A file system for safely interacting with untrusted USB flash drives

Ke Zhong, Zhihao Jiang[★], Ke Ma[★], and Sebastian Angel
University of Pennsylvania [★]Shanghai Jiao Tong University

Most Storage has moved to cloud!

USB flash drives remain popular

- **Legacy data**
- **No network connections**
- **Store confidential data**
  - Bitcoin keys
  - Medical records
  - ID photos

USB stack has several issues

- **Trust-by-default design principle**

- **Devices can bypass kernel and access memory (DMA)**

- **Driver code tends to be buggy**
  - There are many drivers by third party producers

- **Masquerade as other devices**
  - A device could declare to be a keyboard

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Could be exploited by a malicious flash drive

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Previous work

- **Packet filtering**
  - Cinch: Security’16
  - USBFilter: Security’16

- **Device authentication**
  - ProvUSB: CCS’16

- **Sandbox the device**
  - GoodUSB: ACSAS’15

Limitation

- **Packet filtering**
  - Malicious payload that changes dynamically avoids rule-based detection

- **Device authentication**
  - Require new hardware/kernel modifications

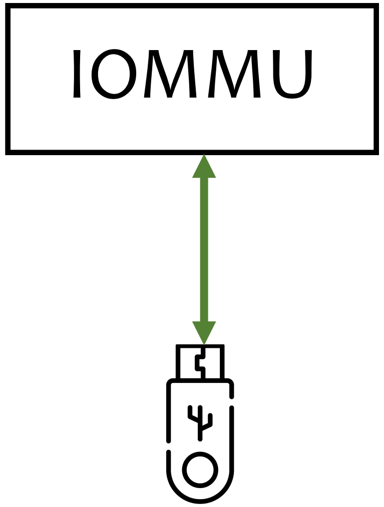
- **Sandbox the device**
  - False negative (i.e., a device is malicious but sandbox says it's ok)

We propose ***RBFuse*,** which is a file system that accesses flash drives without interacting with the USB stack on the host machine

Key idea

RBFuse remaps memory space of
host controller to a virtual machine,
and exports file system of flash drives as
a mountable virtual file system

System overview



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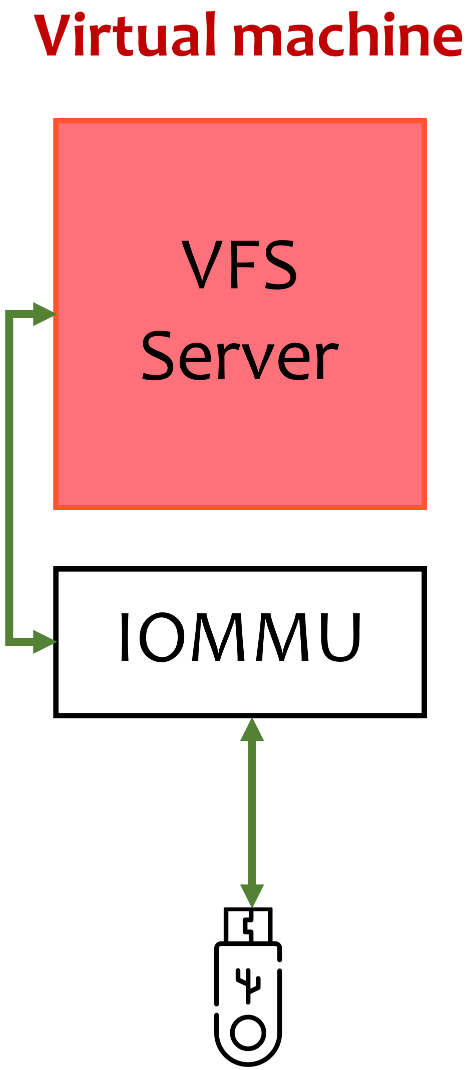

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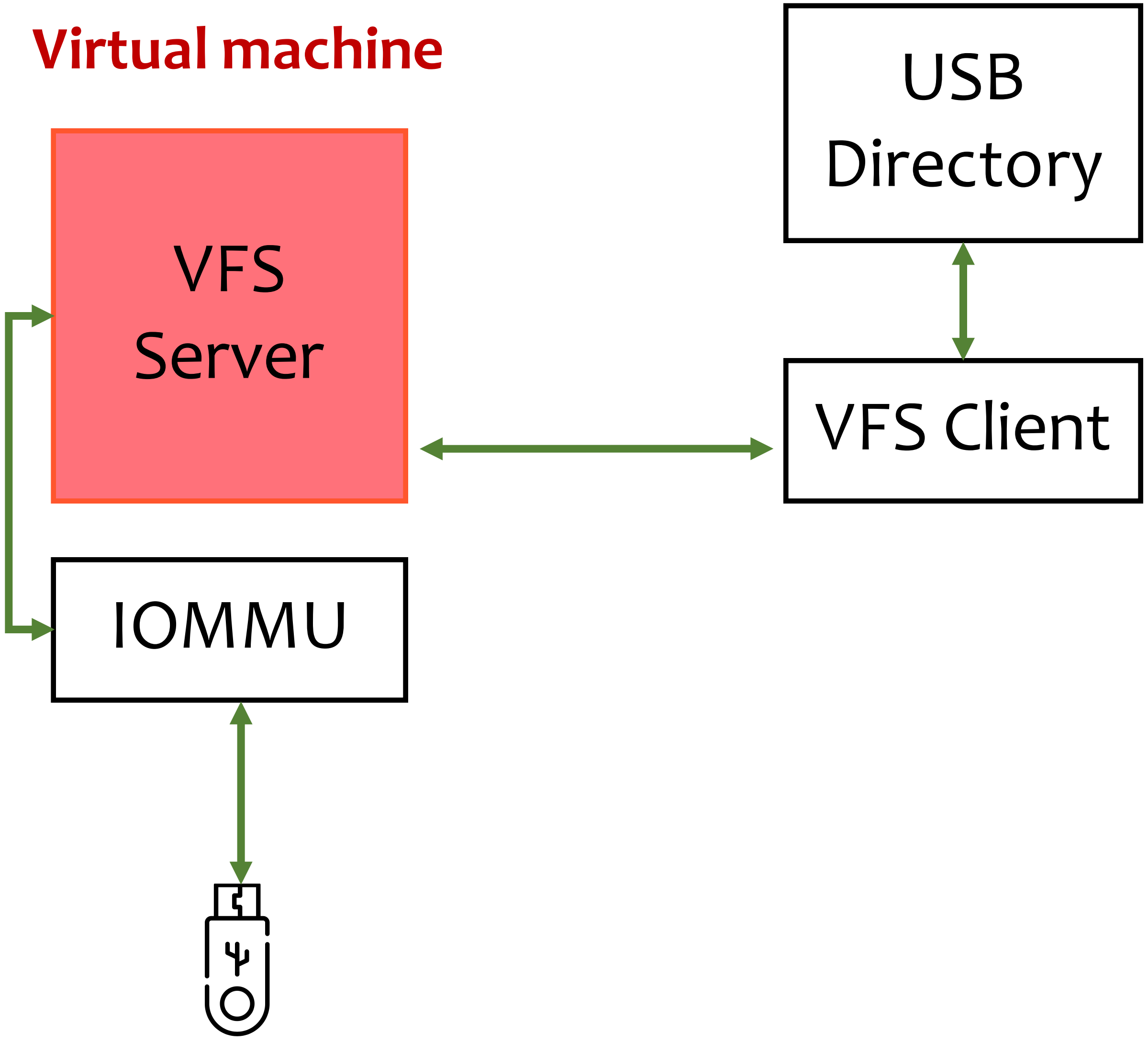

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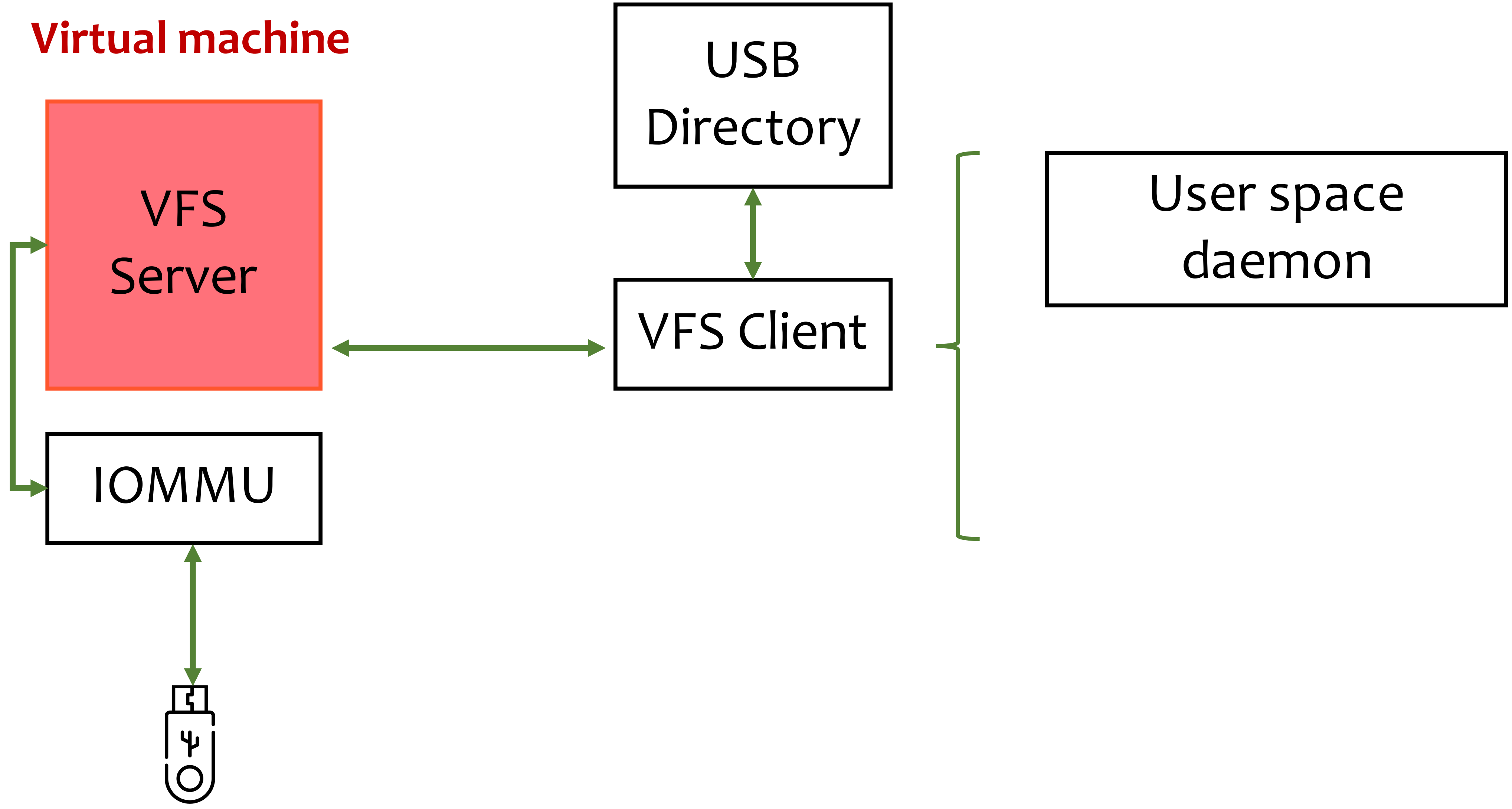

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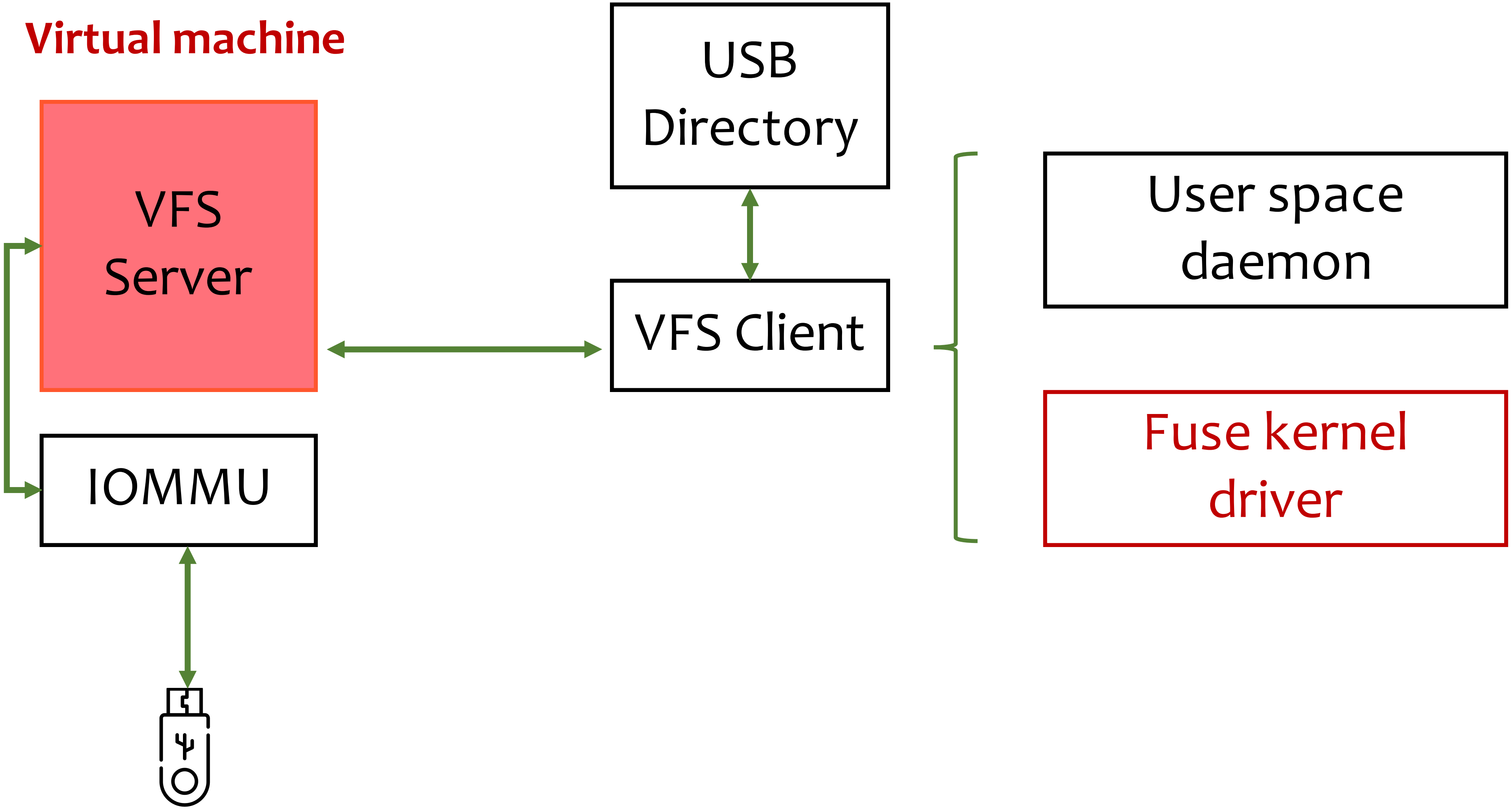
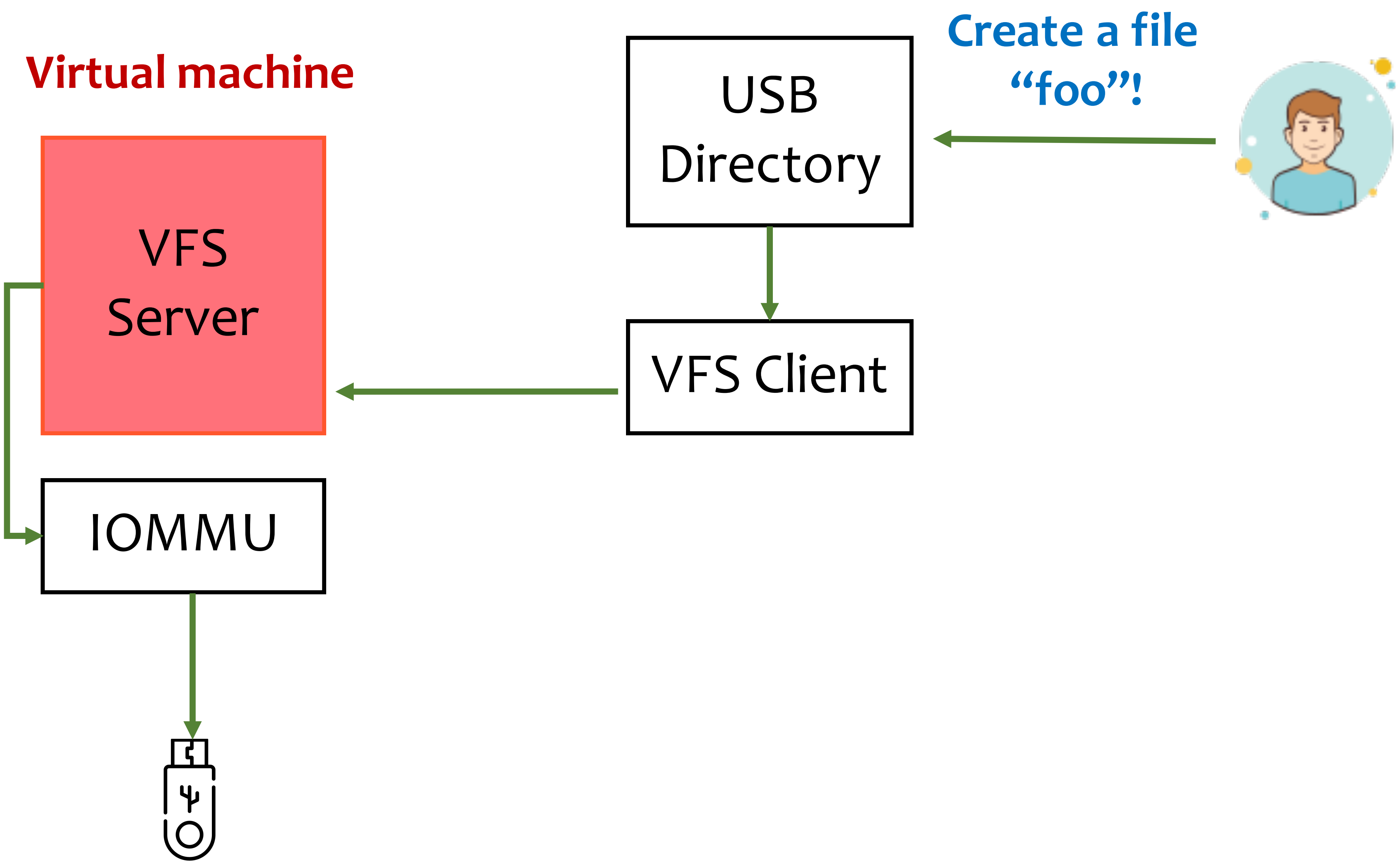


How *RBFuse* runs



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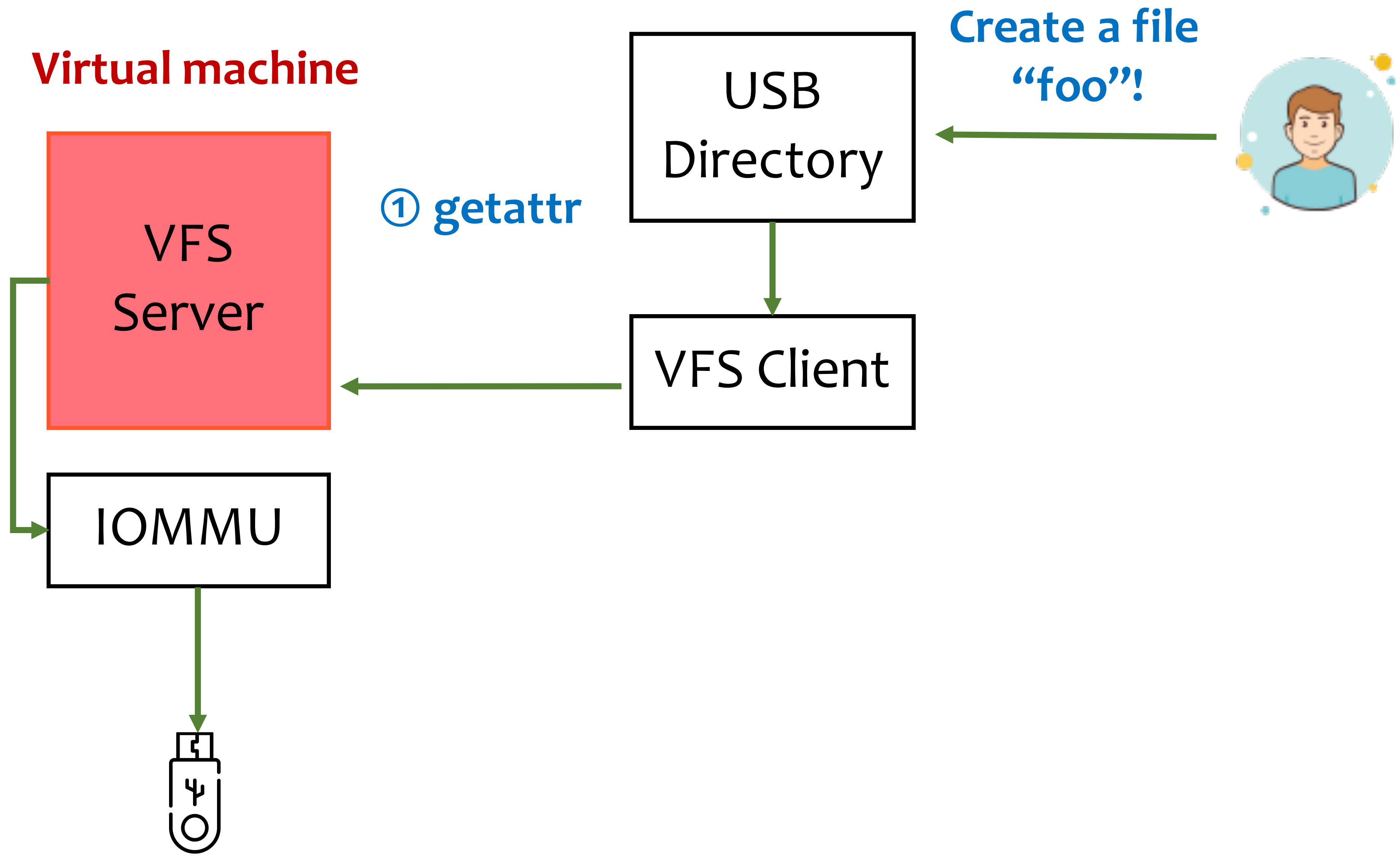

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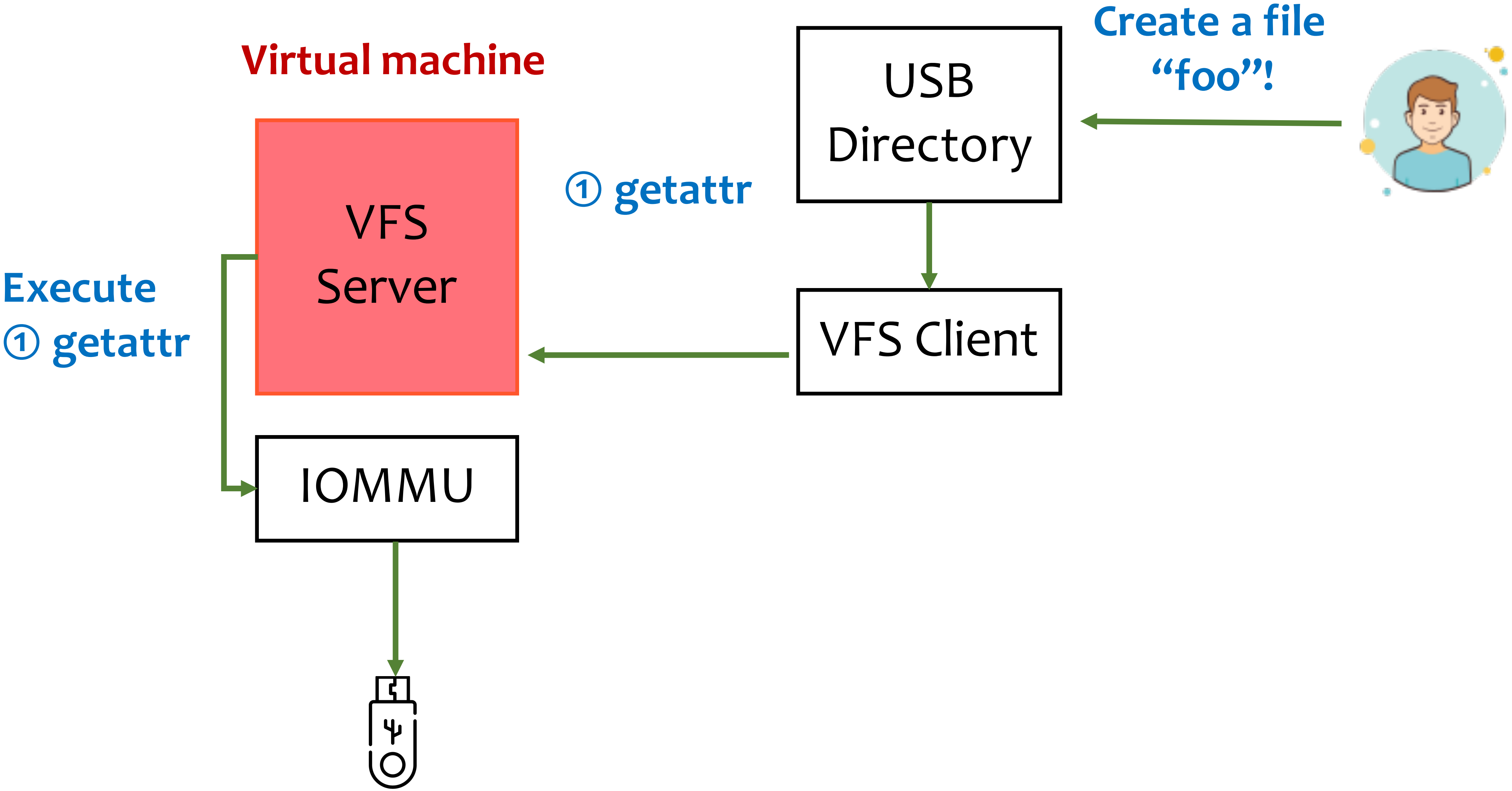

Virtual machine

Create a file "foo"!

① getattr

Execute ① getattr

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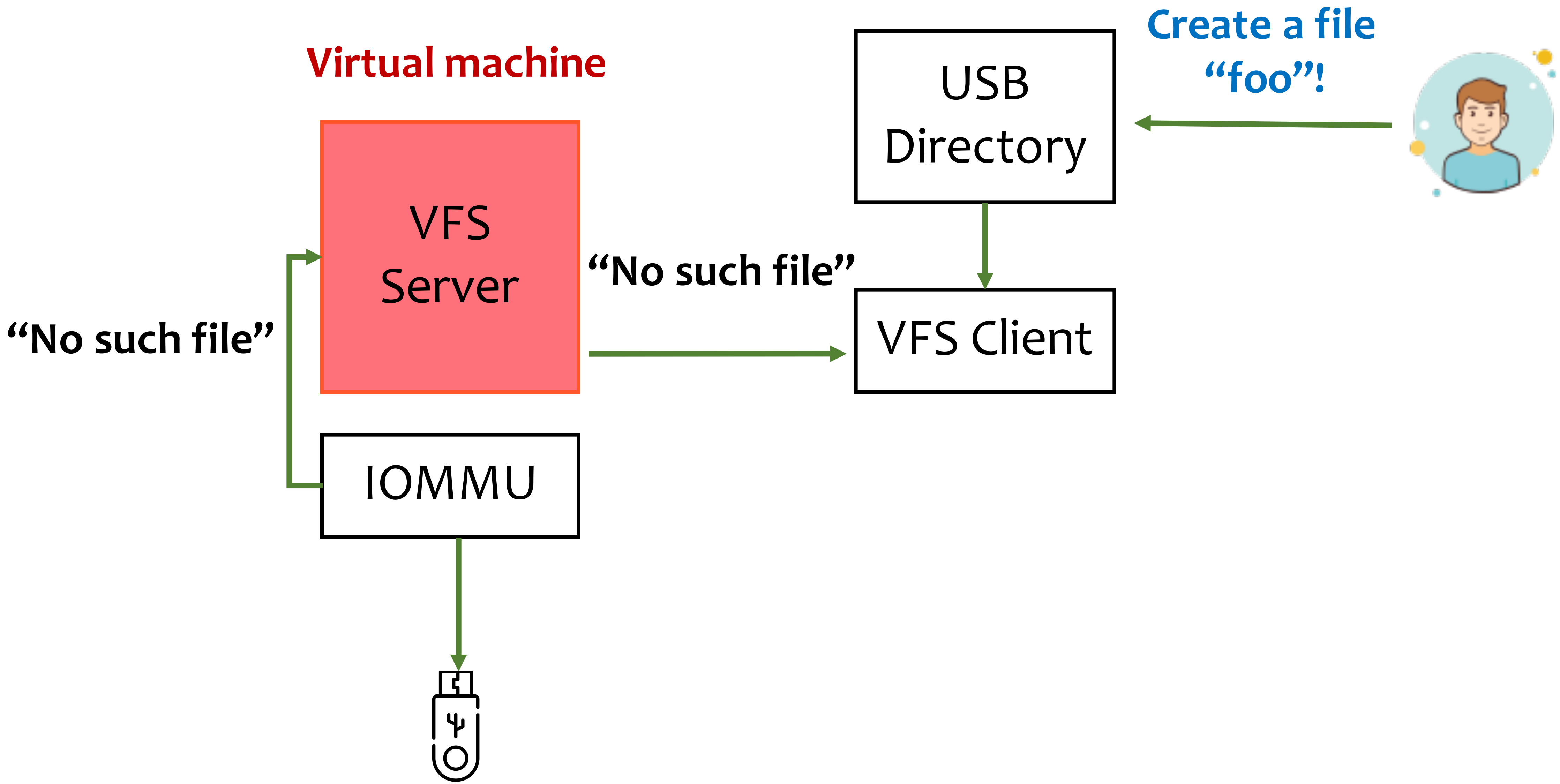

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USB Directory

VFS Server

VFS Client

IOMMU

“No such file”

“No such file”

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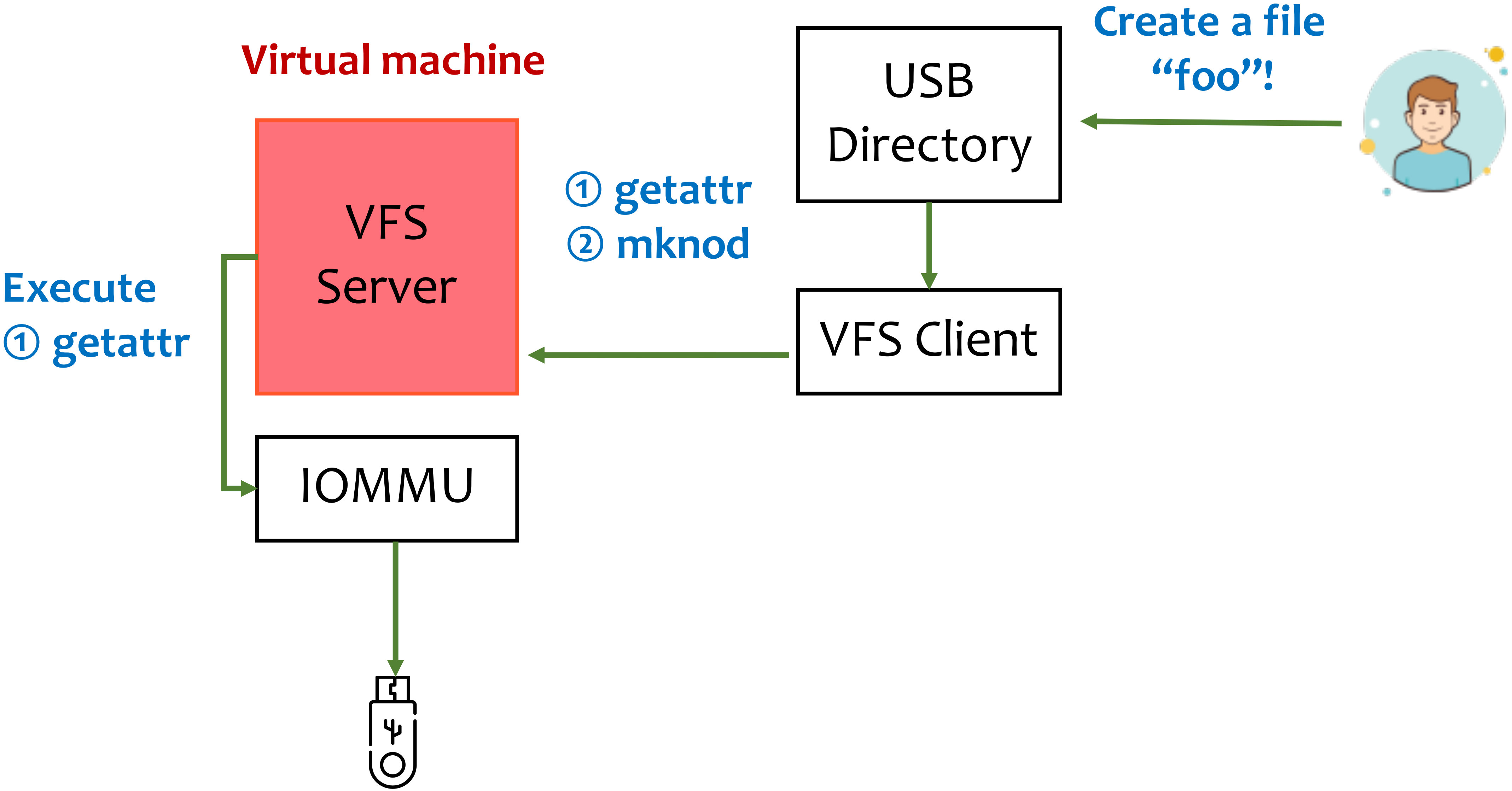

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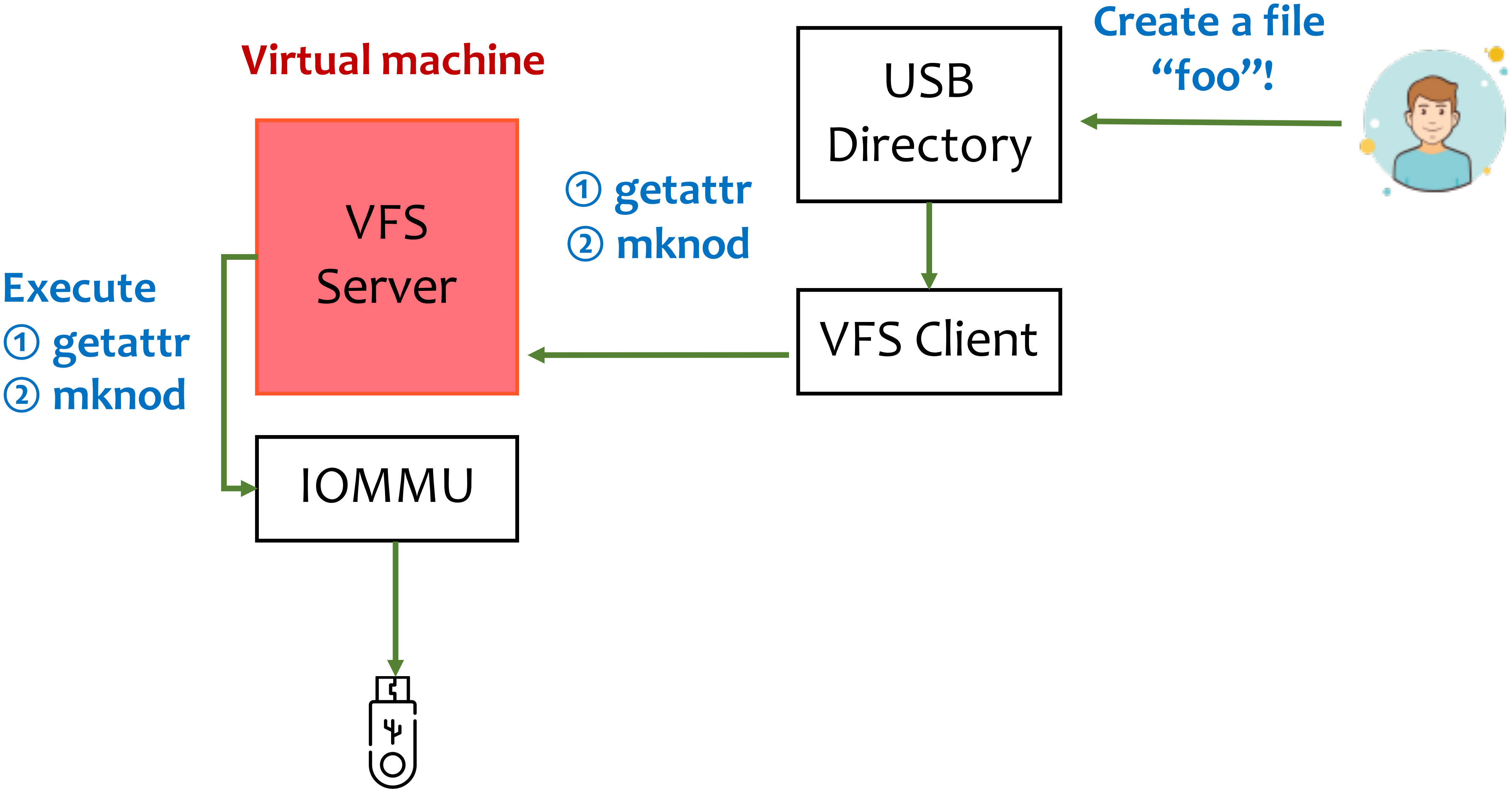

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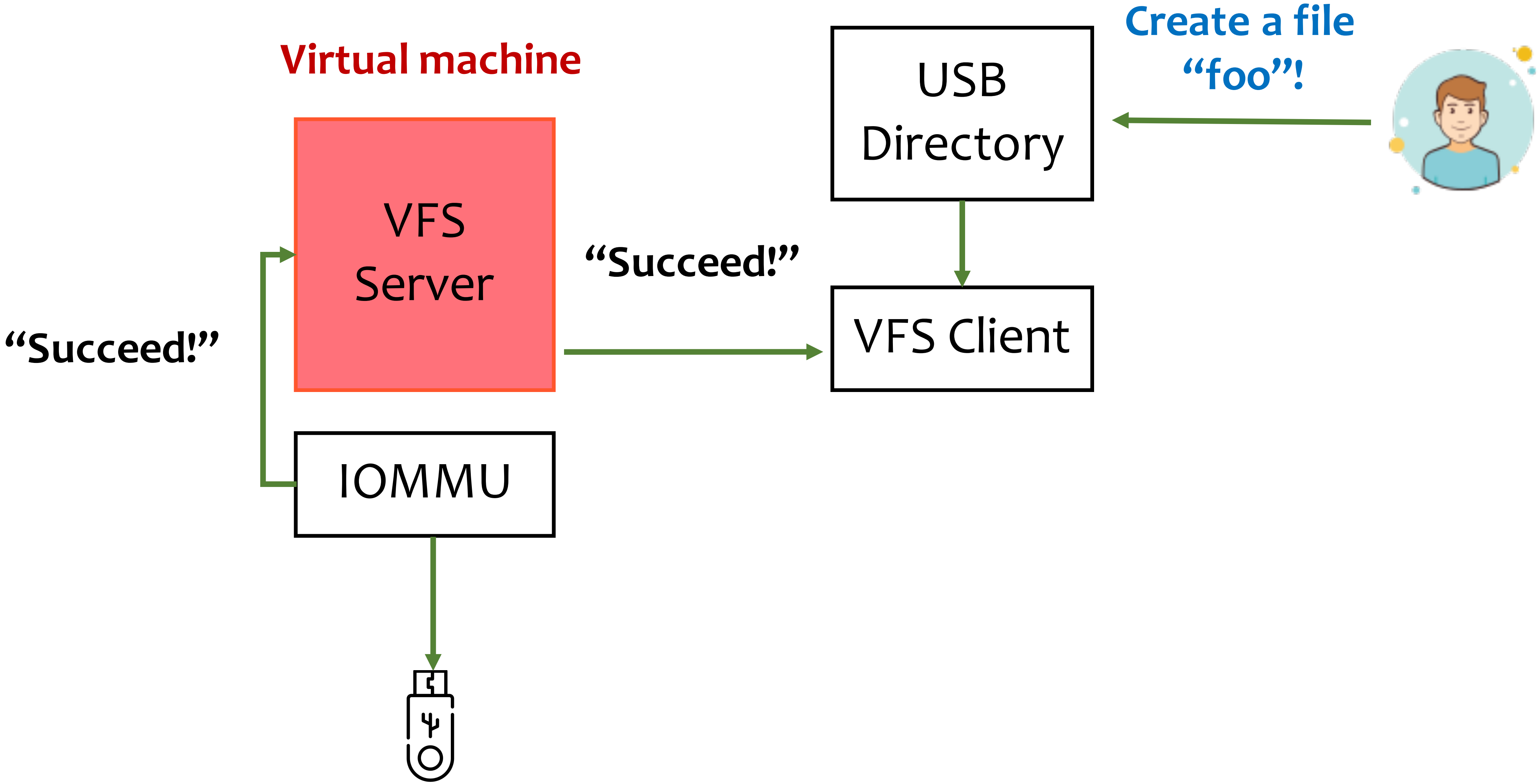

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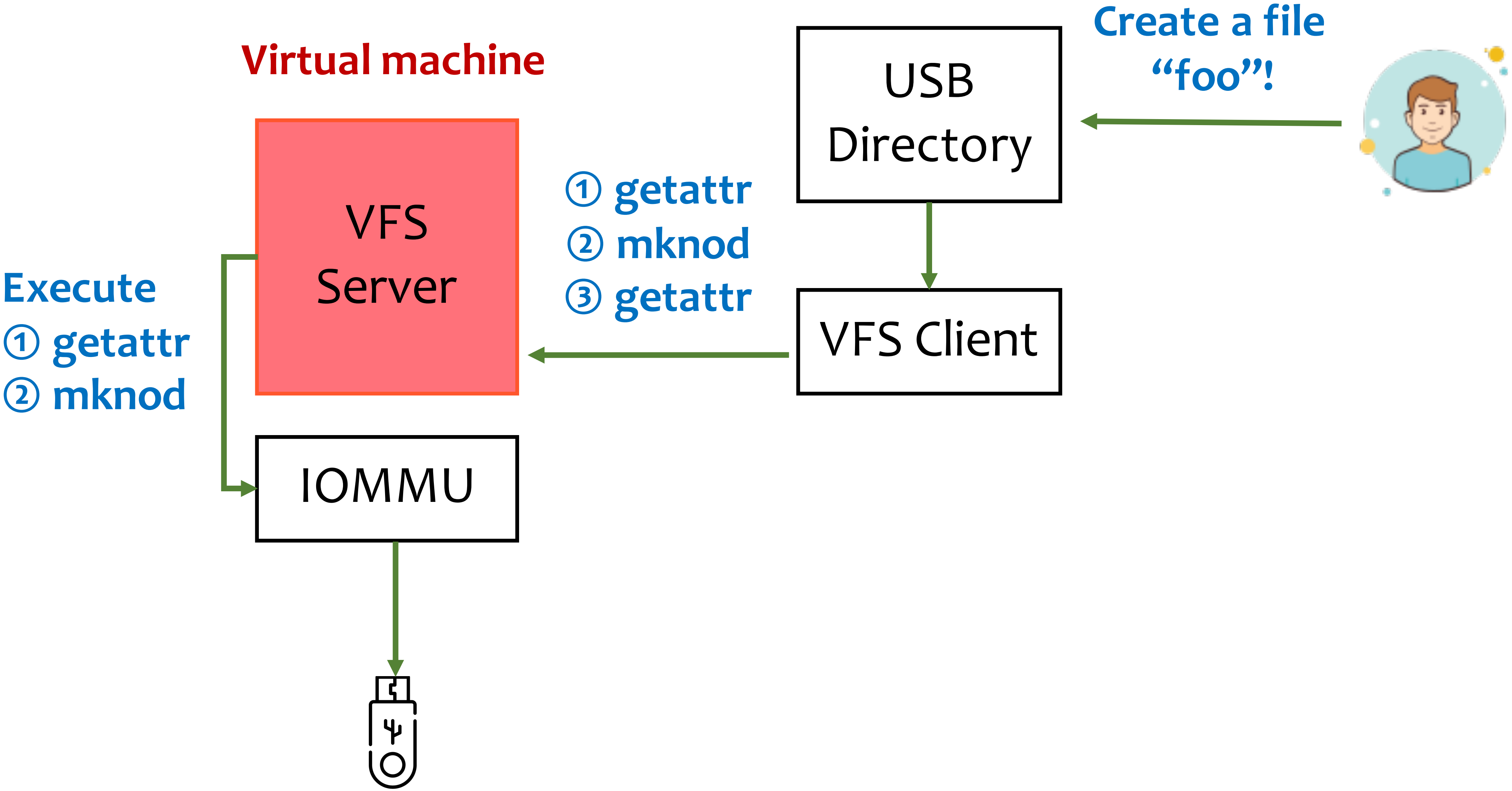

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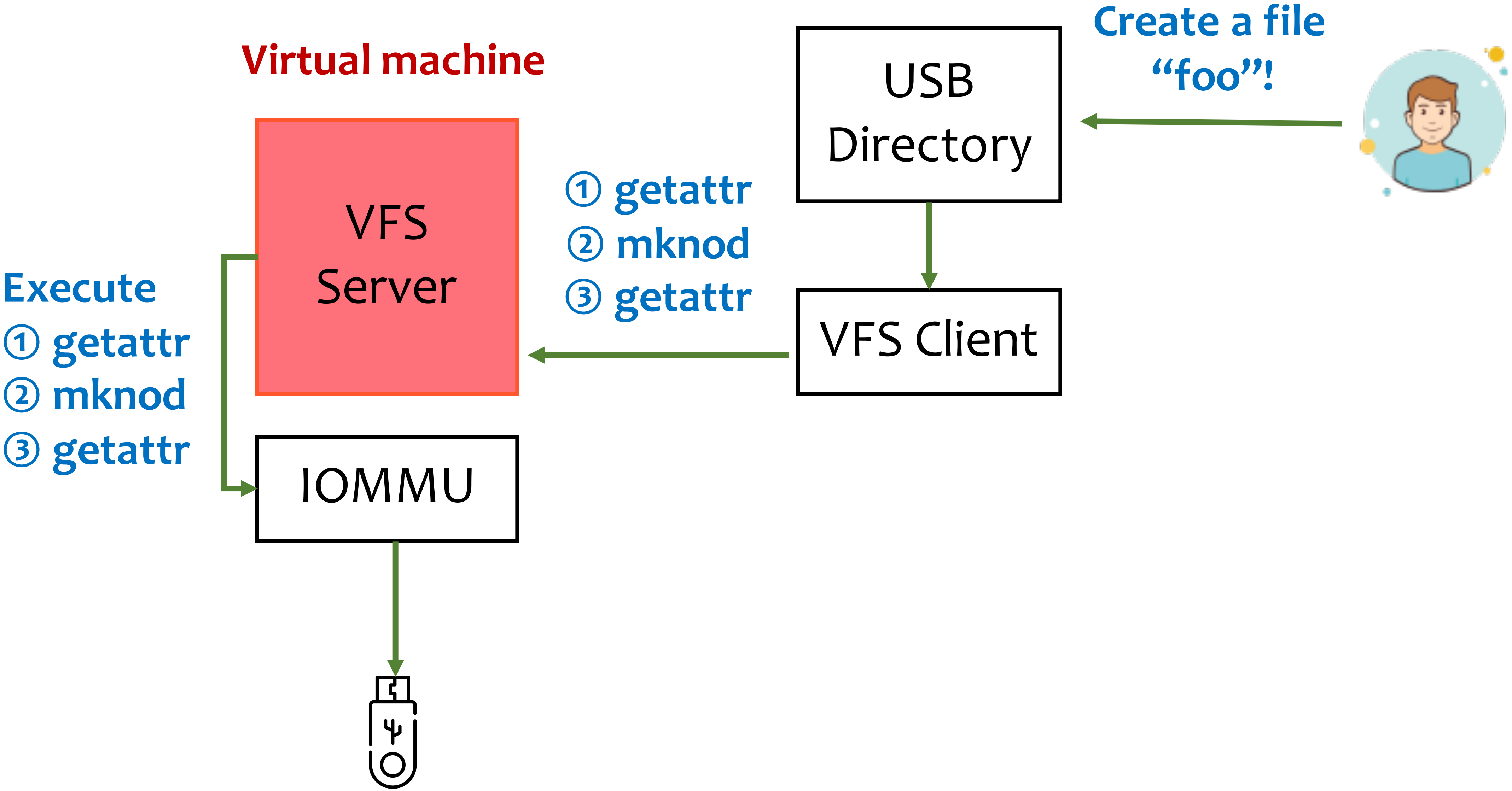

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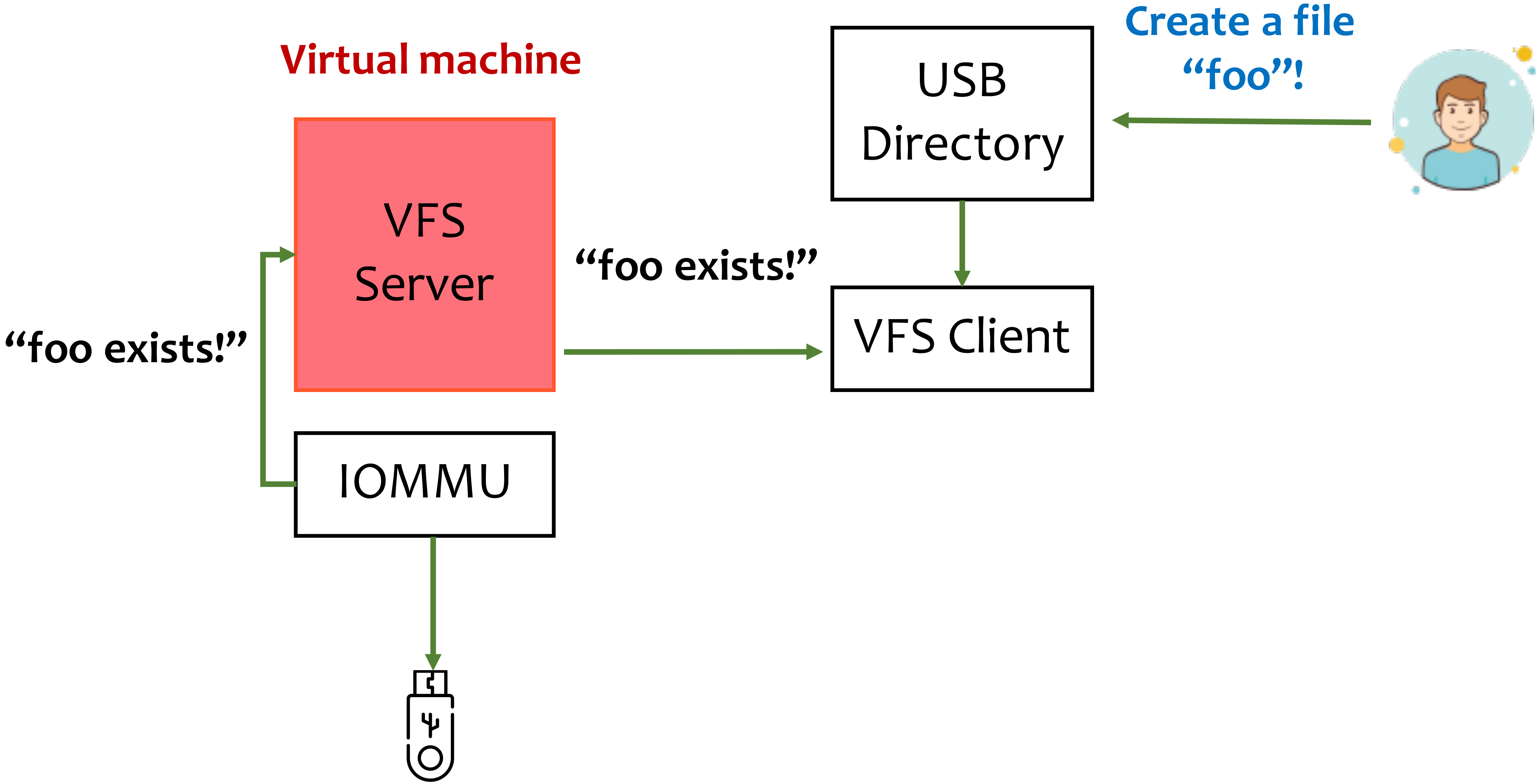

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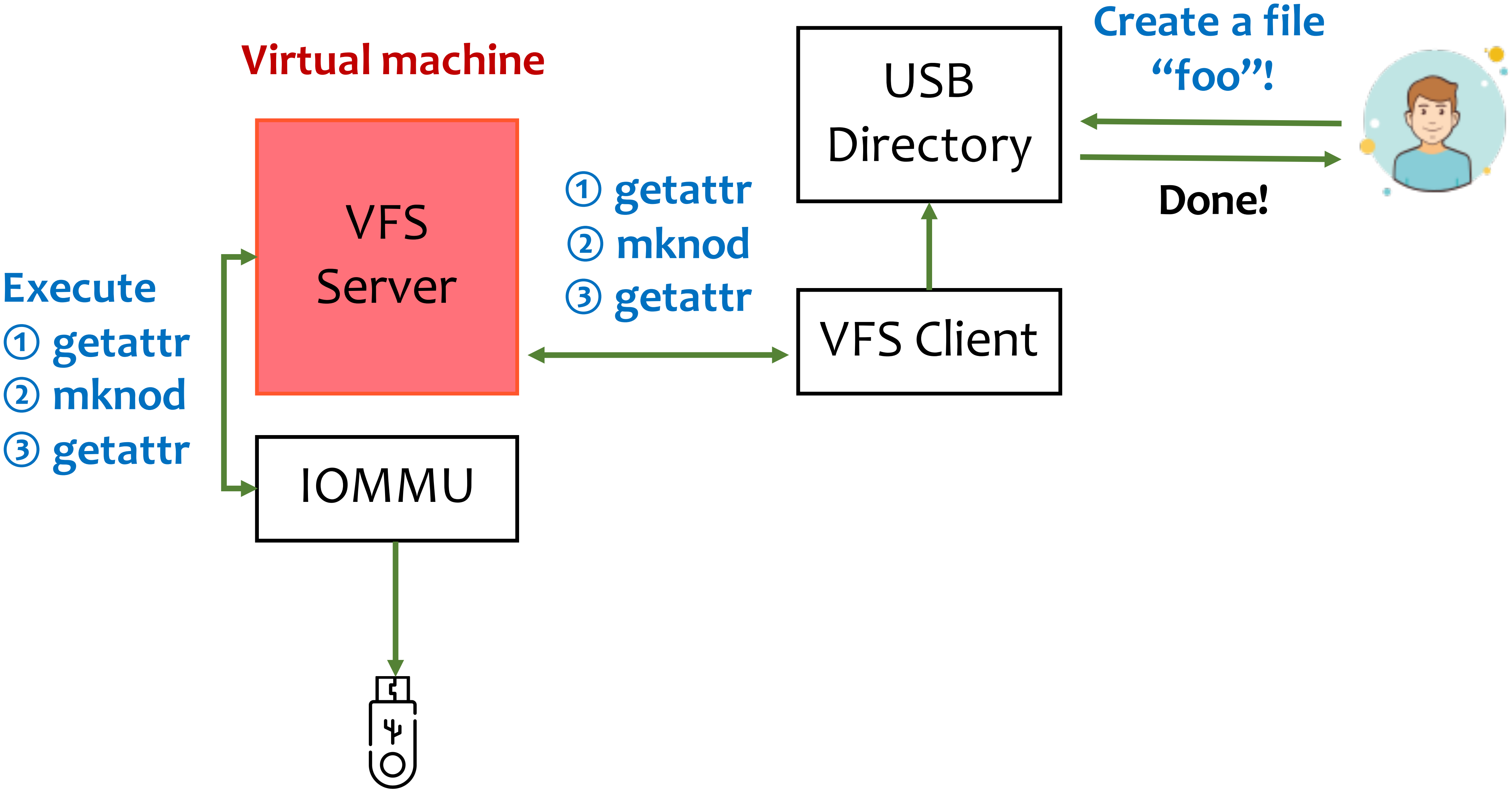
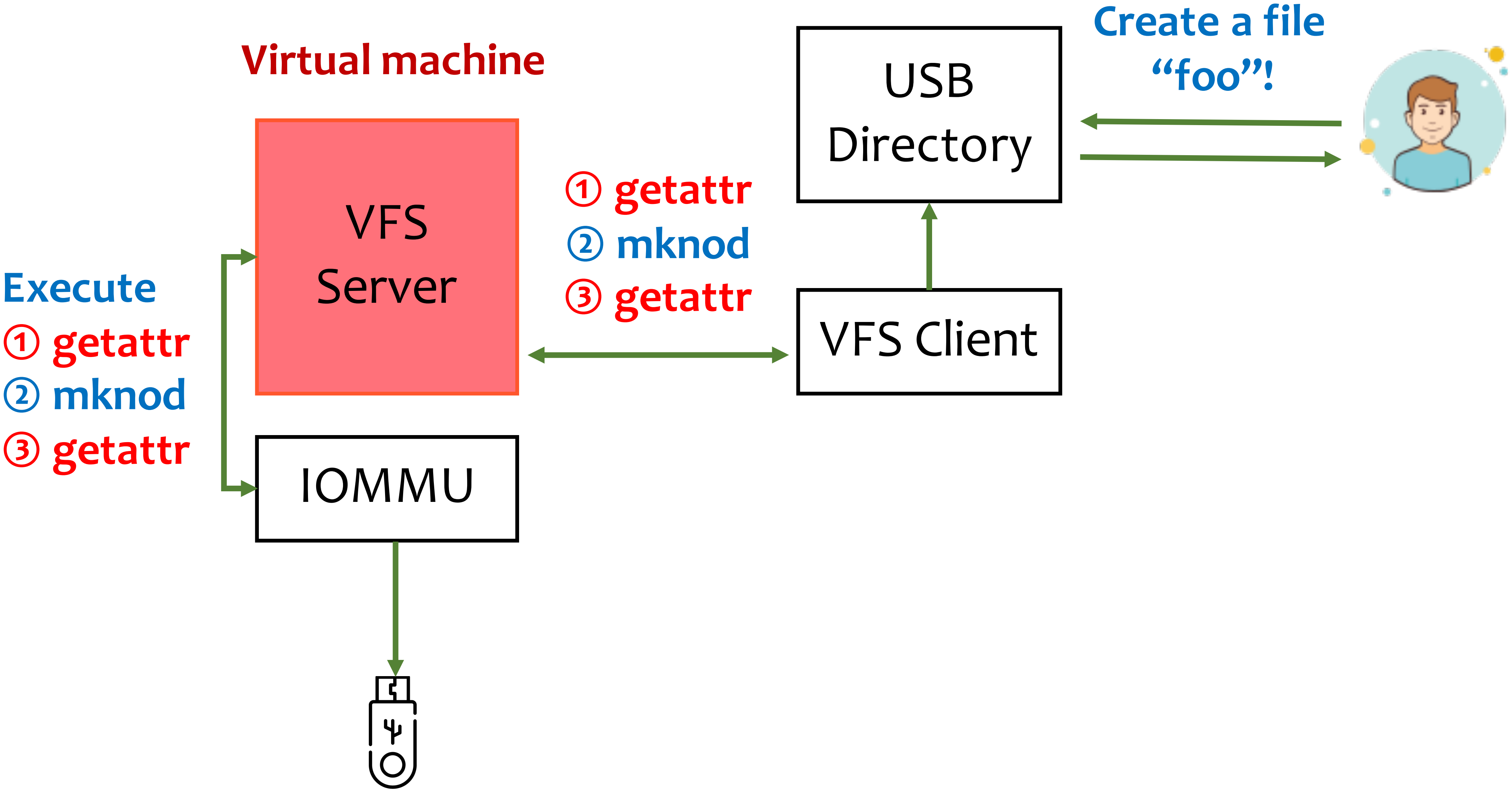


Performance issues



Virtual machine

VFS Server

IOMMU

Execute

① getattr

② mknod

③ getattr

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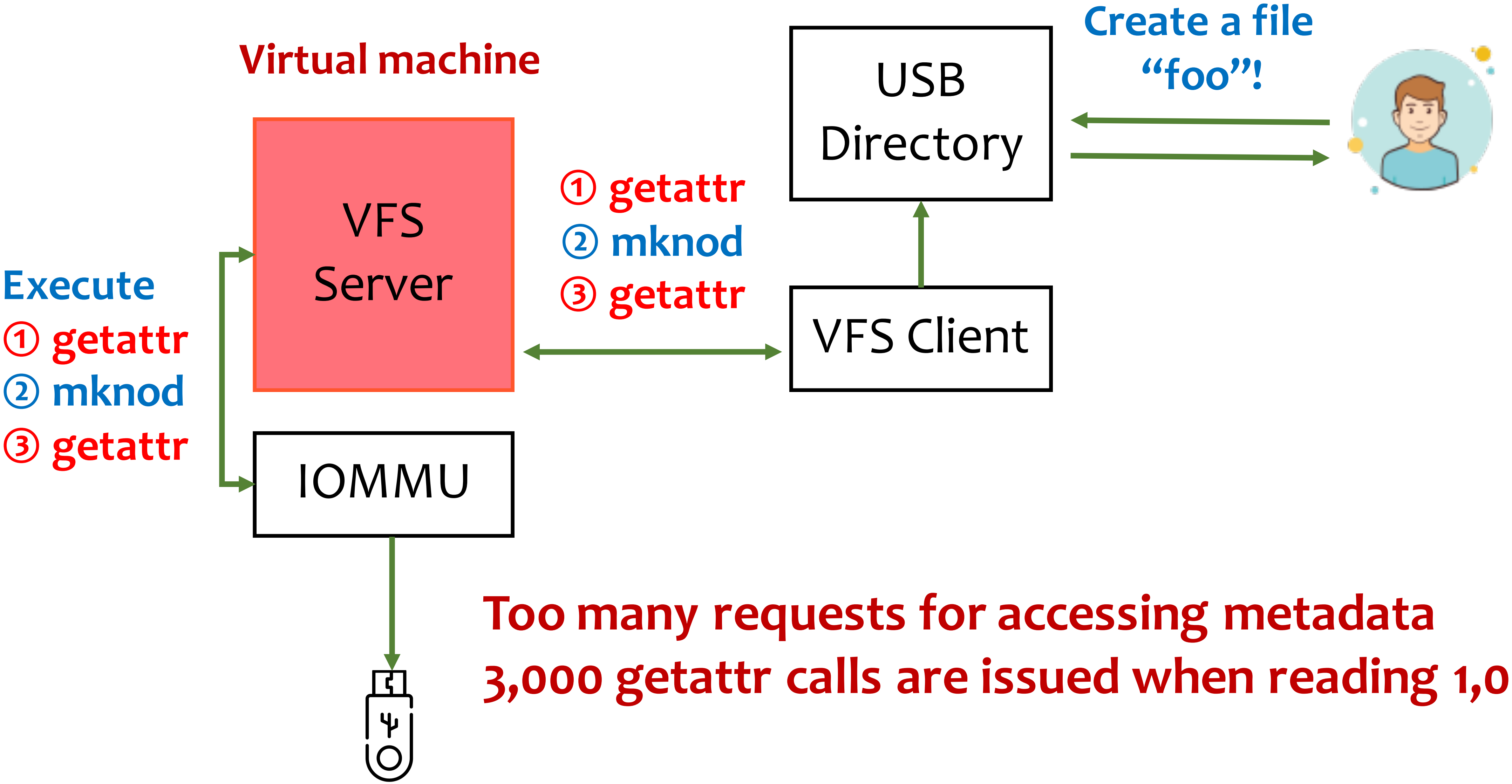
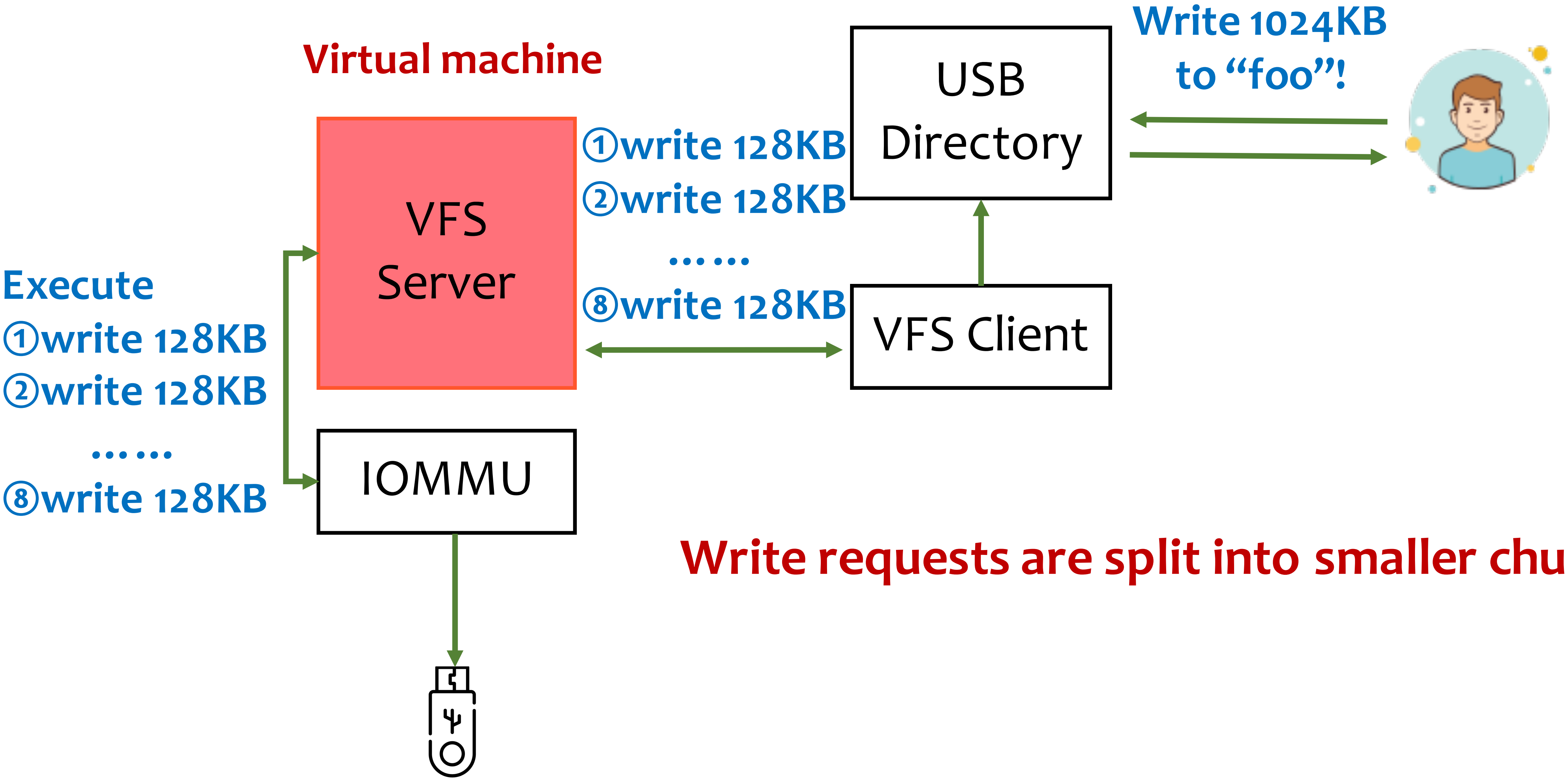


Too many requests for accessing metadata

3,000 getattr calls are issued when reading 1,000 files

Performance issues



Write requests are split into smaller chunks

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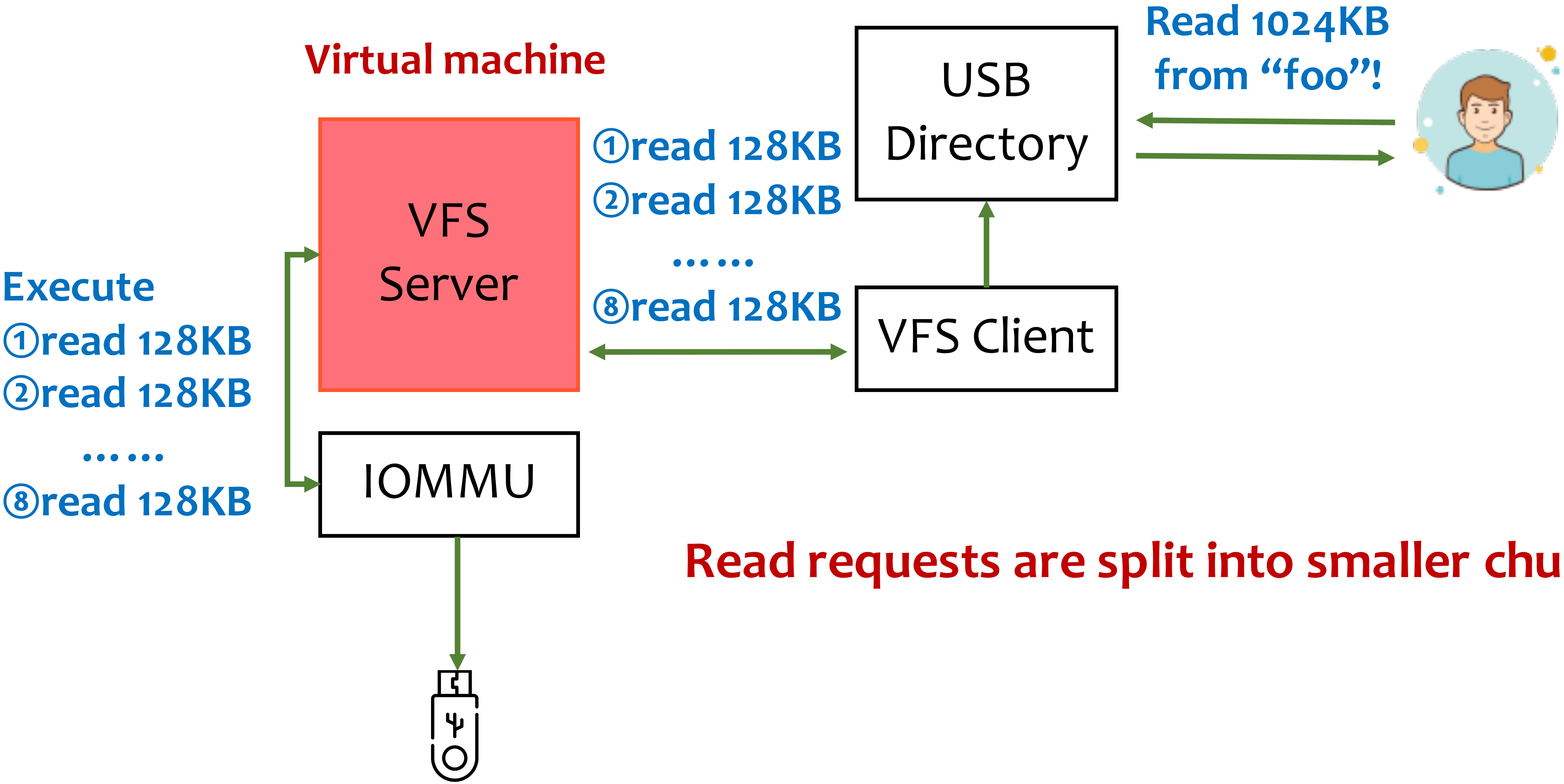

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Execute
①read 128KB
②read 128KB
……
⑧read 128KB

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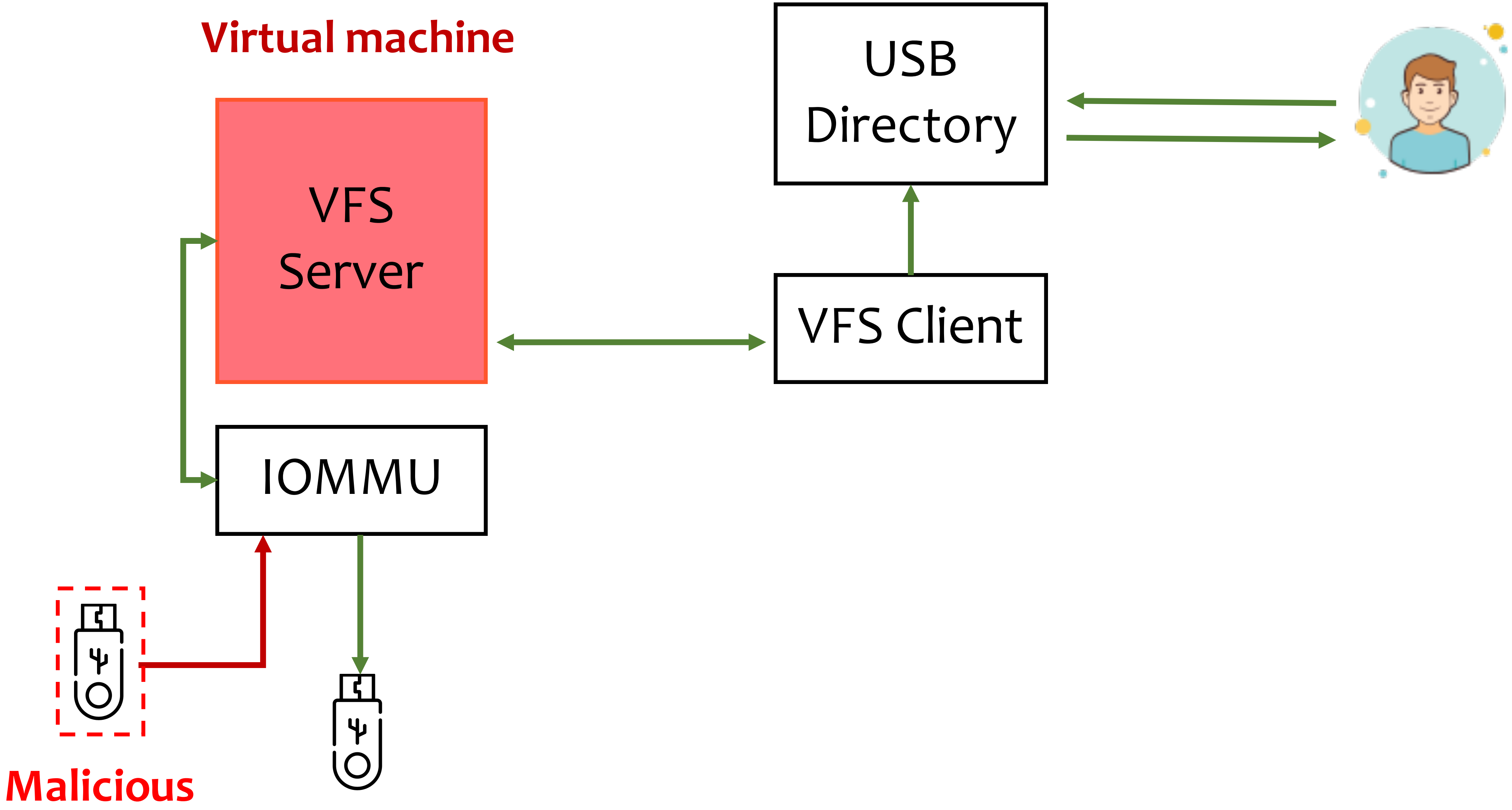
USB Directory

VFS Client

Read 1024KB from "foo"!

Read requests are split into smaller chunks

Compromised virtual machine



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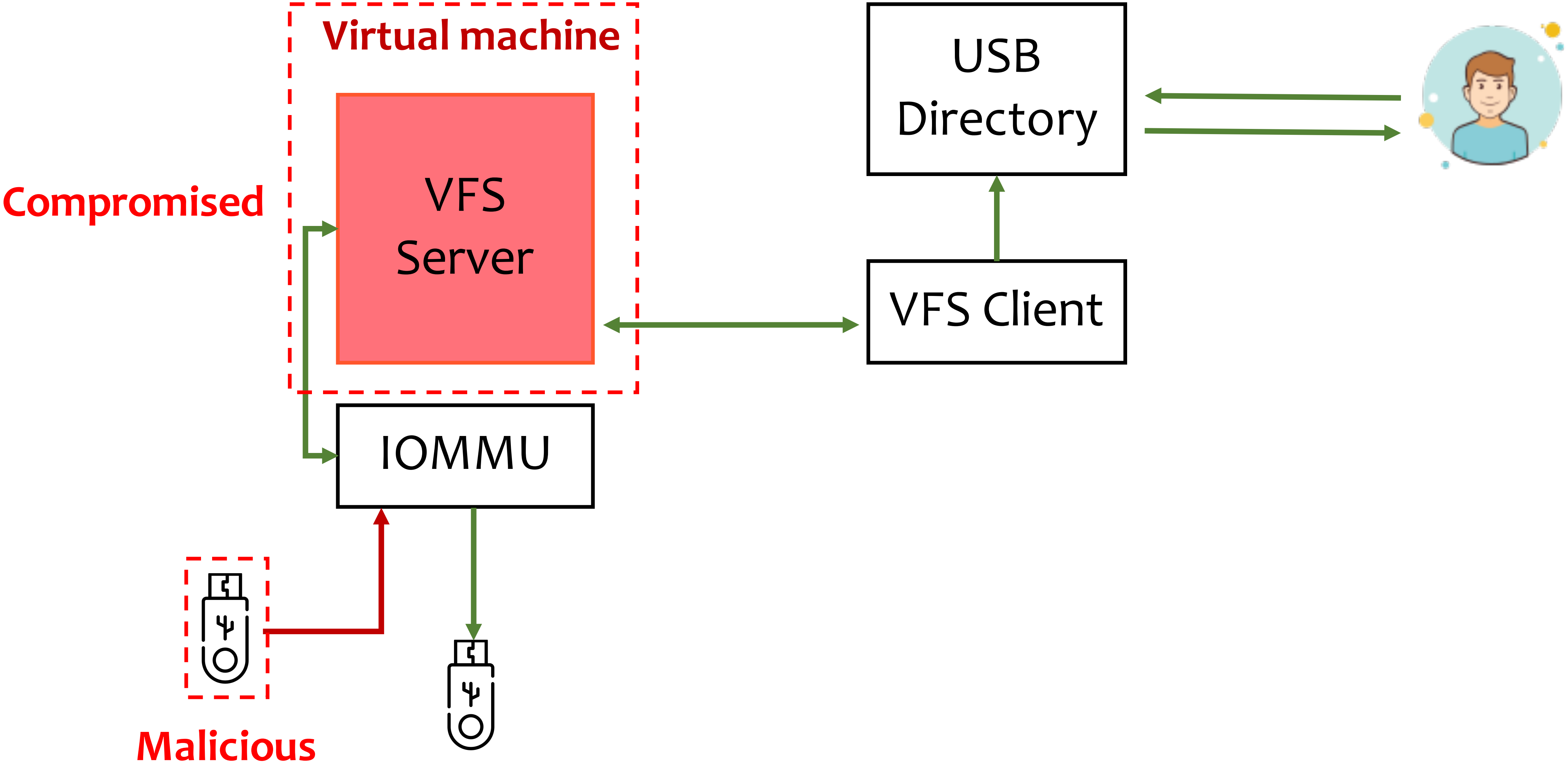

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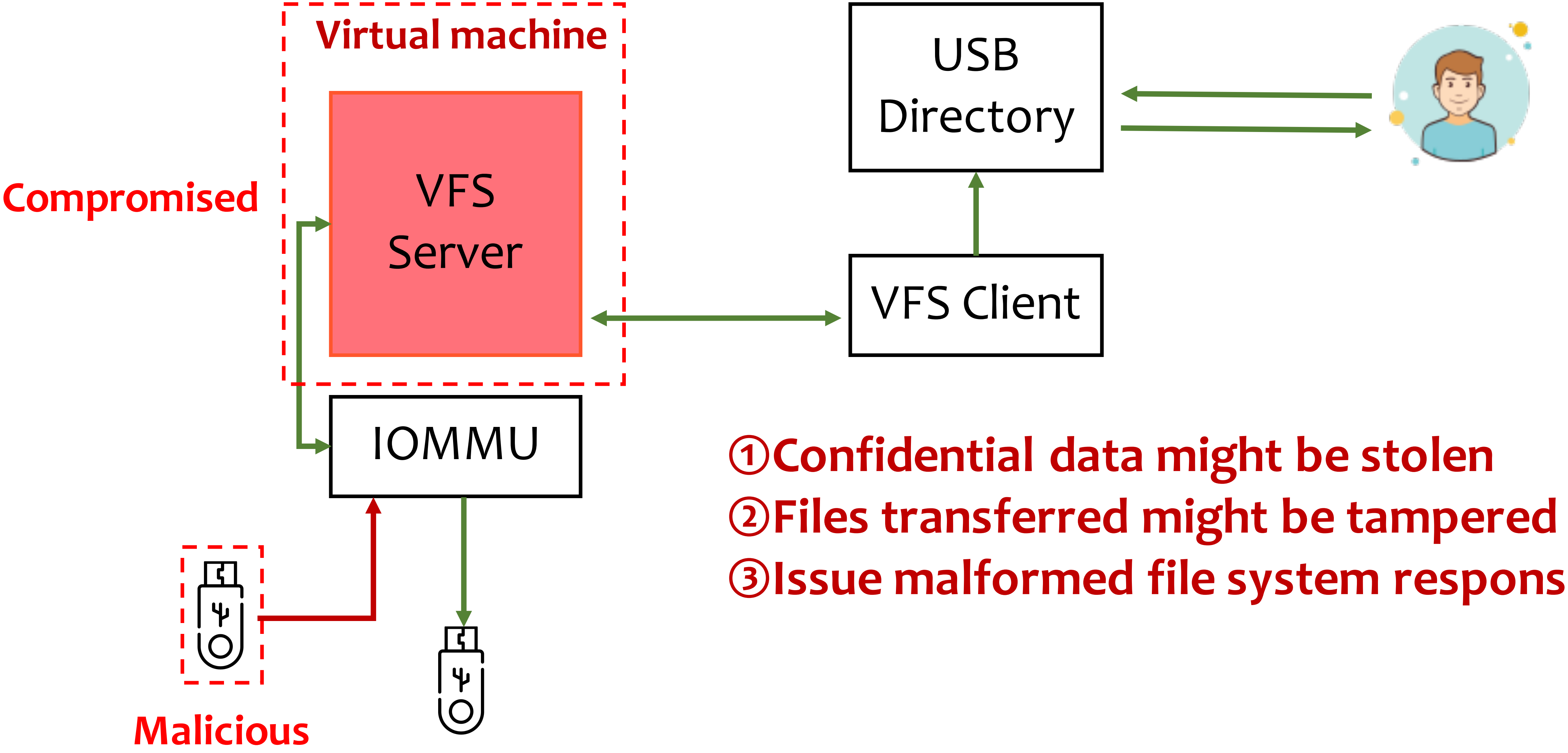
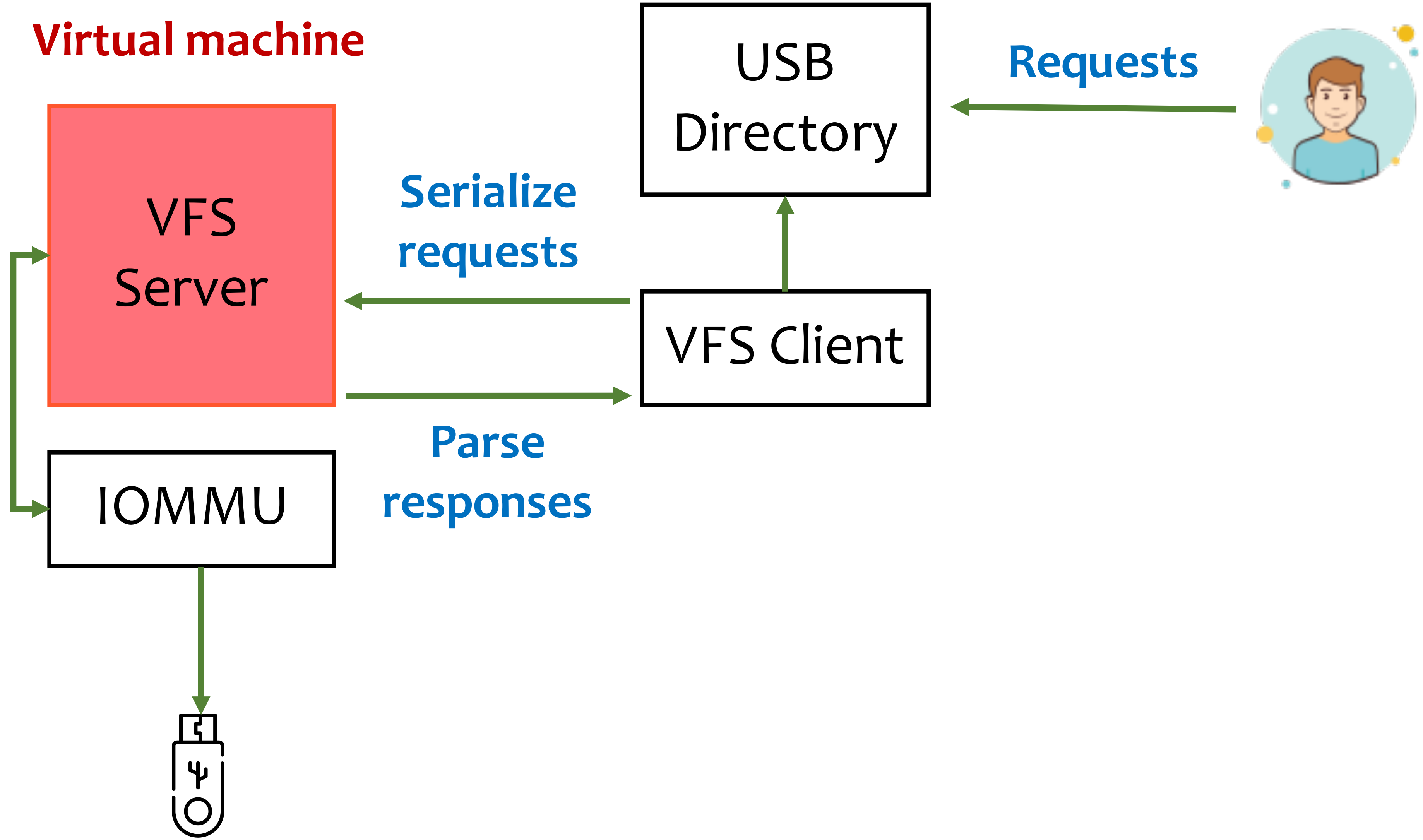


①Confidential data might be stolen

②Files transferred might be tampered

③Issue malformed file system responses

Parsing errors



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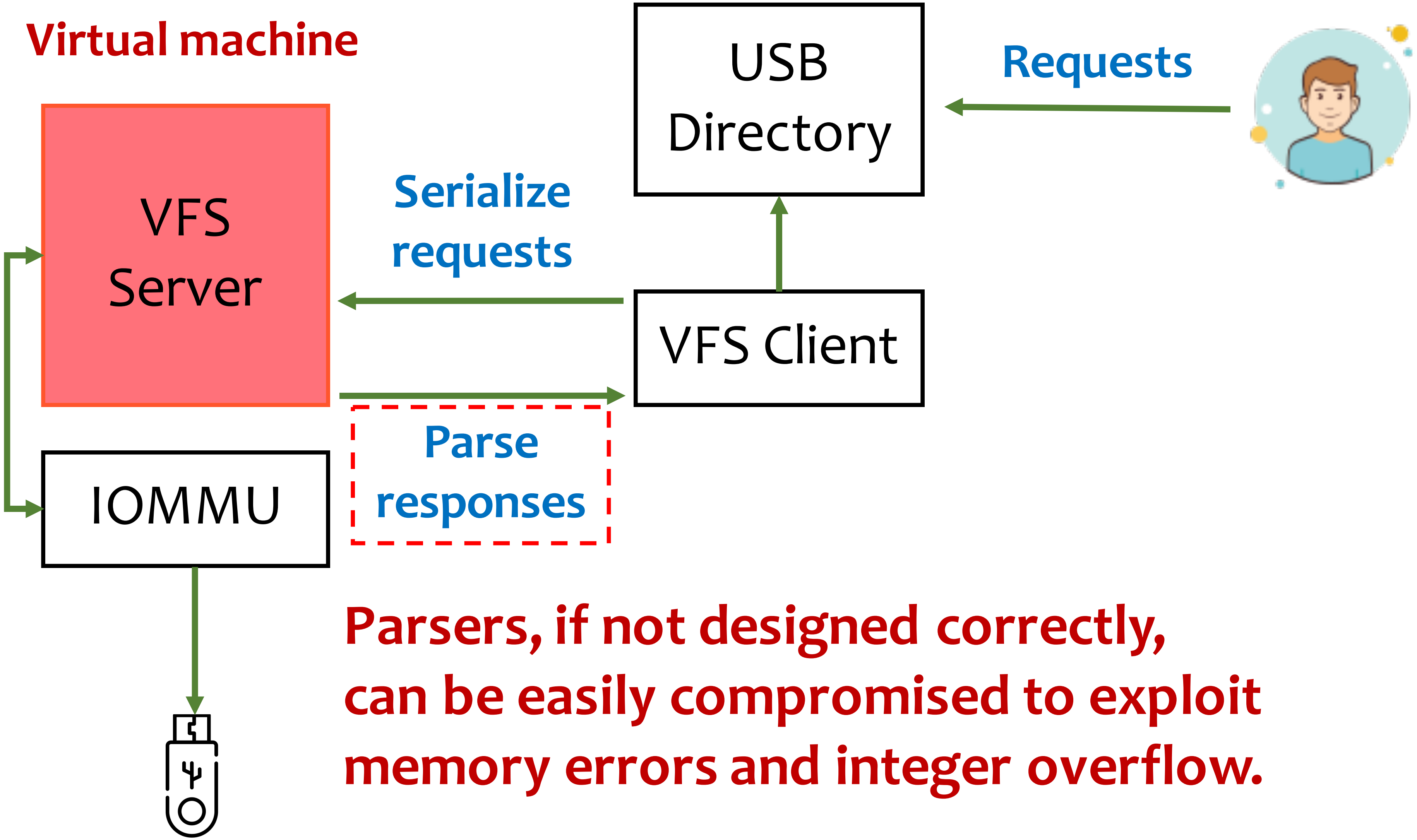

Parsers, if not designed correctly, can be easily compromised to exploit memory errors and integer overflow.

Agenda

- ◆ **How to address those challenges**
  - Optimizations
  - Encrypted communication
  - Formally verified serializer and parser

- ◆ **Preliminary evaluation**

- ◆ **Discussion & Conclusion**

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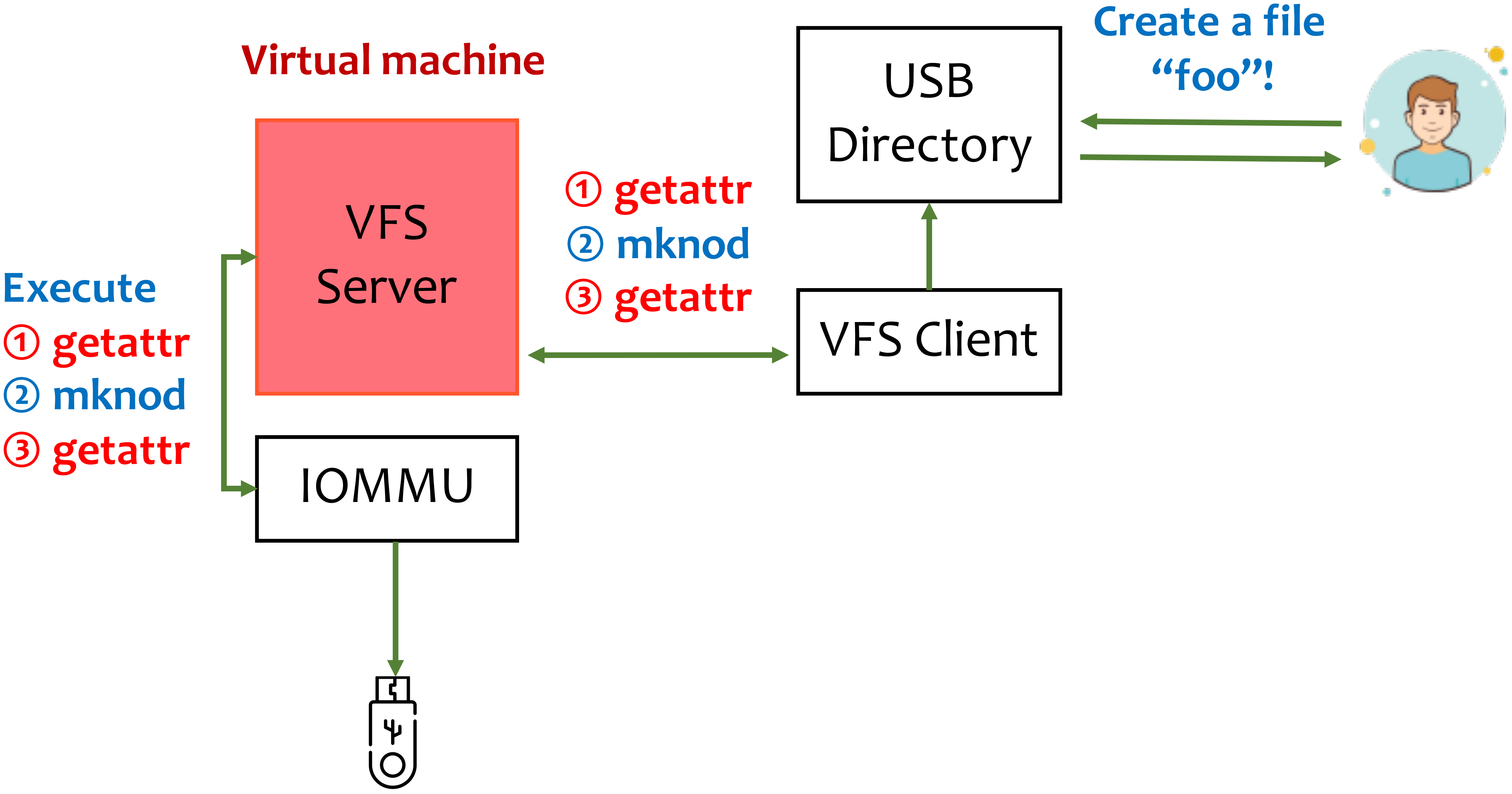
Caching metadata



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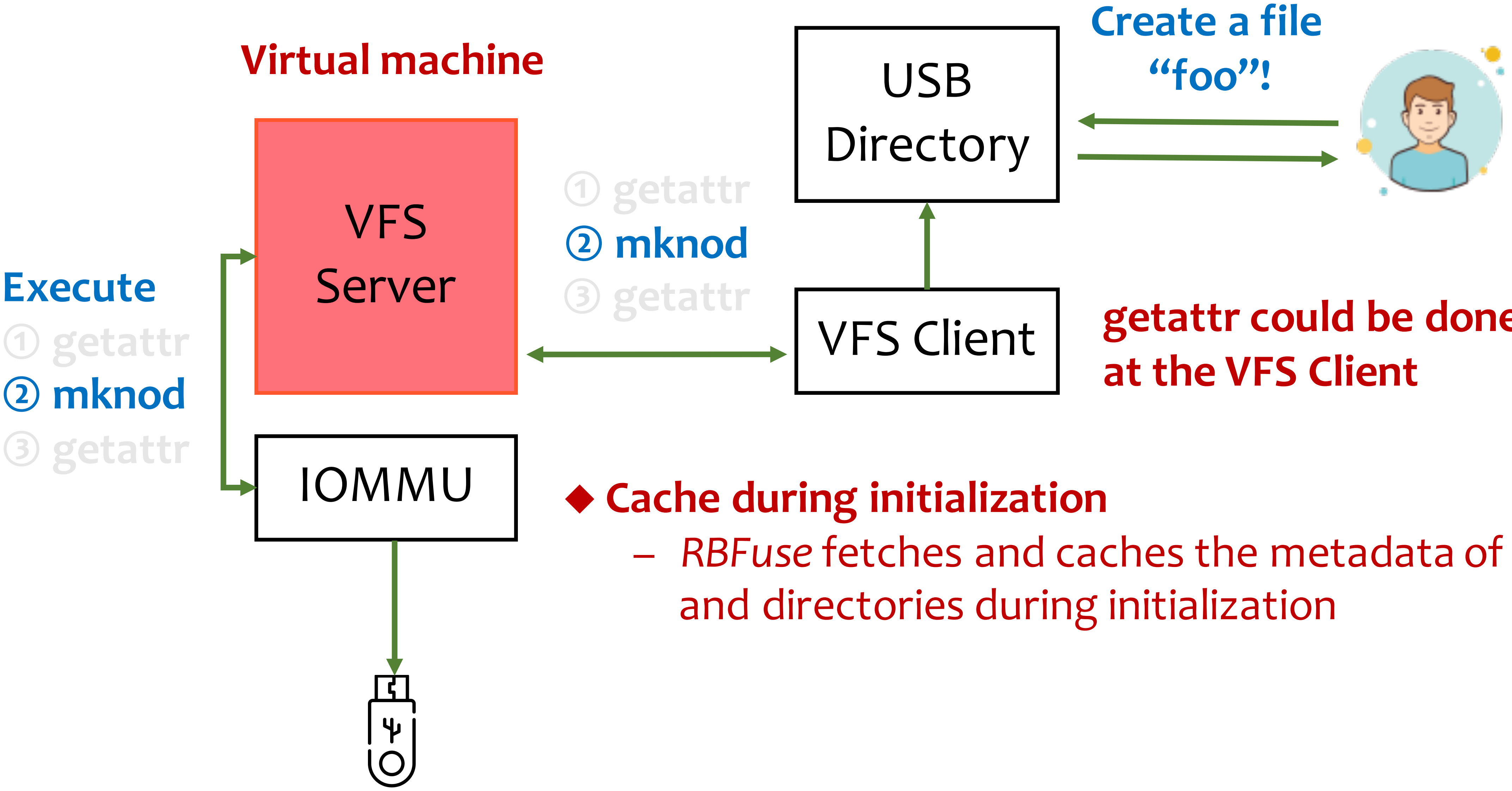
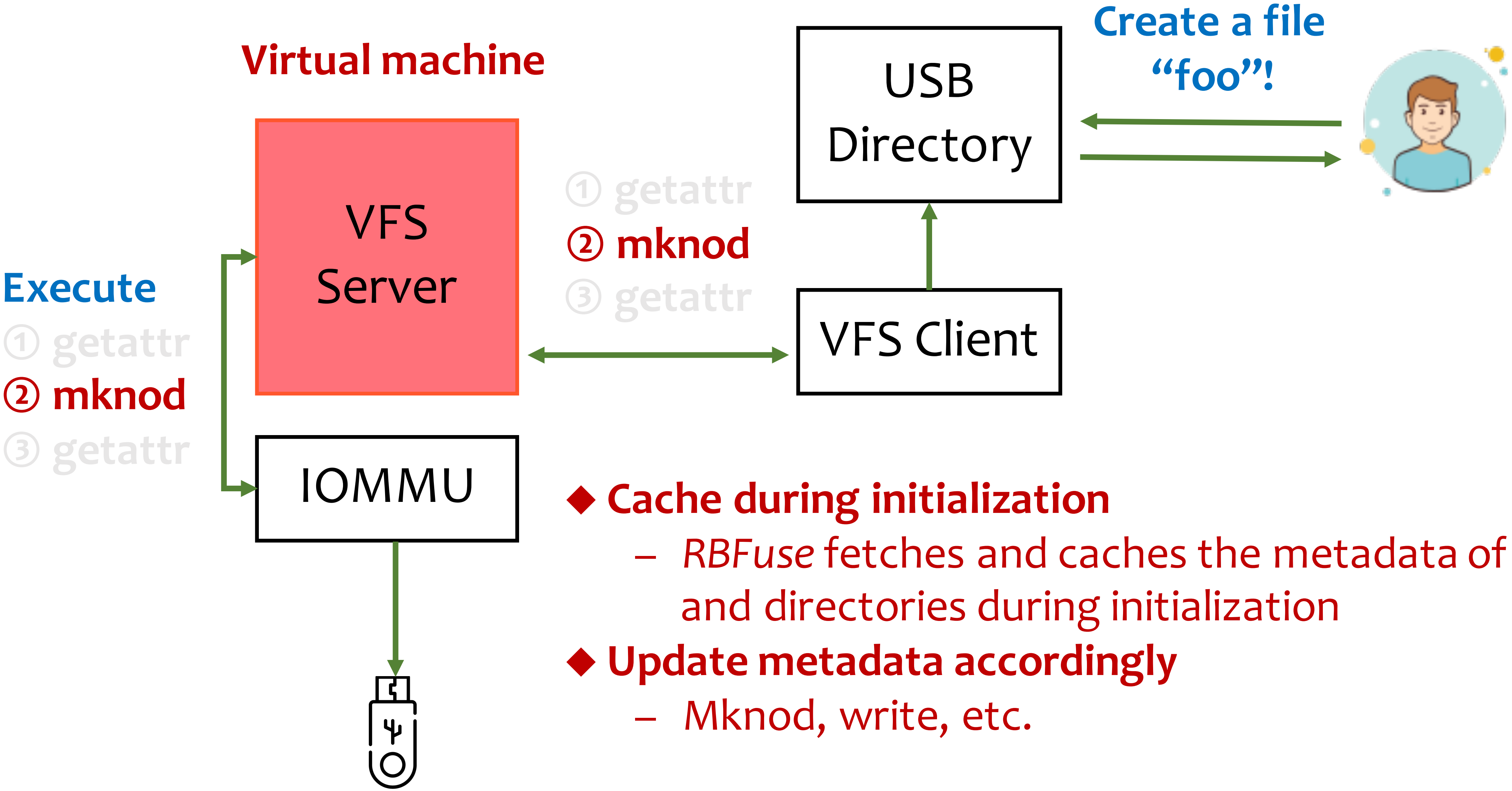


getattr could be done locally at the VFS Client

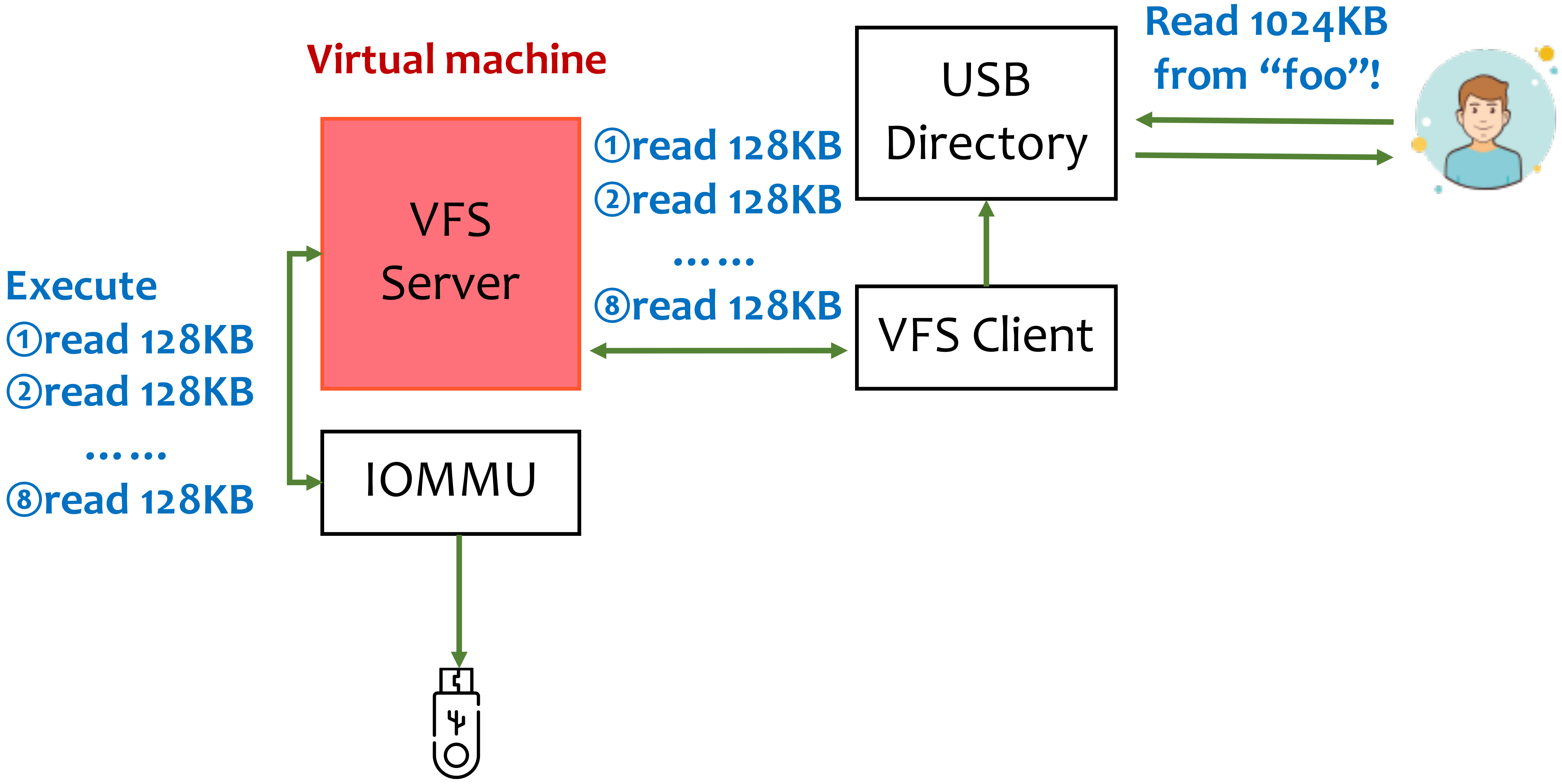
- **Cache during initialization**
  - *RBFuse* fetches and caches the metadata of all files and directories during initialization

Caching metadata



- ◆ **Cache during initialization**
  - – *RBFuse* fetches and caches the metadata of all files and directories during initialization
- ◆ **Update metadata accordingly**
  - – Mknod, write, etc.

Prefetching



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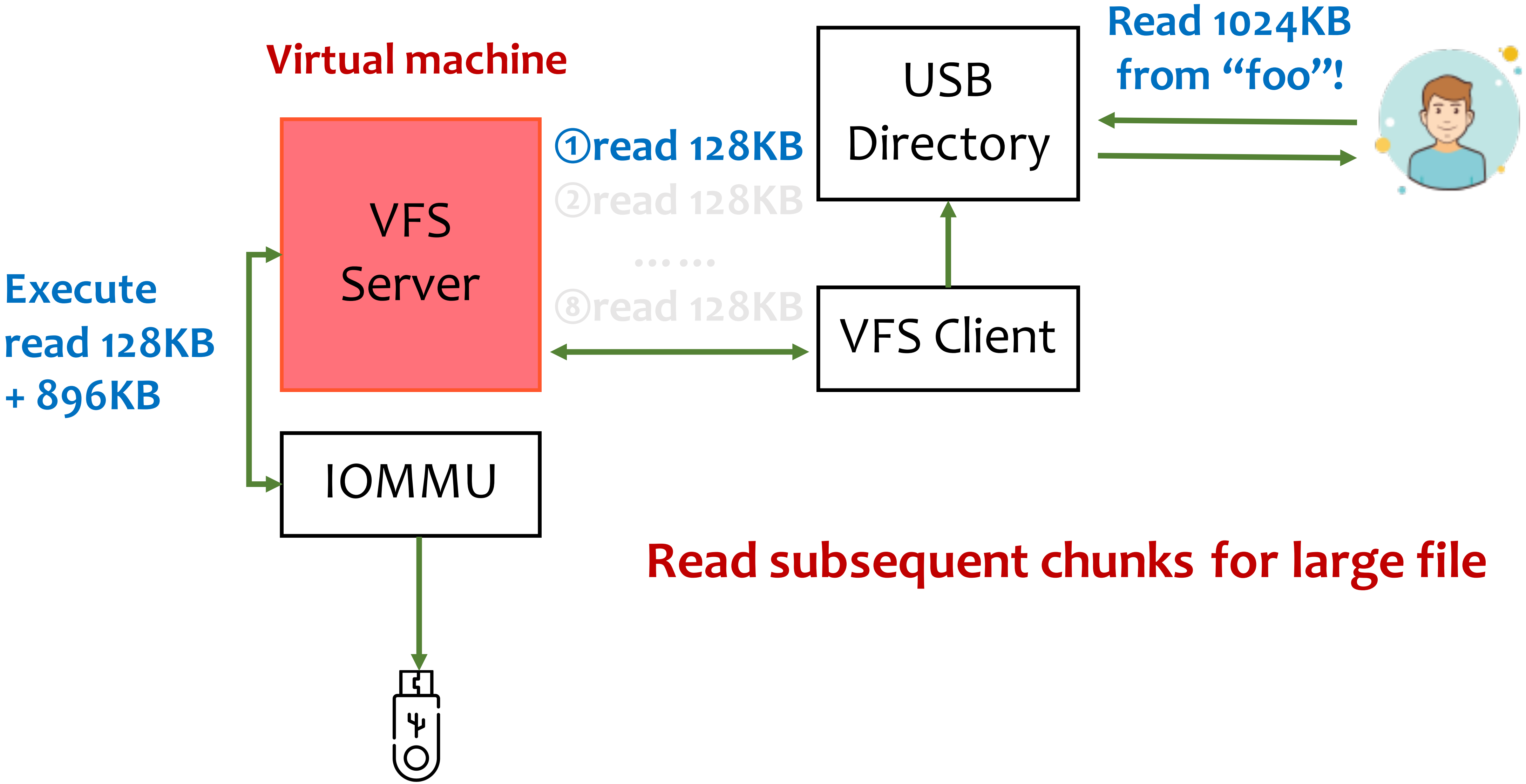

Read subsequent chunks for large file

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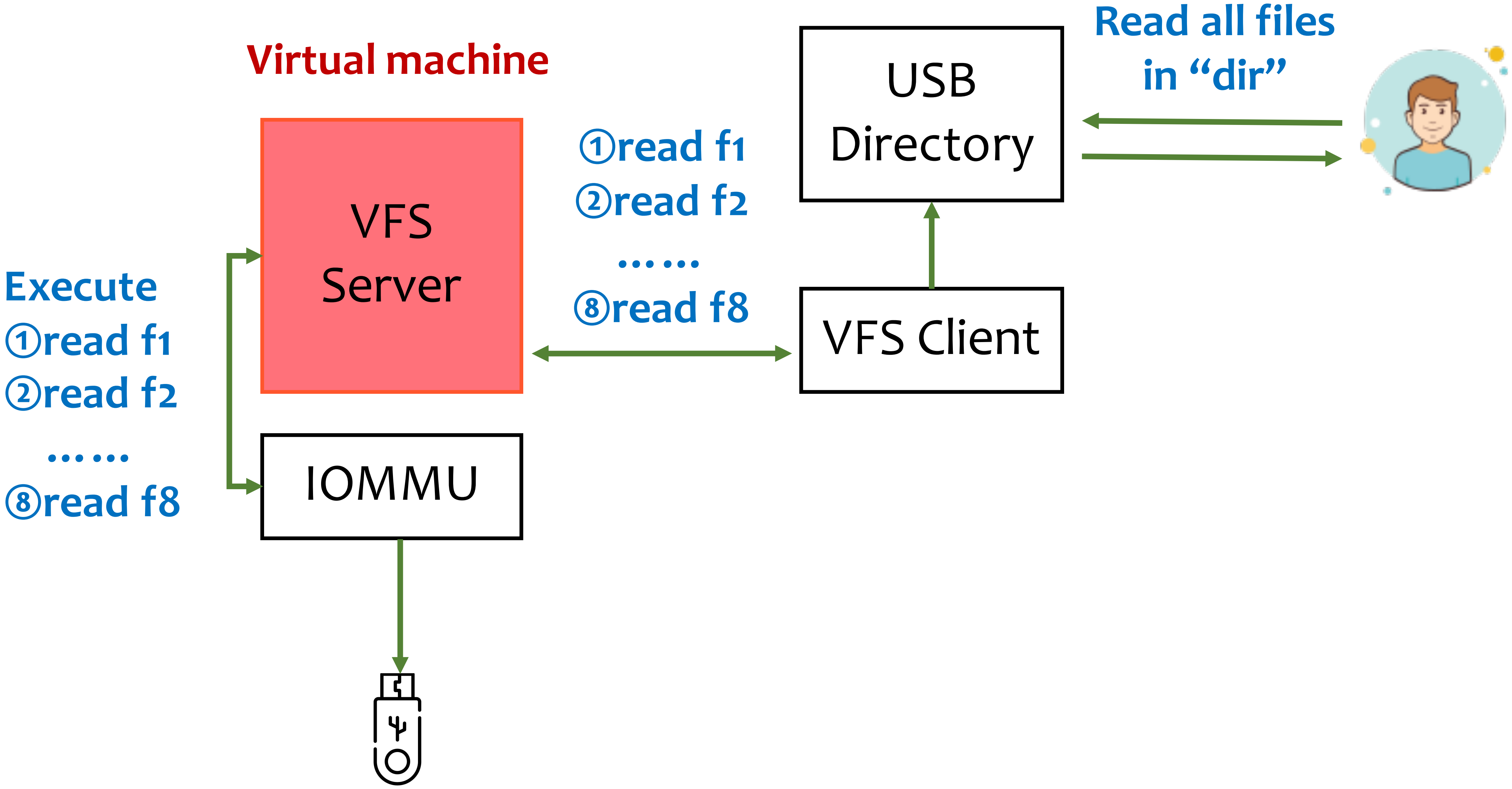


Virtual machine

VFS Server

IOMMU

Execute
①read f1
②read f2
……
⑧read f8

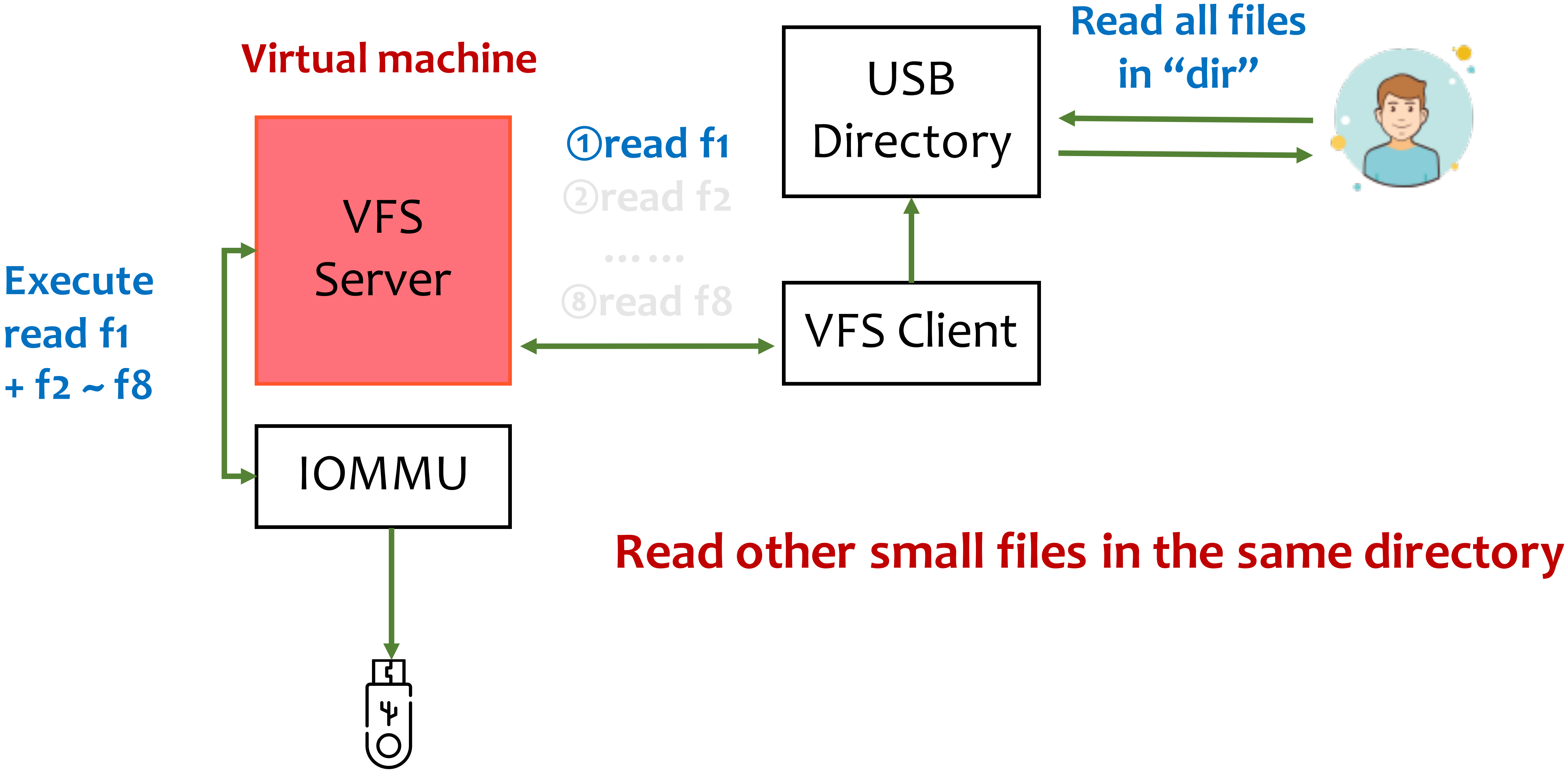
①read f1
②read f2
……
⑧read f8

USB Directory

VFS Client

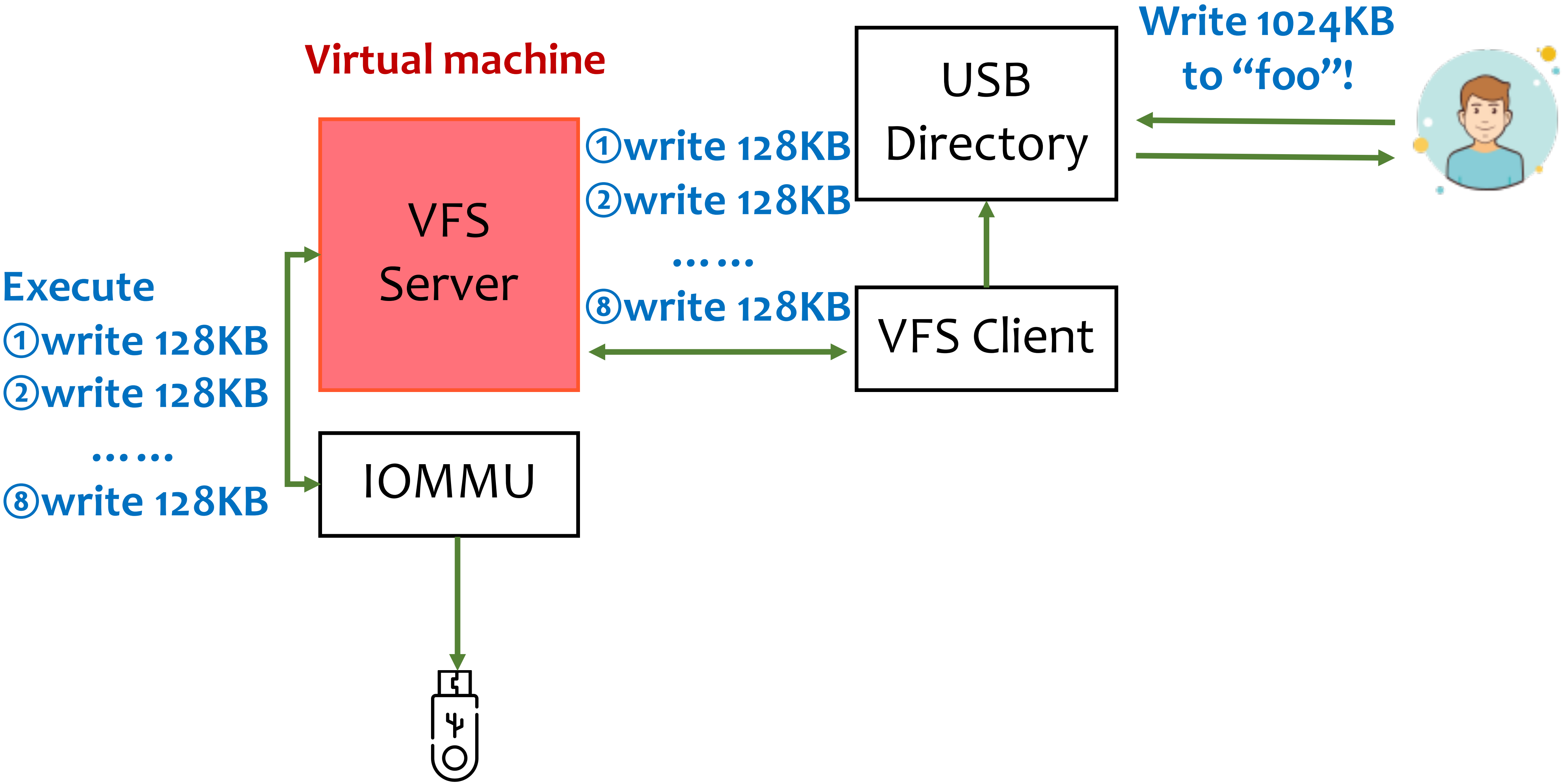
Read all files in "dir"

Prefetching



Read other small files in the same directory

Batching operations



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VFS Server

IOMMU

Execute
①write 128KB
②write 128KB
……
⑧write 128KB

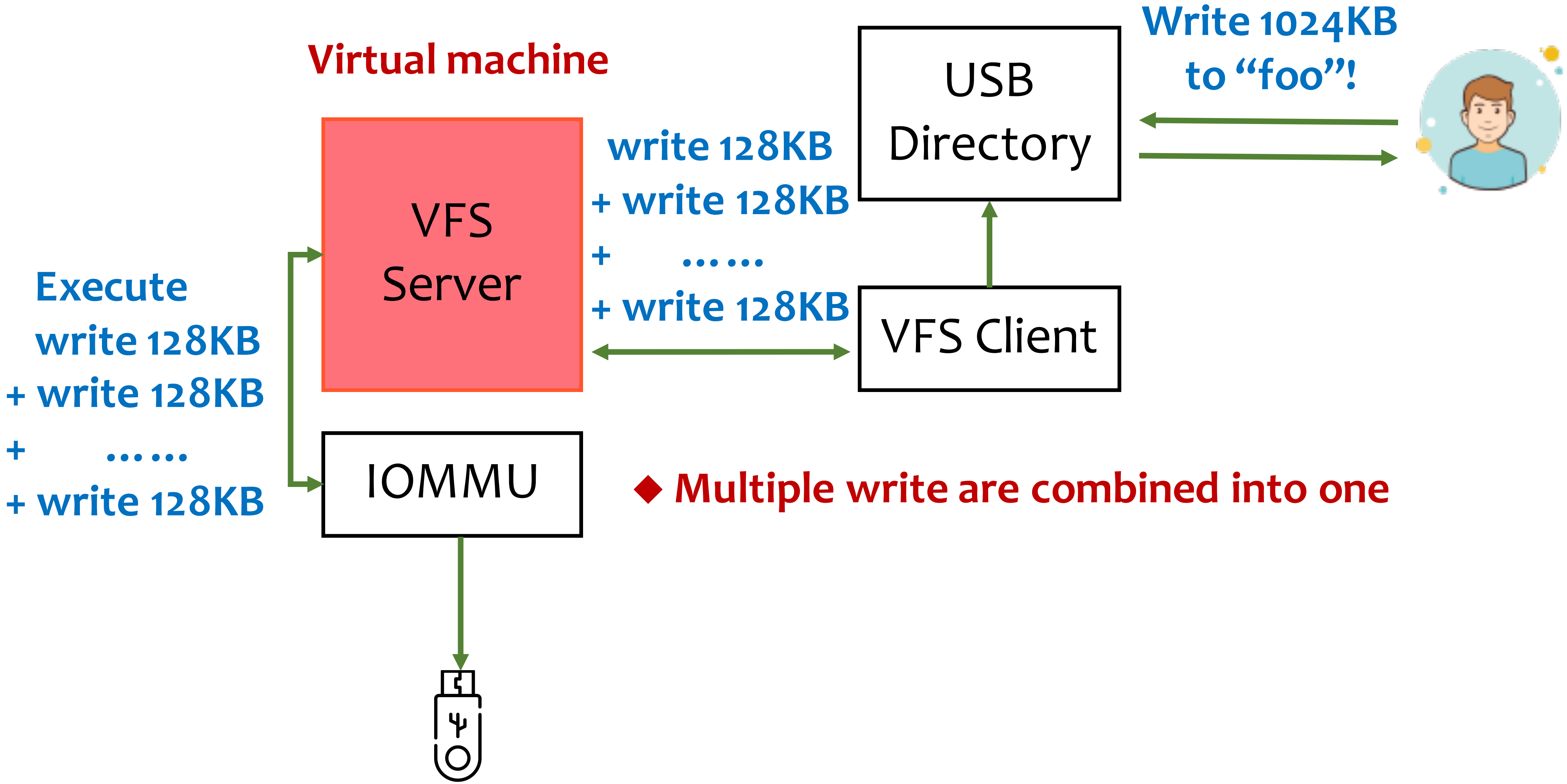
①write 128KB
②write 128KB
……
⑧write 128KB

USB Directory

VFS Client

Write 1024KB to “foo”!

Batching operations



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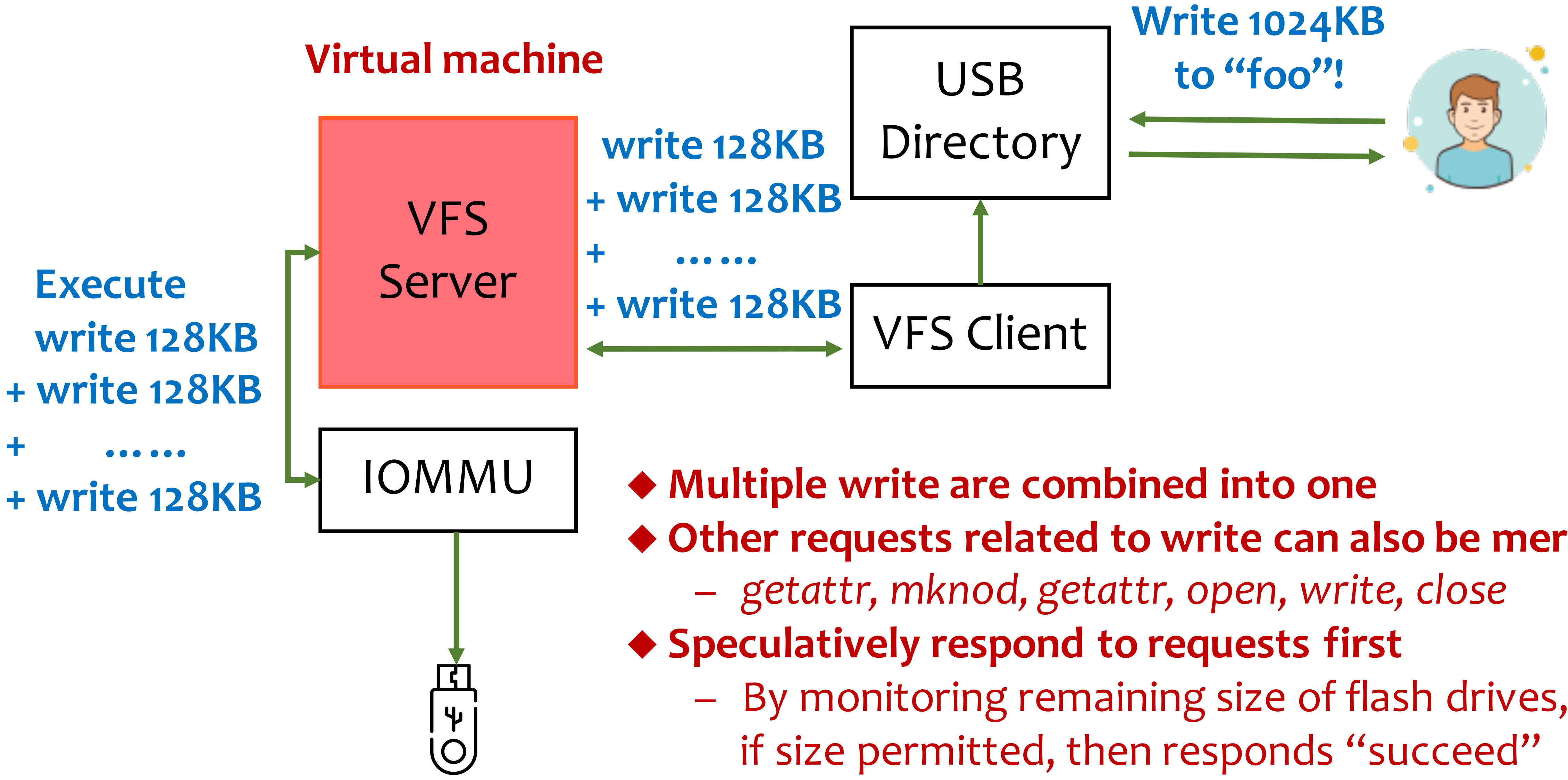

- ◆ **Multiple write are combined into one**
- ◆ **Other requests related to write can also be merged**
  - – *getattr, mknod, getattr, open, write, close*
- ◆ **Speculatively respond to requests first**
  - – By monitoring remaining size of flash drives, if size permitted, then responds "succeed"

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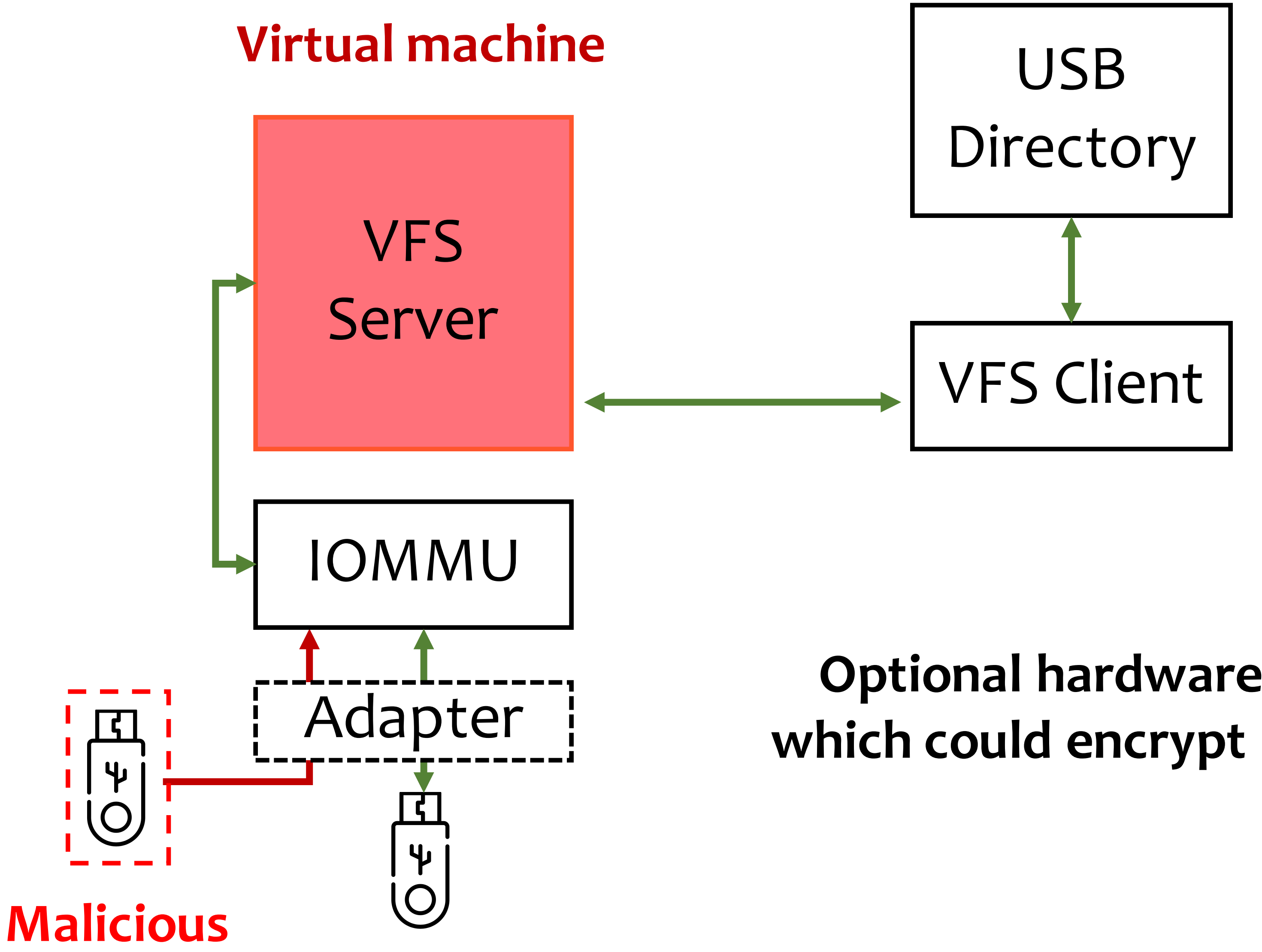
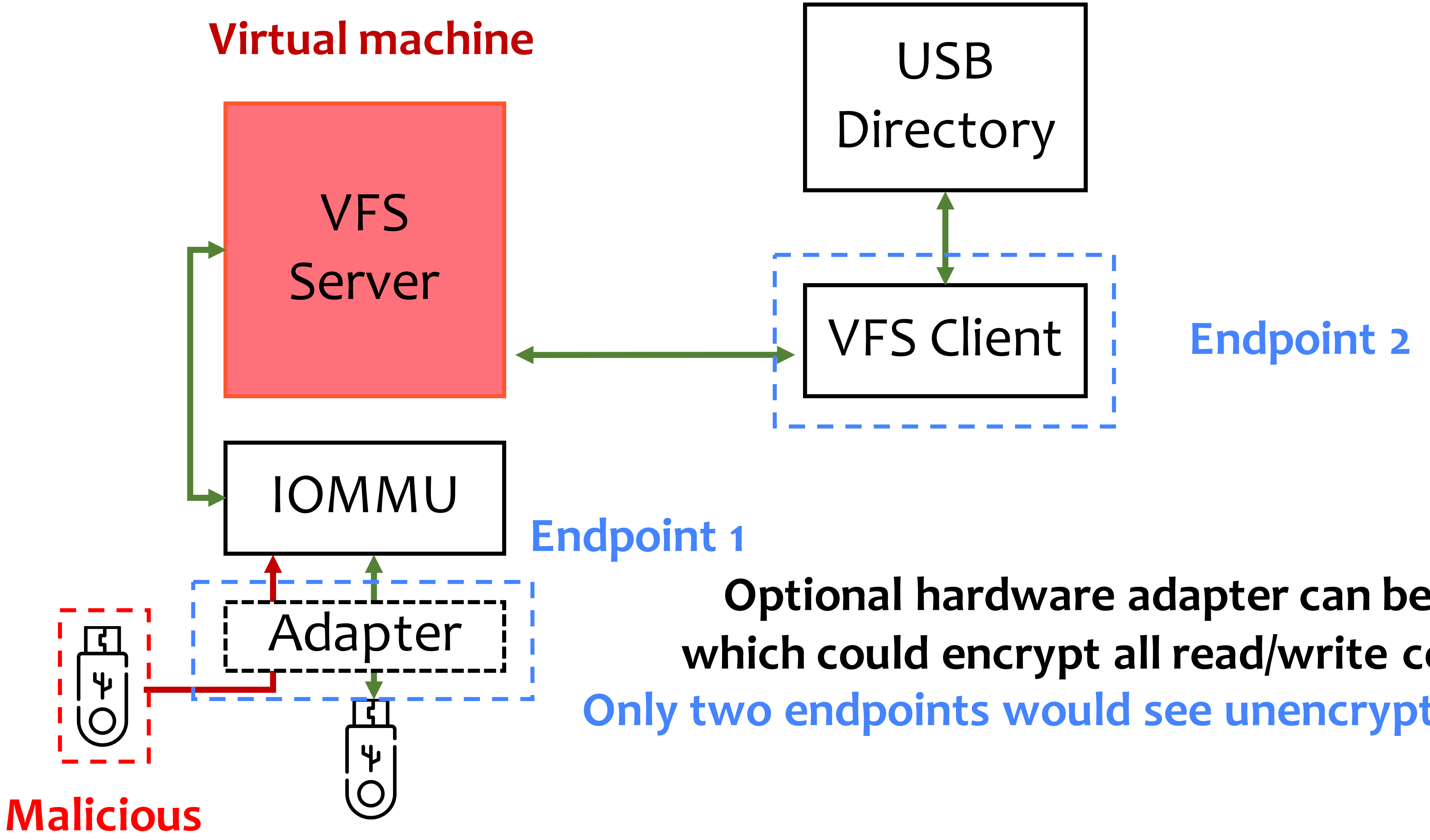
Encrypted communication



Optional hardware adapter can be used which could encrypt all read/write contents

Encrypted communication



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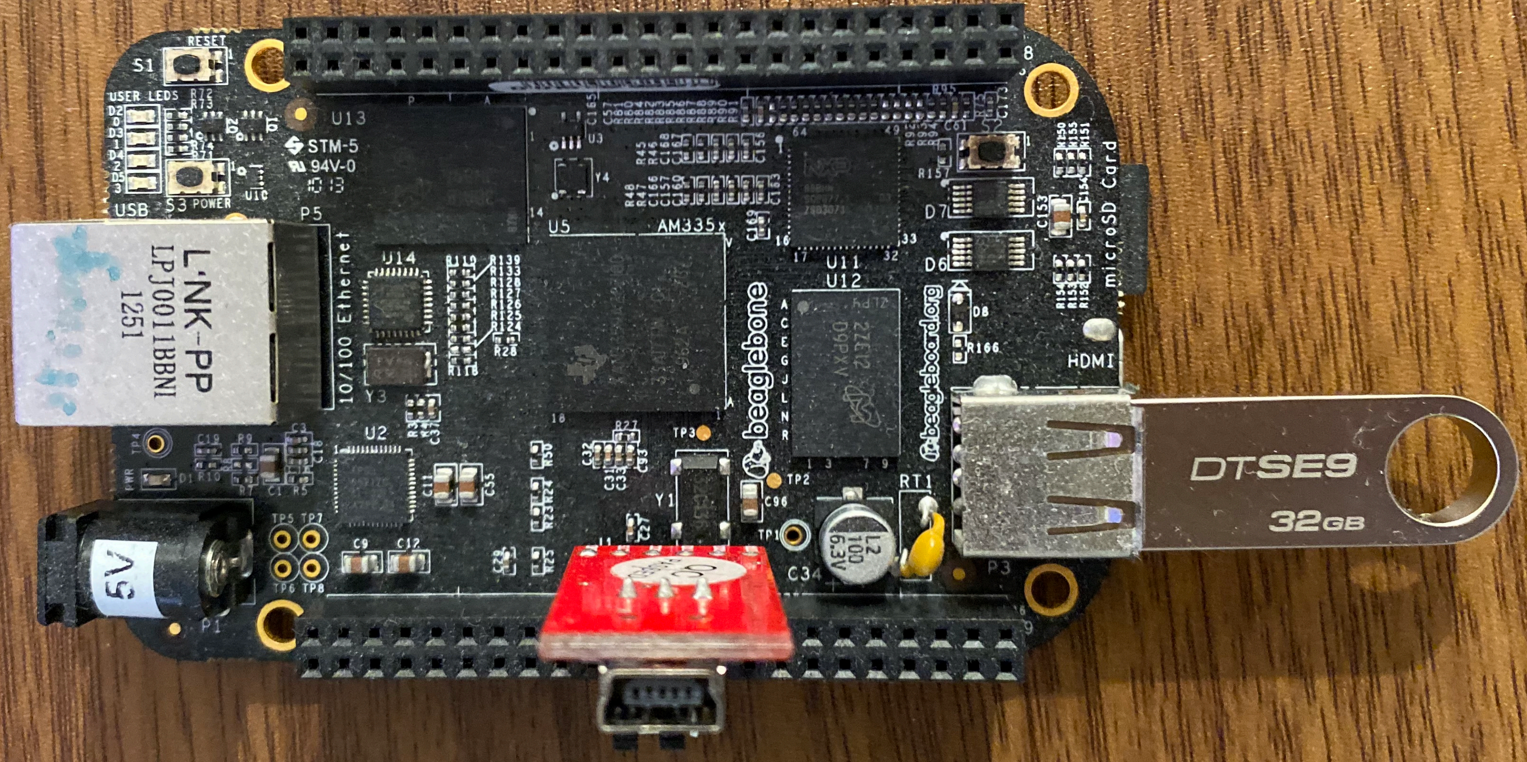
Only two endpoints would see unencrypted contents


RESET
S1
USER LEDS
USB
S3
POWER
U13
STM-5
94V-0
P5
L-NK-PP
LPJ0011BBNL
1251
10/100 Ethernet
U14
Y3
U2
U5
AM335x
U11
U12
beaglebone
beagleboard.org
microSD Card
HDMI
D7
D6
S2
Y1
TP1
TP2
TP3
C34
RT1
P3
P1
5V
DTSE9
32GB

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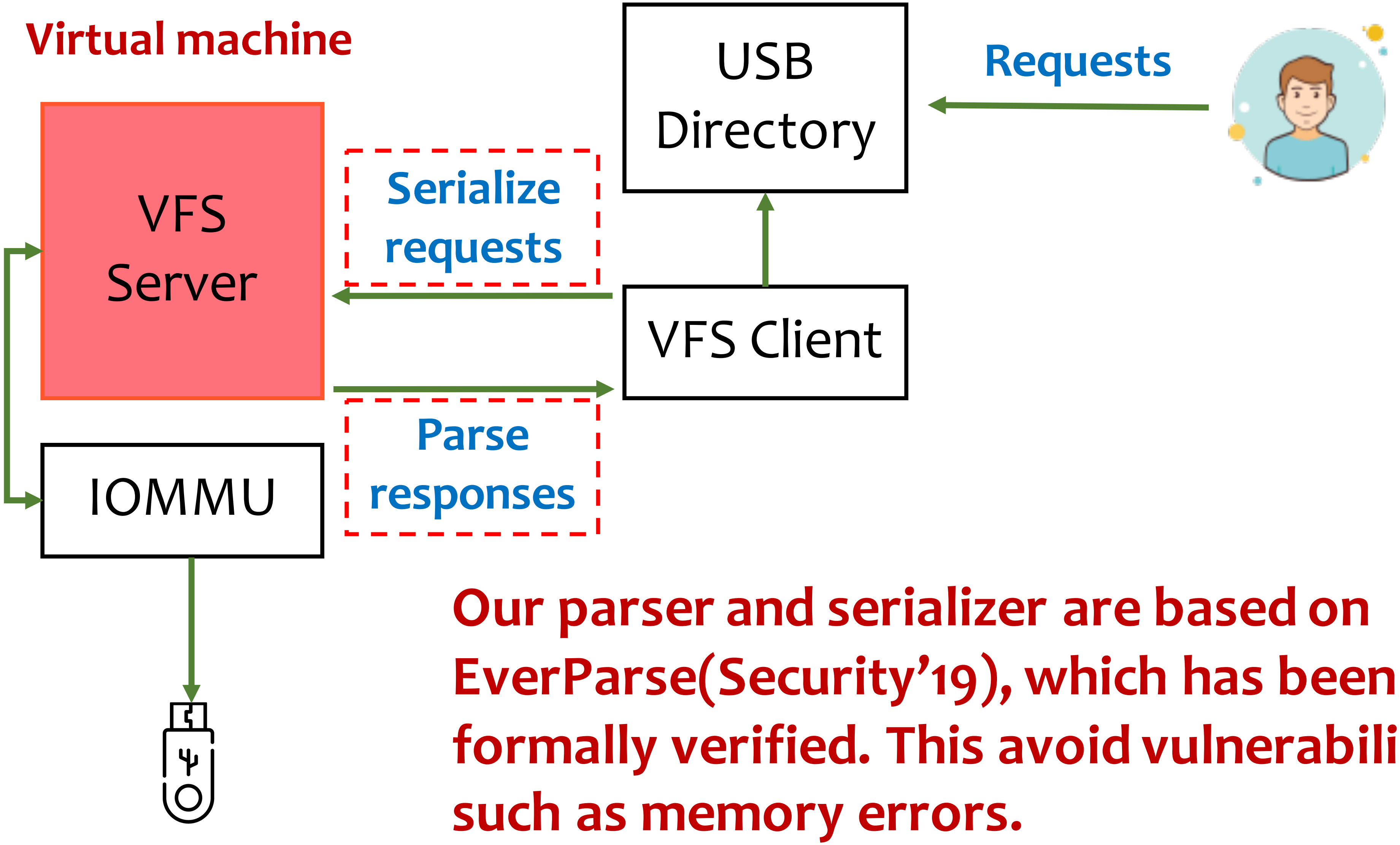
Formally verified serializer and parser



Our parser and serializer are based on EverParse(Security'19), which has been formally verified. This avoid vulnerabilities, such as memory errors.

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Experiment setup

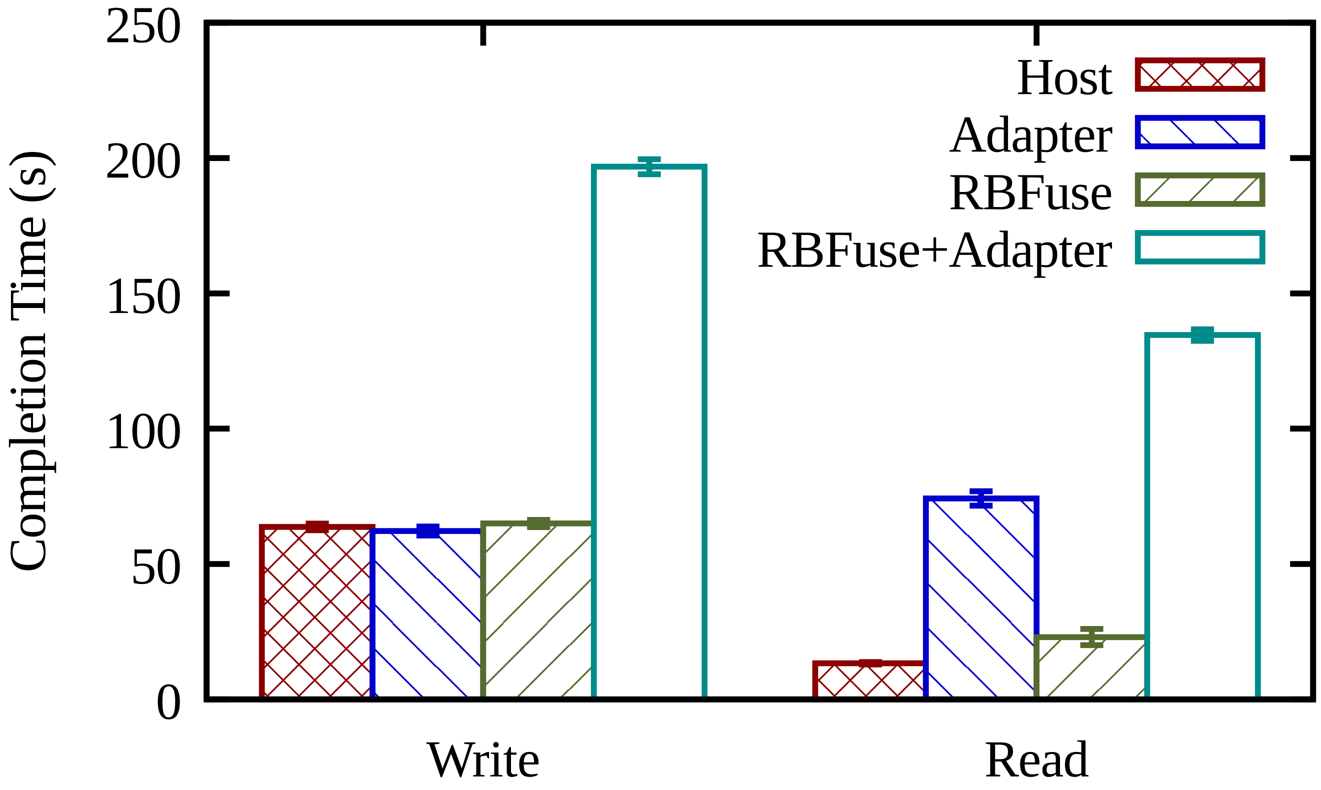
- ◆ For virtual machine we run Ubuntu 16.04 (Linux 4.15.0-45) on QEMU.
  Host machine is also Ubuntu 16.04 with KVM.

- ◆ Adapter for authentication and data encryption is built on a BeagleBone Black which runs Debian 9.1 (Linux 4.4.88-ti-r125).

- ◆ We used *filebench* to run our experiments.

- ◆ Our baseline is flash drive connected to the host without any of our mechanisms.

One large file (500MB)



Takeaway:

① *RBFuse* itself brings little overhead

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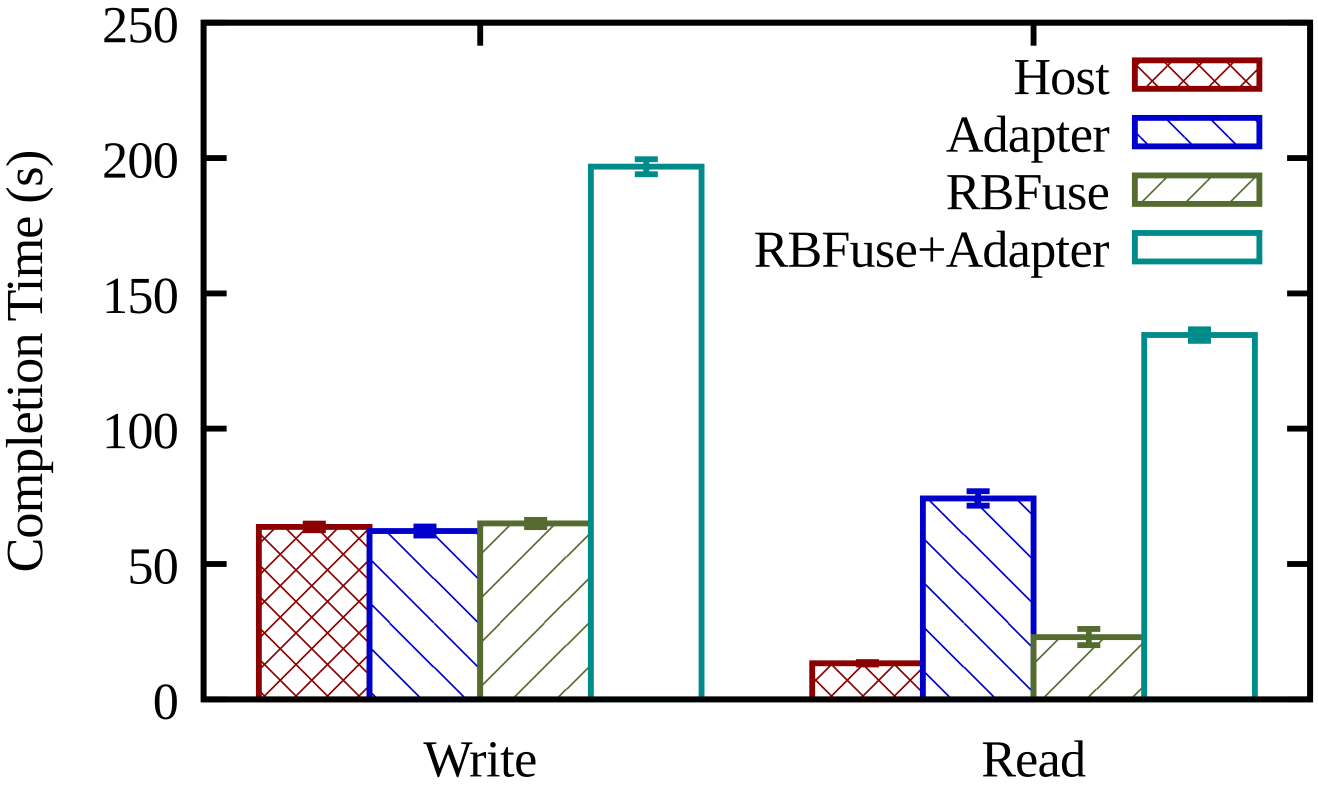

Takeaway:

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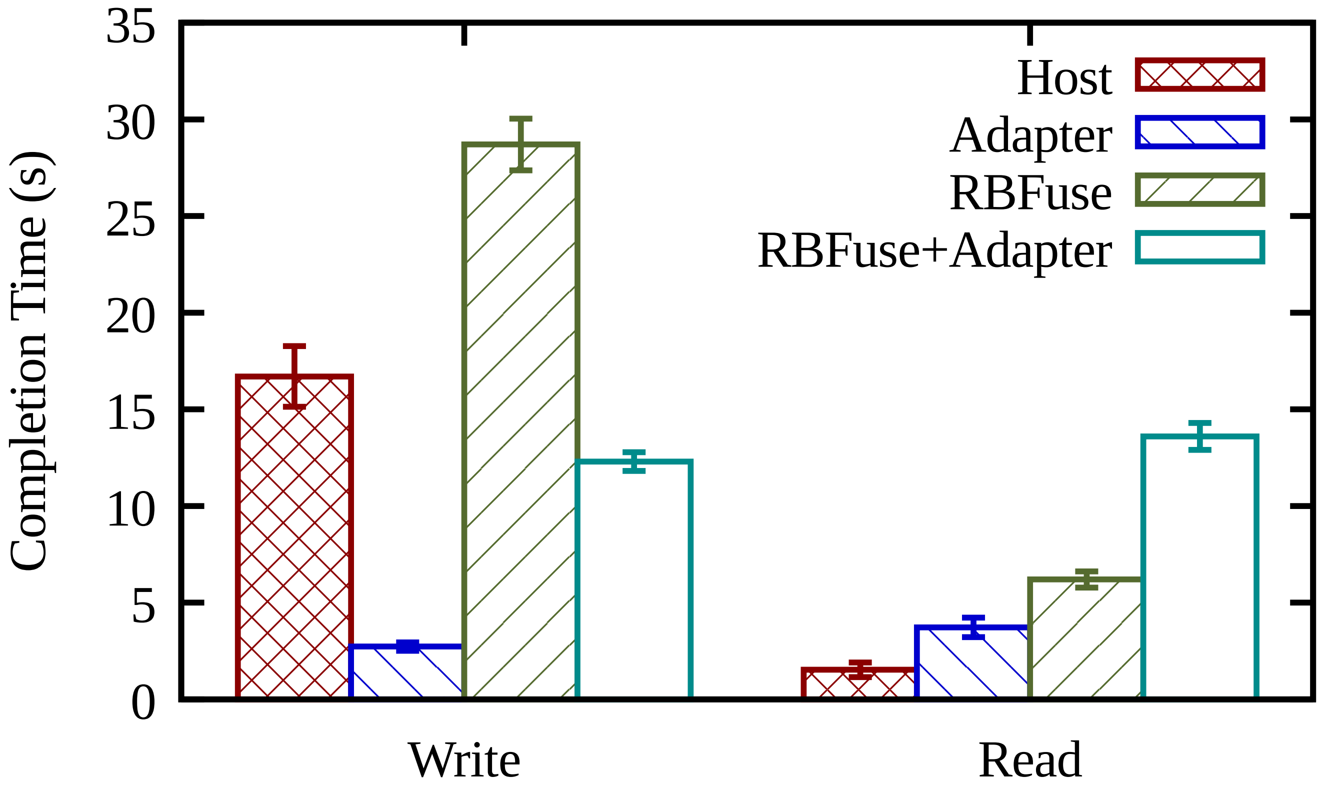
② *RBFuse* + adapter brings about 3x-10x overhead, due to the bad performance of adapter and increased roundtrips between flash drive and host

1,000 small files (16KB each)



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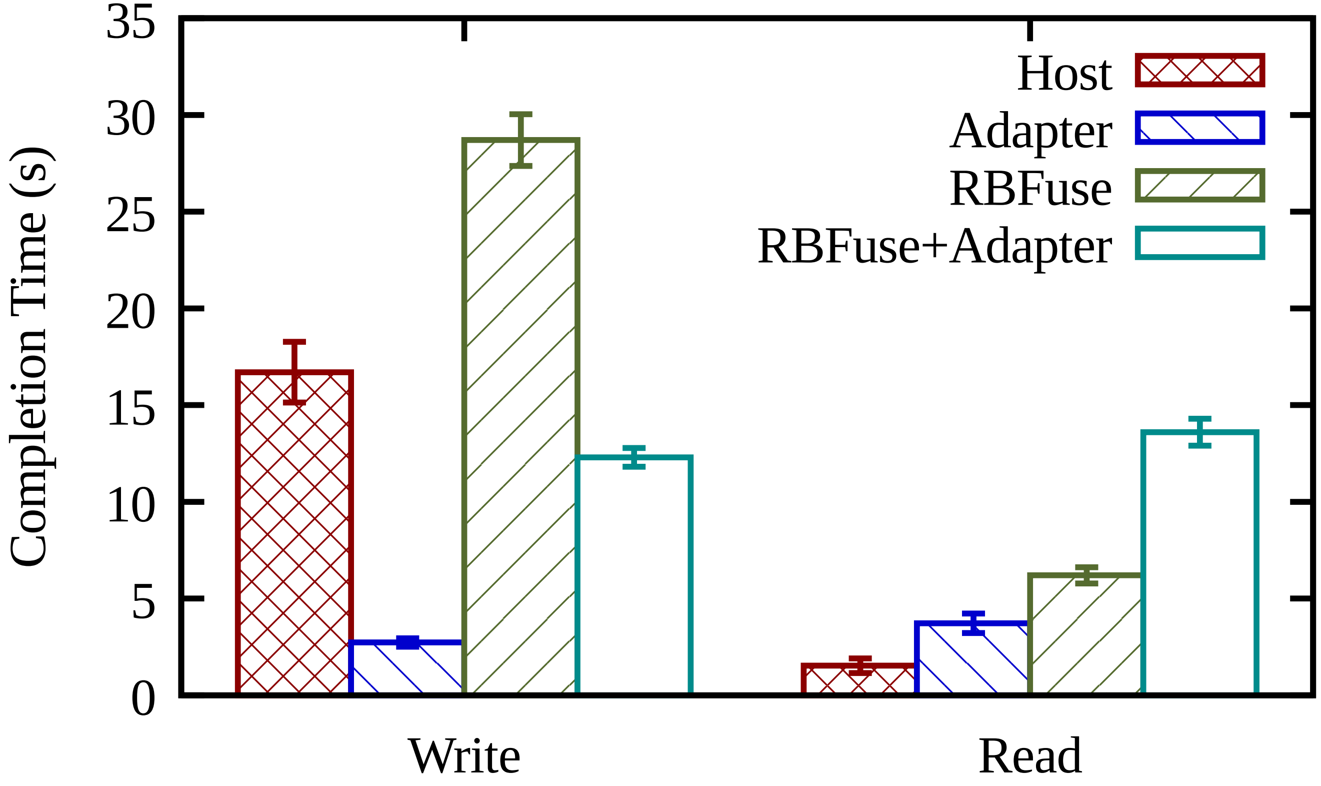

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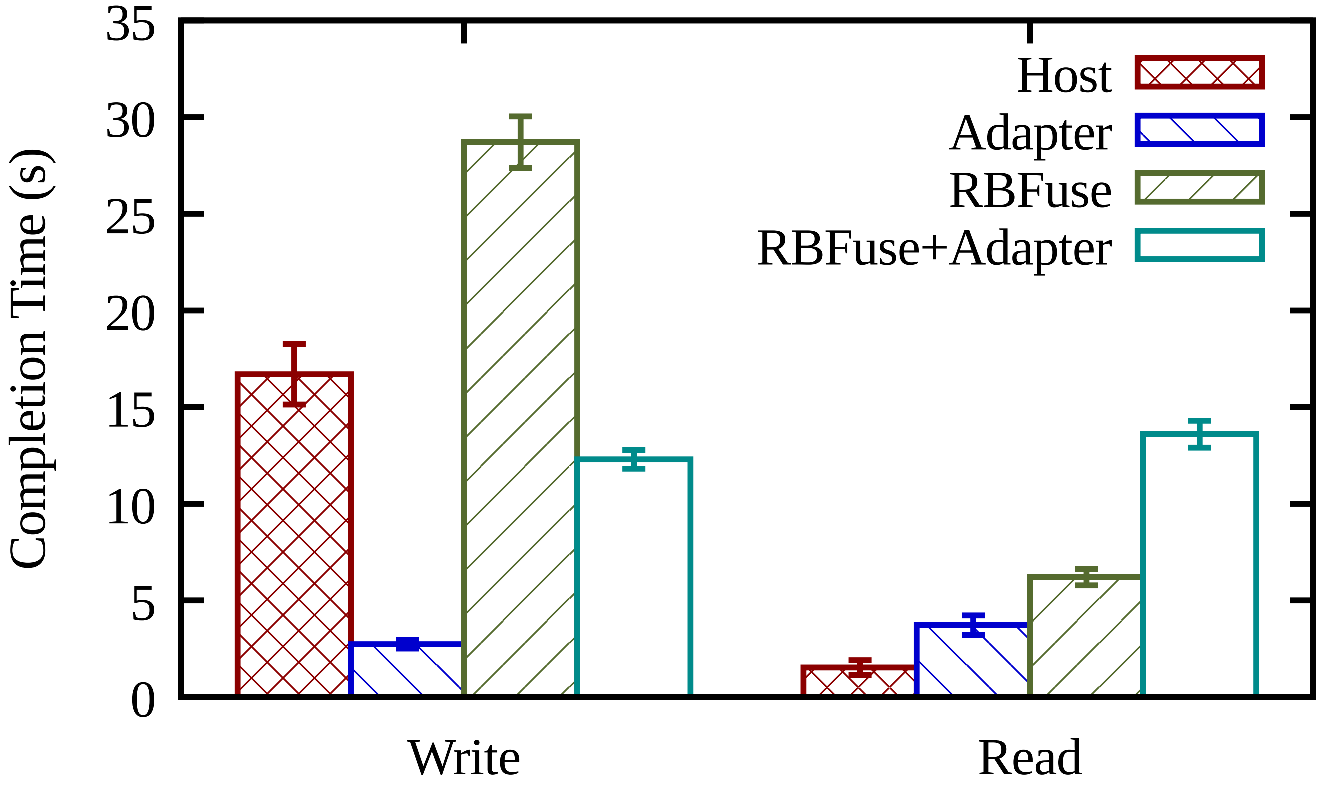
Note: adapter could be viewed as another machine with Debian



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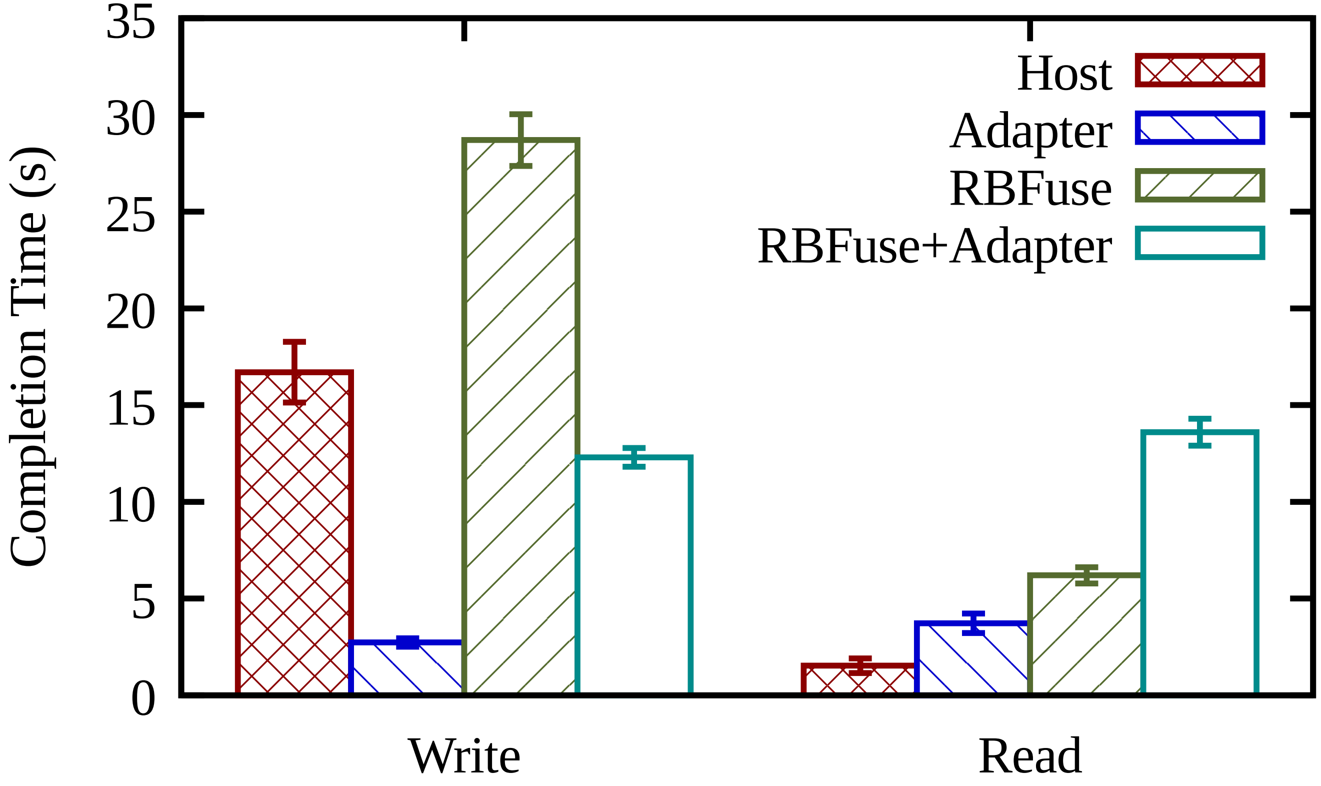

Takeaway:

① *RBFuse* itself brings 2x-4x overhead

② For *write*, *RBFuse* + adapter outperforms directly accessing due to better performance of adapter on this task

③ For read, *RBFuse* + adapter brings 8.8x overhead, due to that adapter itself would bring about 2x overhead

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Crash consistency test

- **We modified and ran crashmonkey (OSDI'18) on *RBFuse***
  - ext4
  - vfat

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open foo O_RDWR|O_CREAT 0777
fsync foo
checkpoint 1
close foo
```

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vfat and RBFuse on vfat would fail!

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fsync foo
checkpoint 1
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```

Hydra (SOSP'19):
Parent directory of foo
need to be ***sync***

vfat and RBFuse on vfat would fail!

Previous file system fuzzing

- Janus (S&P’19): two-dimensional input fuzzing

File system

User(Client)

Previous file system fuzzing

- ◆ **Janus (S&P’19): two-dimensional input fuzzing**

Image fuzzing

File system

User(Client)

Previous file system fuzzing

- Janus (S&P'19): two-dimensional input fuzzing

Image fuzzing

File system

Client program fuzzing

User(Client)

Server side fuzzing

- We assume the (file system) server is malicious

File system
Server
(flash drive)

User(Client)

Server side fuzzing

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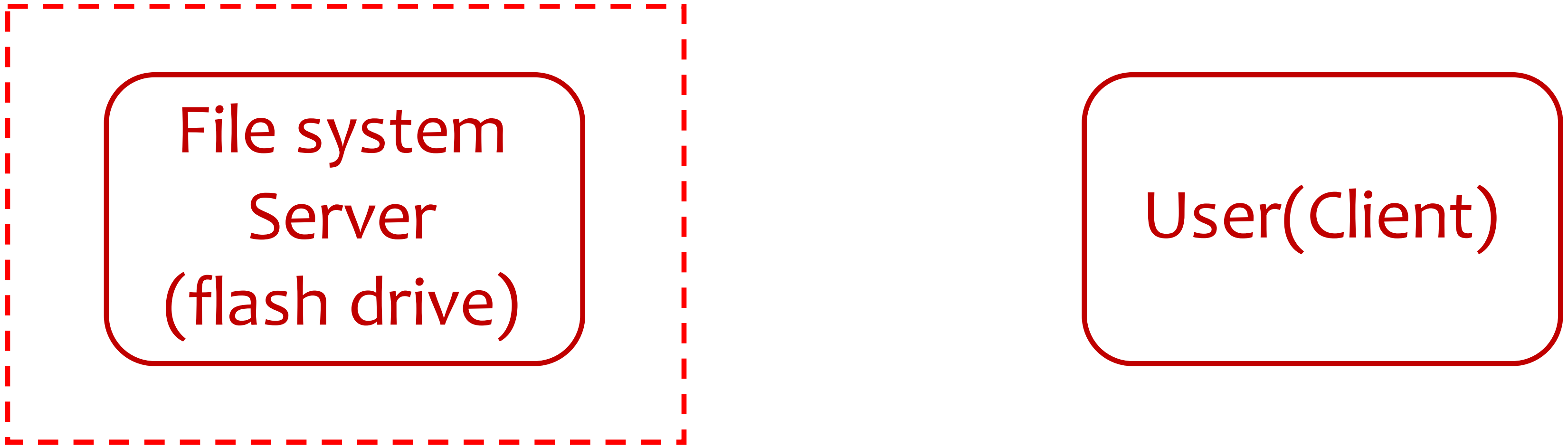

Malicious messages fuzzing

Formal verification

- **VFS interface is small, has better-defined semantics than USB**

- **Formal verification on our system**
  - Getting the virtual file system interface “right”

Conclusion

- **We propose *RBFuse*, which is a file system that accesses flash drives without interacting with the USB stack on the host machine with reasonable overhead**

- **Discussion**
  - Crash consistency test for *RBFuse*
  - Server side fuzzing
  - Formal verification

Thank you! Any questions or suggestions?

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