Markov Blanket Composition of SLOs

TU Wien: Boris Sedlak, Victor Casamayor Pujol, Praveen Kumar Donta, Schahram Dustdar

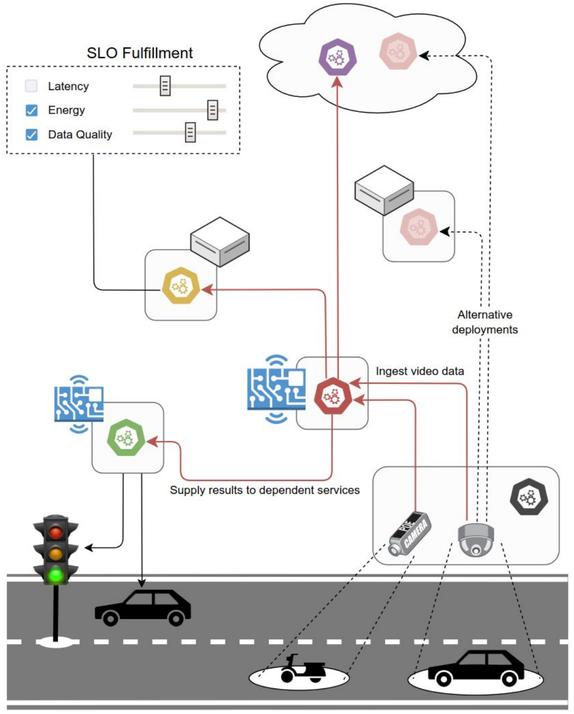
Problem Statement

Sensor systems are ubiquitous, e.g., **smart cities**, factories, etc

Composable microservice pipelines in smart city (e.g., road surveillance ⟶ object detection ⟶ traffic routing / monitoring)

Each service is dependent on the **outcome** of its predecessor; must fulfill QoS and QoE requirements, e.g., latency or quality. Requirements specified as Service Level Objectives (**SLOs**)

Hardware **heterogeneity** and transitive SLOs (imposed by dependent services) constrain where each service should be deployed, i.e., **Edge**, Fog, Cloud



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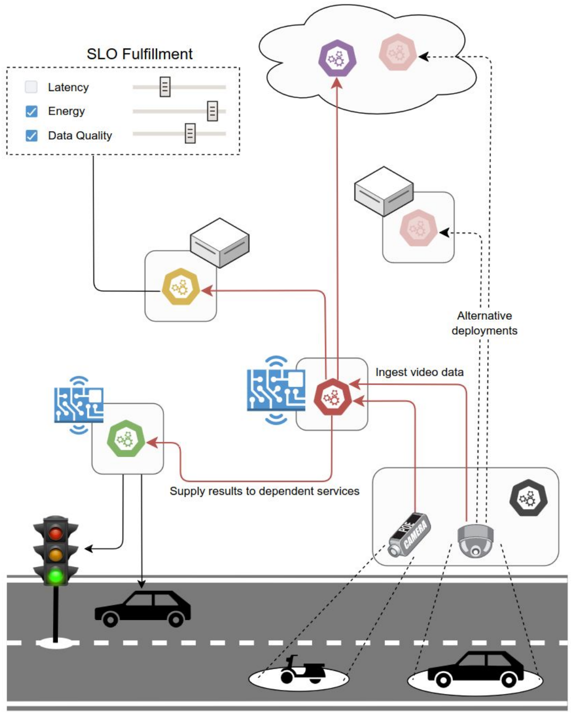

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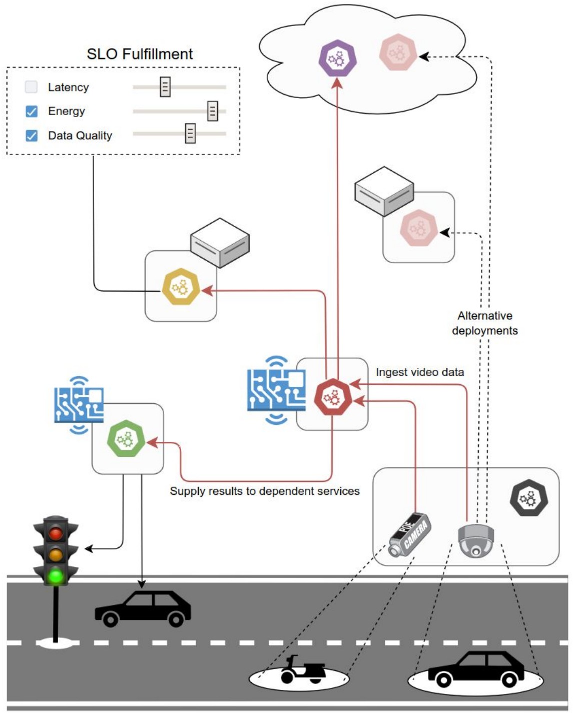
Given a **microservice pipeline** and a set of **heterogeneous hosts**, where to deploy each individual service so that its **own** SLOs and those of **dependent** services are fulfilled?

"Assignment between services and hosts"

Exhaustive comparison of all assignments is impractical due to complexity and lack of understanding; services and hosts change over time, so knowledge must be **transferable** to other setups

→ Intersections between services' dependencies modeled and evaluated through composition of **Markov Blankets** (MBs)



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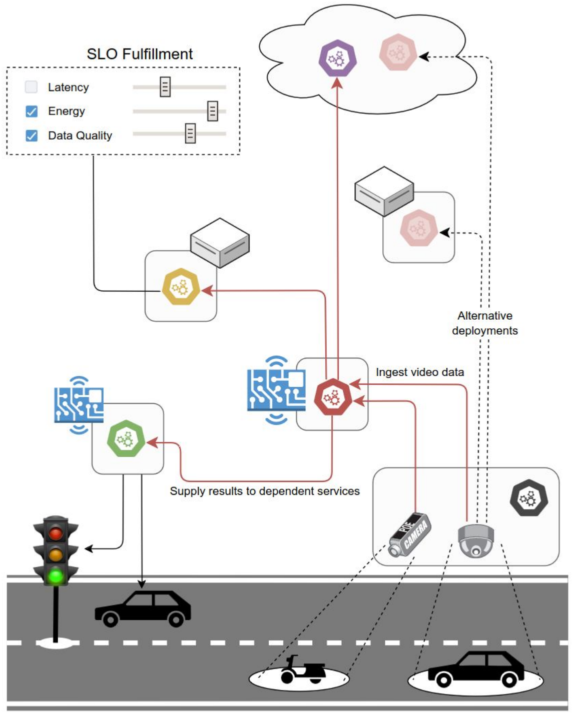
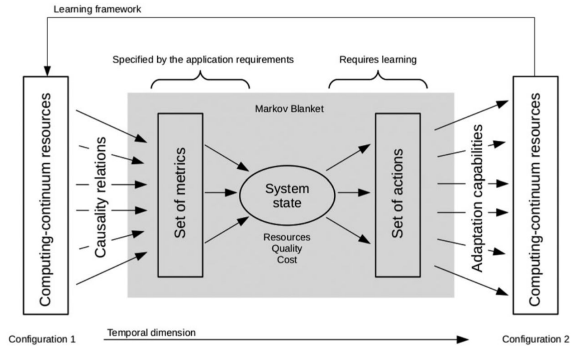


Behavioral Markov Blankets

$$P(x \mid \mathrm{MB}(x), Y) = P(x \mid \mathrm{MB}(x))$$

MBs express how systems interact with their environment through **perception** (e.g., metrics) and **actions** (e.g., scaling)

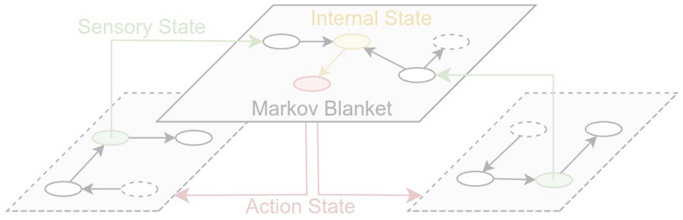
Model the **behavior** of a system in changing environments; focuses on variables that have an impact on taken actions



Behavioral Markov blanket for a system [1]

Composition of MBs to model hierarchical dependencies between different entities and their interfaces

→ How individual services impact SLOs of dependent service



Action-perception cycle between multiple entities

[1] Dustdar, Casamayor Pujol, and Dustdar; On Distributed Computing Continuum Systems (2023)

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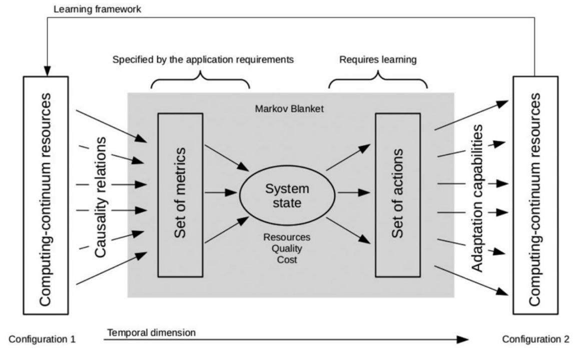

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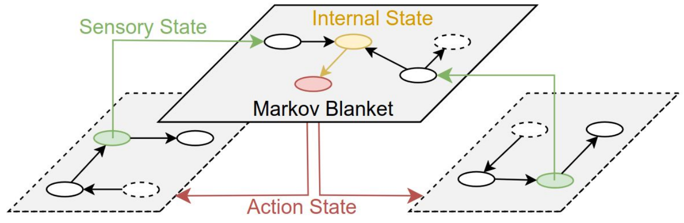

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Methodology

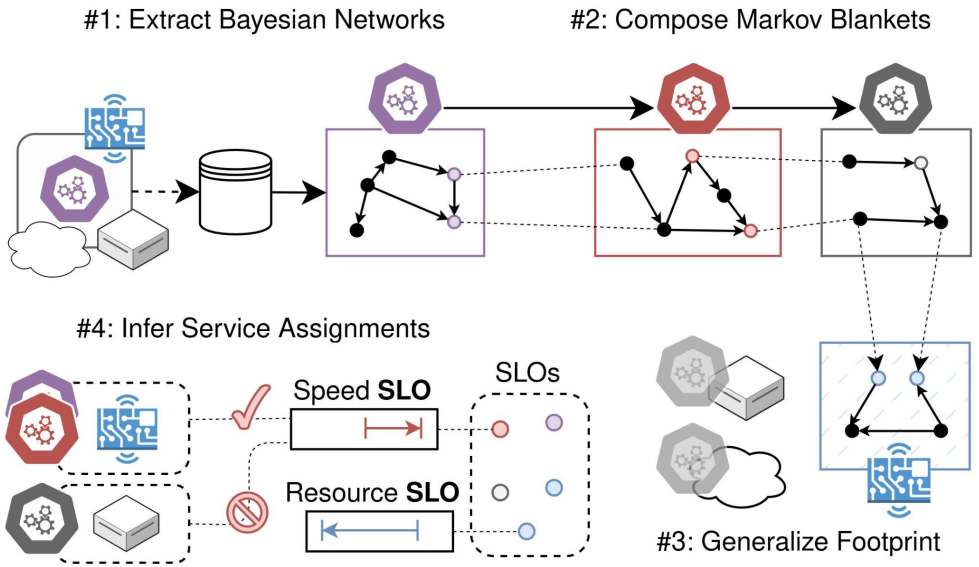
4-Step approach

#1 Extract BN as a probabilistic view into the service execution

#2 identify variable links between dependent services

#3 estimate SLO fulfillment under unknown service-host combinations

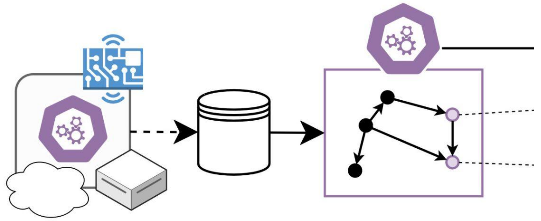
#4 infer the optimal assignment of services and hosting devices


#1: Extract Bayesian Networks
#2: Compose Markov Blankets
#4: Infer Service Assignments
SLOs
Speed SLO
Resource SLO
#3: Generalize Footprint

#1 Markov Blanket Extraction

Monitor service executions on target devices to gain insights into **causal dependencies** of service variables, e.g., *video resolution* → *processing latency*, and the impact on the hardware, e.g., *cpu*

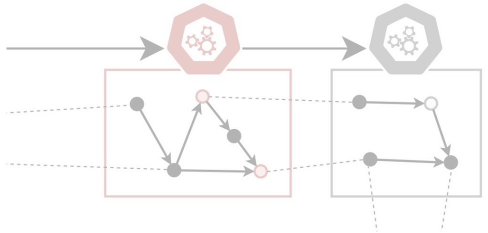
Train causal graph (i.e., BN) and extract the MB around the **SLO variables**, i.e., getting all nodes that impact SLO fulfillment



#2 Markov Blanket Composition (MBC)

Identify **interface variables** that impact the SLOs of **subsequent** services in the processing pipeline. Uses the Wasserstein distance (WSD) to find statistical dependencies between variables.

Can be distorted by linear **confounding variables** external to the MBs, e.g., networking latency, which is still detected by WSD



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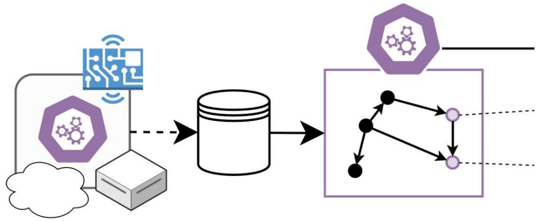

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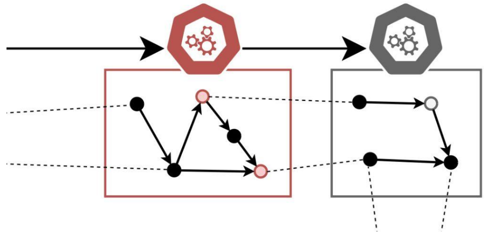
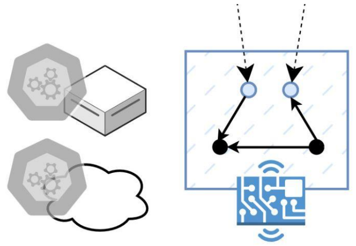


#3 Footprint Generalization

Extrapolate from the implications of running a service at a specific host (i.e., its “footprint”) to other services and devices

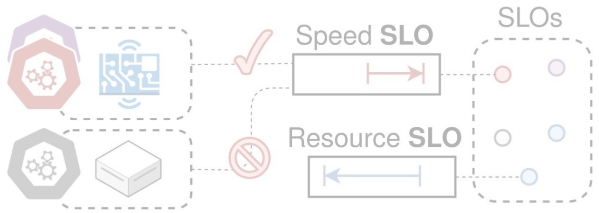
Estimate the expected SLO fulfillment and hardware utilization according to (i) the **relative difference** to known hardware, and (ii) the type of pipeline service, e.g., CV task or consumer



#4 Service Assignment

Assigns a set of services to a set of hosts, while respecting device capabilities and (transitive) SLOs specified per service

Can either assign services **greedily**, i.e., start from the consumer and place at the host that best fulfills its requirements, or **collaboratively**, which exhaustively compares the 2^n options



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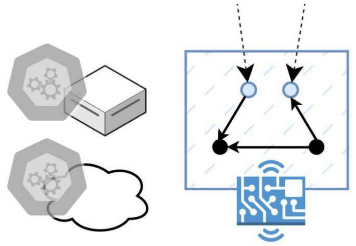

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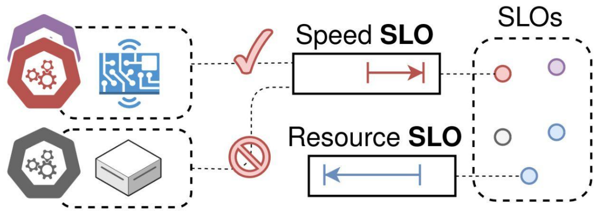
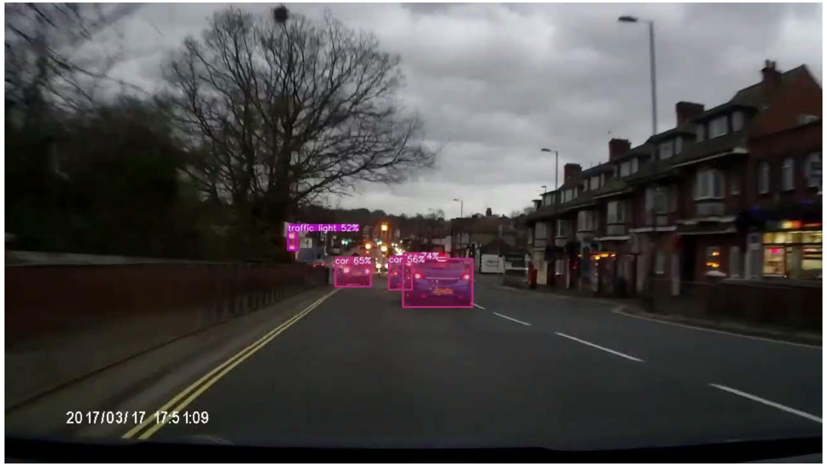
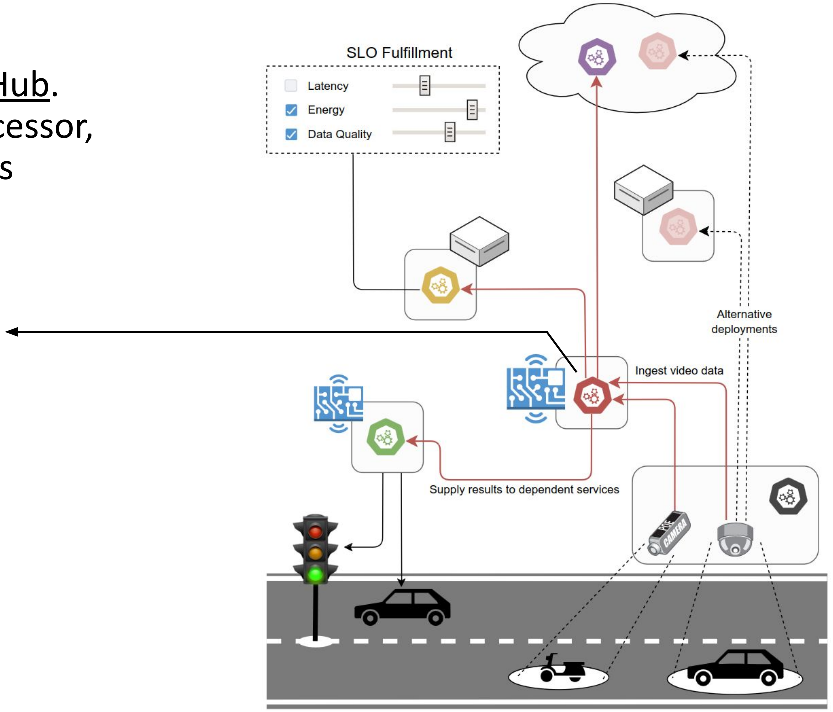


Implementation

Prototype implemented in Python and available on GitHub. Comprises services for (**a**) video provider, (**b**) video processor, and (**c**) three instances of consumers with different SLOs



CV Service with Yolov8 running on the produced videos



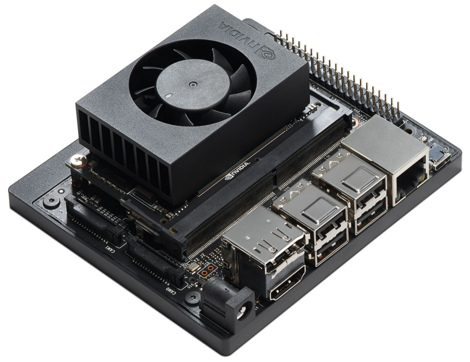
Assigning microservices to infrastructure in a smart city

Experimental Setup

Contains a set of 5 **heterogeneous** devices that will be available for assignment, each classified according to cpu (*p*) and gpu (*g*) capabilities

SLOs specified for each of the services, i.e., for producer (*P*), worker (*W*), and the three consumers (C1, C2, C3). Each with different **thresholds** according to the requirements, e.g., live monitoring has different SLOs than the adaptation of smart traffic lights.

For eight setups, execute the methodology and find best assignment


Nvidia Jetson **Xavier NX** board (image from here)

Full Device Name	ID	Price[6]	CPU	RAM	CUDA GPU	p [1,4]	g [0,3]
Custom Server Build	*Server (S)*	2500 €	AMD Ryzen 7700 (8 core)	64 GB	RTX 3090	Very High (4)	High (3)
ThinkPad X1 Gen 10	*Laptop (L)*	1700 €	Intel i7-1260P (16 core)	32 GB	———	High (3)	None (0)
Nvidia Jetson Orin	*Orin (O)*	500 €	ARM Cortex A78 (6 core)	8 GB	Volta 383	Medium (2)	Medium (2)
Nvidia Jetson Xavier	*Xavier (X)*	300 €	ARM Carmel v8.2 (6 core)	8 GB	Amp 1024	Medium (2)	Low (1)
Nvidia Jetson Nano	*Nano (N)*	200 €	ARM Cortex A57 (4 core)	4 GB	———	Low (1)	None (0)

List of devices in the architecture and their **relative hardware capabilities**

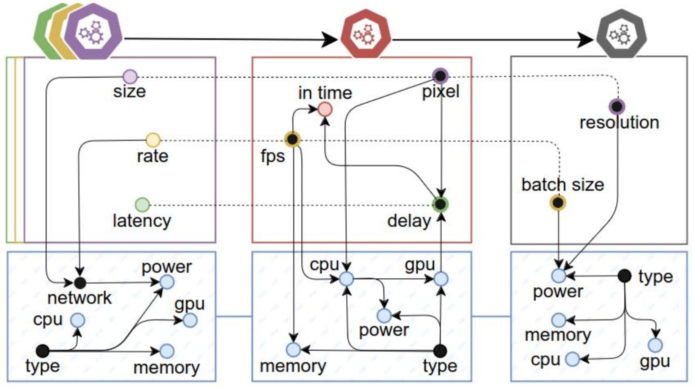
	P	W	C_1	C_2	C_3
latency	–	–	$\leqslant$ 1s	$\leqslant$ 70ms	$\leqslant$ 40ms
image size	–	–	$\geqslant$ 720p	–	–
data rate	–	–	–	$\geqslant$ 25f	–
delta	–	$\leqslant \frac{1}{fps}$	–	–	–
*energy**	$min()$	–	–	–	$min()$

SLOs posed **by** individual services

Results

Composition of MBs provides (1) **understanding** how different service parameters depend on each other, e.g., latency ⟶ delay. Thus, consumers constrain **red's** operation, and **grey's** in turn.

Further, the MB shows (2) the precise impact of the services on the computing hardware, means to what extent **red** utilizes the processing resources (e.g., cpu, gpu) of its host.



Identified variable dependencies between microservices

Considers for pair of dependent services (W & C3) how assigning them to different hosts impacts resulting SLO fulfillment of the latter, i.e., how red must to deploy to more powerful hosts

#	SLO Σ	W	CPU	GPU	Mem	C_3	Power Σ
1	1.70	*Orin*	50	30	119	*Orin*	8 W
2	1.52	*Orin*	24	30	73	*Xavier*	15 W
3	0.92	*Server*	3	31	12	*Laptop*	97 W
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24	0.00	*Nano*	122	35	93	*Laptop*	26 W
25	0.00	*Laptop*	54	0	27	*Laptop*	21 W

Assigning two services {W,C} over the infrastructure

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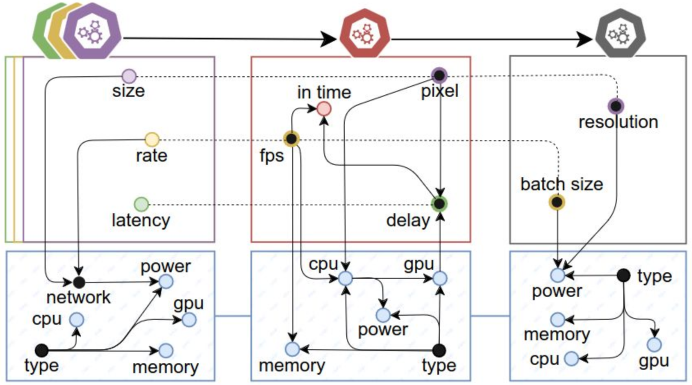

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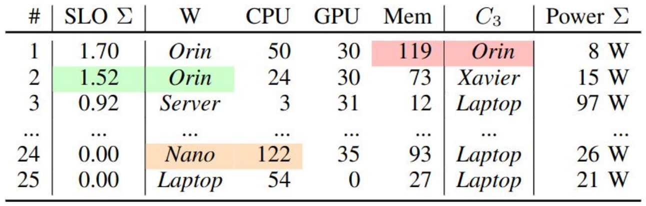

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Assigning two services {W,C} over the infrastructure

Results (2)

Depending on the evaluation scenario, different services had to be assigned to different sets of hosts. Thus, **SLOs**, **processing parameters**, and the optimal **assignment** changed accordingly.

Fulfillment of worker's processing SLO highly dependent on chosen **host** and imposed latency **threshold**. For example, in scenario **t2**, deploying to Orin fulfilled the SLOs, whereas **t3** not

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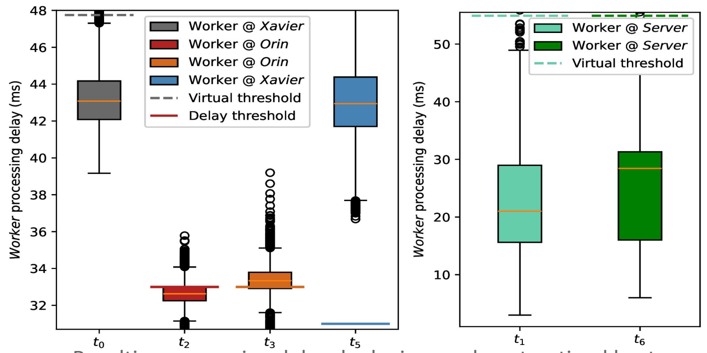
Comparing the empirical SLO fulfillment of all the possible assignments exhaustively showed that we indeed selected the optimal ones, though we extrapolated from other assignments

	Services					Hosts				
t_i	P	W	C_1	C_2	C_3	S	L	O	X	N
0	✓	✓	✓	–	–	✓	✓	✓	✓	✓
1	✓	✓	–	✓	–	✓	✓	✓	✓	✓
2	✓	✓	–	–	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

List of eight evaluation scenarios with services and hosts



Resulting processing delay deploying worker at optimal hosts

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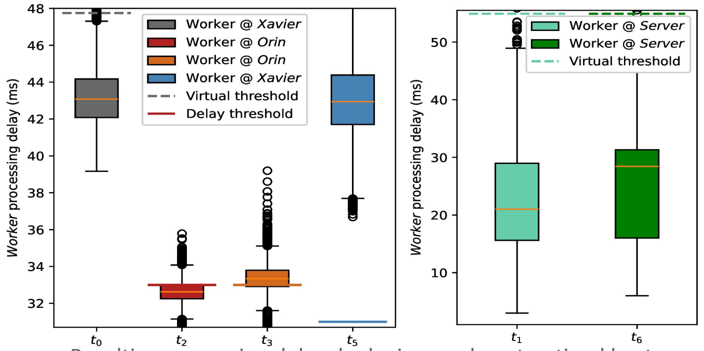

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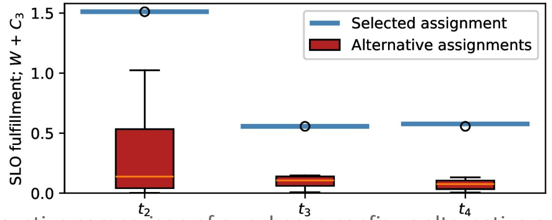
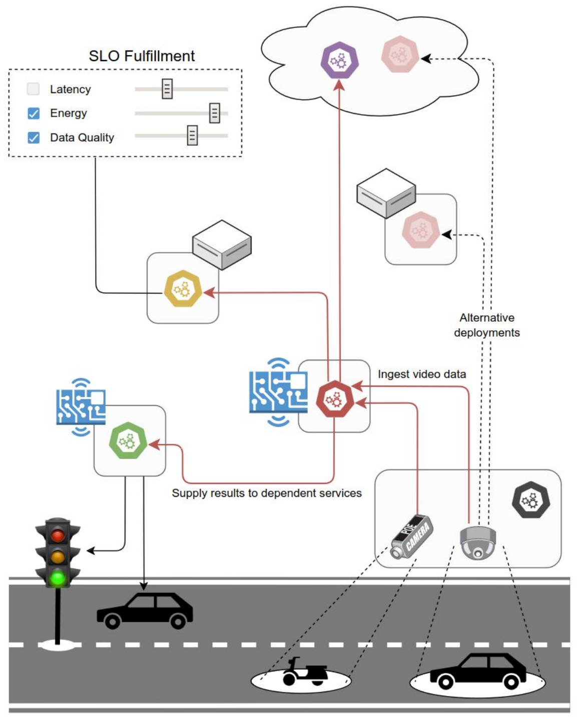


Exhaustive comparison of our chosen config vs alternative ones

Summary

- ❏ Individual services in a microservice pipelines pose SLOs to the overall performance and **dependent** services
- ❏ Constrain how services operate and where they can be deployed over different heterogeneous hosts
- ❏ Find statistical dependencies between services through **composition** of their MBs and inference of assignments
- ❏ Prototype showed how a smart-city pipeline was deployed over a **mutable** set of hosts while maximizing the resulting SLO fulfillment



Let’s **discuss**!

Please come forward with any **question** you have

@

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