Final class

Today

- Back to reliability briefly
- Circle-back to two missed topics
  - Software protection Chap 8.4
  - Fault tolerance 10.3
- Course wrap up
- Evaluations

- How are the VMs working?

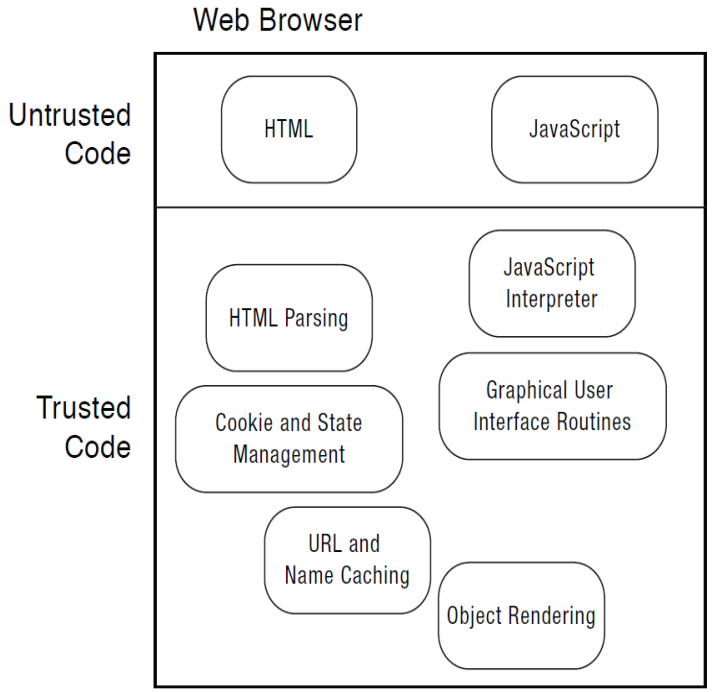
Software Protection

- Talked about hardware protection
  - Address translation, mode bits

- What about doing this in software, reasons:
  - Simplify hardware
  - Application-level protection (e.g. browser needs to protect itself)
  - Protection inside the kernel itself (e.g. 3rd party device drivers)

Methods

- Trap for each instruction?
  - Way too expensive



– Solution (browser as OS)
  - Interpreters, e.g. JavaScript
  - JavaScript attacks: cross-scripting

– Isolate
  - Run browser within a controlled process: protect OS
  - Run tab in its own process: protect browser

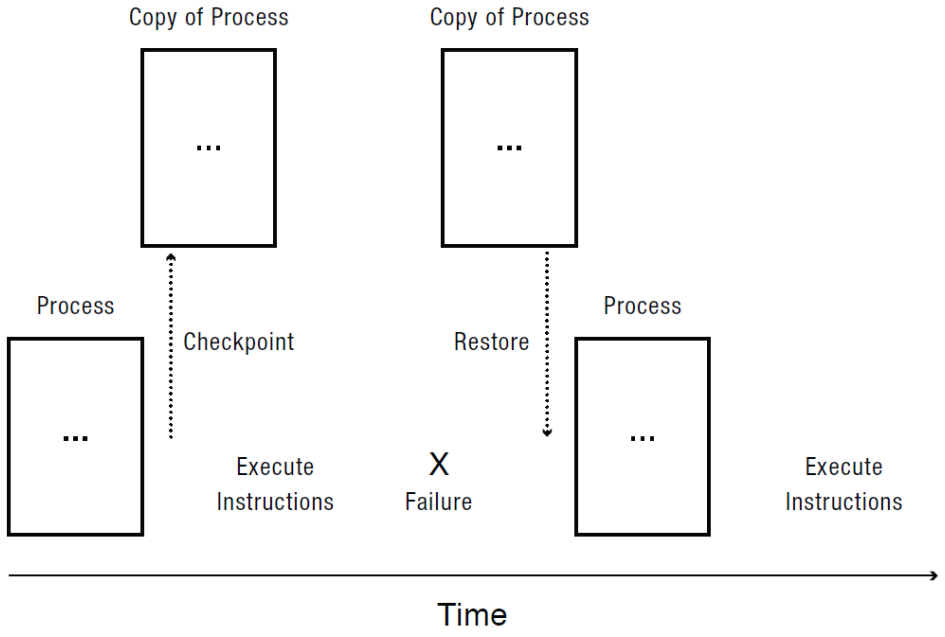
More Methods

- Use safe language, trusted compilers
  - Users don't want to be constrained (e.g. Java everywhere)

- Language-independent solution
  - Sandbox
  - Compile software memory checks into executable
  - E.g. native-client (does this for C code)
  - `mov addr reg =>`
    `if addr between low&high => mov addr reg`
  - Downsides?

Fault Tolerance

- Long-running program meets power-glitch
- Checkpoint/restart
  - User-level
  - System-level
  - Issues?
    - Kernel state
    - Size of checkpoint
  - Block until done or not (copy-on-write)

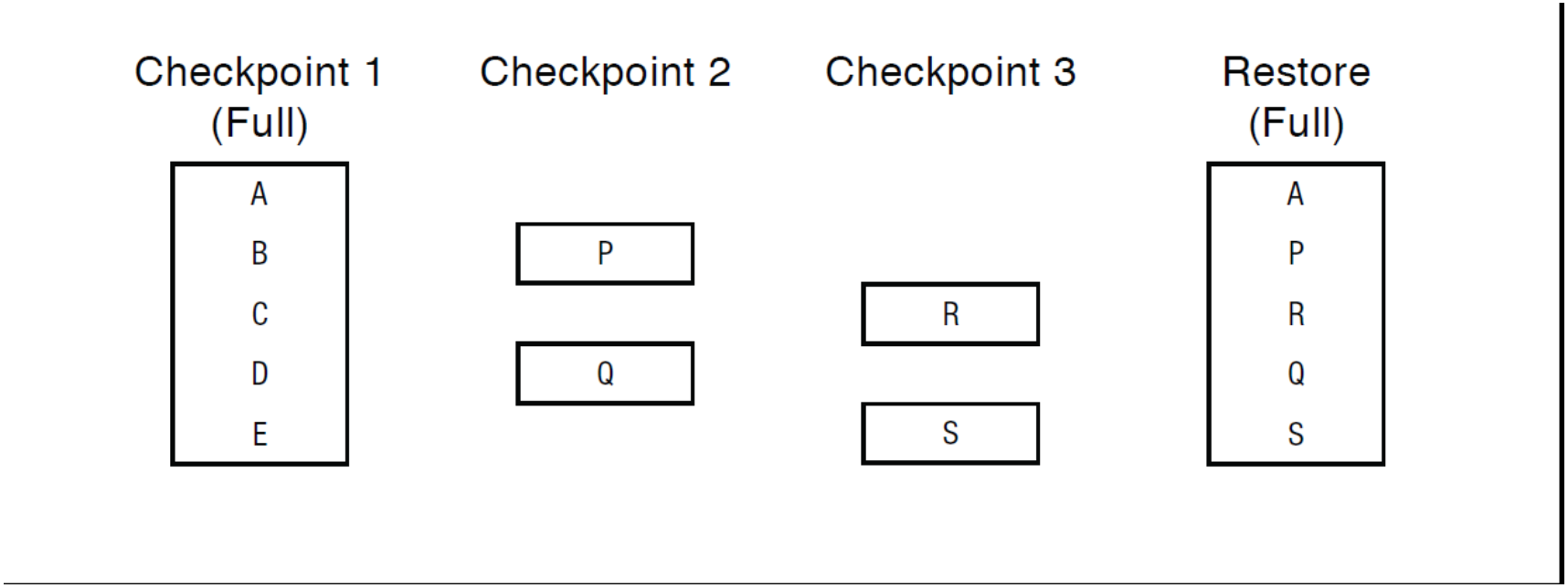


Solutions

- Checkpoints can be large
  - Memory-intensive, virtual machines, kernel state, …
  - Performance issue
- #1 Periodic checkpoints
  - Take periodic snapshots and log of subsequent operations: replay log against most recent checkpoint at restart
    - Restart cost: re-executions
- #2 Take checkpoint as a delta over previous one
    - Restart requires reading many checkpoints

Solutions

- Incremental checkpoints



The END

Major Topics: 100K feet

- Protection
  - Kernel/user mode, system calls
- Concurrency
  - Threads, synchronization, deadlock, scheduling
- Memory management
  - Address translation, demand paging, virtual memory
- File systems
  - Disk, flash, file layout, reliability/transactions

OS as Referee

- Protection
  - OS isolates apps from bugs or attacks in other apps
- CPU scheduling
  - OS decides which application thread is next onto the processor
- Memory allocation
  - OS decides how many memory frames given to each app
- File system
  - OS enforces security policy in accessing file data

OS as Illusionist

Physical Reality	*Abstraction*
Limited # of CPUs	Can assume near infinite # of processes/threads
CPU interrupts and time slicing	Each thread appears to run sequentially (at variable speed)
Limited physical memory	Near-infinite virtual memory
Apps share physical machine	Isolation between apps via processes or VMs
Computers can crash	Changes to file system are atomic and durable

OS as Abstraction Provider

- Locks and condition variables
  - Not test&set instructions
- Named files and directories
  - Not raw disk block storage
- Process
  - Not *x* CPU cycles, *y* memory, *z* open files, …
- Memory-mapped files
  - Not raw disk reads/writes

OS Trends and Future Directions

- Optimize for the computer's time

  => optimize for the user's time
- One processor core => many
- One computer => server clusters
- Disk => persistent solid state memory/PCM
- Modest memory => huge memory
- Operating systems everywhere (at user level)
  - browsers, databases, servers, parallel runtimes, sandboxes
- Operating system for Internet of Things

Some Cross-Cutting Themes

- Indirection
  - Virtual addressing, File storage, …
- Batching to overcome latency
  - Disk access, Disk scheduling, LFS
- Isolation
  - processes, transactions, …

The Final

- Incremental, sort of …
- Chapters 8.4, 9, 10.3, 11, 12, 13, 14
  - Virtual memory > Basics
  - File systems
  - Storage systems
  - Reliable storage
  - Software protection
- Closed book
- 75 minute exam, have over 2 hours
- Mix of short and long questions 1/3 : 2/3

Questions?

Evaluations