A Replay-based Approach to Performance Analysis

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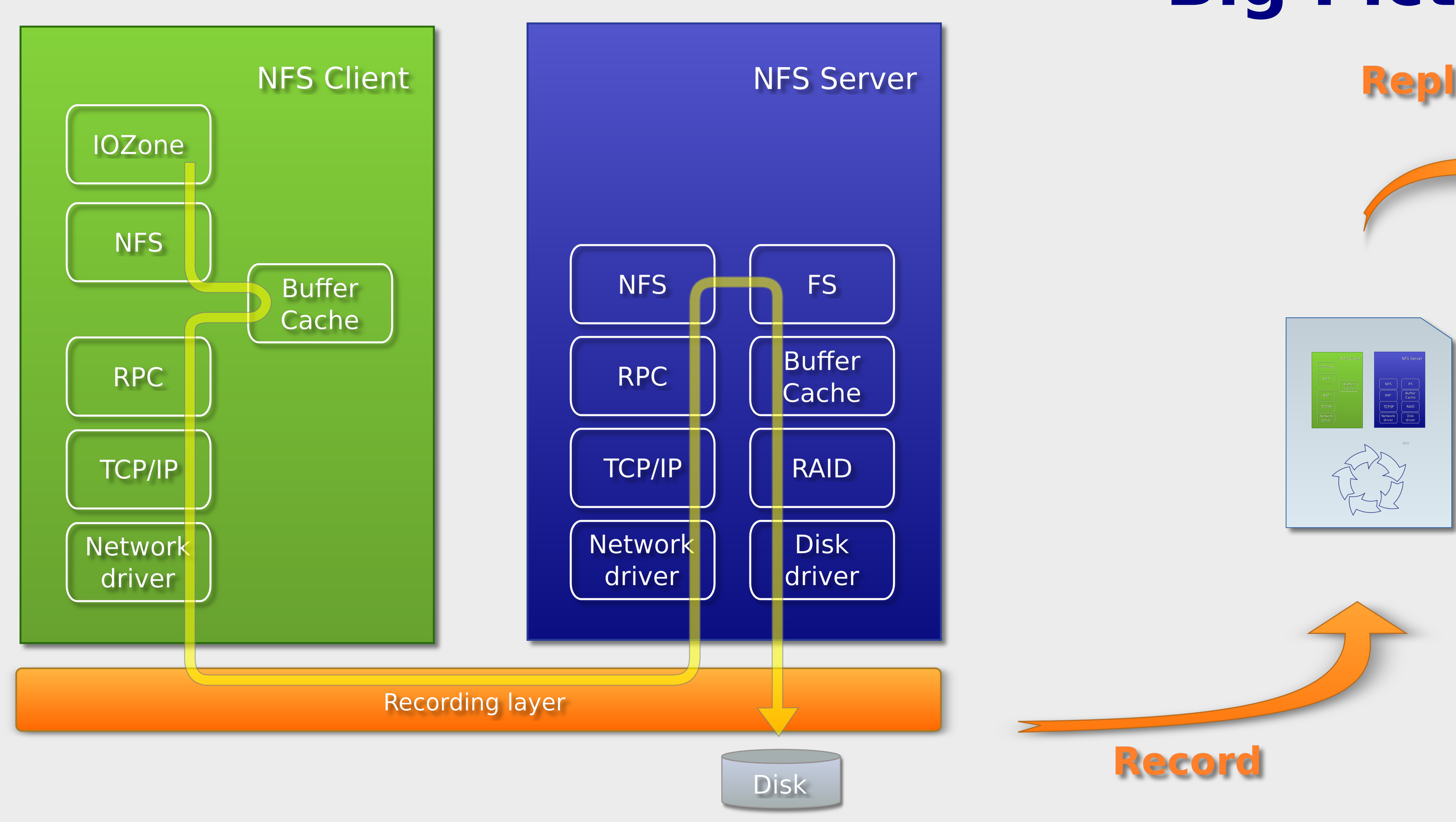
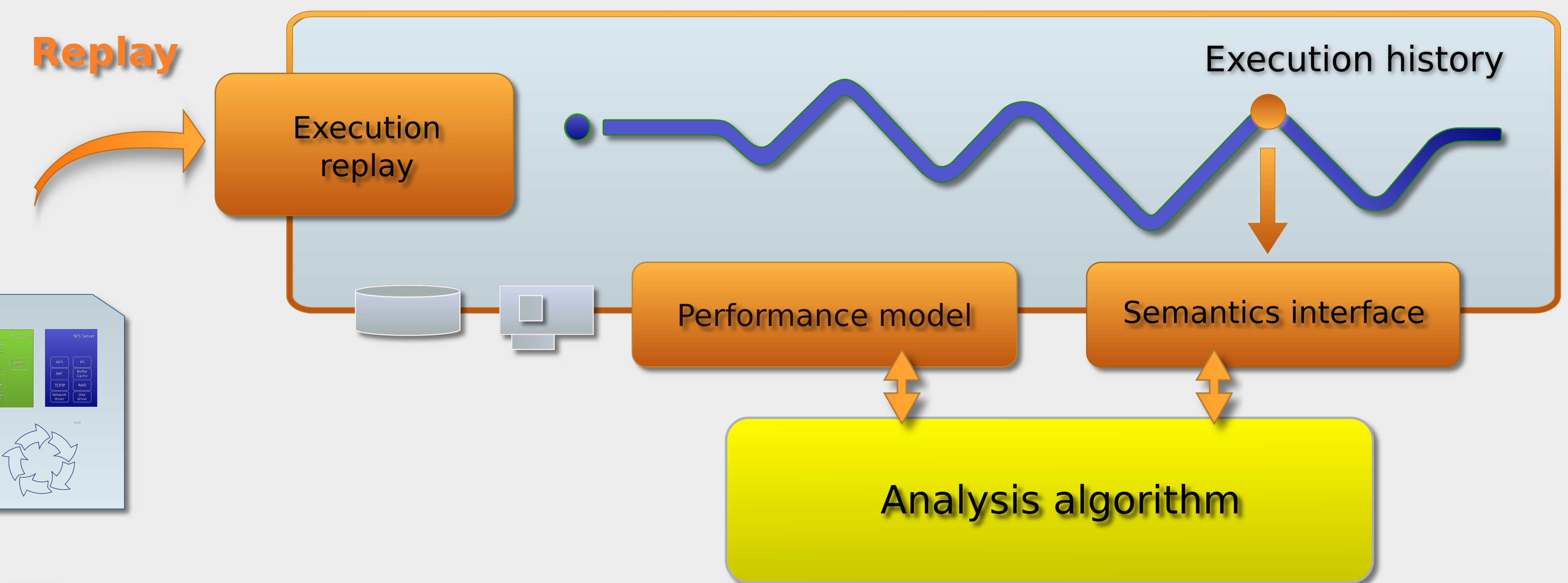
Big Picture





NFS benchmark: IOZone, a filesystem benchmark, runs over an NFS-mounted filesystem on a client machine. Processing of every filesystem write involves two machines and multiple operating system components until it reaches the physical disk. Request path is shown with a yellow line. Configuration of the NFS protocol, number of NFS server threads, size of TCP/IP buffers, configuration of RAID and disk write buffering, and many other factors affect performance of the system.

Analysis framework: We turn performance, a dynamic property of a particular execution, into a static property that can be analyzed separately from an actual instance of a running system. An analysis framework is a low-level mechanism that exports the behavior of a system to a higher level, at which analysis is formulated in a platform-independent manner.

Several unique properties of our approach enable new ways of analyzing the performance of complex systems. The determinism of analyses and the availability of the global run-time state of the system and its execution history provide support for analysis of transient performance anomalies, evaluating effects of multiple interleaving bottlenecks, and correlating the performance behavior of a system with its functional properties

Motivation

Complex systems
- Multiple engineering optimizations
- Composed of simple components that promptly evolve into complex artifacts
- Emergent behavior

Performance is determined by
- Availability of data
- Latencies of communication
- Delays of synchronization
- Efficiency of scheduling

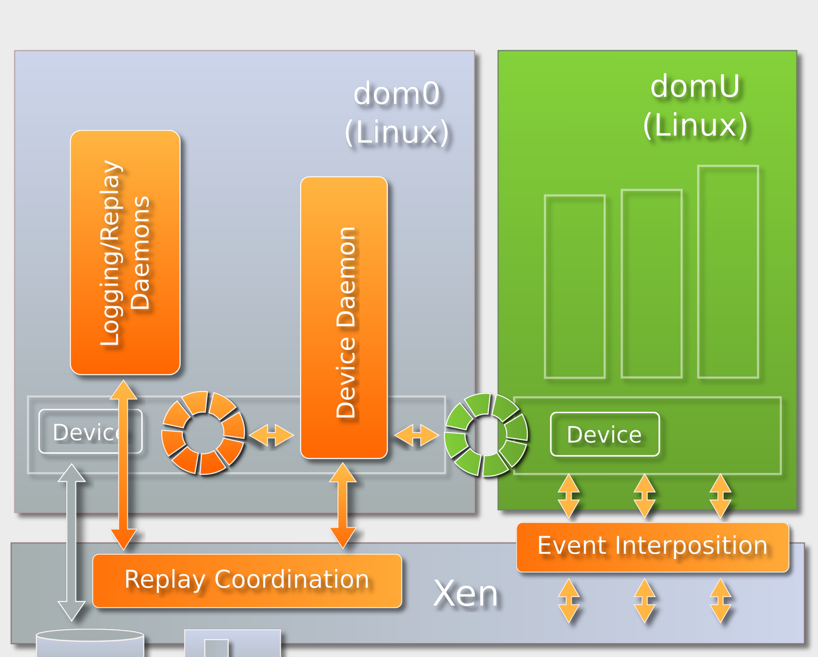
Analysis requires reasoning about
- Dynamic state of multiple components, buffers, and caches
- Control and data flow between them
- Performance of individual requests (slow and fast paths)
- Availability of resources for pipelined and parallel execution

Existing approaches are inherently limited
- Strict requirement of low run-time overhead
- Collect only minimal subset of the run-time state
- No means to correlate collected data with actual system's state

Idea

- Capture complete execution with deterministic replay
- Run analysis offline
  - An old idea (Balzer, AFIPS'69), which is enabled by recent advances in virtualization (Xu et al., MoBS'07)

Execution replay



Goal:
- Realistic systems
- Realistic workloads

Combine recording mechanisms with a full-featured VMM
- Low-overhead recording
- Analysis of the entire software stack

Logging and replay infrastructure: four logging and replay components and a high-bandwidth communication channel across them are designed to implement lightweight recording of all nondeterministic events.

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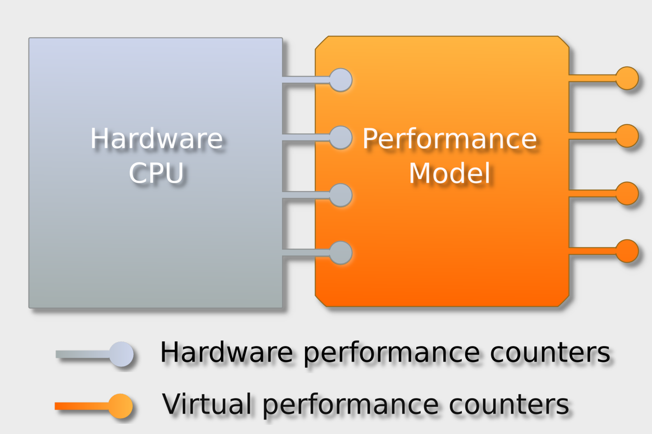
Performance model



Re-execution approach to performance
- Identical hardware
- Recreate conditions of the original run

Performance counters
- Export performance for analysis
- Simple linear model
- Need to record only time

Virtual performance counters: account for effects of replay mechanisms, and translate performance between original and replay runs.

Analysis interface

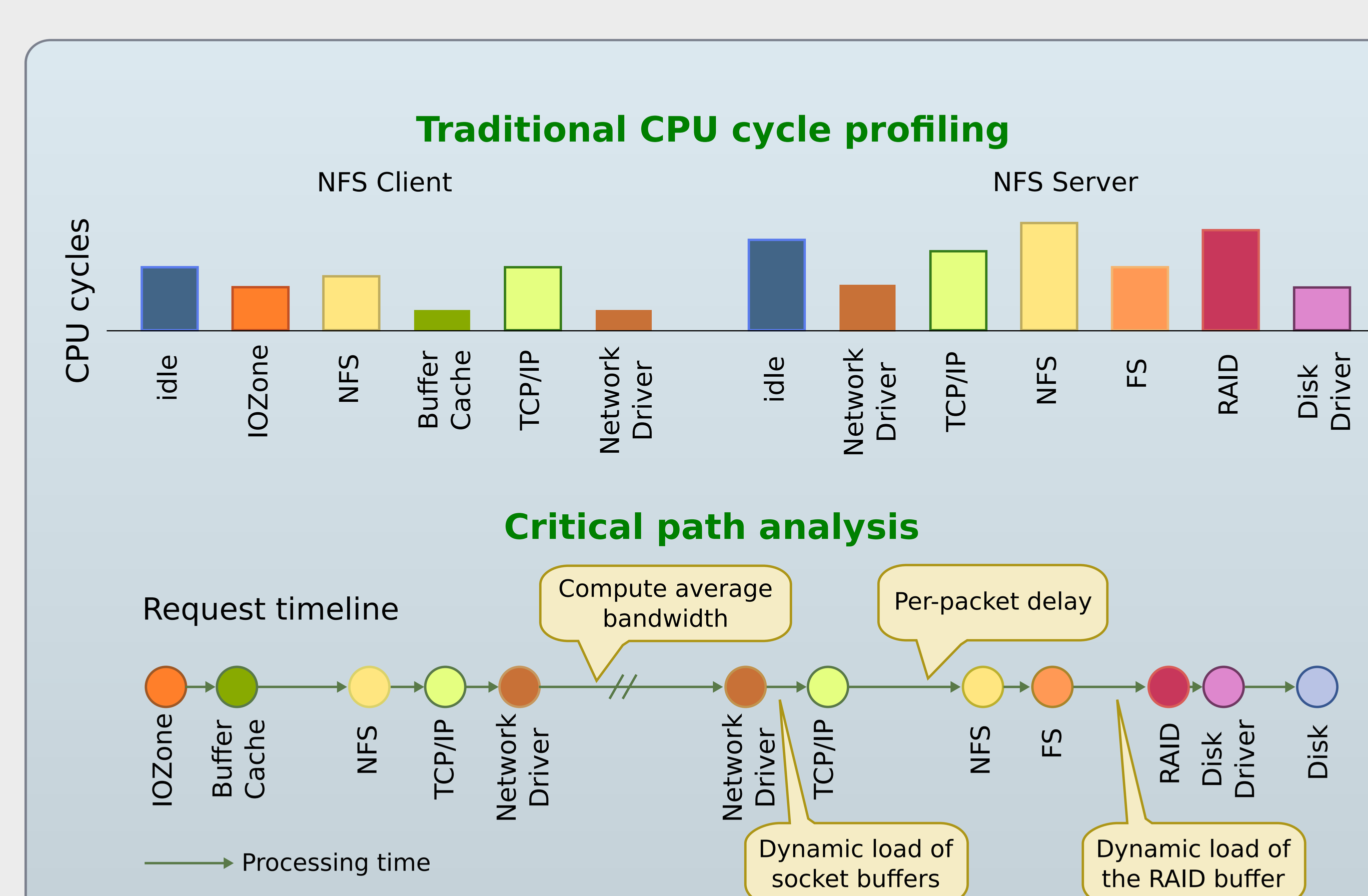
Analysis is driven by changes in run-time state of the system
- "Big step" semantics

Binary rewriting to instrument execution (SystemTap)
- Safe analysis language

```
probe kernel.function(*@mm/*.c).call
      { called[probefunc()] <<< 1 }
```

We integrate it with deterministic replay mechanisms

Insight into analysis algorithms



Multiple replay sessions allow us to run different analyses and collect various performance measurements in a consistent way.

- Automatic generation of the request-processing path
- Fine-grain performance model
- Automatic search for transient performance anomalies
- Combination with static analysis