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SFSM: A Serverless Function Scheduling Method for FaaS Applications over Edge Computing

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Serverless Computing

aws Lambda

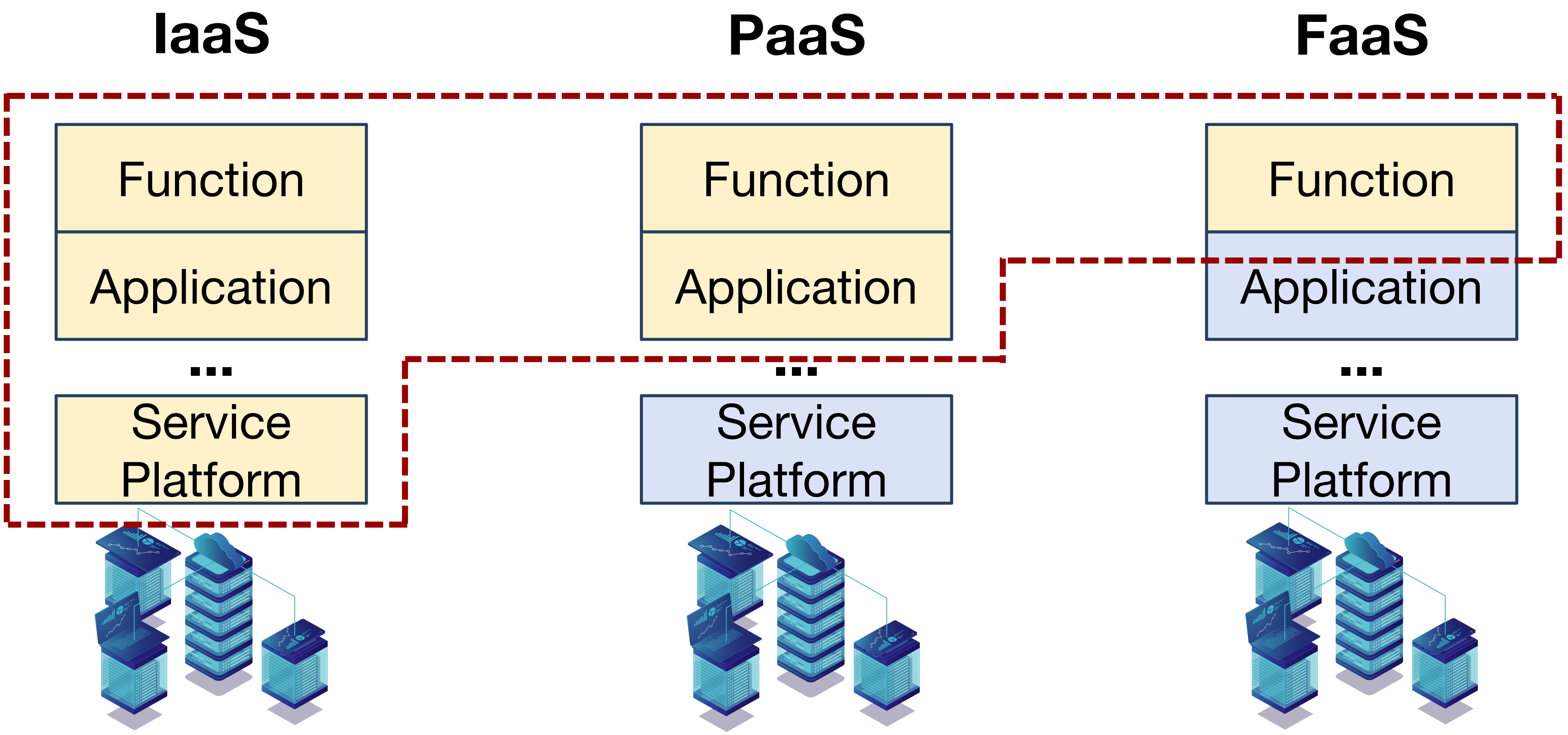
Google Cloud Functions

Azure Functions

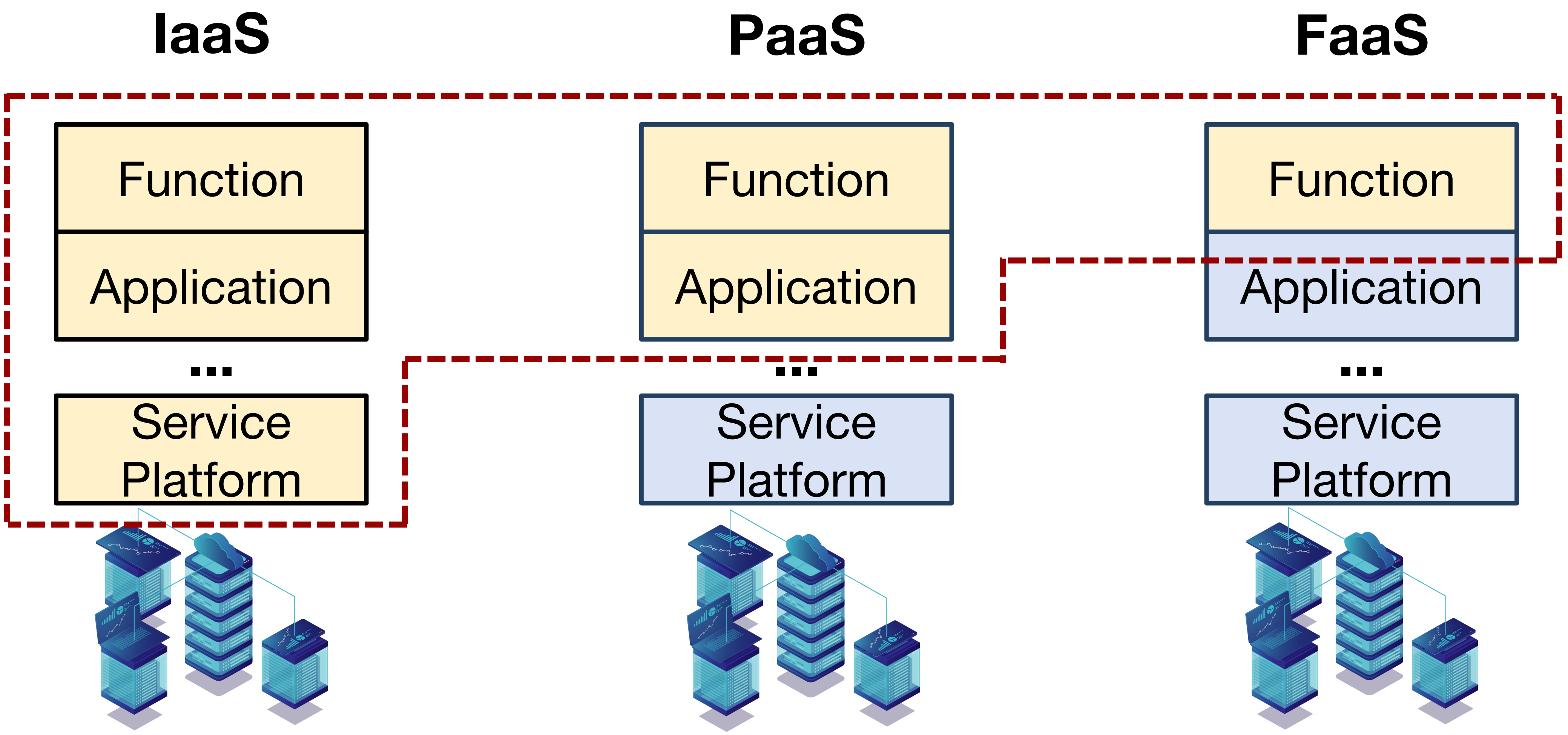
IBM Cloud Functions

[1] AWS Lambda: https://aws.amazon.com/lambda
[2] Google Cloud Functions: https://cloud.google.com/functions
[3] Microsoft Azure Functions: https://azure.microsoft.com/en-us/products/functions
[4] IBM Cloud Functions: https://cloud.ibm.com/functions

Function as a Services (FaaS)



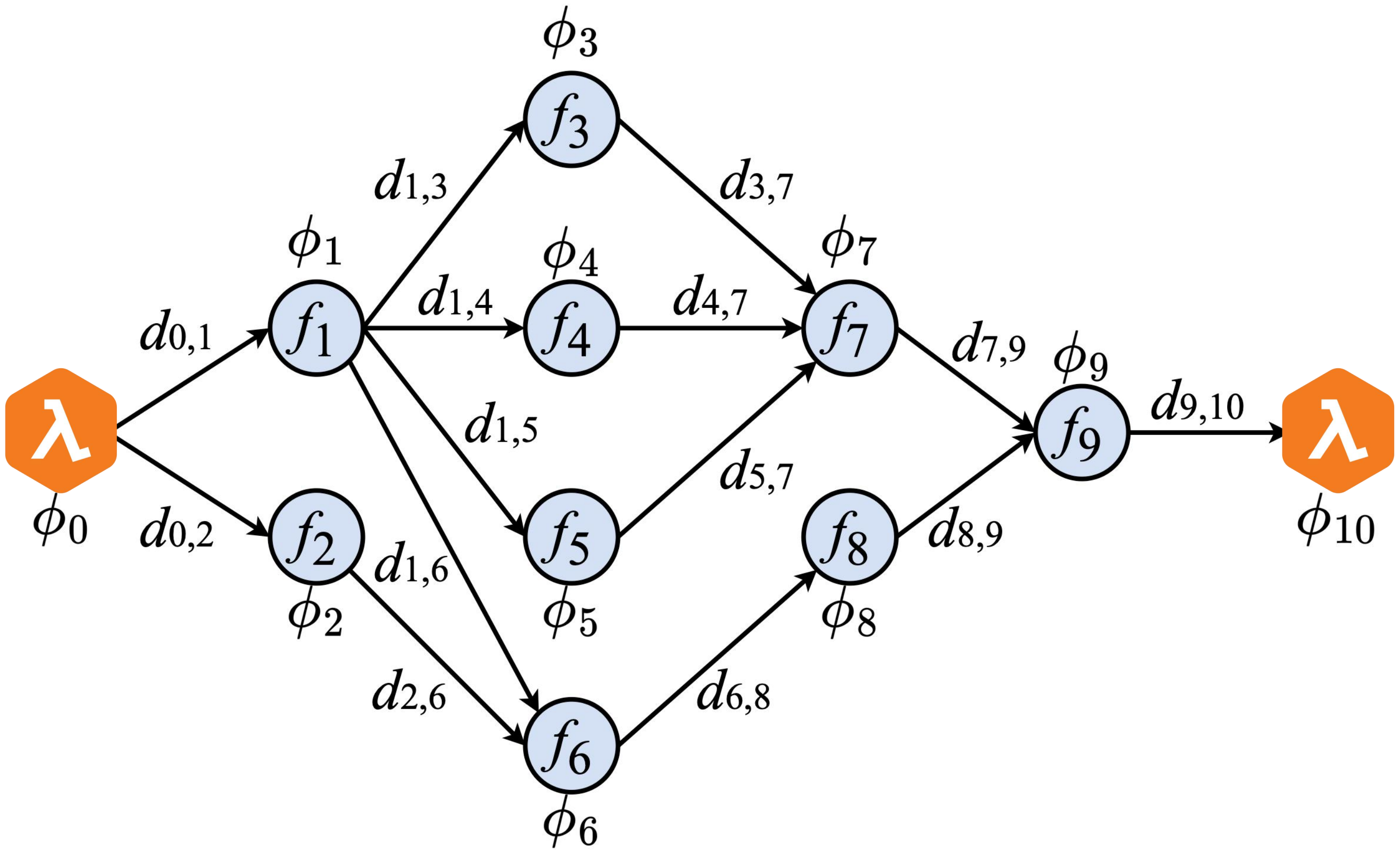
Function as a Services (FaaS)



Pay only for what you use!

Serverless Workloads

- Abstract as a Direct Acyclic Graph (DAG)
- Constrained by computation & data dependencies



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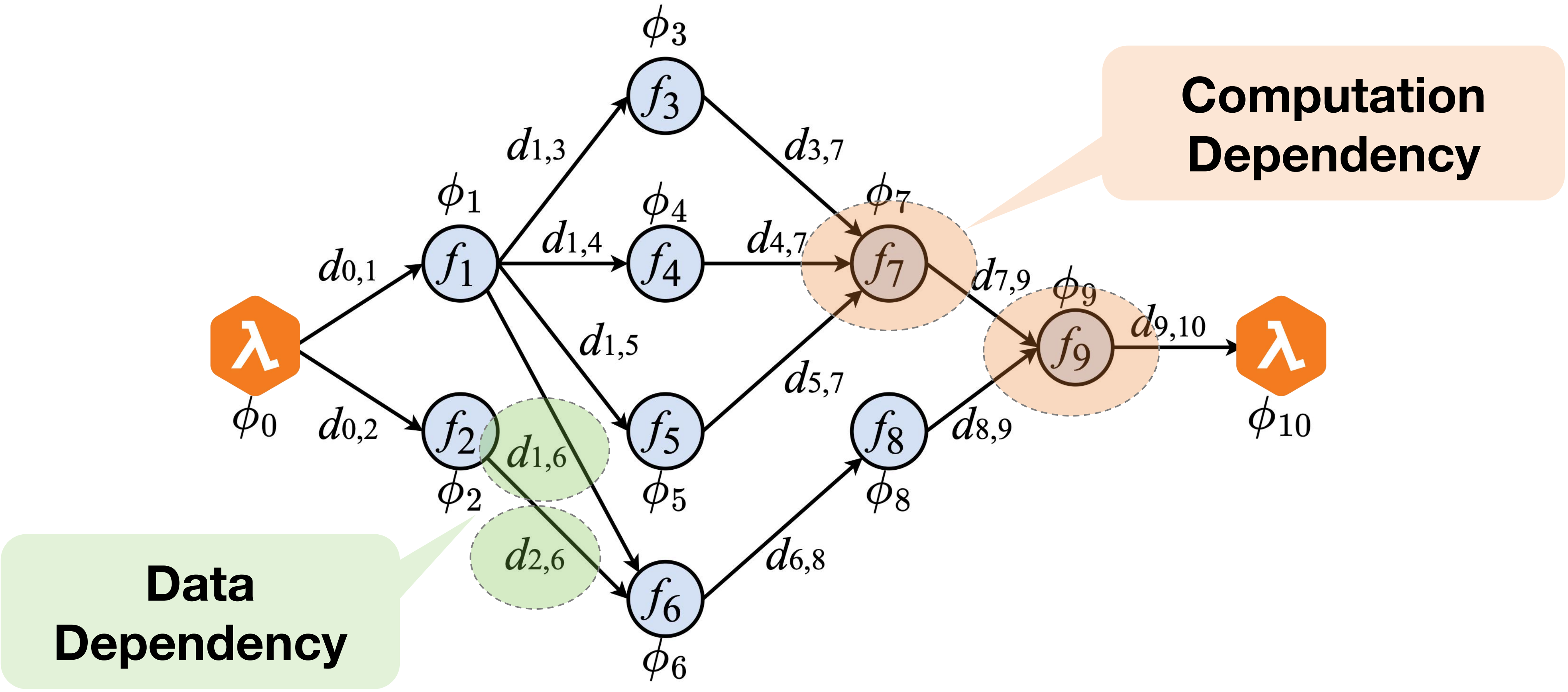
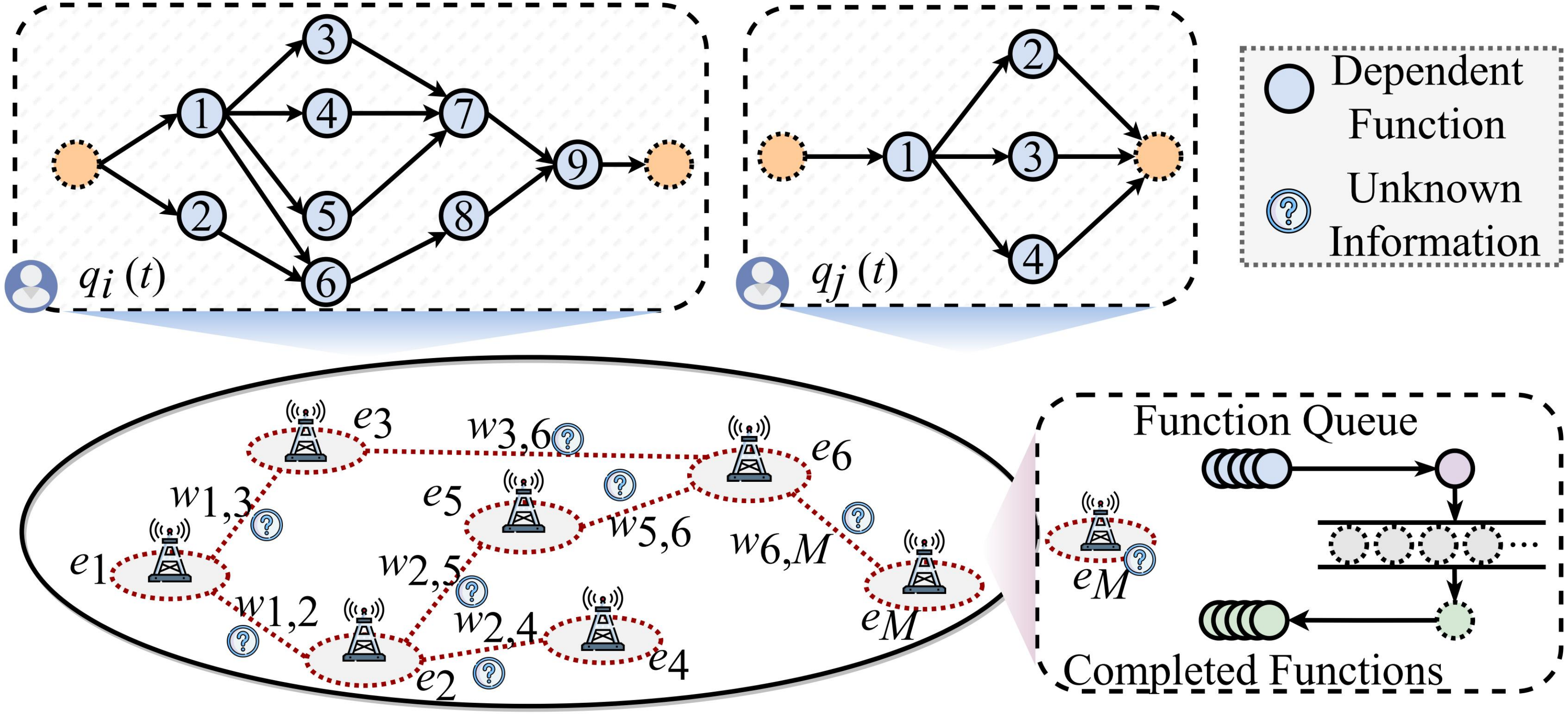


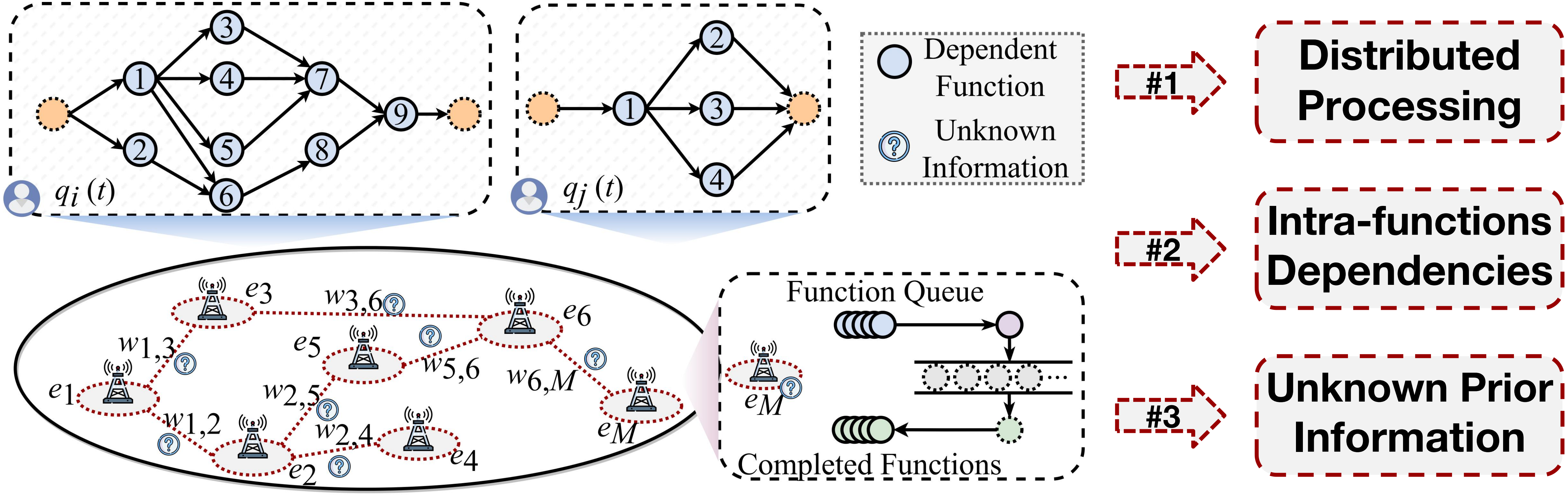
Serverless Edge Computing

- Unleash resources **from cloud to network edge**
- To meet **latency-sensitive** FaaS application demands



- **Low Latency**
- **High Scalablity**
- **Cost-Efficiency**

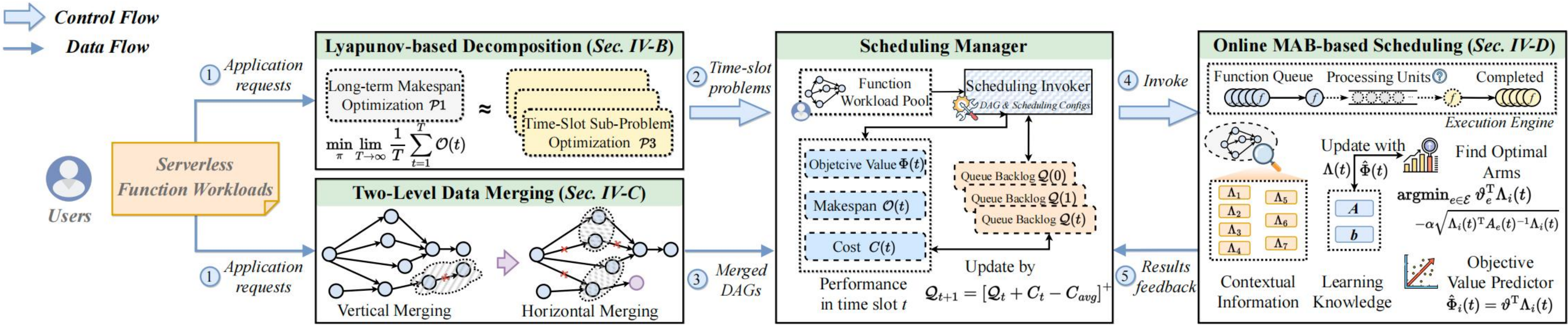
Motivation



How to schedule serverless functions in edge coputing systems with no priors?

Our Solution: SFSM

SFSM Overview

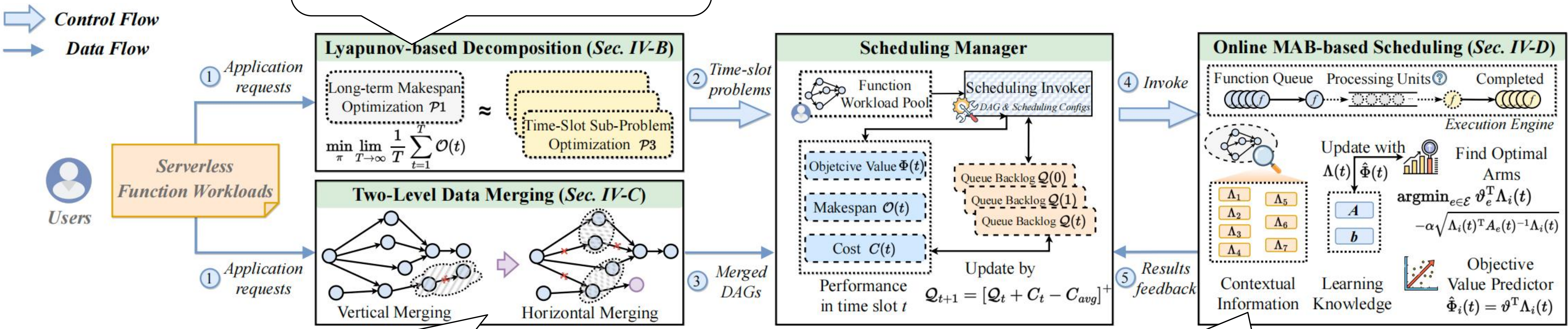


Our Solution: SFSM

(Step 1)

Layapunov-based Decomposition

SFSM Overview



Two-Level Data Merging

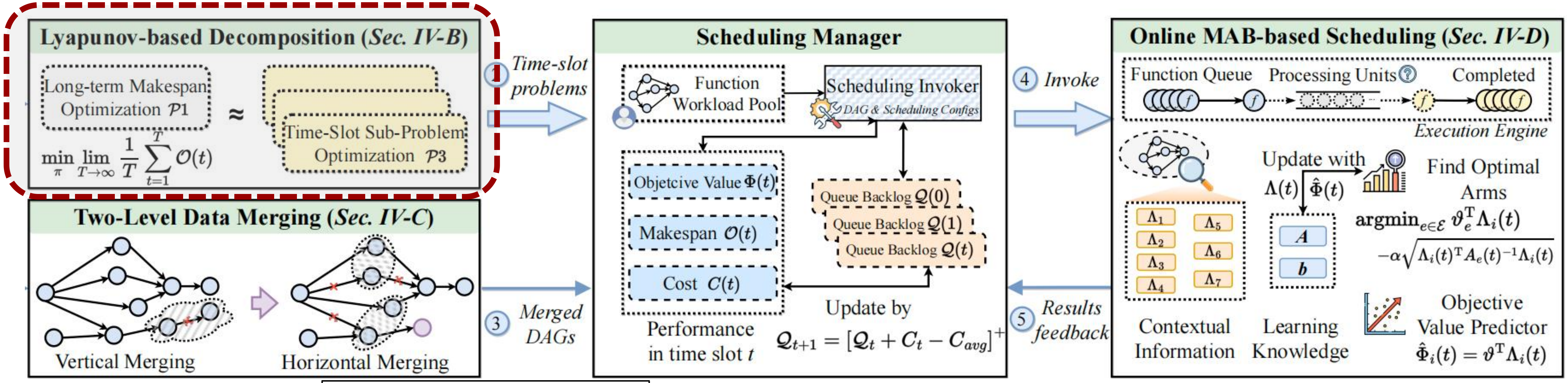
(Step 2)

Online MAB-based Scheduling

(Step 3)

Design of SFSM

Step 1: Layapunov-based Decomposition



$$\mathcal{P}1: \quad \min_{\pi} \lim_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T} \mathcal{O}(t)$$

Long-term averaged makespan

$$\text{s.t.} \quad \mathcal{O}^{es}_{i,k}(t) \ge \max_{j\in\nu(f_i)} \{\mathcal{O}^{com}_{j,k}(t) + \mathcal{O}^{tr}_{i,j,k}(t)\},$$

$$\mathcal{O}^{es}_{i,k}(t) \ge \mathcal{O}^{conf}_{i,k}(t), \forall i \in \mathcal{F}, k \in \mathfrak{A},$$

$$\lim_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T} C(t) \le C_{avg},$$

$$\rho_{\pi_{f_i}(t),k}(t) \le \zeta_{\pi_{f_i}(t)}, \forall i \in \mathcal{F}, k \in \mathfrak{A},$$

$$\sum_{k=1}^{|\mathbf{q}|} \rho_{\pi_{f_i}(t),k}(t) \le \zeta_{\pi_{f_i}(t)}, \forall i \in \mathcal{F}.$$

Lyapunov-drift-plus-penalty

$$\mathcal{P}2: \quad \min_{\pi} \mathbb{E}\left[\Delta(\mathcal{Q}(t)) + V \cdot \mathcal{O}(t) | \mathcal{Q}(t)\right]$$

Approximated by upper bound

$$\mathcal{P}3: \quad \min_{\pi} \Phi(t) = B + V \cdot \mathcal{O}(t) + \mathcal{Q}(t)\left(C(t) - C_{avg}\right)$$

Design of SFSM

Step 1: Layapunov-based Decomposition

Algorithm 1: Long-term problem decomposition by Lyapunov optimization

---

Input: $\mathcal{U}$, $\mathfrak{A}$, C_{avg}, V, $\mathcal{Q}(0)$;
Output: $\pi(t)$ in each time slot $\forall t \in \mathcal{T}$;

for $t = 1$ *to* T **do**
    for $i = 1$ *to* I **do**
        if *Request* i *arrives* **then**
            Obtain the merged $\mathcal{A}_i(t)$ by **Alg.** 2;
            Derive the scheduling decision $\pi_i(t)$ by **Alg.** 3;
            Calculate $\mathcal{O}_i(t)$ and $C_i(t)$;
        end
        Update the virtual cost queue by Eq. (9);
        Set $\pi(t) \leftarrow \pi(t) \cup \pi_i(t)$;
    end
end
Return $\{\pi(1), \pi(2), \cdots, \pi(T)\}$.

Call Alg. 2 (data merging)
&
Alg. 3 (online scheduling)

Design of SFSM

Step 1: Layapunov-based Decomposition

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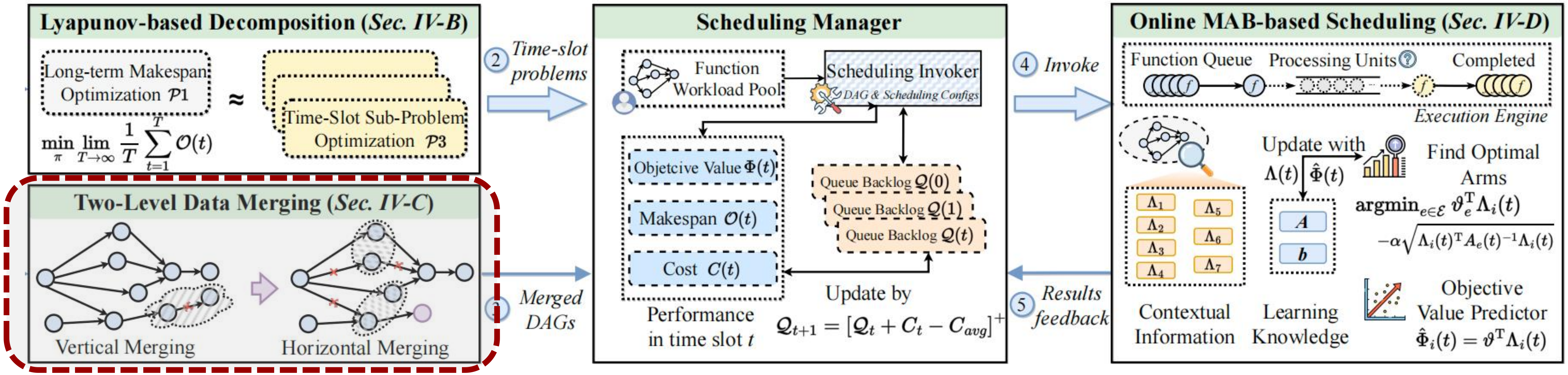
Update virtual cost queue based on Lyapunov optimization technique

Design of SFSM

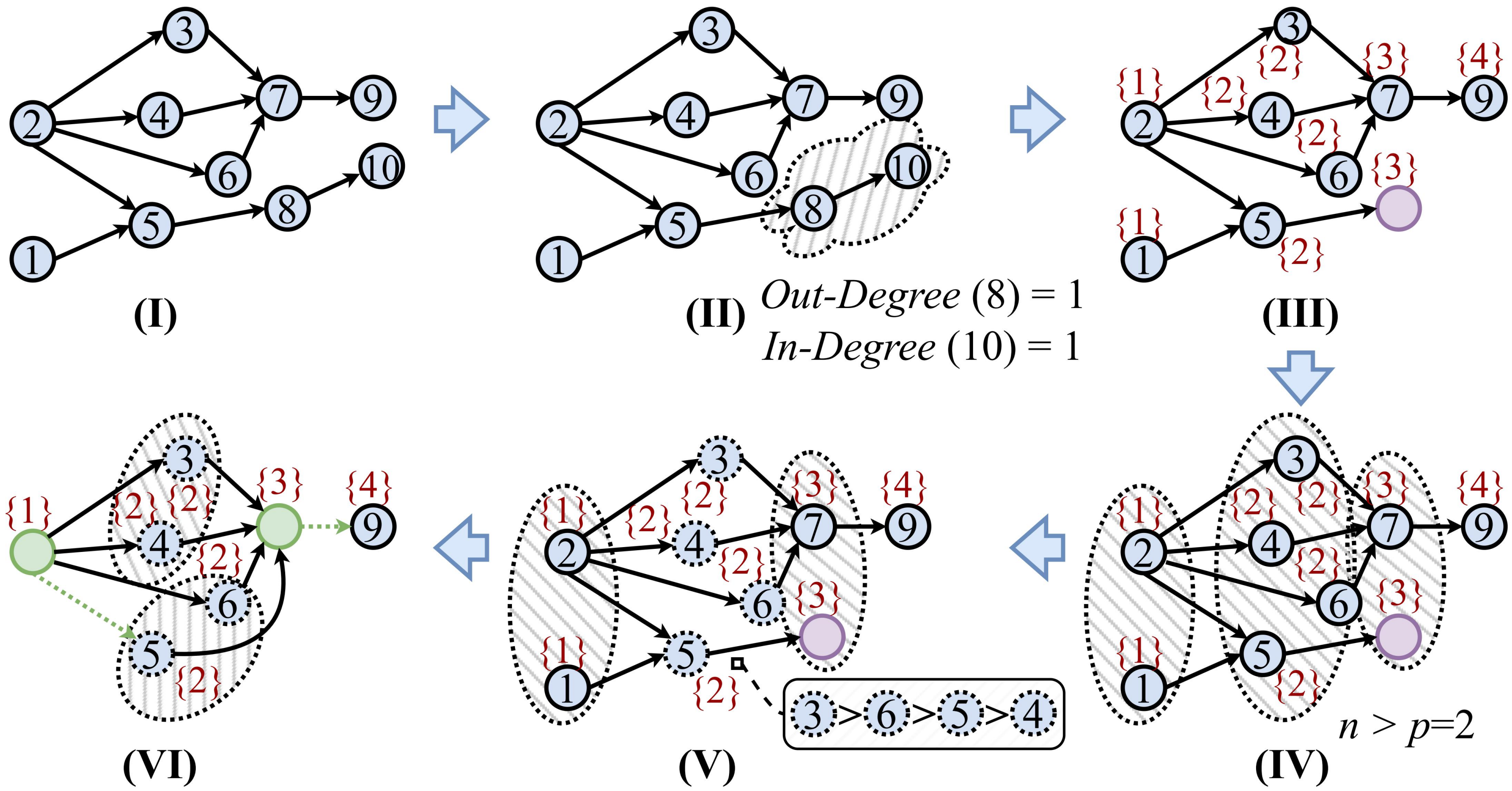
Step 2: Two-Level Data Merging



- **Vertical Merging:** find the node that only has one successor and its successor also has one predecessor.
- **Horizontal Merging:** integrate nodes at the same node levels to improve the parallel performance.

Design of SFSM

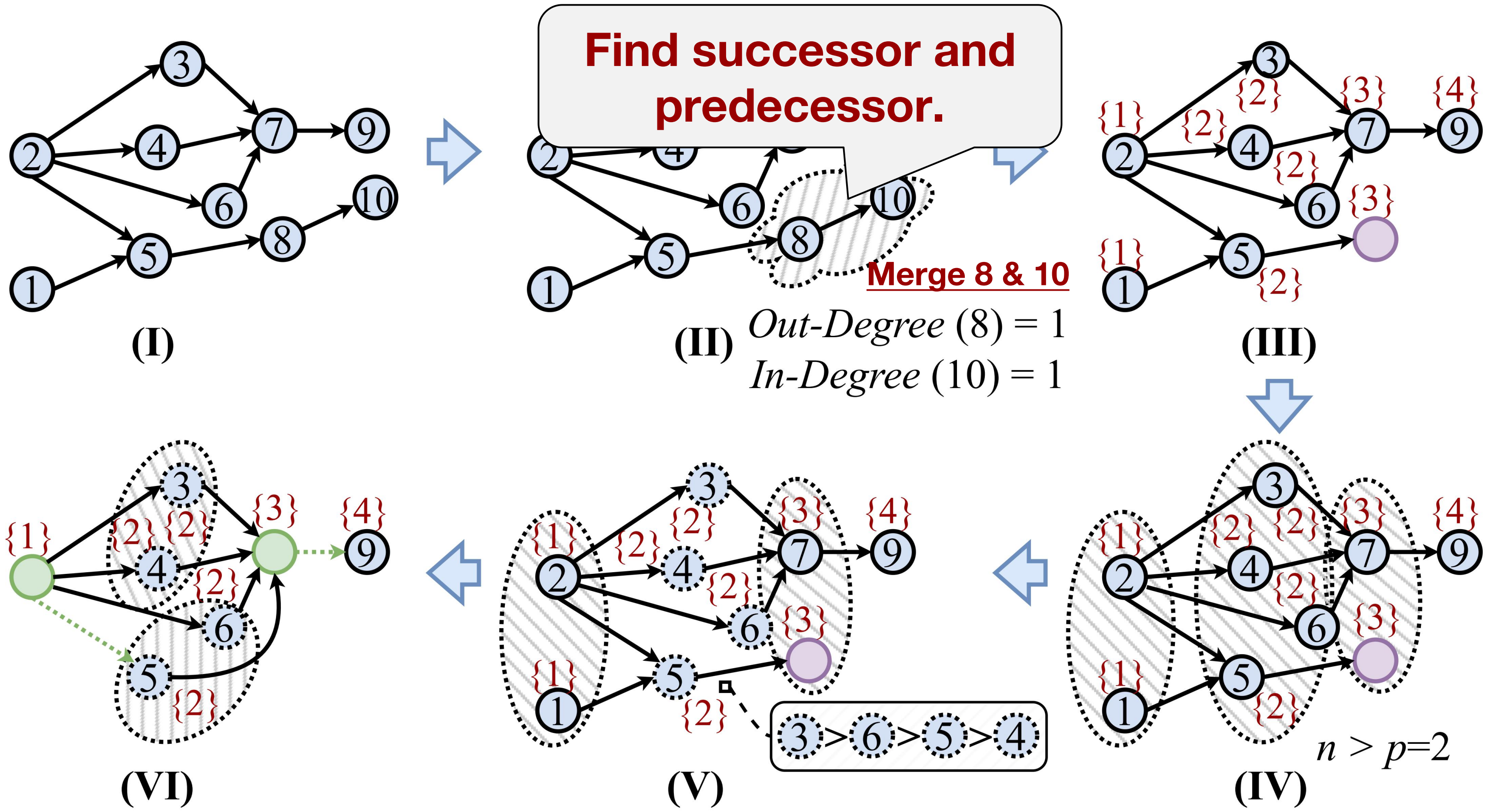
Step 2: Two-Level Data Merging



An example of 10 serverless functions

Design of SFSM

Step 2: Two-Level Data Merging



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Design of SFSM

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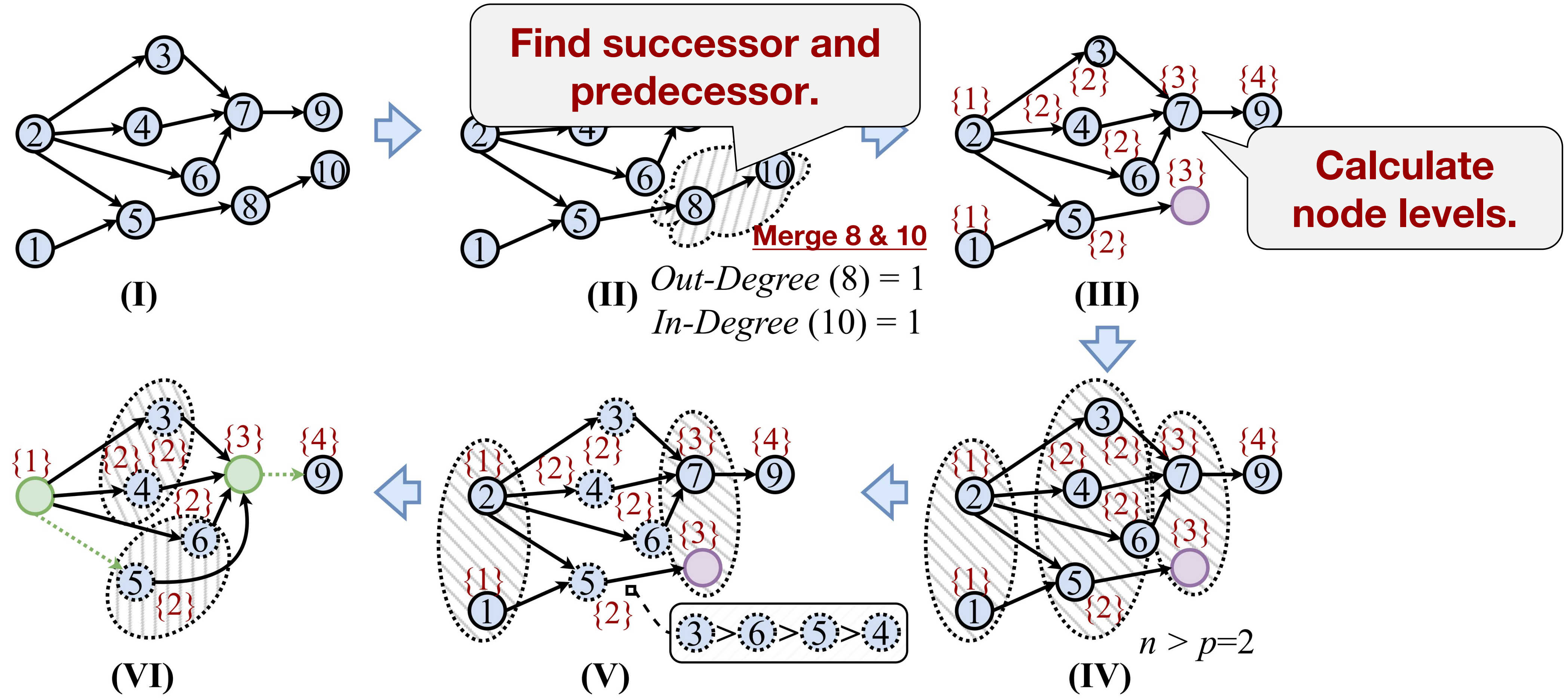

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Design of SFSM

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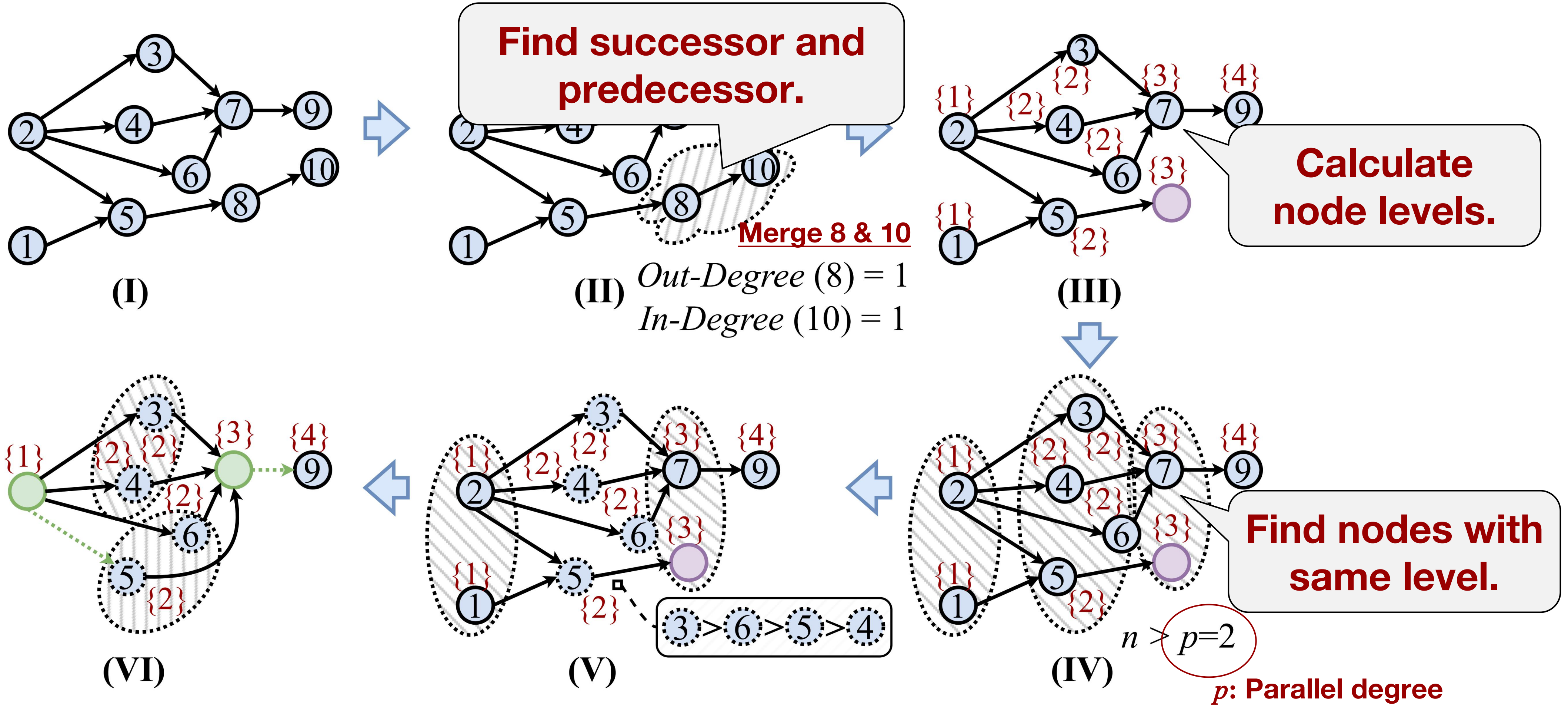

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Design of SFSM

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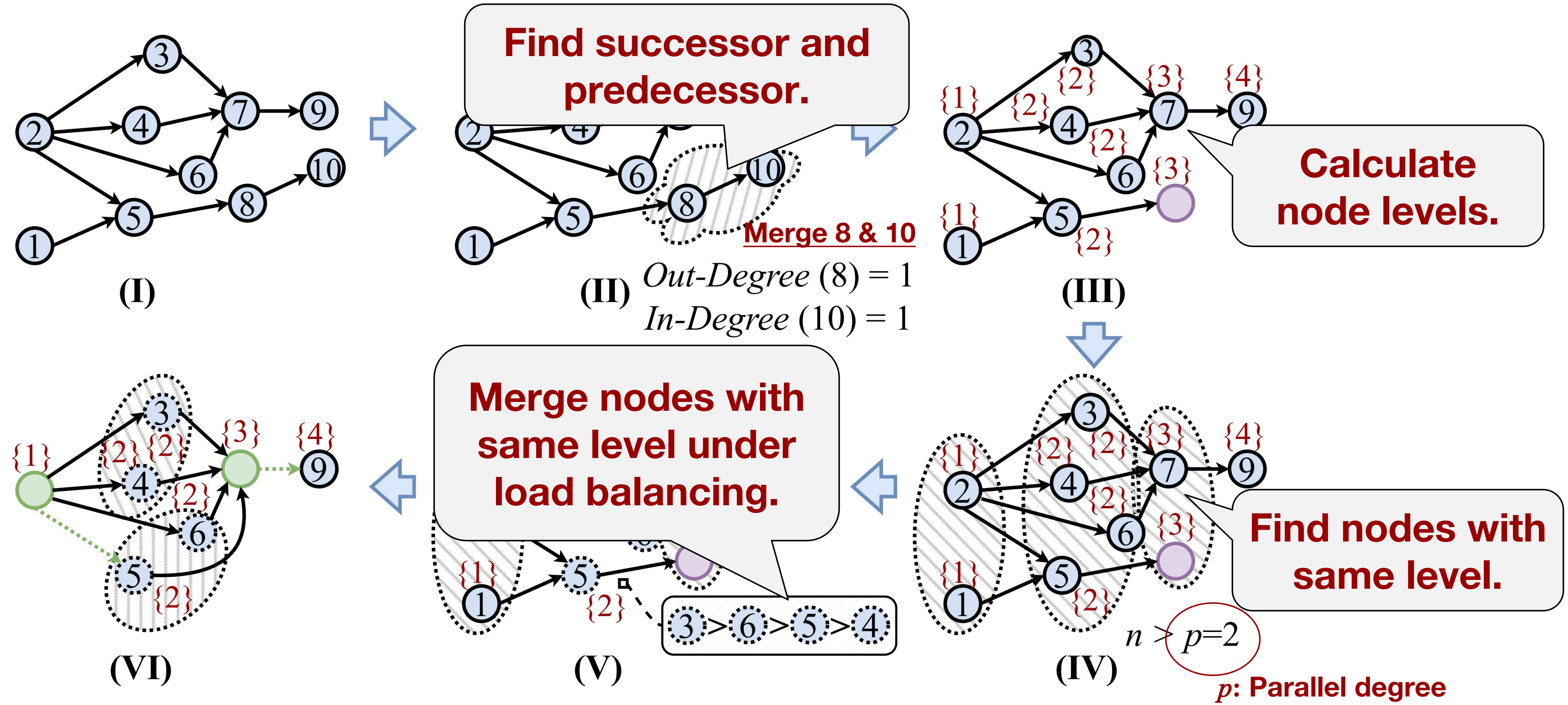

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Design of SFSM

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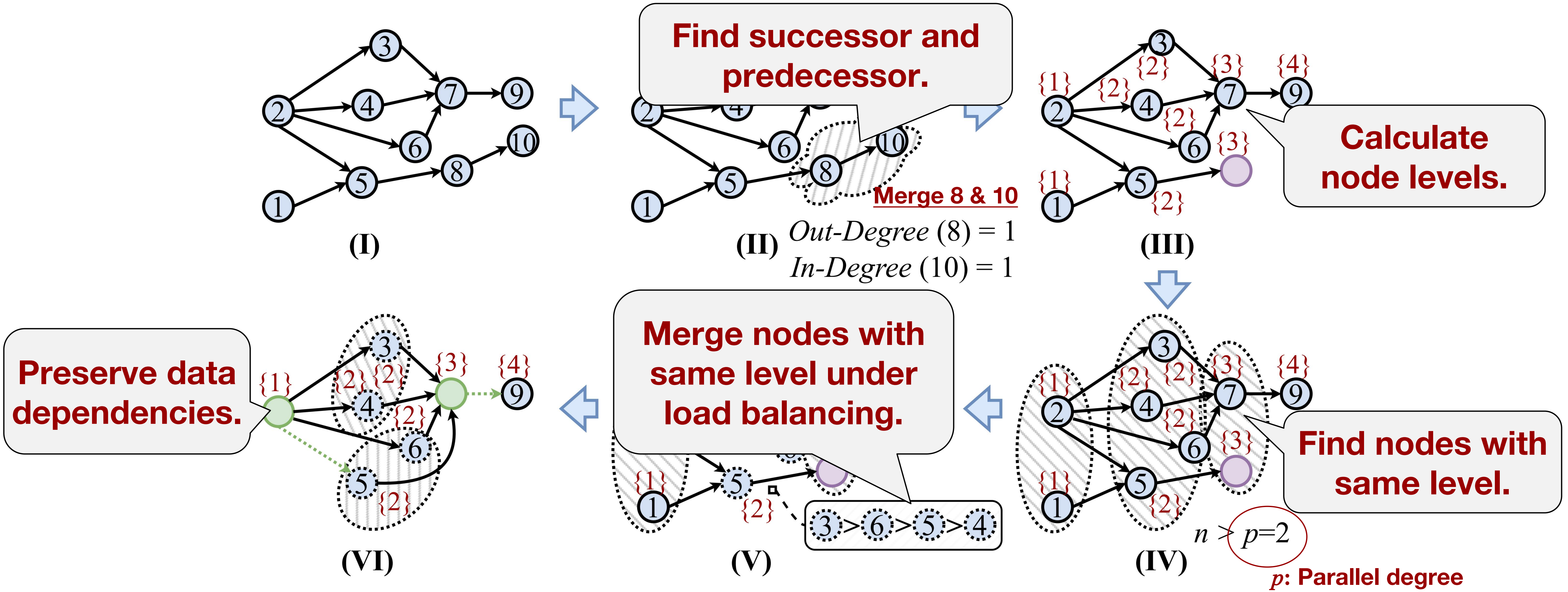


An example of 10 serverless functions

Design of SFSM

Step 2: Two-Level Data Merging

Algorithm 2: Two-level data merging

Input: $\mathcal{A}$, p, L;
Output: Merged DAG $\mathcal{A}'$;

for f *in topological sort of* $\mathcal{A}$ **do**
  if *out-degree*(f) *is* 1 **then**
    $g \leftarrow suc(f)$;
    if *in-degree*(g) *is* 1 *and pre*(g) *is* f **then**
      $\phi_f \leftarrow \phi_f + \phi_g$;
      $suc(f) \leftarrow suc(g)$;
      $del(g)$;
    end
  end
end

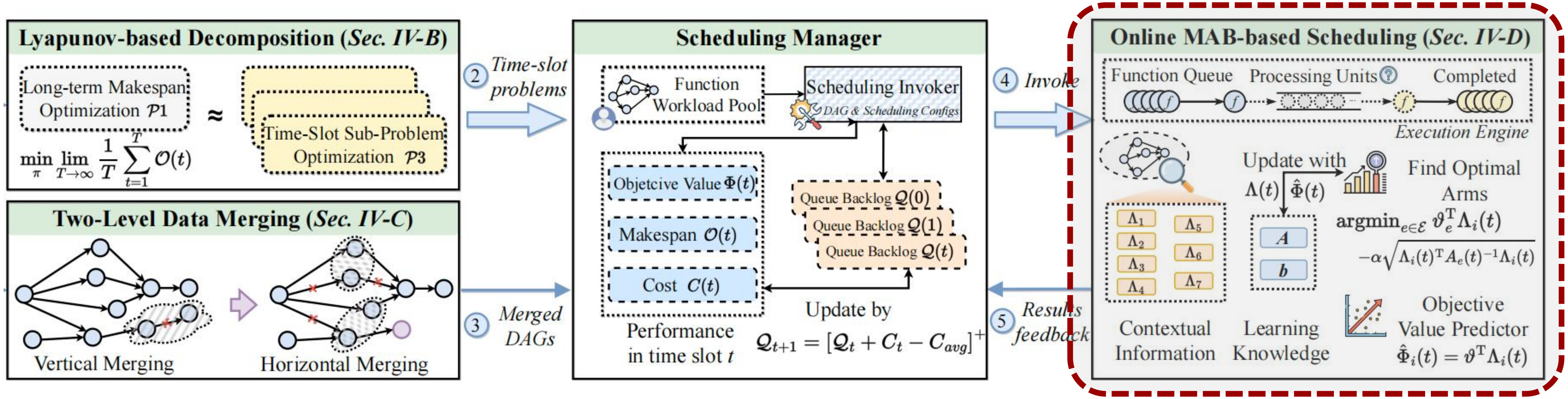
Vertical Merging

for $l = 1$ *to* L **do**
  for f *in group* l **do**
    $\mathbf{w} \leftarrow \mathbf{w} \cup \phi_f$;
  end
  Sort $\mathbf{w}$ in descending order;
  $i \leftarrow 1$, $j \leftarrow |\mathbf{w}|$;
  while $i < j$ **do**
    $n \leftarrow min(p, j - i + 1)$;
    $merge(\mathcal{A}', n)$;
    $\phi_{f1} \leftarrow \{\phi_{f1}, \phi_{f2}, \cdots, \phi_{fn}\}$;
    $suc(f_i) \leftarrow \{suc(f_i), suc(f_j), \cdots, suc(f_{i+\lceil \frac{n}{2} \rceil}), suc(f_{j-\lfloor \frac{n}{2} \rfloor})\}$;
    $pre(f_i) \leftarrow \{pre(f_i), pre(f_j), \cdots, pre(f_{i+\lceil \frac{n}{2} \rceil}), pre(f_{j-\lfloor \frac{n}{2} \rfloor})\}$;
    $del(\mathcal{A}', n)$;
    $i \leftarrow i + \lceil \frac{p}{2} \rceil$, $j \leftarrow j - \lfloor \frac{p}{2} \rfloor$;
  end
end
Return $\mathcal{A}'$.

Horizontal Merging

Design of SFSM

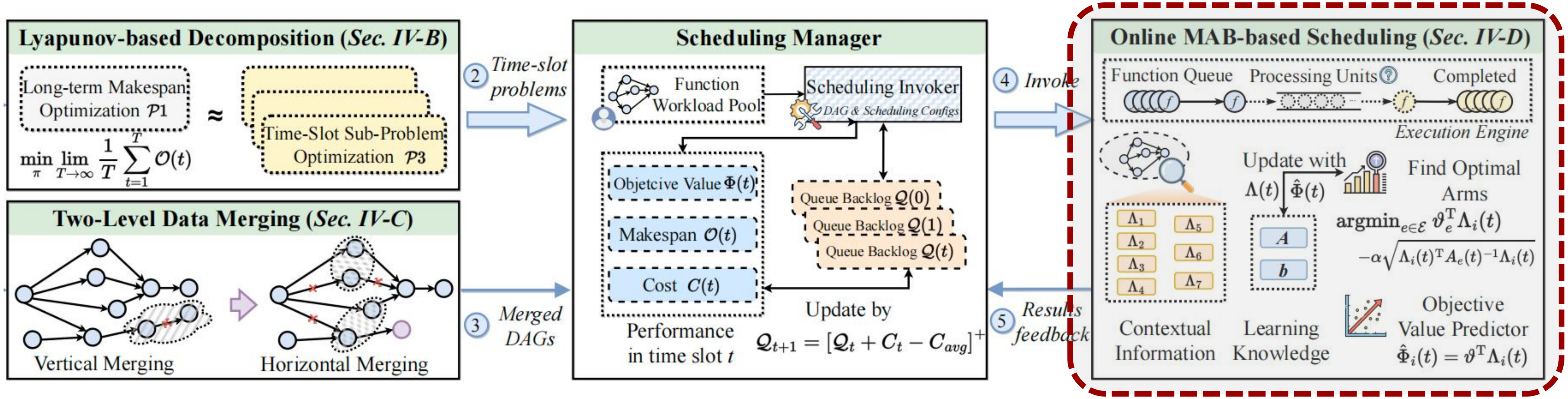
Step 3: Online MAB-based Scheduling



- **Contextual information:** request info, computations, data, etc.
- **Without any priors of edge networks:** i.e., transmission link and computing resources

Design of SFSM

Step 3: Online MAB-based Scheduling



$$\pi_i(t) = \text{argmin}\ \vartheta^{\mathrm{T}} \Lambda_i(t)$$

ridge regression

$$\pi_i(t) = \text{argmin}_{e\in\mathcal{E}} \left[\vartheta_e^{\mathrm{T}} \Lambda_i(t) - \alpha \sqrt{\Lambda_i(t)^{\mathrm{T}} A_e(t)^{-1} \Lambda_i(t)} \right]$$

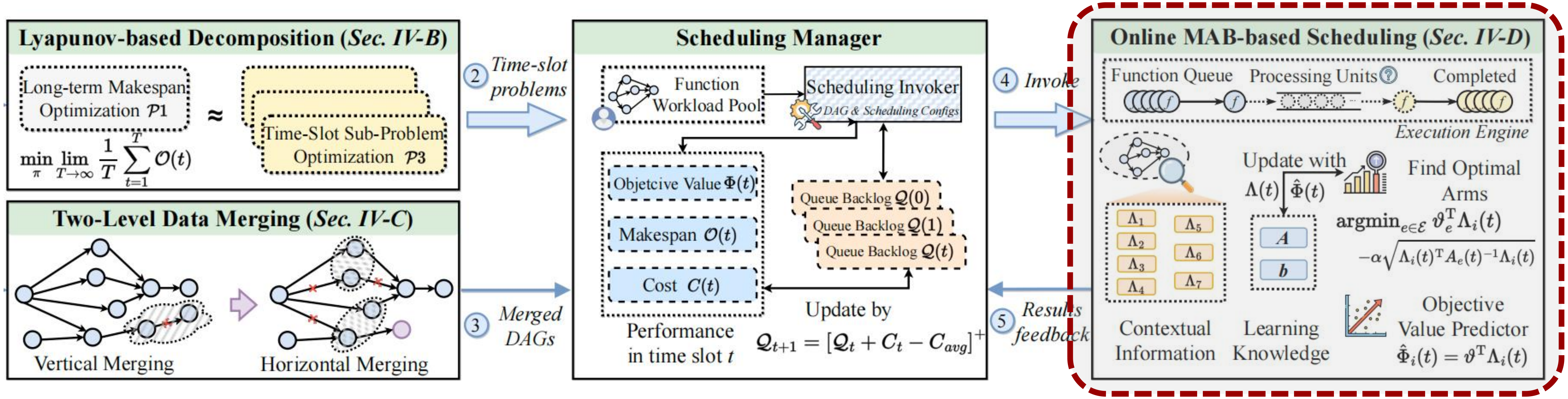
learnable weight

matrix of contextual information

balance exploration and exploitation

Design of SFSM

Step 3: Online MAB-based Scheduling



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exploration

learnable weight

matrix of contextual information

balance exploration and exploitation

Design of SFSM

Step 3: Online MAB-based Scheduling

Algorithm 3: Online serverless function scheduling

Input: $\mathcal{A}'_i$, $\mathcal{U}$;
Output: π_i;

Construct the contextual knowledge $\Lambda_i(t)$;
Initialize A_e and b_e, $\forall e \in \mathcal{E}$;
repeat
  for *f in topological sort of $\mathcal{A}'_i$* **do**
    for $e = 1$ *to* $|\mathcal{E}|$ **do**
      $\hat{\vartheta}_e(h) \leftarrow A_e^{-1}(h-1)b_e(h-1)$;
      $\hat{\Phi}_{f,e}(h) \leftarrow \hat{\vartheta}_e(h)^{\mathrm{T}}\Lambda_i(h) - \alpha\sqrt{\Lambda_i(h)^{\mathrm{T}}A_e(h)^{-1}\Lambda_i(h)}$;
    end
    $\pi_{i,f}(h) \leftarrow \operatorname{argmin}_{e\in\mathcal{E}}\hat{\Phi}_{f,e}(h)$;
    $\pi_i(h) \leftarrow \pi_i(h) \cup \pi_{i,f}(h)$;
  end
  for *Activated* $e \in \mathcal{E}$ **do**
    $A_e(h) \leftarrow A_e(h-1) + \Lambda_i(h)\Lambda_i(h)^{\mathrm{T}}$;
    $b_e(h) \leftarrow b_e(h-1) + \Lambda_i(h)\hat{\Phi}_{f,e}(h)$;
  end
  $\pi_i \leftarrow \pi_i \cup \pi_i(h)$;
until *Learning step h finished*;
Return π_i.

Calculate weight and predict objective value

Design of SFSM

Step 3: Online MAB-based Scheduling

Algorithm 3: Online serverless function scheduling

Input: $\mathcal{A}'_i$, $\mathcal{U}$;
Output: π_i;
Construct the contextual knowledge $\Lambda_i(t)$;
Initialize A_e and b_e, $\forall e \in \mathcal{E}$;
repeat
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  end
  $\pi_i \leftarrow \pi_i \cup \pi_i(h)$;
until *Learning step h finished*;
Return π_i.

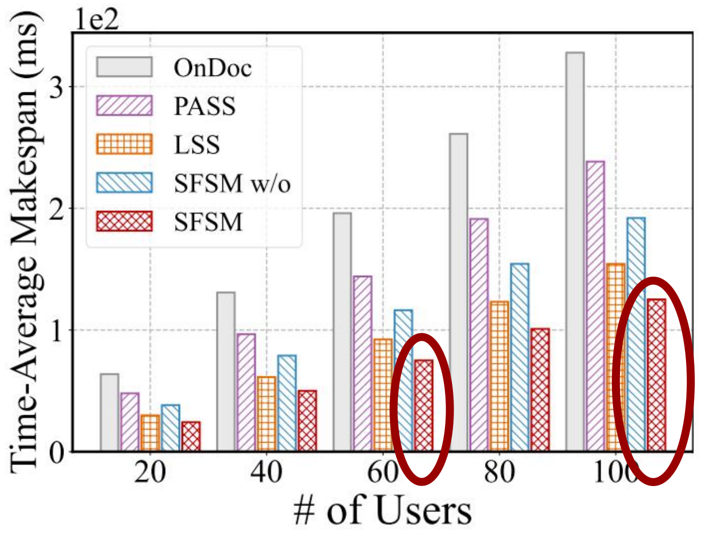
Select the target scheduling edge server with minimum value $\hat{\Phi}_i(t)$

Evaluation Settings

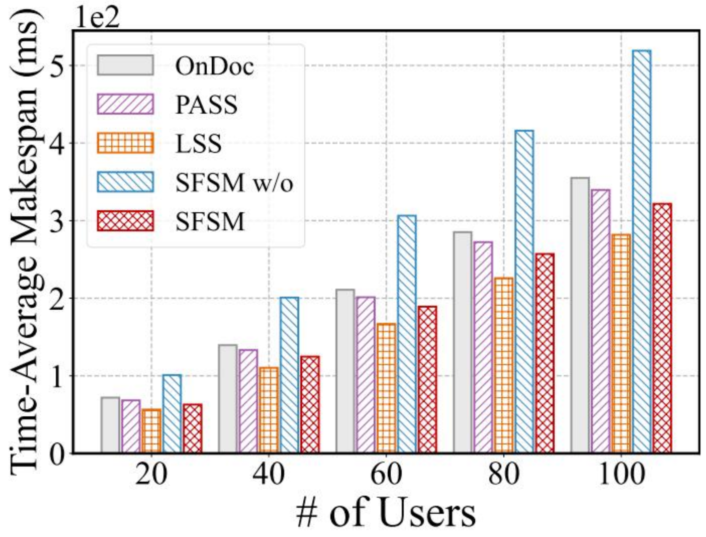
- **Workloads**
  - Alibaba cluster trace[1], which includes about 4000 machines in a periods of 8 days, over 20,000 applications
  - Three request modes, i.e., data-intensive, computation-intensive and both data and computation-intensive
- **Baselines**
  - OnDoc [TOSN 2023]
  - PASS [IWQoS 2022]
  - Latency-myopic Static Scheduling (LSS) [TPDS 2022, IWQoS 2019]
  - SFSM w/o
- **Metircs**
  - Time-Average Makespan
  - Time-Average Cost

[1] https://github.com/alibaba/clusterdata

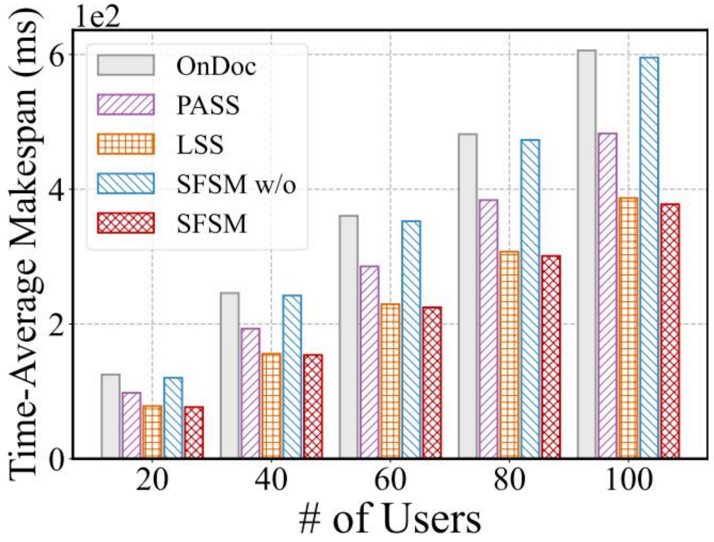
Evaluation: Makespan



(a) data-intensive



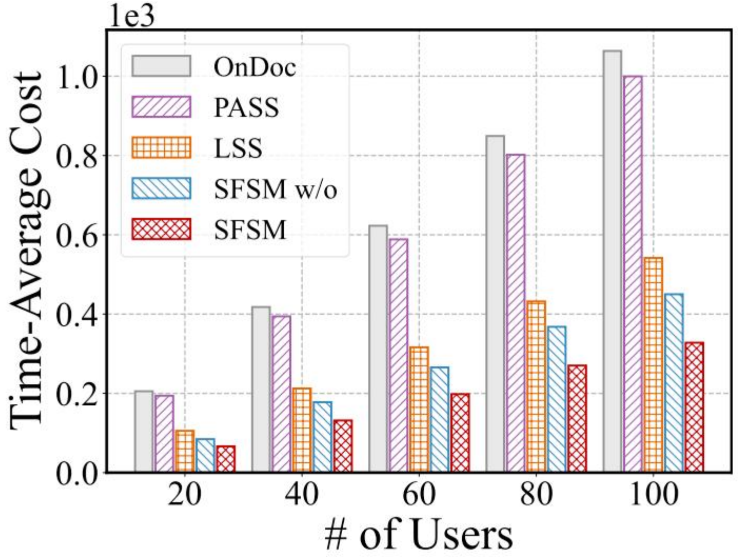
(b) computation-intensive



(c) both data and computation-intensive

Lower makespan, especially with intensive data req.

Evaluation: Cost



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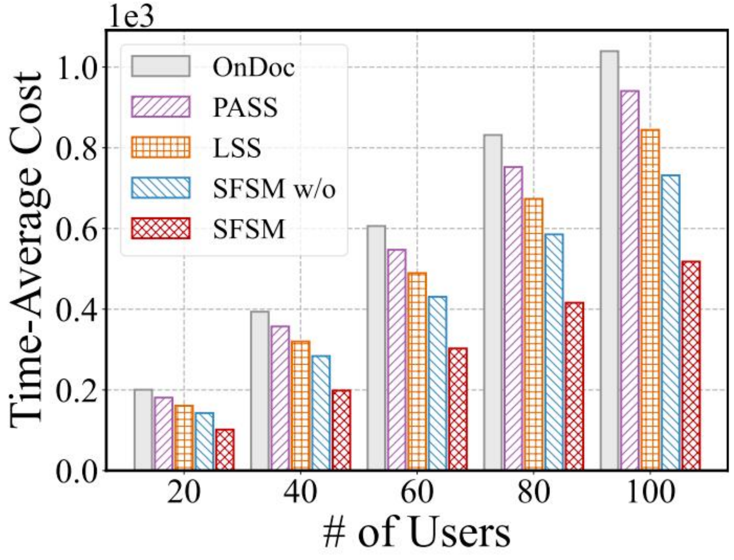
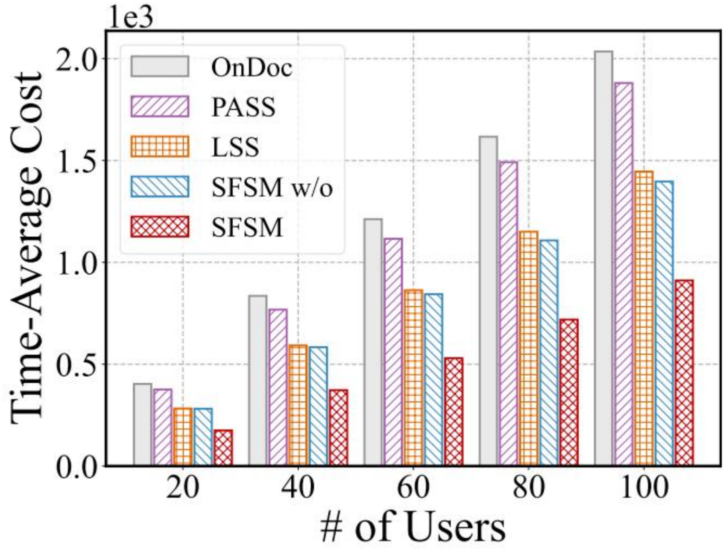


(b) computation-intensive



(c) both data and computation-intensive

Lower cost within different request modes

Conclusion

- SFSM aims to achieve the **long-term makespan** minimization while improving the execution cost
- Two-level data merging algorithm to **mitigate the transmission overhead** of redundant data
- **Online** contexual shceduling **without priors** to realize fine-grained decisions

Thank You For Your Attention!