Data center resource management for in-network processing

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Introduction

"**Modern Internet services**, *such as search, social networking and e-commerce*, **critically depend on high-performance key-value stores**. *Rendering even a single web page often requires hundreds or even thousands of storage accesses.*" NetChain [6] authors

"*As the number of compute elements grows, and the need to expose and utilize higher levels of parallelism grows,* **it is essential to [...] focus on developing architectures that lend themselves better to providing extreme-scale simulation capabilities**." SHArP [3] authors

In-Network Processing (INP)

- INP refers to the technique of **offloading some parts of the computation to network devices** (e.g., programmable switches, network accelerators, middleboxes, etc.), hence reducing the load on servers
- Advantages:
    1. Serve network requests on the fly with low latency
    2. Reduce data center traffic and mitigate network congestion
    3. Save energy by running servers in a low-power mode
- Few solutions out there already: Daiet [10], SHArP [3], NetChain [6], IncBricks [8]

Thesis goals

Problem statement

For the time being, it seems that there is still no Resource Manager (RM) that takes into account the presence of a network having a data plane that supports (partially or completely) INP

Goals

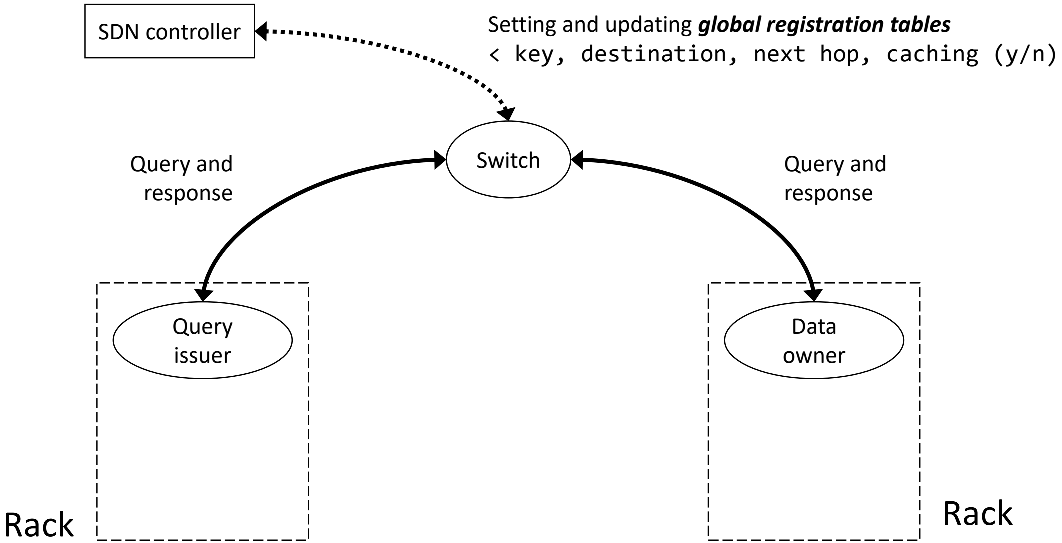
1. Model and evaluate an API through which applications can ask for INP resources
2. Discuss the importance of a scheduler which can reject INP requests and propose their server-only equivalent when needed (e.g., high switch utilization)

Analysis

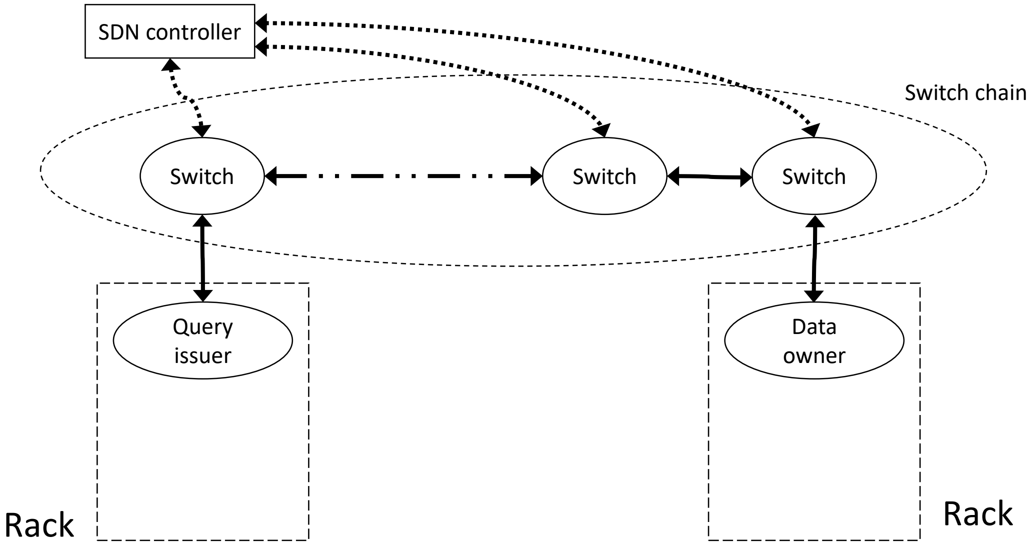
Currently existing INP solutions

1. IncBricks (In-network caching system)
2. NetChain (Coordination services)
3. Daiet (In-network aggregation)
4. SHArP (Aggregation protocol)

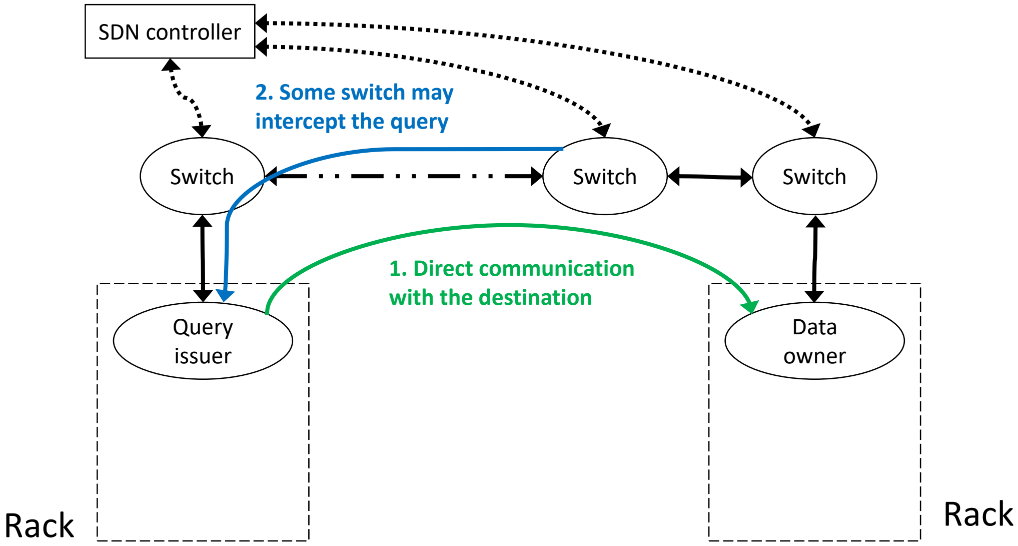
In-network caching system: IncBricks



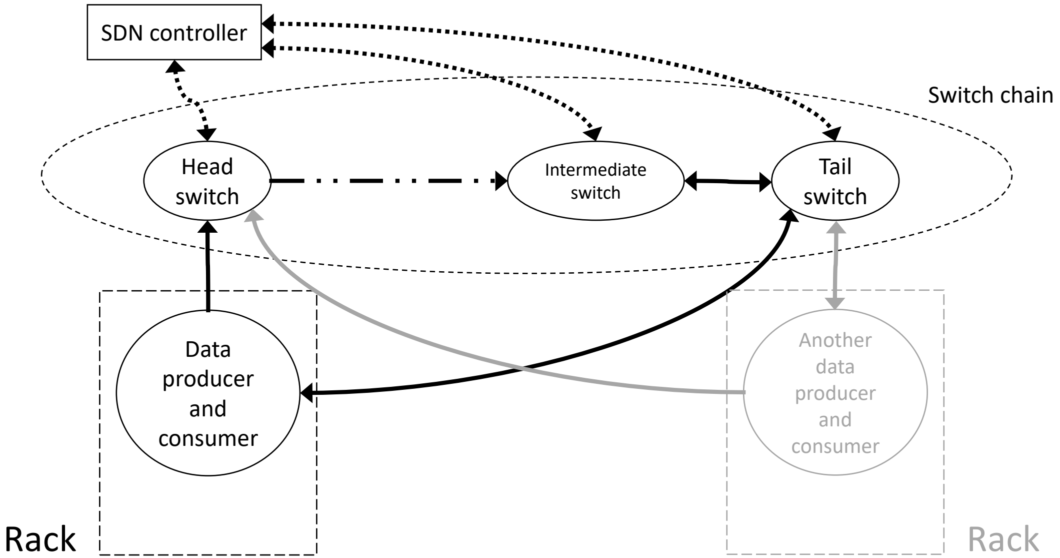
In-network caching system: IncBricks



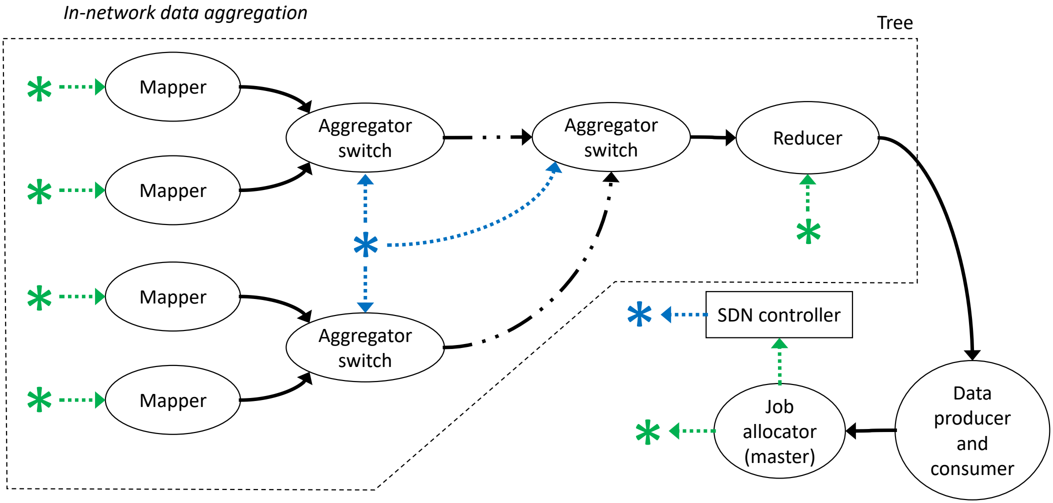
In-network caching system: IncBricks



Coordination services: NetChain

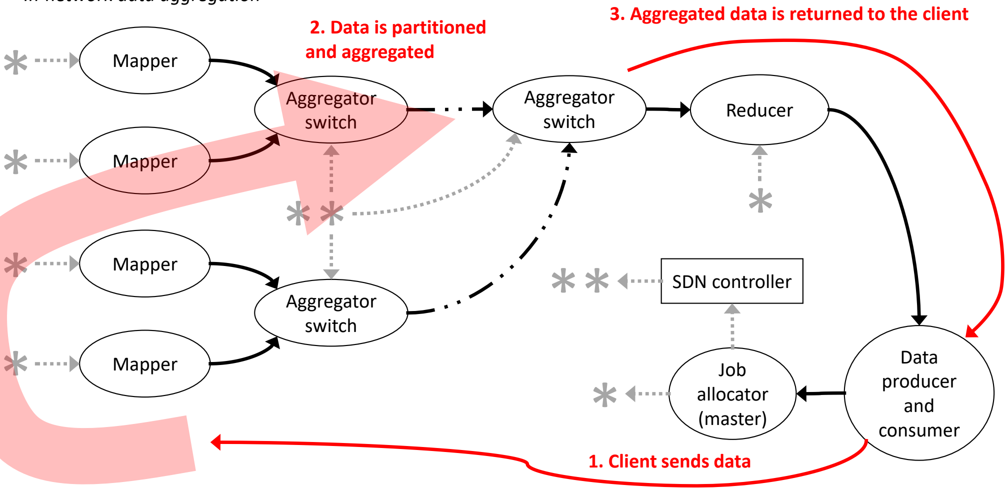


In-network aggregation: Daiet

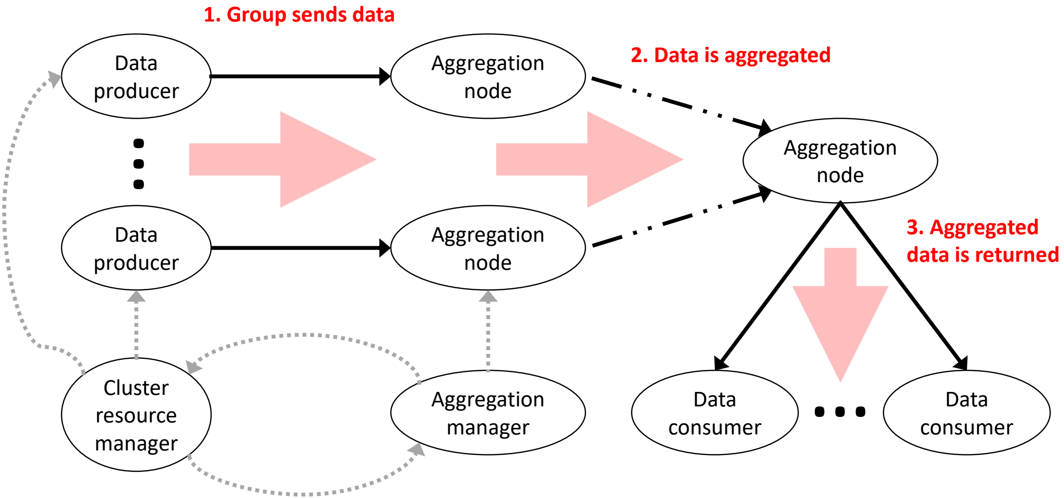


In-network aggregation: Daiet

In-network data aggregation

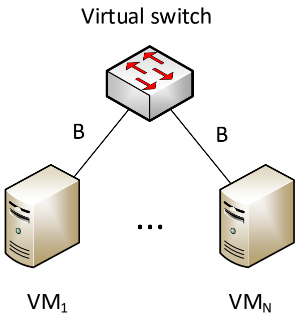


Aggregation protocol: SHArP



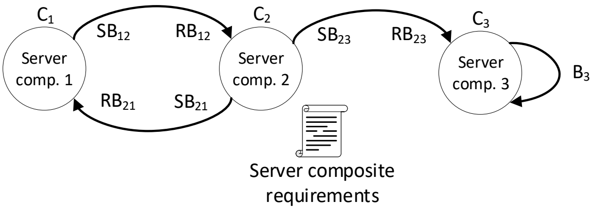
Resource models (3.4)

1. Virtual Cluster (VC)



2. Virtual Oversubscribed Cluster (VOC)
   - *N* VCs connected to a single root virtual switch

3. Tenant Application Graph (TAG)



4. Fine-grained resource requests
   - List of server-only resource demands
5. High-level goals
   - E.g., job completion time (Bazaar [5])

Level of network awareness in RMs

- VMs proximity-aware
  - Spreading VMs across different failure domains (e.g., racks, power domains, etc.)
  - Omega [11], Apache™ YARN [12], Mesos [4], etc.
- Bandwidth-aware
  - Allowing tenants to specify bandwidth demands
  - "Virtual network" models (i.e., VCs, VOCs and TAGs)
  - CloudMirror [7], Oktopus [1], Kraken [2], Proteus [13], etc.
- Network resources-aware
  - At the time of writing, there seemed to be only one embedding solution[1] considering switch resources
  - The scheduler places server and switch resources in separate rounds

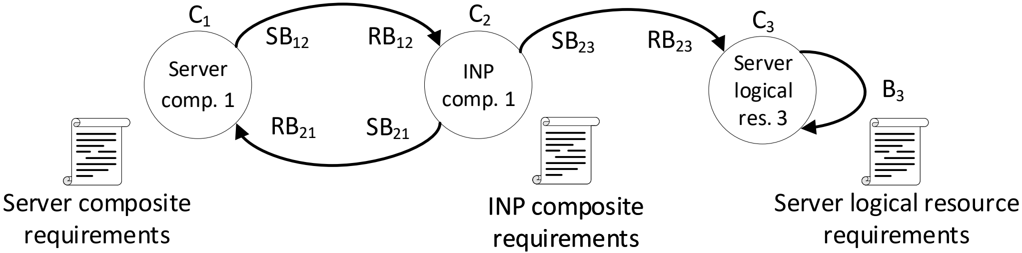
[1] Rabbani, Md Golam, et al. "On tackling virtual data center embedding problem." *2013 IFIP/IEEE International Symposium on Integrated Network Management (IM 2013)*. IEEE, 2013. [9]

Design

Composites

- A composite is a template that describes high-level logical components
  - It can be of two types:
    - Server (e.g., “web server”, “database”, ...)
    - INP (e.g., “IncBricks caching system”, “NetChain locking system”, ...)
  - It can be made out of
    - Other Composites
      - A composite loop must not be valid, since it would be impossible to place
    - Logical resources

The extended-Tenant Application Graph (eTag)

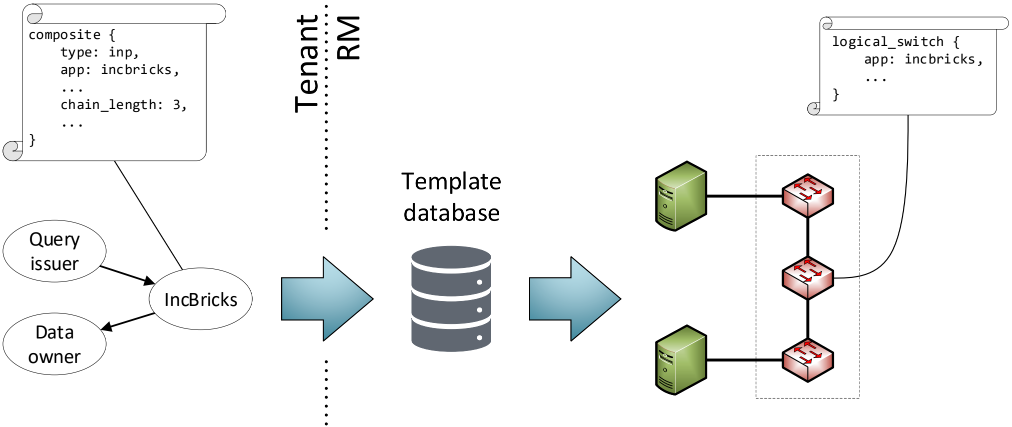


Generic groups

- In-network **storage**
  - Switches must
    - dedicate part of their local memory to store a distributed map
    - form a chain
  - IncBricks [8], NetChain [6]
- In-network **data aggregation**
  - Switches must
    - form a tree whose root is connected to data consumers and whose leaves are connected to data producers
    - dedicate part of their local memory to store a key-value map
    - be able to perform basic operations on data, such as writing and hashing
    - wait for all its children to send aggregated data
  - Daiet [10], SHArP [3]

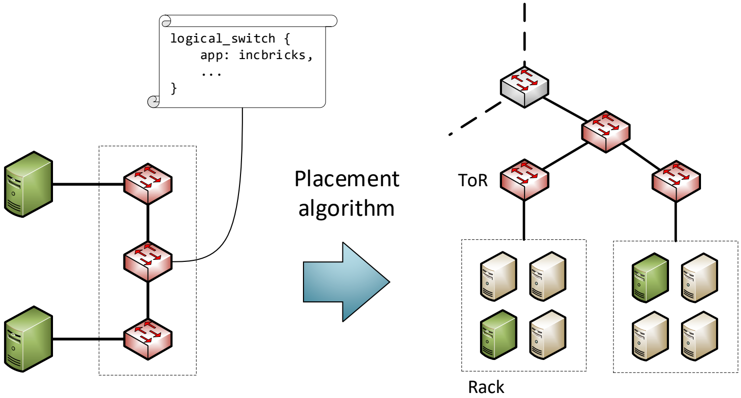
Mapping composites to logical resources

- The *template database* maps composites (or generic groups) to their equivalent made out of just logical resources

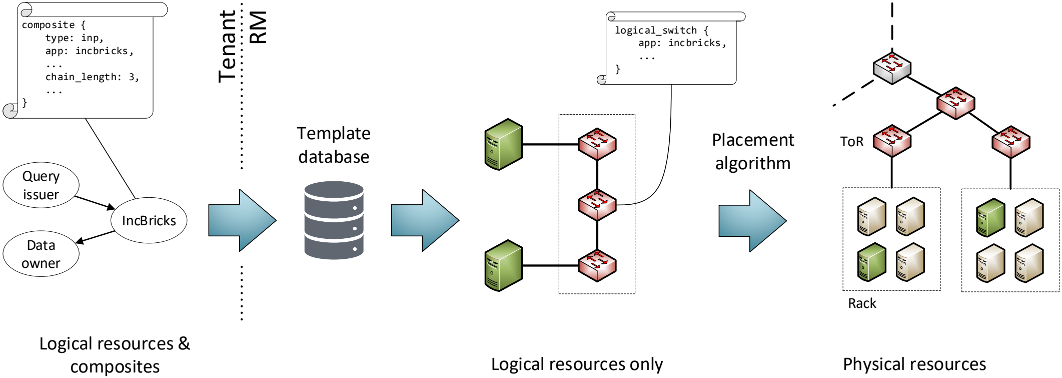


Placing logical resources

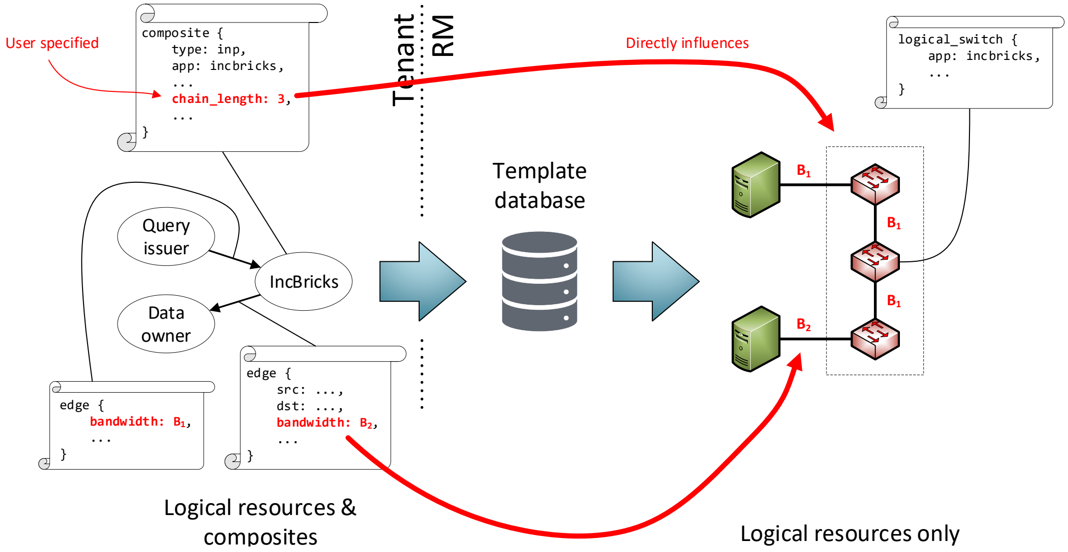
- The placement algorithm places logical resource onto physical ones
- Three types of physical resources:
  - Server
  - Switch
  - Link



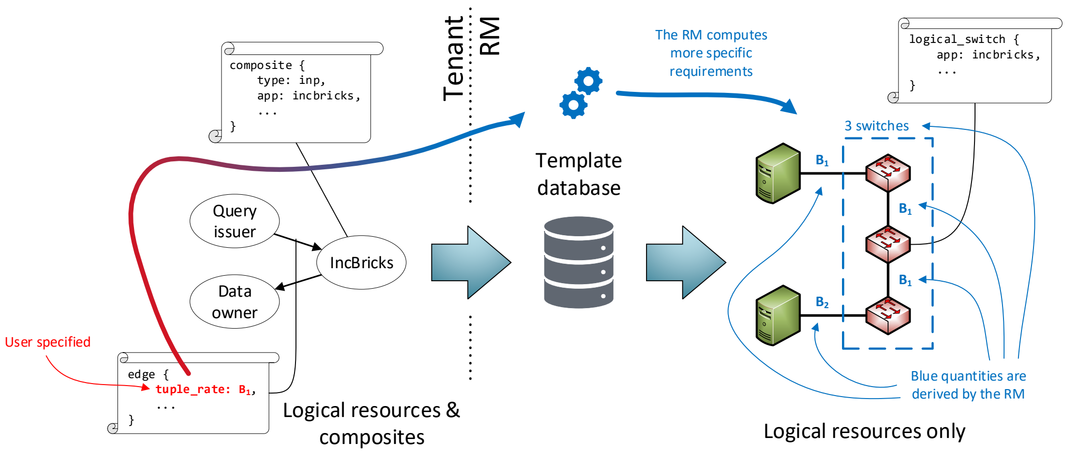
The whole picture



1st approach: passive template mapping



2nd approach: active template mapping



Evaluation

Simulation 1/2

- Simulator built from the ground up
  - Inspired by Omega's [11] *lightweight simulator*[2]
  - Supports multiple resource dimensions, switch resources, and composites
  - Switches have *properties* (e.g., supported INP solutions)
- Simulated data center physical architecture: fat-tree with 4 pods
- 3 days-long randomly-generated workload
  - Job properties (e.g., requirements, requests' interarrival time, etc.) are sampled from exponential distributions
- Simple greedy scheduler

[2] Available at github.com/google/cluster-scheduler-simulator

Simulation 2/2

- The template database contains two entries for the previously-mentioned generic groups
  - In-network storage (switch chain)
  - In-network data aggregation (switch tree)
- Server Tasks Cutback (STC): the reduction of server tasks once an INP solution is introduced

$$STC = \frac{\#server\ tasks\ without\ INP}{\#server\ tasks\ with\ INP} \tag{1}$$

- Sweep: percentage of requests including INP composites

Results 1/3

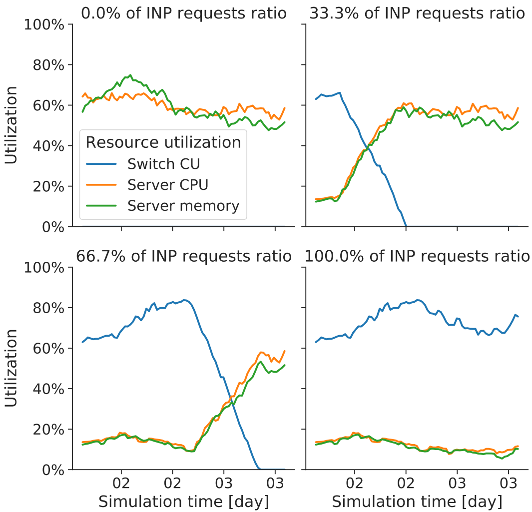


Figure 1: physical resource utilization for different amounts of INP requests

Results 2/3

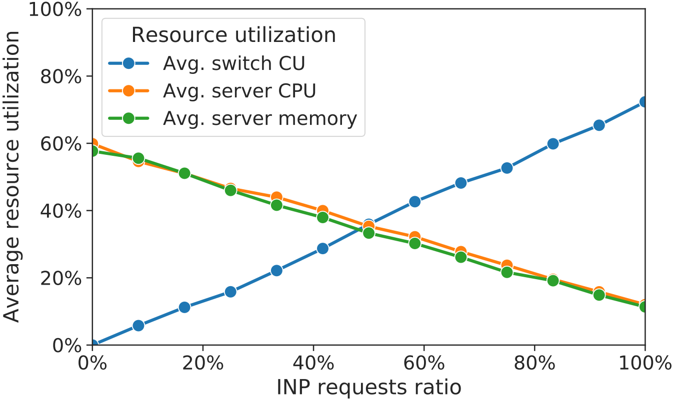


Figure 2: Average resource utilization as a function of the INP requests ratio

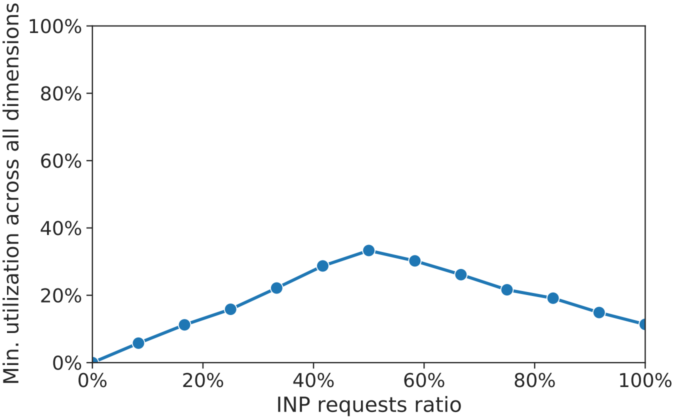


Figure 3: Minimum resource utilization across all dimensions

Conclusions

Conclusions

This thesis aims to foresee some features that an ideal fully-INP aware Resource Manager should have, as well as some open problems in the INP resource management field.

Fully INP-aware RM features

- Conjunct placement of server and switch resources
- INP alternatives

Open problems

- Accurately determine STC values for all INP solutions
- Determine number of needed switch tasks for INP solutions
- Differentiate INP solutions based on their life cycle (e.g., short-term batch jobs vs. long-term services)

Questions?

Thank you

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