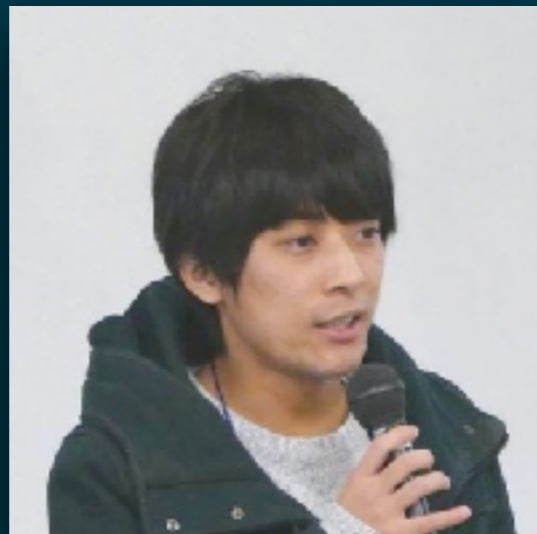# Noah

Hypervisor-Based Darwin Subsystem for Linux

Takaya Saeki, Yuichi Nishiwaki

Self Introduction

Noah Development Team

Takaya Saeki

Yuichi Nishiwaki

They both are graduate students at the University of Tokyo. They are developing Noah in their free time.

Noah was selected one of MITOH projects, which is a financial assistance program by the government of Japan for outstanding young programmers

Noah

- A middleware that runs
  unmodified Linux ELF applications on macOS

- Reduce cost of creating / waiting for mac OS port of
  Linux apps

- Accomplish it by special hypervisor. Load ELF
  binary into VM and let it run instead of kernel, trap
  system calls from it by hypervisor, and translate
  them to corresponding system calls on macOS.

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We discuss the architecture in detail later!

Short Demo;
What it looks like

Agenda

- What is Noah (Done!)

- **<u>Background</u>**

- Noah in Detail

  - Architecture Overview

  - Advantages of Noah Architecture

  - Subsystem Implementation

    - Memory management, VFS, and the other

  - Current Implementation Status and Performance

- Related Technologies and Comparison
(Windows Subsystem for Linux, Linuxulator, and so on)

- Their Possible Impact on Cross Platform Development

Background

Linux

- One of the most important operating systems today

- Most popular OS for WEB servers

- <u>Many apps and middleware come from the Linux ecosystem, and they are ported to other operating systems for developers</u>

Problem: Porting cost

Porting cost

- Many Linux applications are ported to macOS, FreeBSD, and Windows…

- But it takes time and effort!

- Windows decided to have Linux compatibility layer called "Windows Subsystem for Linux" in 2016 to benefit from the Linux ecosystem directly

- FreeBSD also already has Linux compatibility layer

- macOS does not have Linux compatibility layer yet despite its large number of developers

- Noah fills the missing piece!
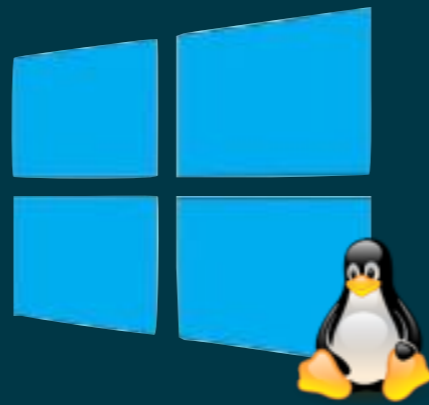
If major operating systems have Linux compatibility, developers don't have to port Linux applications nor wait for them to be ported

Architecture Overview of Noah

Architecture Overview

Noah's architecture consists of three components

1. VT-x Virtual Machines

   They have <u>NO</u> kernel inside it, but directly boot an ELF binary and let it run instead.
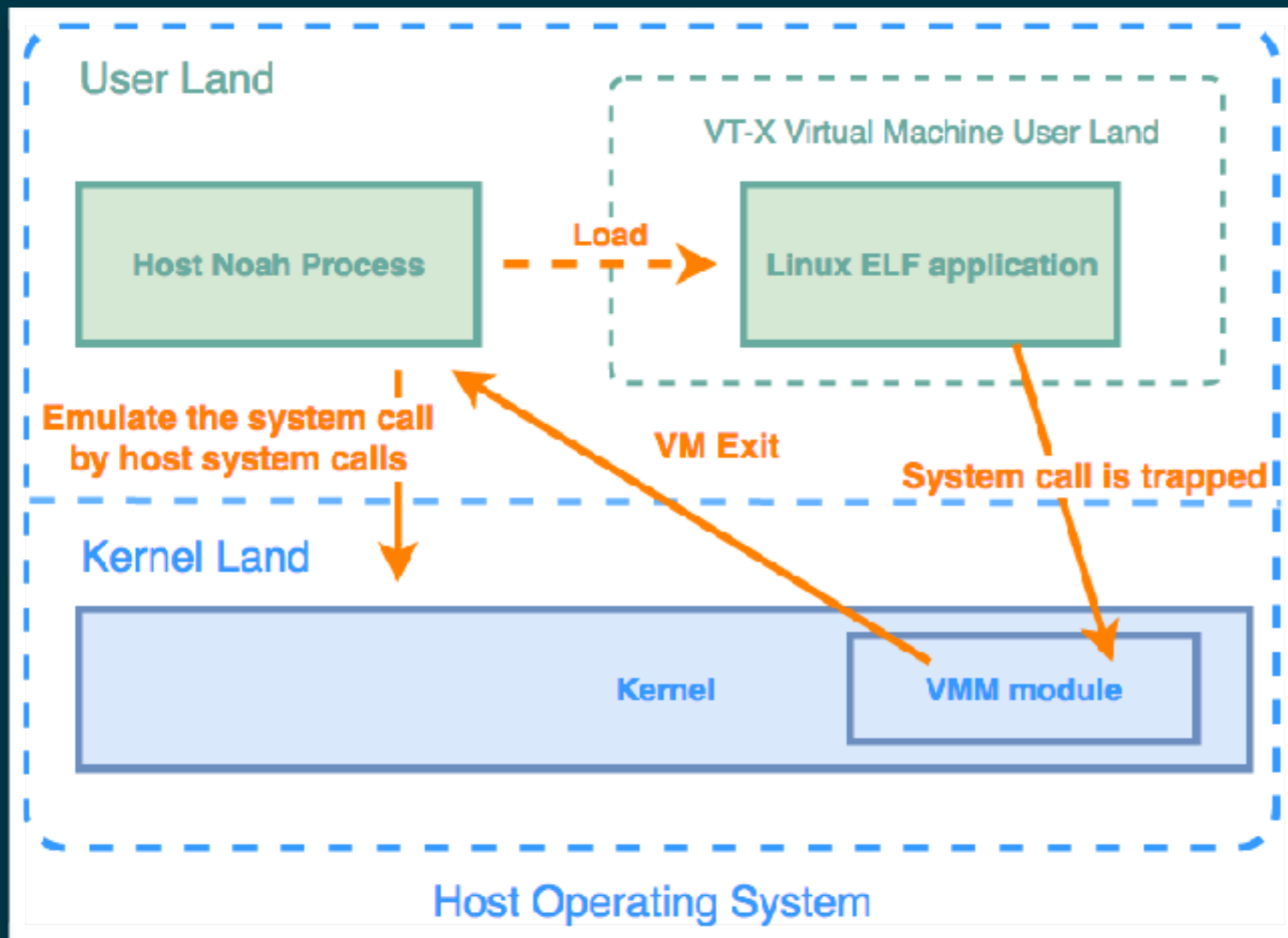
2. Host Noah Processes

   Processes that run on the host OS, which actually work as Linux compatibility layer

3. Virtual Machine Monitor module (VMM).

   Actually, not a part of Noah itself, but a kernel API of the host OS for virtualization. Apple Hypervisor Framework in macOS, KVM in Linux, for example.

Architecture Overview

User Land

VT-X Virtual Machine User Land

Host Noah Process

Linux ELF application

Load

Emulate the system call by host system calls

VM Exit

System call is trapped

Kernel Land

Kernel

VMM module

Host Operating System

1. Host Noah process launches a new VM and loads ELF inside it by ELF loader implemented in the host Noah process

2. The VM runs ELF in its virtualized userland

3. The ELF application fires Linux system calls when running

4. VMM module traps the system call and passes it to the host Noah process

5. Host Noah process emulates the behavior of Linux system call by host OS's system calls
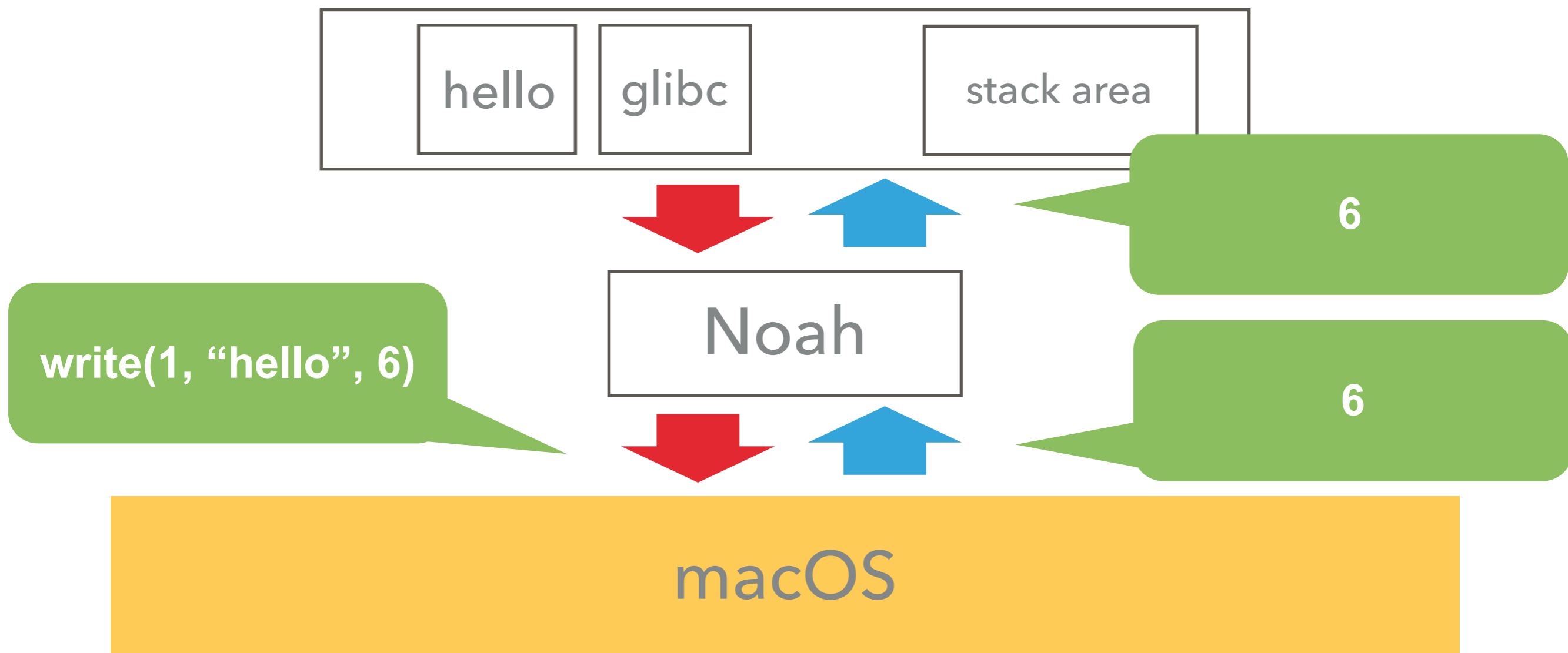
Architecture Overview
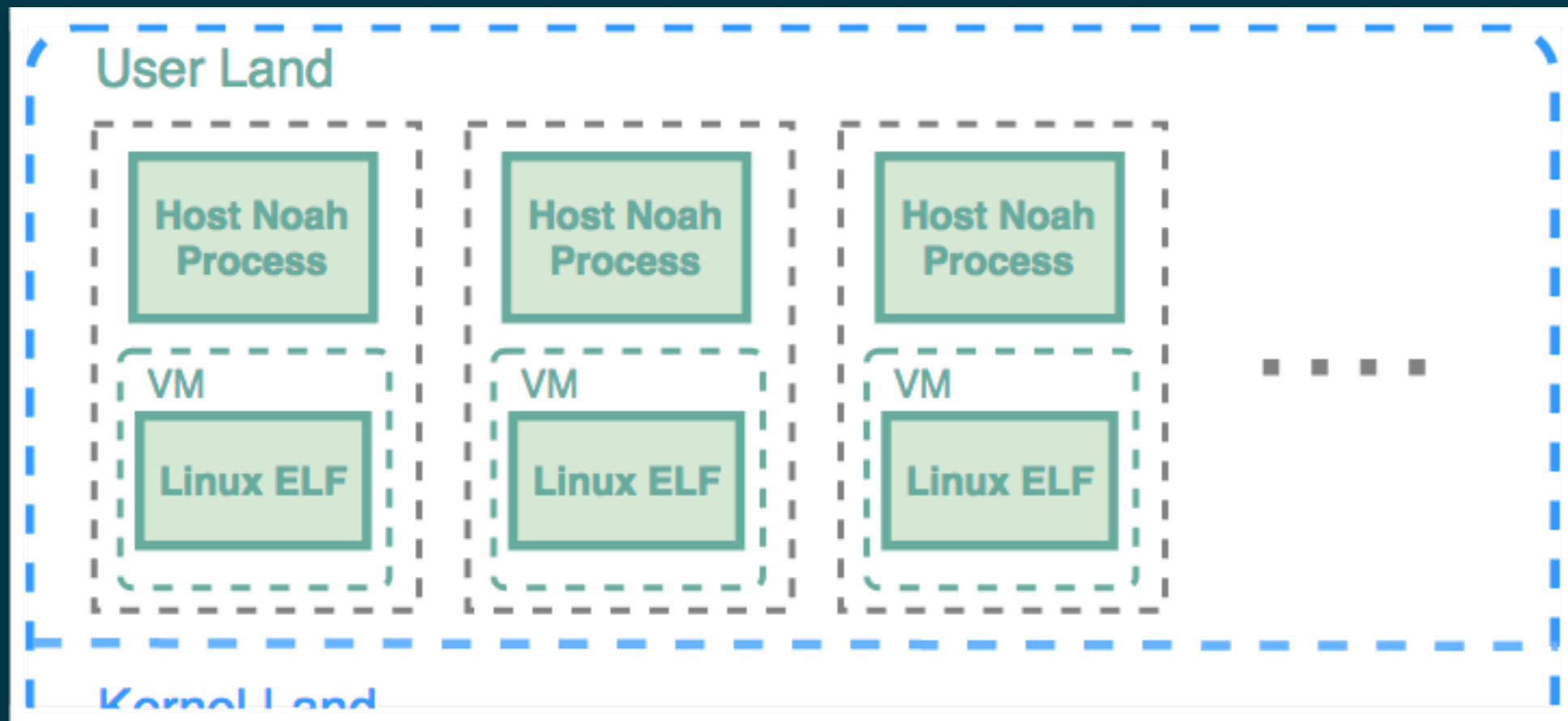
A pair of host Noah process and VM corresponds to a Linux application. So, when there are multiple Linux applications, there are also multiple pairs of host Noah process and VM.
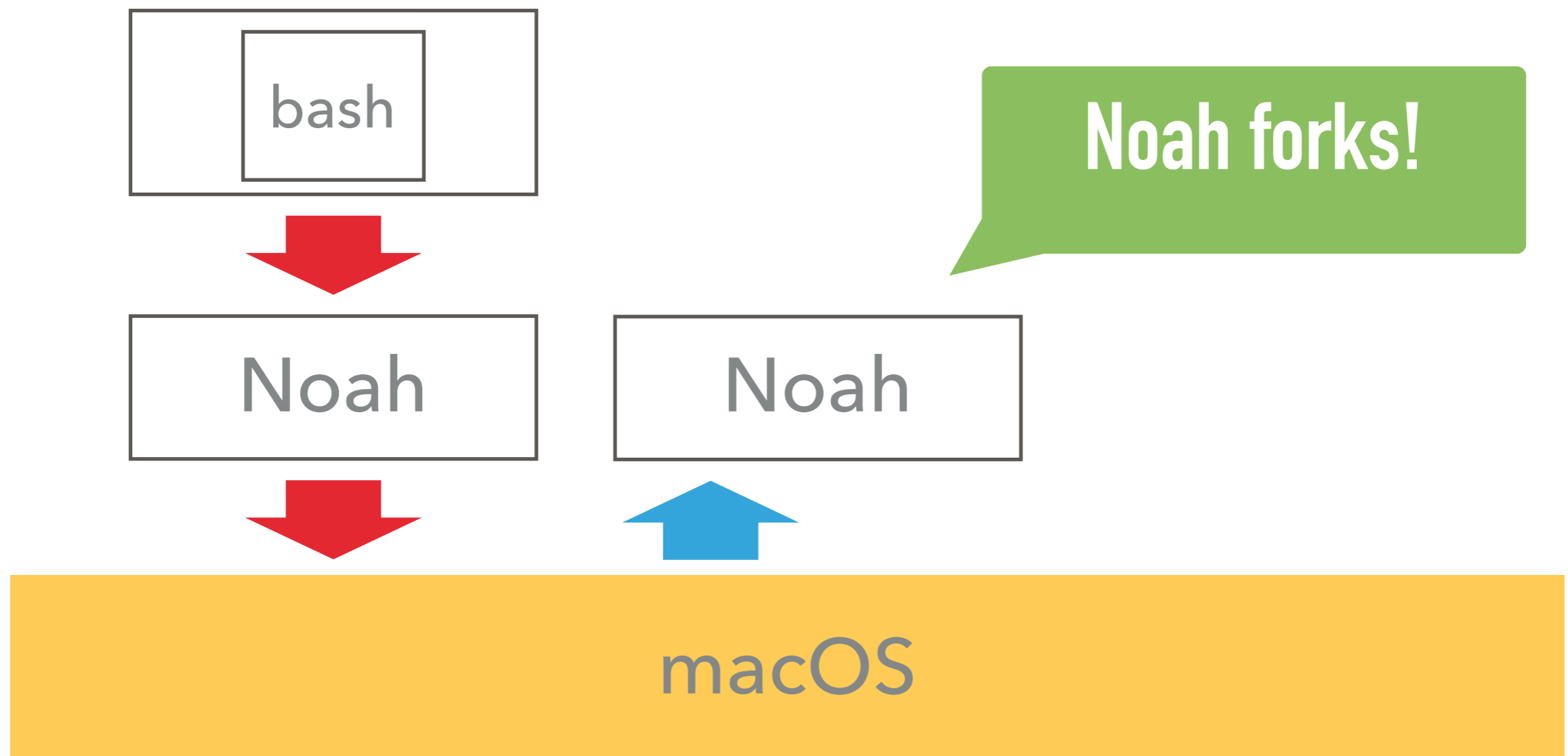
Example1: How "Hello, world" works

```
$ noah /bin/hello
```
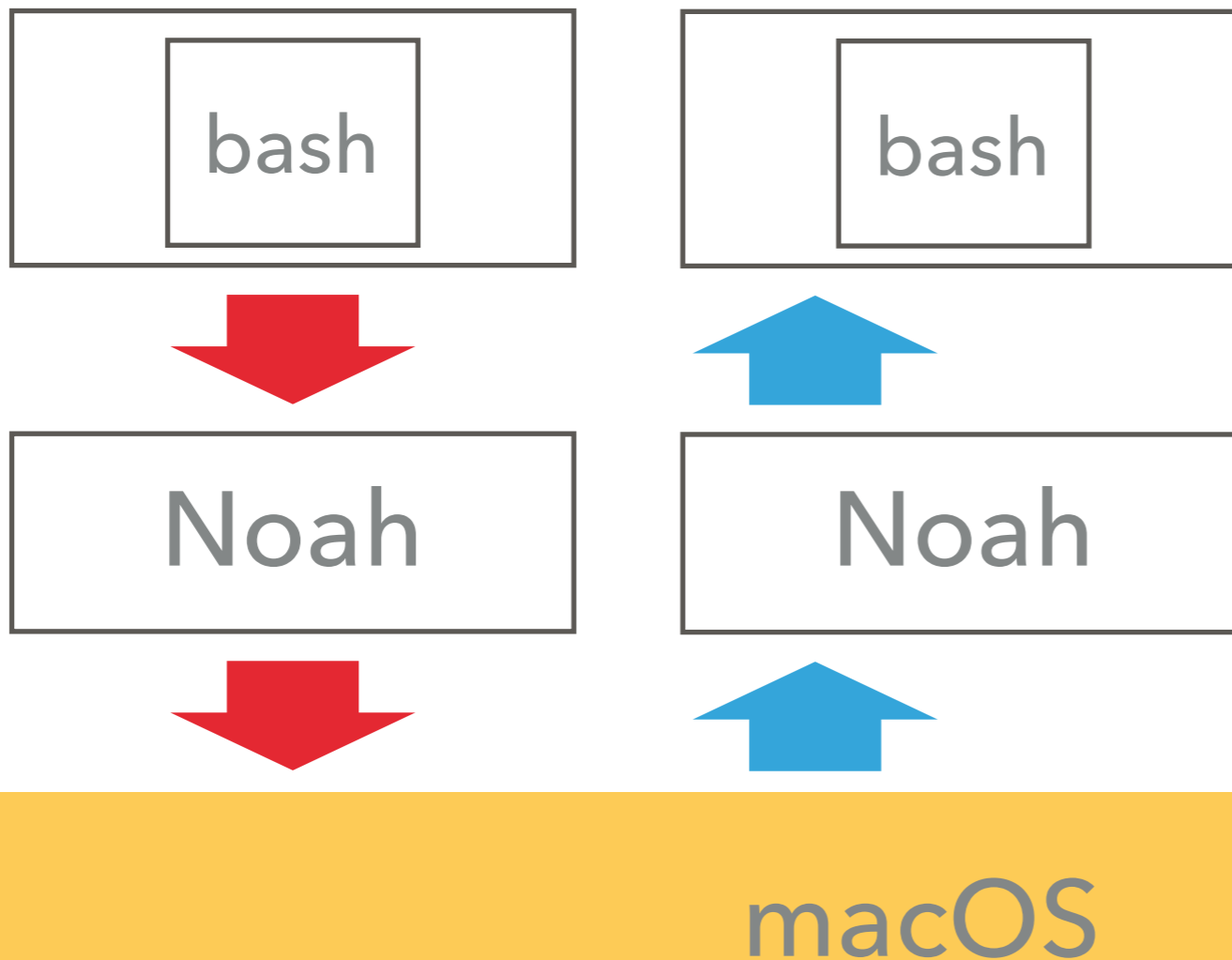
Example2: Interaction between processes

```
$ cat file | grep 2017
```
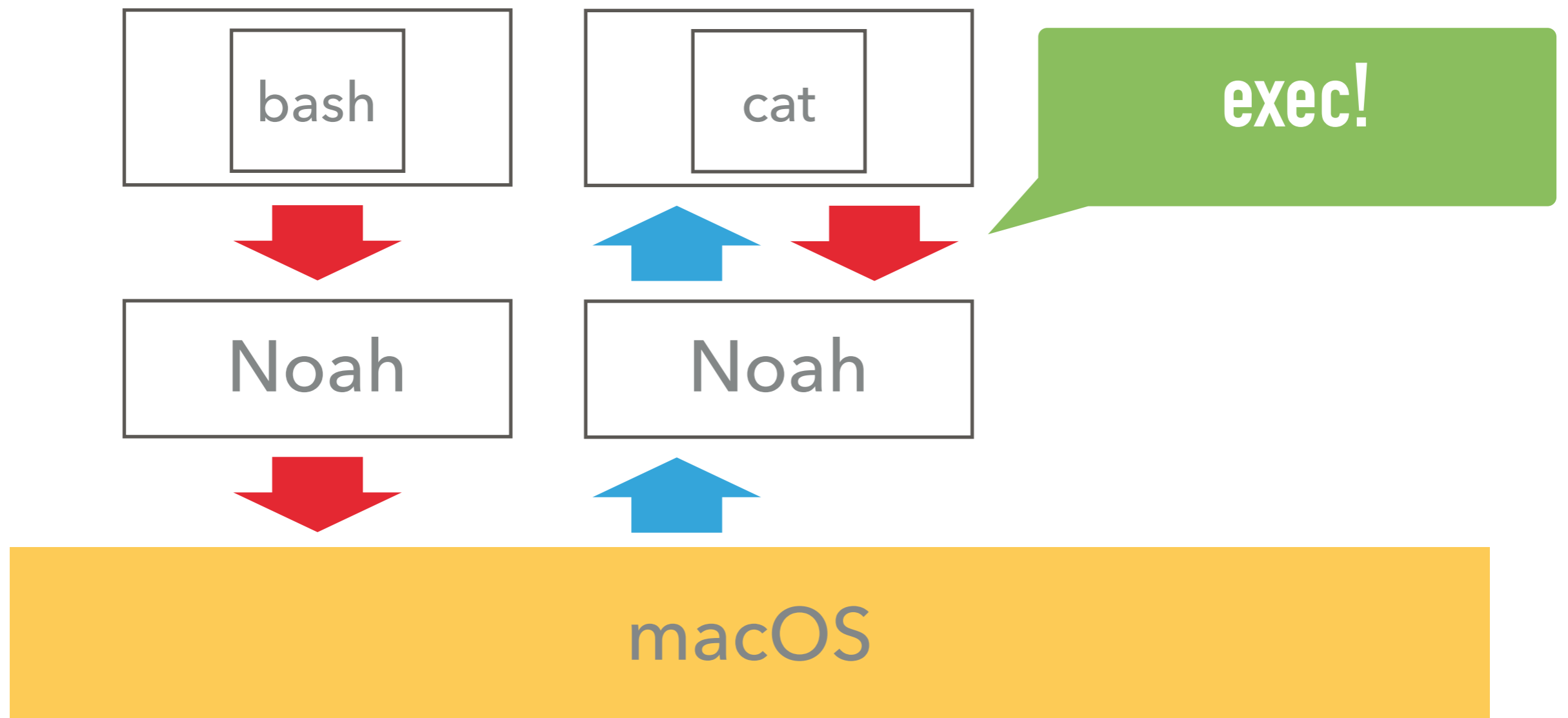
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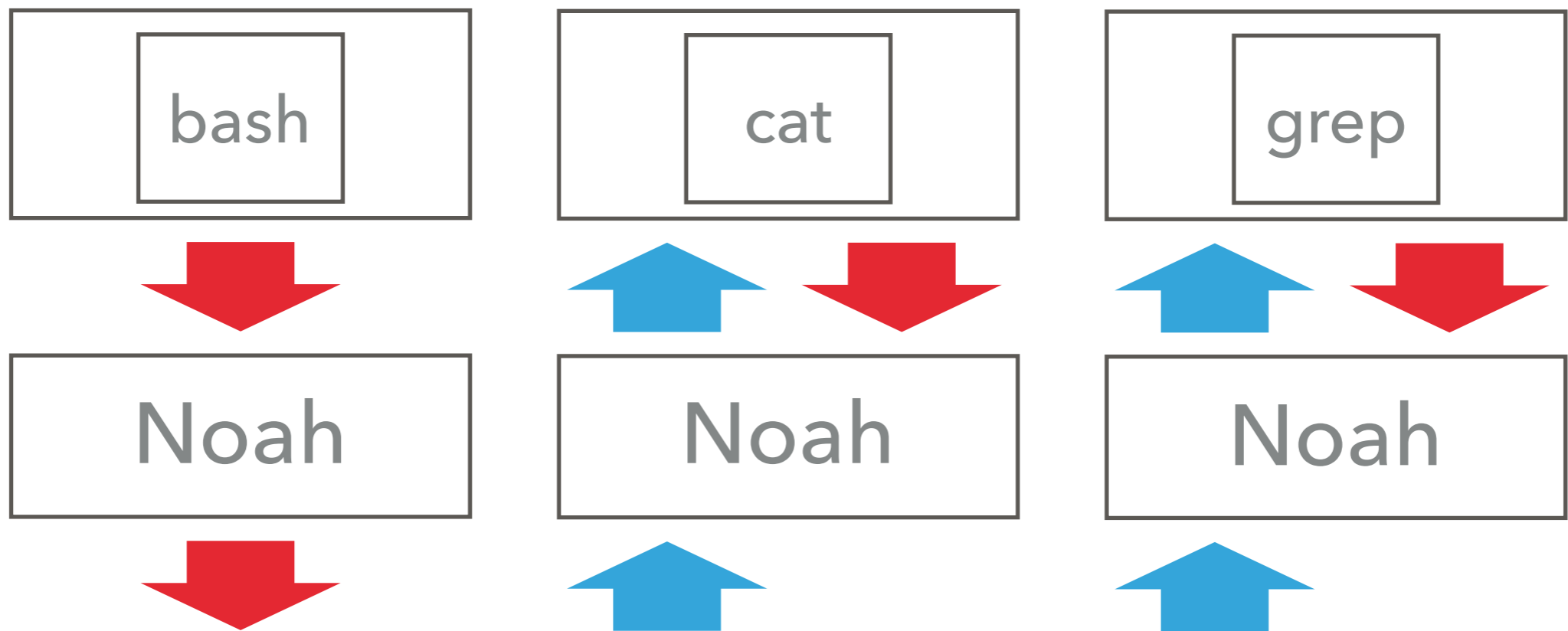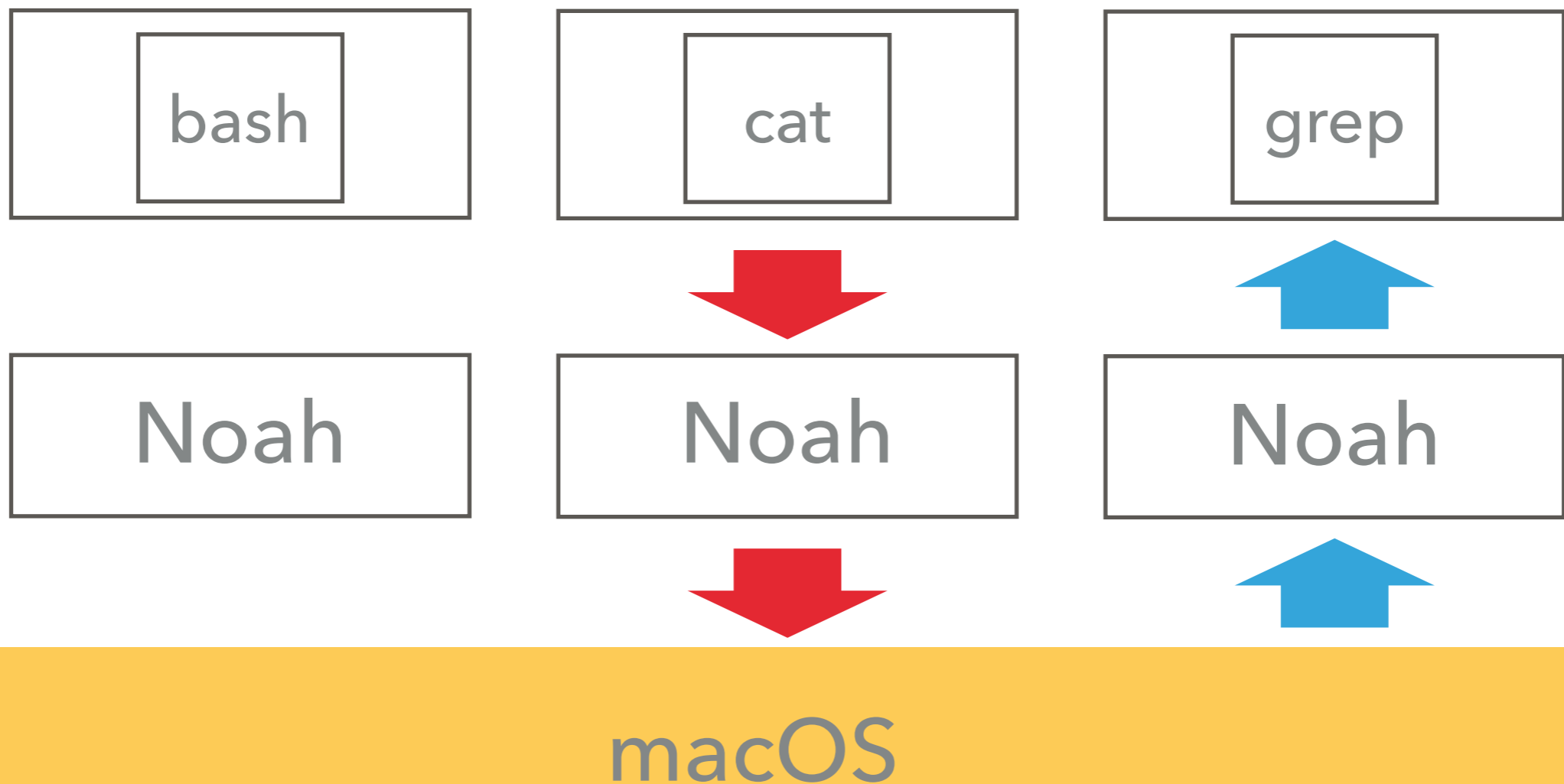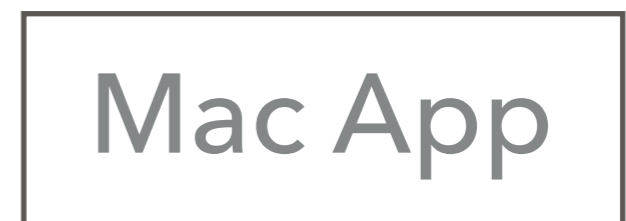# Example2: Interaction between processes

```
$ cat file | grep 2017
```

Example2: Interaction between processes

```
$ cat file | grep 2017
```

Linux and macOS applications can also communicate naturally

bash		cat

Noah	Noah	Mac App

macOS

Advantages of Noah Architecture

Unique Characteristics

1. All syscall translation done in user land instead of kernel land

    - Still, any sensitive events are trappable with VT-x

2. Launch as many VMs as virtual Linux processes

    - No kernel running inside VMs

3. Virtualization is per syscall, not per device I/O

    - No care about hardware device emulation

Advantages of Noah Architecture

1. Robustness

   Bugs in Noah never cause kernel panic because Noah is just an ordinary userland program (let's google "WSL bluescreen" now).

2. Portability

   The architecture is independent from host OS's architecture. Syscall calling convention, memory layout, page fault handling rules, …etc are all configurable.

3. Smooth interaction with host OS

   Linux process runs as if it is the host OS's process. Resources such as memory, network, and so on are managed by host OS. No need to worry about the amount of virtual memory allocation like full virtual machines.

Agenda

- ~~What is Noah~~

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- ~~Noah in Detail~~

  - ~~Architecture Overview~~

  - ~~Advantages of Noah Architecture~~

  - **Subsystem Implementation**

    - Memory management, VFS, and the other

  - Current Implementation Status and Performance

- Related Technologies and Comparison
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Subsystem Implementation

Noah Subsystems

Noah consists of subsystems such as memory management, IPC, or file system just like a real kernel.

Some of them have some difficulty because of the nature of Noah's architecture.

Noah Subsystems
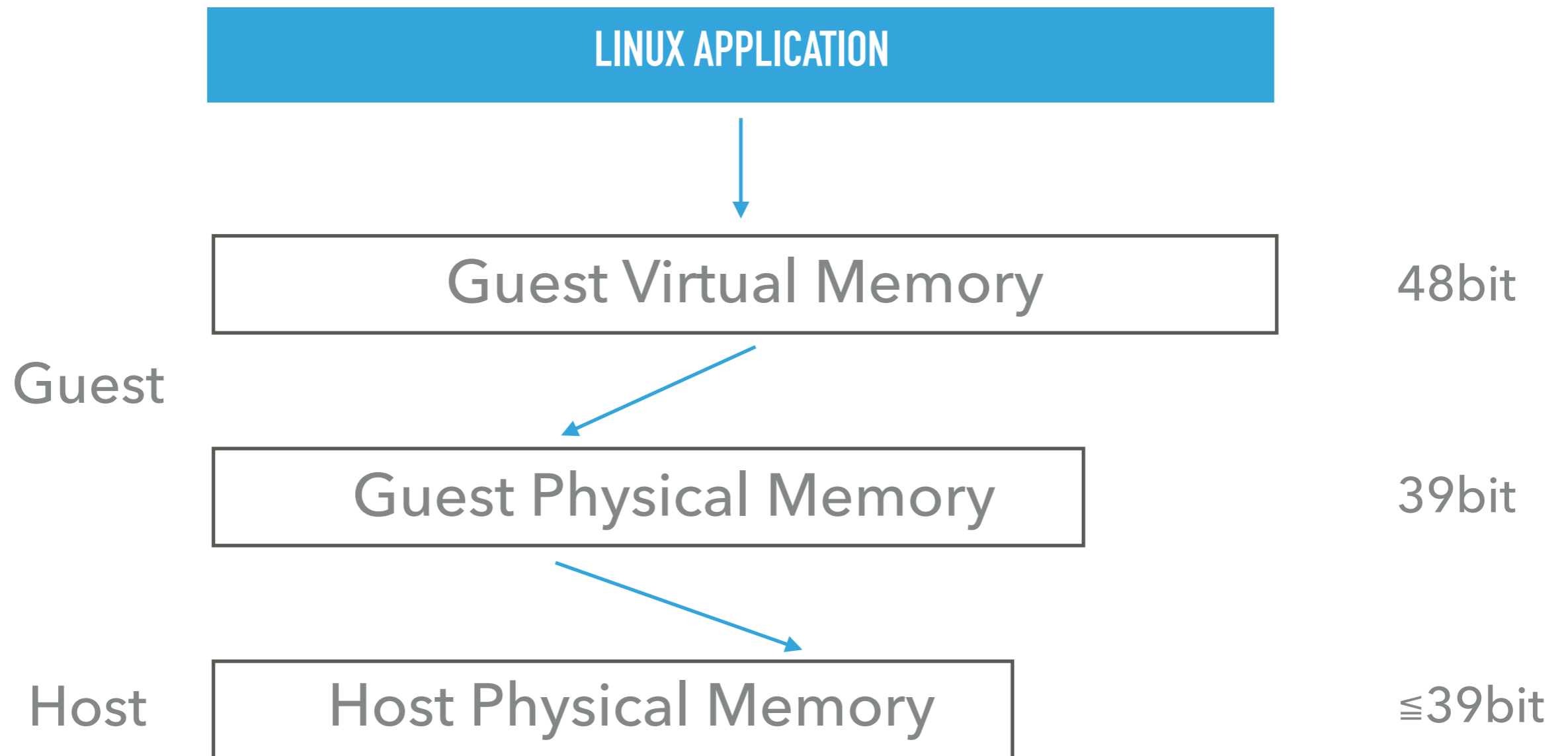
Today we explain two subsystems in detail.

1. Memory management

2. Virtual file system

Memory Management

Memory Management

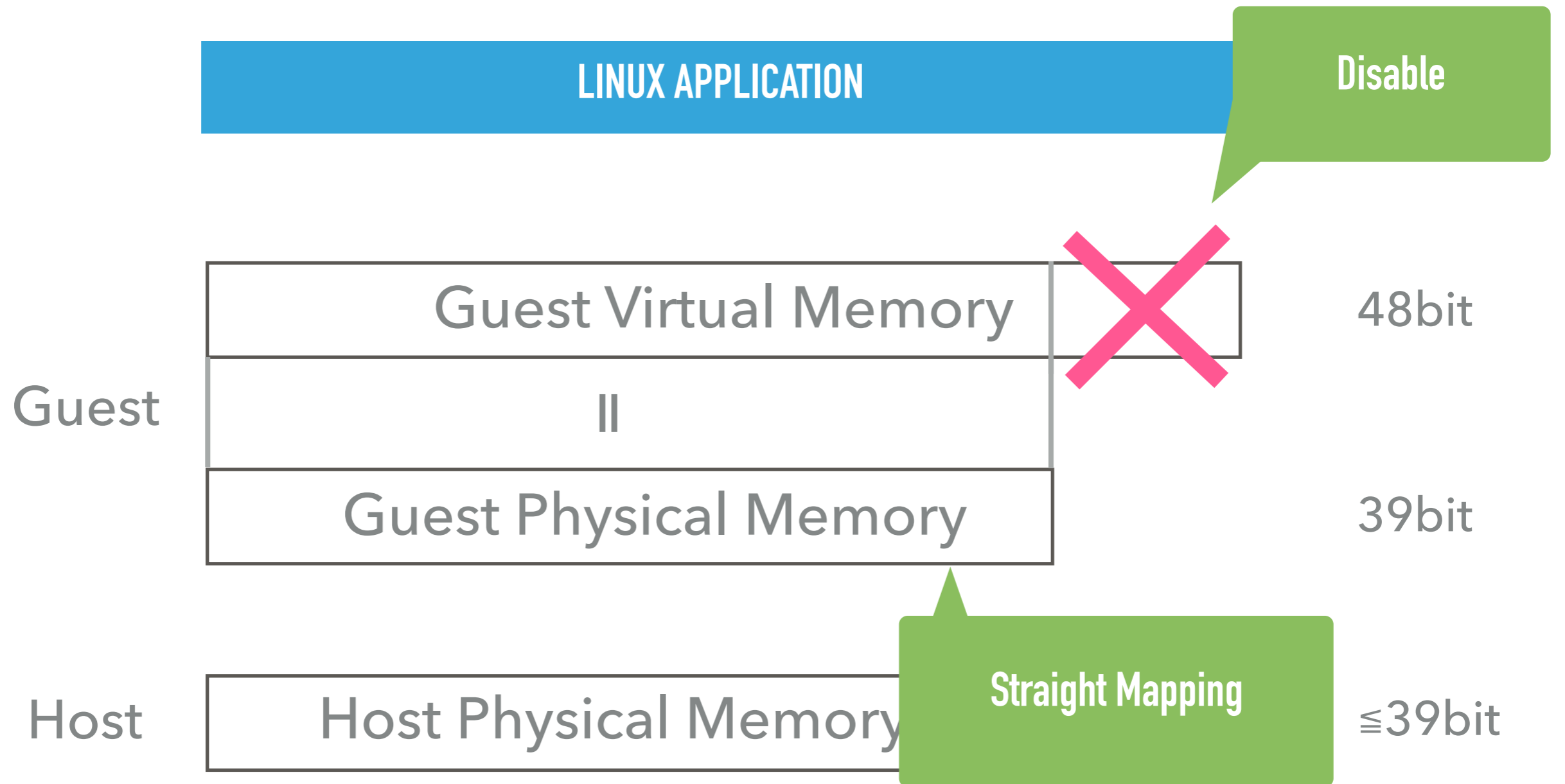- Since Linux ELF binary runs inside VM, Noah must manage address translation between the VM memory space and the host memory space

- It gives us Copy on Write ability, Efficient exec implementation, but also some difficulty

Memory Translation

LINUX APPLICATION

Guest

Guest Virtual Memory — 48bit

Guest Physical Memory — 39bit

Host

Host Physical Memory — ≦39bit

Duplicated Address Translation!

Memory Translation

LINUX APPLICATION

Guest Virtual Memory ❌ 48bit

Guest = ⋮

Guest Physical Memory 39bit

Host Physical Memory ≦39bit

Guest

Host
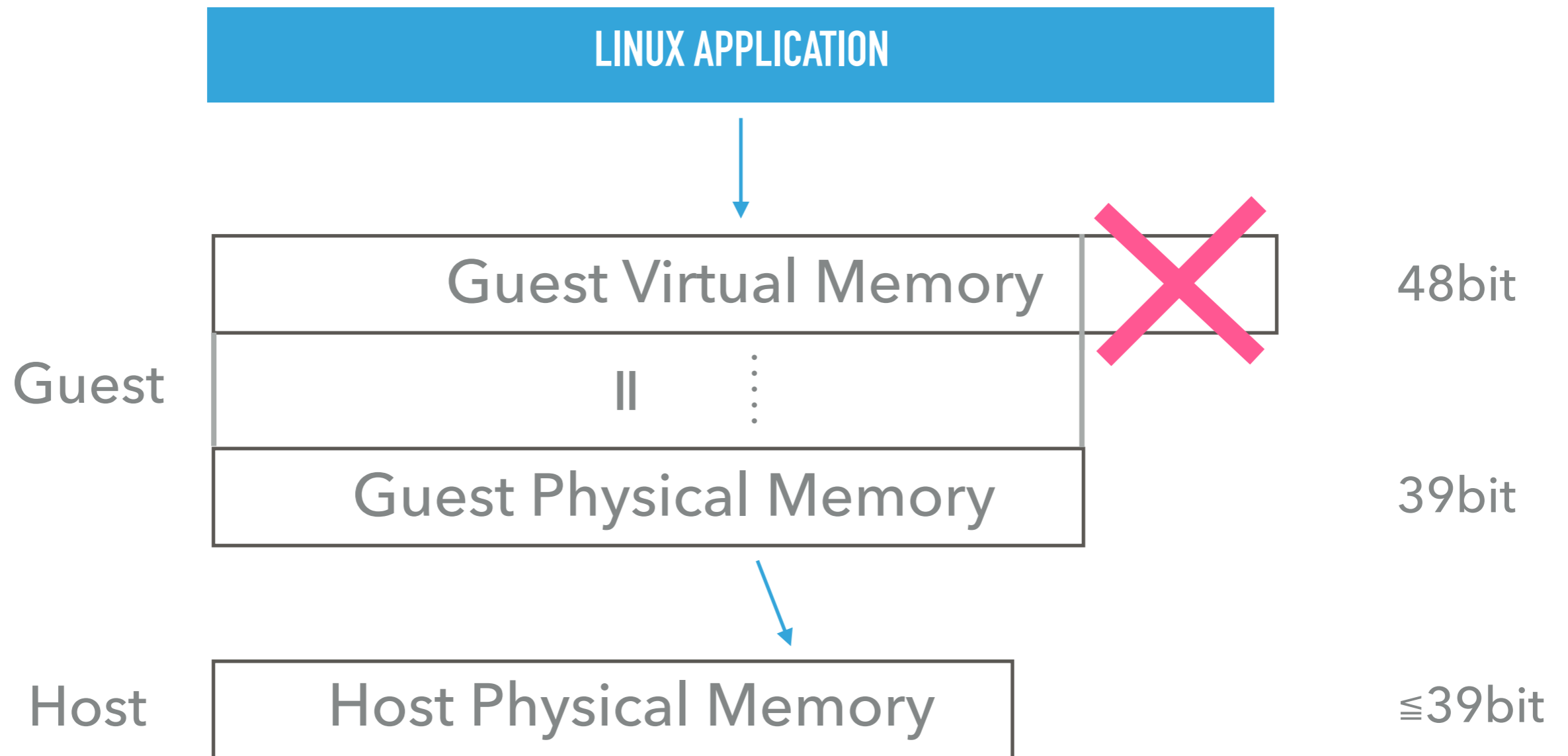
Single Address Translation

Virtual File System

Virtual File System

- open system call

from user

flag_conv → **strncpy_from_user**

resolve_path → **fs.ops.open** → to user

OOP
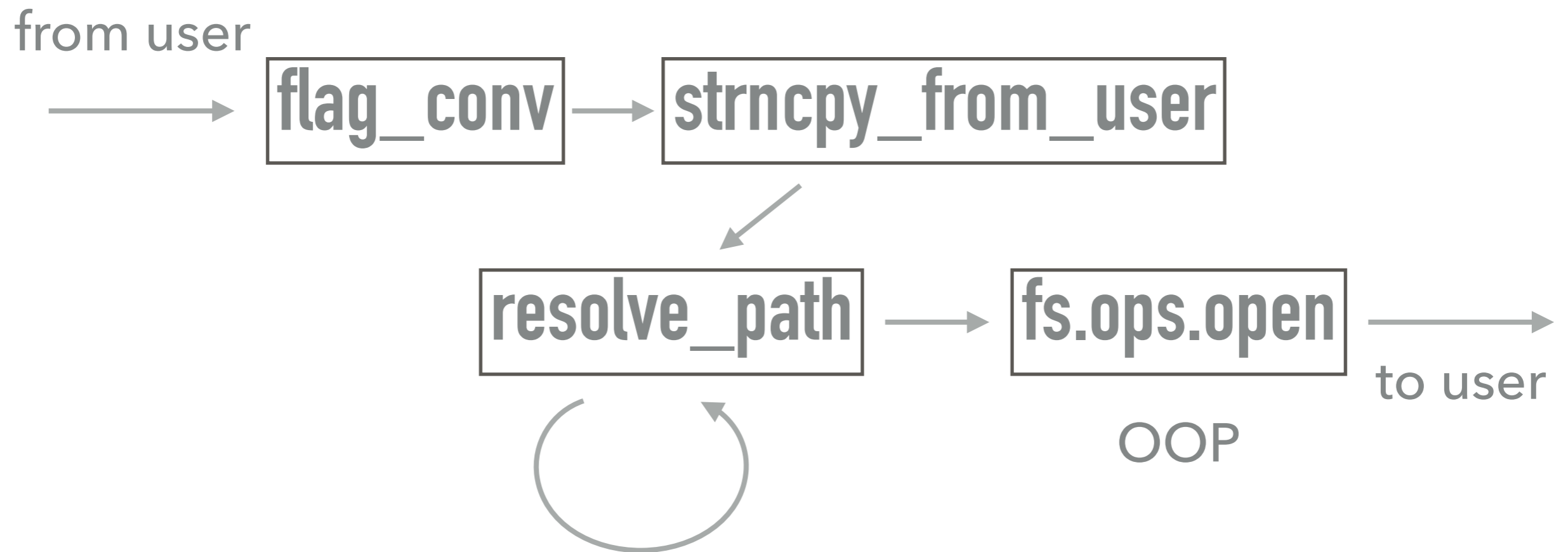
Symlinks & Mountpoints

Virtual File System

```
/
├── Users      ───→  /Users
├── dev        ───→  /dev
├── usr        ───→  ~/.noah/tree/usr
├── etc        ───→  ~/.noah/tree/etc
└── tmp        ───→  /tmp
```

Other System Calls

Just call macOS's one

getuid   getpid

getgid   getpgid

alarm   time

semget

Need conversion

futex   emulate with conditional value

socket   integrate with VFS

sigaction   create signal frame inside VM

gettid   generate from threadid

Current Implementation Status of Noah

Current Implementation Status of Noah

- Still in development

- Currently capable of running

  - apt-get, pacman (Not all subcommands are supported yet)

  - vim, gcc, make

  - Ruby

  - Binutils, ls, cat, …

  - X applications; xeyes, xclock, xfwrite, doom 3, …

  - sudo, curl, nc, man, …

- The most easiest way to build Linux kernel on macOS is to use Noah!

Performance

- Performance data will be public in the presentation since it contains unpublished materials

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- ~~What is Noah~~

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- **<u>Related Technologies and Comparison</u>**
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Related Technologies

Linux Compatibility Layers

- OS Built-in

  - Windows Subsystem for Linux

  - FreeBSD's Linuxulator

- Third Party Middleware

  - Foreign LINUX

Windows Subsystem for Linux (WSL)

- Built-in Linux compatibility layer for Windows 10 by Microsoft

- Picoprocess contains a Linux ELF binary. Kernel drivers (LXCore and LXSS) handle system calls from it in kernel mode

Quoted from https://blogs.msdn.microsoft.com/wsl/2016/04/22/windows-subsystem-for-linux-overview/
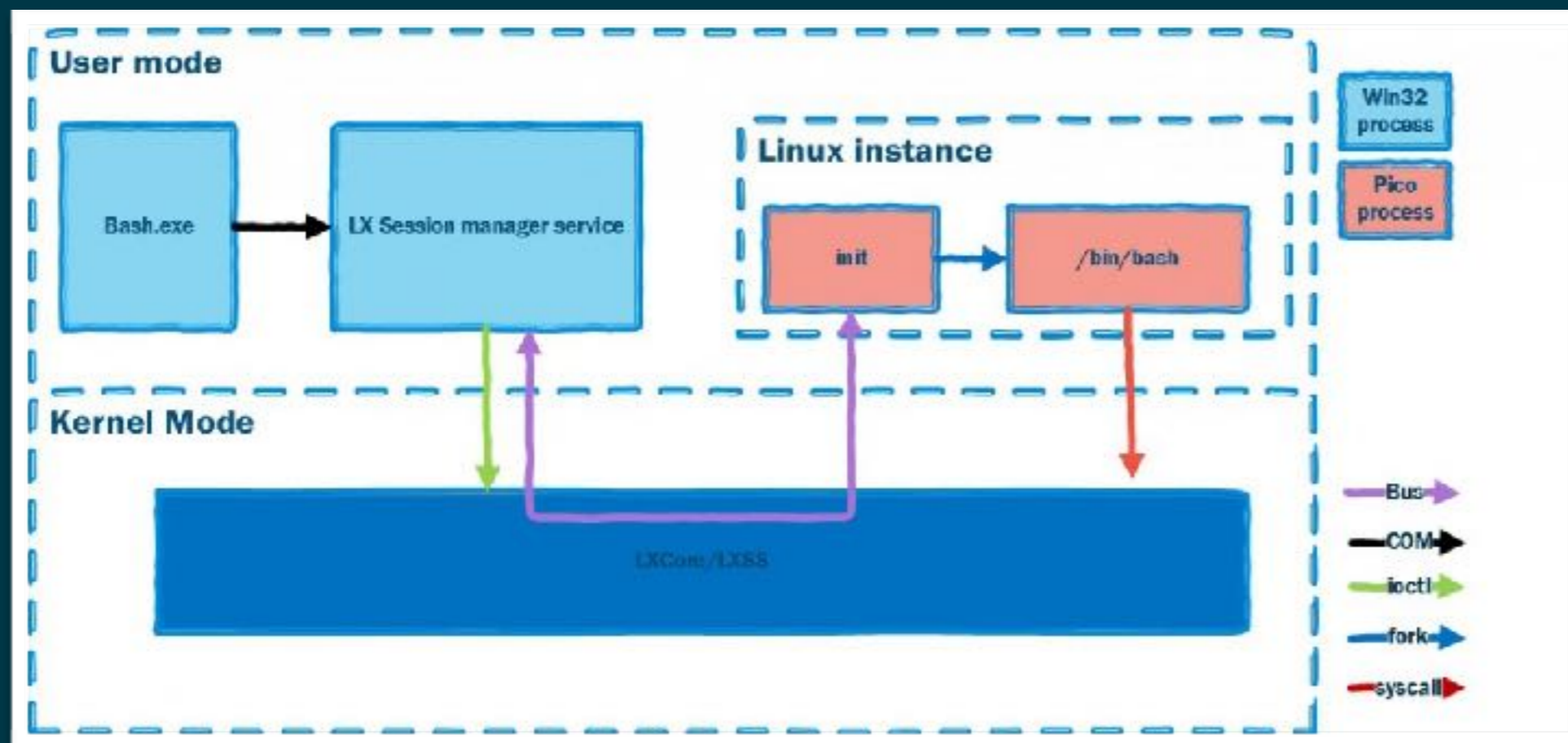
Linuxulator

- Built-in Linux compatibility layer for FreeBSD

- FreeBSD has a loader for Linux ELF and implementations of Linux system calls

- Similar approach to WSL's LXSS / LXCore (Linuxulator is older, though)

Foreign Linux

- https://github.com/wishstudio/flinux

- Run unmodified Linux applications on Windows by dynamic binary translation and system call emulation

- It seems that the overhead of dynamic binary translation is a bit heavy, however…

Comparison

	OS	Binary Compatibility	Portable	No Kernel Modification	Smooth Interaction	Low Overhead
Noah	macOS	✔	✔	✔	✔	✔
WSL	Windows	✔	�’	✗	✔	✔
Linuxulator	FreeBSD	✔	✗	✗	✔	✔
Foreign LINUX	Windows	✔	✔	✔	✔	✗
Full VM	Any	✔	✔	✔	✗	✔ *with processor hardware virtualization

Future Cross Platform Development
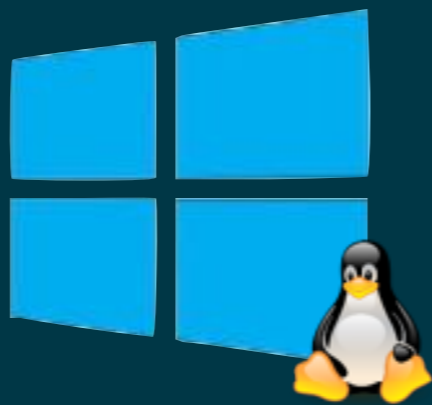
Now major four operating
systems have Linux compatibility

- Linux could be regarded as "standard" like POSIX

- In the future, once you write a Linux application, it simply could run any platforms

- Noah could help it!
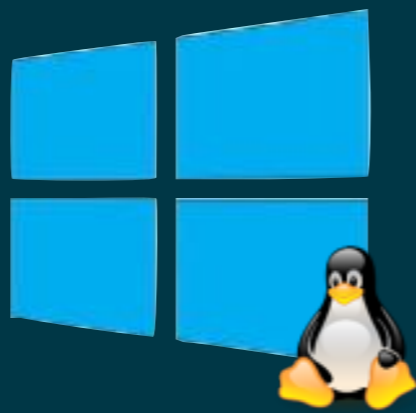
Summary

- We introduced Noah, which is a middleware that runs unmodified Linux ELF applications on macOS

- Noah adopts a new hypervisor based approach with many merits

- Now four major operating systems have Linux compatibility. In the future, your Linux applications could run anywhere!