Portability

Application binary interfaces (ABI)

- most Windows laptops, Linux laptops and pre-M1 Macs share the same ISA: x86_64
- iPhones, Android phones, M1 to M4 Macs share the same ISA: AArch64

Q: Why, then, do applications need to be recompiled separately for each platform?
e.g. iPhone vs. Android phone

A: Because platforms have different OSs and ABIs.

What is an ABI?

An application binary interfaces (ABI) defines:

- file format for
  - object files
  - dynamically-linked files (shared objects / dll)
  - and executable files
- convention for function calls
- convention for system calls

It is called **binary** because it is independent of the language in which applications are written
(i.e. it is related to the machine code, not to the source code)

ABI: function calls (x86_64)

```c
#include <stdio.h>

int main()
{
    puts("Hello\n");
    return 0;
}
```

clang / Linux / x86_64

```
main:
        push    rax
        lea     rdi, [rip + .L.str]
        call    puts@PLT
        xor     eax, eax
        pop     rcx
        ret
.L.str:
        .asciz  "Hello\n"
```

MSVC / Windows / x86_64

```
_DATA   SEGMENT
$SG9391 DB      'Hello', 0aH, 00H
_DATA   ENDS

main    PROC
$LN3:
        sub     rsp, 40
        lea     rcx, OFFSET FLAT:$SG9391
        call    puts
        xor     eax, eax
        add     rsp, 40
        ret     0
main    ENDP
```

ABI: function calls (AArch64)

```c
#include <stdio.h>

int main()
{
    puts("Hello\n");
    return 0;
}
```

clang / MacOS / AArch64

```
main:
        stp     x29, x30, [sp, #-16]!
        mov     x29, sp
        adrp    x0, .L.str
        add     x0, x0, :lo12:.L.str
        bl      puts
        mov     w0, wzr
        ldp     x29, x30, [sp], #16
        ret
.L.str:
        .asciz  "Hello\n"
```

MSVC / Windows / AArch64

```
        IMPORT  |puts|

|main|  PROC
|$LN3|
        stp         fp,lr,[sp,#-0x10]!
        mov         fp,sp
        adrp        x8,|$SG4901|
        add         x0,x8,|$SG4901|
        bl          puts
        mov         w0,#0
        ldp         fp,lr,[sp],#0x10
        ret

        ENDP
```

Try it for yourself:
godbolt.org

Calling convention

```c
int function(int a1, int a2, int a3, int a4, int a5, int a6, int a7)
{
    return a1;
}
```

platform	a1	a2	a3	a4	a5	a6	a7	a8	…	return value
AArch64	x0	x1	x2	x3	x4	x5	x6	x7	(stack)	x0
“SysV” x86_64	rdi	rsi	rdx	rcx	r8d	r9d	(stack)	(stack)	(stack)	rax
Windows x86_64	rcx	rdx	r8d	r9d	(stack)	(stack)	(stack)	(stack)	(stack)	rax

Note: floating-point parameters are passed separately

Some specifications

SysV x86_64 ABI:	repo, pdf
AArch64 ABI:	repo
Linux-specific stuff:	documents

Remarks:

- OS vendors may or may not adhere to the ABI spec of the hardware:
  - Microsoft Windows does their own thing on x86_64
  - MacOS follows AArch64 calling convention,
    but uses Mach-O (not ELF) as an object file format
- Some part of the ABI may be defined by OS vendors
  (e.g. system call convention)
- The ABI is language-independent,
  but the C language (sometimes C++ as well) has a special status
  The ABI is defined **in terms of** C function calls and C datastructures.

Portable code

How do we ship code that work across all platforms?

Option 1: interpreters

- use interpreted languages, ship source
  - Python, Javascript, …
- languages that compile to virtual machine code
  - ship VM code
  - optionally, ship VM interpreter
  - Java, C#

Option 2: multiple compilations

- compile one executable on each platform
- in some cases, cross-compilation is possible
  - MacOS $\longrightarrow$ iOS
  - Linux $\longrightarrow$ Android

What if we cannot (or do not want to) recompile?

Option 3: Translation

Use case: same OS, different ISA

- Translation is a form of compilation
- From machine code
- To machine code (of a different ISA)

Example: Apple Rosetta 2 translates x86_64 into AArch64

Option 4: Compatibility layers

Use case: different OSs, same ISA

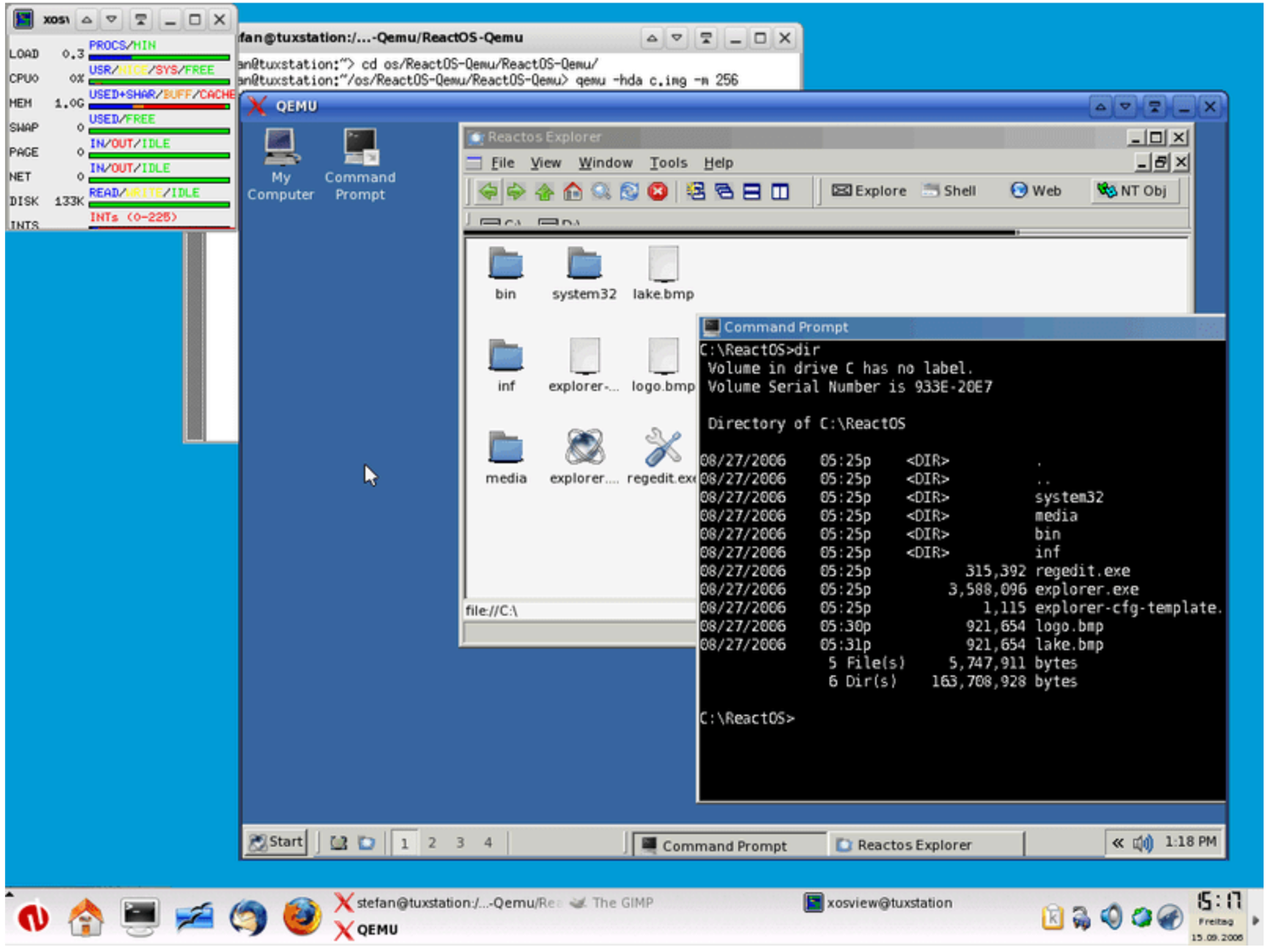
- add OS support for a foreign ABI
  - foreign file formats (for objects, DLLs and executables)
  - foreign convention for system calls
- add libraries for foreign ABI
  - foreign convention for function calls

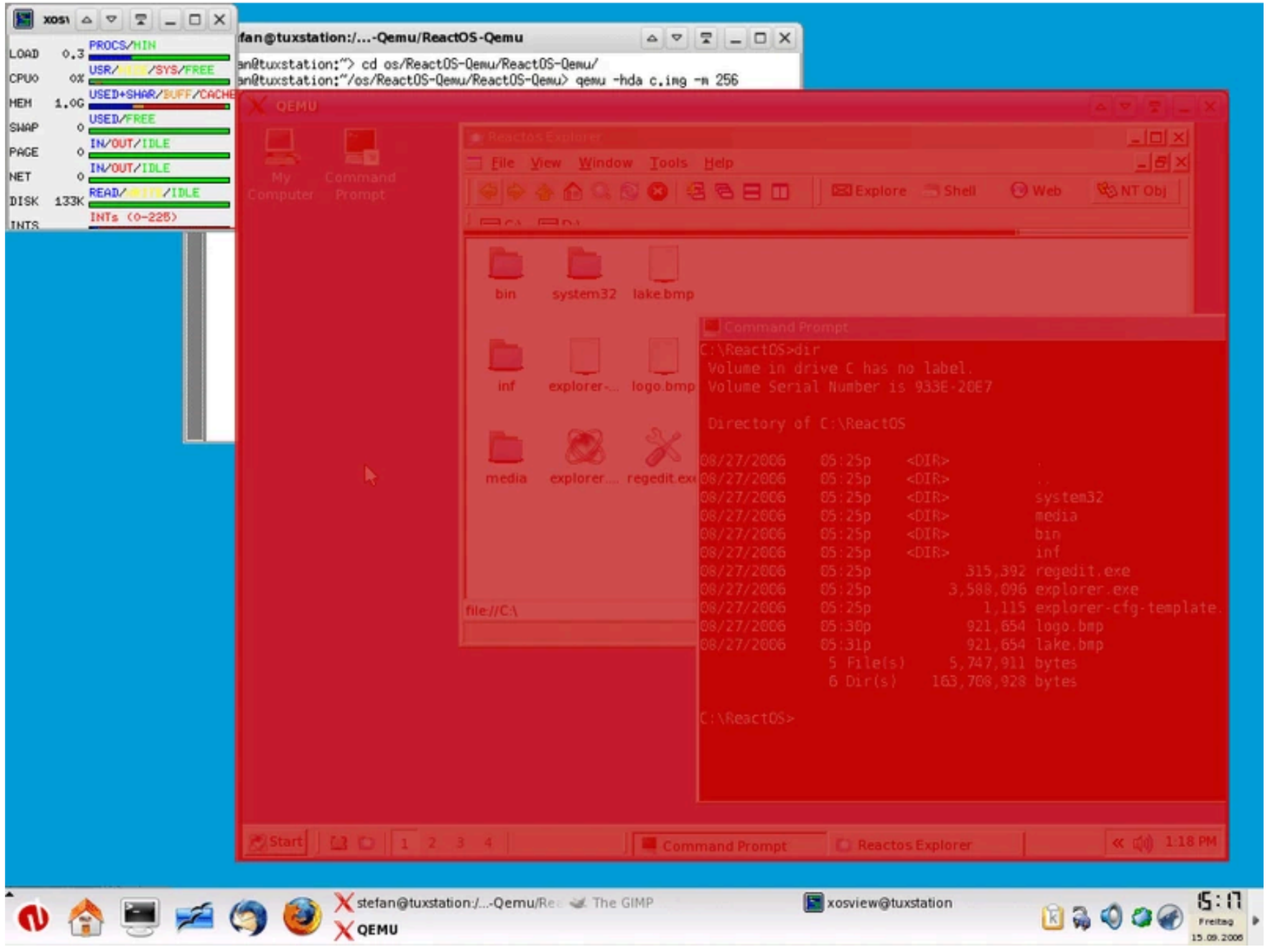
Examples:

- Wine allows running Windows apps on Linux.
- WSLv1 allows running Linux apps on Windows.

Option 5: emulation

- an emulator is an interpreter for machine code (e.g. QEmu)
- much slower than running the code
- JIT can mitigate slowness, to some extent
- typically, a full-blown operating system runs inside the interpreter!


xosview
LOAD 0.3
CPU0 0%
MEM 1.0G
SWAP 0
PAGE 0
NET 0
DISK 133K
INTS
PROCS/MIN
USR/NICE/SYS/FREE
USED+SHAR/BUFF/CACHE
USED/FREE
IN/OUT/IDLE
IN/OUT/IDLE
READ/WRITE/IDLE
INTs (0-225)
stefan@tuxstation:/...-Qemu/ReactOS-Qemu
an@tuxstation:~> cd os/ReactOS-Qemu/ReactOS-Qemu/
an@tuxstation:~/os/ReactOS-Qemu/ReactOS-Qemu> qemu -hda c.img -m 256
QEMU
My Computer
Command Prompt
Reactos Explorer
File View Window Tools Help
Explore Shell Web NT Obj
bin
system32
lake.bmp
inf
explorer-...
logo.bmp
media
explorer....
regedit.exe
file://C:\
Command Prompt
C:\ReactOS>dir
Volume in drive C has no label.
Volume Serial Number is 933E-20E7
Directory of C:\ReactOS
08/27/2006 05:25p <DIR> .
08/27/2006 05:25p <DIR> ..
08/27/2006 05:25p <DIR> system32
08/27/2006 05:25p <DIR> media
08/27/2006 05:25p <DIR> bin
08/27/2006 05:25p <DIR> inf
08/27/2006 05:25p 315,392 regedit.exe
08/27/2006 05:25p 3,588,096 explorer.exe
08/27/2006 05:25p 1,115 explorer-cfg-template.
08/27/2006 05:30p 921,654 logo.bmp
08/27/2006 05:31p 921,654 lake.bmp
5 File(s) 5,747,911 bytes
6 Dir(s) 163,708,928 bytes
C:\ReactOS>
Start
1 2 3 4
Command Prompt
Reactos Explorer
1:18 PM
stefan@tuxstation:/...-Qemu/Re
The GIMP
QEMU
xosview@tuxstation
5:17
Freitag
15.09.2006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an@tuxstation:"> cd os/ReactOS-Qemu/ReactOS-Qemu/
an@tuxstation:"/os/ReactOS-Qemu/ReactOS-Qemu> qemu -hda c.img -m 256
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My Computer
Command Prompt
ReactOS Explorer
File View Window Tools Help
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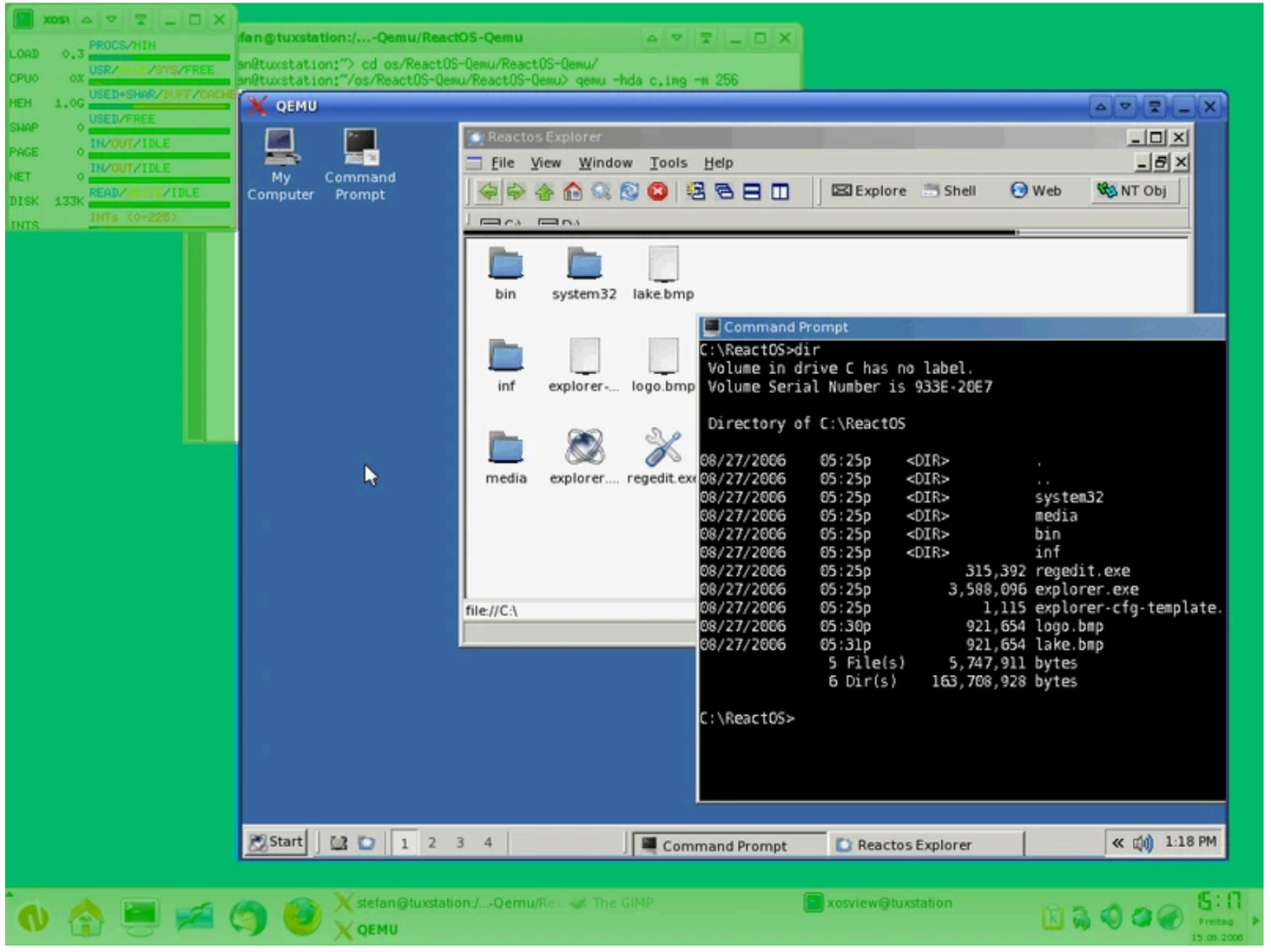
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CPU0 0%
MEM 1.0G
SWAP 0
PAGE 0
NET 0
DISK 133K
PROCS/MIN
USED/FREE
IN/OUT/IDLE
IN/OUT/IDLE
INTs (0-228)
The GIMP
xosview@tuxstation
QEMU

Option 6: virtualization

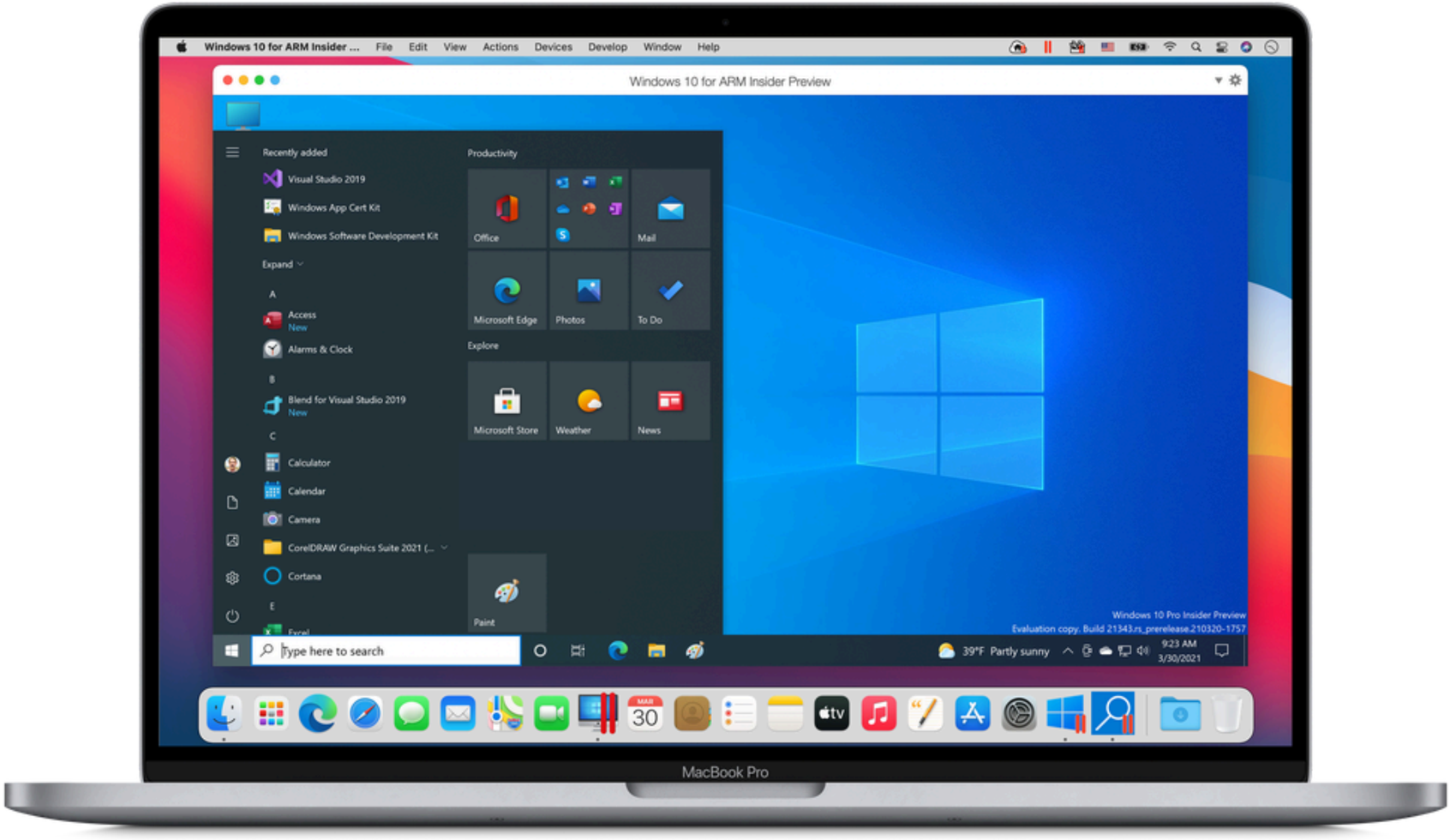
- virtualization is essentially hardware-assisted emulation

  (e.g. Xen, KVM, VirtualBox, VMWare, Apple Parallels, WSLv2)

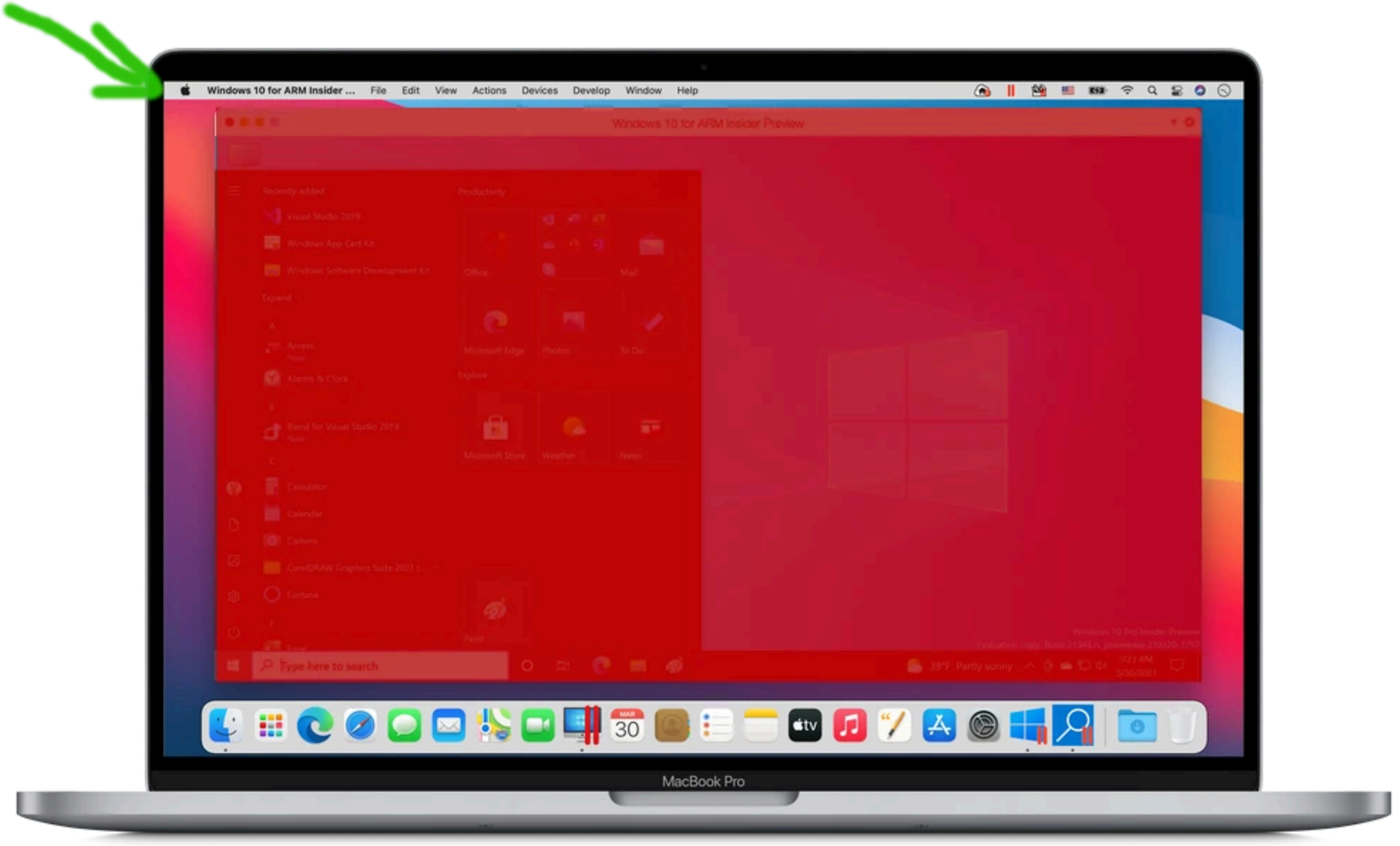
- virtualized software must target the same ISA as hardware

- like emulation, runs a full-blown operating system

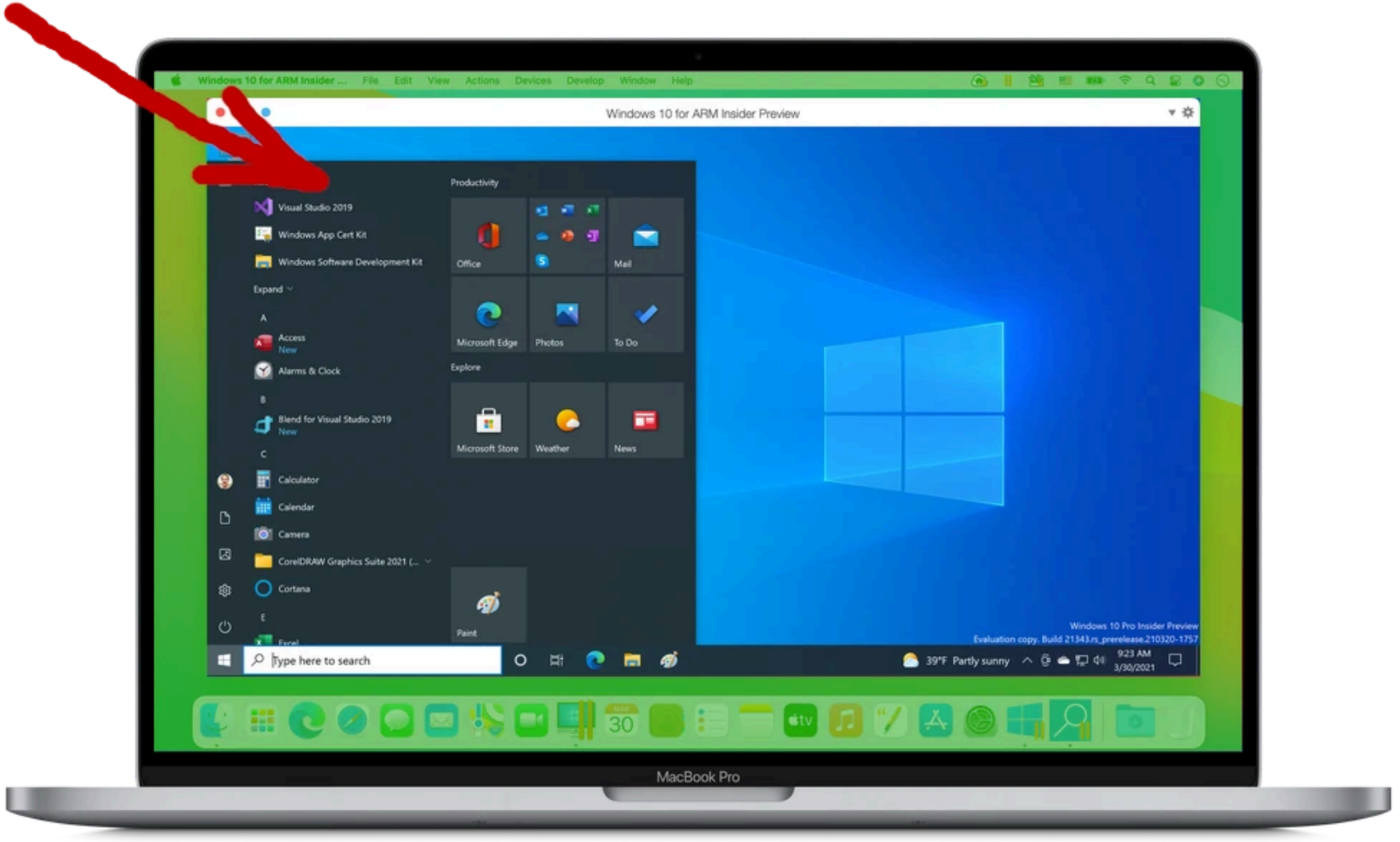
Example: Apple Parallels



Host OS


Windows 10 for ARM Insider ...
File
Edit
View
Actions
Devices
Develop
Window
Help
Windows 10 for ARM Insider Preview
MacBook Pro

Guest OS


Windows 10 for ARM Insider Preview
Productivity
Visual Studio 2019
Windows App Cert Kit
Windows Software Development Kit
Expand
Office
Mail
Microsoft Edge
Photos
To Do
Explore
Access
New
Alarms & Clock
Blend for Visual Studio 2019
New
Microsoft Store
Weather
News
Calculator
Calendar
Camera
CorelDRAW Graphics Suite 2021 (...
Cortana
Paint
Excel
Type here to search
39°F Partly sunny
9:23 AM
3/30/2021
Windows 10 Pro Insider Preview
Evaluation copy. Build 21343.rs_prerelease.210320-1757
MacBook Pro

Definitions

- The *hypervisor* is the software that manages the guest OS.
- It can be the host OS itself (“Type 1”: Xen, KVM)
- It can be a process within the host OS (“Type 2”: Apple Parallels)

Virtualization mainly deals with security:

Let guest OSs believe they have direct access to hardware…

… but every hardware access is tightly controlled by the hypervisor

Virtualization is the main technology enabling “cloud computing”.

- Amazon Web Services runs Xen
- Google Cloud Platform runs KVM
- Customers rent a virtual machine in a datacenter
  - They can connect (remotely) to this machine
  - It runs their (guest) OS of choice
  - It acts as if it was physical hardware

Option 7: containers

Use case: Same ISA, same kernel, different OS.

- Containers are a lightweight form of virtualization.
- The host's kernel also acts as a kernel for the guest.
- Mainly: filesystems, libraries and applications are separated.

Examples:

- A Debian Linux guest on a Fedora Linux host
- A Debian 11 Linux guest on a Debian 12 host
- A Debian 12 guest with specific libraries installed, on a Debian 12 host

Application programming interfaces (API)

Definition

An API defines how a library (or any other service) is to be used.

Library API

```c
FILE *fopen(const char *path, const char *mode);
```

```python
open(file, mode='r', buffering=- 1, encoding=None, errors=None, newline=None, closefd=True, opener=None)
```

Web API

```
GET https://www.google.com/search?q=<query>
```

Example:

```
google-chrome https://www.google.com/search?q=Software%20Engineering
```

```
GET https://cloudflare.com/cdn-cgi/trace
```

Example:

```
curl -4s "https://cloudflare.com/cdn-cgi/trace"
```

```
PUT https://api.cloudflare.com/client/v4/zones/{zone_identifier}/dns_records/{identifier}
```

Example:

```
curl --request PUT \
  --url https://api.cloudflare.com/client/v4/zones/zone_identifier/dns_records/identifier \
  --header 'Content-Type: application/json' \
  --header 'X-Auth-Email: ' \
  --data '{
  "content": "198.51.100.4",
  "name": "example.com",
  "proxied": false,
  "type": "A",
  "comment": "Domain verification record",
  "tags": [
    "owner:dns-team"
  ],
  "ttl": 3600
}'
```

APIs and portability

- many APIs are cross-platform
  - C standard library
  - Almost all Python modules
  - Qt, Electron, Flutter, … (frameworks for GUI applications)
  - WEB APIs only depend on an internet connection
- some are specific to a platform
  - Windows UI Library, MacOS Cocoa

Dependencies

- your code requires libA version >= 1.1, lib B version >= 4.5
  - lib B version 4.5 requires libX version 2.0 and libA version 0.8
  - lib B version 4.7 requires libX version 2.0 and libA version 1.1
  - lib B version 4.6 requires libX version 2.0 and libA version 2.0
  - lib X version 2.0 requires libA version <= 1.9

How do we install all this?

Which version do we install?

Package managers

Package managers solve this problem for you.

They can solve it…

- at the OS level:
  - MacOS: `brew install <package>`
  - Debian/Ubuntu Linux: `apt-get install <package>`
  - Fedora/Suse Linux: `dnf install <package>`
- at the language level:
  - Python: `pip install <module>`
  - JavaScript/Node: `npm install <package>`
  - Rust: `cargo install <crate>`

Limitations

- package selection may be limited (packaging is labor-intensive)
- security and trust