PERFORMANCE MONITORING OF ARCHITECTURALLY DIVERSE SYSTEMS

Joseph M. Lancaster, Roger D. Chamberlain
Dept. of Computer Science and Engineering
Washington University in St. Louis
{lancaster, roger}@wustl.edu

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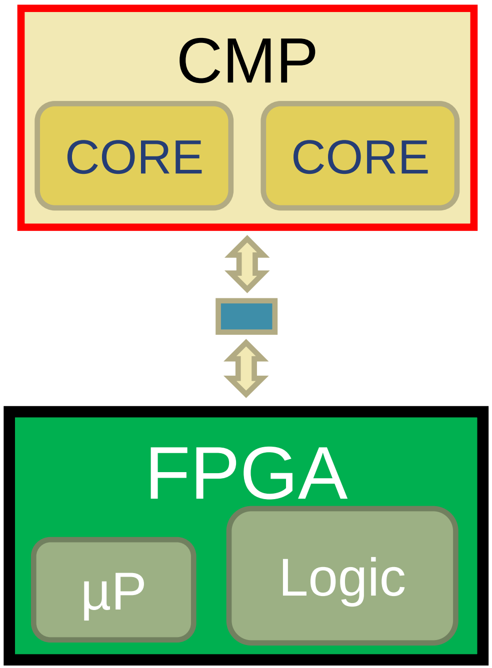
We want apps that…

- Run correctly
  - Do not dead-lock
  - Meet hard real-time deadlines
- Run fast
  - High-throughput / low latency
  - Low rate of soft deadline misses

Infrastructure should help us debug when it runs incorrectly or slow

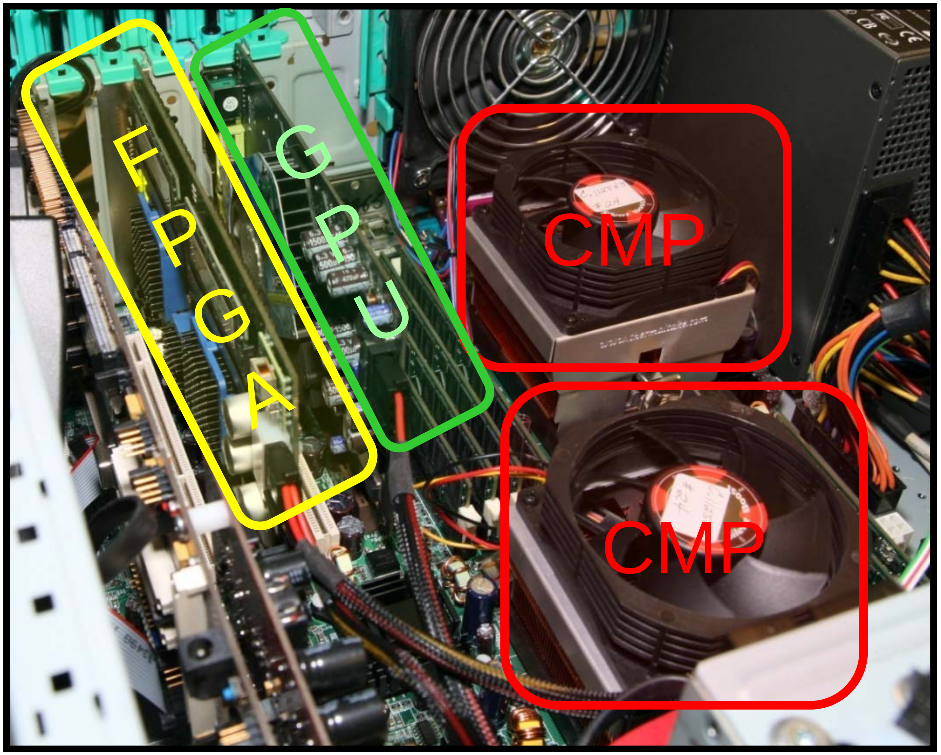
Diverse Computing

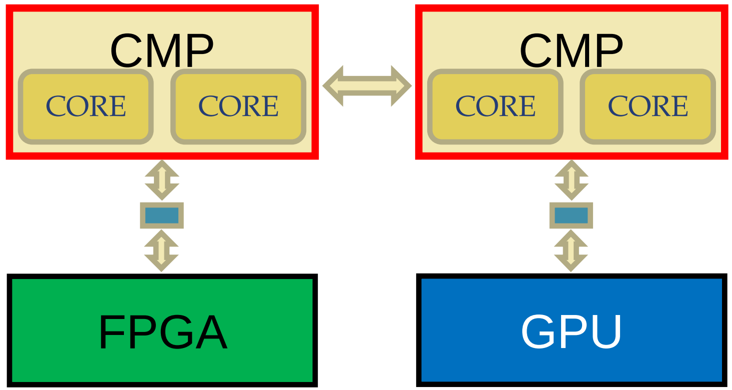
- Increasingly common in HPEC systems
- e.g. Mercury, XtremeData, DRC, Nallatech, ClearSpeed



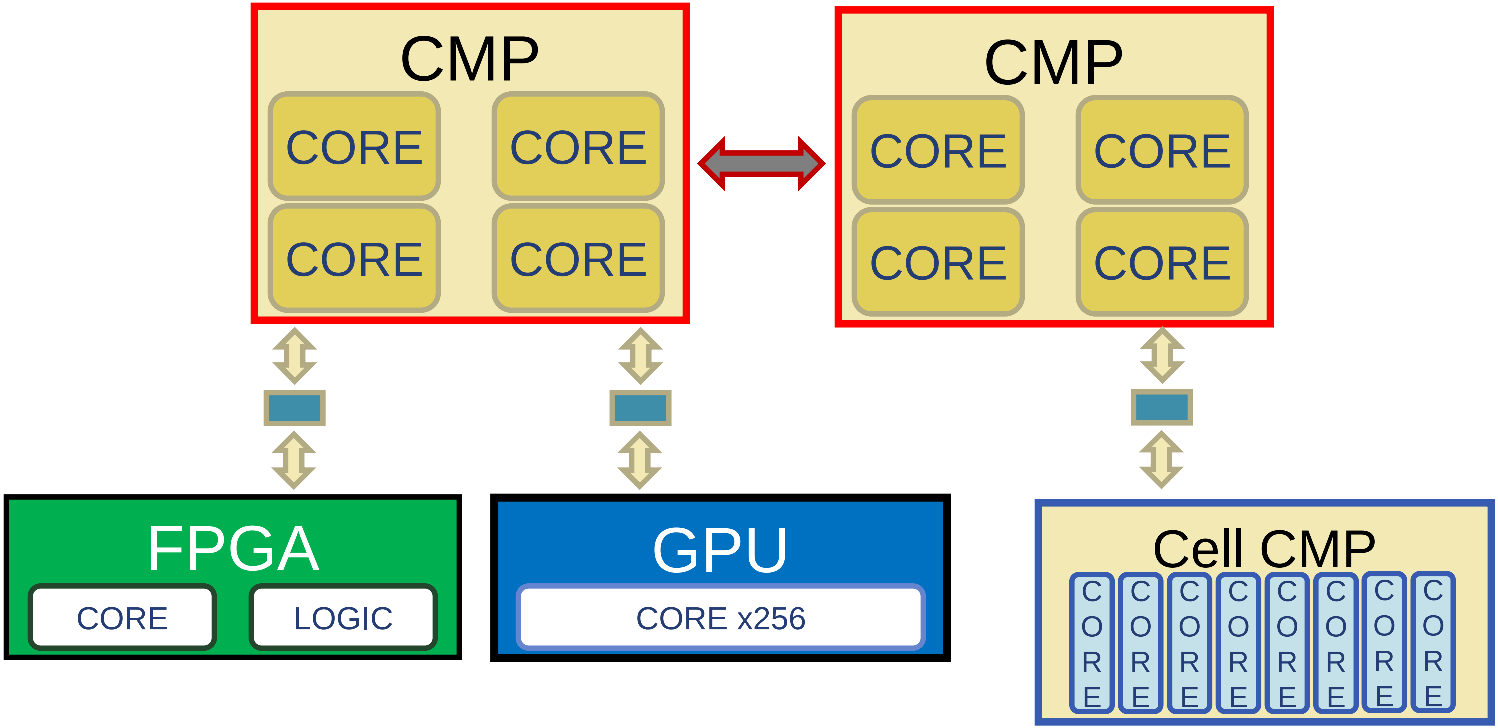
Diverse Computing

- App deployed using all four components





Diverse Computing



Benefits and Challenges

+ Large performance gains realized
+ Power efficient compared to CMP alone

– Requires knowledge of individual architectures/languages
– Components operate independently
  - Distributed system
  - Separate memories and clocks

Motivation

Tool support for these systems insufficient

- Many architectures lack tools for monitoring and validation
- Tools for different architectures not integrated
- Ad hoc solutions

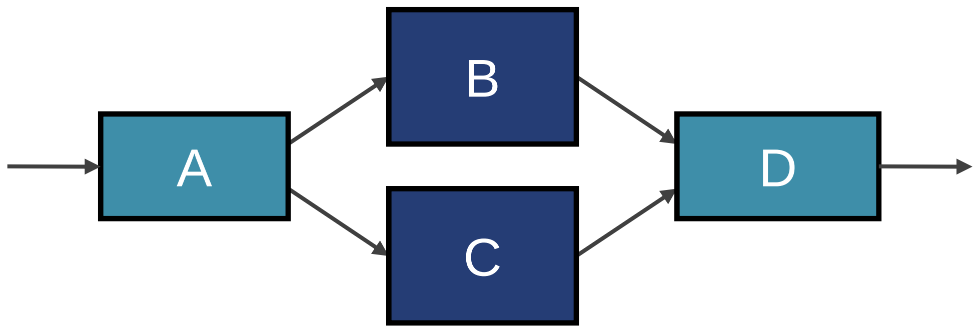
Solution: Runtime performance monitoring and validation for diverse systems!

Outline

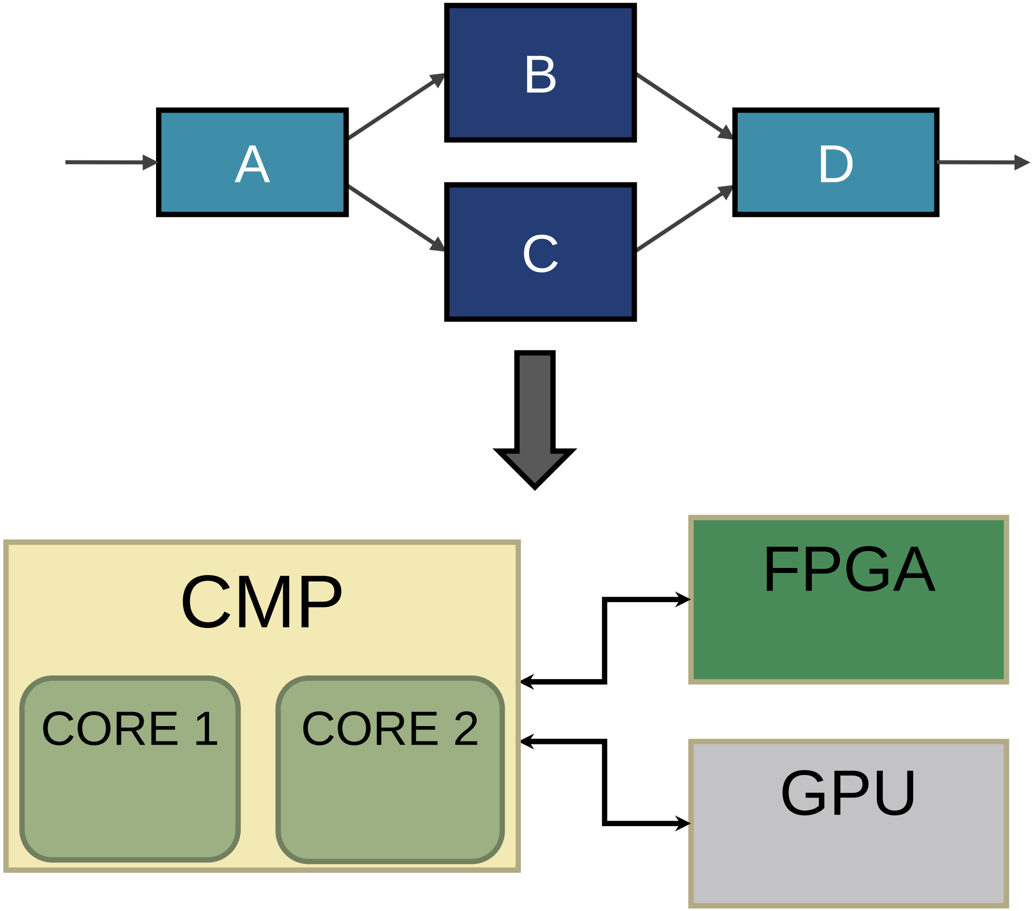
- Introduction
- **Runtime performance monitoring**
- Frame monitoring
- User-guidance

Stream Programming

- Natural fit for diverse HPEC systems
- Dataflow model
  - Composed of blocks and edges
  - Blocks compute concurrently
  - Data flows along edges
- Languages: StreamIt, Streams-C, X



Mapping Process



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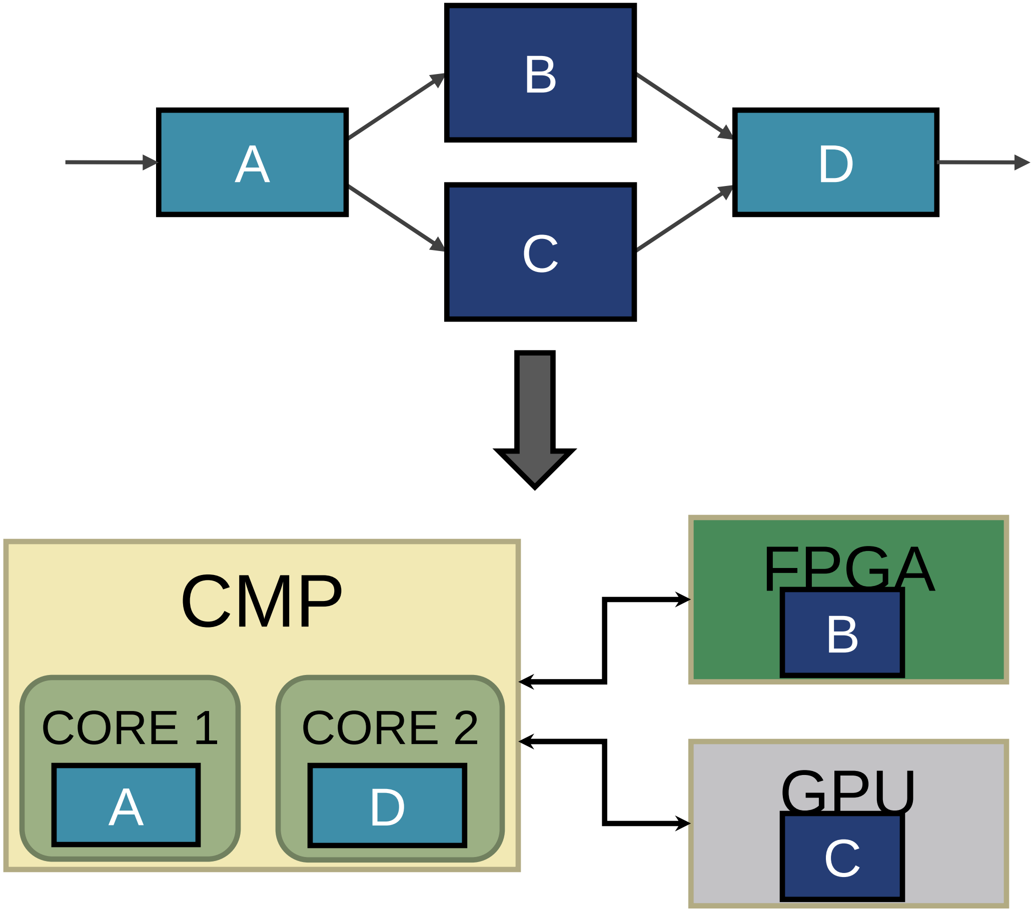


Existing Performance Tools

Programming model	Strategy	Tools / Environments
Shared Memory	Execution profiling	gprof, Valgrind, PAPI
Message Passing	Execution profiling, message logging	TAU, mpiP, PARAVER
Stream Programming	Simulation	StreamIt [MIT], StreamC [Stanford], Streams-C [LANL], Auto-Pipe [WUSTL]

Traditional Performance Monitoring

- Limitations for diverse systems
  - No universal PC or architecture
  - No shared memory
  - Different clocks
  - Communication latency and bandwidth

Diverse System Performance Monitoring

- Simulation is a useful first step but:
  - Models can abstract away system details
  - Too slow for large datasets
  - HPEC applications growing in complexity

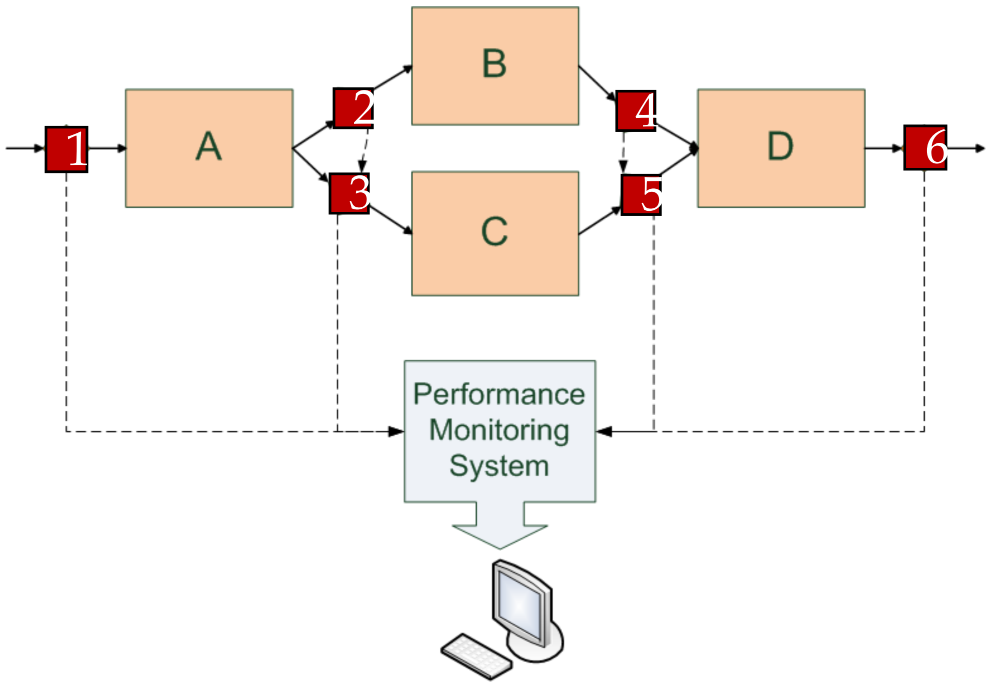
- Need to monitor deployed, running app
  - Measure ***actual*** performance of system
  - Validate performance of ***large, real-world*** datasets

Goals

- Report more than just aggregate statistics
  - Capture rare events
- Quantify measurement impact where possible
  - Overhead due to sampling, communication, etc.
- Measure runtime performance efficiently
    - Low overhead
    - High accuracy
- Validate performance of real datasets
- Increase developer productivity

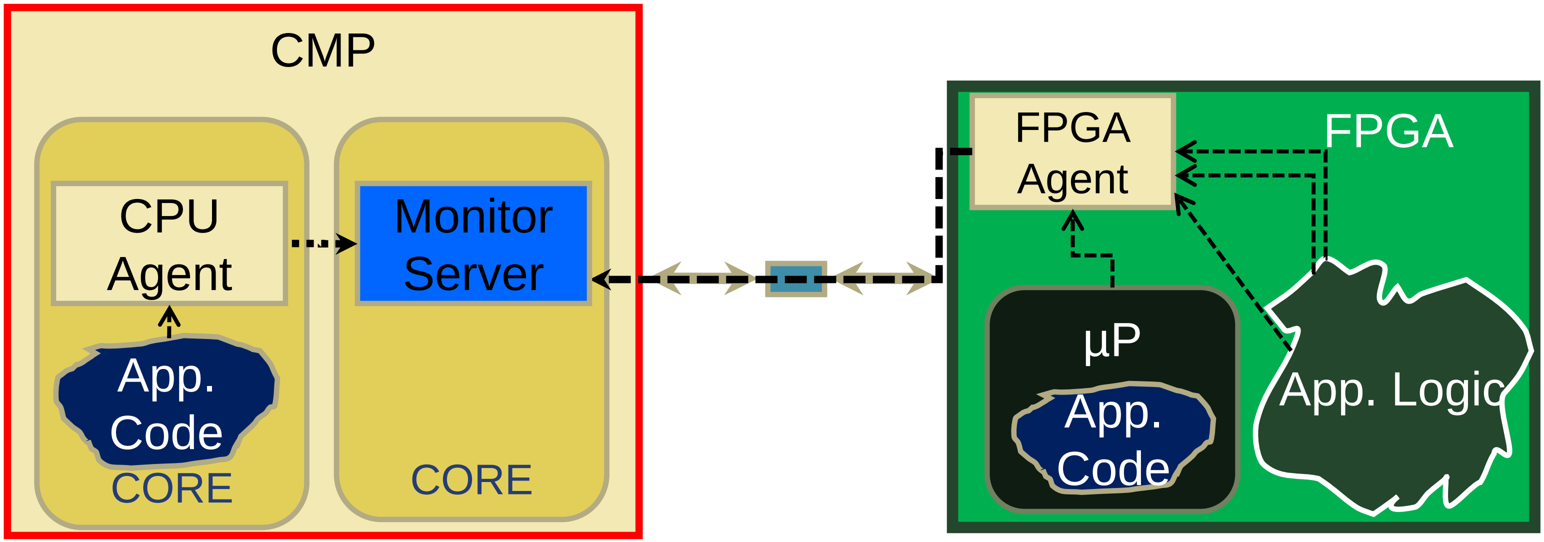
Monitoring Strategy

- Monitor edges / queues
- Find bottlenecks in app
  - Change over time?
  - Computation or communication?
- Measure latency between two points



Implementation

- Interconnects are a precious resource
- Uses same interconnects as application
- Stay below bandwidth constraint → Keep perturbation low



Reducing Impact

- Understand measurement perturbation
- Dedicate compute resources when possible
- Aggressively reduce amount of performance meta-data stored and transmitted
  - Utilize compression in both time resolution and fidelity of data values
  - Use knowledge from user to specify their performance expectations / measurements

Dedicating Resources

- Use CMP core as the server monitor
  - Monitor other cores for performance information
  - Process data from agents (e.g. FPGA, GPU)
  - Combine hardware and software information for global view
    - Use logical clocks to synchronize events
- Dedicate unused FPGA area to monitoring

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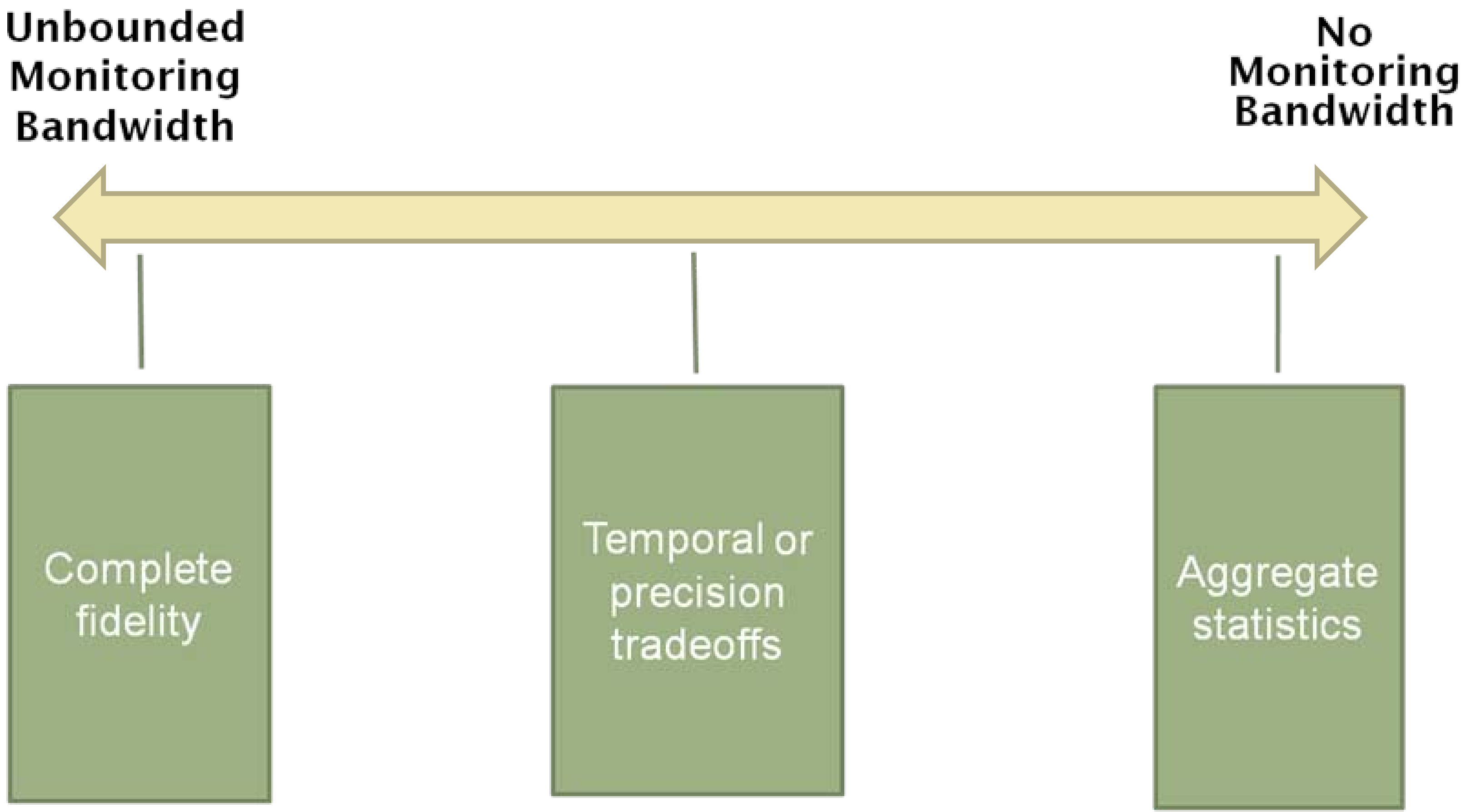
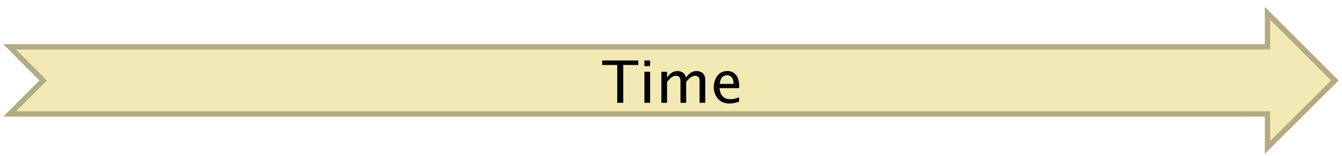
Temporal Monitoring Continuum



Frame Monitoring

- A frame summarizes performance over a period of the execution
- Maintain some temporal information
  - Capture system performance anomalies



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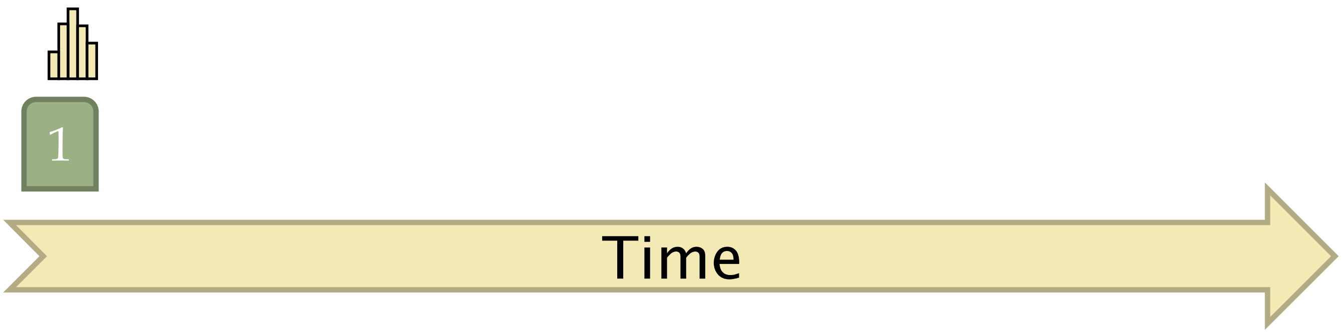

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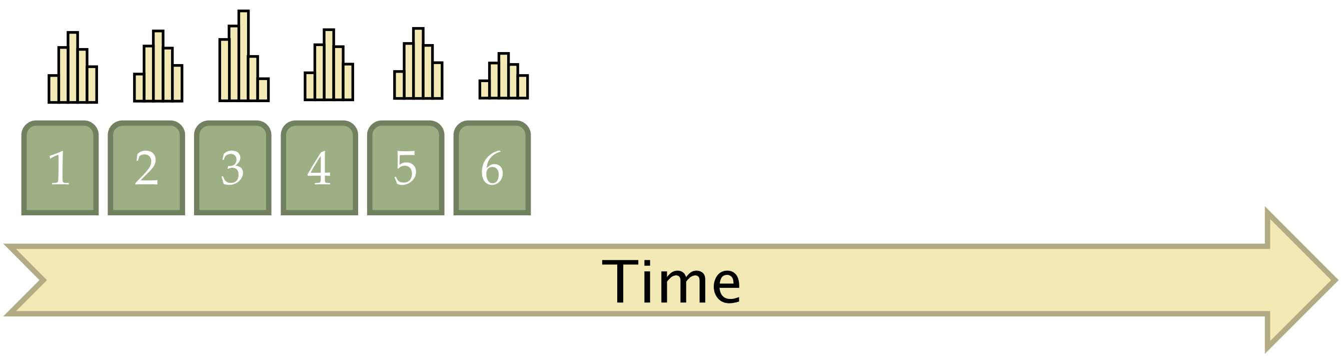

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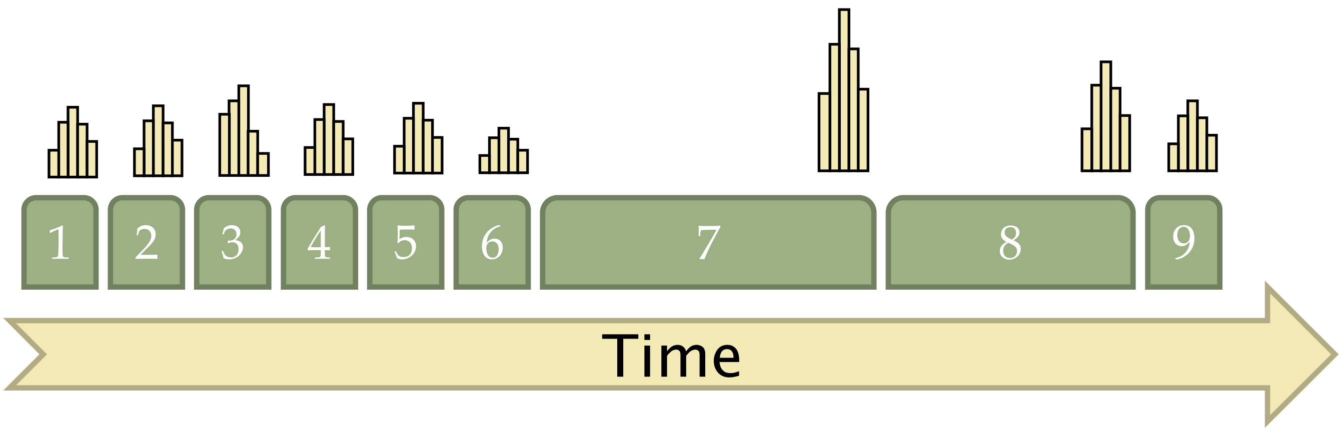

Properties of Frames

- Each frame reports one performance metric
- Frame size can be dynamic
  - Dynamic bandwidth budget
  - Low variance data / application phases
  - Trade temporal granularity for lower perturbation
- Frames from different agents will likely be unsynchronized and different sizes
- Monitor server presents user with consistent global view of performance

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User-guided Collection

- ***Why?***
- *Related work: Performance Assertions for Mobile Devices* [Lenecevicius’06]
  - Validates user performance assertions on multi-threaded embedded CPU
- Our system enables validation of performance expectations **across diverse architectures**

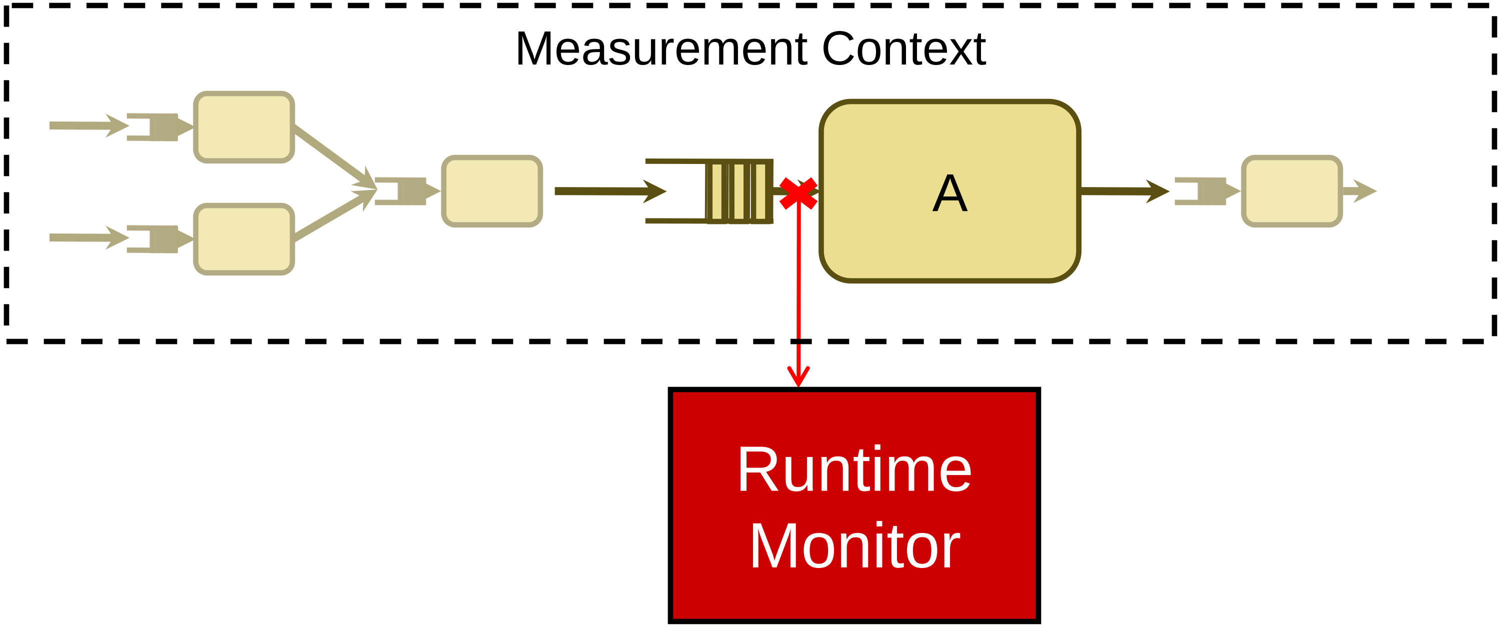
User-Guided Collection

1. Measurement
   - User specifies a set of "taps" for agent
   - Taps can be off an edge or an input queue
   - Agent then records events on each tap

- Supported measurements for a tap:
  - Average value + standard deviation
  - Min or max value
  - Histogram of values
  - Outliers (based on parameter)
- Basic arithmetic and logical operators on taps:
  - Arithmetic: add, subtract, multiply, divide
  - Logic: and, or, not

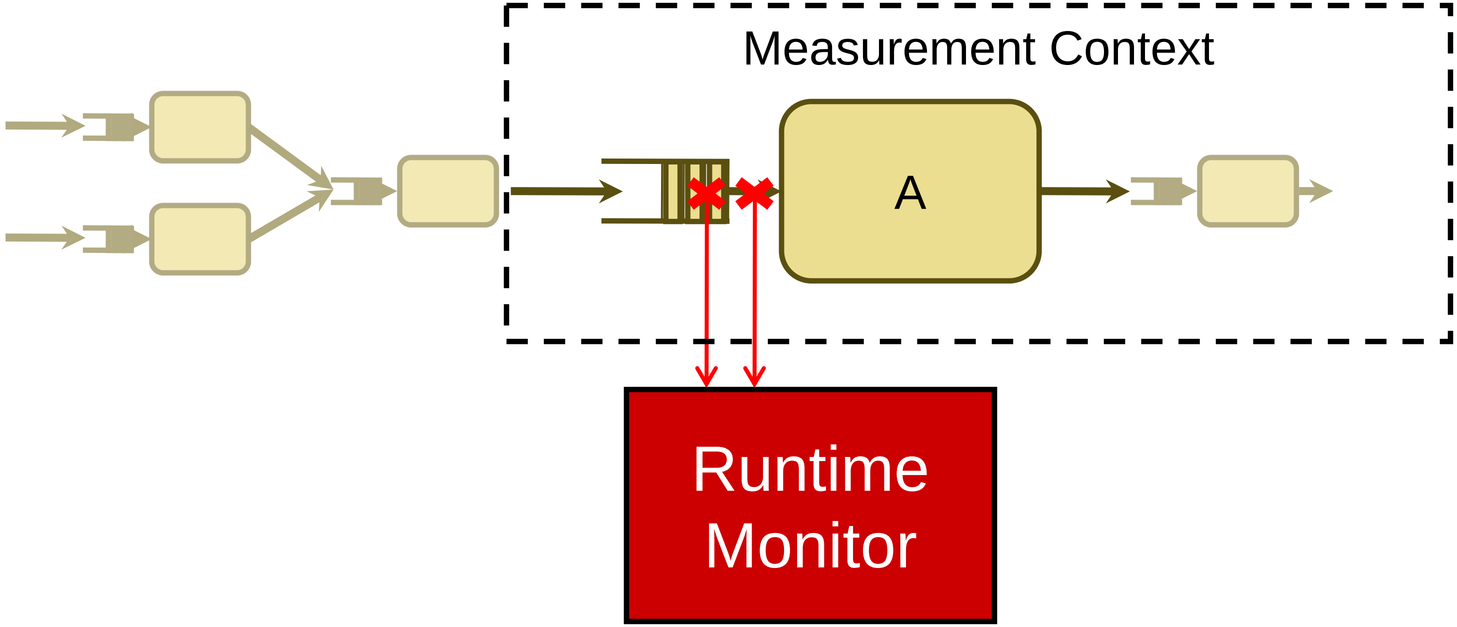
Direct Measurement Example

- What is the throughput of block A?



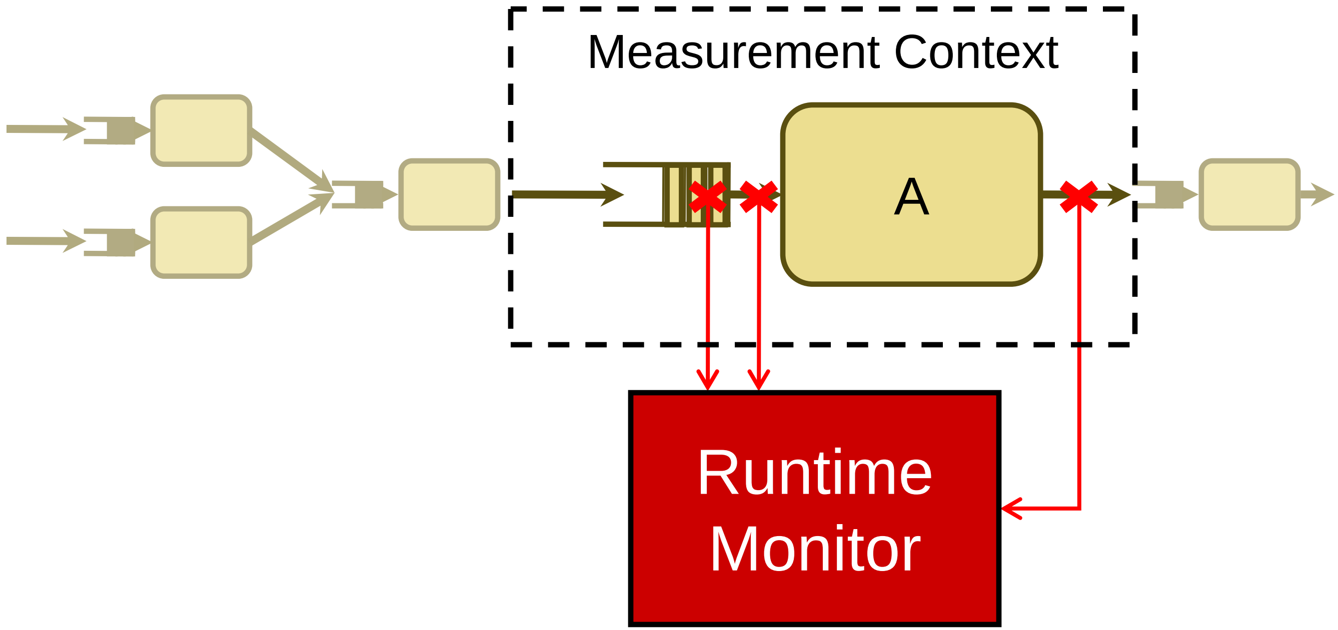
Direct Measurement Example

- What is throughput of block A when it is not data starved?



Direct Measurement Example

- What is the throughput of block A when
  - not starved for data **and**
  - no downstream congestion



User-Guided Collection (2)

1. Measurement
   - Set of “taps” for agent to count, histogram, or perform simple logical operations on
   - Taps can be an edge or an input queue
2. Performance assertion
   - User describes their performance expectations of an application as assertions
   - Runtime monitor validates these assertions by collecting measurements and evaluating logical expressions
     - Arithmetic operators: +, -, *, /
     - Logical operators: and, or, not
     - Annotations: t, L

Logic of Constraints

- throughput: "at least 100 A.*Input* events will be produced in any period of 1001 time units"
  - $t(A.Input[i+100]) - t(A.Input[i]) \leq 1001$
- latency: "*A.Output* is generated no more than 125 time units after *A.Input*"
  - $t(A.Output[i]) - t(A.Input[i]) \leq 125$
- queue bound: "*A.InQueue* never exceeds 100 elements"
  - $L(A.InQueue[i]) \leq 100$

Abstraction Hierarchy

- Runtime measurements
  - Query CMP/GPU performance counters
  - Custom FPGA counters
- Local assertions
  - Can be evaluated within a single agent
  - No need for communication with other agents/system monitor
- Global assertions
  - Requires aggregating results from more than one agent on different compute resources

Constraint Properties

- Some assertions impose prohibitive memory requirements
  - Either disallow these or warn user of large monitoring impact
- Other assertions are compute intensive
- A few are both!
- Fortunately, much can be gained from simple queries
  - Input queue lengths over time

Status

- FPGA Agent mostly operational
  - Monitor only, no user assertions yet
- Initial target application is the BLAST biosequence analysis application
  - CPU + FPGA hardware platform
  - [Jacob, et al. TRETS '08]
- Next target application is computational finance
  - CPU + GPU + FPGA
  - Performance significantly worse than models

Conclusions & Future Work

- Runtime performance monitoring enables
  - More efficient development
  - Better testing for real-time systems

- Support correctness assertions
- Investigate ways to best present results to developer