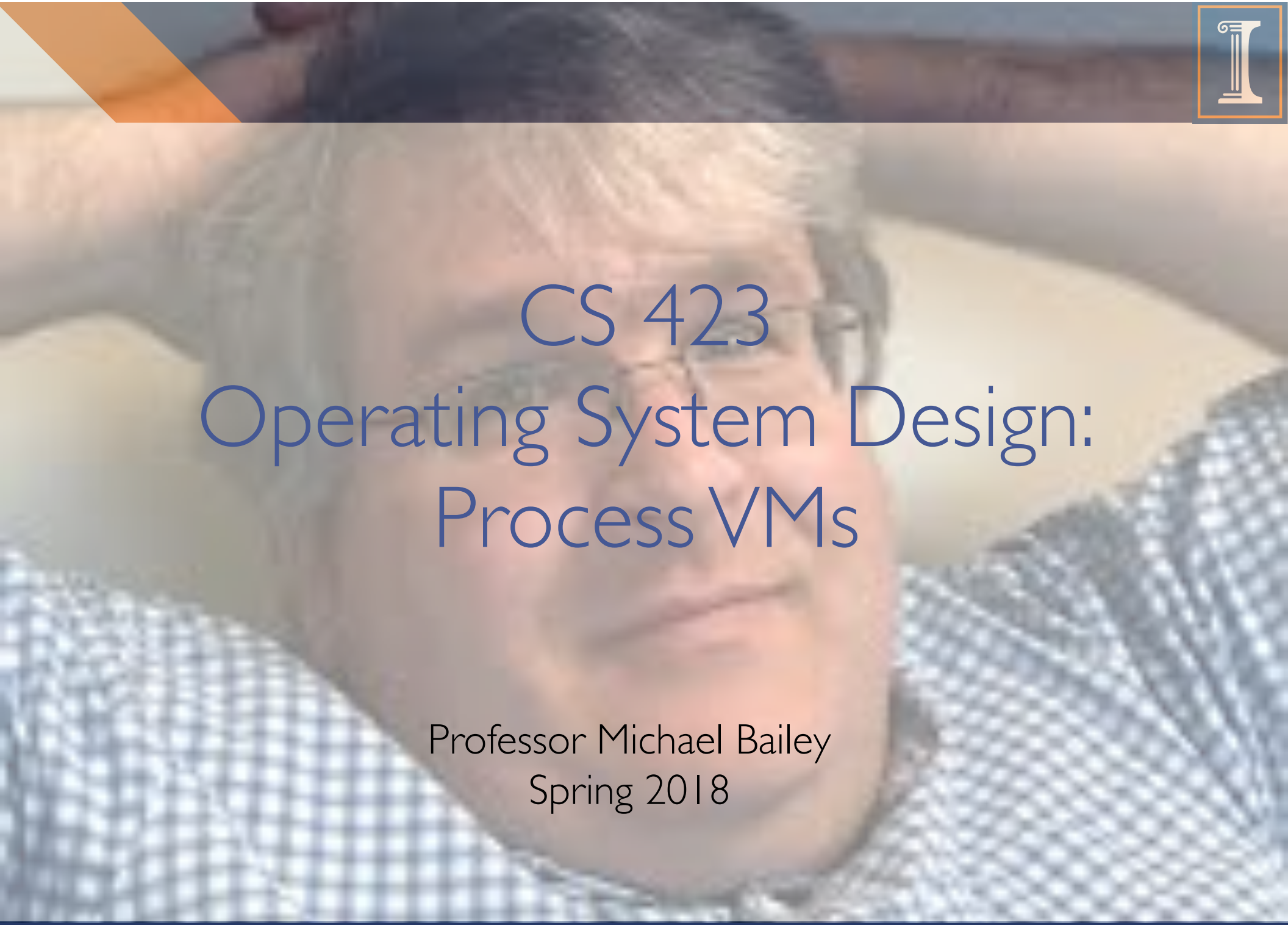


CS 423
Operating System Design: Process VMs

Professor Michael Bailey
Spring 2018

Goals for Today

- Learning Objective:
  - Conclude discussion of virtualization w/ process VMs
- Announcements, etc:
  - MP3 due April 5th
  - Midterm scores released!
    - In-class discussion of tricky questions on Wednesday
    - More questions? Bates office hours are on Tue @ 11am

<—— Your instructor for the day

Reminder: Please put away devices at the start of class

Recap: Emulation/Interpretation

- Problem: Emulate guest ISA on host ISA
- Solution: Basic Interpretation

```
new             inst = code (PC)
                opcode = extract_opcode (inst)
                routineCase = dispatch (opcode)
                jump routineCase
                …

routineCase                     call routine_address
                                jump new
```

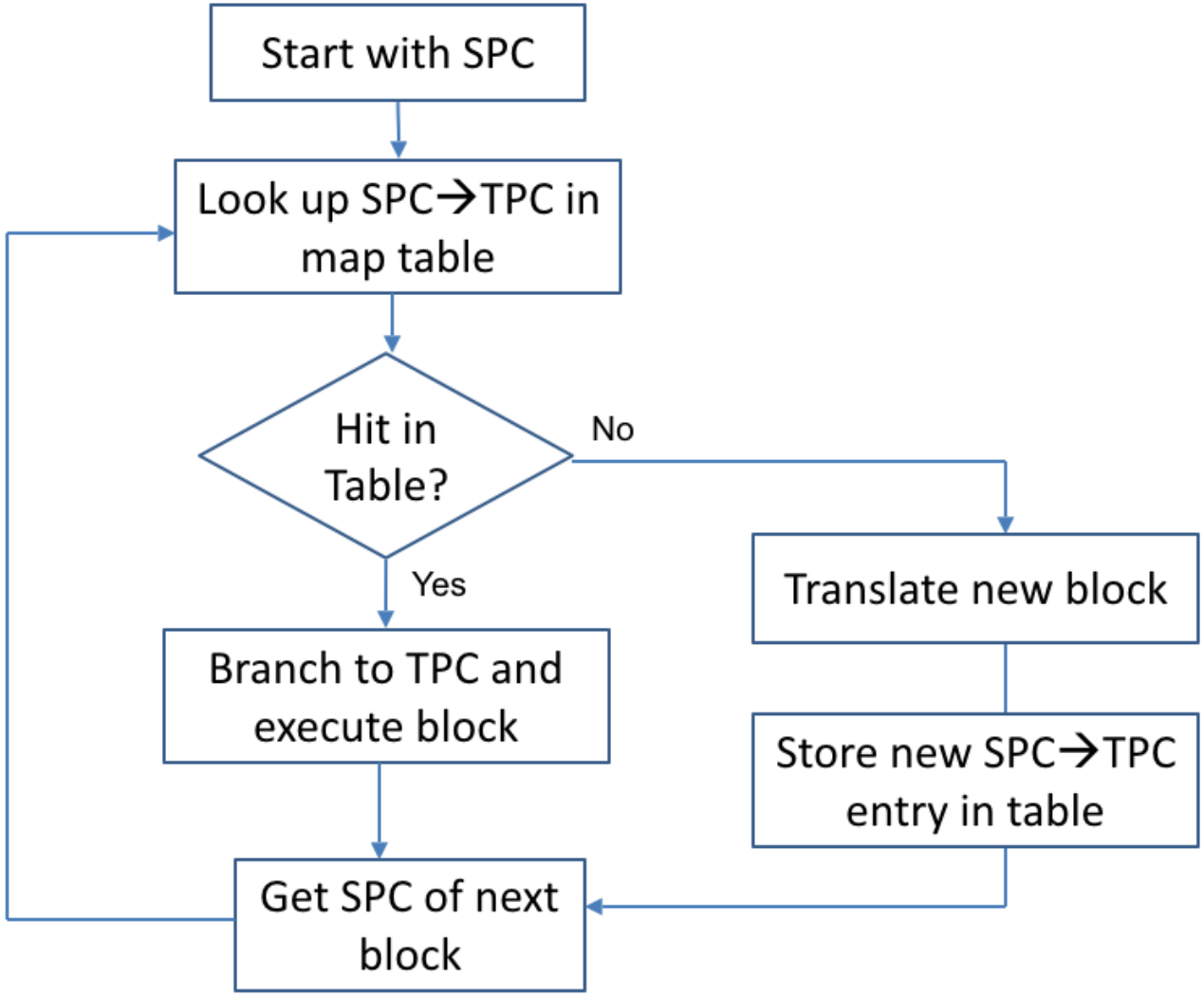
Recap: Emulation vs. Binary Translation

- Emulation:
  - Guest code is traversed and instruction classes are mapped to routines that emulate them on the target architecture.
- Binary translation:
  - The entire program is translated into a binary of another architecture.
  - Each binary source instruction is emulated by some binary target instructions.

Recap: Static Binary Translation?

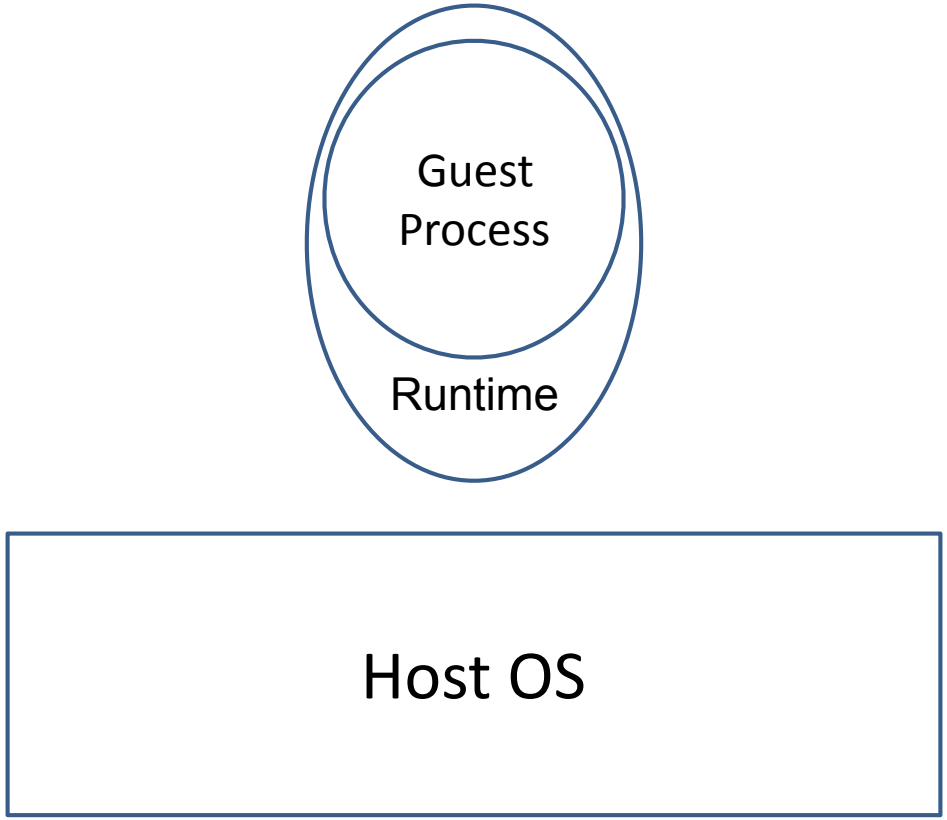
- Code discovery and dynamic translation
  - How to tell whether something is code or data?
  - Consider a jump instruction: Is the part that follows it code or data?
- Code location problem
  - How to map source program counter to target program counter?
  - Can we do this without having a table as long as the program for instruction-by-instruction mapping?

Recap: Dynamic Binary Translation

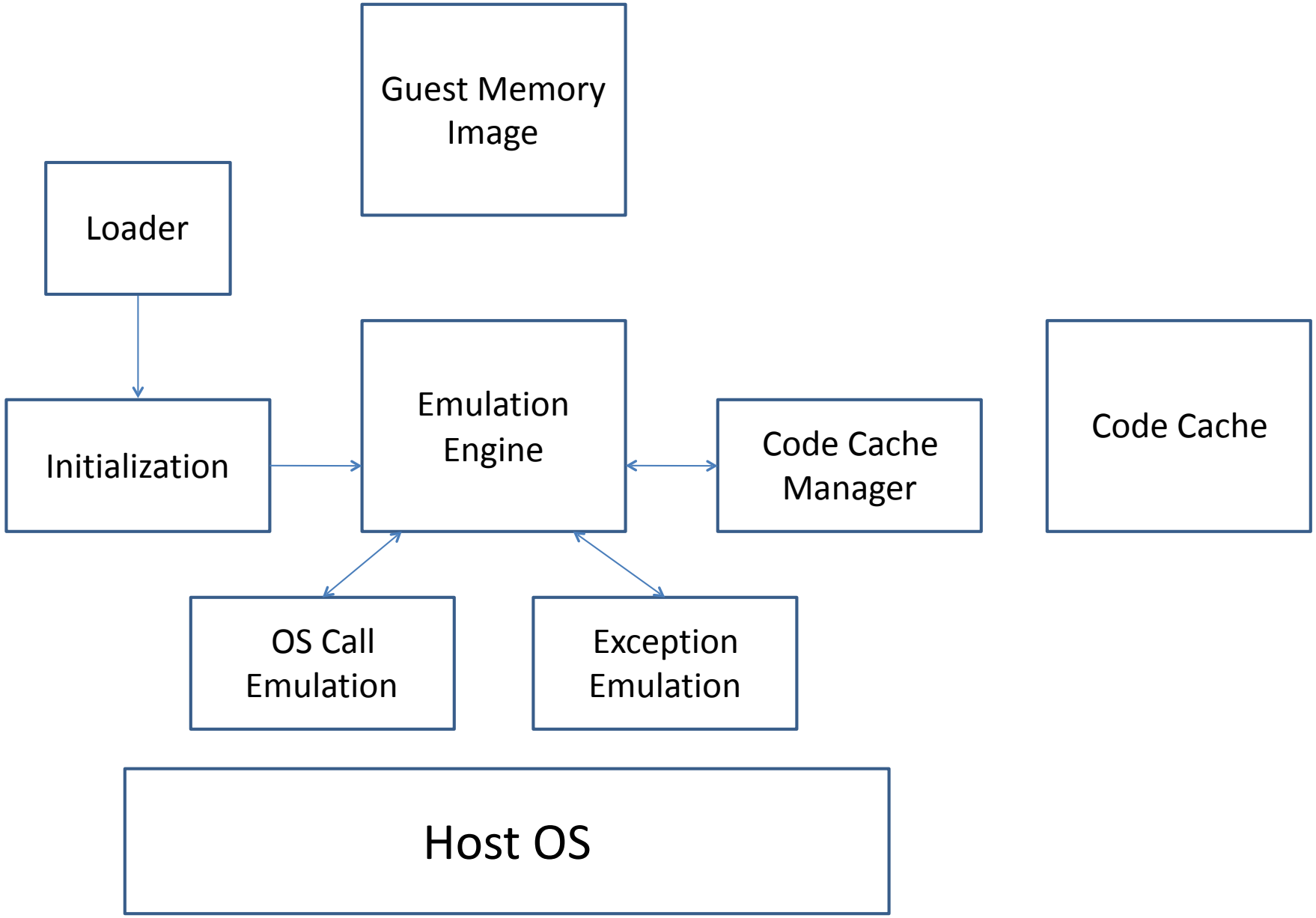


Process VMs

- Present the abstraction of a different machine and OS to a *process*.



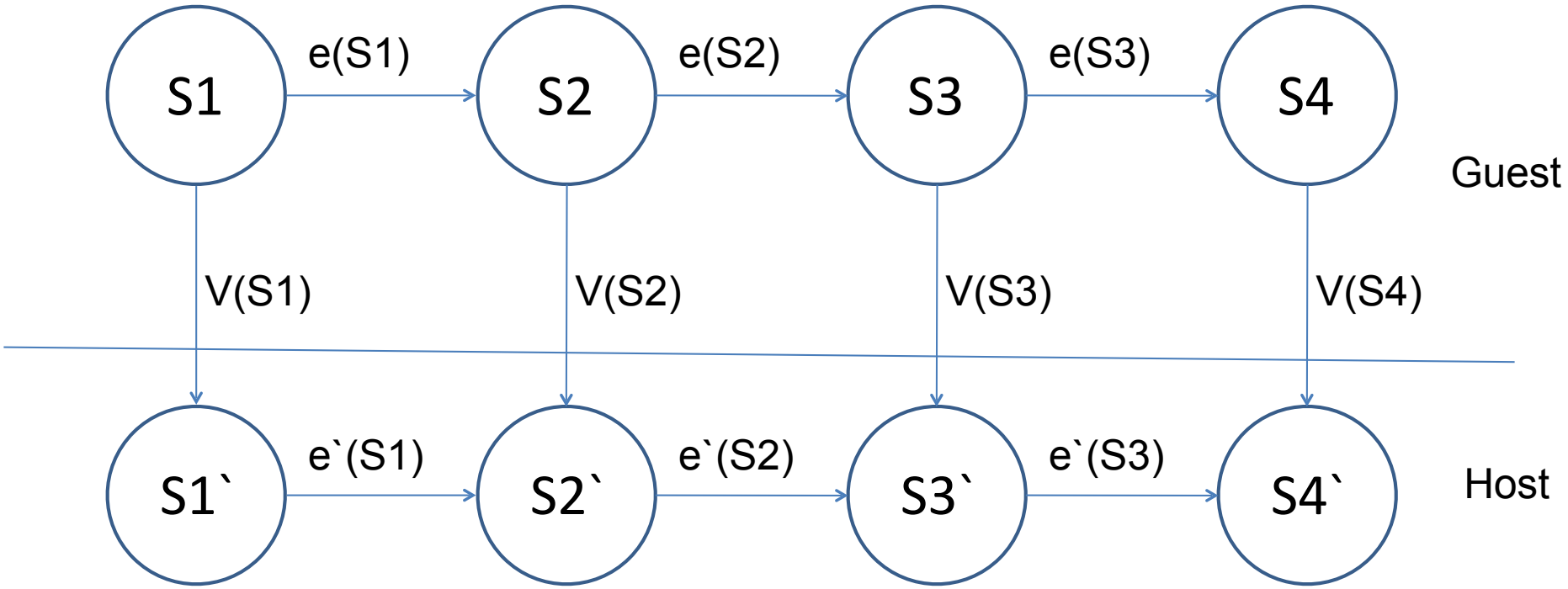
Emulation Architecture



Note: Compatibility

- Process state equivalence at the point of interaction with the "external world"
  - When control transfers from guest process to host OS, state equivalence must hold
  - When control transfers back to guest process, state equivalence must hold (both of user managed and OS managed state)
- Consequences:
  - State does not need to be mapped correctly in between interactions with OS

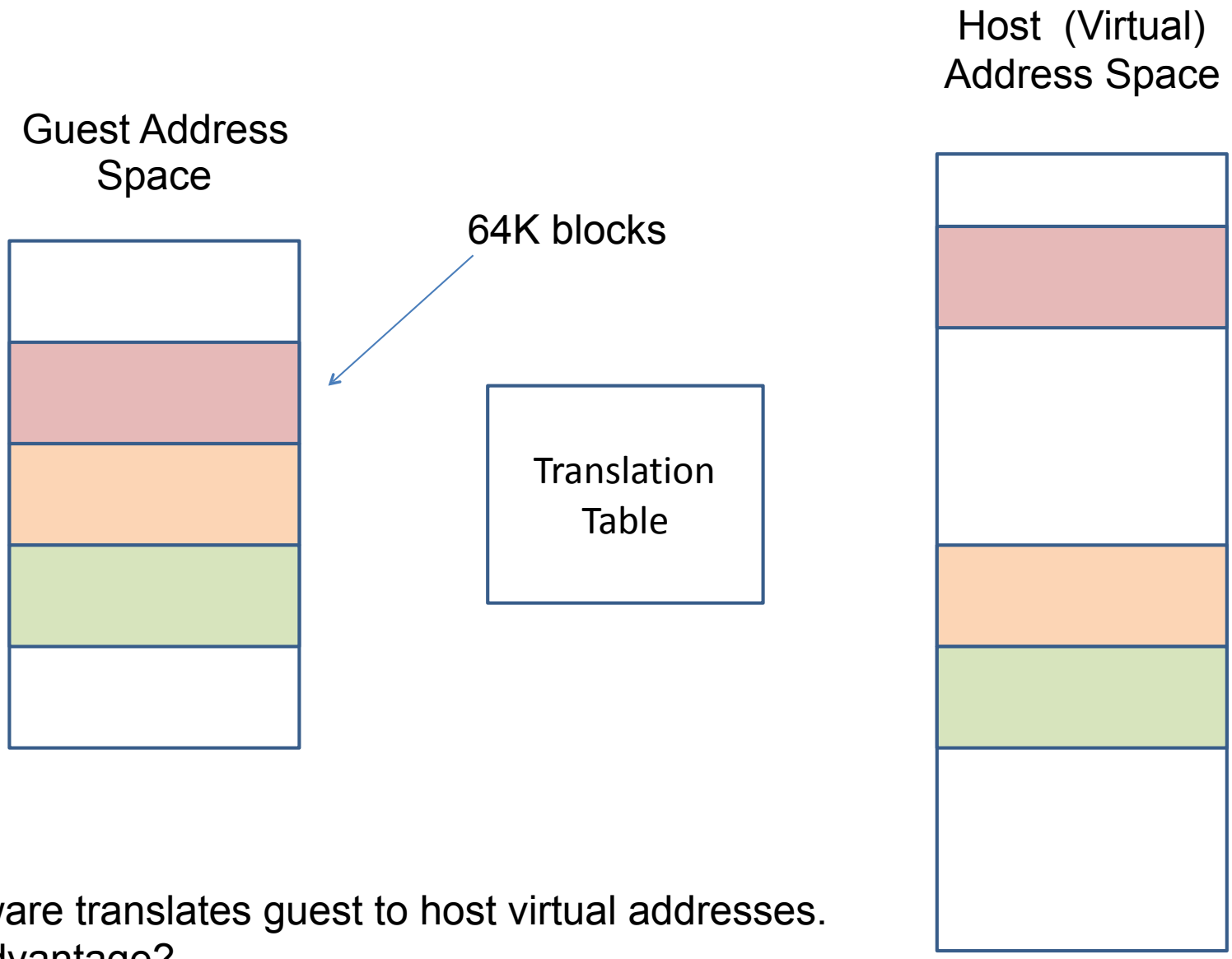
Isomorphism Revisited



State Mapping

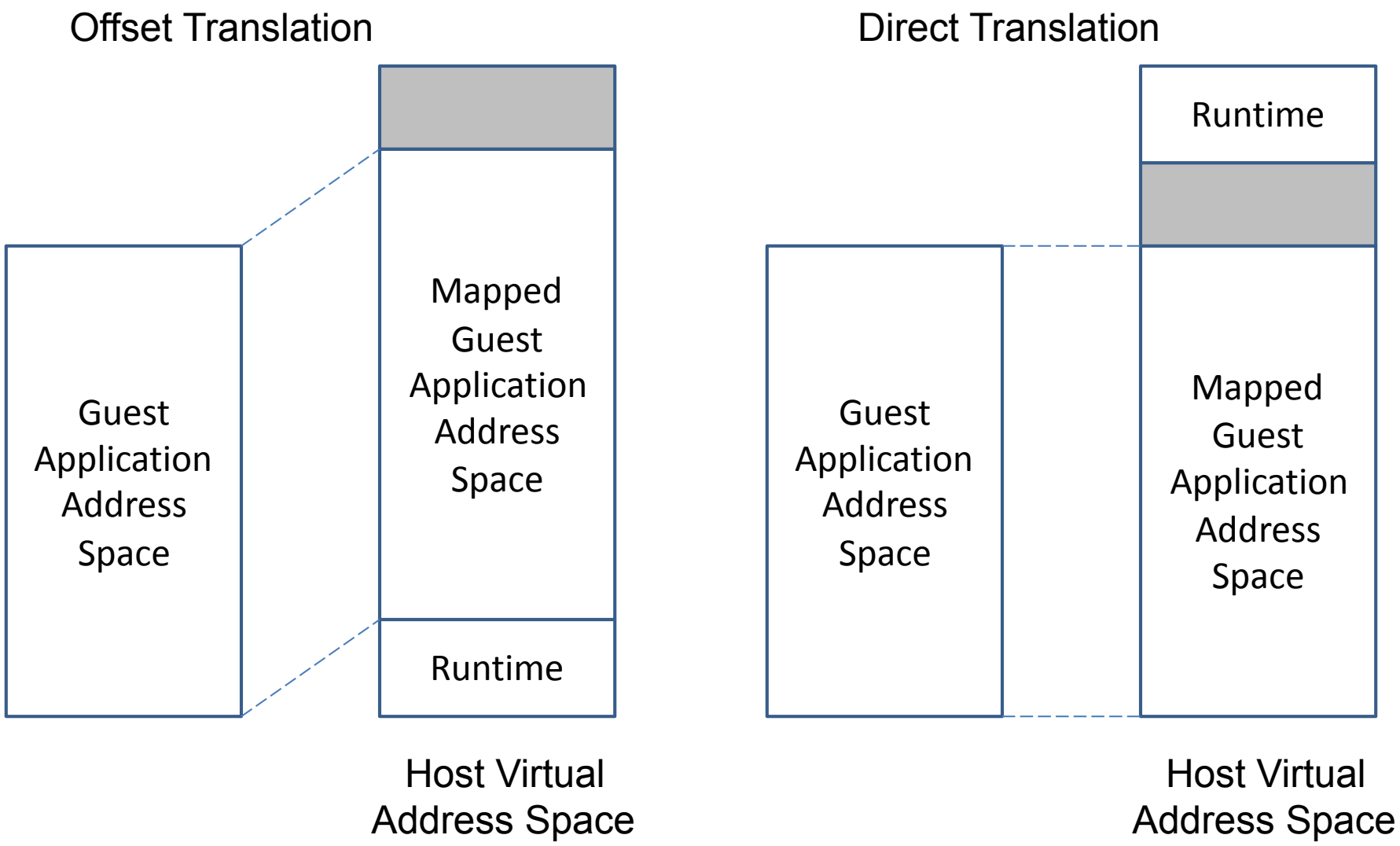
- Guest registers → Host registers/Memory
  - Guest context (and context switch)
  - Depends on who has more registers
- Memory address space mapping
  - Guest application (virtual) address space
    → Host application (virtual) address space

Translation Table

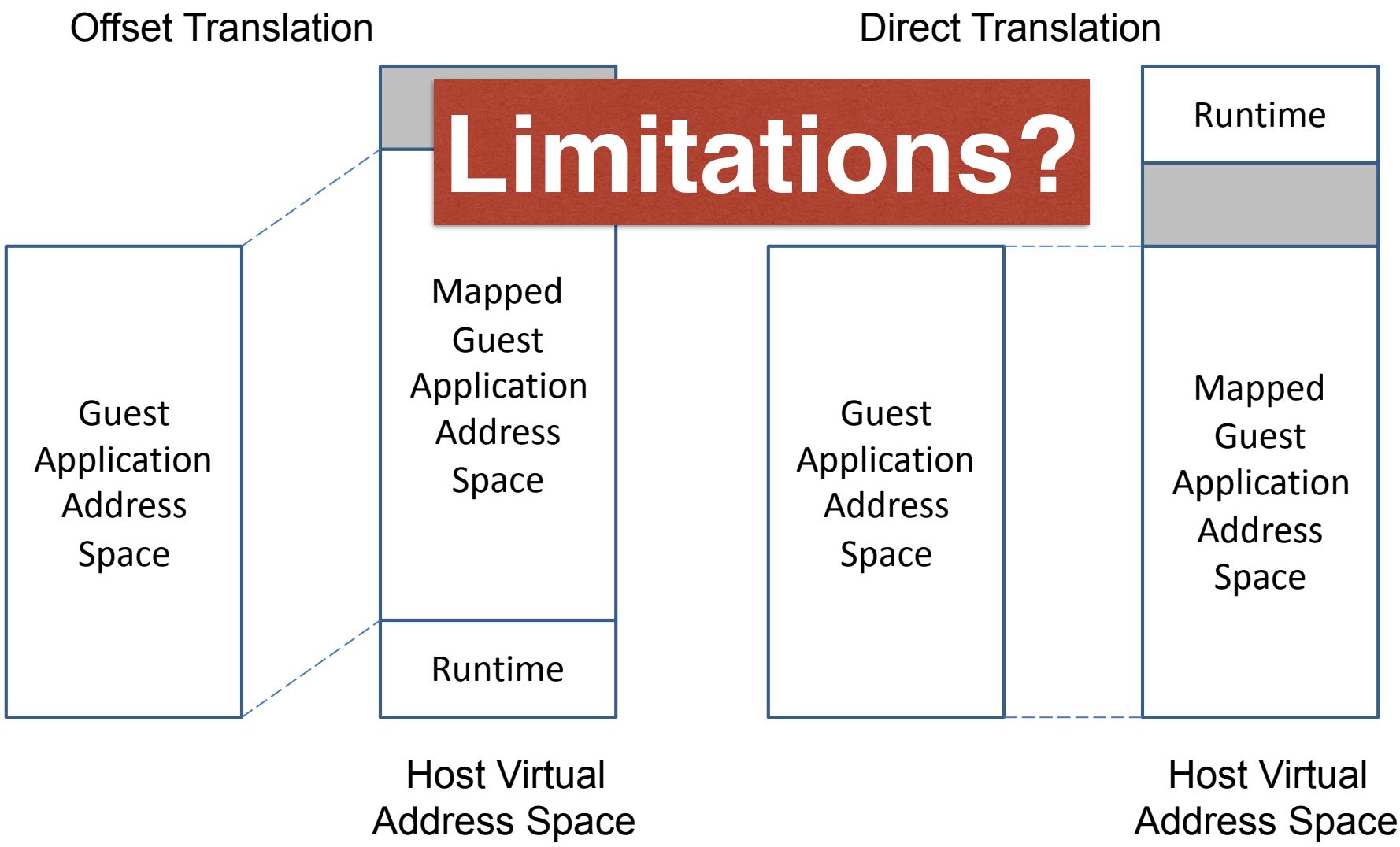


Software translates guest to host virtual addresses.
Disadvantage?

Direct Access Translation



Direct Access Translation



Memory Arch Emulation

- Host OS Offers:
  - A system call to set memory protection (specifies page and access privileges)
  - A signal for a memory protection violation that can be delivered to the application (runtime)
- Memory protection
  - Each page has protection bits such as read/write or read/write/execute (e.g., you cannot execute data, or overwrite code)
  - What if guest architecture has read/write/execute protection whereas host has read/write only?

Page Size Issues

- What if page size on guest is a multiple of page size on host?
- What if page size on host is a multiple of page size on guest?

Page Size Issues

- What if page size on guest is a multiple of page size on host?
  - No problem. Just replicate page protection
- What if page size on host is a multiple of page size on guest?
  - Different guest pages mapped to same host page?
    - Problems?
  - Pad guest pages to size of host page?
    - Problems?

Page Size Issues

- What if page size on host is a multiple of page size on guest?
  - Different guest pages mapped to same host page? Problems?
    - What if pages have different protection?
    - Use the more conservative bits and handle violations accordingly
  - Pad guest pages to size of host page?
    - Makes address translation more difficult

Instruction Emulation

- Interpretation versus binary translation?
  - Interpretation:
    - no startup overhead
    - High overhead per instruction
  - Binary translation:
    - High startup overhead
    - Low overhead per instruction
  - Can we combine the best of both worlds?

Instruction Emulation

- Interpretation versus binary translation?
  - Interpretation:
    - no startup overhead
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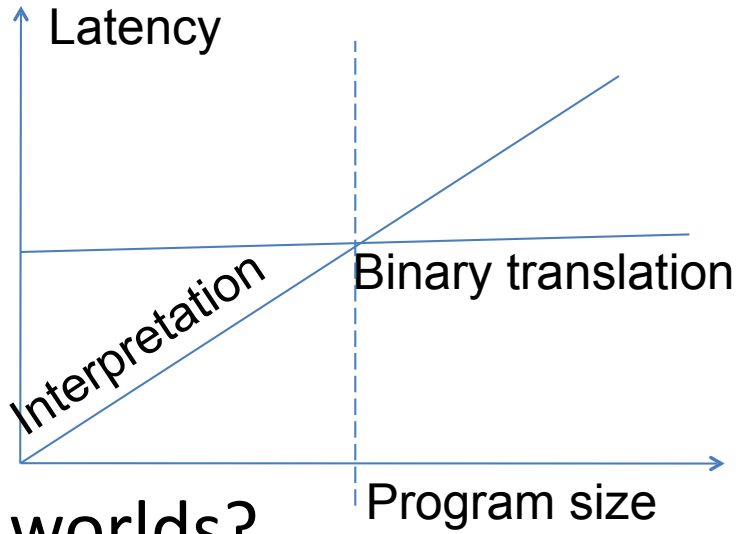
  - Can we combine the best of both worlds?
    - Small program: Do interpretation
    - Large program: Do binary translation



Instruction Emulation

- Initially assume small program
  - Do Interpretation
- Count the number of times each block is executed
- If a block is executed more than N times, do binary translation on this block

Interrupts Emulation

- Two types:
  - Traps (caused by instructions in the program)
  - Hardware interrupts (caused by asynchronous external events)
- For Traps and Exceptions:
  - Ensure that all instructions prior to trap have been executed
  - Ensure that none of the instructions after the trap have been executed
- For Interrupts:
  - Emulated code must be in interruptible state

Traps & Exceptions

- How to detect them?
  - Both guest and host support same trap (e.g., page fault). Map guest trap to host trap: capture trap signal, execute the translated guest handler
    - Runtime intercepts all signals and handles them
  - Guest supports trap/exception that host does not support (or does not deliver to the application). Check for exception conditions in the emulated software explicitly

Interrupts

- When an interrupt occurs:
  - Interpretation: When an interrupt occurs, finish interpreting the current instruction and execute the interrupt handler
  - Binary translation: When an interrupt occurs, the emulated code may be in non-interruptible state (what does that mean?)
    - Need well-defined boundaries where emulated code is interruptible.
    - What is a suitable boundary?
    - When interrupt occurs, execute emulated guest code until boundary is reached, then execute the interrupt handler.

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What if blocks are chained?

Interrupts in Binary Translation

- When an interrupt occurs, the emulated code may be in non-interruptible state
  - Determine which block is currently running
  - Unchain the block from the next by replacing the jump at the end of the block to a transfer of control to the emulation manager.
  - Let the block finish
  - Control is transferred to emulation manager which invoked interrupt handler.

Note: Guest OS Emu

- Does not have to translate guest OS instructions one a time
  - Translate entire functions into equivalent ones
  - Example: replace a disk I/O system call on the guest with an equivalent disk I/O call on the host
- Not all guest system calls need to be translated to host calls; some are handled by the runtime.
  - Example: Calls installing a new signal handler may be handled by the runtime since runtime intercepts all signals and maintains their handlers.
- Generally an ad hoc process (case-by-case).