From Data Centers to Fog Computing: The Evaporating Cloud

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RESCOM 2017 summer school
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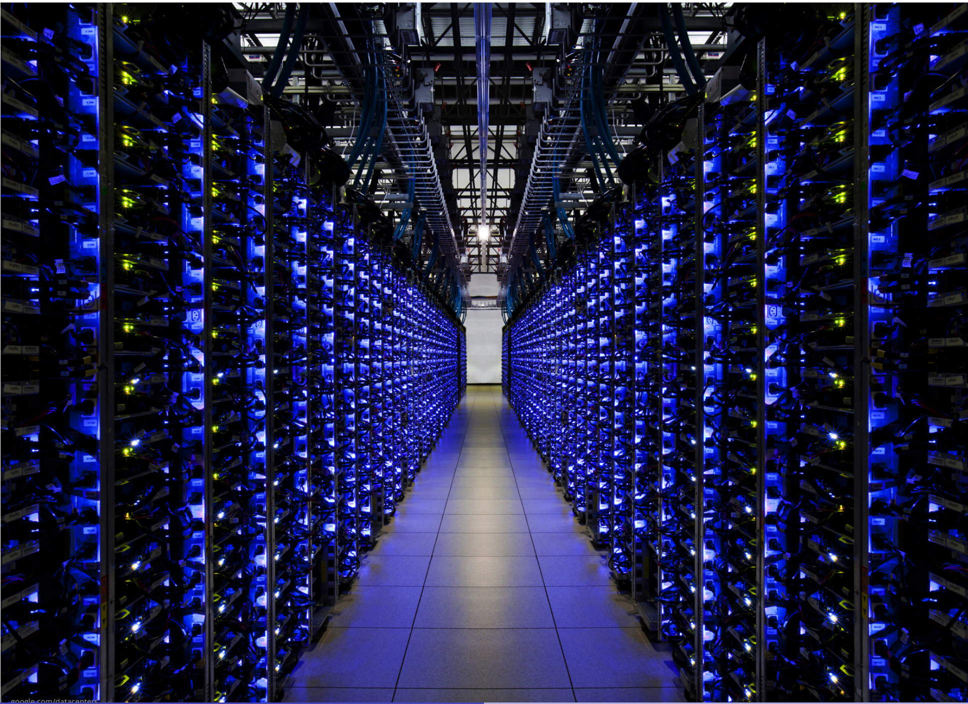
google.com/datacenters

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5 Using a Raspberry Pi as a cloud node

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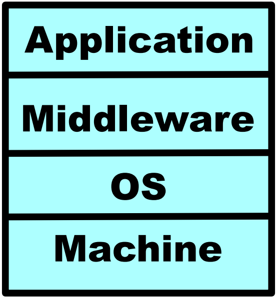
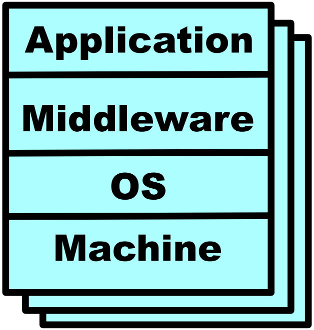
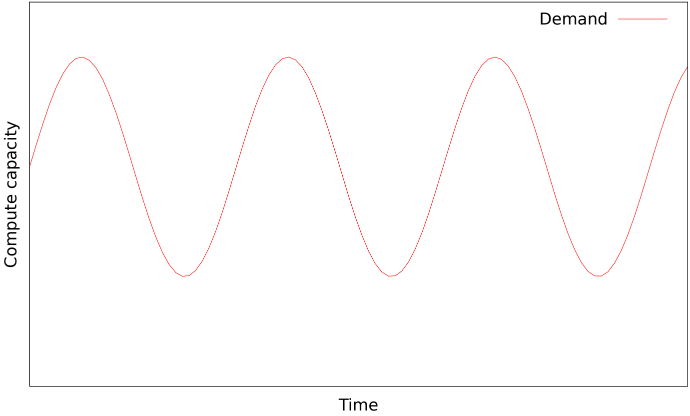


Traditional architecture



Traditional architecture

The varying capacity problem



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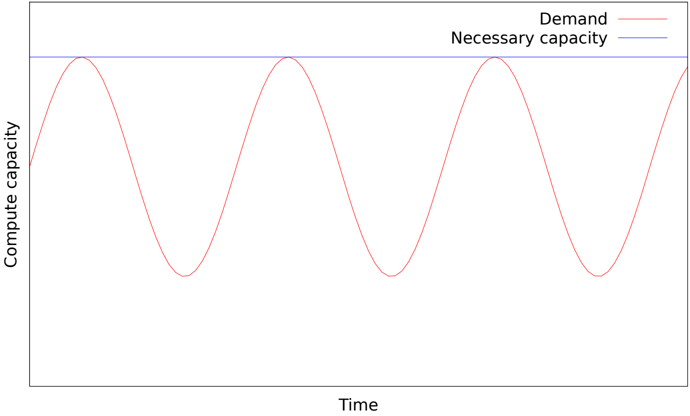
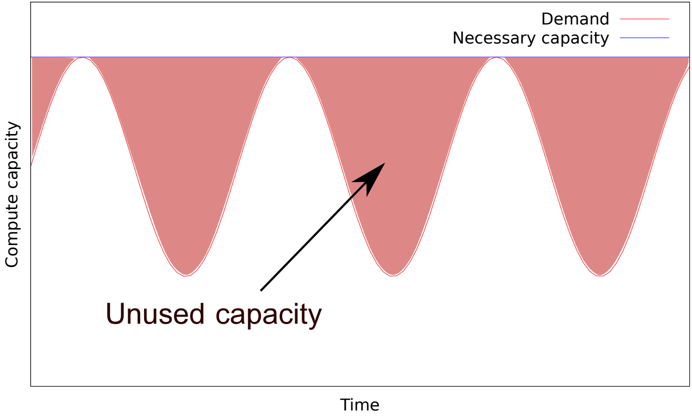
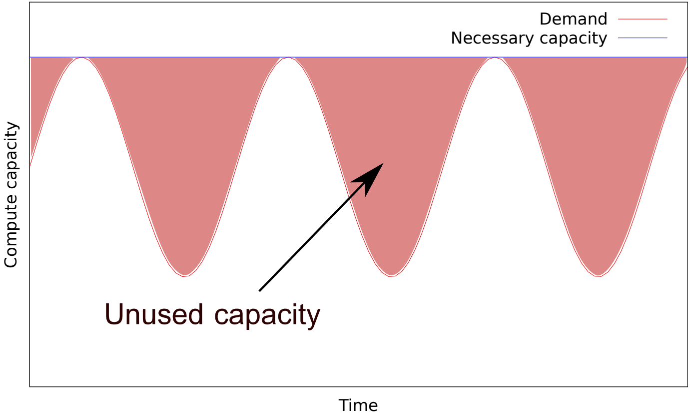



Demand
Necessary capacity
Compute capacity
Unused capacity
Time

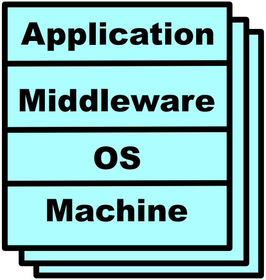
The varying capacity problem



What if demand increases beyond the capacity?

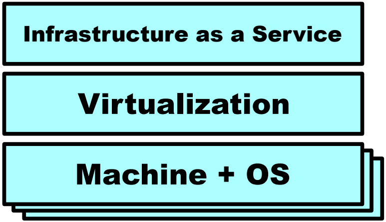
Cloud Computing

- Difficult to vary capacity!
- Manual resource management

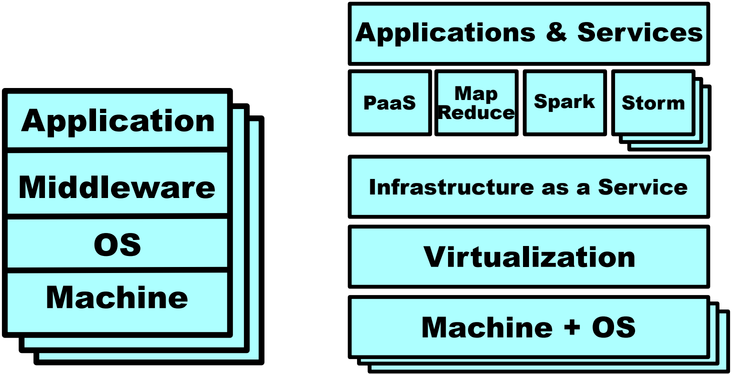


Traditional architecture

- Resources available on demand
- Resource management is fully automated
- Pay only for what you use



Cloud architecture



Traditional architecture

Cloud architecture

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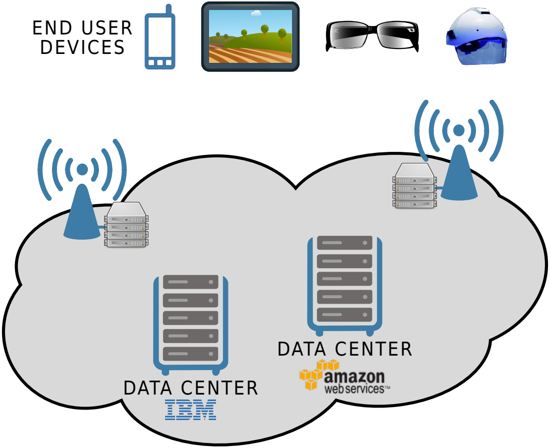
Since 2016: **mobile network traffic > fixed traffic**

END USER
DEVICES

Since 2016: **mobile network traffic > fixed traffic**

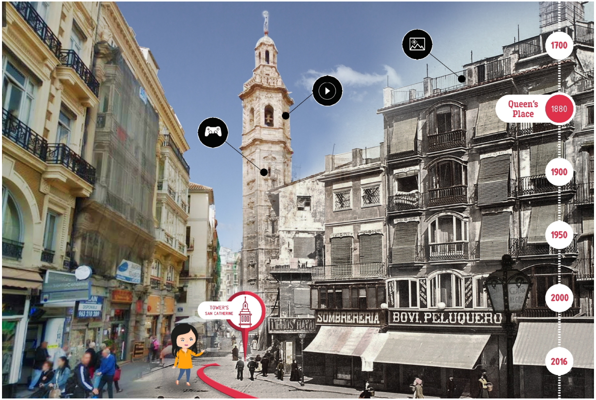


(example application)

New types of mobile applications

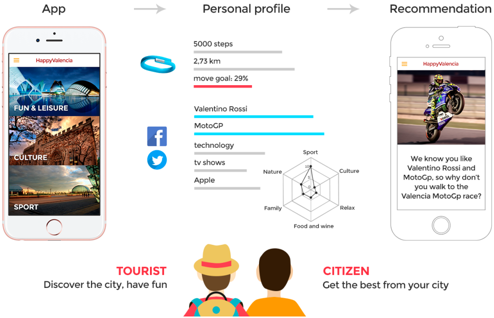
Interactive applications require ultra-low network latencies

- E.g., augmented reality require end-to-end delays under 20 ms
- But latencies to the closest data center are 20-30 ms using wired networks, up to 50-150 ms on 4G mobile networks!!!



Throughput-oriented applications require local computations

- E.g., distributed videosurveillance is relevant only close to the cameras
- Why waste long-distance network resources?
- Fact: IoT-generated traffic grows faster than the Internet backbone capacity



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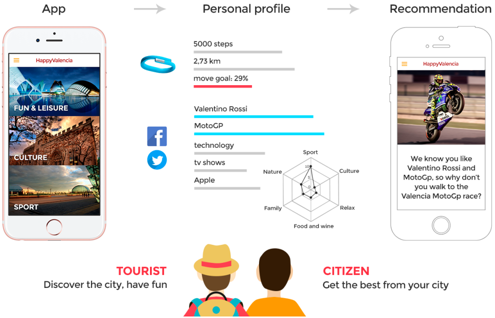

Question: **who owns computing resources located closest to the mobile end users?**

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Mobile network operator's revenues

- **Where does mobile network operator's revenues come from?**
  - 1990's: Voice (not any more)
  - 2000's: Text/SMS (not any more)
  - 2010's: Data (not for very long. . .)
  - What's next?

Mobile network operator's revenues

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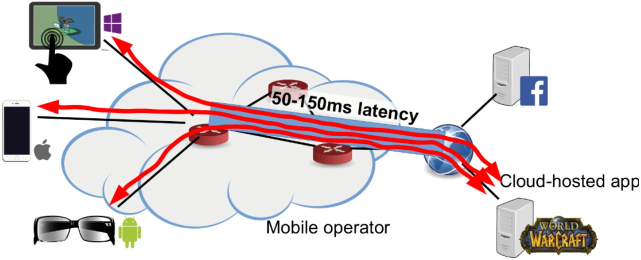
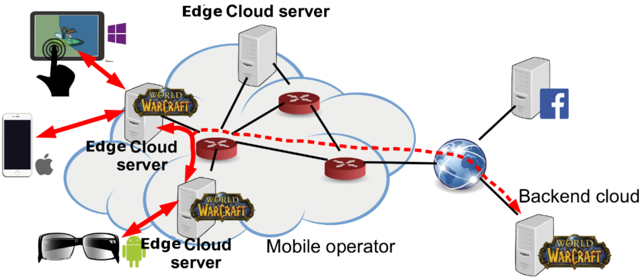
  - 1990's: Voice (not any more)
  - 2000's: Text/SMS (not any more)
  - 2010's: Data (not for very long. . .)
  - What's next? **Services!**
- Let's steal part of the cloud computing business. . .
  - No cloud data center can be closer to the users than us! 🙂

Before:



After:



Standardization efforts

- European Telecommunications Standards Institute: ~~Mobile~~ Multi-Access Edge Computing
  - Fujitsu, Hewlett-Packard, Huawei, Intel, Juniper, Motorola, NEC,Nokia, Orange, Samsung, Sony, Vodafone, ...
  - Focus: integration within mobile phone networks

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- Open Fog Consortium
  - ARM, Cisco, Dell, Intel, Microsoft, . . .

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  - ARM, Cisco, Dell, Intel, Microsoft, ...
- Fog/Edge/Massively Distributed Clouds WG at OpenStack

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Fog computing = cloud + edge + end-user devices
as a single execution platform

- Low latency
- Localized traffic (privacy, less global traffic...)

Fog > Cloud

- We need cloud servers close to the users, but the users are everywhere (and they are mobile)
  - Let's place one cloud server within 1-hop WiFi range of any end-user device
  - ⇒ Fog computing resources will need to be distributed in thousands of locations

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- Fog nodes will be connected with commodity networks
  - Forget your multi-Gbps data center networks!

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- Fog nodes must be small, cheap, easy to deploy and to replace
  - We started using single-board computers as our (powerful!) cloud servers

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Raspberry PIs are more powerful than you may think

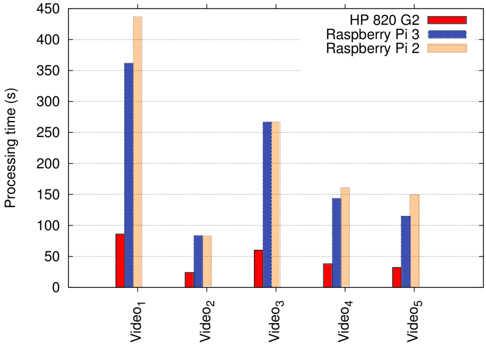
	RPi3	Pine A64+	HP 820 G2
CPU (s)	46.5	4.1	2.8
Memory (MB/s)	933	1098	5658
Network (Mb/s)	94.2	922	935
Storage (MB/s)	2.53	2.42	23.9
Power when idle (W)	2	2	15
Power under load (W)	4.4	4.1	24.5
Price	∼ 92 €	∼ 74 €	∼ 1600 €

We chose RPi3 as our base platform for the time being

- Mostly because of easy purchase options and community support. . .

What about a real application?

- Input: live video stream
- Processing: face recognition algorithm running inside Apache Flink



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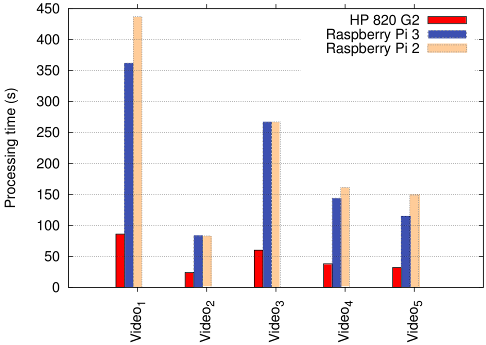

- The RPIs are "only" 3-5 times slower than my laptop
- But they are 17 times cheaper
- If my applications scale horizontally I can use as many RPIs as necessary

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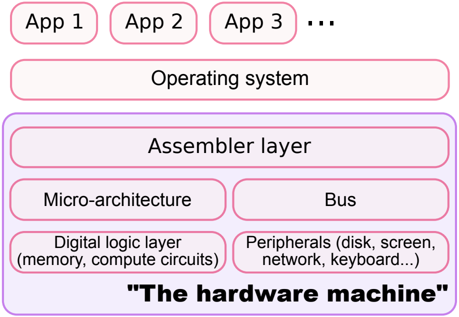
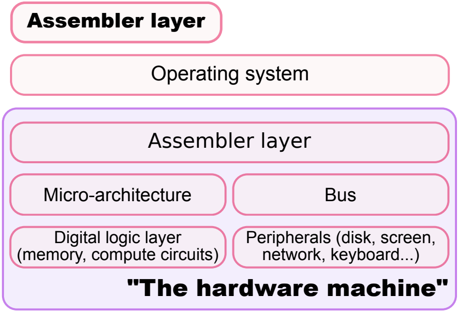
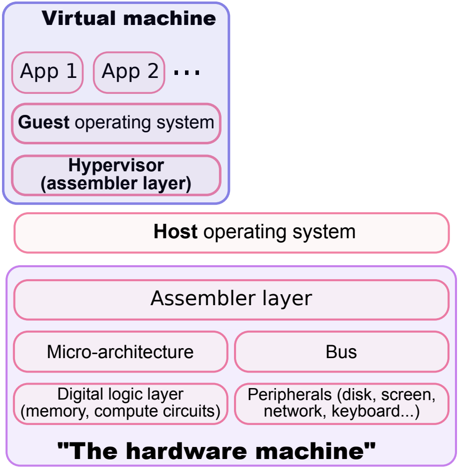


Traditional machine architecture:

- Applications
- Operating system
- Hardware



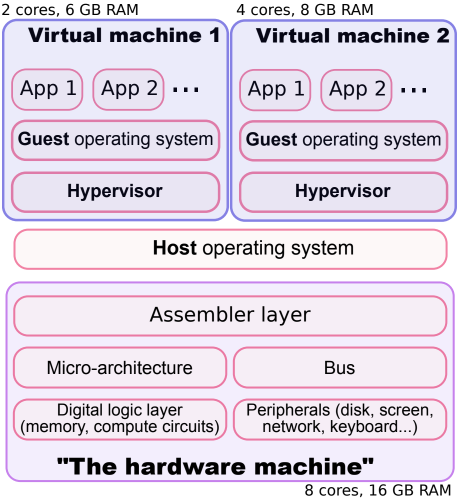
Let's create a "special application" which behaves exactly the same as the assembler layer...



We can execute any operating system on top of it...

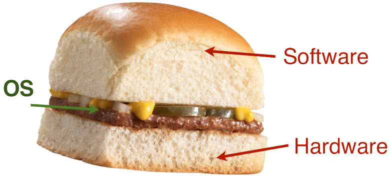
... and any application over the guest operating system

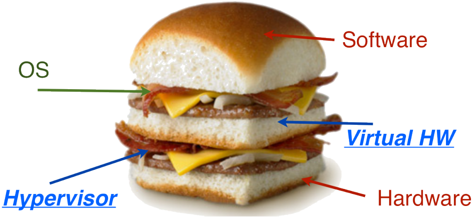
$\Rightarrow$ We have a virtual machine



We can run multiple virtual machines on the same physical machine:

- Each virtual machine runs in full isolation from the other VMs
- Each virtual machine owns a subset of the hardware resources of the physical machine


Software
OS
Hardware


Software
OS
Virtual HW
Hypervisor
Hardware

Why is virtualization interesting for cloud providers?

Isolation: I can create multiple VMs on the same machine and give each VM to a different user (they will not see nor interfere with each other)

Customization: Each user can customize their VMs according to their own requirements.

Consolidation: Few applications can really exploit a large server machine to its maximum capacity. With virtualization I can split this capacity in smaller units and thereby increase my resource utilization.

Management: Virtualization simplifies resource management: I can measure how many resources each user is using, migrate VMs from one host to another, etc.

Virtualization technologies

Virtualization technologies are now totally mainstream:

- Commercial: VMware, Microsoft App-V, ...
- Open-Source: KVM, VirtualBox, Xen, ...

Paravirtualization vs. full virtualization:

- Paravirtualization works on any hardware platform but it requires special support in the guest OS. Slow!
- Full virtualization exploits special features of modern CPUs, does not require special support in the guest OS. Faster!

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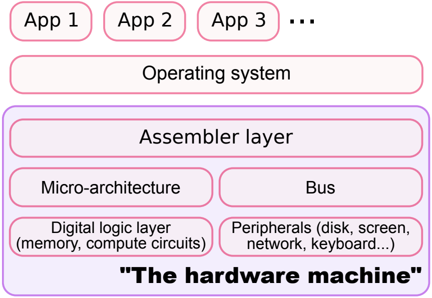
Virtual machines are waaaaaayyyyyy too heavyweight for a RPI

- Each guest OS needs lots of memory
- Each OS needs to execute lots of background stuff
- Impossible to run 100+ VMs on a single machine...

Containers



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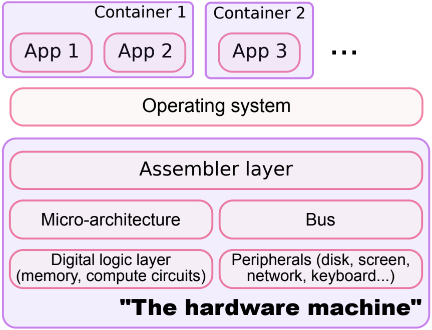


Let's create groups of processes which belong together:

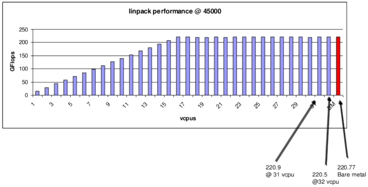
- Process groups are totally isolated from each other
- Each process group belongs to a single user
- Each process group has its own hardware resource limits (CPU, RAM, ...)
- Each process group has its own network access policy
- Etc.

$\Rightarrow$ We have containers

Container technologies

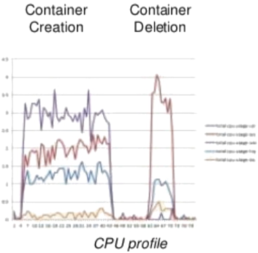
- Containers are an operating system feature
  - No need for special CPU support
  - Fully supported in Linux, Windows, ...
  - We usually add an extra software layer to simplify management: Docker
- Containers are less customizable than VMs
  - Container owners cannot choose their OS
  - But was that really necessary in the first place? Not always.
- Containers are much more lightweight than VMs
  - No need to run lots of (mostly identical) operating systems next to each other
  - Containers often start in less than 1 second
  - We can easily run hundreds of containers on a mid-sized machine

Performance



Performance is extremely close to bare-metal

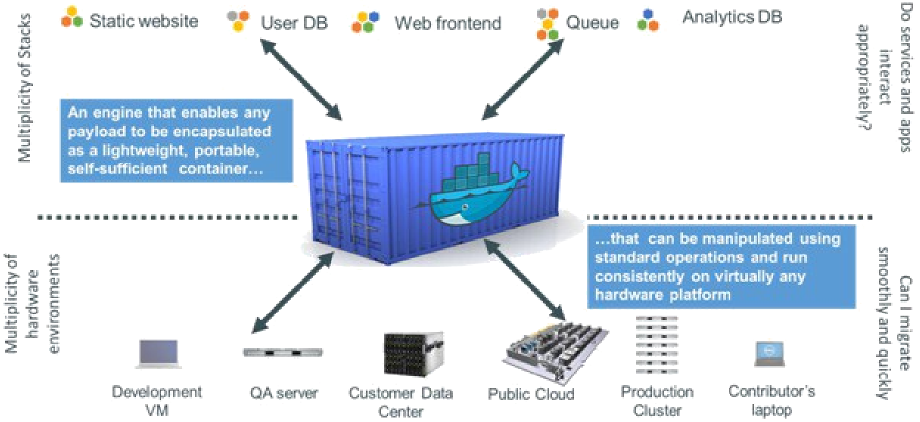
Agility



- Starting 150 containers w/ Apache
  - Total time: 36 s (240 ms/container)
  - Consumes about 2% of CPU
  - Memory usage: ∼10 MB/container
- Stopping 150 containers:
  - Total time: 9 seconds

http://www.slideshare.net/BodenRussell/realizing-linux-containerslxc

Docker is a shipping container system for code

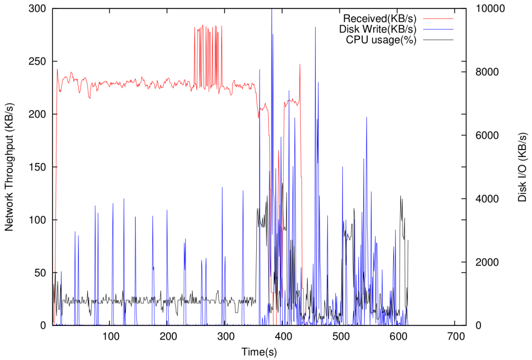


https://impythonist.wordpress.com/2015/06/21/

docker-the-future-of-virtualization-for-your-django-web-development/

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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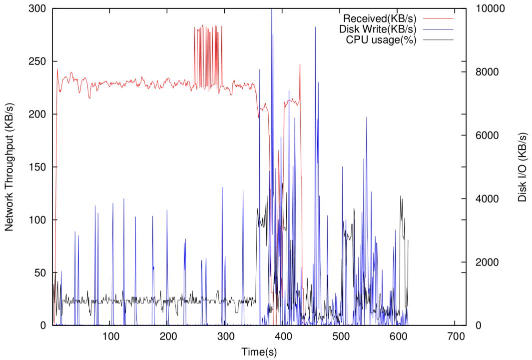
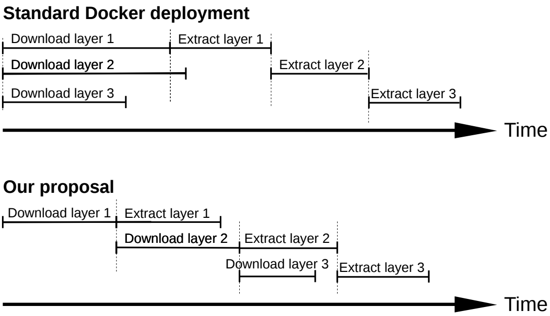


- Total deployment time: **over 10 minutes!!!**
- Docker downloads all layers then decompresses then writes to disk

Very preliminary results

- **Idea:** let's parallelize the deployment process to use the bandwidth and disk I/O simultaneously



Very preliminary results

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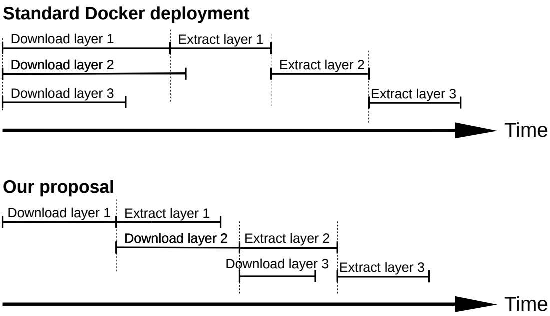

- Current improvement ∼10%
- Greater improvements over slow networks
- We still have lots of performance improvement potential. . .

This is only the beginning

Lots of remaining research problems:

- How do we develop a fog computing application?
  - One VM per user: easy but (mostly) useless
  - Multiuser applications: much harder!!! We need fog-aware middlewares
- How do we manage applications?
  - How do we express the resource/location/performance requirements for each application component?
  - When should we migrate/replicate/delete components to maintain performance?
  - Etc.
- How do we manage resources?
  - Assign specific resources to each container (and manage conflicts)
  - Monitoring / anomaly detection
  - System upgrades
  - Etc.

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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

A European H2020 project named FogGuru will start soon on similar issues: France (PI), Germany, Italy, Sweden, Spain

- Application and resource management in scalable fog platforms
- Stream processing middleware systems for fog applications
- Blueprints for innovative fog applications
- Full-scale experimental deployment in Valencia (Spain)

We are looking for:

- 8 ambitious and talented PhD students
- 1 project manager / postdoc researcher