Multi-model Maintenance Scheduling

Christian Brunbjerg Jespersen

Technical University of Denmark

Introduction

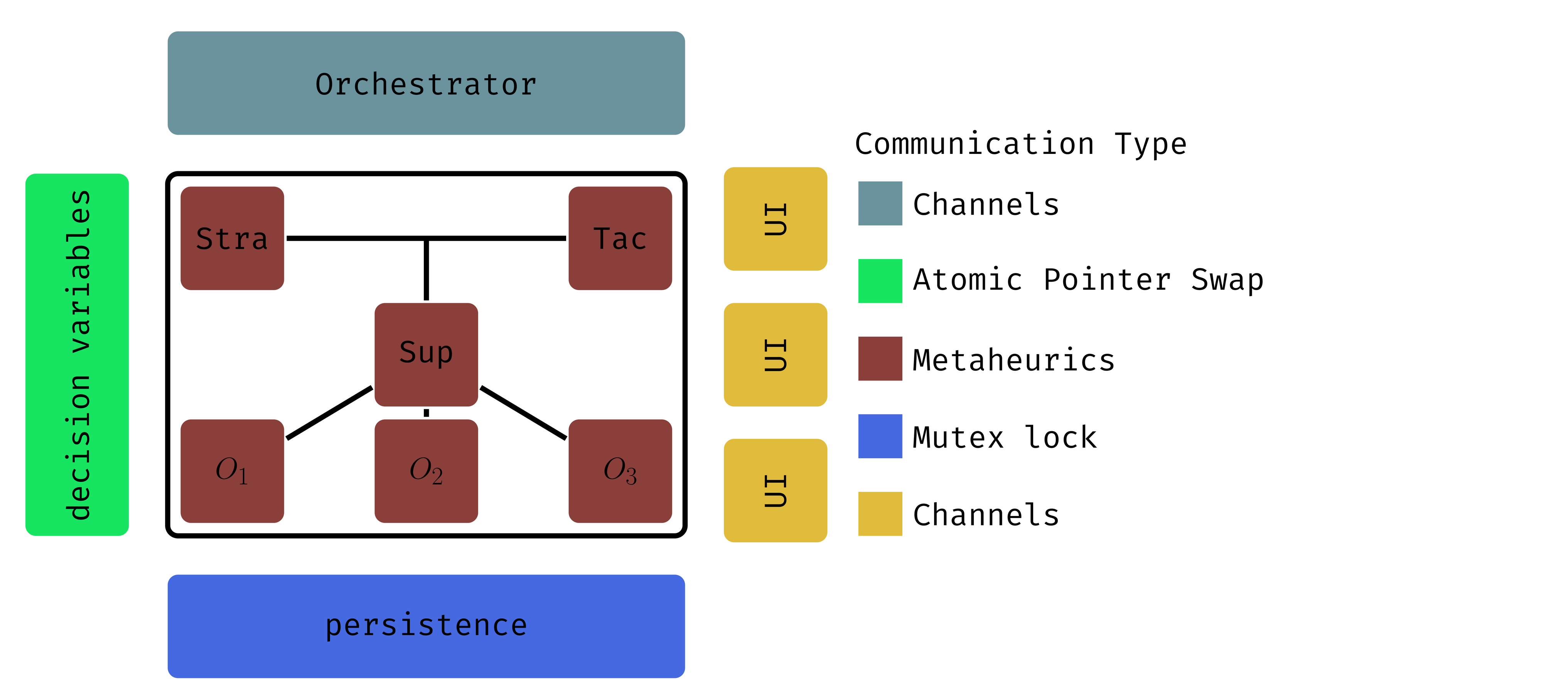
Current Operation Research methods have proven difficult to implement in operational settings. The poster presents a methodology to decompose a large-scale decision process into a series of modules that each represents the decisions taken by each individual stakeholder making up the scheduling process.

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
    Q.push(m)
until
```

Future Work

- Extend the approach to international supply chains.
- Incorporate real-time data analytics for dynamic decision-making.
- Explore applications in other sectors like healthcare and transportation.

Conclusion

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:

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

Results

Contact Information:

- **Email:** cbrje@dtu.dk
- **Phone:** 0045 28 43 39 74
-

ties.