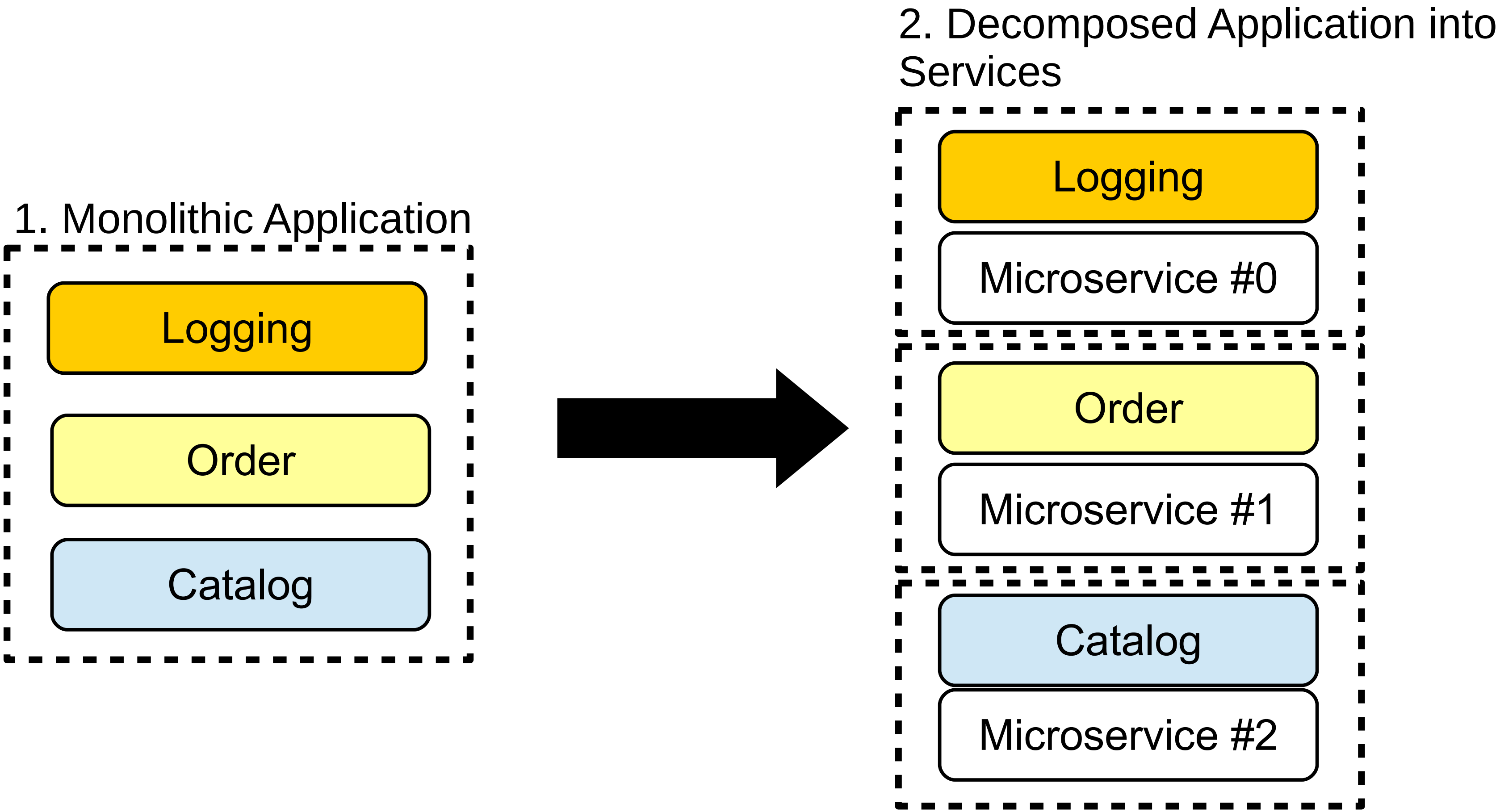
Toro, a Dedicated (Uni)kernel for Microservices

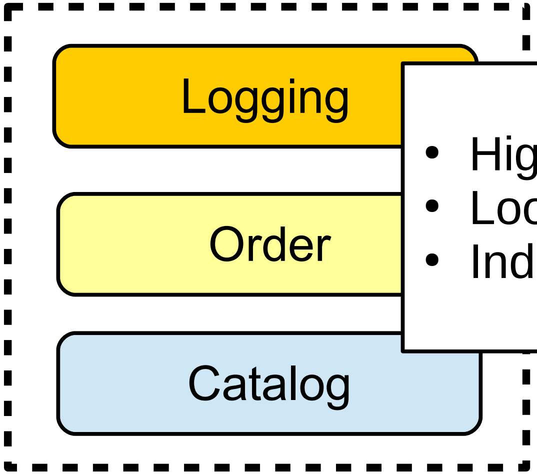
Dr. Matias E. Vara Larsen

What are microservices?

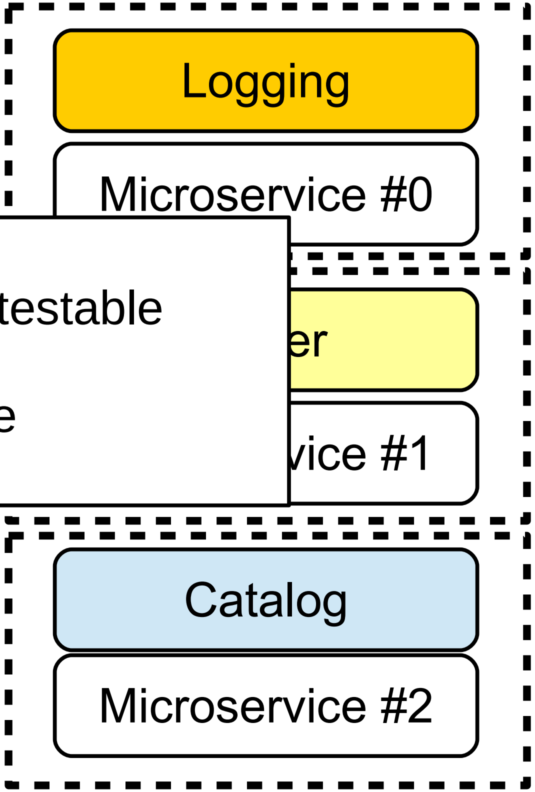


What are microservices?

1. Monolithic Application

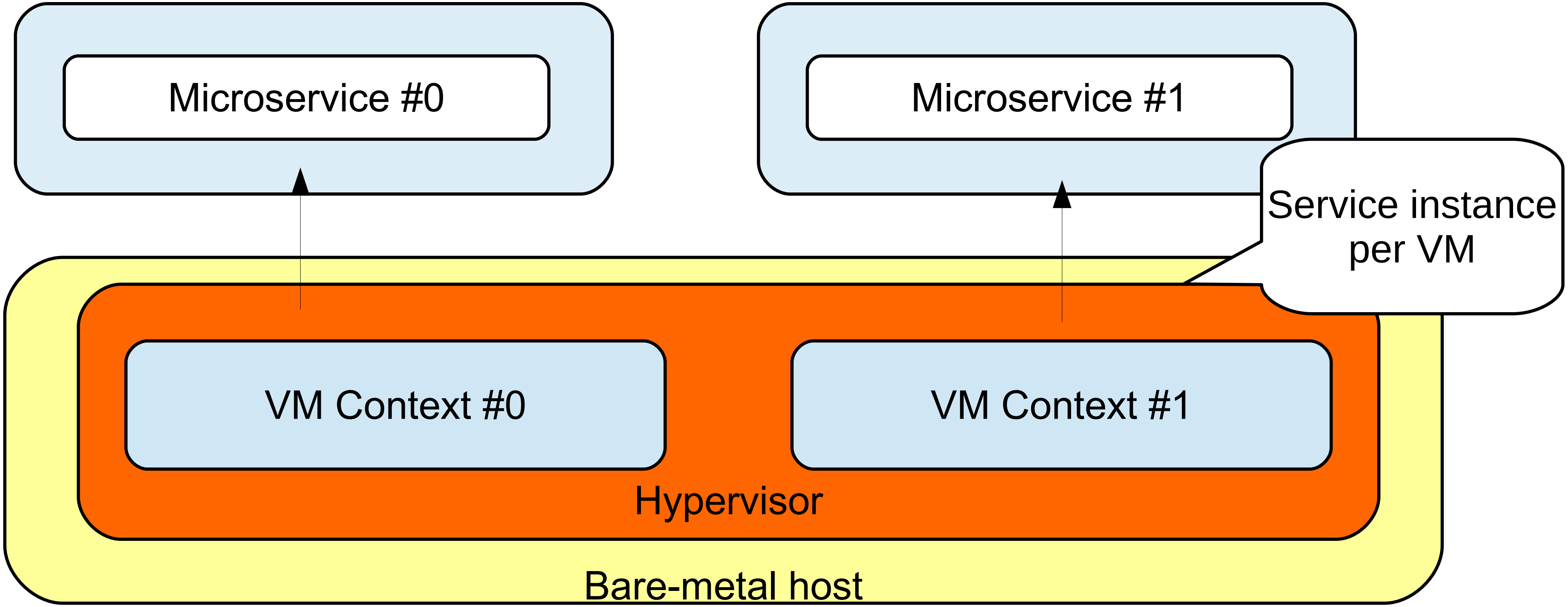


2. Decomposed Application into Services

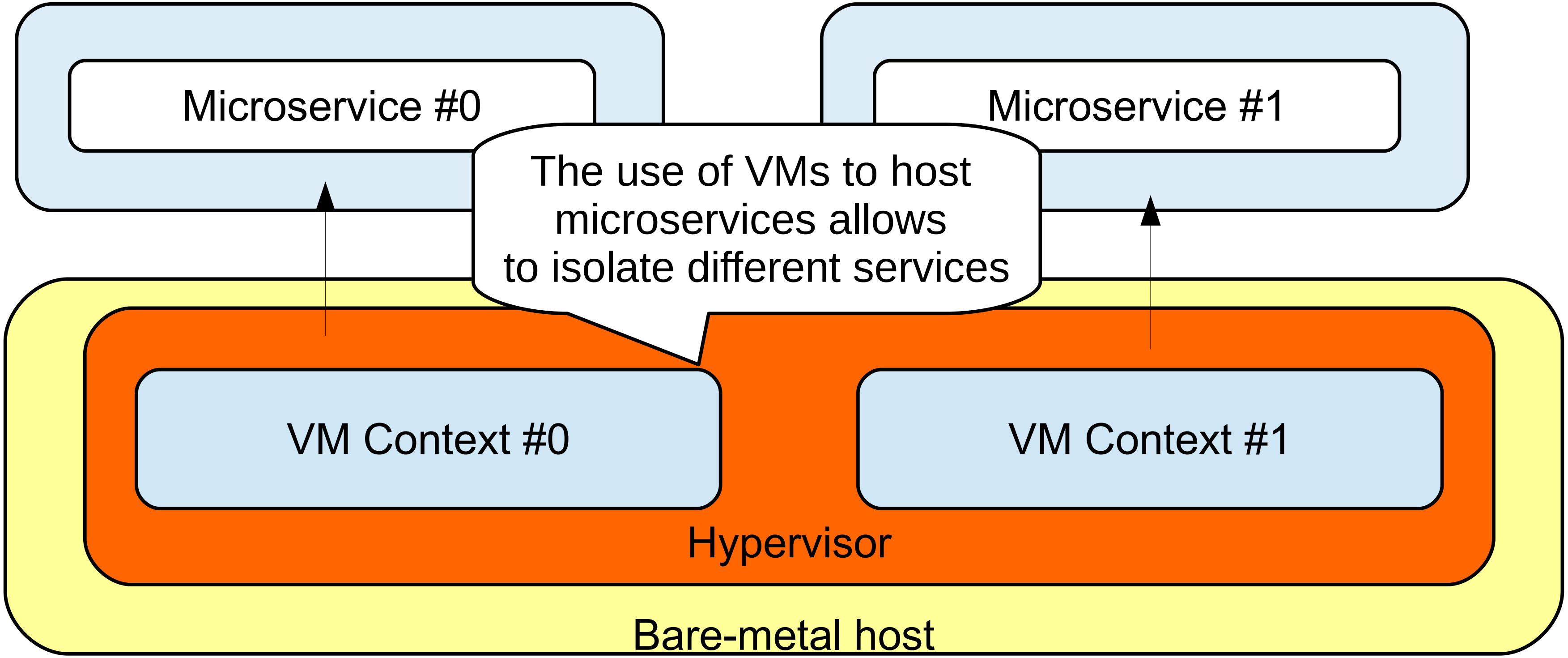


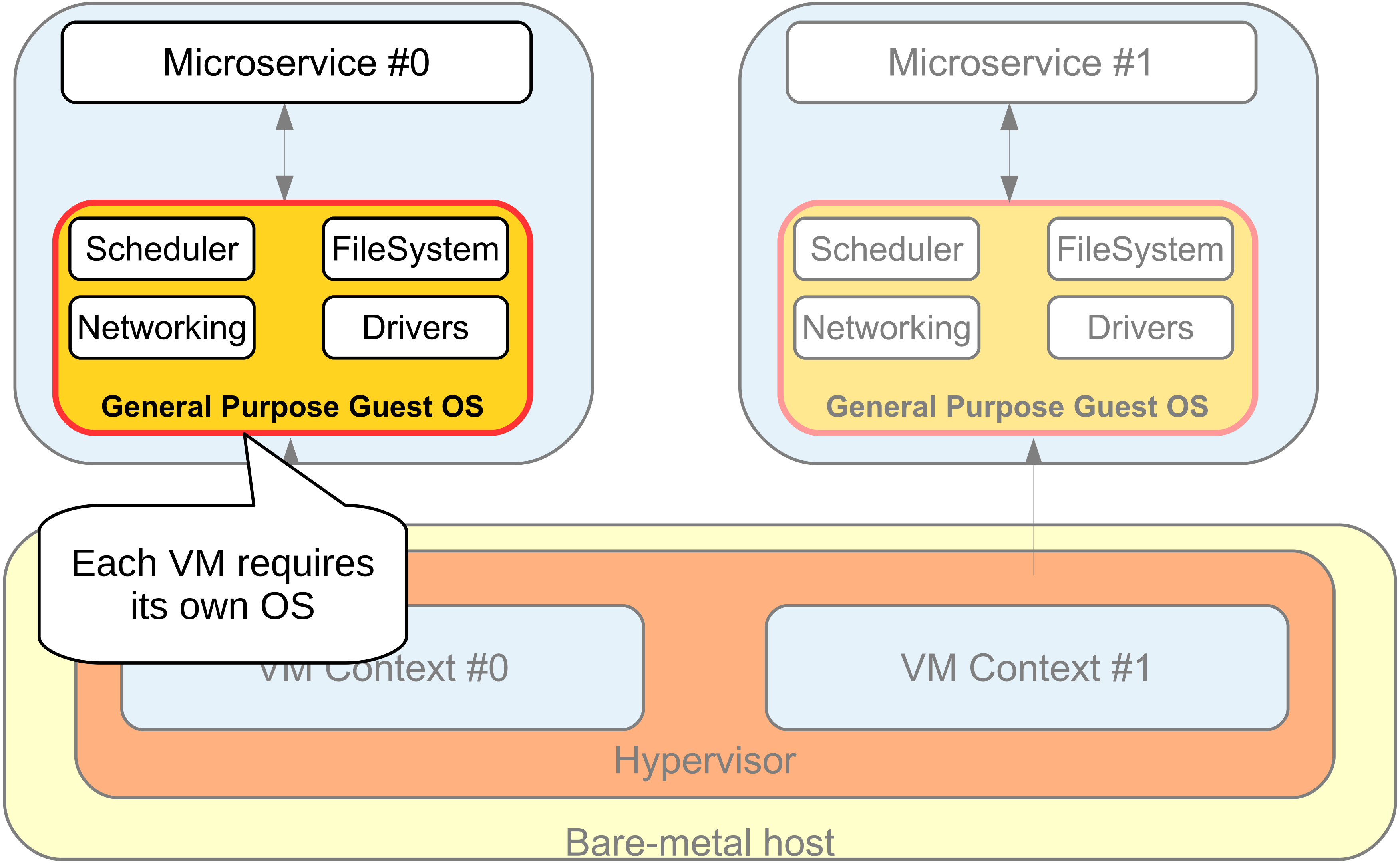
- Highly maintainable and testable
- Loosely coupled
- Independently deployable

How are microservices deployed?

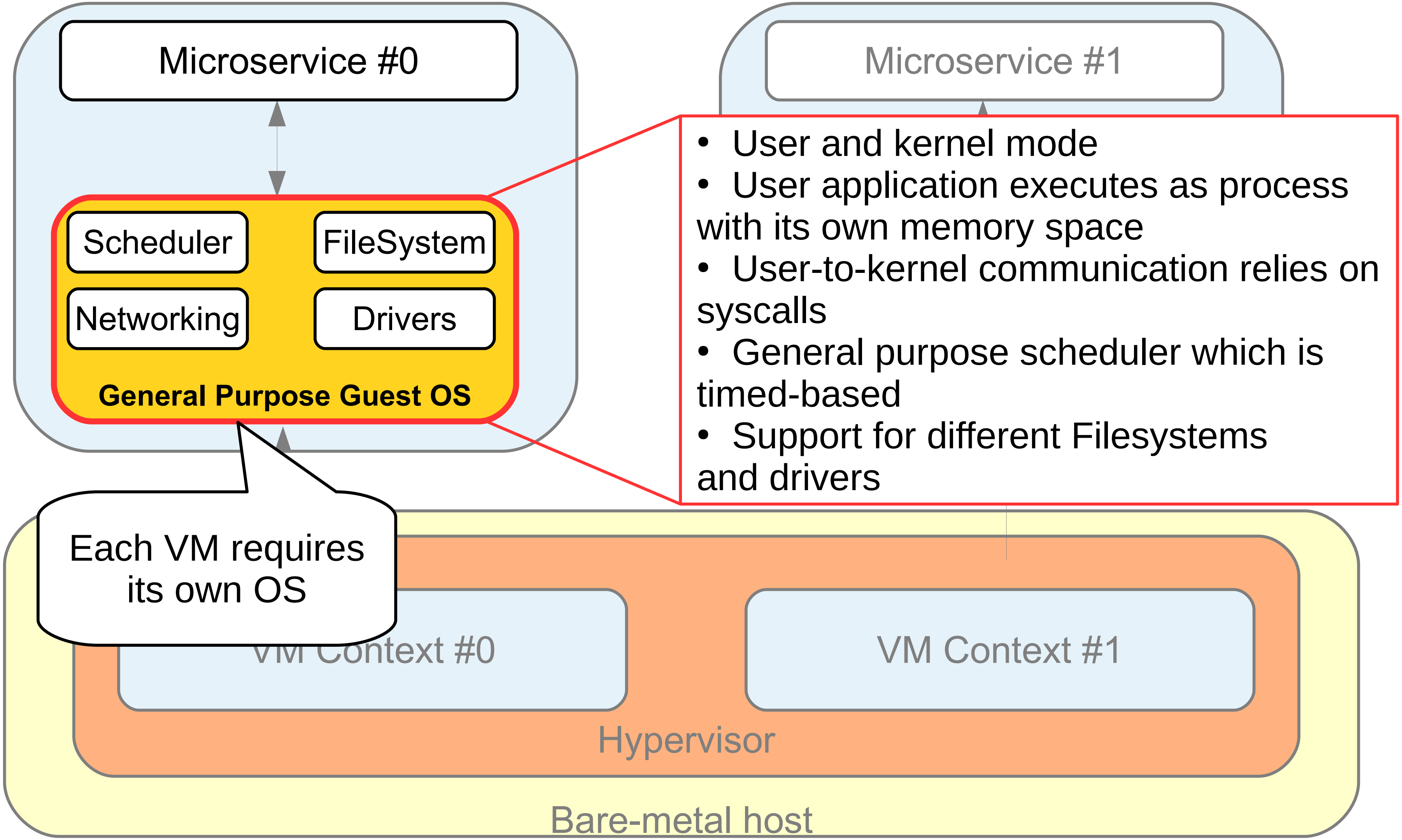


How are microservices deployed?

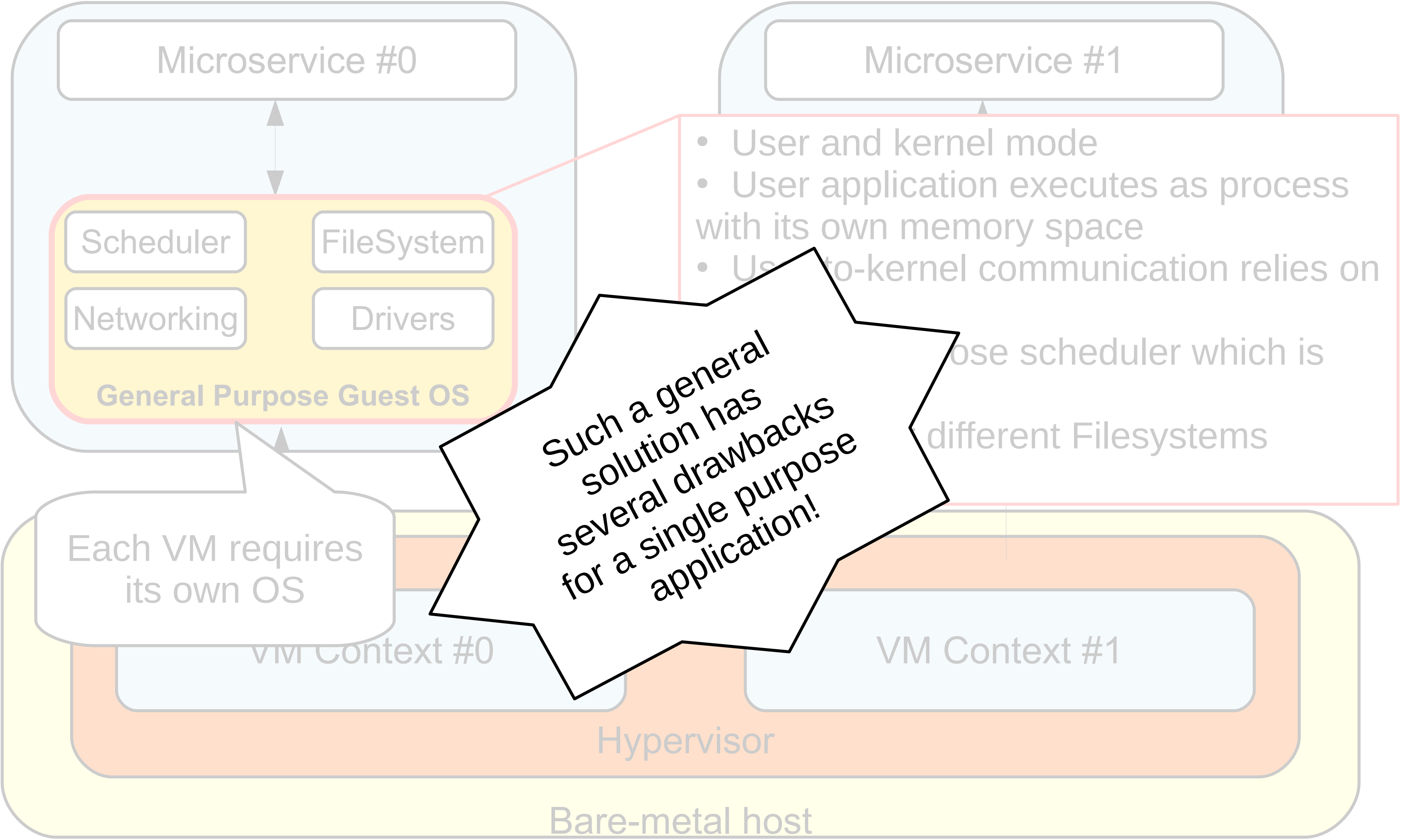




Microservice #0
Scheduler
FileSystem
Networking
Drivers
General Purpose Guest OS
Microservice #1
Scheduler
FileSystem
Networking
Drivers
General Purpose Guest OS
Each VM requires its own OS
VM Context #1
Hypervisor
Bare-metal host



Microservice #0
Microservice #1
Scheduler
FileSystem
Networking
Drivers
General Purpose Guest OS
• User and kernel mode
• User application executes as process with its own memory space
• User-to-kernel communication relies on syscalls
• General purpose scheduler which is timed-based
• Support for different Filesystems and drivers
Each VM requires its own OS
VM Context #0
VM Context #1
Hypervisor
Bare-metal host


Microservice #0
Microservice #1
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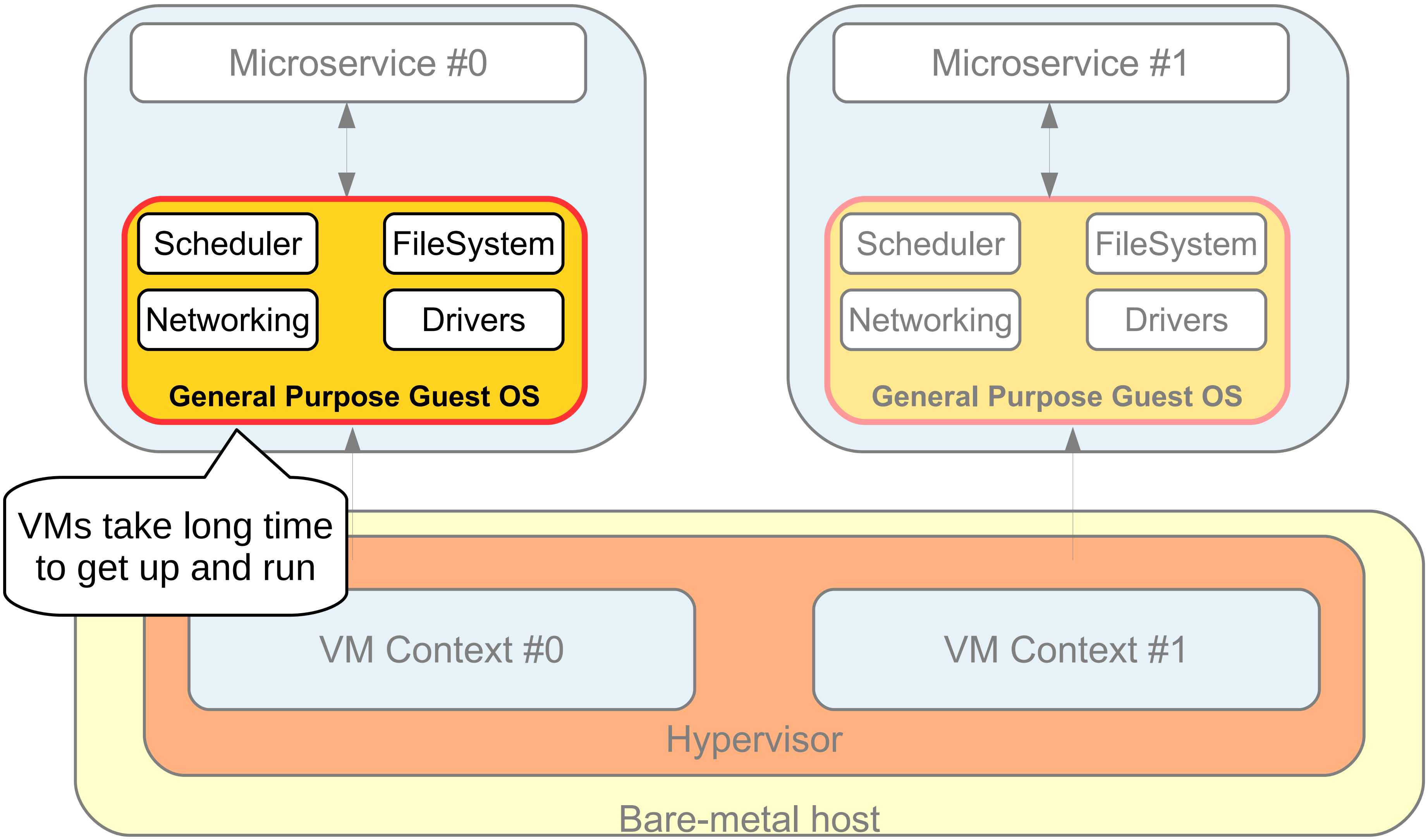
General Purpose Guest OS
User and kernel mode
User application executes as process with its own memory space
different Filesystems
Each VM requires its own OS
Such a general solution has several drawbacks for a single purpose application!
VM Context #0
VM Context #1
Hypervisor
Bare-metal host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VMs take long time to get up and run
VM Context #0
VM Context #1
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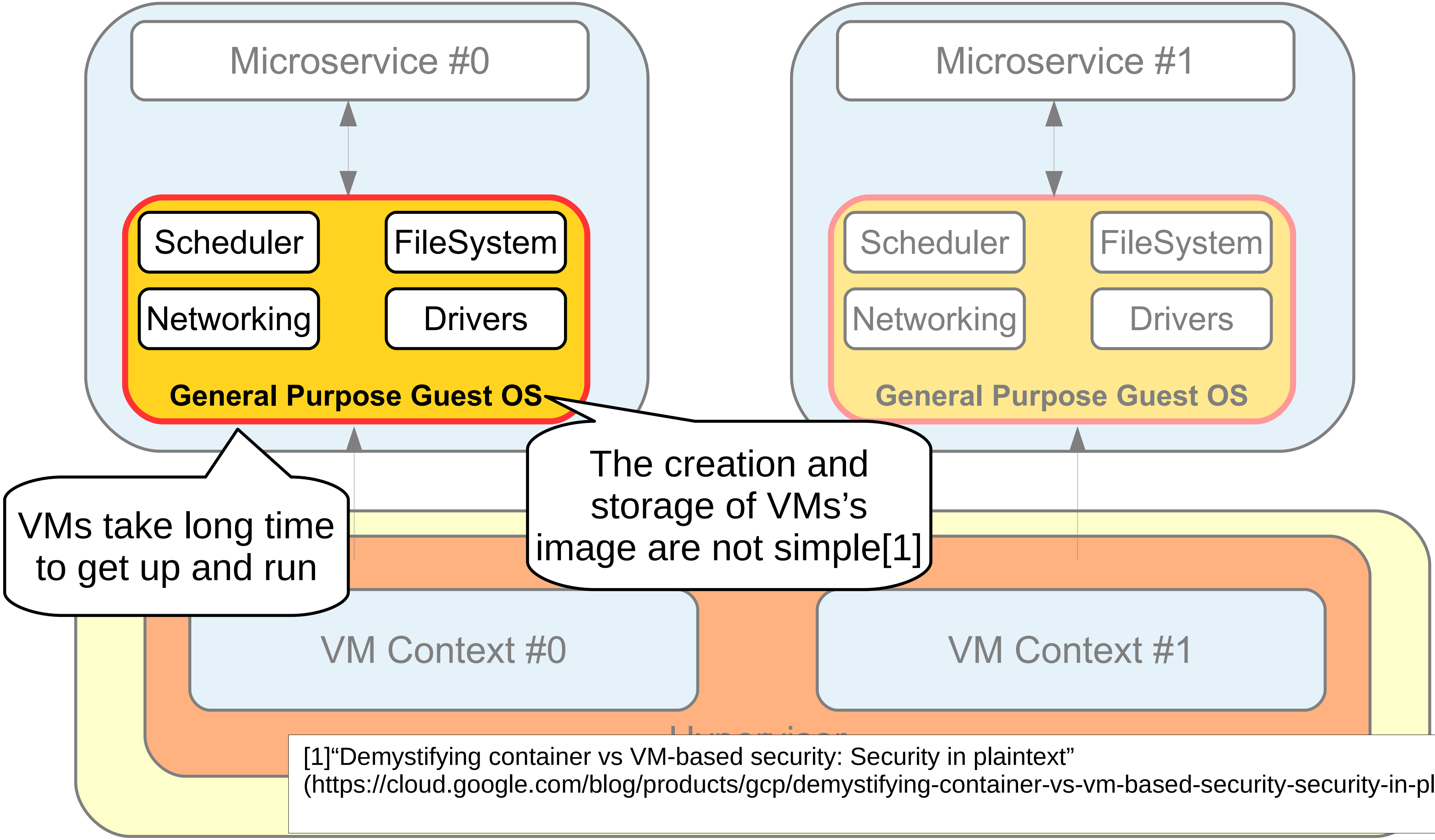
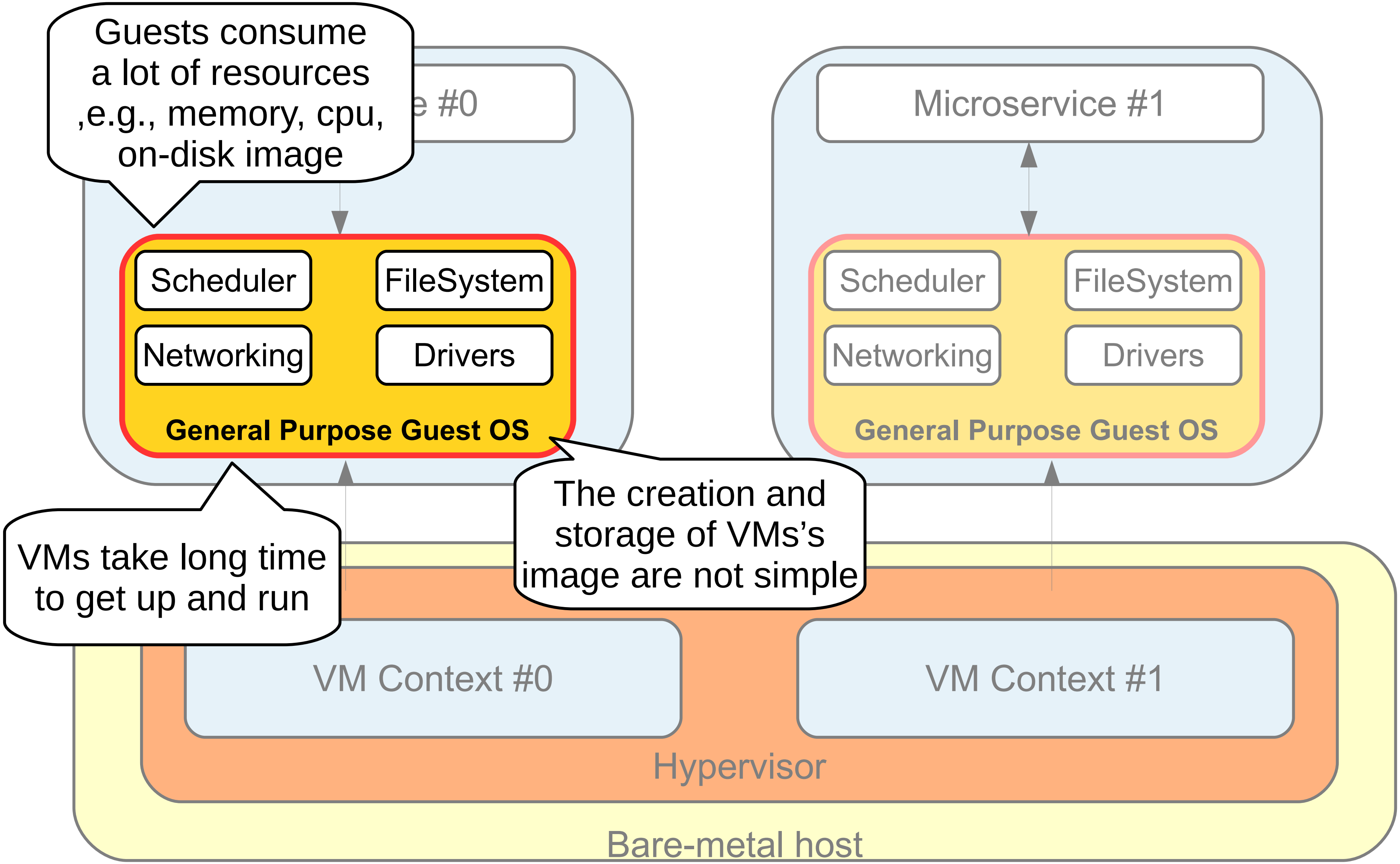
Bare-metal host



[1]"Demystifying container vs VM-based security: Security in plaintext" (https://cloud.google.com/blog/products/gcp/demystifying-container-vs-vm-based-security-security-in-plaintext)


Guests consume a lot of resources ,e.g., memory, cpu, on-disk image
e #0
Microservice #1
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The creation and storage of VMs's image are not simple
VM Context #0
VM Context #1
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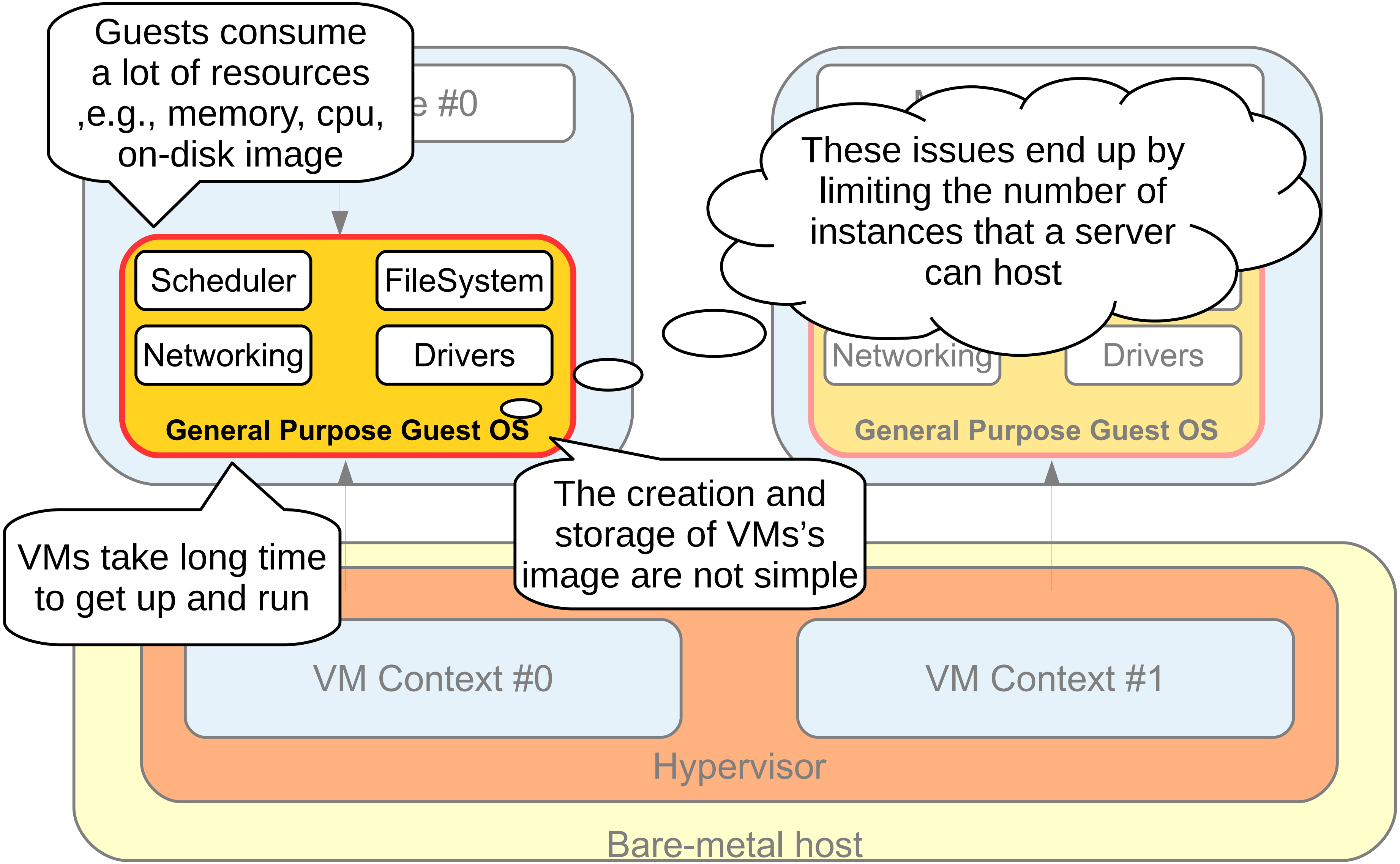
Guests consume a lot of resources ,e.g., memory, cpu, on-disk image
e #0
These issues end up by limiting the number of instances that a server can host
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FileSystem
Networking
Drivers
General Purpose Guest OS
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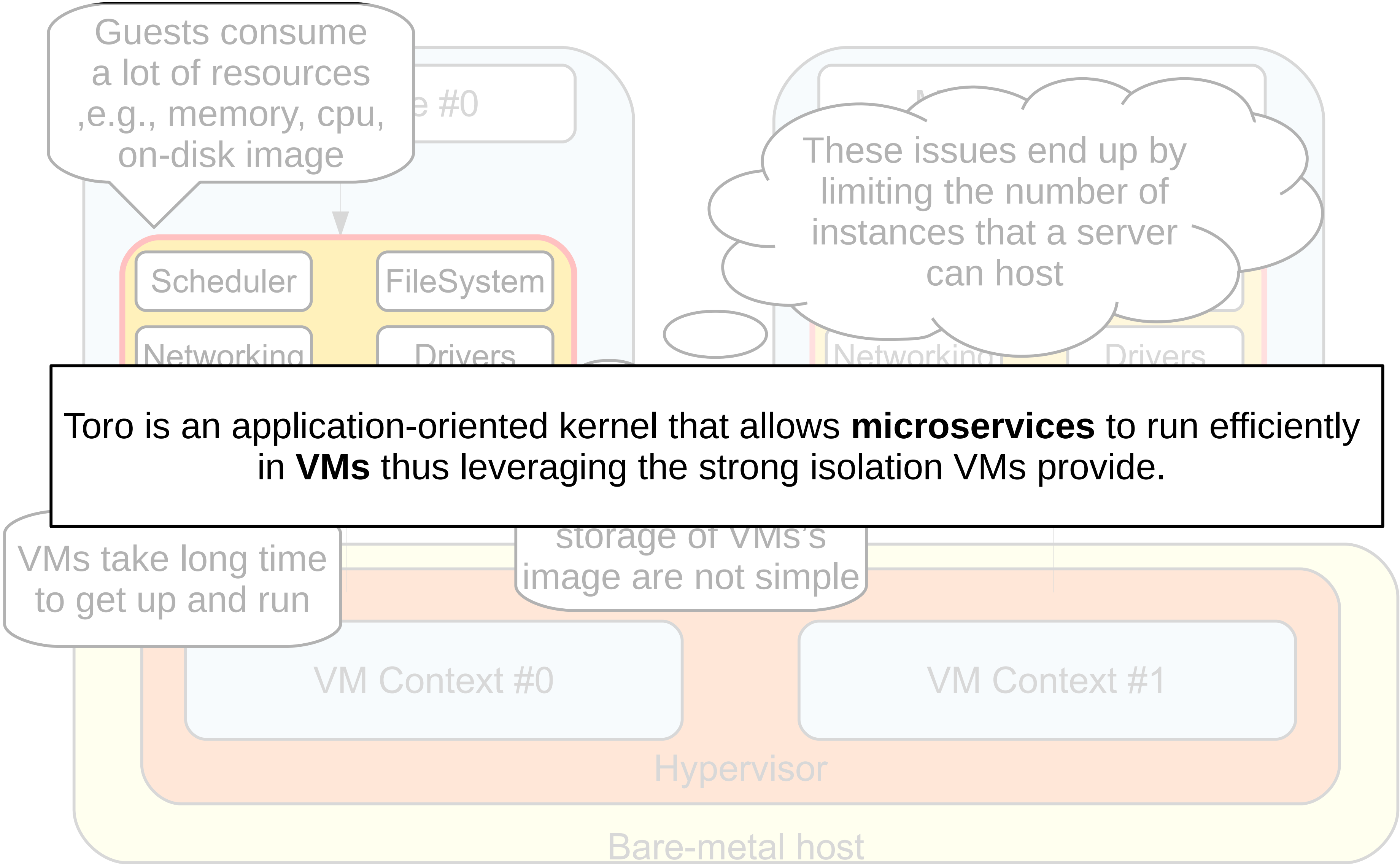
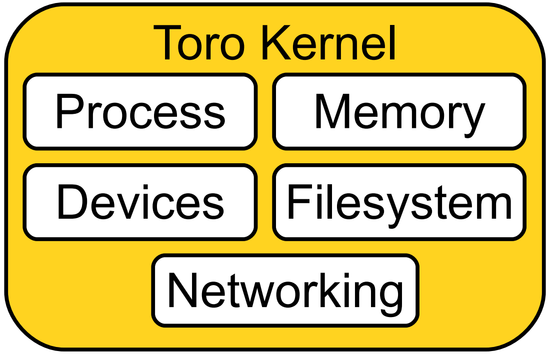


Toro is an application-oriented kernel that allows **microservices** to run efficiently in **VMs** thus leveraging the strong isolation VMs provide.

Ingredients for ToroKernel

- Application-oriented Kernel
- Simple Scheduler
- Dedicated Resources
- Microservice-oriented Networking

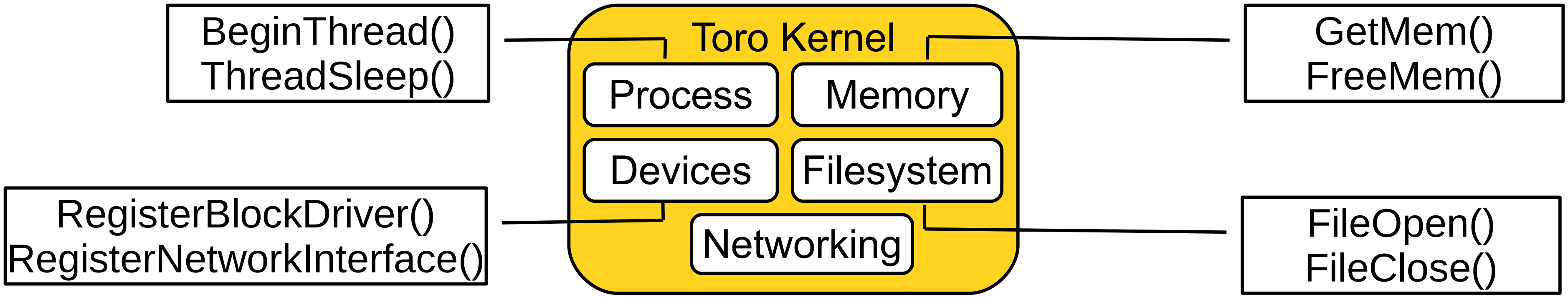
Application-oriented Kernel



Toro is an embedded kernel including five units:
- Process
- Memory
- Filesystem
- Networking
- Devices, e.g., Block Device, Network Device

Each unit provides minimalist APIs accessible from the embedded application

Application-oriented Kernel



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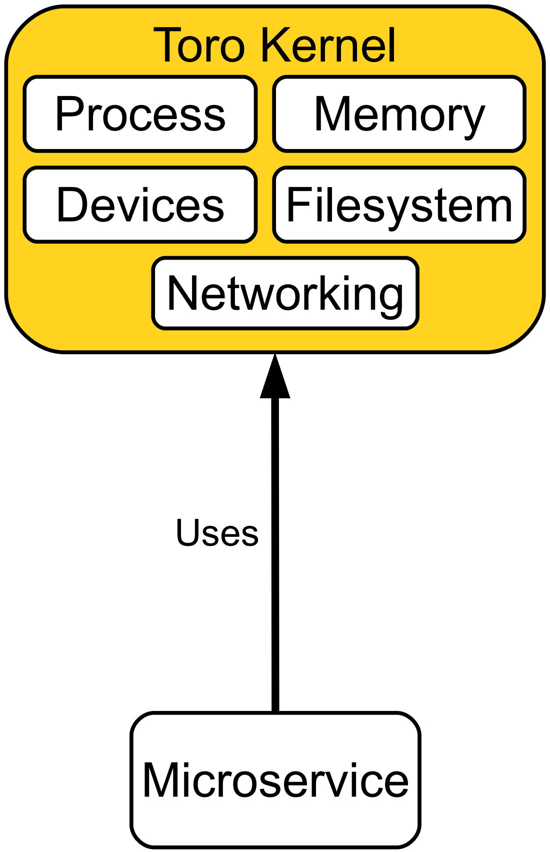
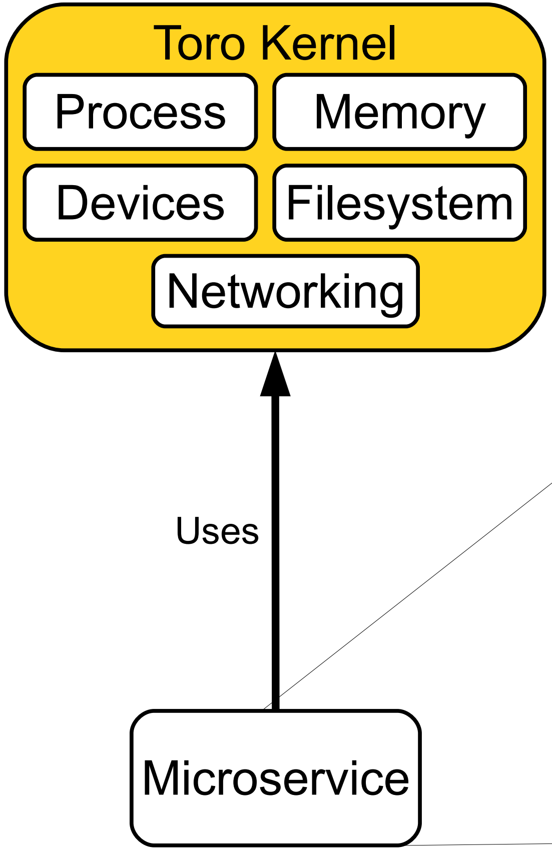


- User application and kernel units are compiled in a single binary
- The application includes only the component required

Application-oriented Kernel



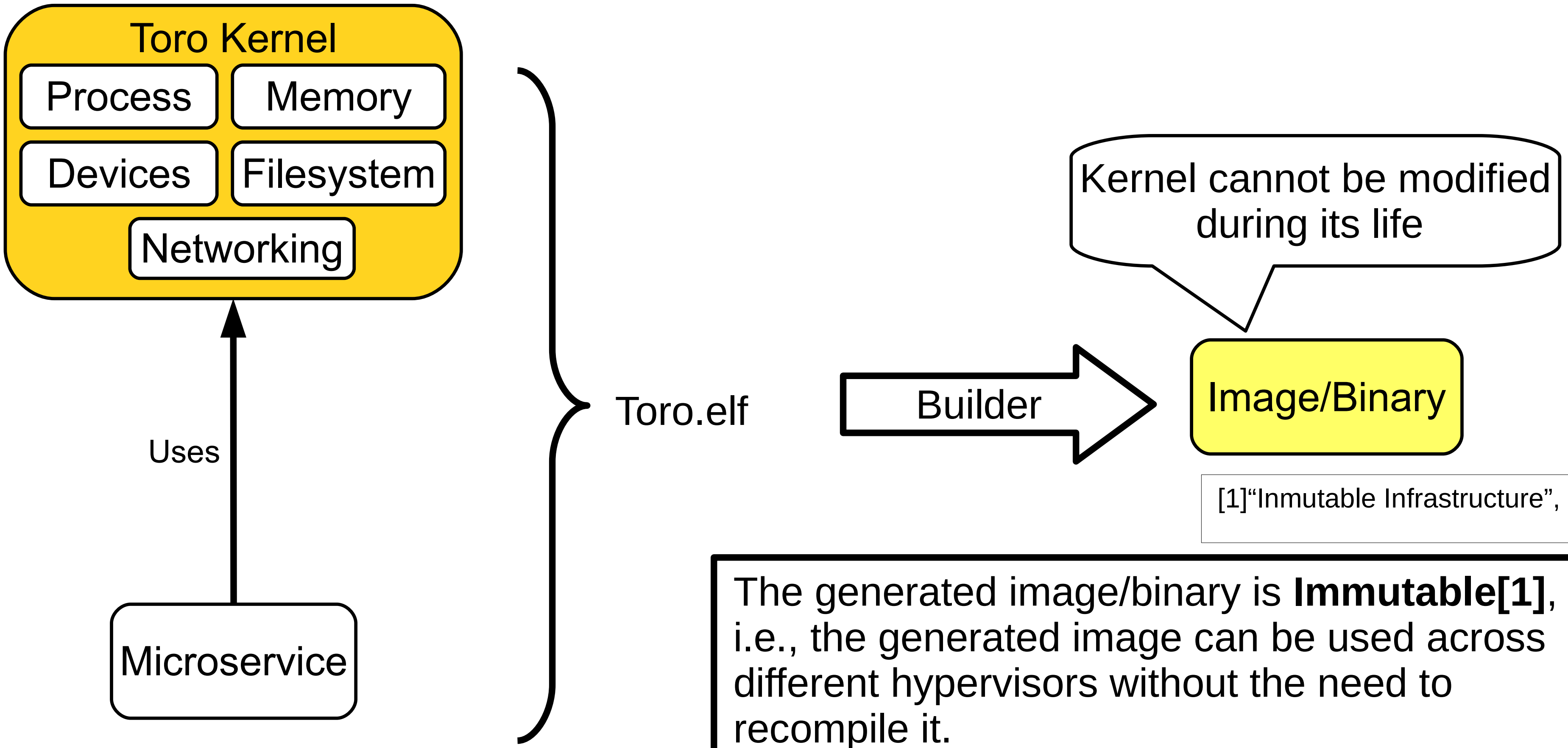
- User application and kernel units are compiled in a single binary
- The
com

```
program HelloWorldMicroservice;

uses
  Memory,
  Filesystem,
  Ext3,
  E1000;

Begin
//
// Your Code
//
End.
```

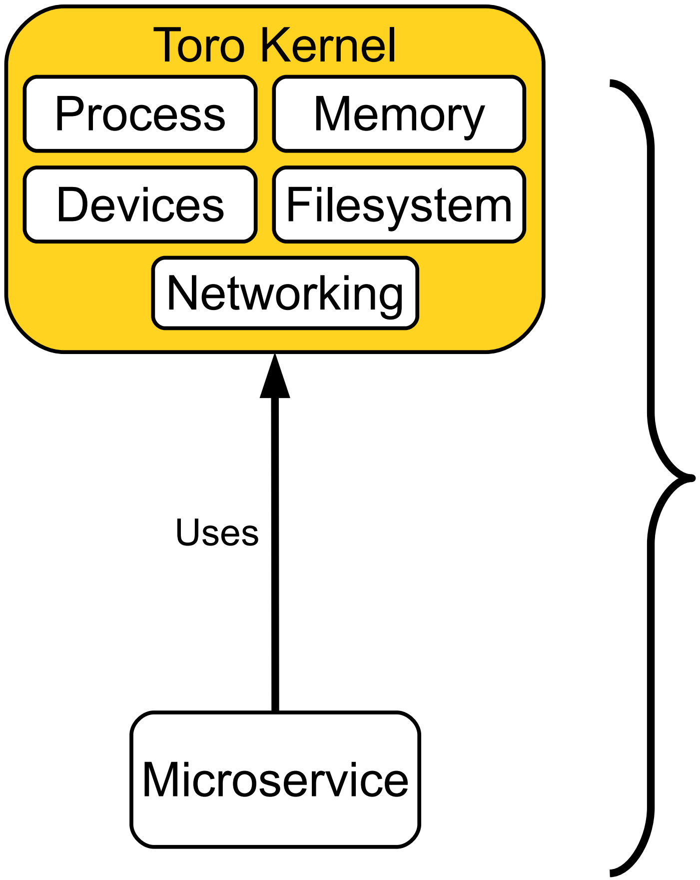
Application-oriented Kernel

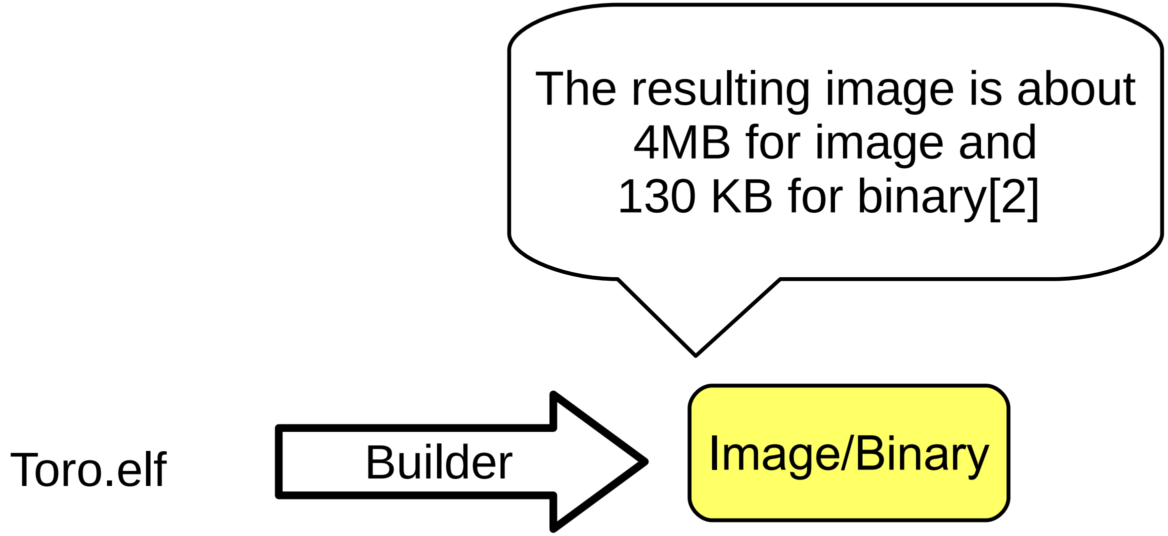


[1]“Inmutable Infrastructure”, Stella

The generated image/binary is **Immutable[1]**, i.e., the generated image can be used across different hypervisors without the need to recompile it.

Application-oriented Kernel





[2] Speed up booting time of a Toro appliance, FOSDEM’19

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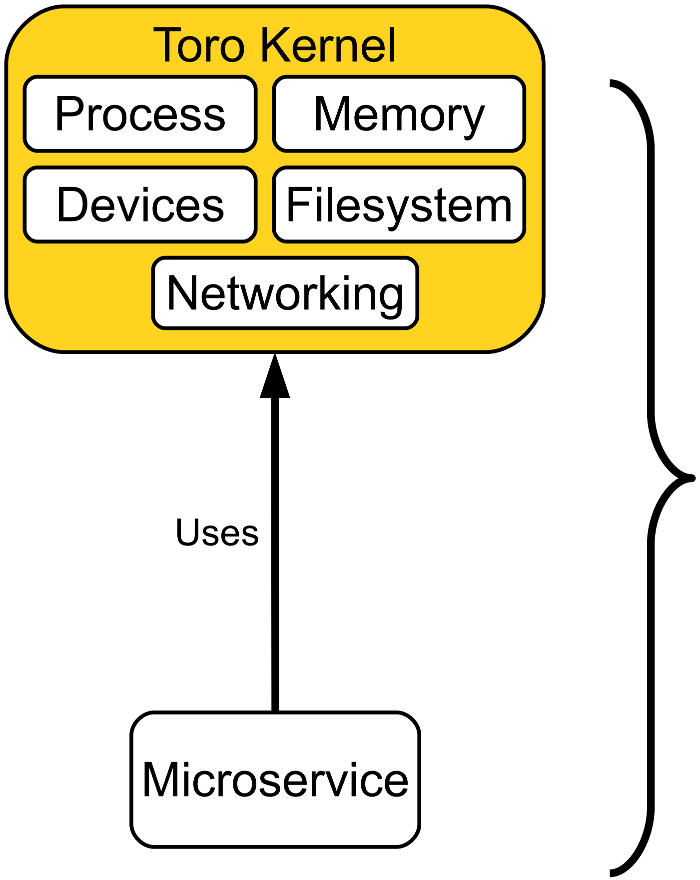
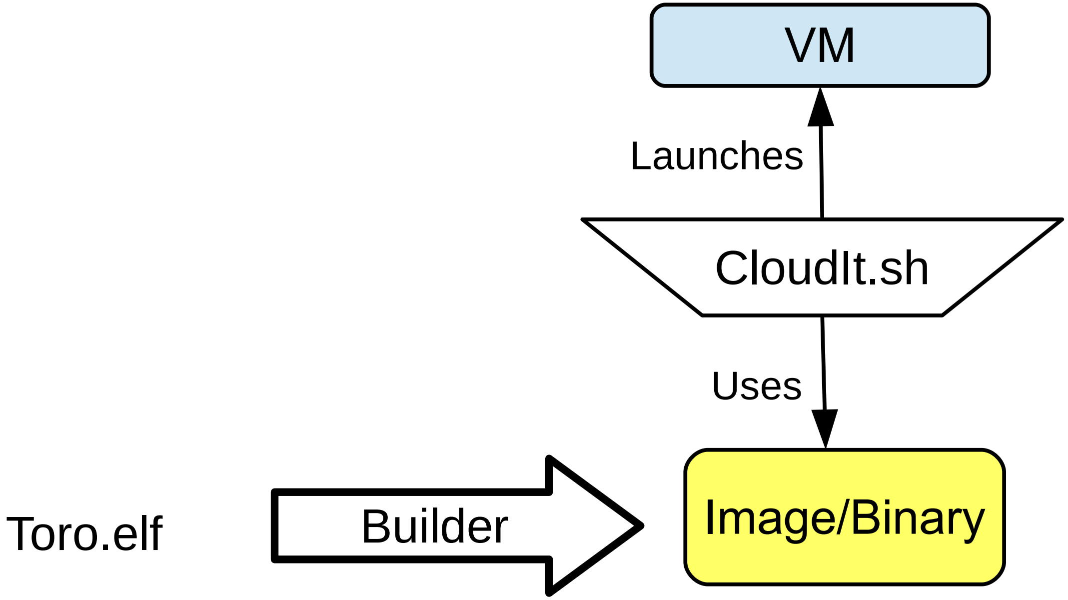
Application-oriented Kernel





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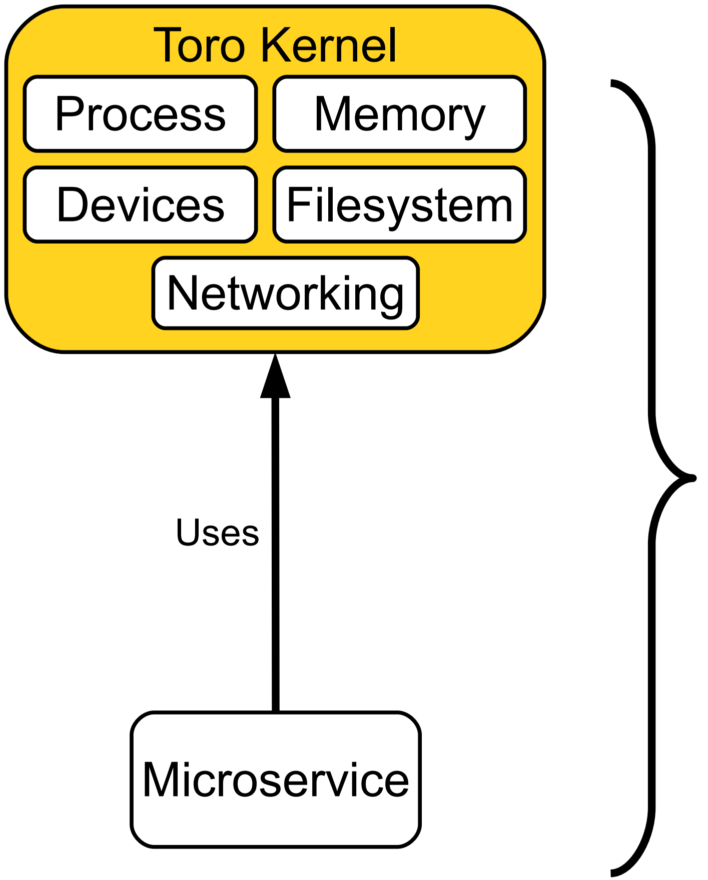

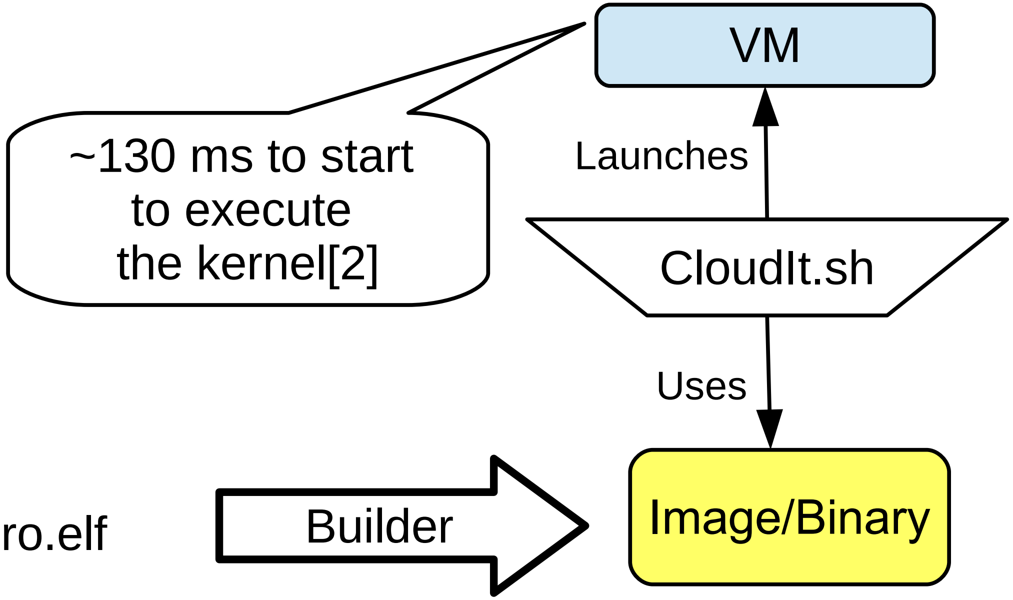

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Benefits of Application-oriented Kernel

- Security is based on the hypervisor which ensures a reduced attack surface
- The kernel size is smaller since it only includes the units required for the application
- The smaller kernel size reduces the booting time and eases image manipulation, i.e., your kernel is your program!
- No communication overhead since application is using the kernel APIs

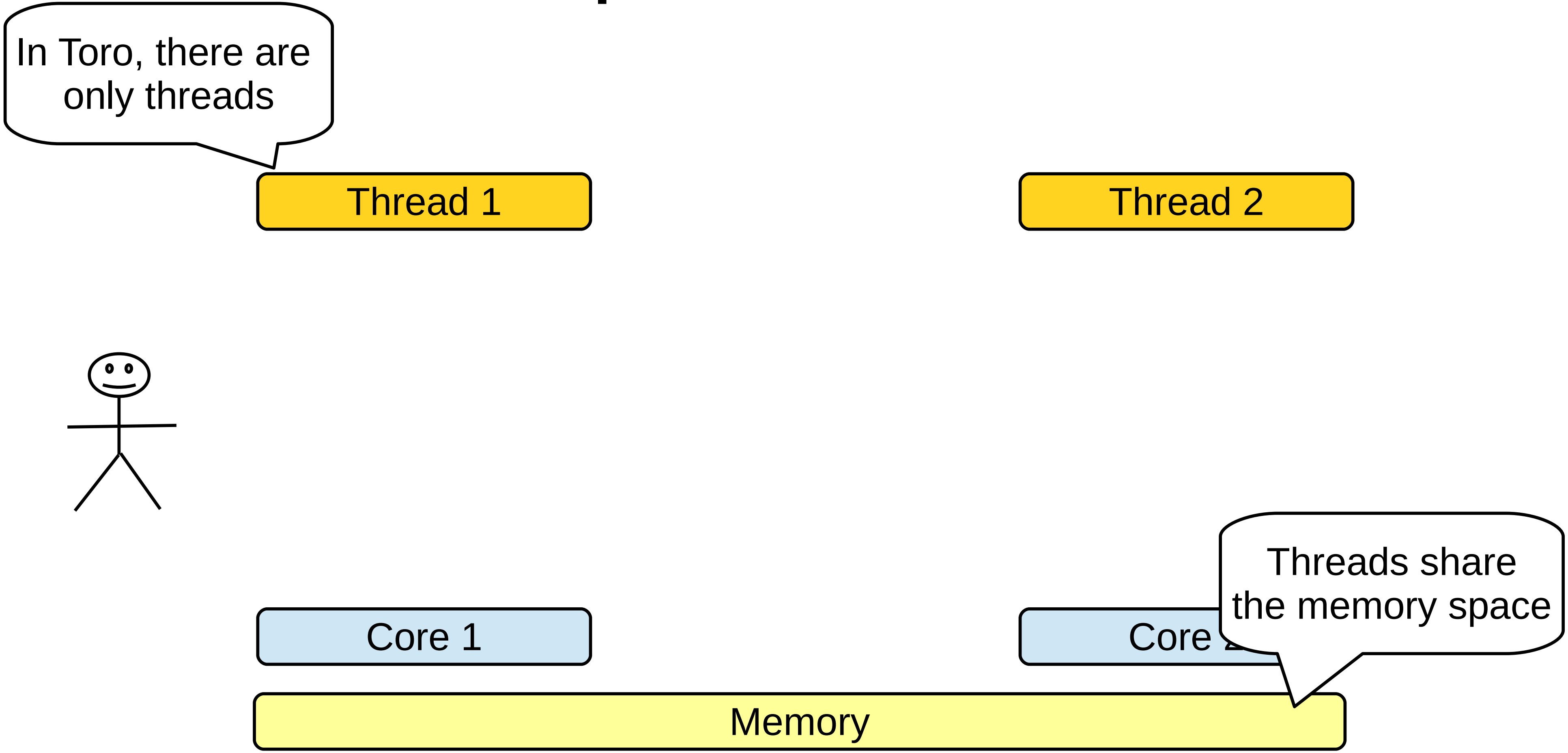
Ingredients for ToroKernel

- Application-oriented Kernel
- Simple Scheduler
- Dedicated Resources
- Microservice-oriented Networking

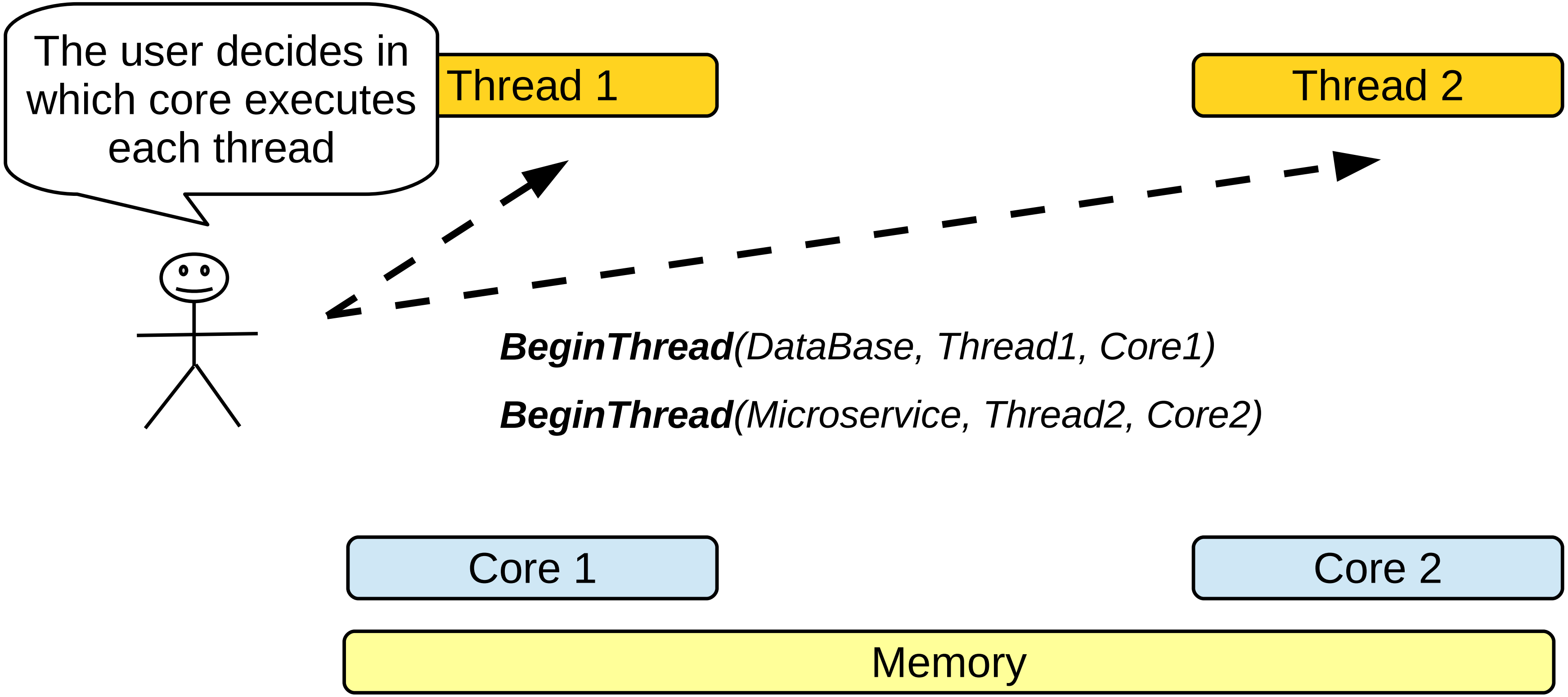
Simple Scheduler Requirements

- Scale with the number of cores
- Simple scheduler’s algorithm, i.e., Cooperative threading model
- Minimalist context switches

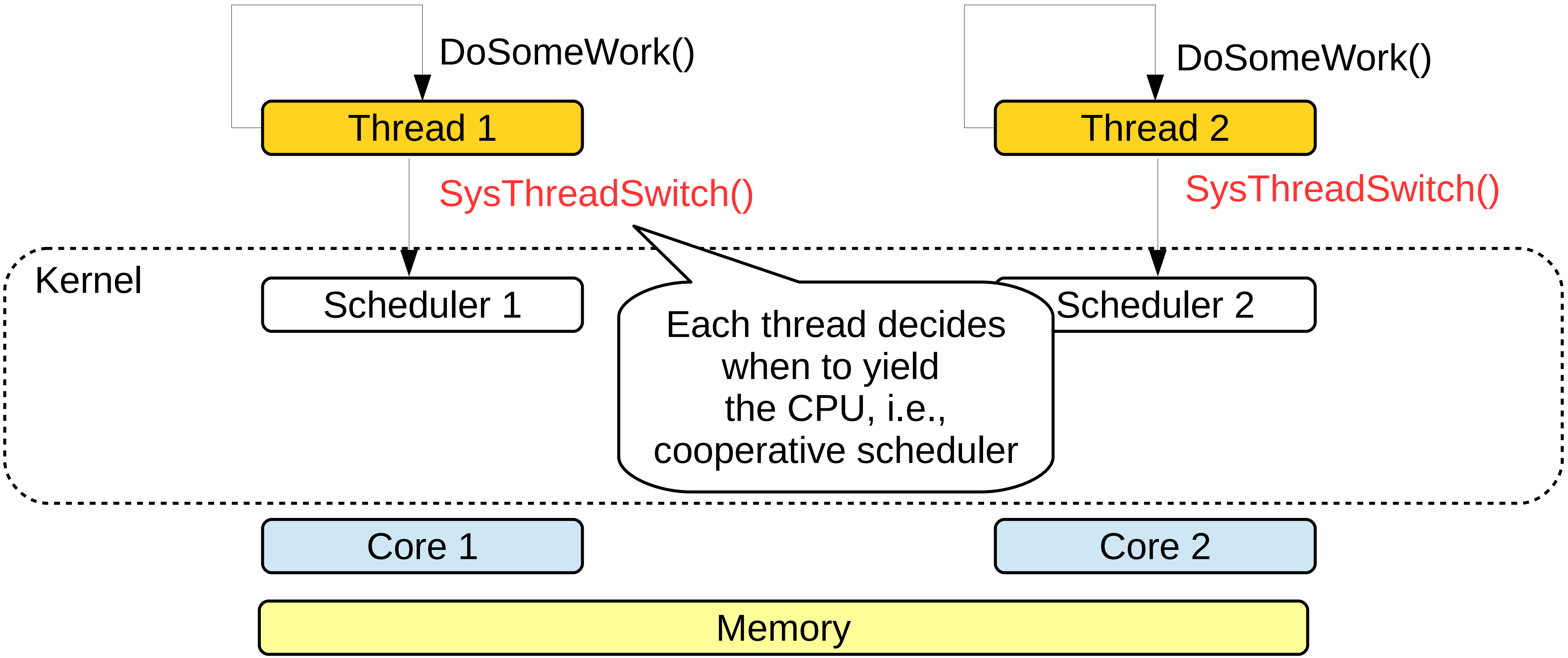
Simple Scheduler



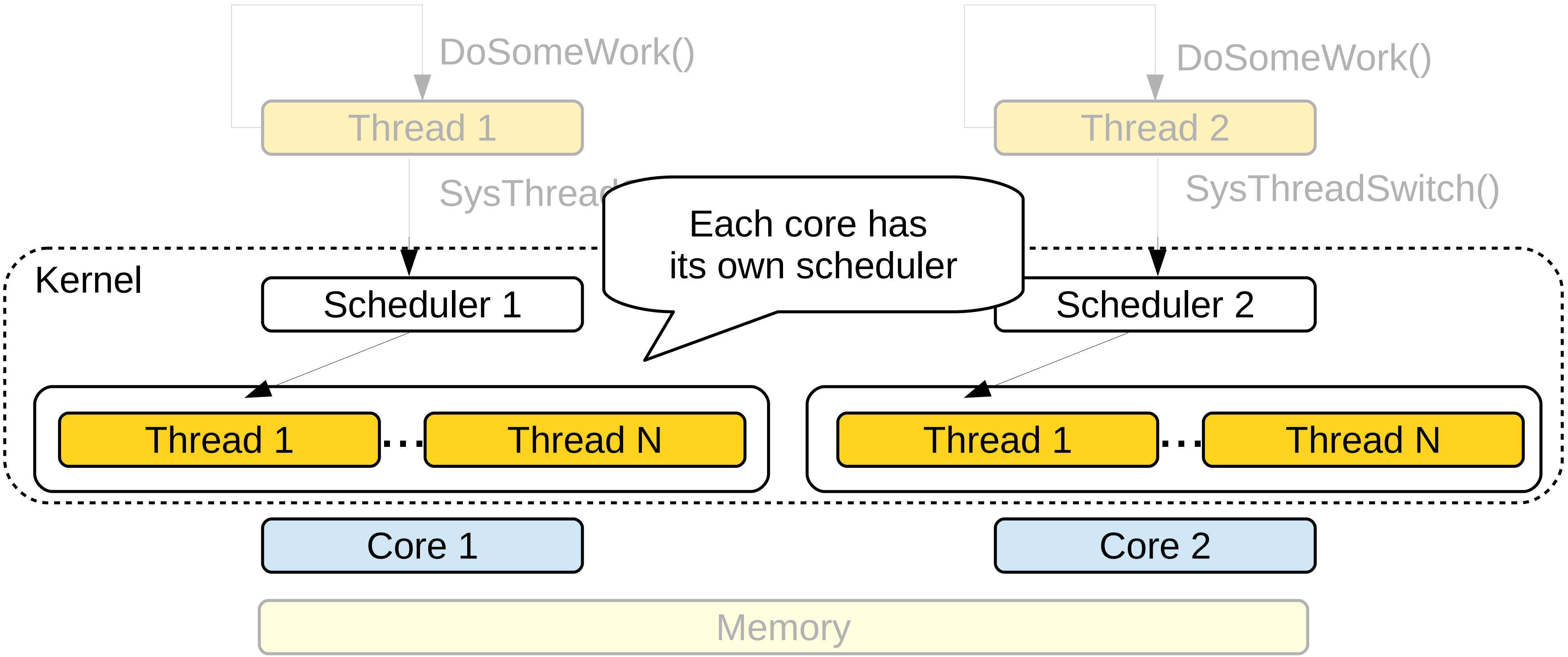
Simple Scheduler



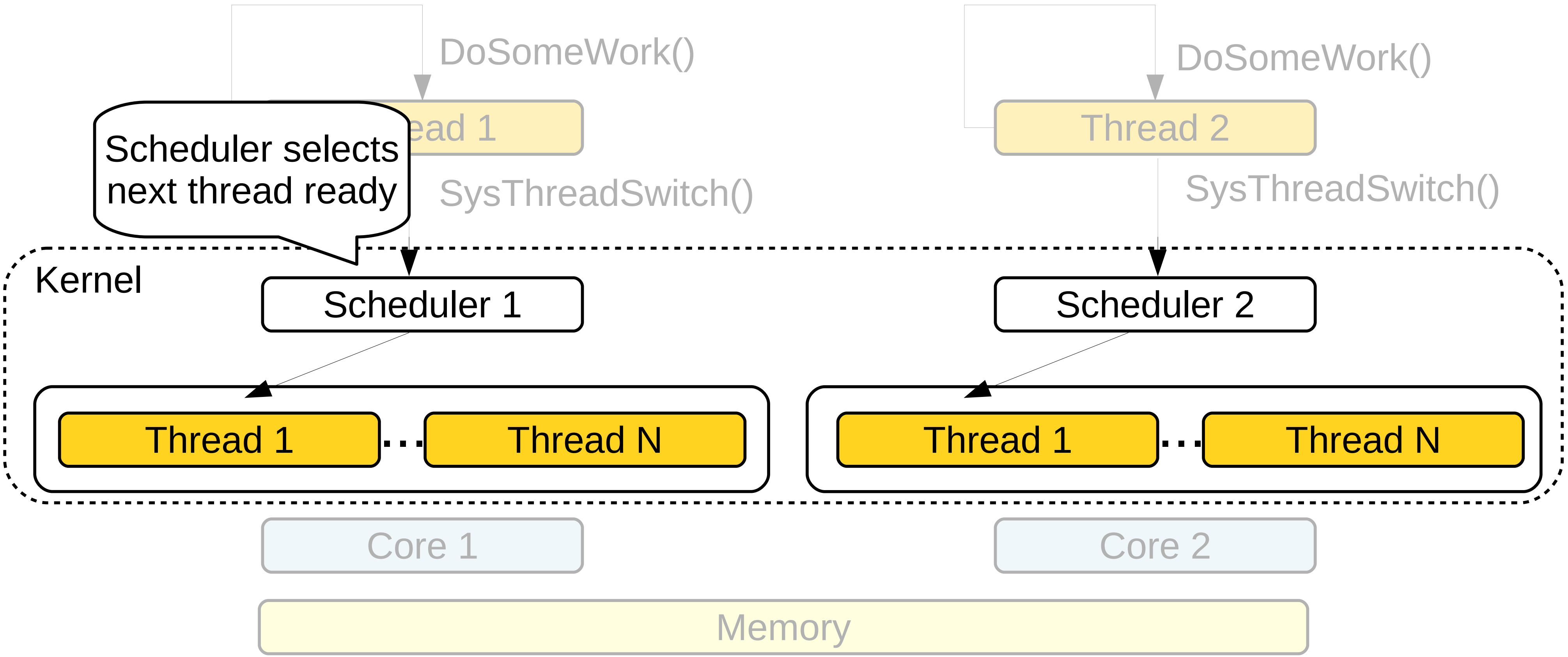
Simple Scheduler



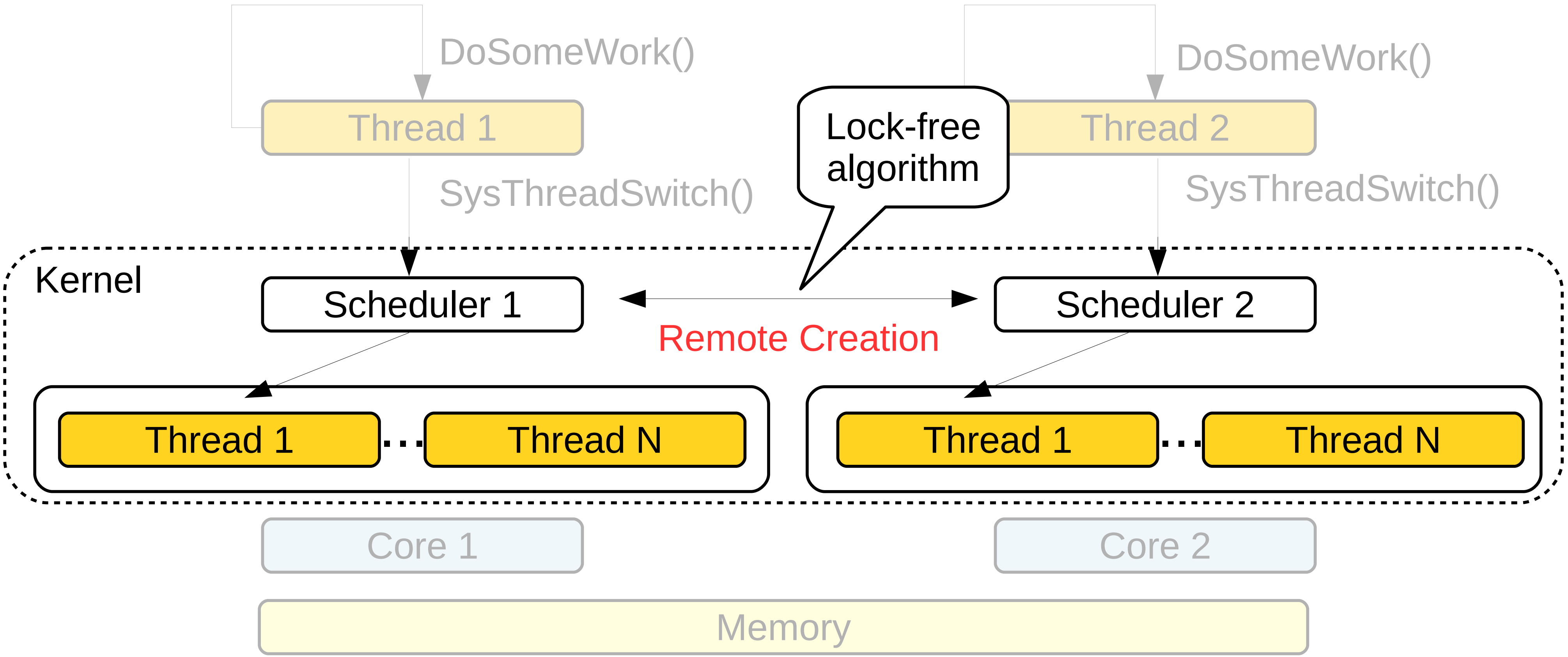
Simple Scheduler



Simple Scheduler



Simple Scheduler



Benefits of Simple Scheduler

- The use of threads makes context switching cheaper
- The use of a cooperative scheduler:
  - simplifies user’s and kernel’s code by avoiding to implement protection inside the scheduler
  - reduces number of context switches since it does not relies on interruptions

Ingredients for ToroKernel

- Application-oriented Kernel
- Simple Scheduler
- Dedicated Resources
- Microservice-oriented Networking

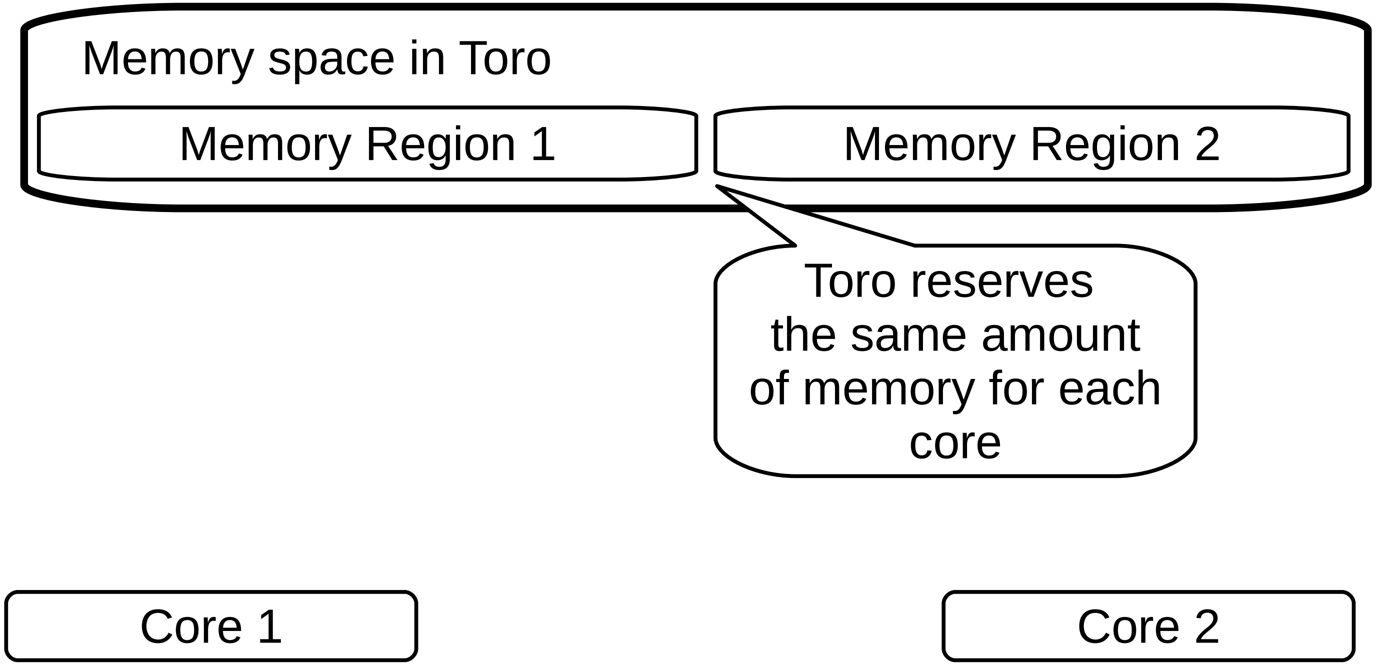
Dedicated Resources

- In a multicore system, the problematic resource is the shared memory. The use of shared memory causes:
  - Overhead in the memory bus
  - Overhead in the cache to keep it coherent
  - Overhead to guaranty mutual exclusion when spin-locks are used

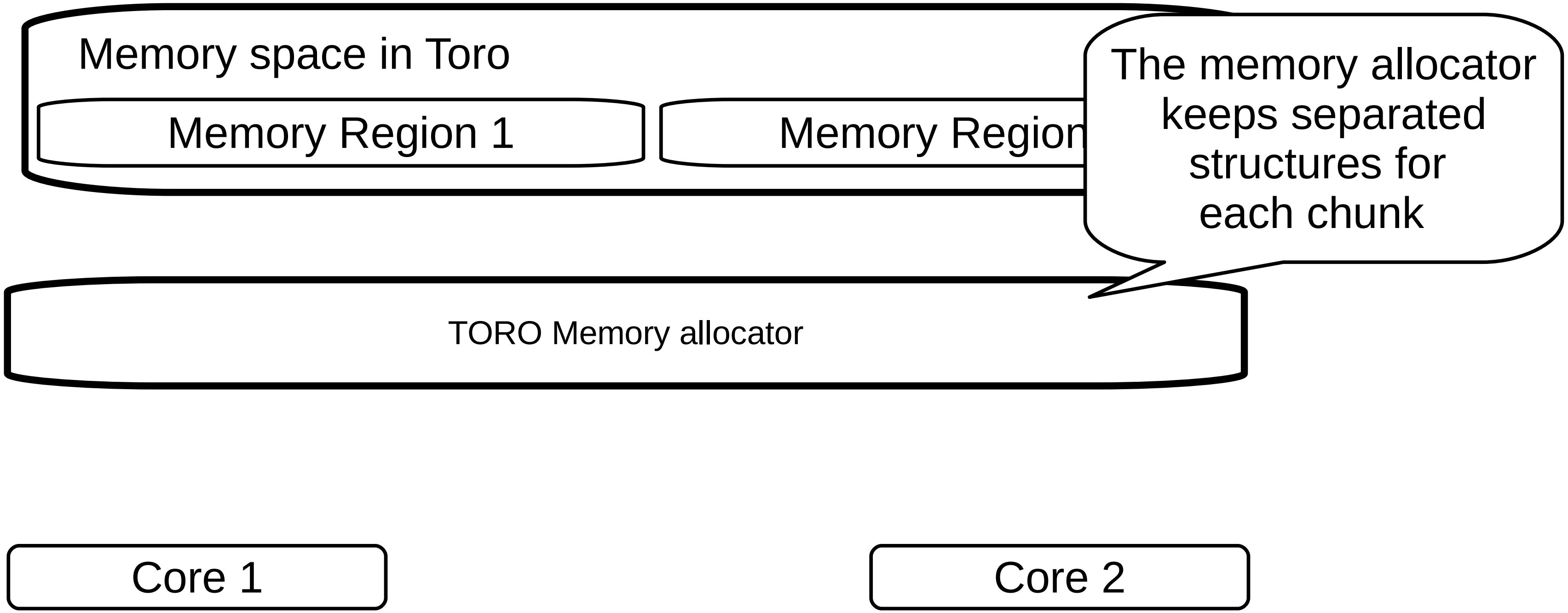
Dedicated Resources Proposal

- Toro improves memory access by
  - keeping the resources locals:
    - The memory is dedicated per core
    - The kernel data structures are dedicated per core
    - The access to kernel data structures is lock free
  - leveraging NUMA technologies, e.g., Hypertransport, Intel QuickPath

Dedicated Resources Memory



Dedicated Resources
Memory



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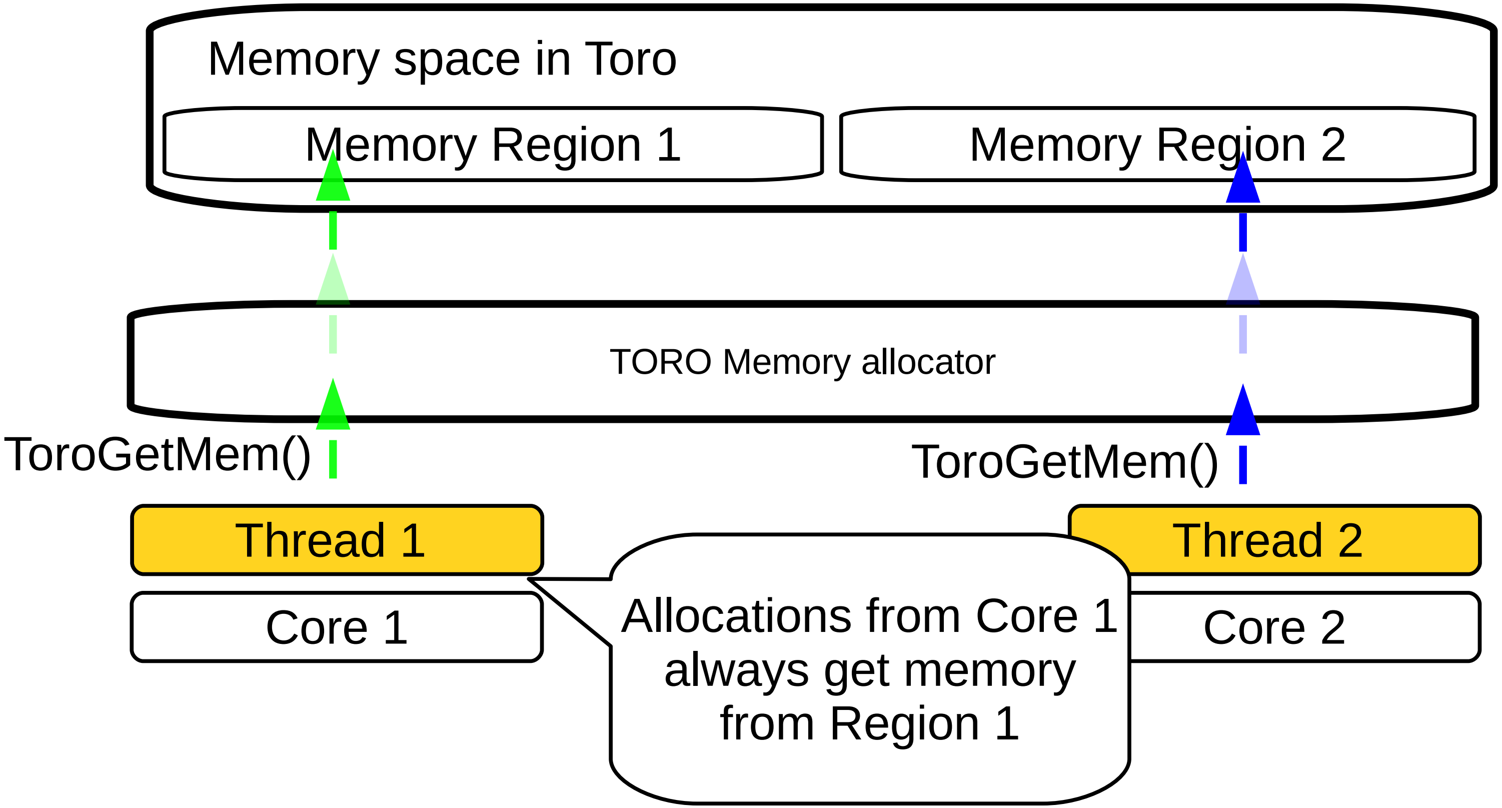

Dedicated Resources
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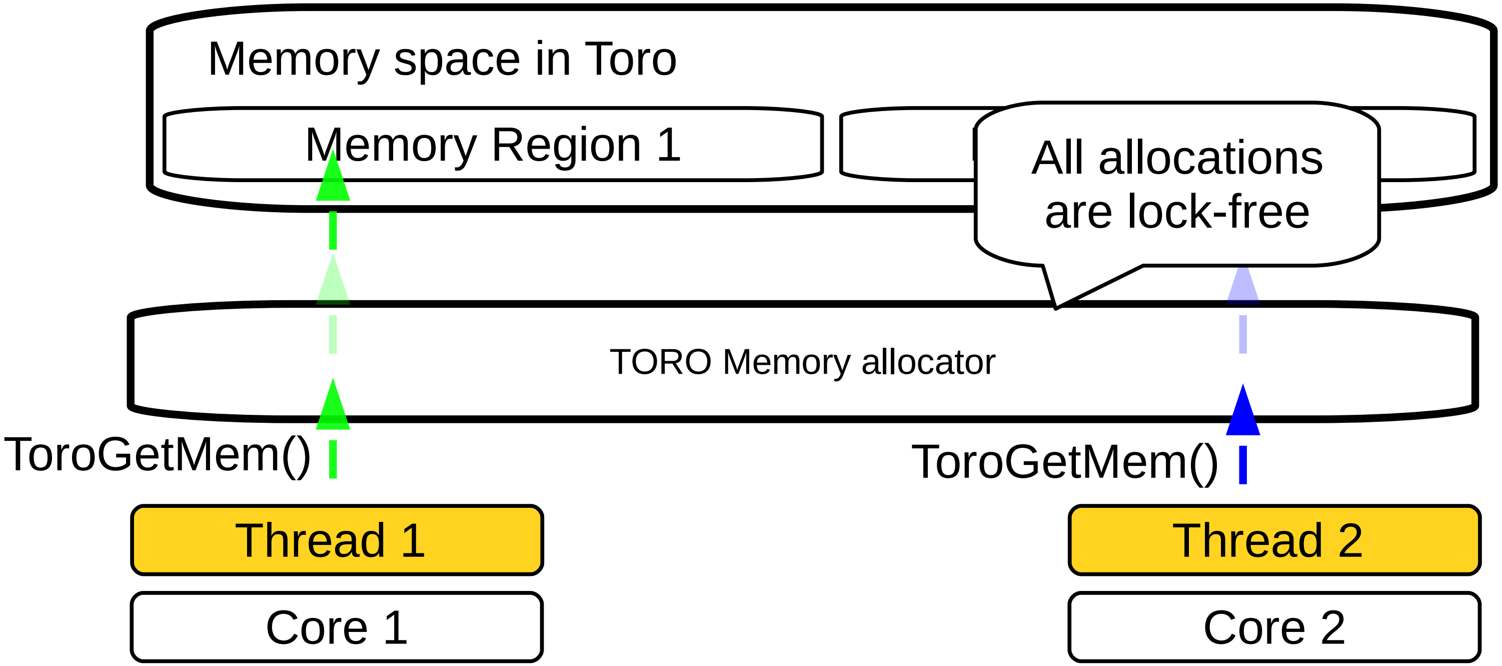
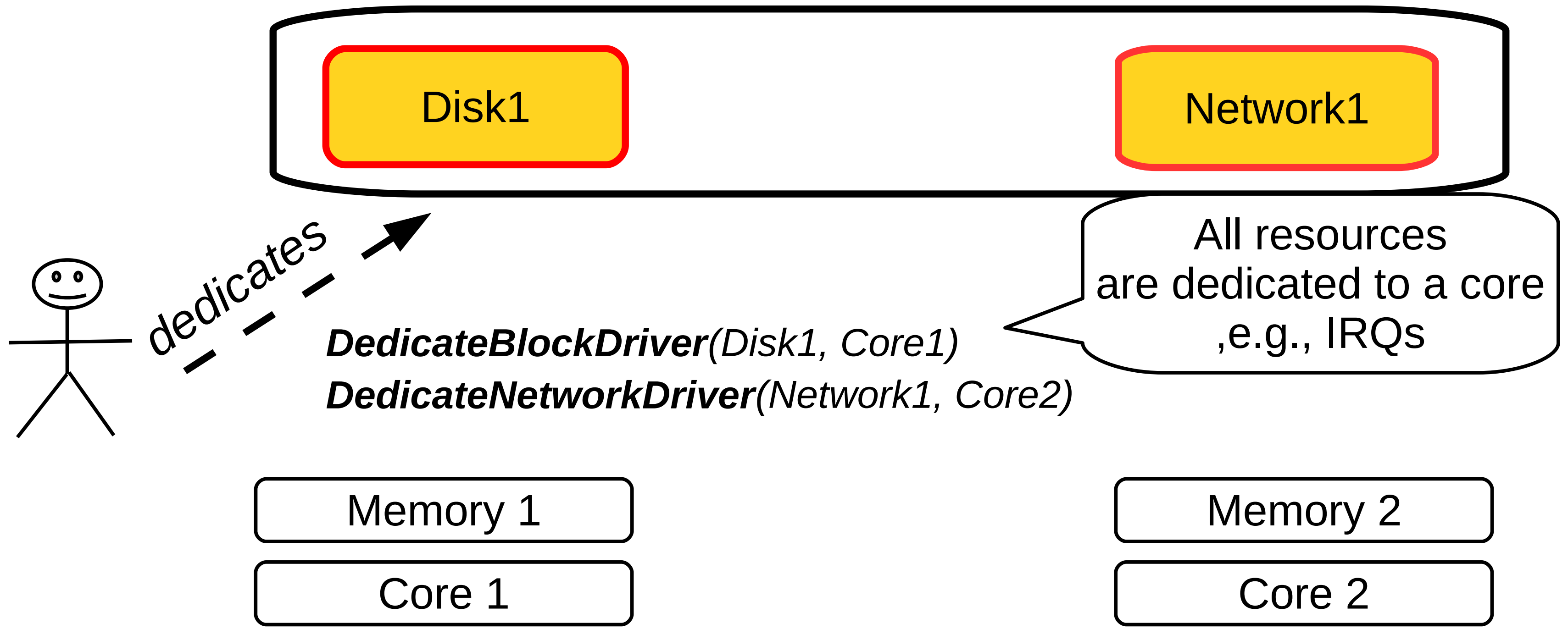
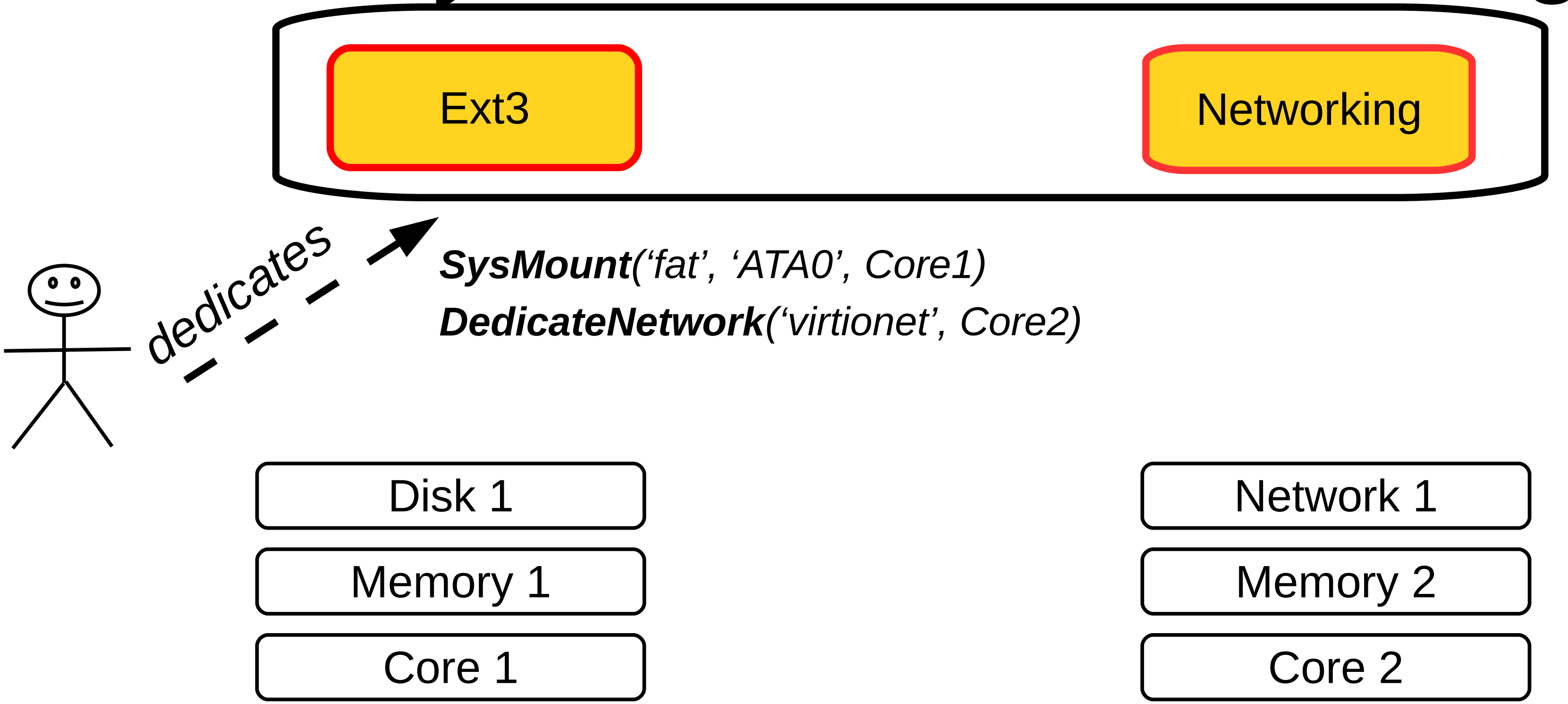


Dedicated Resources
Devices



Dedicated Resources
Filesystems and Networking



Dedicated Resources
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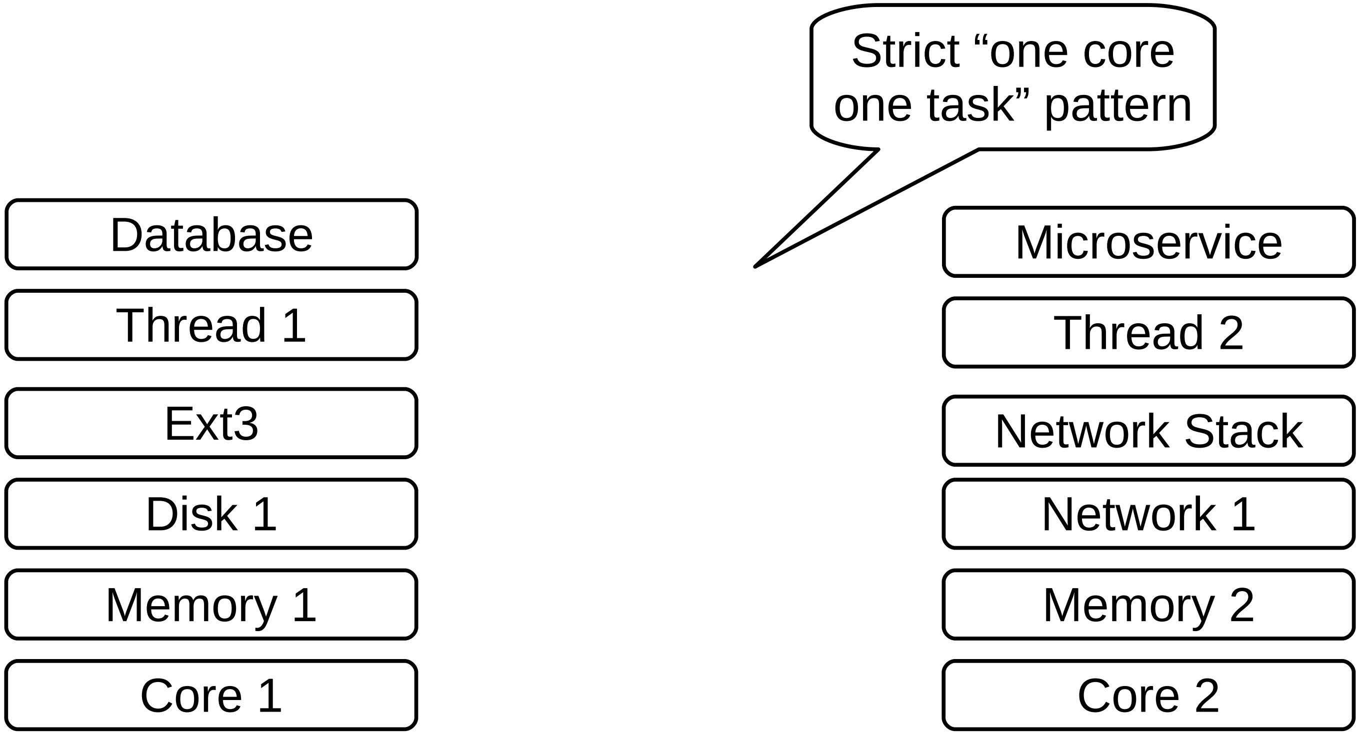


Ingredients for ToroKernel

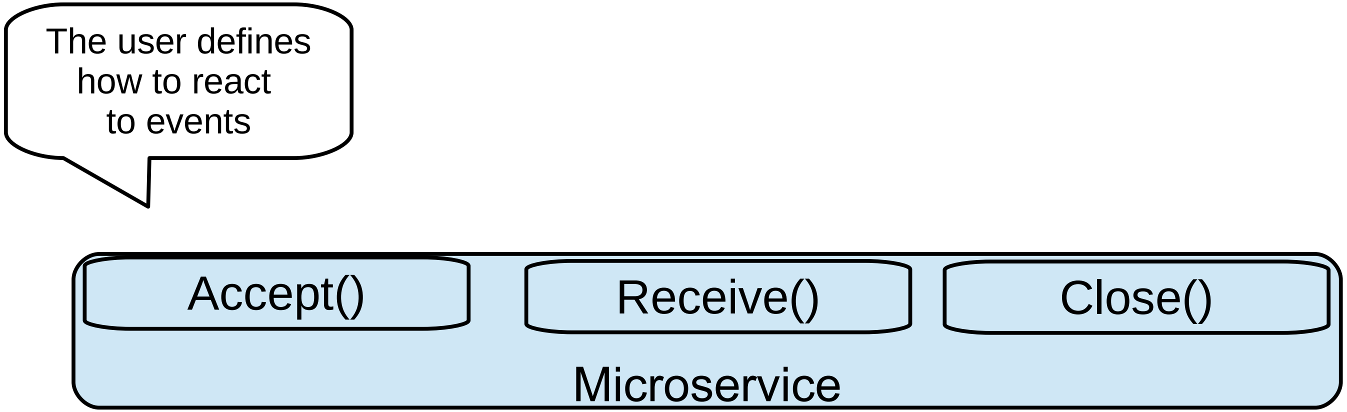
- Application-oriented Kernel
- Simple Scheduler
- Dedicated of Resources
- Microservice-oriented Networking

Microservice-oriented Networking

- The kernel provides a dedicated API to create microservices
- Toro proposes two ways to develop microservices:
  - Single thread event loop model[2] for non-blocking microservices
  - Classical Berkeley sockets for those microservices that do IO
- Event loop has been optimized to reduce CPU's usage[3]

[2] Node JS Architecture – Single Threaded Event Loop
[3] Reducing CPU usage of a Toro Appliance, FOSDEM'18

Non-Blocking Microservices



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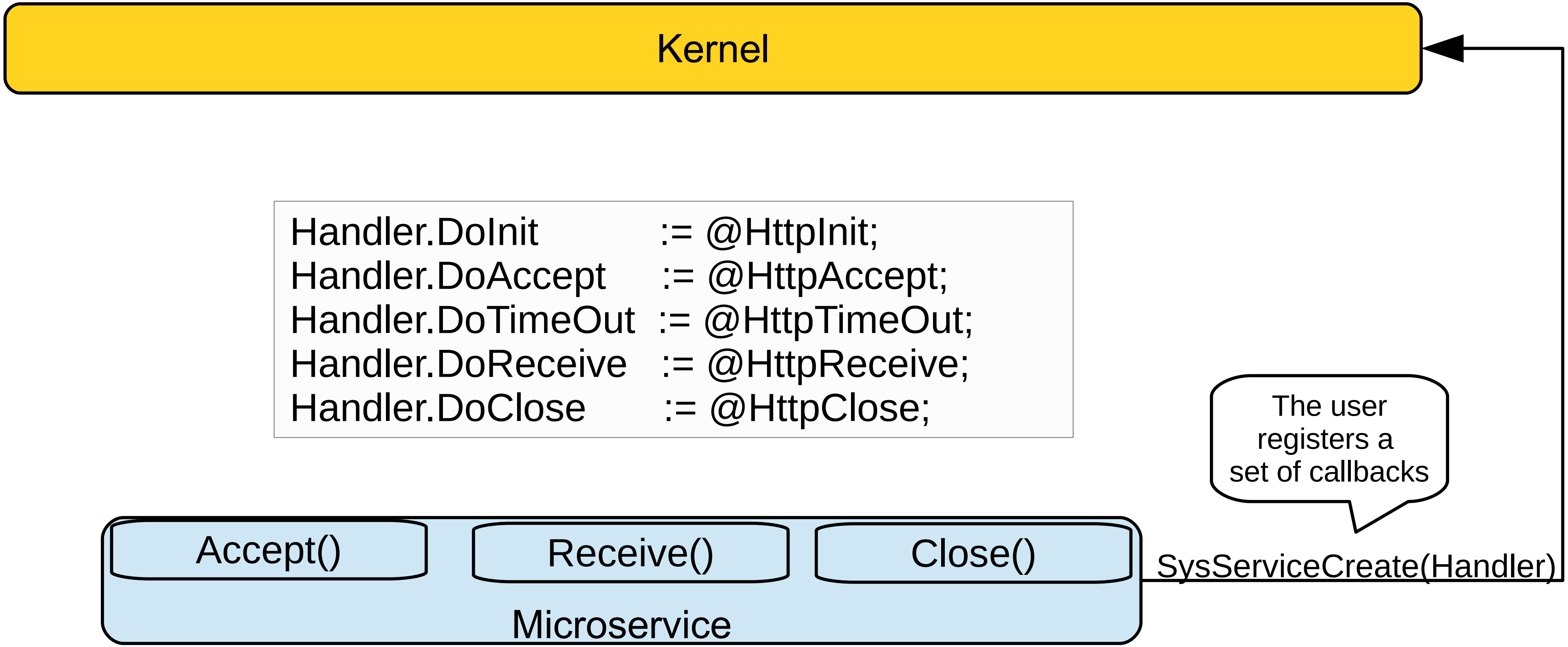

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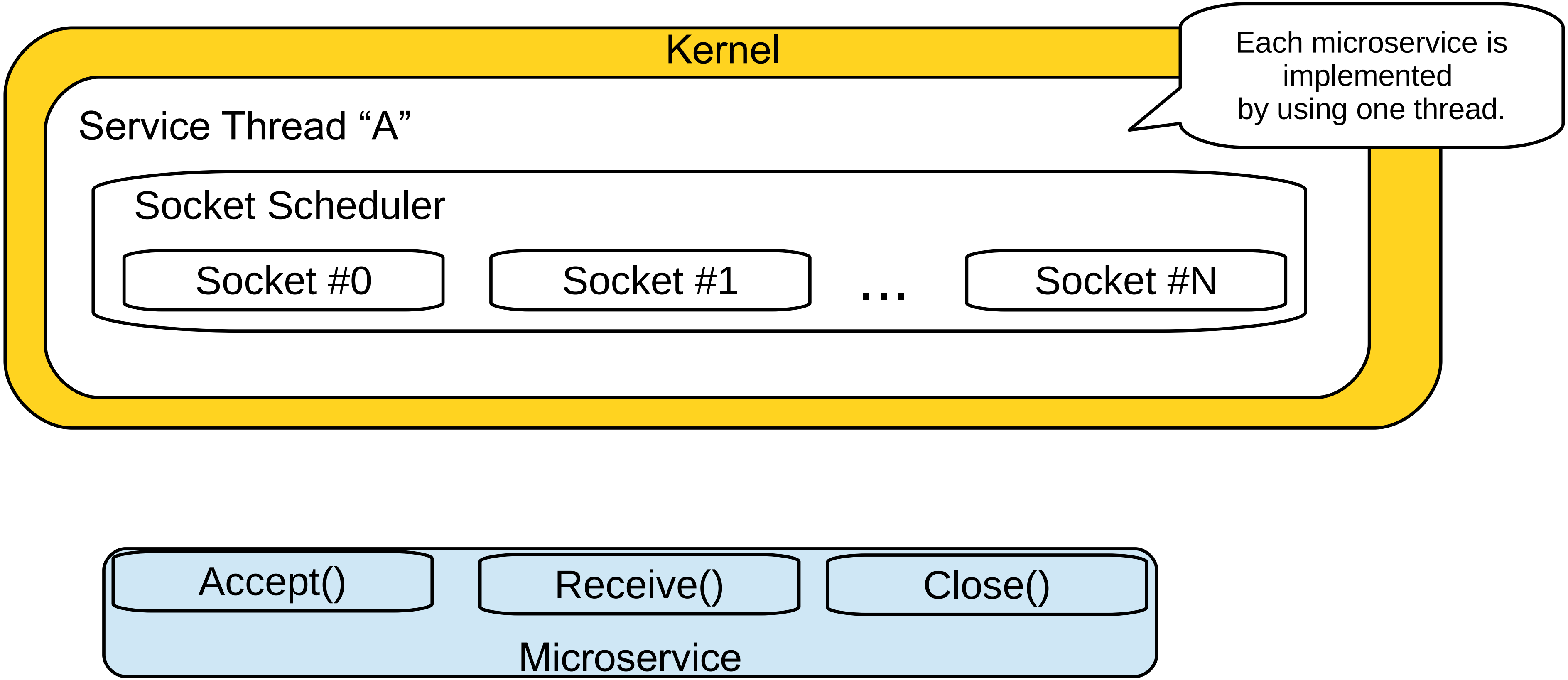

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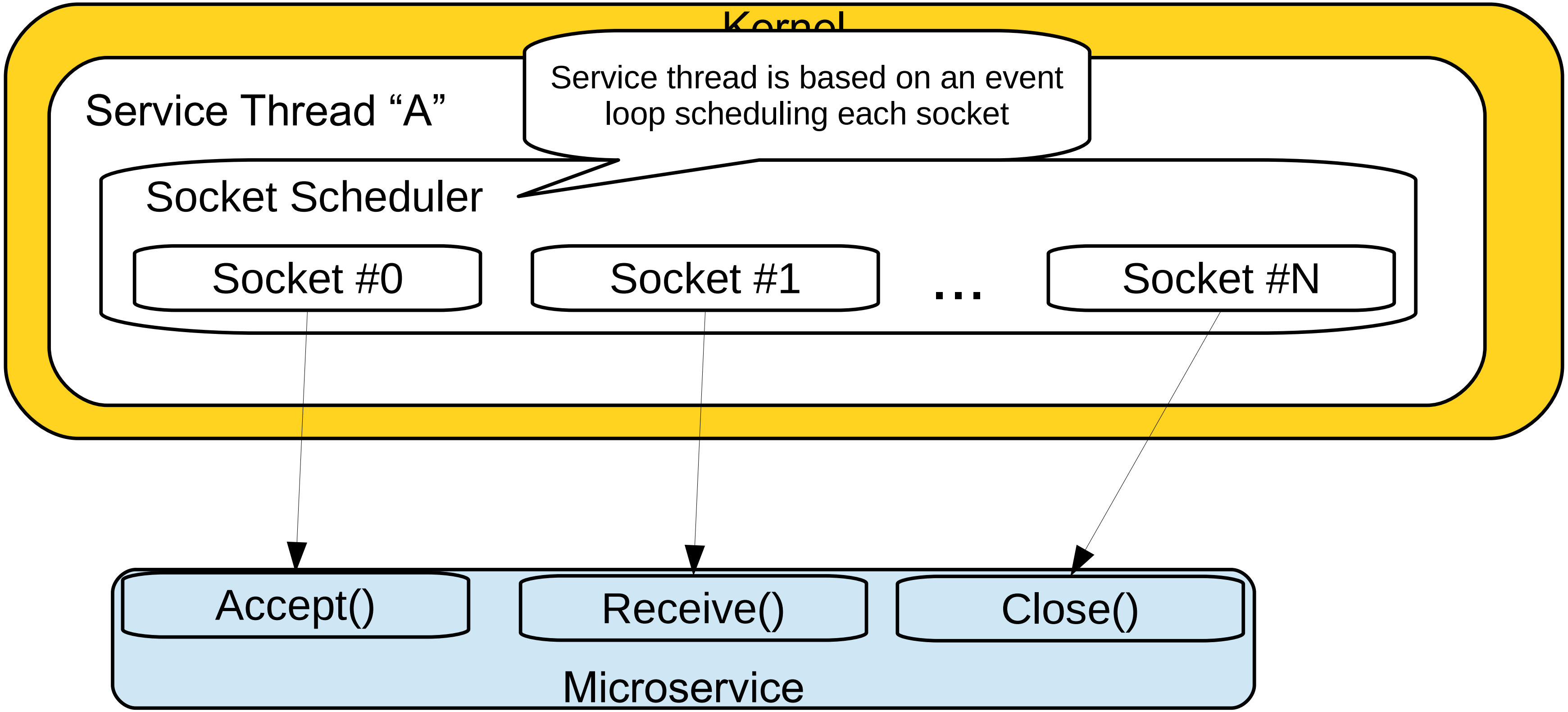

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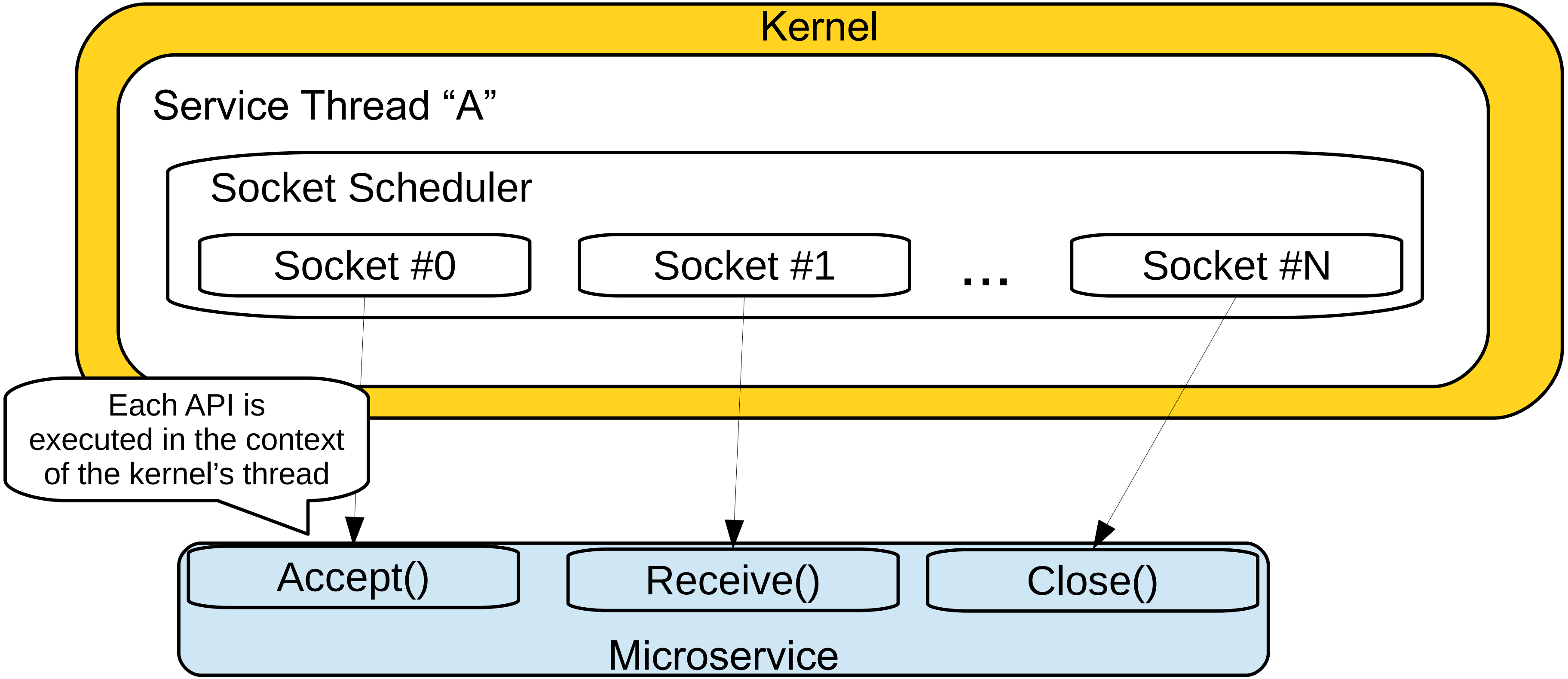

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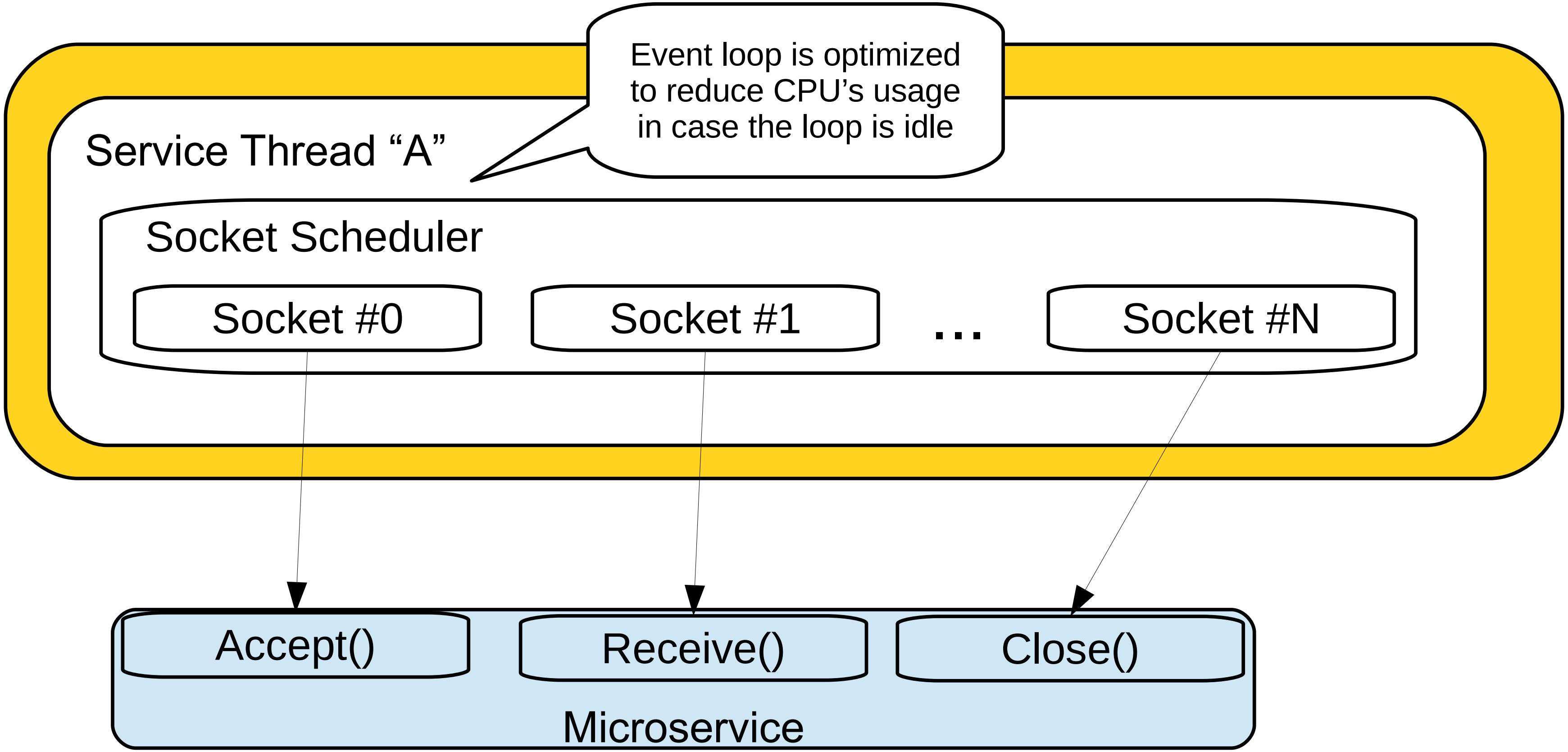

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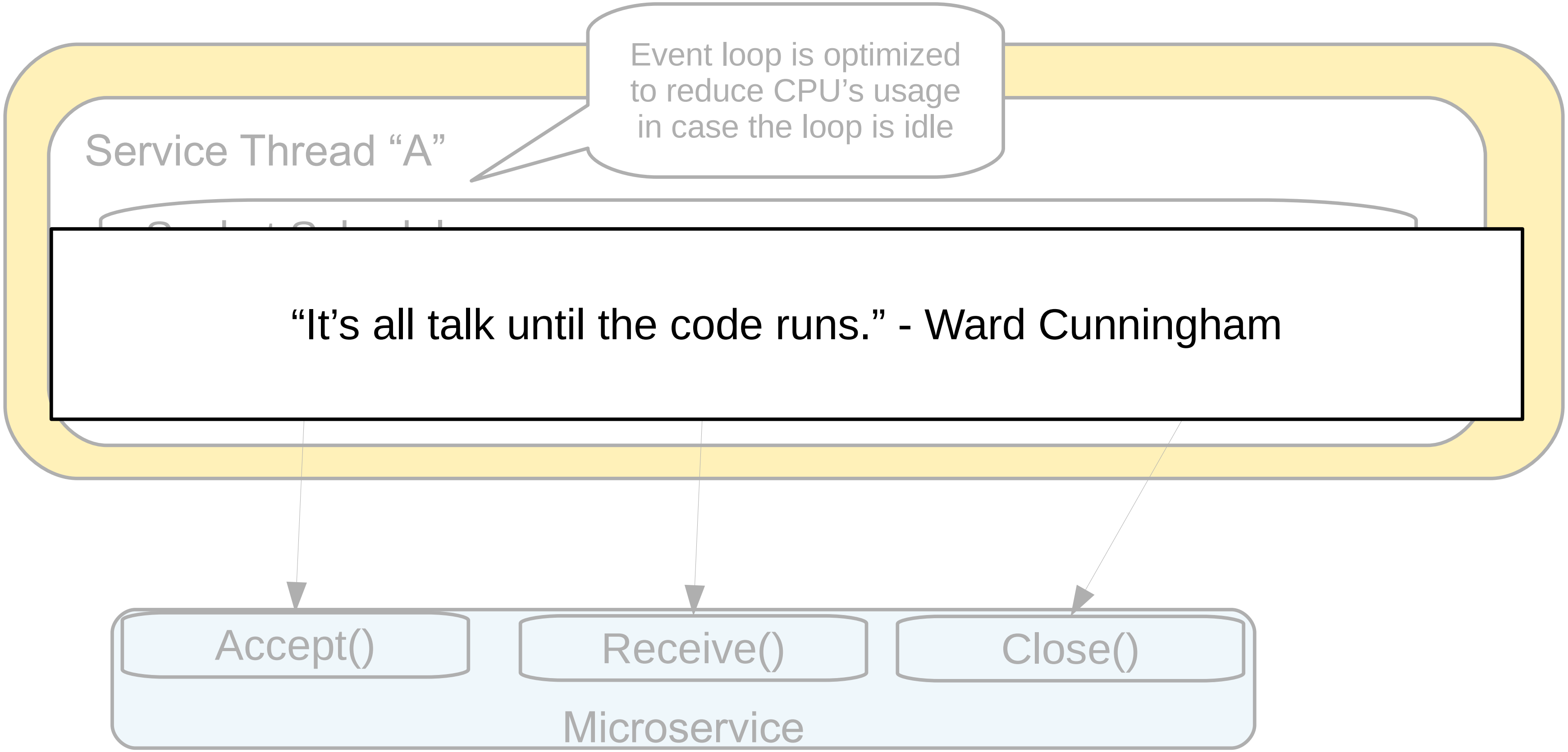


"It's all talk until the code runs." - Ward Cunningham

Evaluation

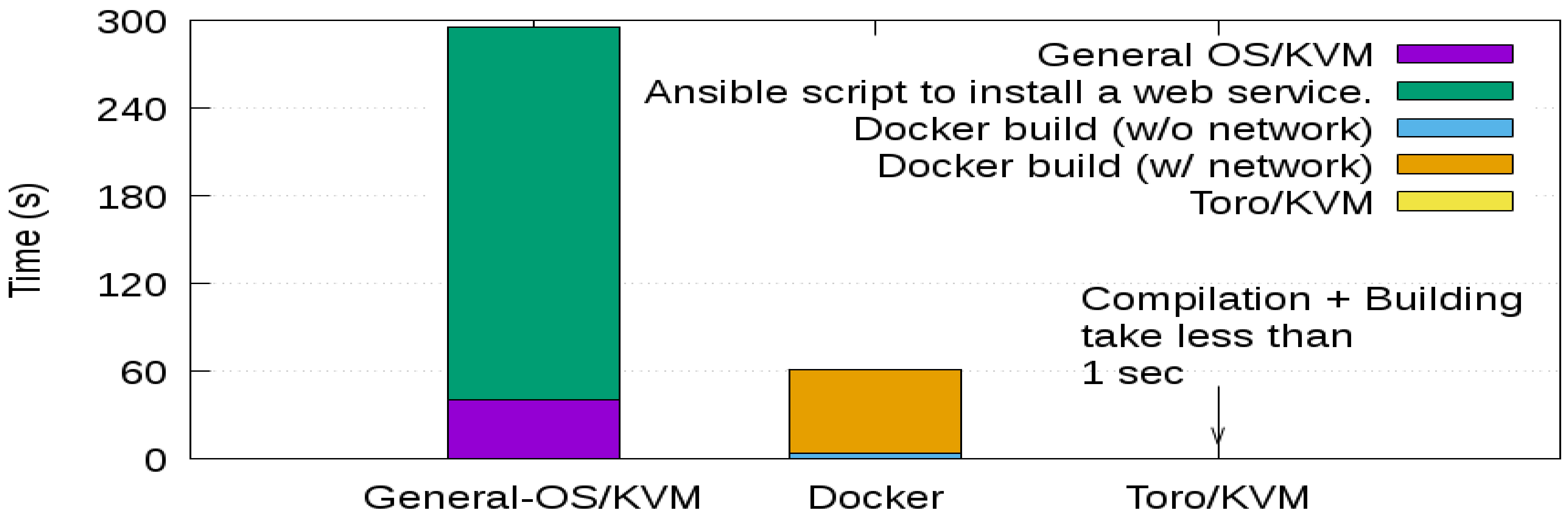
- We implement a “Hello World” microservice[4] (see https://github.com/MatiasVara/torokernel/tree/master/examples/HelloWorldMicroservice)
- We deploy it in Docker, Ubuntu (KVM Guest) and Toro (KVM Guest)
- We chose the following technology:
  - NGINX, UWSGI (4 processes) and Flask
- Memory is limited in all the platforms
- We compare these approaches in term of:
  - Deploying Time
  - Bootstrap Time
  - Image Size
  - CPU usage
  - Time per Request

Microservice’s footprint

[4] “Toro, a Dedicated Kernel for Microservices”, OSSummit’18

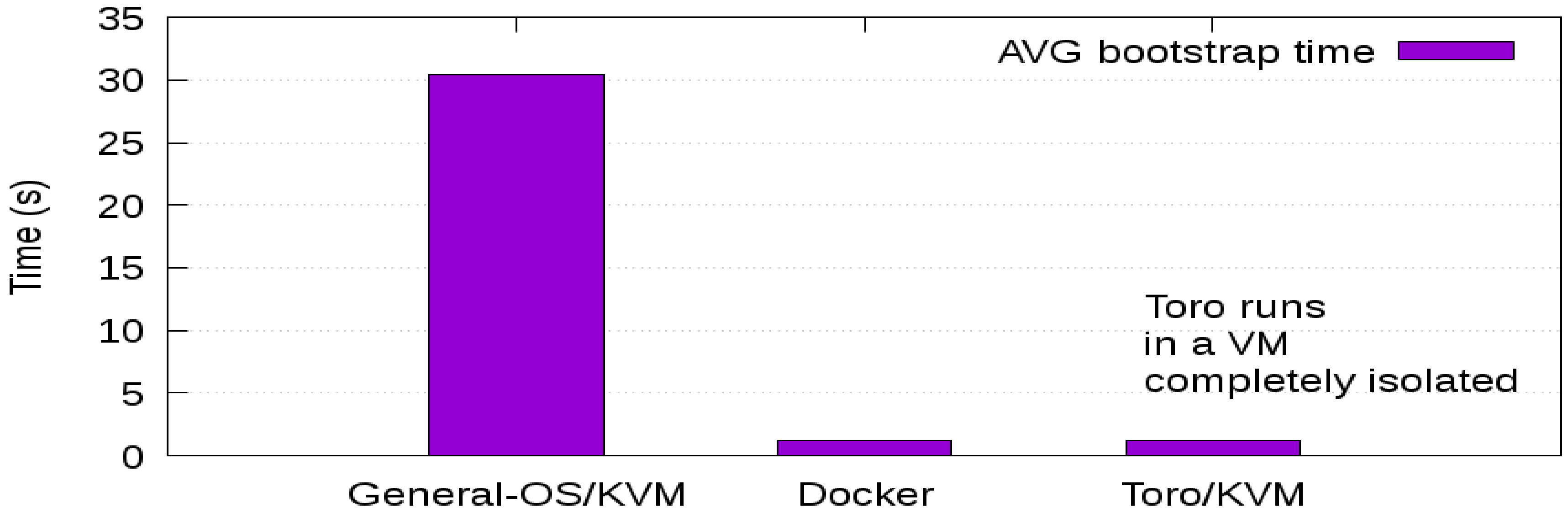
Deploying Time

- Time required to build an image within the microservice



Bootstrap Time

- Time to boot and to serve the first request



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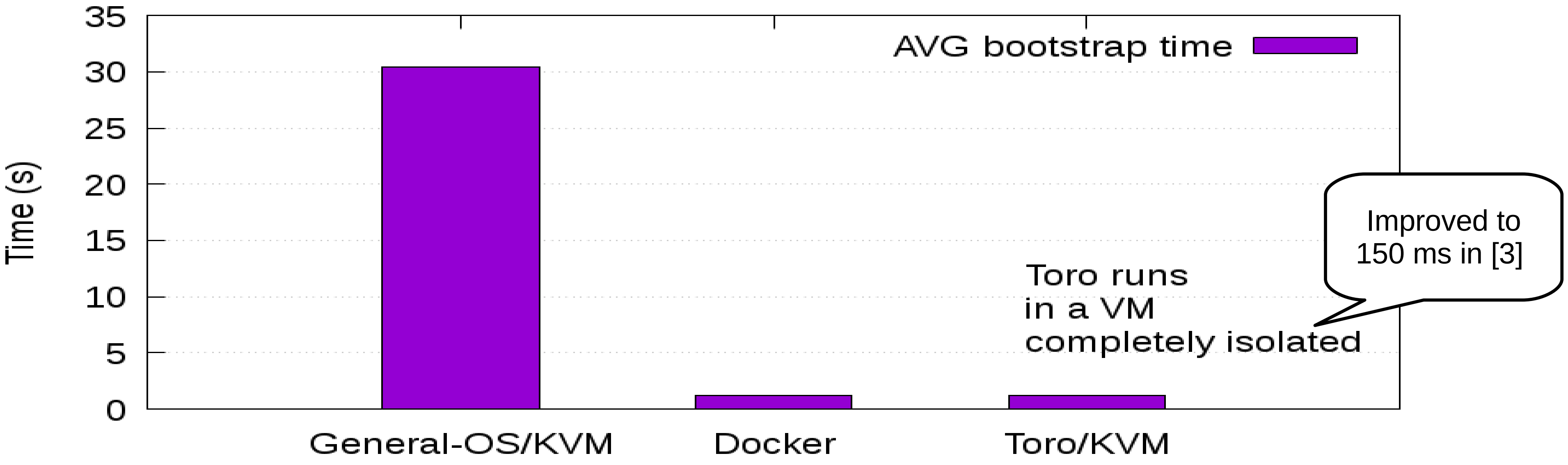
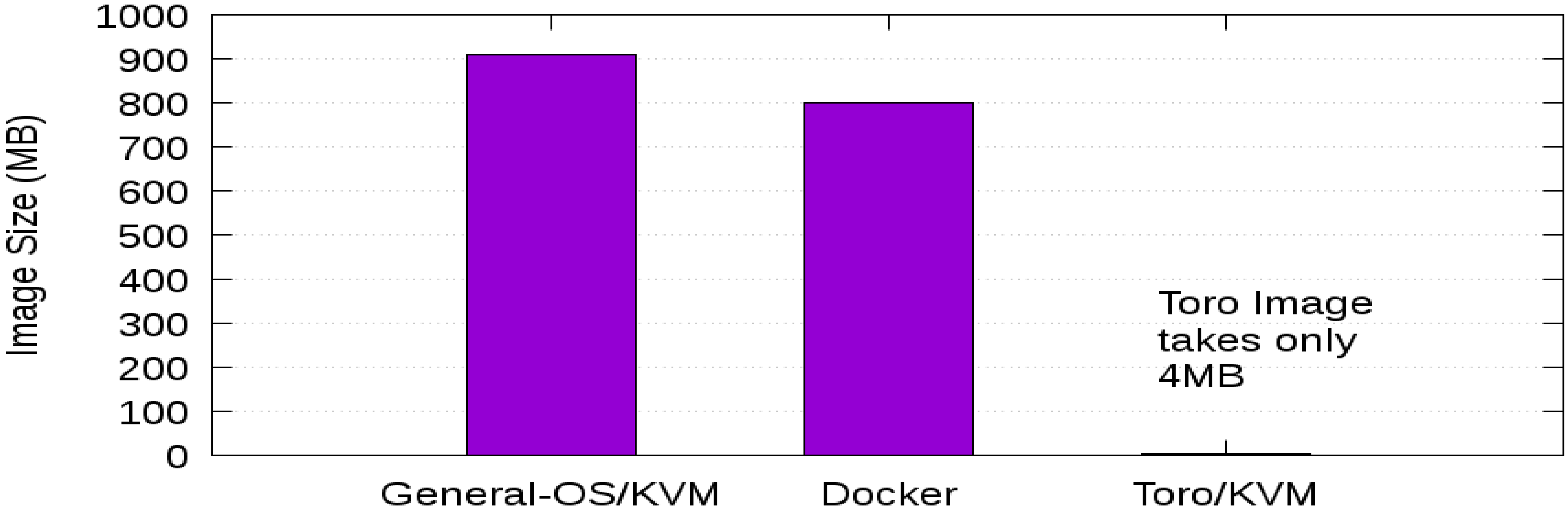


[3] Speed up Booting time of a Toro Appliance, FOSDEM’19

Image Size

- Size of the image that contains the microservice and its dependencies.



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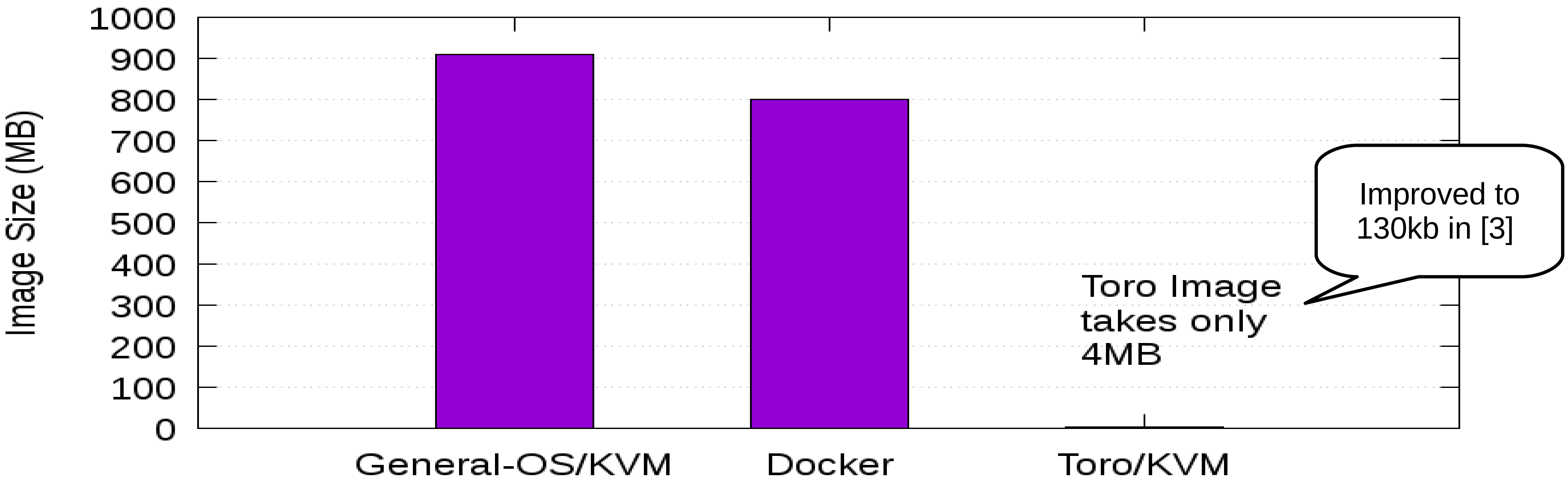
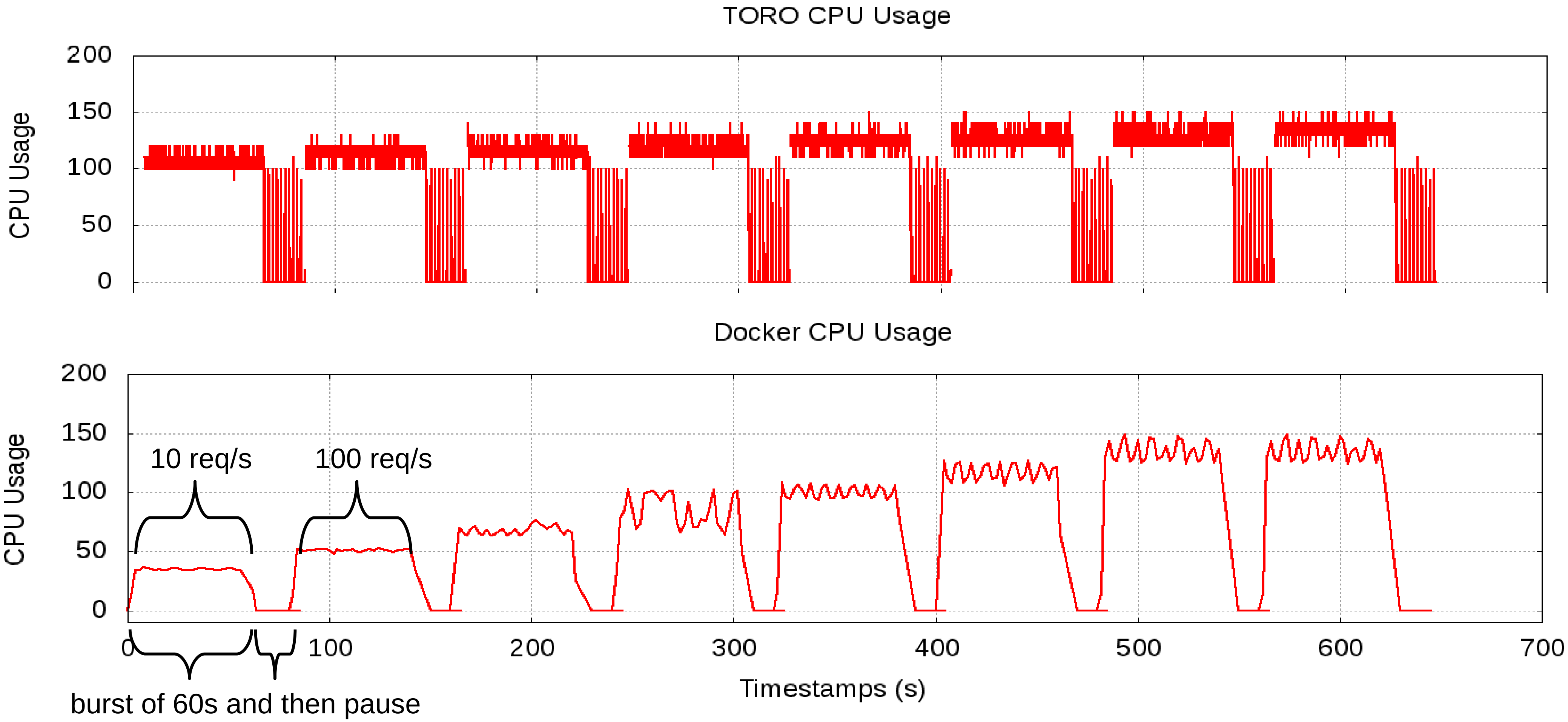


CPU Usage


TORO CPU Usage
CPU Usage
200
150
100
50
0
Docker CPU Usage
CPU Usage
200
150
100
50
0
10 req/s
100 req/s
0
100
200
300
400
500
600
700
Timestamps (s)
burst of 60s and then pause

End-User Delay

- Benchmark with ab and measuring the Time per Request (mean) [ms]

		Number of Concurrent Request		
Approach	CPUs	200	500	1000
Docker	4	139.980 ms	333.937 ms	801.422
Ubuntu/KVM	1	94.507 ms	238.149 ms	560.513 ms
TORO/KVM	1	120.065 ms	301.736 ms	596.792 ms

Take away lessons

- Toro image is about 15-times less than NGINX docker image
- 1 sec to re-deploy a microservice
  - Deploy an OS w/similar configuration takes 300 sec, with docker ~50 sec
- Comparable time per request with cutting edge technology (NGINX)
- CPU Usage comparable with Docker
- Safer than Docker

Demo time

Summary

- Toro design is improved in five main points:
  - Booting time and building time
  - Kernel API with zero overhead function call
  - Access to shared memory
  - Networking
  - CPU usage

Future Work

- Improve tooling to build, test and debug microservices
- Investigate new use-cases
- Port networking applications to provide starter kits: SMTP relay, HTTP proxy, Web tracking
- Investigate new ideas to improve the network stack for microservices, e.g., improve socket scheduling for http, resource allocation algorithm
- Investigate the use of microVM technologies, e.g., Firecraker, NEMU.
- Investigate the use of OpenStack to ease the deployment of Toro appliances

QA

- http://www.torokernel.io
- torokernel@gmail.com
- Twitter @torokernel
- Torokernel wiki at github
  - My first Three examples with Toro
- Test Toro in 5 minutes (or less...)
  - torokernel-docker-qemu-webservices at Github

QA

- http://www.torokernel.io
- torokernel@gmail.com
- T... torokernel
- ...ki at github
- ...e examples with Toro
- ...5 minutes (or less...)
- ...nel-docker-qemu-webservices at Github

That's all folks!