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

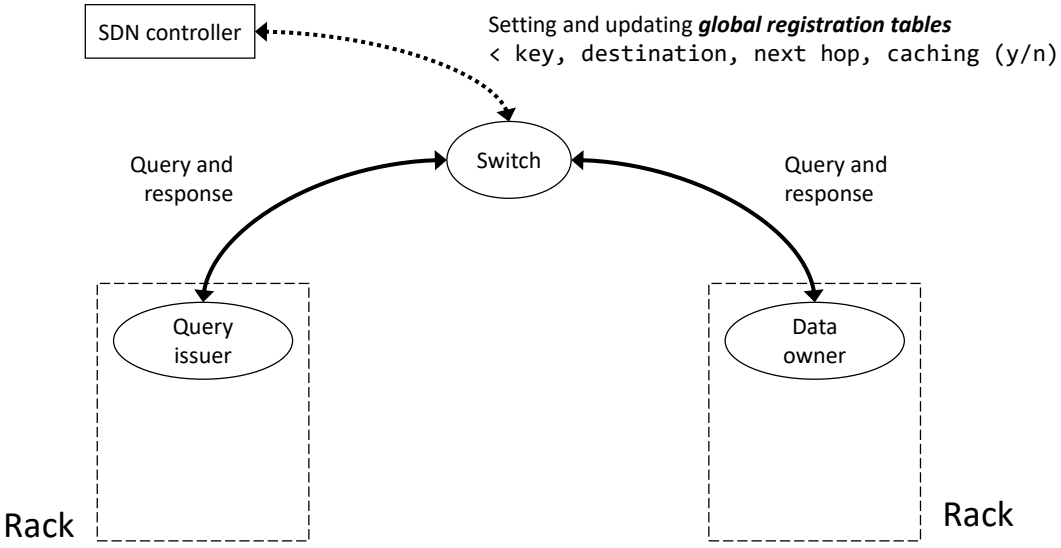
1. Model and evaluate an API through which applications can ask for INP resources
2. Discuss the importance of a scheduler which can reject INP requests and propose their server-only equivalent when needed (e.g., high switch utilization)

Analysis

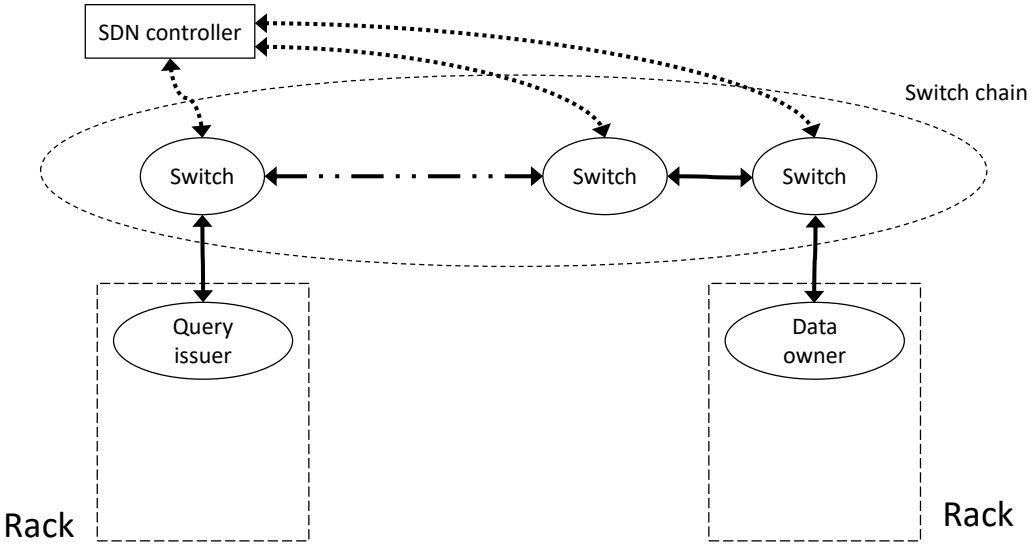
Currently existing In-Network Processing (INP) solutions

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

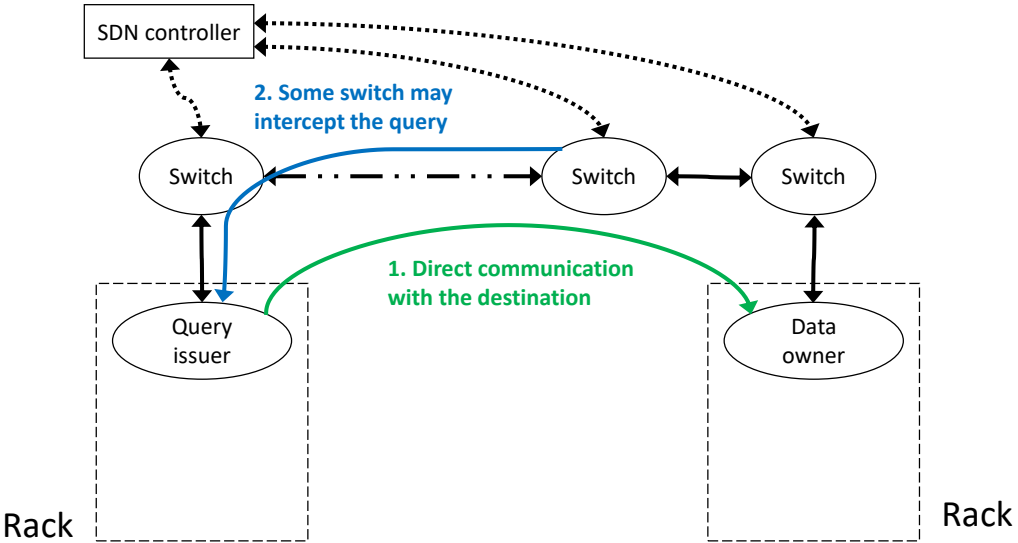
In-network caching system: IncBricks



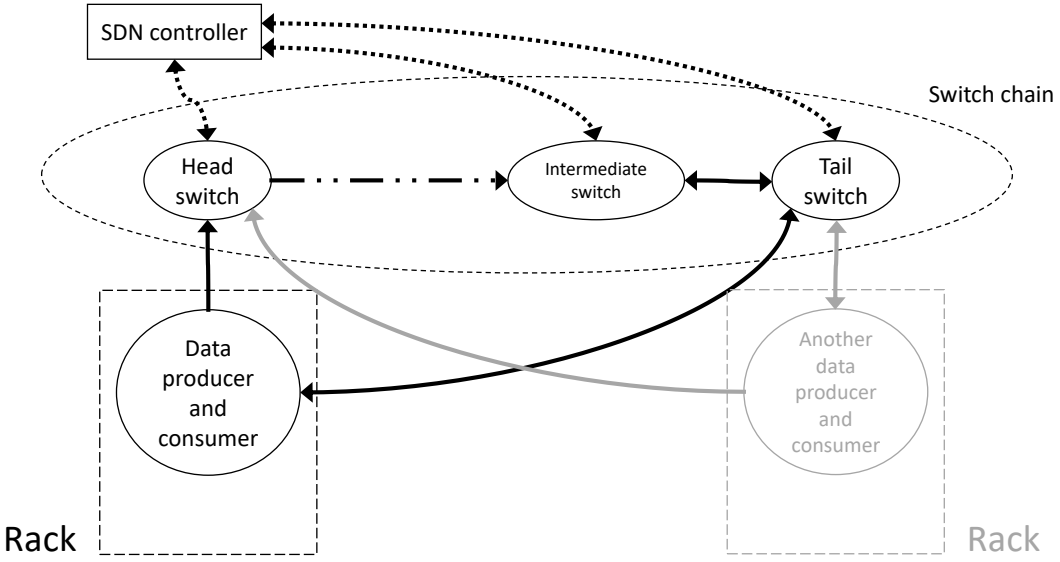
In-network caching system: IncBricks



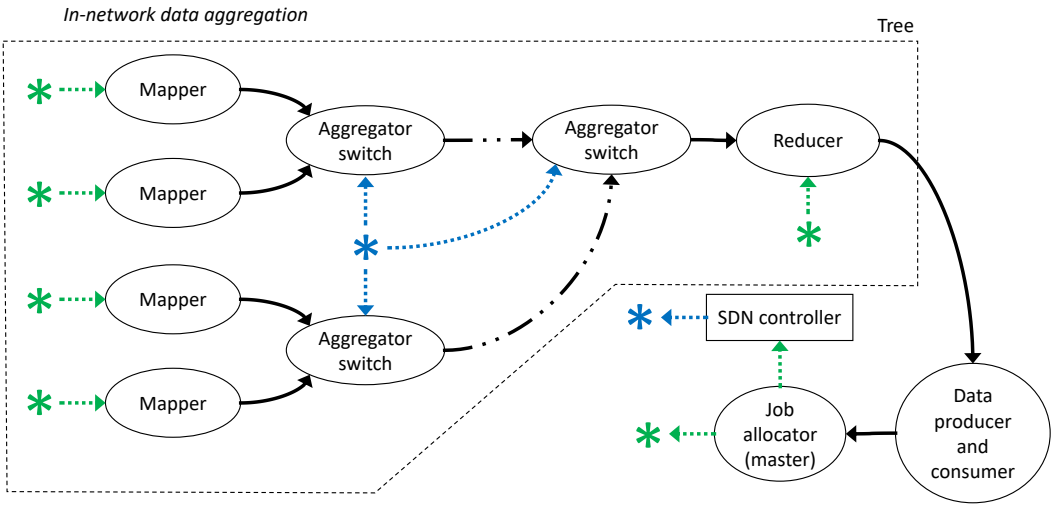
In-network caching system: IncBricks



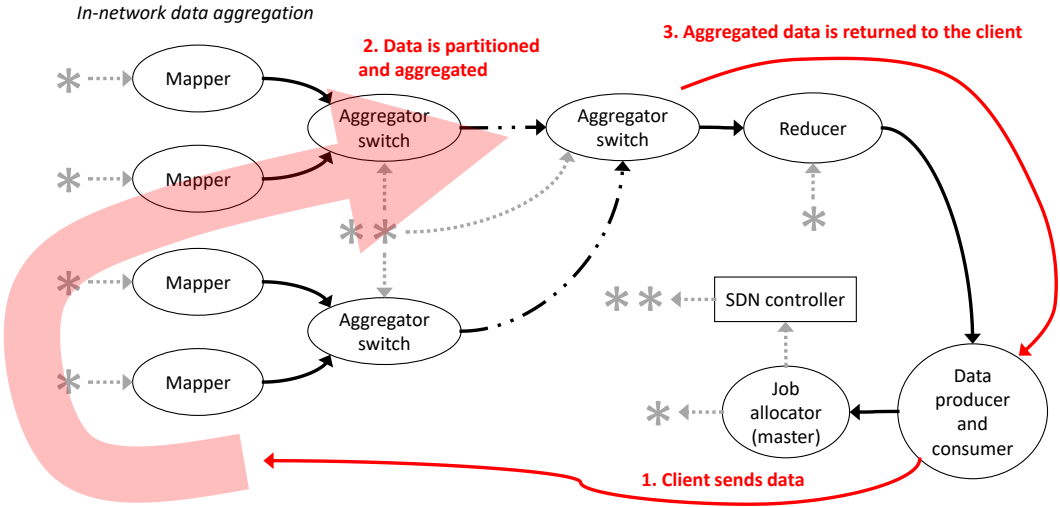
Coordination services: NetChain



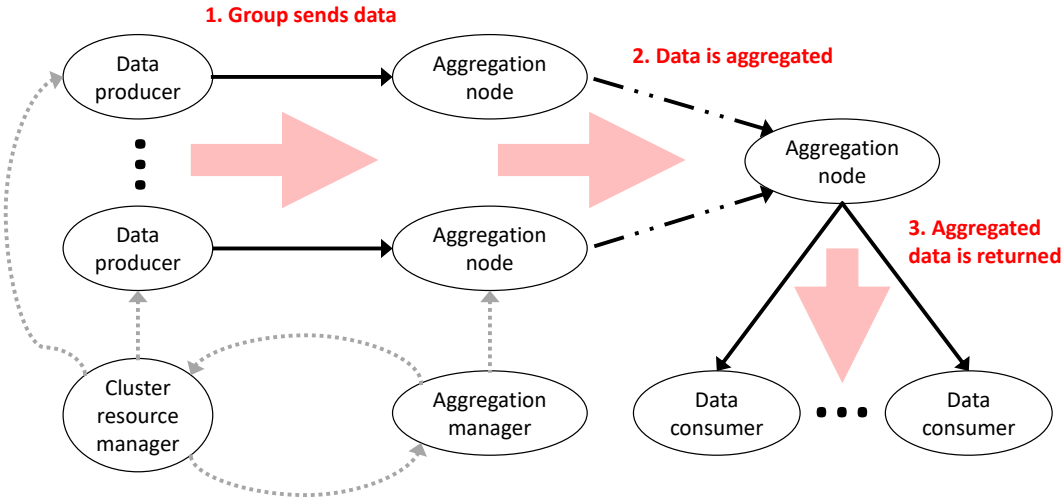
In-network aggregation: Daiet



In-network aggregation: Daiet

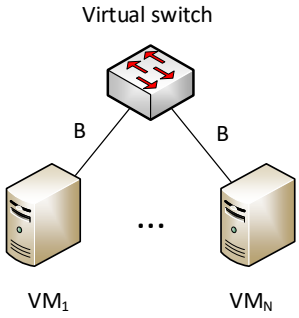


Aggregation protocol: SHArP



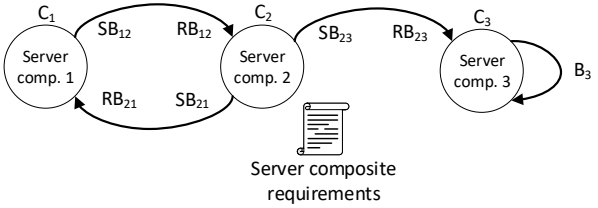
Resource models (3.4)

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

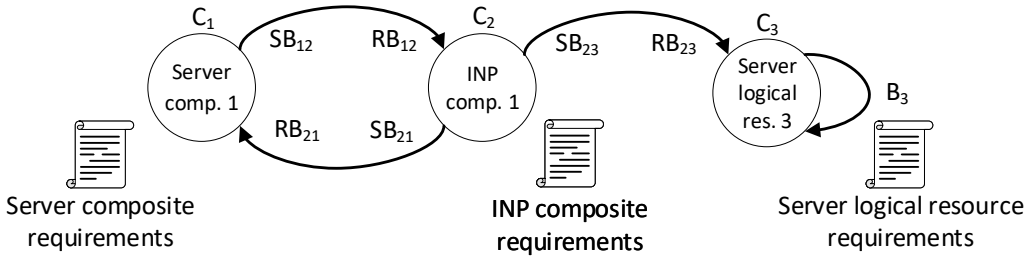
[1] Rabbani, Md Golam, et al. "On tackling virtual data center embedding problem." *2013 IFIP/IEEE International Symposium on Integrated Network Management (IM 2013)*. IEEE, 2013. [9]

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)

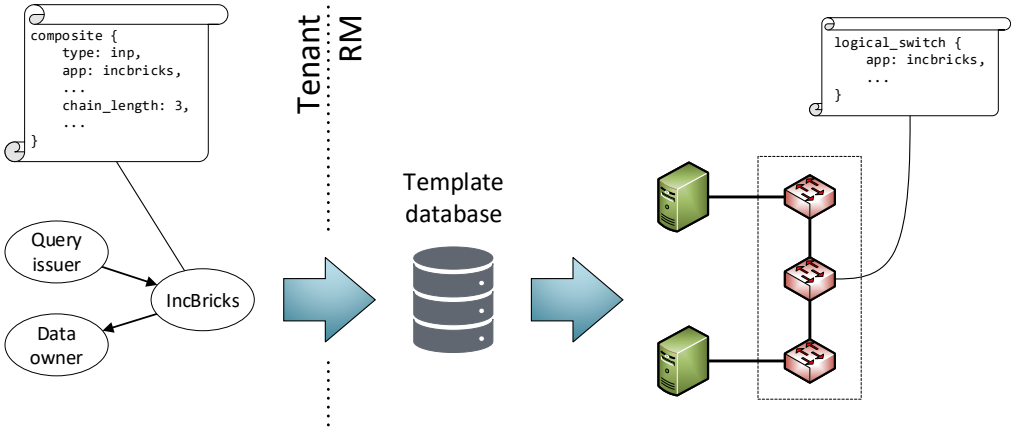


Generic groups

- 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]

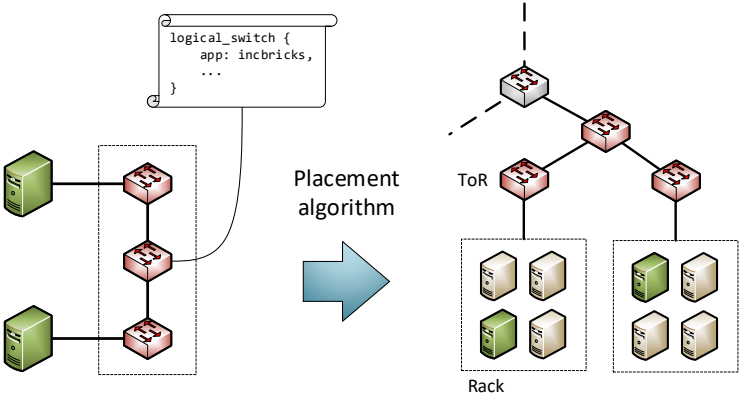
Mapping composites to logical resources

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

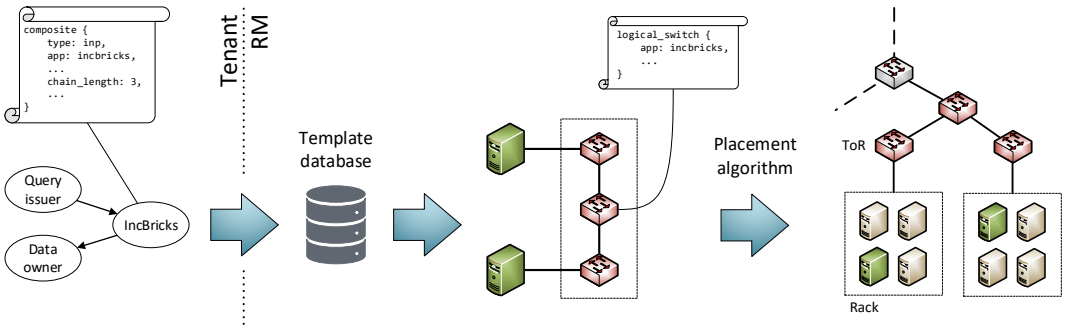


Placing logical resources

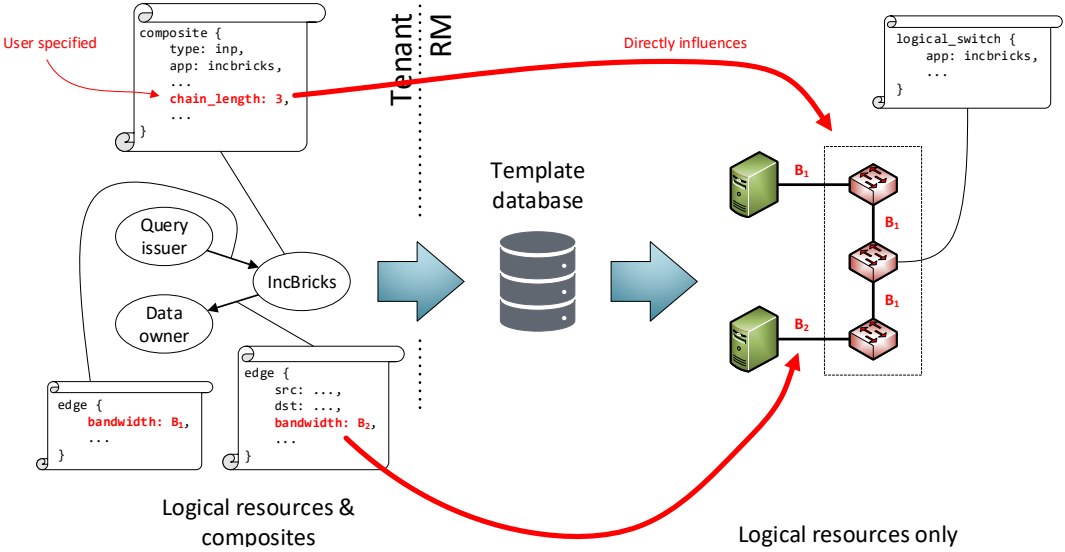
- The placement algorithm places logical resource onto physical ones
- Three types of physical resources:
  - Server
  - Switch
  - Link



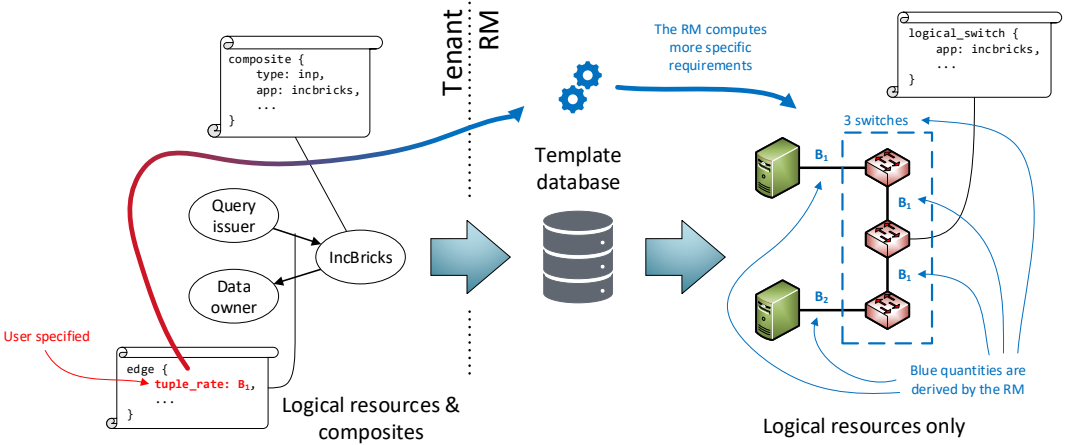
The whole picture



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

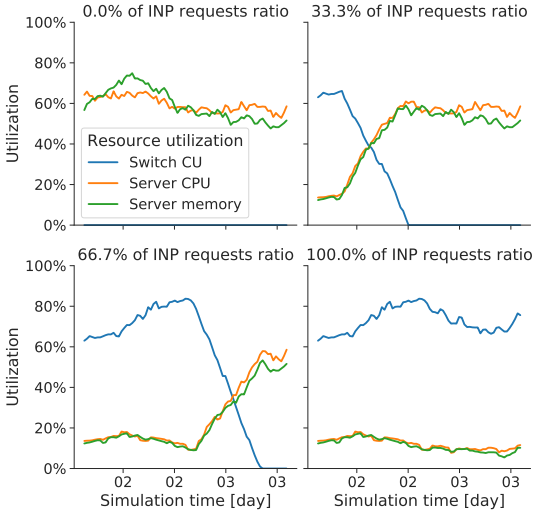


Figure 1: Physical resource utilization for different amounts of INP requests

Results 2/3

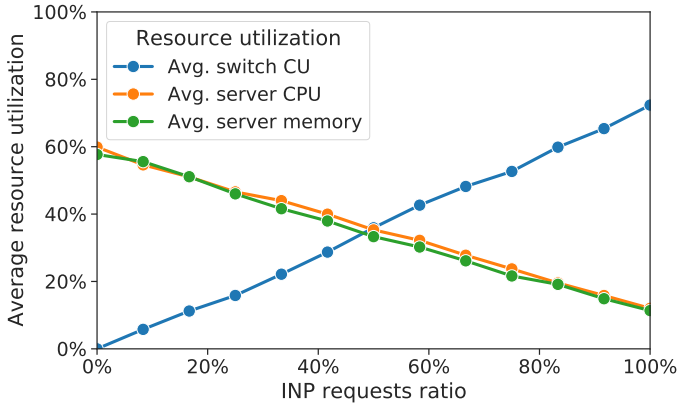


Figure 2: Average resource utilization as a function of the INP requests ratio

Results 3/3

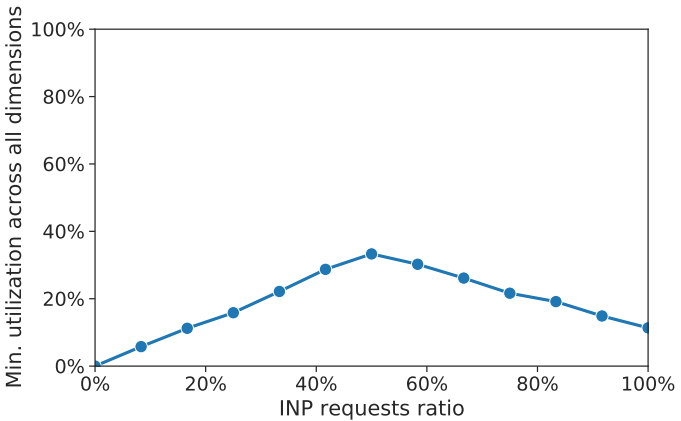


Figure 3: Minimum resource utilization across all dimensions

Conclusions

Questions?

Thank you

Bibliography i


H. Ballani, P. Costa, T. Karagiannis, and A. Rowstron.
Towards predictable datacenter networks.
In *Proceedings of the ACM SIGCOMM 2011 Conference*, SIGCOMM '11, pages 242–253, New York, NY, USA, 2011. ACM.


C. Fuerst, S. Schmid, L. Suresh, and P. Costa.
Kraken: Online and elastic resource reservations for multi-tenant datacenters.
In *INFOCOM 2016-The 35th Annual IEEE International Conference on Computer Communications, IEEE*, pages 1–9. IEEE, 2016.

R. L. Graham, D. Bureddy, P. Lui, H. Rosenstock, G. Shainer, G. Bloch, D. Goldenerg, M. Dubman, S. Kotchubievsky, V. Koushnir, et al.
Scalable hierarchical aggregation protocol (sharp): a hardware architecture for efficient data reduction.
In *Proceedings of the First Workshop on Optimization of Communication in HPC*, pages 1–10. IEEE Press, 2016.

B. Hindman, A. Konwinski, M. Zaharia, A. Ghodsi, A. D. Joseph, R. H. Katz, S. Shenker, and I. Stoica.
Mesos: A platform for fine-grained resource sharing in the data center.
In *NSDI*, volume 11, pages 22–22, 2011.


V. Jalaparti, H. Ballani, P. Costa, T. Karagiannis, and A. Rowstron.
Bridging the tenant-provider gap in cloud services.
In *Proceedings of the Third ACM Symposium on Cloud Computing*, SoCC '12, pages 10:1–10:14, New York, NY, USA, 2012. ACM.


X. Jin, X. Li, H. Zhang, N. Foster, J. Lee, R. Soulé, C. Kim, and I. Stoica.
Netchain: Scale-free sub-rtt coordination.
In *15th USENIX Symposium on Networked Systems Design and Implementation (NSDI 18)*, pages 35–49, Renton, WA, 2018. USENIX Association.

J. Lee, Y. Turner, M. Lee, L. Popa, S. Banerjee, J.-M. Kang, and P. Sharma.
Application-driven bandwidth guarantees in datacenters.
In *Proceedings of the 2014 ACM Conference on SIGCOMM*, SIGCOMM '14, pages 467–478, New York, NY, USA, 2014. ACM.

M. Liu, L. Luo, J. Nelson, L. Ceze, A. Krishnamurthy, and K. Atreya.
Incbricks: Toward in-network computation with an in-network cache.
In *Proceedings of the Twenty-Second International Conference on Architectural Support for Programming Languages and Operating Systems*, ASPLOS '17, pages 795–809, New York, NY, USA, 2017. ACM.


M. G. Rabbani, R. Esteves, M. Podlesny, G. Simon, L. Z. Granville, and R. Boutaba.
On tackling virtual data center embedding problem.
In *IM 2013: IFIP/IEEE International Symposium on Integrated Network Management*, 2013.


A. Sapio, I. Abdelaziz, A. Aldilaijan, M. Canini, and P. Kalnis.
In-network computation is a dumb idea whose time has come.
In *Proceedings of the 16th ACM Workshop on Hot Topics in Networks*, HotNets-XVI, pages 150–156, New York, NY, USA, 2017. ACM.


M. Schwarzkopf, A. Konwinski, M. Abd-El-Malek, and J. Wilkes.
Omega: flexible, scalable schedulers for large compute clusters.
In *SIGOPS European Conference on Computer Systems (EuroSys)*, pages 351–364, Prague, Czech Republic, 2013.


V. K. Vavilapalli, A. C. Murthy, C. Douglas, S. Agarwal, M. Konar, R. Evans, T. Graves, J. Lowe, H. Shah, S. Seth, B. Saha, C. Curino, O. O'Malley, S. Radia, B. Reed, and E. Baldeschwieler.
Apache hadoop yarn: Yet another resource negotiator.
In *Proceedings of the 4th Annual Symposium on Cloud Computing*, SOCC '13, pages 5:1–5:16, New York, NY, USA, 2013. ACM.


D. Xie, N. Ding, Y. C. Hu, and R. Kompella.
The only constant is change: incorporating time-varying network reservations in data centers.
ACM SIGCOMM Computer Communication Review, 42(4):199–210, 2012.