OSv on bhyve

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What is OSv?

- OSv is open source OS which designed to execute a single application on top of a hypervisor
- Better performance, easy to manage
- Developing by Cloudius Systems, Islaeli startup
  Core member are come from Qumranet
  CTO: Avi Kivity('Father' of KVM)
- Official site: http://osv.io/
- Github: http://github.com/cloudius-systems/osv

A Historical Anomaly

Your App

Application Server

JVM provides protection and abstraction

Operating System provides protection and abstraction

Hypervisor provides protection and abstraction

Hardware

Too Many Layers, Too Little Value

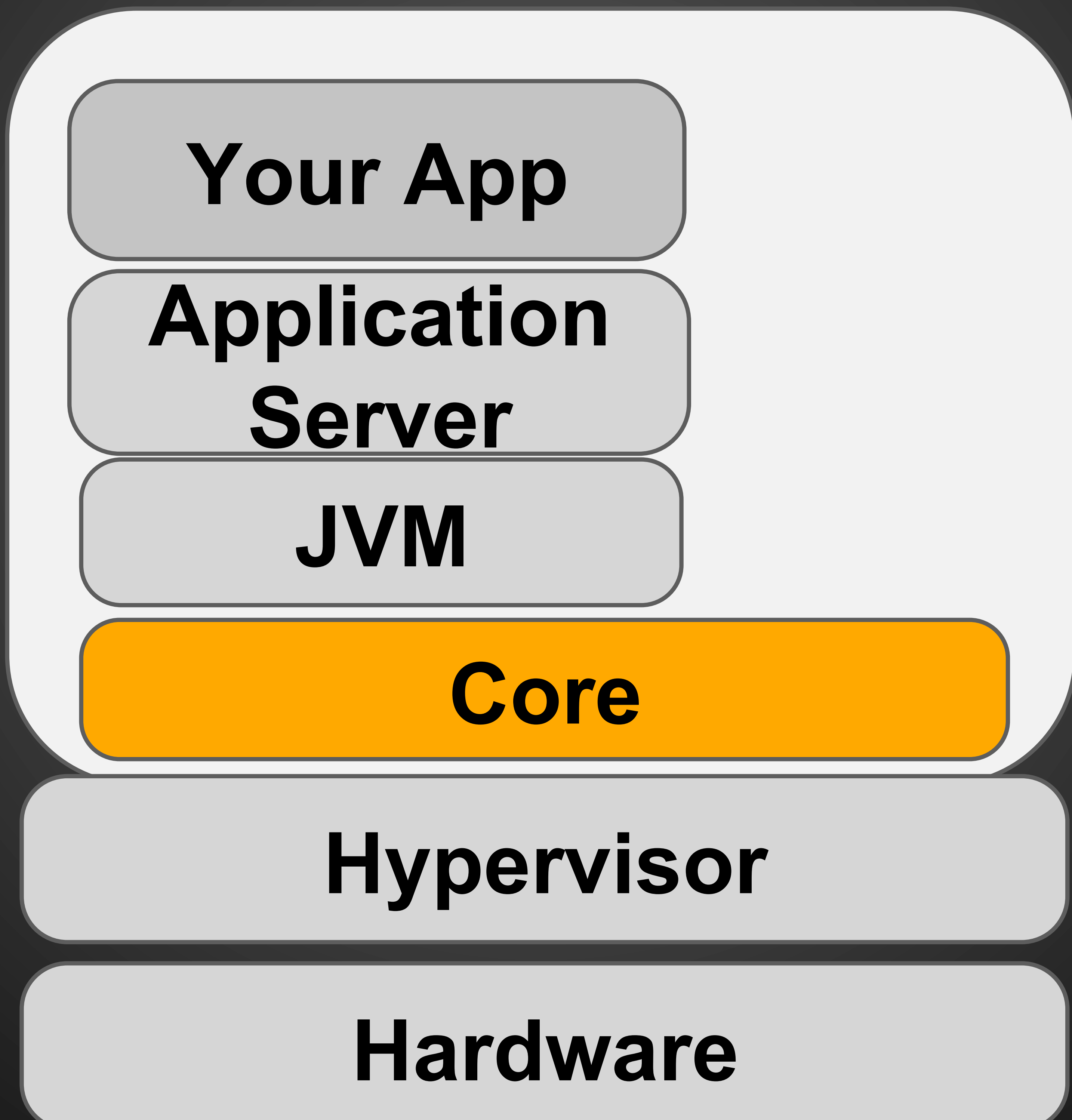
Property/Component	VMM	OS	runtime
Hardware abstraction	V	V	V
Isolation	V	V	V
Resource virtualization	V	V	V
Backward compatibility	V	V	V
Security	V	V	V
Memory management	V	V	V
I/O stack	V	V	
Configuration		V	

Duplication

The new Cloud Stack - OSv

Single Process

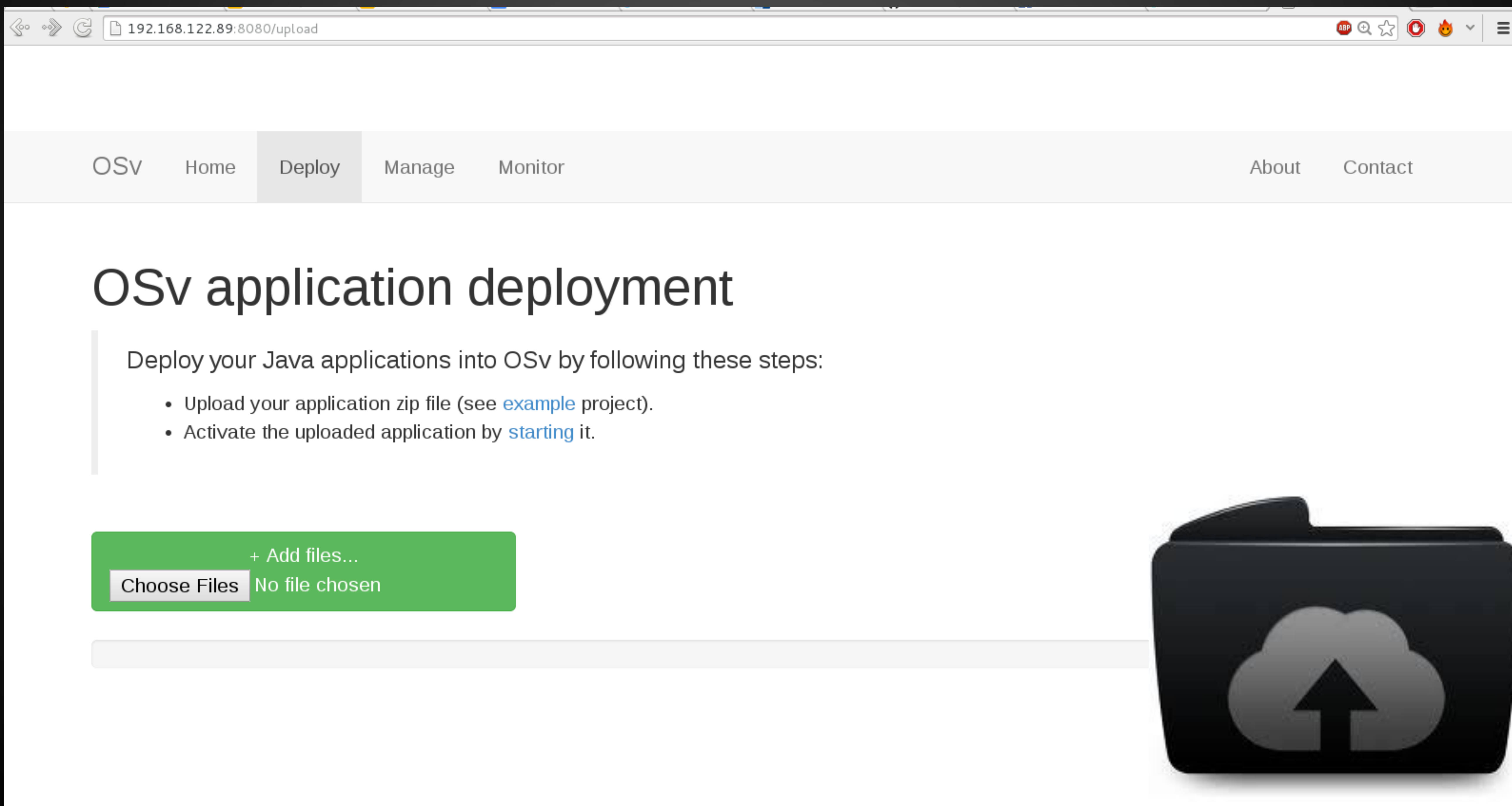
Kernel space only



Linked to existing JVMs

App sees no change

Management


192.168.122.89:8080/upload
OSv
Home
Deploy
Manage
Monitor
About
Contact
OSv application deployment
Deploy your Java applications into OSv by following these steps:
Upload your application zip file (see example project).
Activate the uploaded application by starting it.
+ Add files...
Choose Files
No file chosen

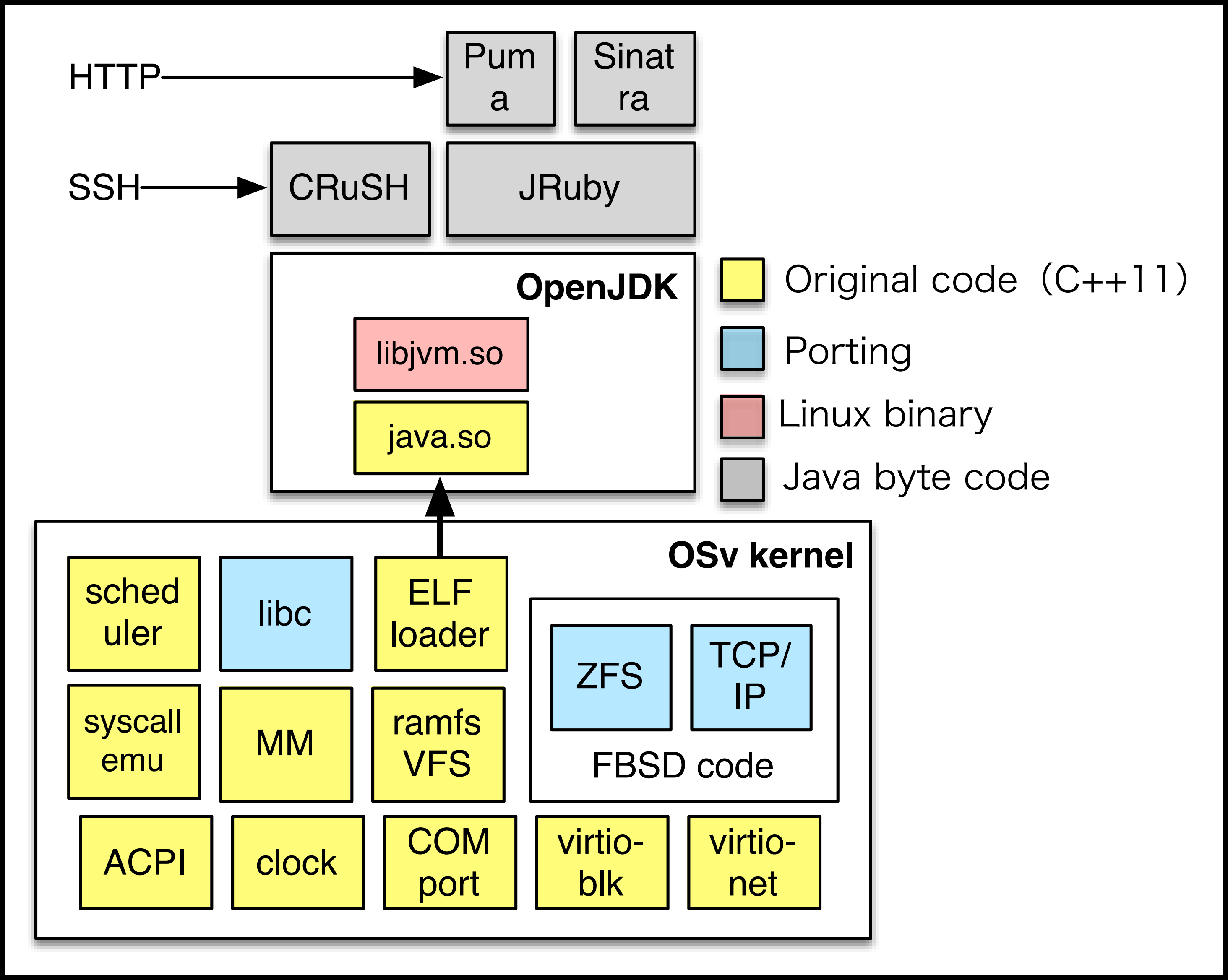
Use cases

- Rent-an-instance on a public cloud
- Internal instance on a private cloud
- Pre-packaged apps
  - MemCache, NoSQL
- OEM virtual appliance

Design of OSv

- **Single process + thread support**
- **Single memory space**, no switch page table
- **Application runs on kernel mode**, no switch privilege mode
- Binary compatibility with Linux app (with some limitation)

OSv internal structure



- Thin OS core + FreeBSD ZFS, TCP/IP and musl-libc
- Able to load & run Linux binary of OpenJDK

C app on OSv

- All application should be compiled with:
  CFLAGS+=-fPIC
  LDFLAGS=-shared
  → Shared library, but with main()

- You can load Linux shared library, but need to recompile executables

- Linux compatibility is implemented on libc layer

- No syscall!

Available apps?

- OpenJDK
  - Cassandra
  - Tomcat
- haproxy
- memcached
- rogue
- mruby
- sqlite
- benchmarks (netperf, iperf, specjvm)

Supported Hypervisor

- Linux KVM
- Xen
- VirtualBox (work in progress)
- VMware (work in progress)

Device drivers

- virtio-blk, virtio-net
- Xen PV drivers
- VMware PV drivers
- SATA
- IDE
- COM port
- VGA & keyboard
- Clock(HPET)

Let's support bhyve!

- Device drivers should work on bhyve (COM port, virtio-net, virtio-blk)
- Main problem is bootloader
- bhyve does not have BIOS, need to implement OSLoader for OSv

bhyveosvload

- Implemented, but still work-in-progress:
- https://github.com/syuu1228/bhyveosvload

What OSLoader do?

- It executes boot procedure on **HostOS side**
- VM launch from 64bit entry point of guest kernel

Traditional boot procedure with BIOS

- BIOS loads boot sector from MBR on a disk
- Boot sector loads and jumps to boot loader (BIOS call used for IO)
- Boot loader initializes page table, GDT and special registers
- Boot loader locates and loads kernel (BIOS call used for IO)
- Boot loader switches to 64bit mode, jumps to kernel entry point

Direct boot

- BIOS loads boot sector from MBR on a disk
- Boot sector loads and jumps to boot loader
  ~~(BIOS call used for IO)~~
- Boot loader initializes page table, GDT and special registers
- Boot loader locates and loads kernel
  ~~(BIOS call used for IO)~~

Do it in HostOS

- Boot loader switches to 64bit mode, jumps to kernel entry point

How to implement it?

- Read assembly code in boot loader, translate it to C code on HostOS, manually

code example(1)

- Print string on console(BIOS INT10h)

```
printf()
```

- Read disk(BIOS INT13h)

```
fd = open(disk_image)
read(fd, buf, len)
```

- memory access

```
ctx = vm_open(vm_name)
ptr = vm_map_gpa(ctx, offset, len)
memcpy(ptr, data, len)
```

code example(2)

- Register write(normal registers)

```
ctx = vm_open(vm_name)
vm_set_register(ctx, cpuno,
VM_REG_GUEST_RFLAGS, val)
```

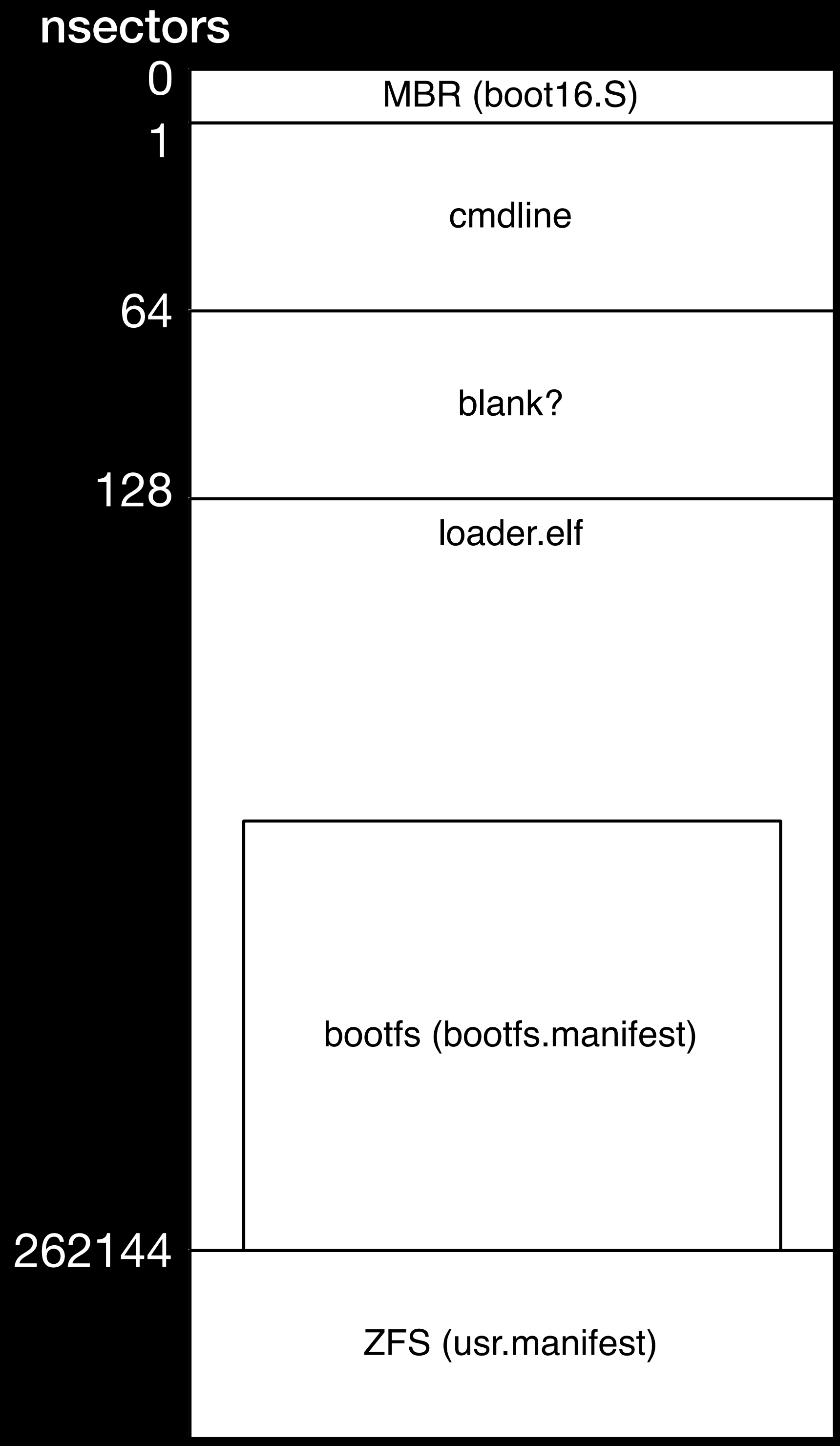
- Register write(Segment registers)

```
ctx = vm_open(vm_name)
vm_set_desc(ctx, cpuno, VM_REG_GUEST_CS,
base, limit, access)
vm_set_register(ctx, cpuno,
VM_REG_GUEST_CS, selector)
```

Let's begin to translate boot16.S

- https://github.com/cloudius-systems/osv/blob/master/arch/x64/boot16.S
- It's on MBR boot sector
    - Load kernel argument from disk
    - Load kernel ELF binary from disk
    - Get memory map from BIOS(e820)
    - Entry to kernel 32bit protected mode code

disk image layout of OSv



- Does not use standard boot loader(Ex:GRUB) to boot faster
- kernel argument, kernel ELF binary are placed on fixed sector

Translate bootcode(1): cmdline load

```
cmdline = 0x7e00

mb_info = 0x1000
mb_cmdline = (mb_info + 16)

int1342_boot_struct: # for command line ← DAP
        .byte 0x10 ← size of DAP
        .byte 0 ← unused
        .short 0x3f   # 31.5k ← number of sectors to be read
        .short cmdline ← segment:offset pointer to the memory buffer（offset側）
        .short 0 ←（segment側）
        .quad 1 ← absolute number of the start of the sectors to be read

init:
        xor %ax, %ax
        mov %ax, %ds ← DS = 0

        lea int1342_boot_struct, %si ← DS:SIでDAPを指定
        mov $0x42, %ah
        mov $0x80, %dl
        int $0x13 ← INT 13h AH=42h: Extended Read Sectors From Drive
        movl $cmdline, mb_cmdline ← mb_info->mb_cmdlineに0x7e00を代入
```

INT 13h AH=42h: Extended Read Sectors From Drive [edit]

Parameters:

Registers	
AH	42h = function number for extended read
DL	drive index (e.g. 1st HDD = 80h)
DS:SI	segment:offset pointer to the DAP, see below

DAP : Disk Address Packet		
offset range	size	description
00h	1 byte	size of DAP = 16 = 10h
01h	1 byte	unused, should be zero
02h..03h	2 bytes	number of sectors to be read, (some Phoenix BIOSes are limited to a maximum of 127 sectors)
04h..07h	4 bytes	segment:offset pointer to the memory buffer to which sectors will be transferred (note that x86 is little-endian: if declaring the segment and offset separately, the offset must be declared before the segment)
08h..0Fh	8 bytes	absolute number of the start of the sectors to be read (1st sector of drive has number 0)

Results:

CF	Set On Error, Clear If No Error
AH	Return Code

Translate bootcode(1): cmdline load

```
char *cmdline;
struct multiboot_info_type *mb_info;

cmdline = vm_map_gpa(ctx, 0x7e00, 1 *
512);
pread(disk_fd, cmdline, 0x3f * 512, 1 *
512);

mb_info = vm_map_gpa(ctx, 0x1000,
sizeof(*mb_info));
mb_info->cmdline = 0x7e00;
```

Translate bootcode(2): kernel load

```
tmp = 0x80000
count32: .short 4096 # in 32k units, 4096=128MB
int1342_struct:
        .byte 0x10
        .byte 0
        .short 0x40   # 32k
        .short 0
        .short tmp / 16
lba:
        .quad 128

read_disk:
        lea int1342_struct, %si
        mov $0x42, %ah
        mov $0x80, %dl
        int $0x13
        jc done_disk
        cli
        lgdtw gdt
        mov $0x11, %ax
        lmsw %ax
        ljmp $8, $1f
1:
        .code32
        mov $0x10, %ax
        mov %eax, %ds
        mov %eax, %es
        mov $tmp, %esi
        mov xfer, %edi
        mov $0x8000, %ecx
        rep movsb
        mov %edi, xfer
        mov $0x20, %al
        mov %eax, %ds
        mov %eax, %es
        ljmpw $0x18, $1f
1:
        .code16
        mov $0x10, %eax
        mov %eax, %cr0
        ljmpw $0, $1f
1:
        xor %ax, %ax
        mov %ax, %ds
        mov %ax, %es
        sti
        addl $(0x8000 / 0x200), lba
        decw count32
        jnz read_disk ← count32回ループ
done_disk:
```

Translate bootcode(2): kernel load

```
char *target;

target = vm_map_gpa(ctx, 0x200000, 1 *
512);
pread(disk_fd, target, 0x40 * 4096 *
512, 128 * 512);
```

Translate bootcode(3): memory map(e820)

```
mb_info = 0x1000
mb_mmap_len = (mb_info + 44)
mb_mmap_addr = (mb_info + 48)
e820data = 0x2000

        mov $e820data, %edi ← ES:DI  Buffer Pointer
        mov %edi, mb_mmap_addr ← mb_info->mb_mmap_addrに0x2000を代入
        xor %ebx, %ebx ← Continuation
more_e820:
        mov $100, %ecx ← Buffer Size
        mov $0x534d4150, %edx ← Signature 'SMAP'
        mov $0xe820, %ax
        add $4, %edi
        int $0x15 ← INT 15h, AX=E820h - Query System Address Map
        jc done_e820
        mov %ecx, -4(%edi)
        add %ecx, %edi
        test %ebx, %ebx
        jnz more_e820
done_e820:
        sub $e820data, %edi
        mov %edi, mb_mmap_len ← mb_info->mb_mmap_lenにe820dataのサイズを代入
```

Translate bootcode(3): memory map(e820)

```
struct e820ent *e820data;

e820data = vm_map_gpa(ctx, 0x1100, sizeof(struct e820ent) * 3);
e820data[0].ent_size = 20;
e820data[0].addr = 0x0;
e820data[0].size = 654336;
e820data[0].type = 1;
e820data[1].ent_size = 20;
e820data[1].addr = 0x100000;
e820data[1].size = mem_size - 0x100000;
e820data[1].type = 1;
e820data[2].ent_size = 20;
e820data[2].addr = 0;
e820data[2].size = 0;
e820data[2].type = 0;

mb_info->mmap_addr = 0x1100;
mb_info->mmap_length = sizeof(struct e820ent) * 3;
```

Translate bootcode(4): entry to protected mode

```
cmdline = 0x7e00
target = 0x200000
entry = 24+target
mb_info = 0x1000

        ljmp $8, $1f
1:
        .code32
        mov $0x10, %ax
        mov %eax, %ds
        mov %eax, %es
        mov %eax, %gs
        mov %eax, %fs
        mov %eax, %ss
        mov $target, %eax ← 0x200000をeaxに設定
        mov $mb_info, %ebx ← 0x1000をebxに設定
        jmp *entry ← 32bit protected modeのコードを動かすつもりはないので無視
```

Translate bootcode(4): entry to protected mode

```
vm_set_register(ctx, 0, VM_REG_GUEST_EAX,
0x200000);
vm_set_register(ctx, 0, VM_REG_GUEST_EBX,
0x1000);
```

Translate boot.S

- https://github.com/cloudius-systems/osv/blob/master/arch/x64/boot.S
- 32bit entry point on kernel
  - Initialize GDT and Page Table, switch to 64bit mode

Translate bootcode(5): Initialize GDT

```
gdt_desc:
    .short gdt_end - gdt - 1
    .long gdt

.align 8
gdt = . - 8
    .quad 0x00af9b000000ffff # 64-bit code segment
    .quad 0x00cf93000000ffff # 64-bit data segment
    .quad 0x00cf9b000000ffff # 32-bit code segment
gdt_end = .

lgdt gdt_desc
```

Translate bootcode(5): Initialize GDT

```
/* gdtrは空いてそうな適当な領域に置く */
uint64_t *gdtr = vm_map_gpa(ctx, 0x5000,
sizeof(struct uint64_t) * 4);
gdtr[0] = 0x0;
gdtr[1] = 0x00af9b000000ffff;
gdtr[2] = 0x00cf93000000ffff;
gdtr[3] = 0x00cf9b000000ffff;

vm_set_desc(ctx, 0, VM_REG_GUEST_GDTR, gdtr,
sizeof(struct uint64_t) * 4 - 1, 0);
```

Translate bootcode(6): Initialize Page Table

```
.data
.align 4096
ident_pt_l4:
    .quad ident_pt_l3 + 0x67
    .rept 511
    .quad 0
    .endr
ident_pt_l3:
    .quad ident_pt_l2 + 0x67
    .rept 511
    .quad 0
    .endr
ident_pt_l2:
    index = 0
    .rept 512
    .quad (index << 21) + 0x1e7
    index = index + 1
    .endr

lea ident_pt_l4, %eax
mov %eax, %cr3
```

Translate bootcode(6): Initialize Page Table

```
uint64_t *PT4;
uint64_t *PT3;
uint64_t *PT2;

/* PT4-2は空いてそうな適当な領域に置く */
PT4 = vm_map_gpa(ctx, 0x4000, sizeof(uint64_t) * 512);
PT3 = vm_map_gpa(ctx, 0x3000, sizeof(uint64_t) * 512);
PT2 = vm_map_gpa(ctx, 0x2000, sizeof(uint64_t) * 512);

for (i = 0; i < 512; i++) {
     PT4[i] = (uint64_t) ADDR_PT3;
     PT4[i] |= PG_V | PG_RW | PG_U;
     PT3[i] = (uint64_t) ADDR_PT2;
     PT3[i] |= PG_V | PG_RW | PG_U;
     PT2[i] = i * (2 * 1024 * 1024);
     PT2[i] |= PG_V | PG_RW | PG_PS | PG_U;
}

vm_set_register(ctx, 0, VM_REG_GUEST_CR3, 0x4000);
```

Translate bootcode(7): Initialize special registers for 64bit mode

```
#define BOOT_CR0 ( X86_CR0_PE \
                 | X86_CR0_WP \
                 | X86_CR0_PG )

#define BOOT_CR4 ( X86_CR4_DE         \
                 | X86_CR4_PSE        \
                 | X86_CR4_PAE        \
                 | X86_CR4_PGE        \
                 | X86_CR4_PCE        \
                 | X86_CR4_OSFXSR     \
                 | X86_CR4_OSXMMEXCPT )
    and $~7, %esp
    mov $BOOT_CR4, %eax
    mov %eax, %cr4 ← PAE有効など
    mov $0xc0000080, %ecx
    mov $0x00000900, %eax
    xor %edx, %edx
    wrmsr ← EFERのLMEフラグを立てている
    mov $BOOT_CR0, %eax
    mov %eax, %cr0 ← PE,PG有効など
    ljmpl $8, $start64
.code64
.global start64
start64:
```

Translate bootcode(7): Initialize special registers for 64bit mode

```
vm_set_register(ctx, 0, VM_REG_GUEST_RSP,
ADDR_STACK);
vm_set_register(ctx, 0,
VM_REG_GUEST_EFER, 0x00000d00);
vm_set_register(ctx, 0, VM_REG_GUEST_CR4,
0x000007b8);
vm_set_register(ctx, 0, VM_REG_GUEST_CR0,
0x80010001);
```

Translate bootcode(8): 64bit entry point

```
#define BOOT_CR0 ( X86_CR0_PE \
                 | X86_CR0_WP \
                 | X86_CR0_PG )

#define BOOT_CR4 ( X86_CR4_DE         \
                 | X86_CR4_PSE        \
                 | X86_CR4_PAE        \
                 | X86_CR4_PGE        \
                 | X86_CR4_PCE        \
                 | X86_CR4_OSFXSR     \
                 | X86_CR4_OSXMMEXCPT )
    and $~7, %esp
    mov $BOOT_CR4, %eax
    mov %eax, %cr4
    mov $0xc0000080, %ecx
    mov $0x00000900, %eax
    xor %edx, %edx
    wrmsr
    mov $BOOT_CR0, %eax
    mov %eax, %cr0
    ljmpl $8, $start64
.code64
.global start64  ← Want to set RIP here
start64:
```

Ouch…

- This function is NOT have fixed address
- Address may changed on recompiling

Let's parse ELF header

Implement symbol name to address function using elf(3) and gelf(3)

int elfparse_open_memory(char *image, size_t size, struct elfparse *ep);

```
int elfparse_close(struct elfparse *ep);
```

```
uintmax_t elfparse_resolve_symbol(struct
elfparse *ep, char *name);
```

Translate bootcode(8): 64bit entry point

```
struct elfparse ep;
uint64_t start64;

if (elfparse_open_memory(target, 0x40 *
4096 * 512, &ep));
start64 = elfparse_resolve_symbol(&ep,
"start64");
vm_set_register(ctx, 0, VM_REG_GUEST_RIP,
start64);
```

Completed implementation!

```
# /usr/local/sbin/bhyveosvload -m 1024 -d ../loader.img osv0
sizeof e820data=48
cmdline=java.so -jar /usr/mgmt/web-1.0.0.jar app prod
start64:0x208f13
ident_pt_l4:0x8d5000
gdt_desc:0x8d8000
# /usr/sbin/bhyve -c 1 -m 1024 -AI -H -P -g 0 -s 0:0,hostbridge -s 1:0,virtio-net,tap0 -s 2:0,virtio-blk,../loader.img -S 31,uart,stdio osv0
ACPI: RSDP 0xf0400 00024 (v02 BHYVE )
ACPI: XSDT 0xf0480 00034 (v01 BHYVE  BVXSDT   00000001 INTL 20130823)
ACPI: APIC 0xf0500 0004A (v01 BHYVE  BVMADT   00000001 INTL 20130823)
ACPI: FACP 0xf0600 0010C (v05 BHYVE  BVFACP   00000001 INTL 20130823)
ACPI: DSDT 0xf0800 000F2 (v02 BHYVE  BVDSDT   00000001 INTL 20130823)
ACPI: FACS 0xf0780 00040
Assertion failed: st == AE_OK (../../drivers/hpet.cc: hpet_init: 171)
Aborted
```

Development Status

- OSLoader implementation is completed
- Still have some problem to boot OSv, because of lack of device driver