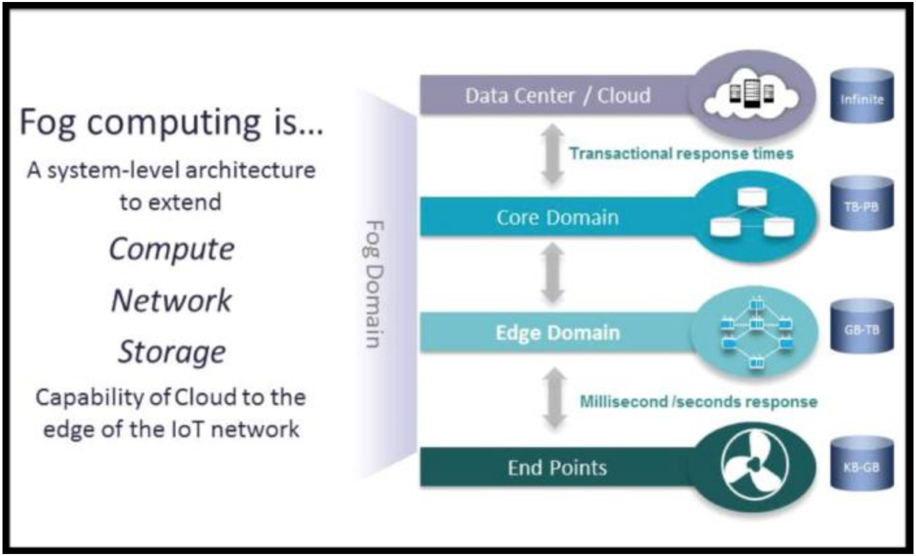
Advanced Cloud Infrastructures

From Data Centers to Fog Computing (part 2)

Guillaume Pierre

Master 2 CCS & SIF, 2017



Fog computing is...

A system-level architecture to extend

Compute

Network

Storage

Capability of Cloud to the edge of the IoT network

Source: Cisco

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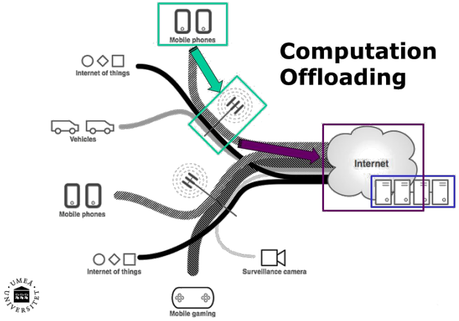
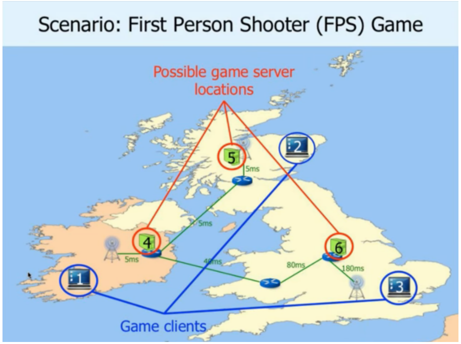
Computation offloading



http://slideplayer.com/slide/5737709/

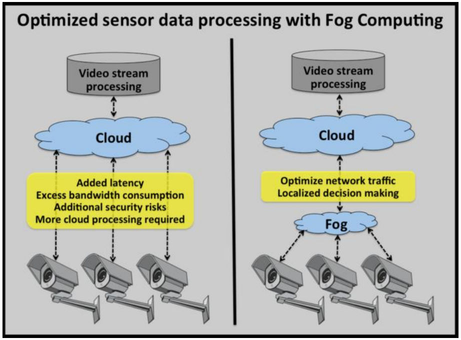
- Parts of the application is offloaded out of the mobile device

Low-latency mediation between multiple users


Scenario: First Person Shooter (FPS) Game
Possible game server locations
5
4
6
1
2
3
5ms
5ms
5ms
40ms
80ms
180ms
Game clients

(example application)

IoT analytics


Optimized sensor data processing with Fog Computing
Video stream processing
Cloud
Added latency
Excess bandwidth consumption
Additional security risks
More cloud processing required
Video stream processing
Cloud
Optimize network traffic
Localized decision making
Fog

https://www.networkworld.com/article/3147085/internet-of-things/

which-iot-applications-work-best-with-fog-computing.html

- Data processing is intelligently partitioned between fog nodes co-located with IoT devices and the cloud.
- This enables real-time tracking, anomaly detection, and collection of insights from data captured over long intervals of time.

System-level requirements

We can derive system-level requirements for a fog computing platform from the reference applications:

1. A complete cloud-like service offering
2. Context-aware application/data placement and resource scheduling
3. Fog computing infrastructure management and control
4. Efficient software deployment
5. Efficient container live-migration
6. Efficient data storage
7. Software engineering methodologies and middlewares suitable for fog computing scenarios
8. *And many other open research topics...*

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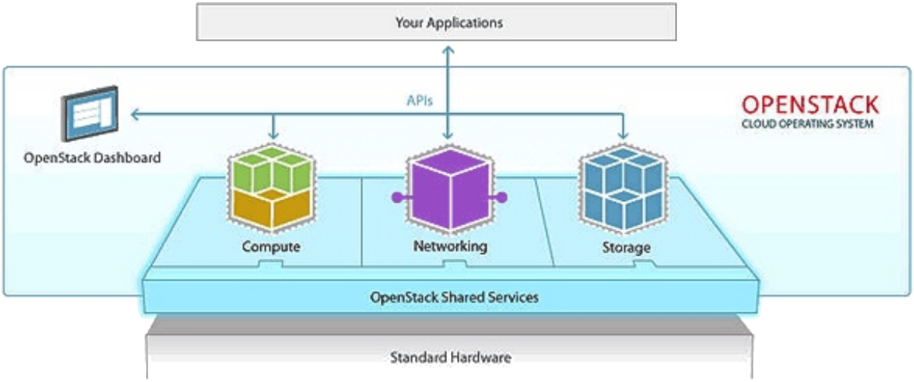
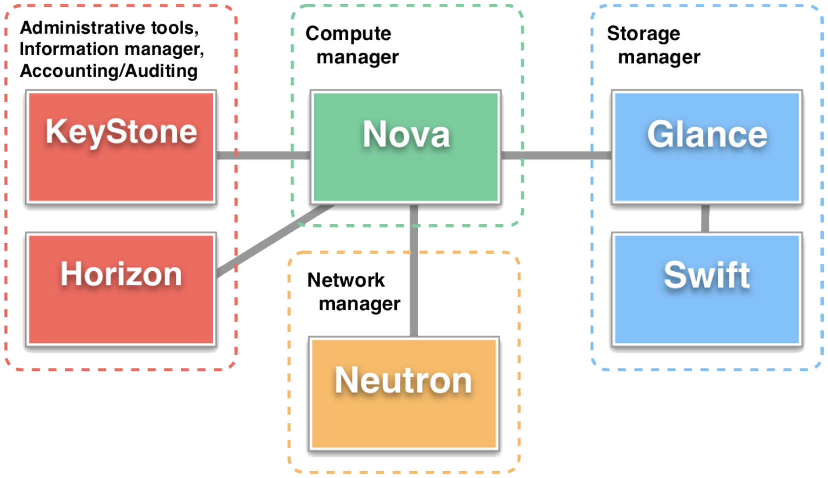
OpenStack overview

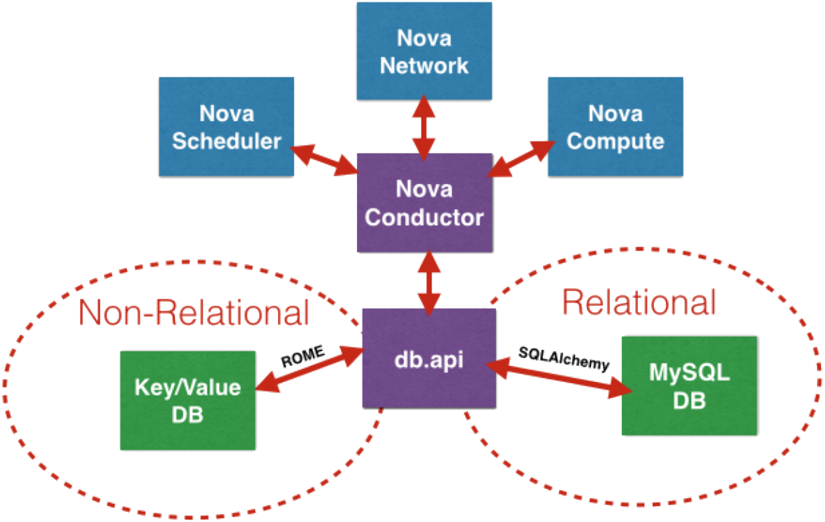


`https://hal.inria.fr/hal-01273427`

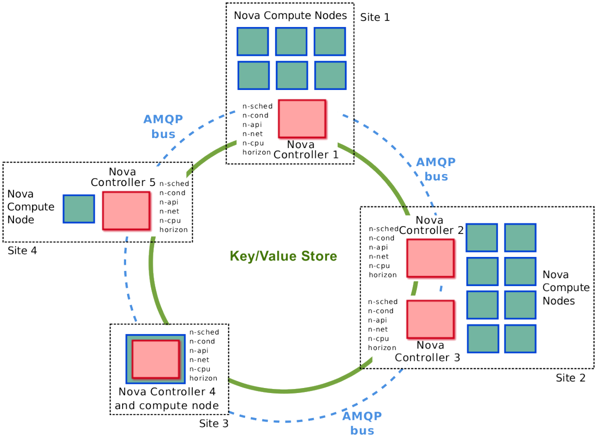
Core services of OpenStack



OpenStack Nova's architecture



Replacing Nova's MySQL DB with Redis



- Replacing MySQL with Redis is not as easy as it sounds:
  - Distributed locking system
  - Support for atomic updates
  - Create secondary index to support join queries
  - ...

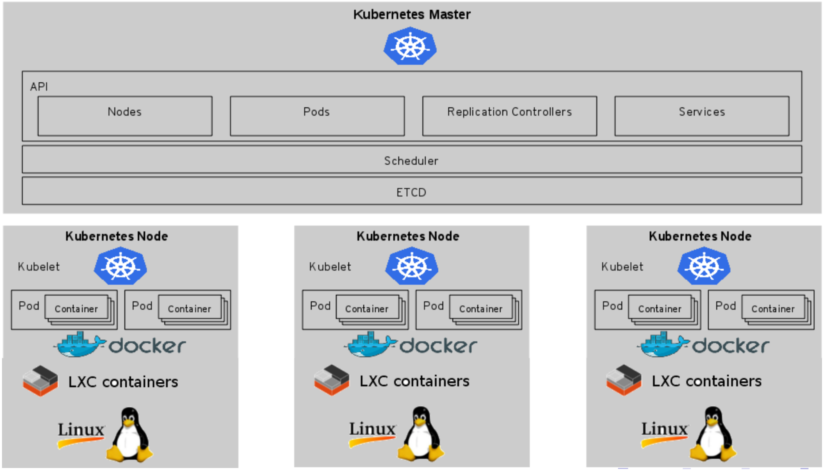
Remaining challenges

- The internal OpenStack message bus is based on RabbitMQ
  - Simple, robust, perfect in a single data center environment
  - Centralized architecture based on a single broker node
  - Every message queue is mirrored in every node
- Problem: RabbitMQ is very sensitive to network latency!

  $\Rightarrow$ Replace RabbitMQ with a P2P message bus (ActiveMQ, ZeroMQ)...

Decentralized clouds $\neq$ fogs

- OpenStack is suitable for highly distributed clouds but not for fogs
  - **Lots** of heavyweight processes
  - VMs are not suitable for very small machines
  - $\Rightarrow$ Let's move to container-based technologies



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Using a RPI as a cloud server

- The RPI is quite a powerful machine
  - 4-core ARM CPU
  - GPU
  - Excellent performance/price/energy ratio

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  - Limited memory (1 GB)
  - Slow disk I/O
  - Slow network throughput

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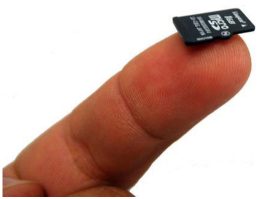
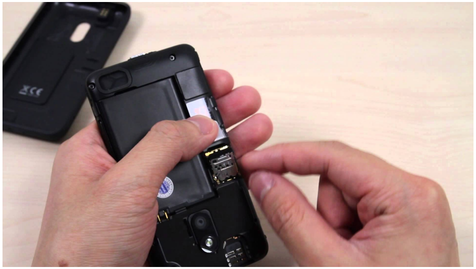
- But it also faces major performance challenges
  - Limited memory (1 GB)
  - Slow disk I/O
  - Slow network throughput
- Traditional cloud systems were not designed for such environments
  - The RPI is an extreme case, but researchers using other “small” machines are facing exactly the same challenges

Generic operating system tuning: file system parameters





- SD Cards were designed to store photos, videos, etc.
  - ▸ Small number of large files
  - ⇒ Large physical block sizes
- But Linux file systems expect small blocks by default
  - ☞ Tune the file system for larger blocks
  - ☞ Align partitions on the erase block boundaries (multiples of 4 MB)

`http://3gfp.com/wp/2014/07/formatting-sd-cards-for-speed-and-lifetime/`

Generic operating system tuning: swappiness

Swappiness is the kernel parameter that defines how much (and how often) your Linux kernel will copy RAM contents to swap. This parameter's default value is "60" and it can take anything from "0" to "100". The higher the value of the swappiness parameter, the more aggressively your kernel will swap. `https://www.howtoforge.com/tutorial/linux-swappiness/`

What's the right swappiness value for us?

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What's the right swappiness value for us?

- RPI-specific linux distributions set it to a very low value (e.g., 1)
- We changed it to the maximum value: 100

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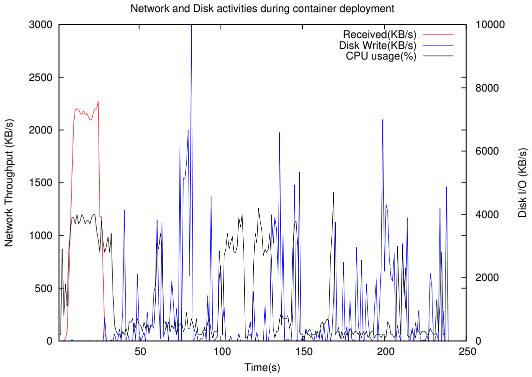
What's the right swappiness value for us?

- RPI-specific linux distributions set it to a very low value (e.g., 1)
- We changed it to the maximum value: 100
  - If your machine is going to swap anyway (because of small memory), then better do it out of the critical path
  - Also the file system cache makes use of all the unused RAM
  - Actually this results in less I/O...

`https://hal.inria.fr/hal-01446483v1`

Container deployment in a RPI

- Let's deploy a very simple Docker container on the RPI3
  - Standard ubuntu container (~45 MB) + one extra 51-MB layer



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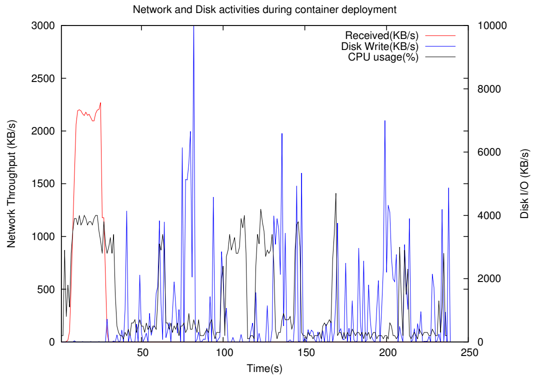

- Total deployment time: **about 4 minutes!!!**
  - ☞ Can we make that faster?

How Docker deploys a new container image

- A container image is composed of multiple layers
  - Each layer complements or modifies the previous one
  - Layer 0 with the base OS, layer 1 with extra config files, layer 2 with the necessary middleware, layer 3 with the application, layer 4 with a quick-and-dirty fix for some wrong config file, etc.
- What takes a lot of time is bringing the image from the external repository to the raspberry pi
  - Starting the container itself is much faster
- Deployment process:
  1. Download all layers simultaneously
  2. Decompress and extract each layer to disk sequentially
  3. Start the container

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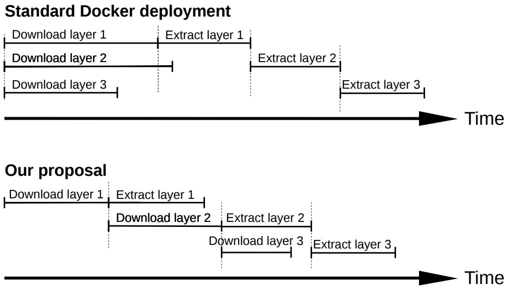
Question: What's wrong with this?

Sequential layer download

- Observation: parallel downloading delays the time when the first download has completed
- Idea: let's download layers sequentially. This should allow the deployment process to use the bandwidth and disk I/O simultaneously



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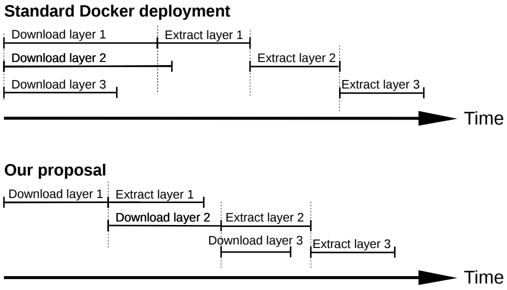


- Performance gains:
  - $\sim 3-6\%$ on fast networks
  - $\sim 6-12\%$ on slow (256 kbps) networks
  - Best gains with several big layers + slow networks

Let's speed up the decompression part

- Image layers are always delivered in compressed form, usually with gzip
  - Docker calls gunzip to decompress the images
  - But gunzip is single-threaded while RPis have 4 CPU cores!
- Let's use a multithreaded gunzip implementation instead

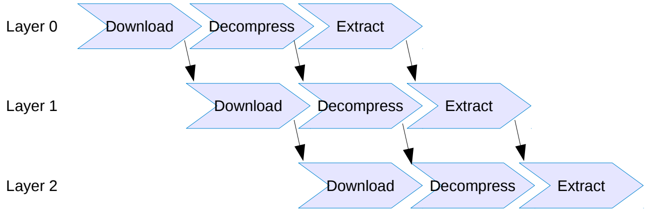
Let's speed up the decompression part

- Image layers are always delivered in compressed form, usually with gzip
  - Docker calls gunzip to decompress the images
  - But gunzip is single-threaded while RPis have 4 CPU cores!
- Let's use a multithreaded gunzip implementation instead
- Performance improvement: ∼15−18% on the entire deployment process
  - Much more if we look just at the decompression part of the process. . .

Let's pipeline the download, decompression and extraction processes

- Idea: let's split the download/decompress/extract process into three threads per layer
  - And pipeline the three parts: start the decompression and extract processes as soon as the first bytes are downloaded

☞ Intersting thread synchronization exercise. . .



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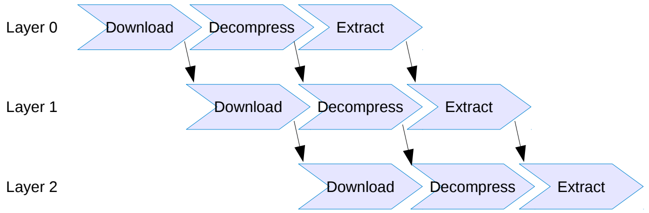
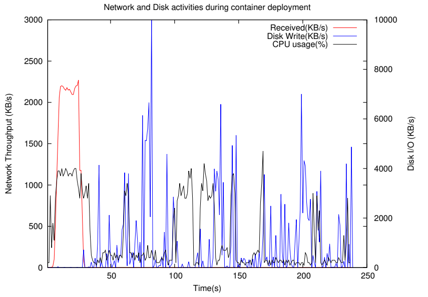
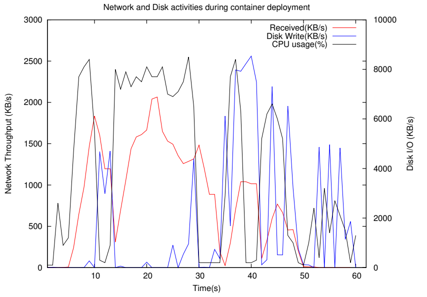


- Performance improvement: $\sim 20-55\%$

Let's combine all three techniques



Before



After

- Combined performance gain: 17 – 73%
  - Lowest gains obtained with low (256 kbps) networks. The network is the bottleneck, not many local optimizations are possible
  - When using a "decent" network connection: $\sim$ **50 – 73% gains**

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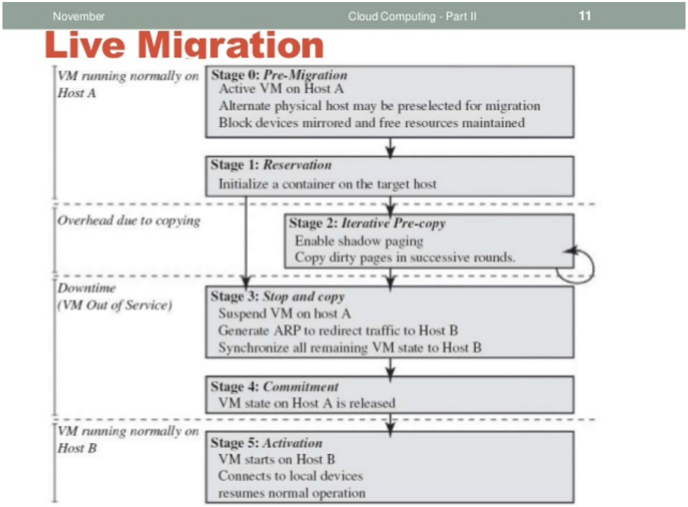
Why do we need migration?

1. Resources are fixed but users are mobile
2. Churn
3. Workload fluctuations
4. Consolidation
5. Competing applications

Live migration was initially designed for VMs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Live Migration

VM running normally on Host A

Stage 0: ***Pre-Migration***
Active VM on Host A
Alternate physical host may be preselected for migration
Block devices mirrored and free resources maintained

Stage 1: ***Reservation***
Initialize a container on the target host

Overhead due to copying

Stage 2: ***Iterative Pre-copy***
Enable shadow paging
Copy dirty pages in successive rounds.

Downtime (VM Out of Service)

Stage 3: ***Stop and copy***
Suspend VM on host A
Generate ARP to redirect traffic to Host B
Synchronize all remaining VM state to Host B

Stage 4: ***Commitment***
VM state on Host A is released

VM running normally on Host B

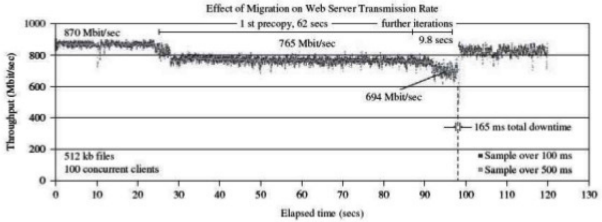
Stage 5: ***Activation***
VM starts on Host B
Connects to local devices
resumes normal operation

`https://www.slideshare.net/mhajibaba/`

`cloud-computing-principles-and-paradigms-5-virtual-machines-provisioning-and-migration-services`

Performance (on a very fast infrastructure)

Live migration effect (on a running web server)



Presented by Majid Hajibaba

Live migration in LXC containers

- The new LXD container system supports live migration
  - Checkpoint/restart based on CRIU-2.0
  - Requires a very recent Linux kernel
  - Still announced as very experimental. . .
  - . . . and the mixed 64-bit (hardware) + 32-bit (OS) configuration of Raspberry PIs is very confusing for CRIU

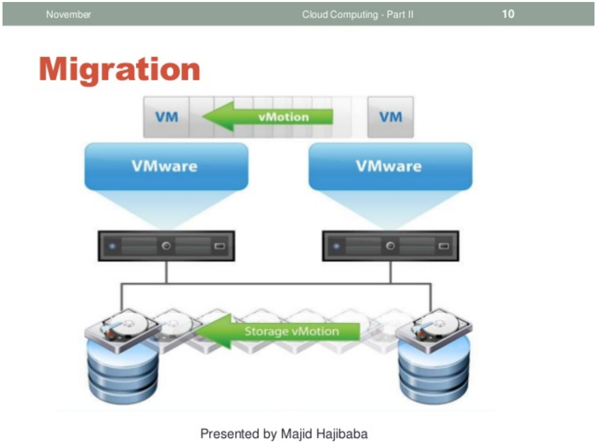
A possible alternative: DMTCP

- DMTCP (Distributed MultiThreaded CheckPointing) checkpoints processes in user space
  - It also checkpoints open file descriptors, PID, sockets, etc.
  - And it replaces them with a “dummy” at the destination node to avoid name clashes

☞ No kernel support required!
  - And a container is nothing more than a group of processes. . .
  - We “just” need support for statically-linked executables and for Linux namespaces

`http://dmtcp.sourceforge.net/`

Migrating the application's data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Migration

VM
vMotion
VM
VMware
VMware
Storage vMotion

Presented by Majid Hajibaba

- In a cloud environment we can rely on network-attached storage
- But in a fog it is pointless to migrate an application without migrating the data as well

Another alternative: elasticity-based migration

- We expect many fog applications to be elastic
  - Easy support for dynamically adding/removing nodes
- Can migration be just a special case of elasticity?
  - Start with X pods
  - Scale up to $X + 1$ pods, make sure the new pod is created at the right location
  - Scale down to X pods, make sure to choose which pod gets stopped
- The hard parts:
  - When can we issue the scale-down operation? Liveness probes
  - What about the application state?

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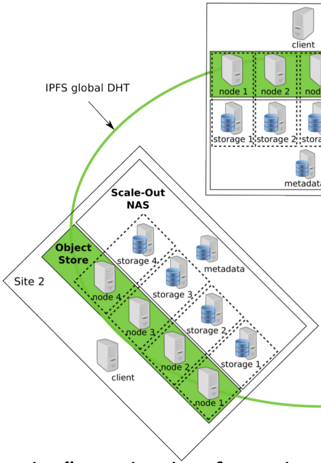
Data storage in fog platforms

- Where should we store fog user's data?
  - In the fog node where data were produced?
  - Replicate in nearby nodes as well?
  - Replicate in *all nodes?* In *all sites?*
  - ☞ At least we need to make data available from everywhere (with decent performance)

- IPFS: the InterPlanetary File System
  - Actually this is a data store rather than a file system: objects are immutable
  - Objects are stored locally and registered in a DHT to allow remote access
  - But IPFS is not aware of the fog topology
    - ★ If an object is available in another node of the same site, IPFS will not prefer this location rather than another site

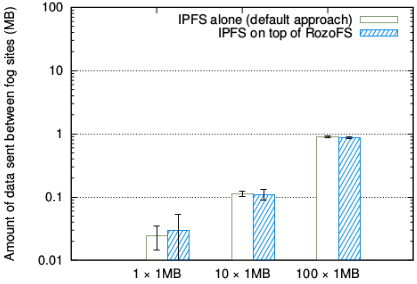
Scale-out NAS



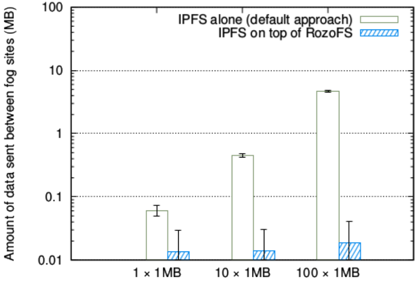
- Each node first checks if an object is present in the local NAS
- Otherwise it locates it using the DHT, and copies it locally for further usage

https://hal.archives-ouvertes.fr/hal-01483702

Accessing local objects

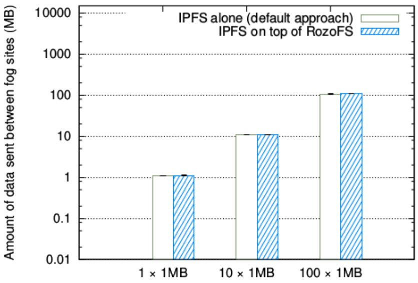


(a) – Write

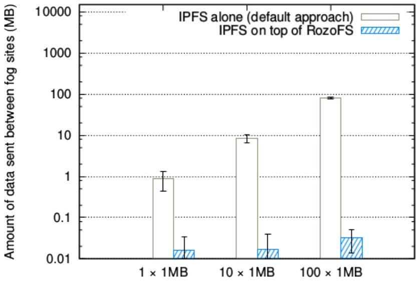


(b) – Read

Accessing remote objects



(a) – First read



(b) – Second read

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Many Fog/IoT application process data streams

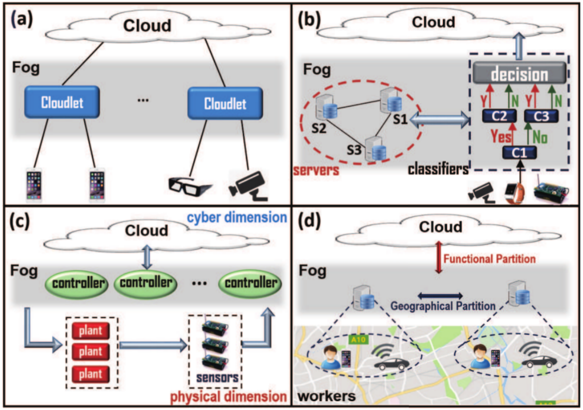
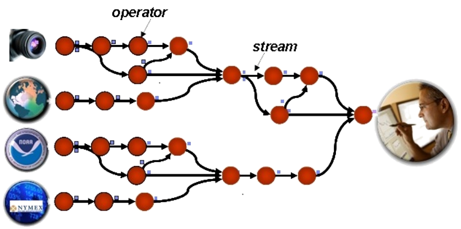


Fig. 1. Examples of typical Fog data streaming Applications.(a) IoT stream query and analytics, (b) Real-time event monitoring, (c) Networked Control Systems (NCS) for Industrial automation, (d) Real-time Mobile Crowdsensing (MCS).

`https://arxiv.org/abs/1705.05988`

Can we use stream processing middlewares in the fog?

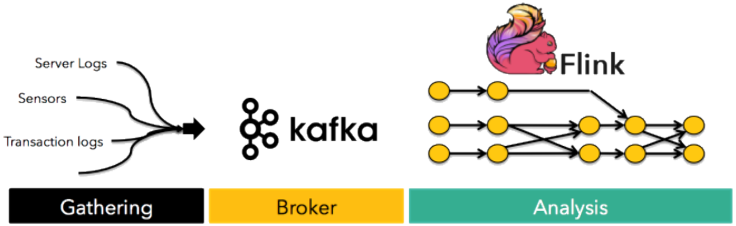


http://researcher.watson.ibm.com/researcher/view_group.php?id=2531

- The data analytics community builds interesting stream processing platforms
  - Storm, Spark, Flink etc.
  - Idea:
    - ★ Define processing as a workflow of operators
    - ★ Let data "flow" through the operators
    - ★ Each operator keeps a window of data items

Stream platforms were designed for big data processing

- Problem: stream platforms were designed for computer clusters
  - Lots of data to be processed
  - Lots of resources
  - Single location



https://www.confluent.io/blog/real-time-stream-processing-the-next-step-for-apache-flink/

Challenges for adapting stream processing to fogs

- Data source/sink placement
  - According to the location(s) where data are produced and consumed
  - Some stream processing systems (e.g., Spark require a shared file system between all nodes)
- Intermediate operator placement
  - To optimize metrics such as processing latency, requested resources, long-distance data volume, etc.
- Operator elasticity
  - Can we rescale stream processing operators dynamically?
  - Easy if we accept to drop data, harder otherwise
- Resource management
  - Can operators use less than 1 full core each?

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Conclusion

- Cloud data centers are very powerful and flexible
  - But not all applications can use them (latency, traffic locality)
- If we evaporate a cloud, then we get a fog
  - Extremely distributed infrastructure: there must be a server node close to every end user
    - ★ Server nodes must be small, cheap, easy to add and replace
    - ★ Server nodes are very far from each other
- This is only the beginning
  - No satisfactory edge/fog platforms are available today (we are not even close)
  - There remains thousands of potential PhD research topics in this domain 🙂

Shameless announcement

The FogGuru European project is starting soon on similar issues: University of Rennes 1, TU-Berlin, Elastisys (Umeå, Sweden), U-Hopper (Trento, Italy), Las Naves (Valencia, Spain)

We are looking for 8 ambitious and talented PhD students:

- All positions co-supervised by one academic + one industrial supervisor
- Extensive doctoral training program (scientific, technical, soft-skills, innovation & entrepreneurship)
- International mobility
- 7 months at Las Naves to deploy technologies in the city center of Valencia & get feedback from real end users

fogguru

www.fogguru.eu