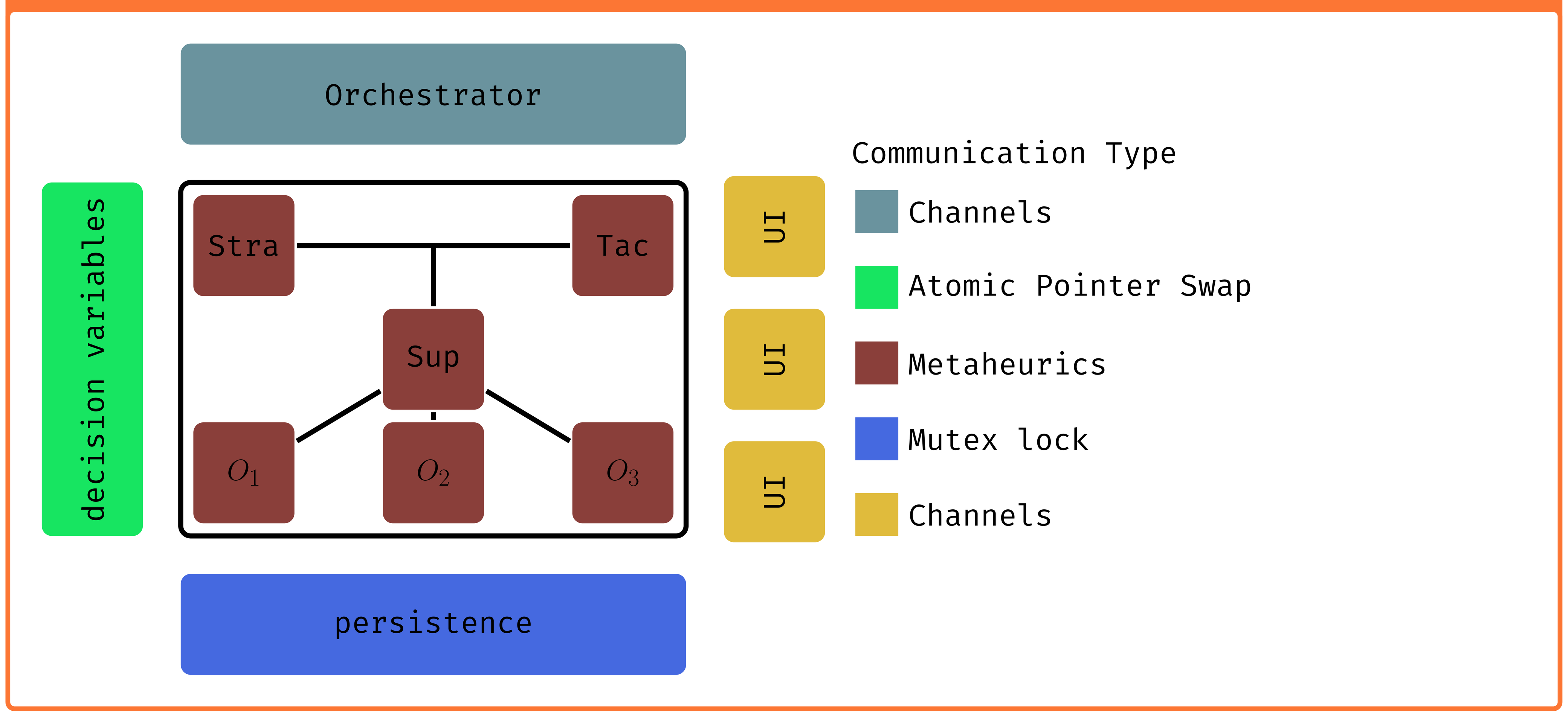
Current Operation Research methods have proven difficult to implement in operational settings. The poster presents a methodology to decompose a large-scale decision process into a series of modules that each represents the decisions taken by each individual stakeholder making up the scheduling process. Which is the most general form is composed of a Scheduler, a set of Supervisors, and groups of technicians that are lead by the supervisors. It is generally believe that maintenance efficiency can be increased by 35% (Palmer 2019) by having a well organized maintenance scheduling system in place. This project will provide an implementable architecture that is able to model and optimize this system through the use of real-time optimization and user interactions.

Research Questions

1. How to implement a scheduling system that can coordinate in real-time?
2. How to coordinate multiple stakeholders in real-time that has different mathematical model requirements?
3. How to synchronize state across a high number of metaheuristics spread across different CPU threads?
4. How to intergrate metaheuristics into the workflow of a working scheduler?
5. Can you coordinate metaheuristics based on different mathematical models in real-time?
6. Which modern software architecture should be used to create scalabily metaheuristic based scheduling systems
7. Which of the latest techniques in modern software development can be utilized to integrate metaheuristics directly into a business' IT infrastructure
8. How to create modular algorithm components that can solve well defined decision problems while also integrating into a larger decision making process
9.

Solution Method

Modular Scheduling System Architecture



Algorithm: Actor based Large Neighborhood Search

Algorithm 1 Actor-based Large Neighborhood Search

```
Input Q = message queue
Input P = problem instance
Input X = initial schedule
Input S = SharedSolution
repeat
    X^t = clone(X)
    while Q.has_message() do
        P.update(S, m)
        X^t.destruct(S, m)
    end while
    X^t.repair(S)
    if accept(X^t, X) then
        X.update(X^t)
    end if
    if c(X^t) < c(X) then
        X.update(X^t)
        S.atomic_pointer_swap(X)
    end if
```

Future Work

- Test Scheduling Application with case company
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Results

- **Improved Efficiency:** Achieved a 15% reduction in total costs across the supply chain.
- **Stakeholder Satisfaction:** Increased satisfaction scores among all actors by 20%.

Methodology

Strategic

Meta variables:

$$s \in S \tag{1}$$
$$\beta(\tau) \tag{2}$$
$$\tau \in [0, \infty] \tag{3}$$

Minimize:

$$\sum_{w\in W(\tau)} \sum_{p\in P(\tau)} strategic\_value_{wp}(\tau) \cdot \alpha_{wp}(\tau) + \sum_{p\in P(\tau)} \sum_{r\in R(\tau)} strategic\_penalty \cdot \epsilon_{pr}(\tau) + \sum_{p\in P(\tau)} \sum_{w1\in W(\tau)} \sum_{w2\in W(\tau)} clustering\_value_{w1,w2} \cdot \alpha_{w1p}(\tau) \cdot \alpha_{w2p}(\tau) \tag{4}$$

Subject to:

$$\sum_{w\in W(\tau)} work\_order\_work_{wr} \cdot \alpha_{wp}(\tau) \leq resource_{pr}(\tau, \beta(\tau)) + \epsilon_{pr}(\tau) \quad \forall p \in P(\tau) \quad \forall r \in R(\tau) \tag{5}$$
$$\sum_{w\in W(\tau)} \alpha_{wp}(\tau) = 1 \quad \forall p \in P(\tau) \tag{6}$$
$$\alpha_{wp}(\tau) = 0 \quad \forall (w,p) \in exclude(\tau) \tag{7}$$
$$\alpha_{wp}(\tau) = 1 \quad \forall (w,p) \in include(\tau) \tag{8}$$
$$\alpha_{wp}(\tau) \in \{0,1\} \quad \forall w \in W(\tau) \quad \forall p \in P(\tau) \tag{9}$$
$$\epsilon_{pr}(\tau) \in \mathbb{R}^+ \quad \forall p \in P(\tau) \quad \forall r \in R(\tau) \tag{10}$$

Tactical

Meta variables:

$$s \in S \tag{11}$$
$$\alpha(\tau) \tag{12}$$
$$\tau \in [0, \infty] \tag{13}$$

Minimize:

$$\sum_{o\in O(\tau,\alpha(\tau))} \sum_{d\in D(\tau)} tactical\_value_{do}(\tau) \cdot \beta_{do}(\tau) + \sum_{r\in R(\tau)} \sum_{d\in D(\tau)} tactical\_penalty \cdot \mu_{rd}(\tau) \tag{14}$$

Subject to:

$$\sum_{o\in O(\tau,\alpha(\tau))} work_o(\tau) \cdot \beta_{do}(\tau) \leq tactical\_resource_{dr}(\tau) + \mu_{rd}(\tau) \forall d \in D(\tau) \quad \forall r \in R(\tau) \tag{15}$$
$$\sum_{d=earliest\_start_o(\tau)}^{latest\_finish_o(\tau)} \sigma_{do}(\tau) = duration_o(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{16}$$
$$\sum_{d^*\in D_{duration_o(\tau)}(\tau)} \sigma_{d^*o}(\tau) = duration_o(\tau) \cdot \eta_{do}(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \quad \forall d \in D(\tau) \tag{17}$$
$$\sum_{o\in O(\tau,\alpha(\tau))} \eta_{do}(\tau) = 1, \quad \forall d \in D(\tau)$$
$$\sum_{d\in D(\tau)} d \cdot \sigma_{do1}(\tau) + \Delta_o(\tau) = \sum_{d\in D(\tau)} d \cdot \sigma_{do2}(\tau) \quad \forall (o1, o2) \in finish\_start_{o1,o2} \tag{18}$$
$$\sum_{d\in D(\tau)} d \cdot \sigma_{do1}(\tau) = \sum_{d\in D(\tau)} d \cdot \sigma_{do2}(\tau) \quad \forall (o1, o2) \in start\_start_{o1,o2} \tag{19}$$
$$\beta_{do}(\tau) \leq number_o(\tau) \cdot operating\_time_o \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{20}$$
$$\beta_{do}(\tau) \in \mathbb{R} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{21}$$
$$\mu_{rd}(\tau) \in \mathbb{R} \quad \forall r \in R(\tau) \quad \forall d \in D(\tau) \tag{22}$$
$$\sigma_{do}(\tau) \in \{0,1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{23}$$
$$\eta_{do}(\tau) \in \{0,1\} \quad \forall d \in D(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{24}$$
$$\Delta_o(\tau) \in \{0,1\} \quad \forall o \in O(\tau, \alpha(\tau)) \tag{25}$$

Supervisor

Meta variables:

$$z \in Z \tag{26}$$
$$\alpha(\tau) \tag{27}$$
$$\theta(\tau) \tag{28}$$
$$\tau \in [0, \infty] \tag{29}$$

Maximize:

$$\sum_{a\in A(\tau,\alpha(\tau))} \sum_{t\in T(\tau)} supervisor\_value_{at}(\tau, \lambda_t(\tau), \Lambda_t(\tau)) \cdot \gamma_{at}(\tau) \tag{30}$$

Subject to:

$$\sum_{a\in A_o(\tau,\alpha(\tau))} \rho_a(\tau) = work_o(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{31}$$
$$\sum_{t\in T(\tau)} \sum_{a\in A_o(\tau,\alpha(\tau))} \gamma_{at}(\tau) = \phi_o(\tau) \cdot number_o(\tau) \quad \forall o \in O(\tau, \alpha(\tau)) \tag{32}$$
$$\sum_{o\in O_w(\tau,\alpha(\tau))} \phi_o(\tau) = |O_w(\tau, \alpha(\tau))| \quad \forall w \in W(\tau, \alpha(\tau)) \tag{33}$$
$$\sum_{a\in A_o(\tau,\alpha(\tau))} \gamma_{at}(\tau) \leq 1 \quad \forall o \in O(\tau, \alpha(\tau)) \quad \forall t \in T(\tau) \tag{34}$$
$$\gamma_{at}(\tau) \leq feasible_{at}(\theta(\tau)) \quad \forall o \in O(\tau, \alpha(\tau)) \quad \forall t \in T(\tau) \tag{35}$$
$$\gamma_{at}(\tau) \in \{0,1\} \quad \forall o \in O(\tau, \alpha(\tau)) \quad \forall t \in T(\tau) \tag{36}$$
$$\rho_a(\tau) \in [lower\_activity\_work_a(\tau), work_a(\tau)] \quad \forall a \in A(\tau, \alpha(\tau)) \tag{37}$$

Operational

Meta variables:

$$t \in T(\tau) \tag{38}$$
$$\alpha(\tau) \tag{39}$$
$$\gamma(\tau) \tag{40}$$
$$\tau \in [0, \infty] \tag{41}$$

Maximize:

$$\sum_{a\in A(\tau,\gamma_t(\tau))} \sum_{k\in K(\gamma(\tau))} \delta_{ak}(\tau) \tag{42}$$

Subject to:

$$\sum_{k\in K(\gamma(\tau))} \delta_{ak}(\tau) \cdot \pi_{ak}(\tau) = activity\_work_a(\tau, \rho(\tau)) \cdot \theta \quad (\tau) \forall a \in A(\tau, \gamma_t(\tau)) \tag{43}$$
$$\lambda_{a21}(\tau) \geq \Lambda_{a1last(a1)}(\tau) + preparation_{a1,a2} \quad \forall a1 \in A(\tau, \gamma_t(\tau)) \quad \forall a2 \in A(\tau, \gamma_t(\tau)) \tag{44}$$
$$\lambda_{ak}(\tau) \geq \Lambda_{ak-1}(\tau) - constraint\_limit \cdot (2 - \pi_{ak}(\tau) + \pi_{ak-1}(\tau)) \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{45}$$
$$\delta_{ak}(\tau) = \Lambda_{ak}(\tau) - \lambda_{ak}(\tau) \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{46}$$
$$\lambda_{ak}(\tau) \geq event_{ie} + duration_{ie} - constraint\_limit \cdot (1 - \omega_{akie}(\tau)) \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{47}$$
$$\Lambda_{ak}(\tau) \leq event_{ie} + constraint\_limit \cdot \omega_{akie}(\tau) \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{48}$$
$$\lambda_{a1}(\tau) \geq time\_window\_start_a(\beta(\tau)) \quad \forall a \in A(\tau, \gamma_t(\tau)) \tag{49}$$
$$\Lambda_{alast(a)}(\tau) \leq time\_window\_finish_a(\beta(\tau)) \quad \forall a \in A(\tau, \gamma_t(\tau)) \tag{50}$$
$$\pi_{ak}(\tau) \in \{0,1\} \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{51}$$
$$\lambda_{ak}(\tau) \in [availability\_start(\tau), availability\_finish(\tau)] \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{52}$$
$$\Lambda_{ak}(\tau) \in [availability\_start(\tau), availability\_finish(\tau)] \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{53}$$
$$\delta_{ak}(\tau) \in [0, work_{a\_to\_o(a)}(\tau)] \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \tag{54}$$
$$\omega_{akie}(\tau) \in \{0,1\} \quad \forall a \in A(\tau, \gamma_t(\tau)) \quad \forall k \in K(\gamma(\tau)) \quad \forall i \in I(\tau) \quad \forall e \in E(\tau) \tag{55}$$
$$\theta_a(\tau) \in \{0,1\} \quad \forall a \in A(\tau, \gamma_t(\tau)) \tag{56}$$

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