CloudSuite on Flexus

Alexandros Daglis

Djordje Jevdjic

Cansu Kaynak

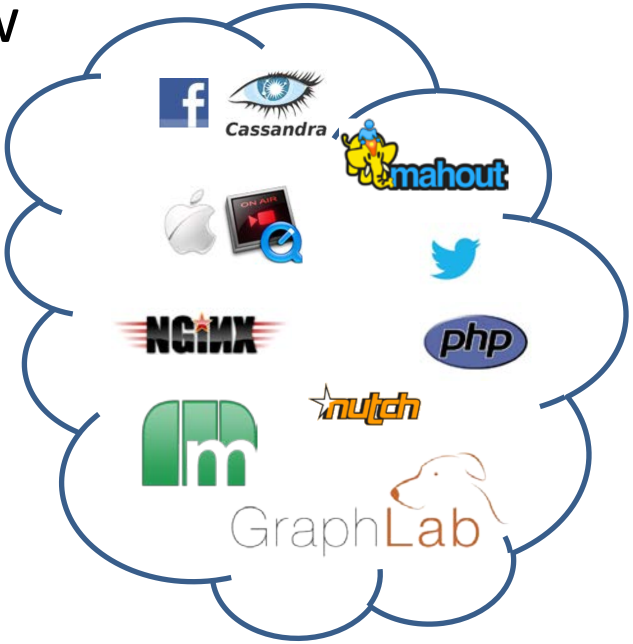
CloudSuite on Flexus

- CloudSuite: Suite for scale-out datacenter services
- Flexus: Fast, accurate & flexible architectural Simulator

- The tutorial is interactive
  – Please ask questions anytime during tutorial

Agenda

- CloudSuite 2.0 benchmarks overview
- Full-system simulation with Simics
- Flexus internals
- Fast simulation via statistical sampling



CloudSuite 2.0:
A Suite for Emerging Scale-out Applications

Cansu Kaynak

Clouds are Scale-out

- Cloud computing is pervasive
  - User base growing exponentially
  - New services appearing daily

- Serving a global-scale audience requires scaling-out
  - Distribute data and computation to many servers

Need scale-out benchmarks

Which Benchmarks to Use?

TPC Transaction Processing Performance Council

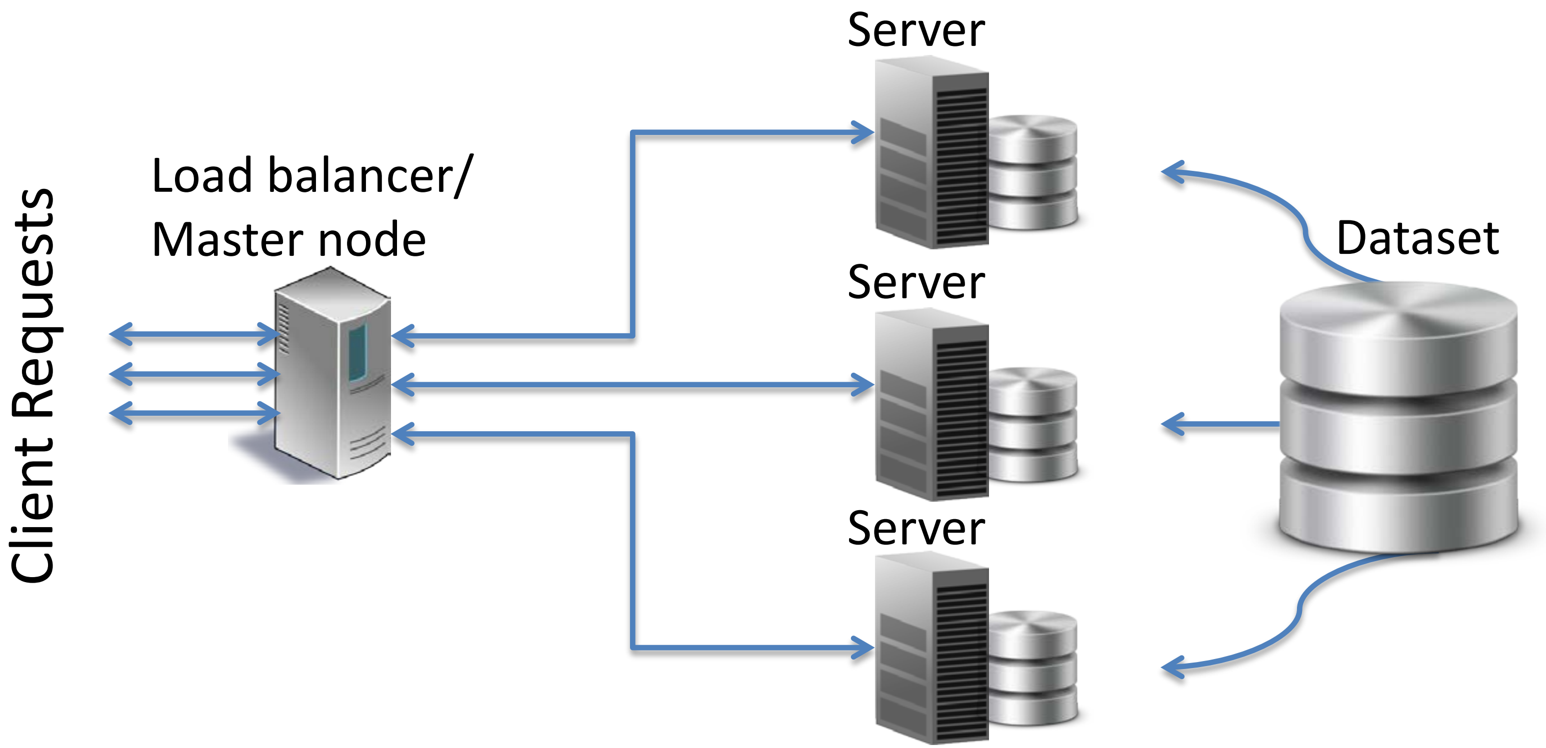
PARSEC
['pär-''sek] A unit of measure

spec®

- Benchmarks designed for scale-up

Don’t represent scale-out applications

Key Scale-Out Characteristics



- Serve independent requests/tasks
- Operate on huge dataset split into shards
- Communicate infrequently

CloudSuite 2.0 Overview

Data Analytics
Machine learning
Wikipedia mahout

Data Caching
Memcached

Data Serving
Cassandra NoSQL
Cassandra

Graph Analytics
TunkRank
GraphLab

Media Streaming
Apple Quicktime Server
ON AIR

SW Testing as a Service
Symbolic constraint solver
Cloud9

Web Search
Apache Nutch
nutch

Web Serving
Nginx, PHP server
NGINX php

Covers popular scale-out services

CloudSuite 2.0

- Data Analytics
- Data Caching
- Data Serving
- Graph Analytics
- Media Streaming
- SW Testing
- Web Search
- Web Serving

Data Analytics

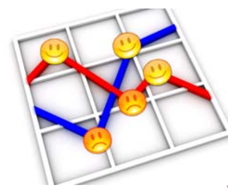
- Massive amounts of human-generated data (Big Data)

- Extract useful information from data
  - Predict user preferences, opinions, behavior
  - Benefit from information (e.g., business, security)

- Several examples
  - Book recommendation (Amazon)
  - Spyware detection (Facebook)

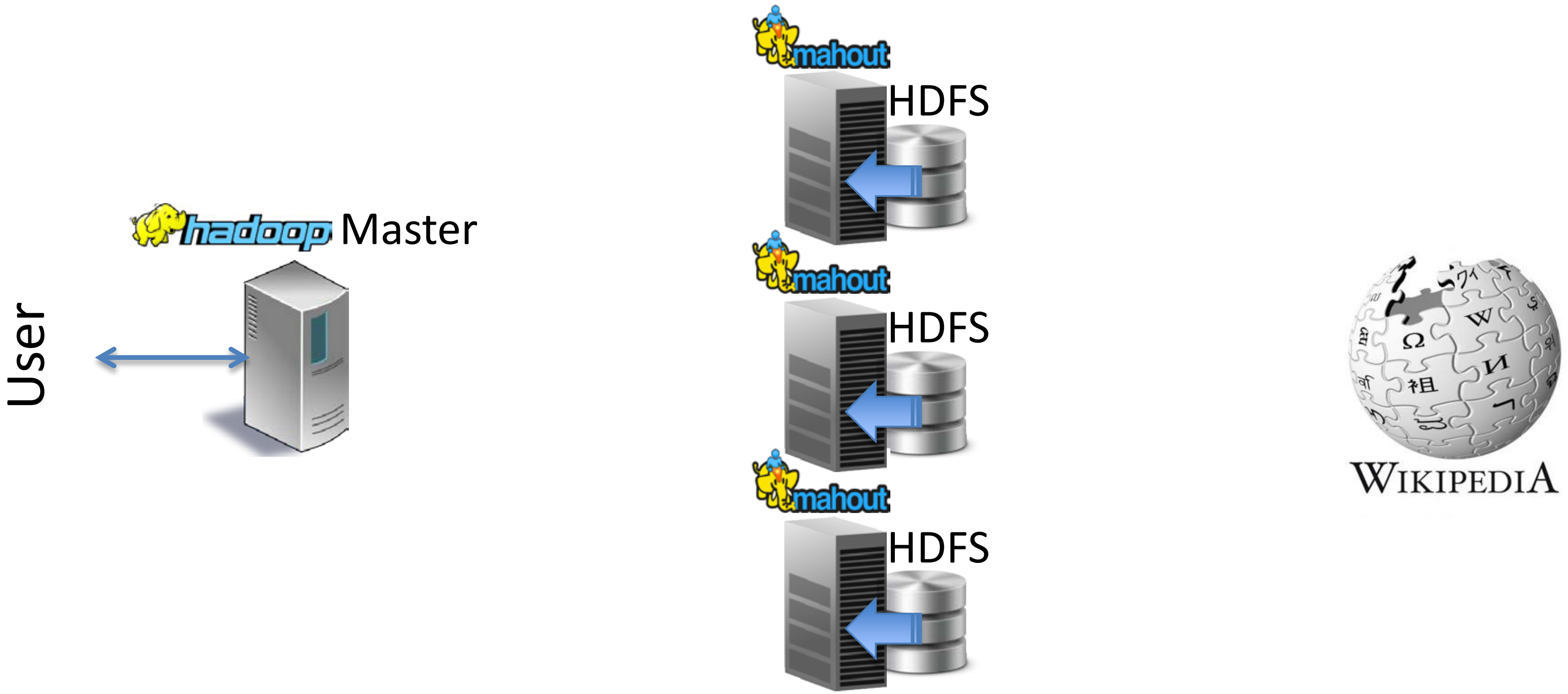
Data Analytics Benchmark

- **Application:** Text classification
  - Sentiment analysis
  - Spam Identification



- **Software**: Mahout (Apache)
  - Popular MapReduce machine learning library
- **Dataset**: Wikipedia English page articles

Data Analytics Benchmark



- Build a model from a Wikipedia training input
- Master sends Wikipedia documents for classification
- Slaves classify documents locally using model
- Slaves send results to master

CloudSuite 2.0

- Data Analytics
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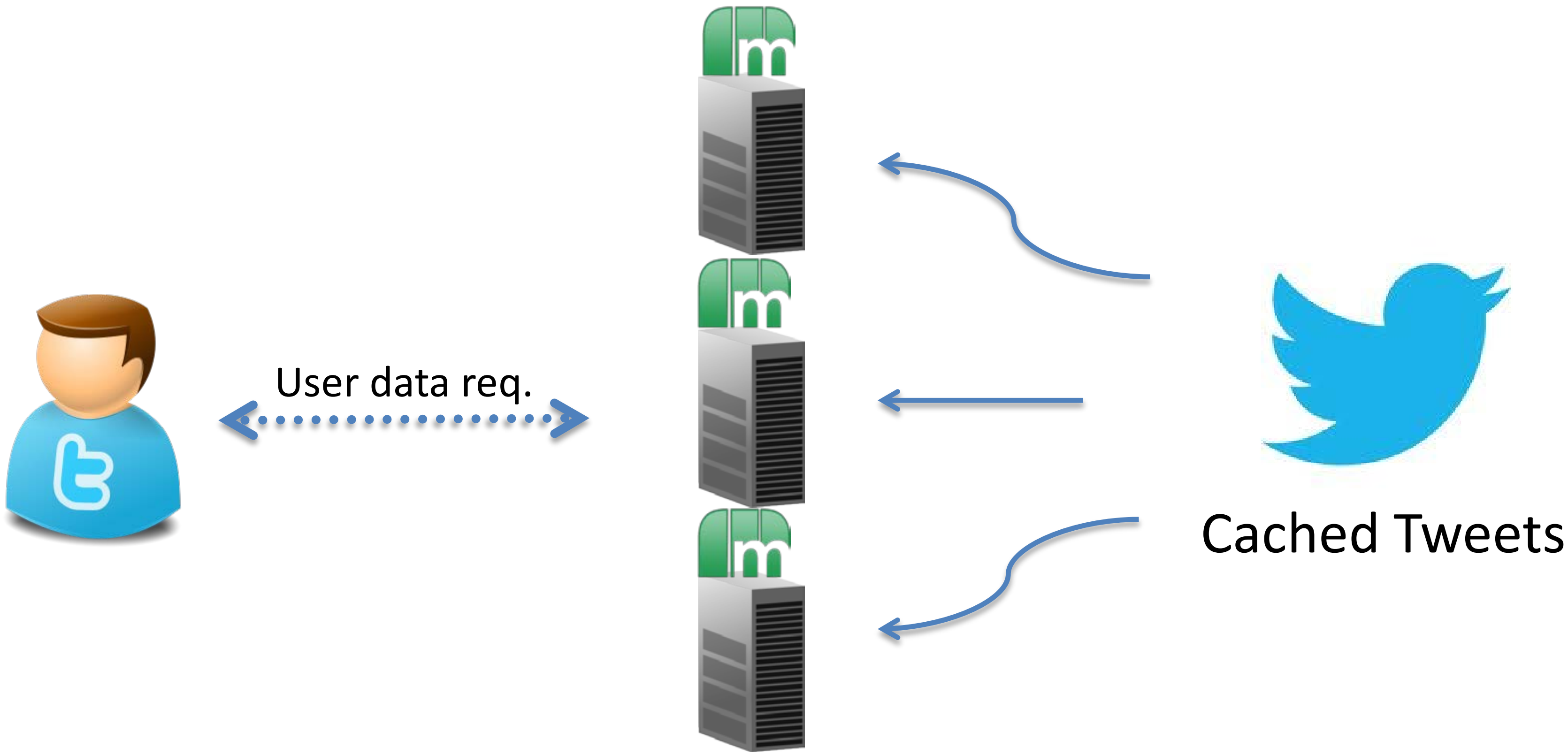
Data Caching

- Web apps are latency-sensitive
- Fetching data from disk is slow
- Caching data in memory for fast data access
  - General-purpose, in-memory key-value store
  - Caches data for other apps, another tier before back-end

Data Caching Benchmark



- Driver emulates Twitter users
- Memcached software to cache data in memory
- If data not found in cache, issues a disk access request

CloudSuite 2.0

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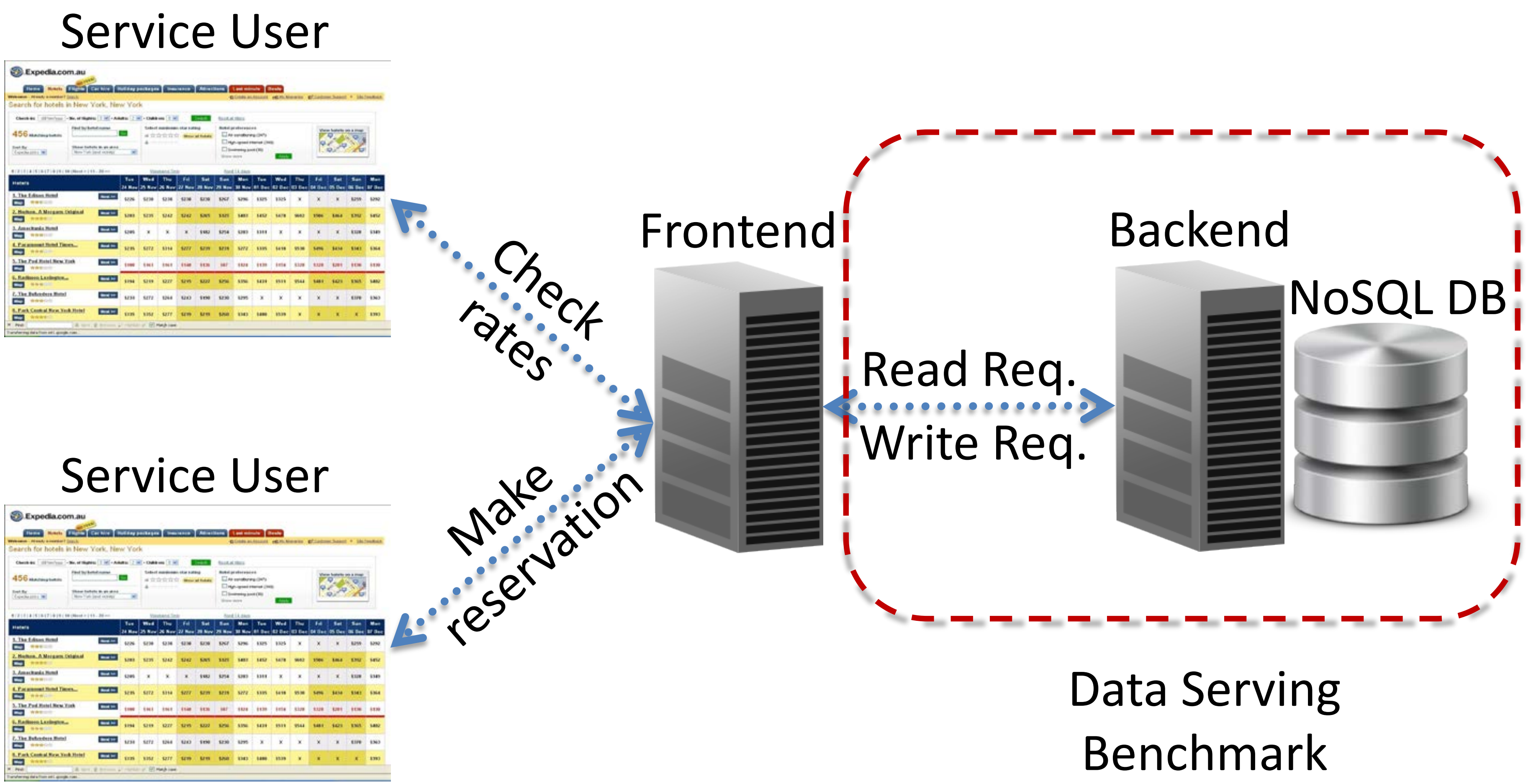
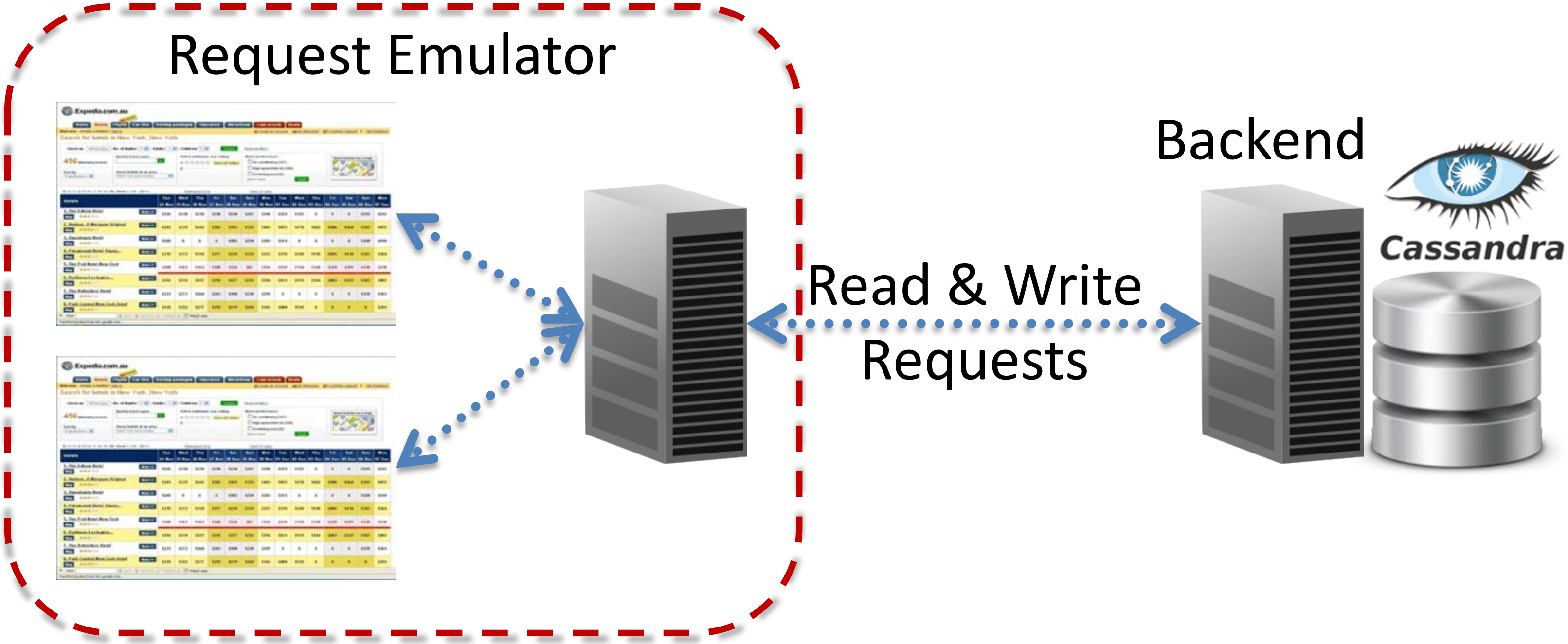
Data Serving

- Global-scale online services rely on NoSQL datastores
  - Inherently scalable
  - Suitable for unpredictable schema changes
- Scale out to meet service requirements
  - Accommodate fast data generation rate

Data Serving Operation

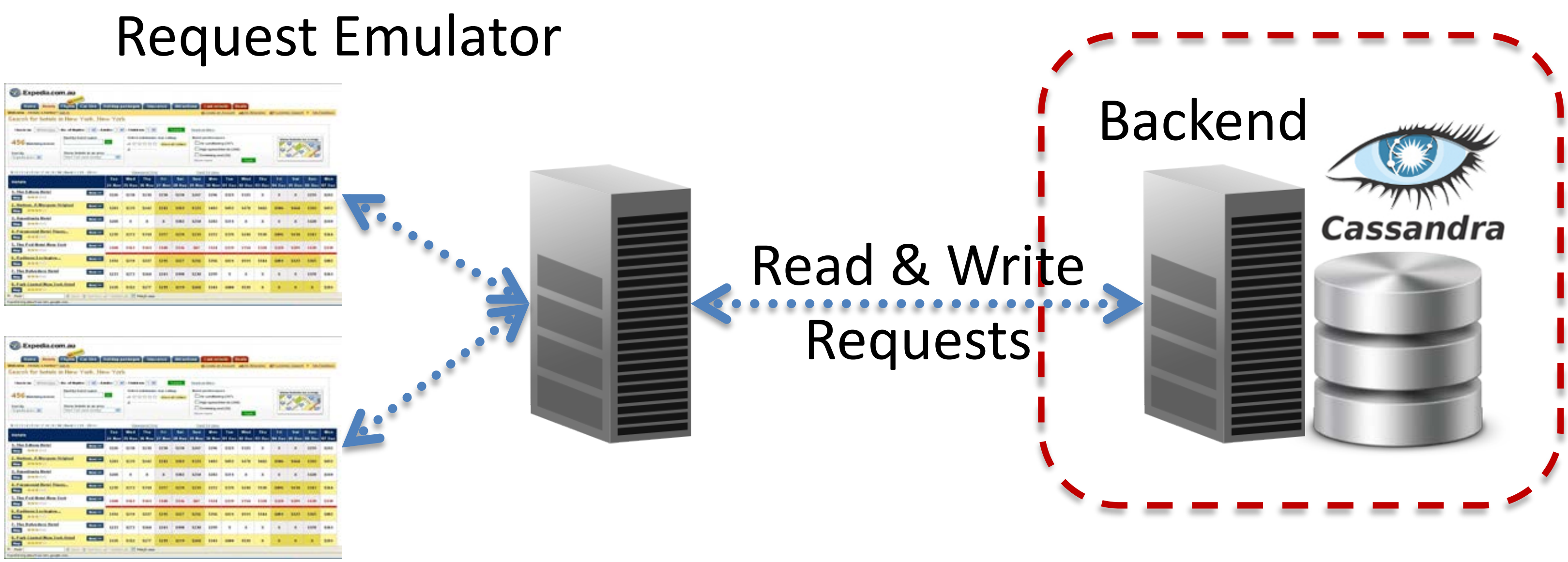


Data Serving Benchmark



- Yahoo! benchmark driver
  - Predefined mixes of read/write operations
  - Popularity of access distributions (e.g., zipfian)
  - Interface to popular datastores (e.g., Cassandra, HBase)

Data Serving Benchmark



- Cassandra datastore
  - Popular NoSQL: many use cases (e.g., Expedia, eBay, Netflix)
- Driver generates dataset
  - Defines number & size of fields
  - Populates datastore

CloudSuite 2.0

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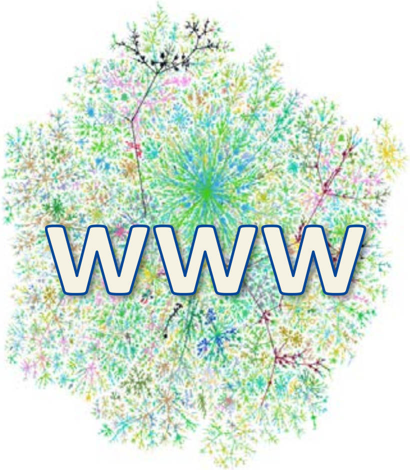
Graph Analytics

- Parallel distributed graph processing

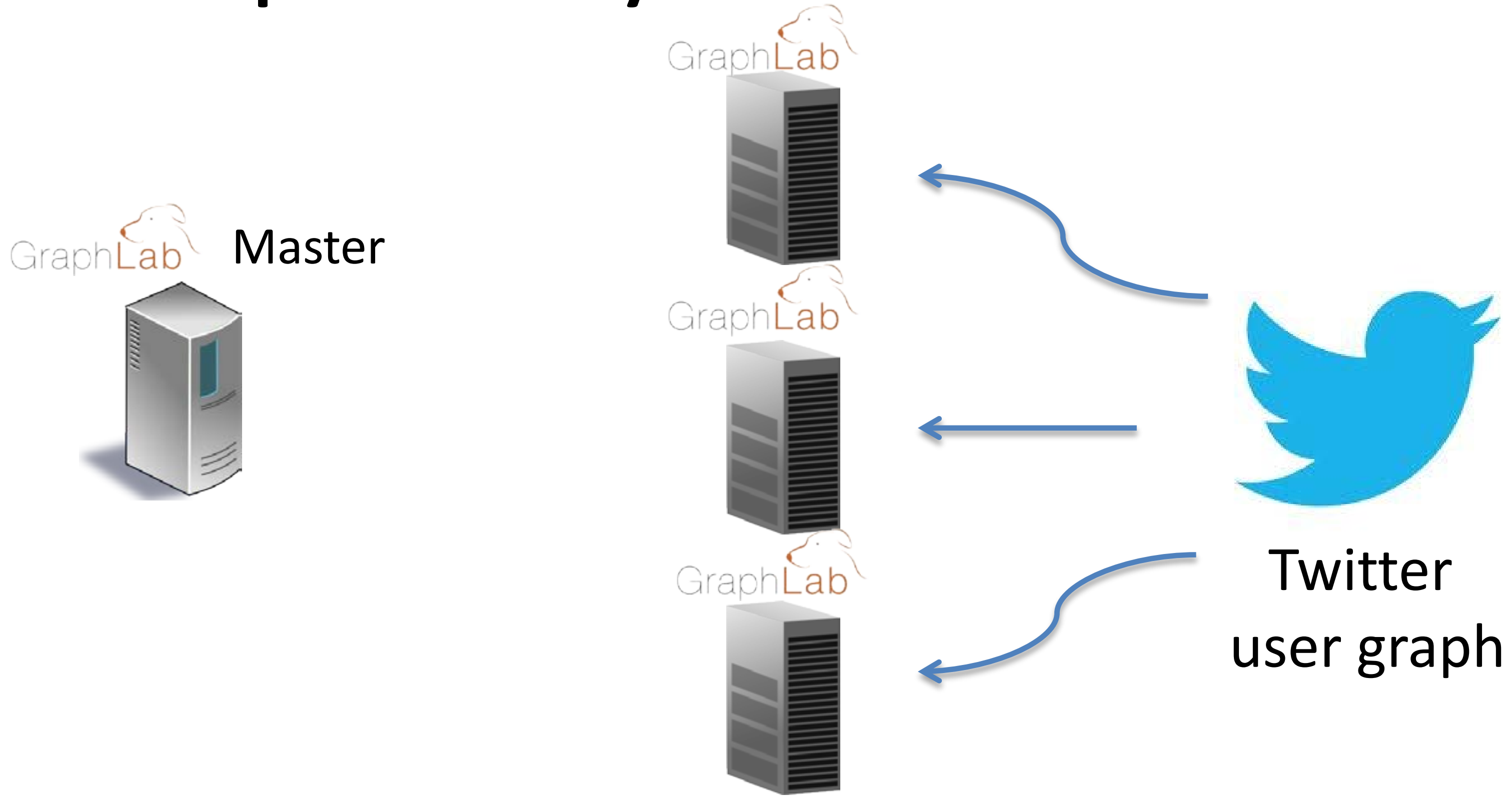
- Data mining on graphs
- Graph examples
  - Social networks (Facebook, Twitter)
  - Web graph



Graph Analytics Benchmark

- Application: TunkRank
  - Measures influence of Twitter users
  - How much attention followers can pay to a user
- Software: GraphLab
  - Parallel framework for graph processing
- Dataset
  - Twitter user graph

Graph Analytics Benchmark



- Distributes the graph across nodes
- Iterative computation: Always with adjacent vertices
- Communication across machines for adjacent vertices
- Outputs influence of each user in the graph

CloudSuite 2.0

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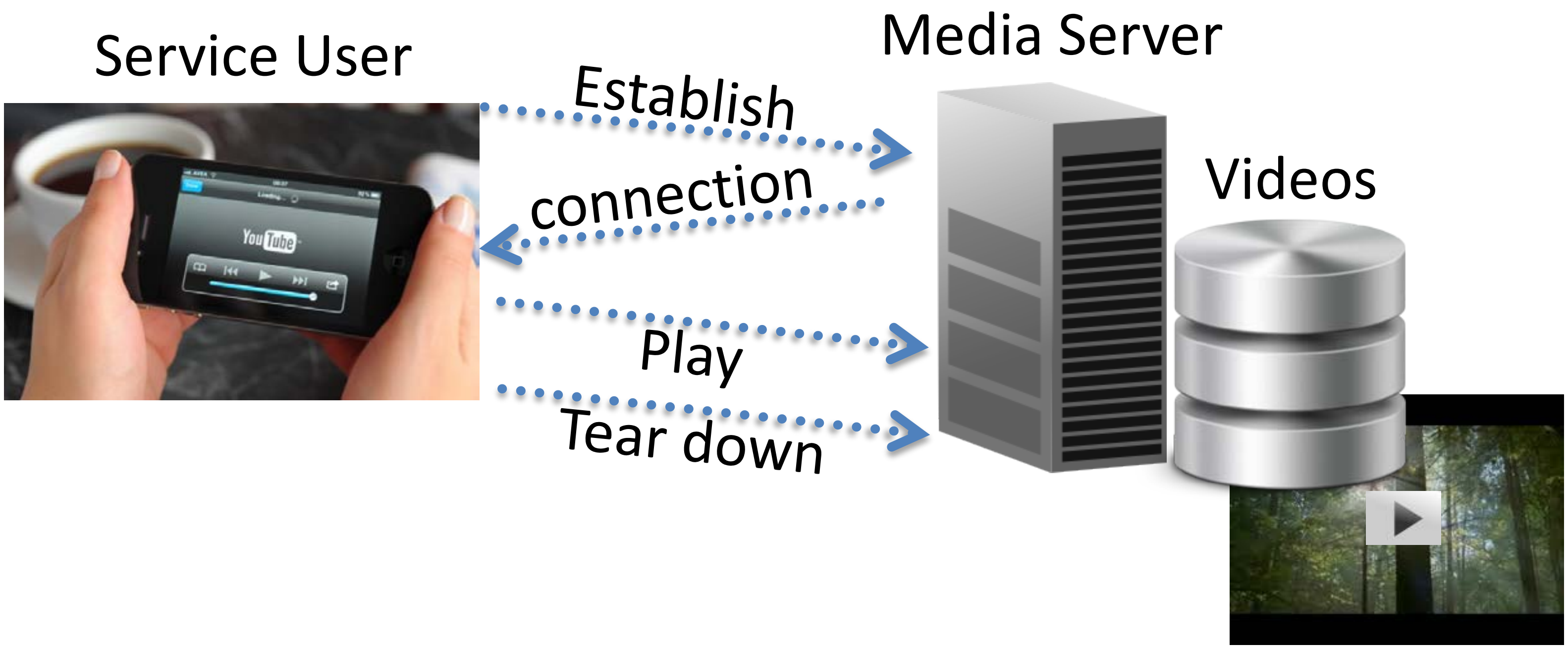
Media Streaming

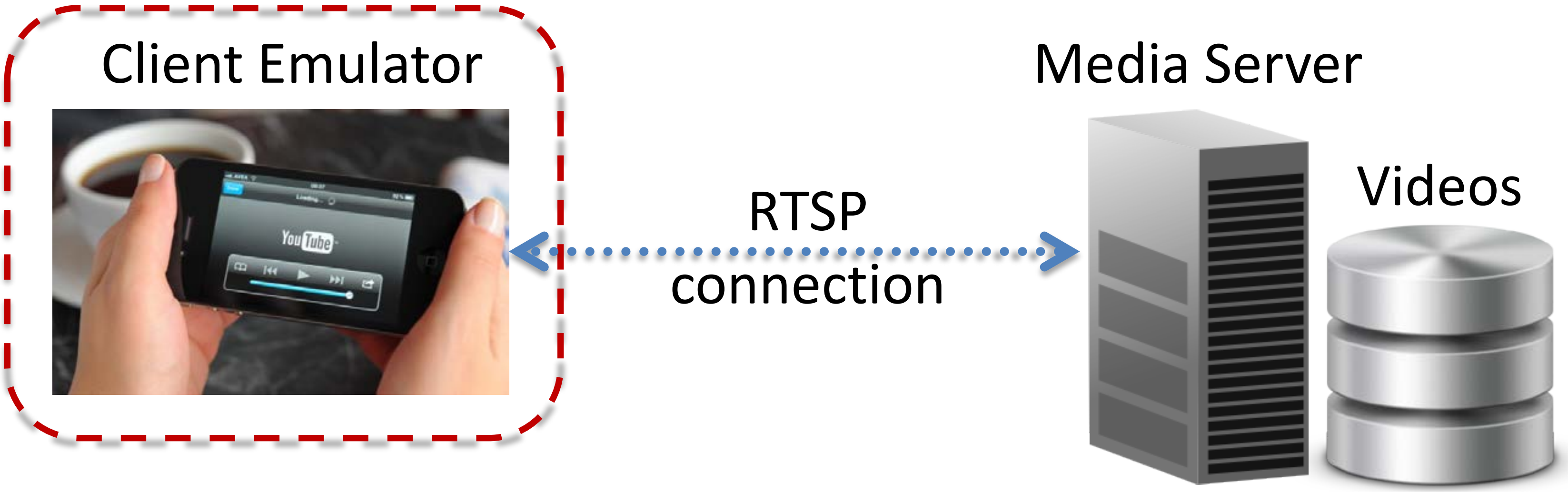
- Media streaming expected to dominate internet traffic

- Increasing popularity of media streaming services
  - Video sharing sites, movie streaming services, etc.

Media Streaming Operation

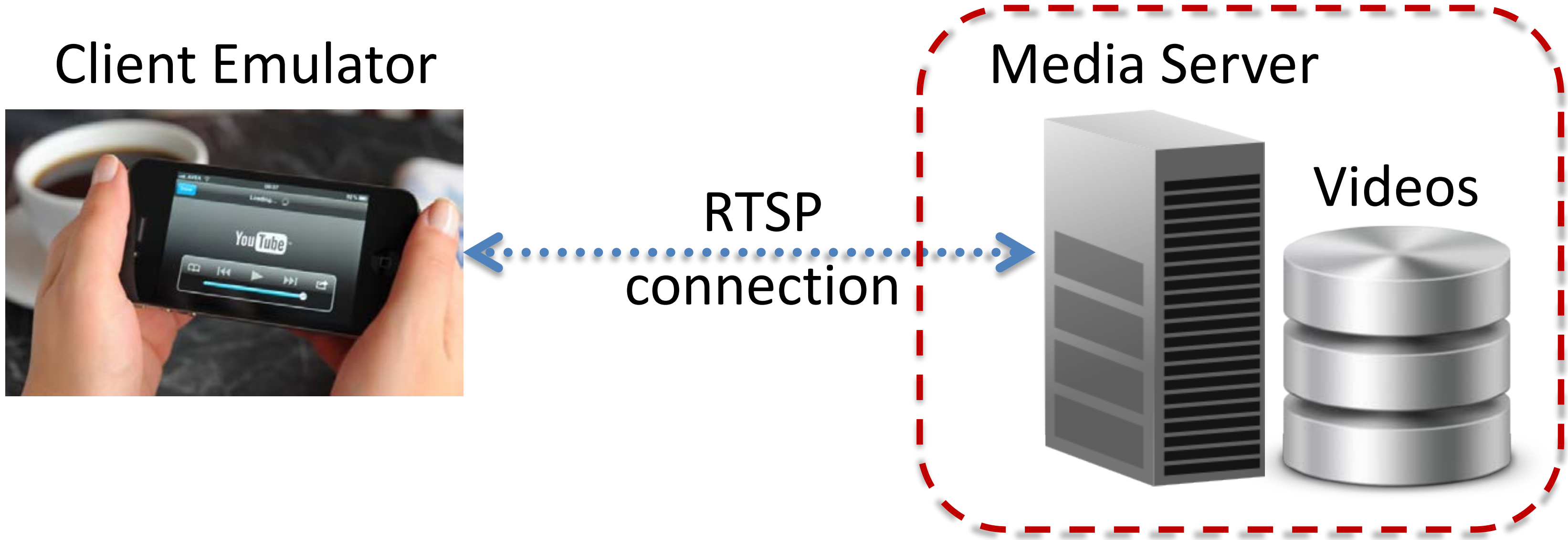


Media Streaming Benchmark



- Implements client-side RTSP communication
- Uses Faban traffic generator
- Allows a flexible mix of requests
  - Durations and bitrates

Media Streaming Benchmark



- Server required to support RTSP
  - Using Apple Darwin Streaming Server
- Dataset consists of a mix of pre-encoded videos
  - Ten durations: [1 – 10 minutes]
  - Five bitrates: [42 – 1500 kbps]

CloudSuite 2.0

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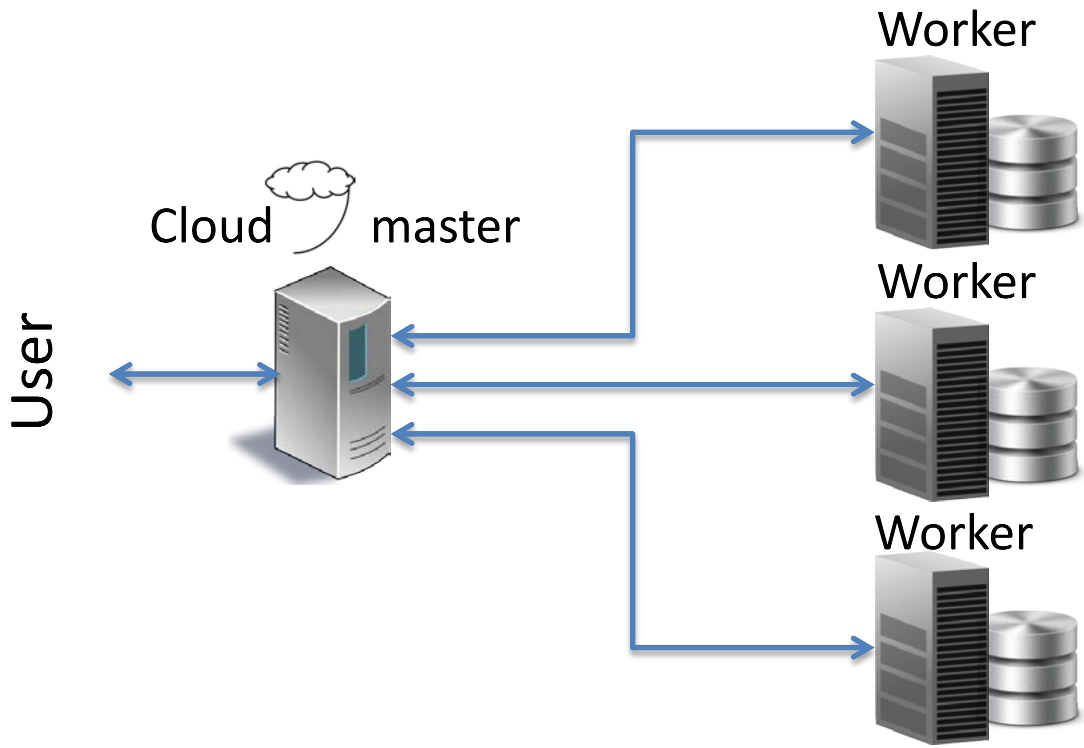
Software Testing

- Clouds allow dynamic resource allocation as needed
  - Enables previously impossible engineering practices
- Software Testing leverages cloud resources
  - Large-scale symbolic execution for SW testing
  - Needed as SW scales & complexity increases
- Scale-out engineering application running in cloud

Software Testing Benchmark



- Cloud9, SW Testing as a Service
- Master coordinates symbolic execution
- State maintained in slave, updated from master
- Master load-balances across slaves

CloudSuite 2.0

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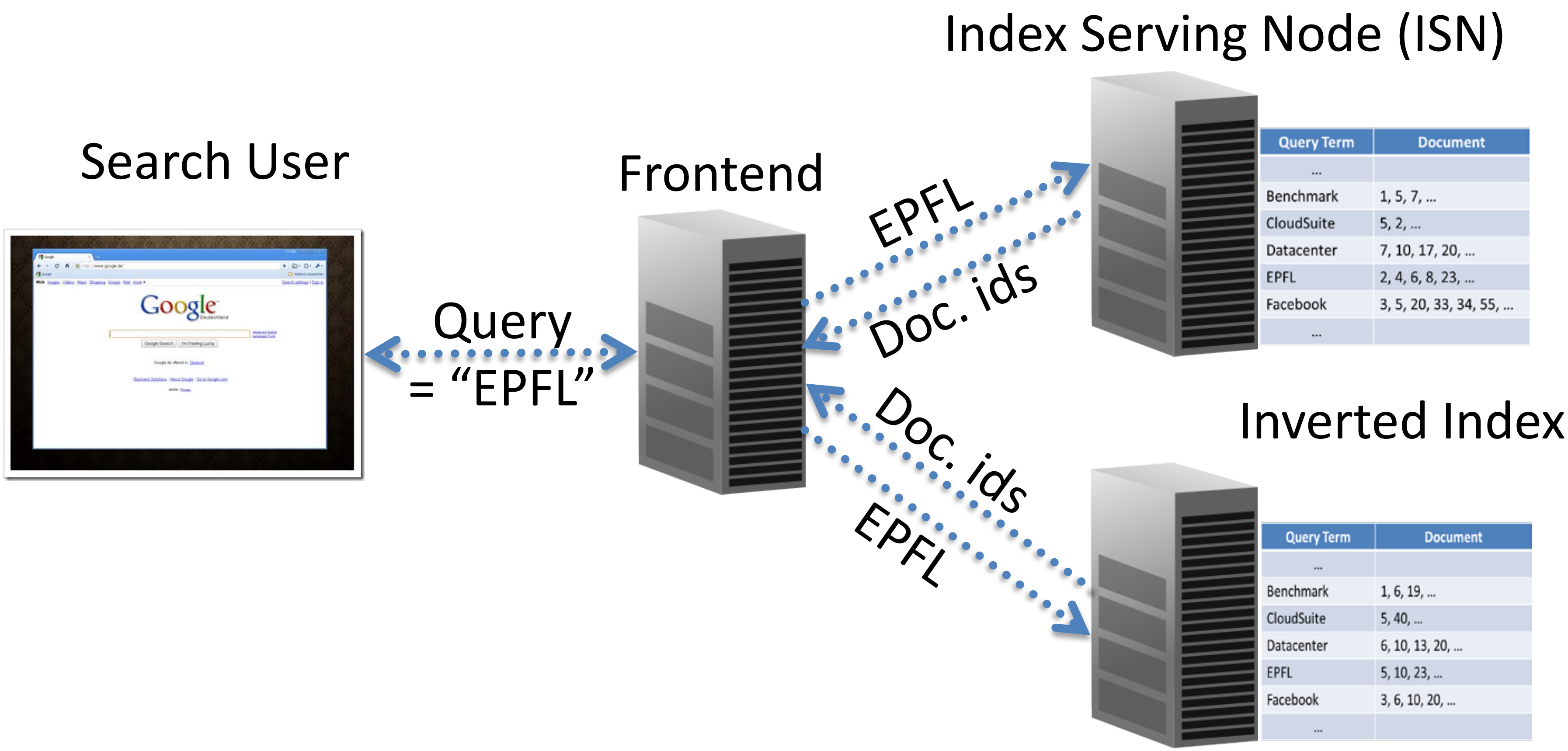
Web Search

- Most popular online service
  - Numerous search engines deployed by industry

Web Search Operation



Query Term	Document
...	
Benchmark	1, 5, 7, ...
CloudSuite	5, 2, ...
Datacenter	7, 10, 17, 20, ...
EPFL	2, 4, 6, 8, 23, ...
Facebook	3, 5, 20, 33, 34, 55, ...
...	

Query Term	Document
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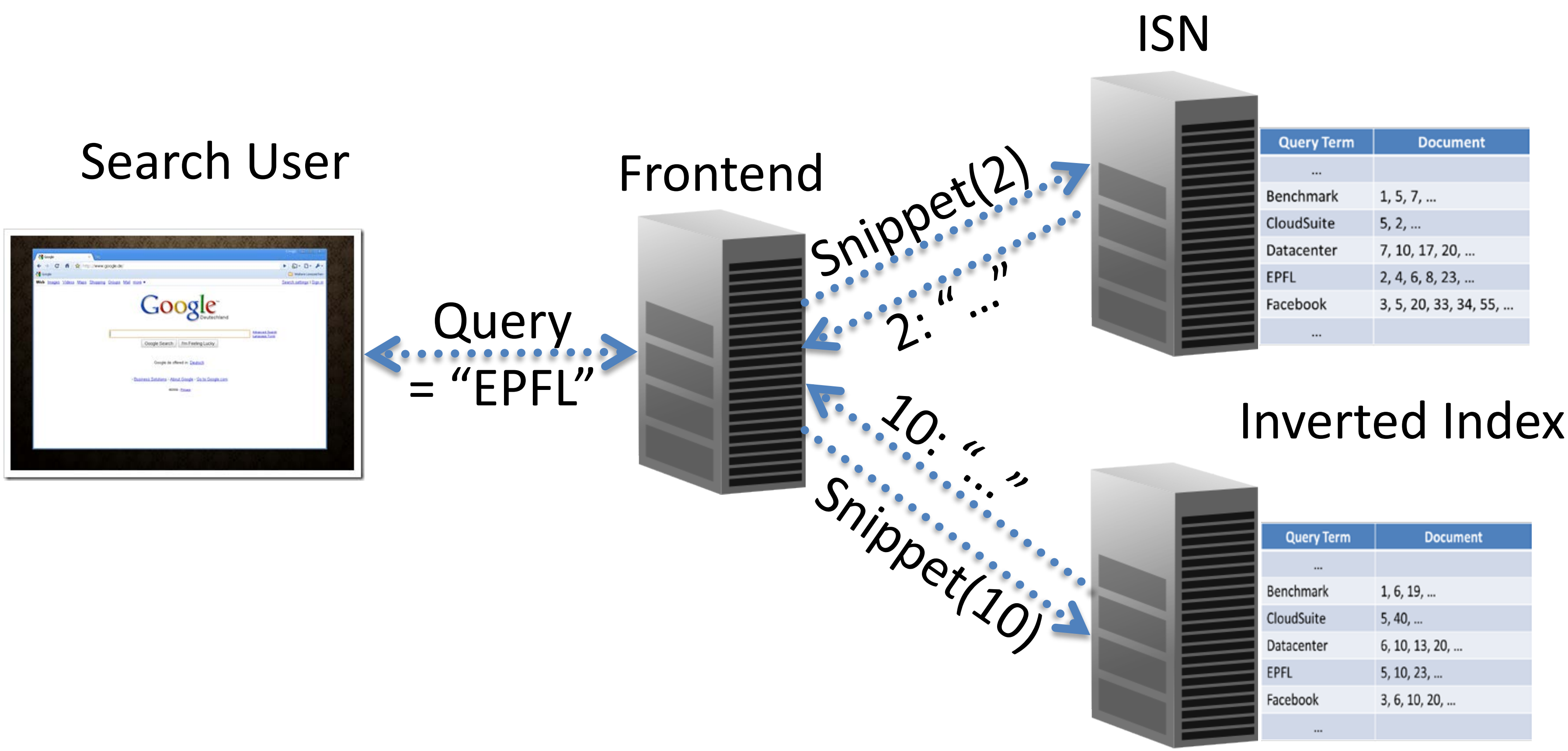
Web Search Operation



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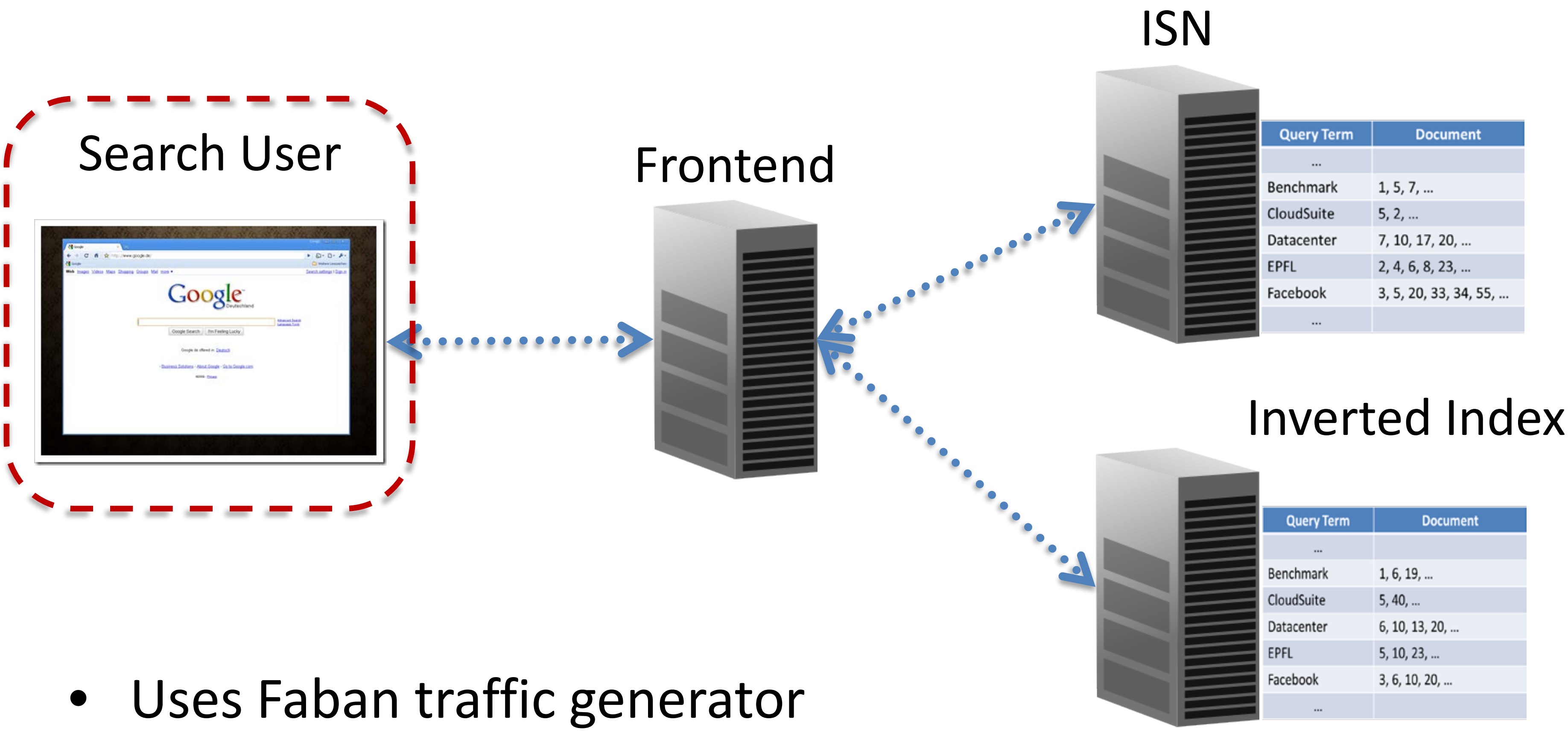

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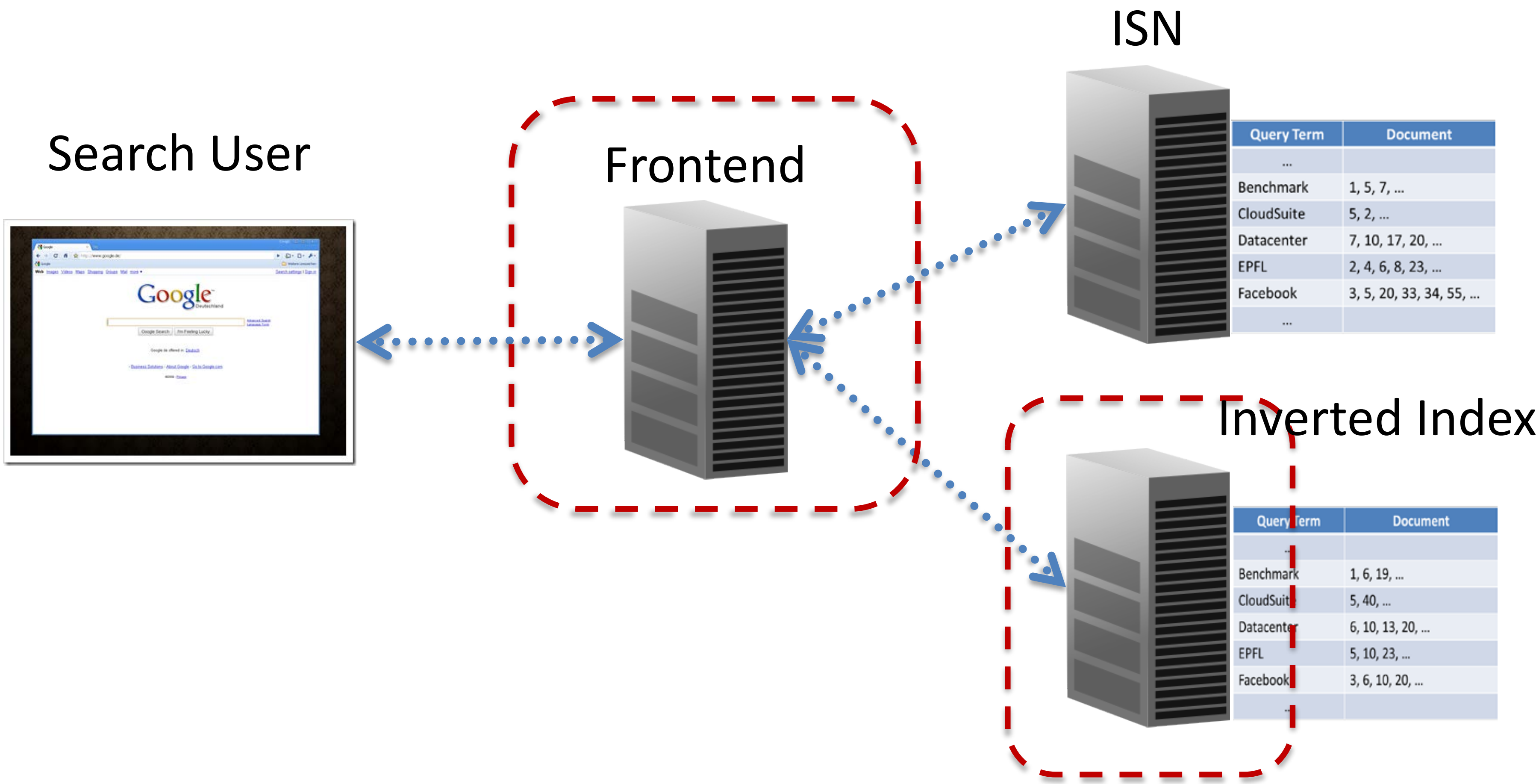
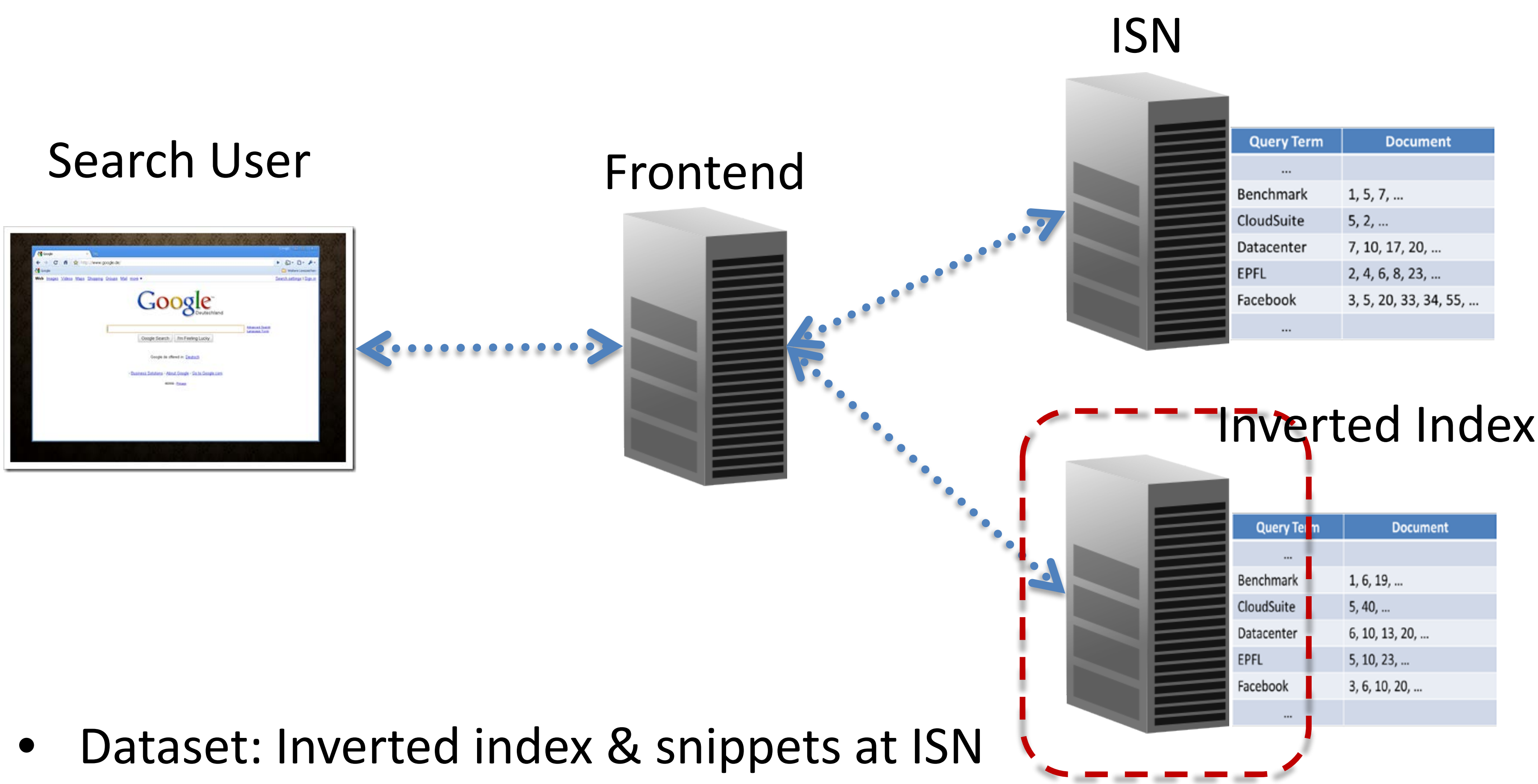
- Uses Faban traffic generator
- Flexible request mixes
  - # terms per request from published surveys
  - Terms extracted from the crawled dataset

Web Search Benchmark



- Apache Nutch search engine for front-end & ISNs

Web Search Benchmark



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- Dataset: Inverted index & snippets at ISN
  - Generated by crawling public web
  - Data at ISN must be memory resident
- Dataset size dictates the number of ISNs

CloudSuite 2.0

- Data Analytics
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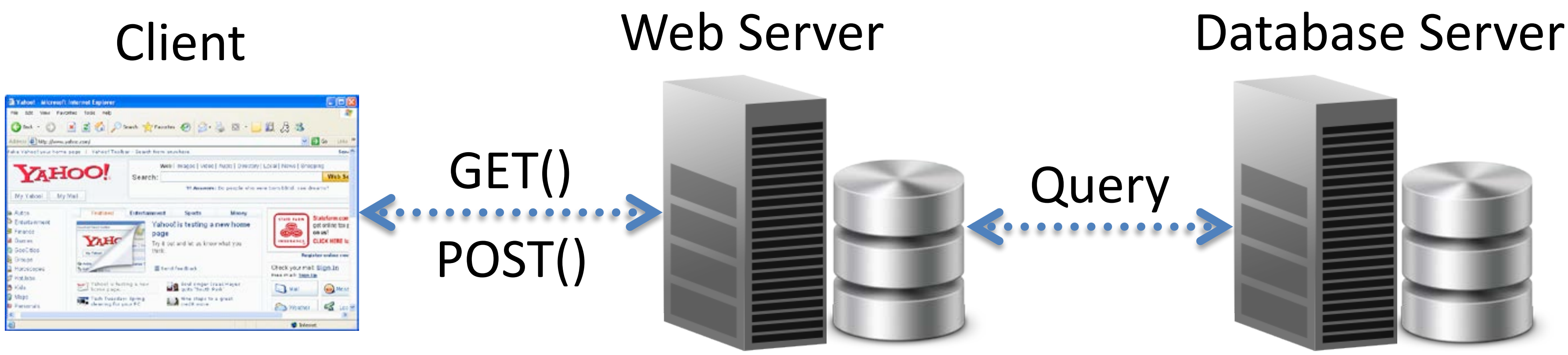
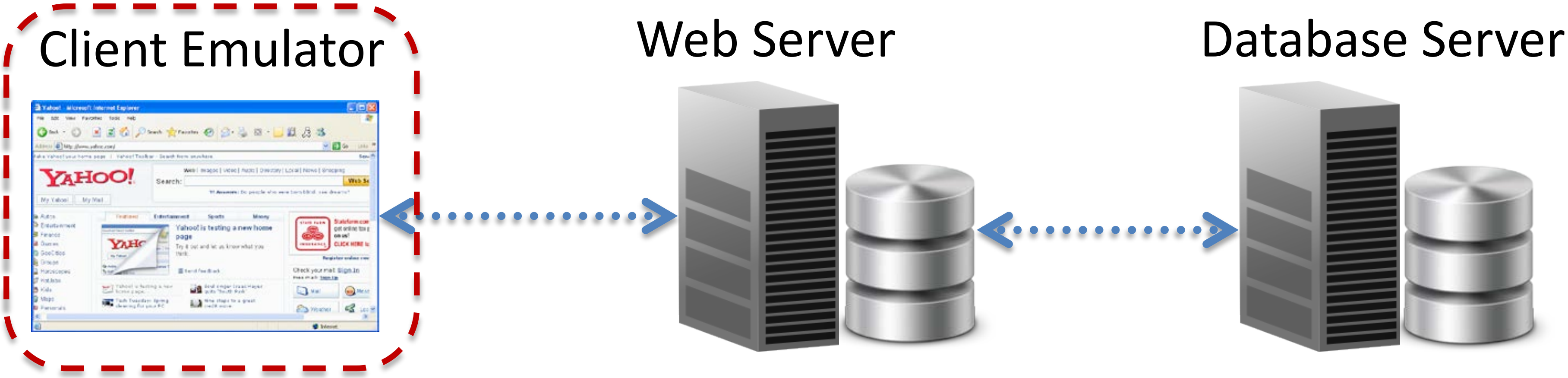
Web Serving

- Key to all internet-based services
- All services are accessed through web servers
- Various technologies construct web content
  - HTML, PHP, JavaScript, Ruby

Web Serving Operation

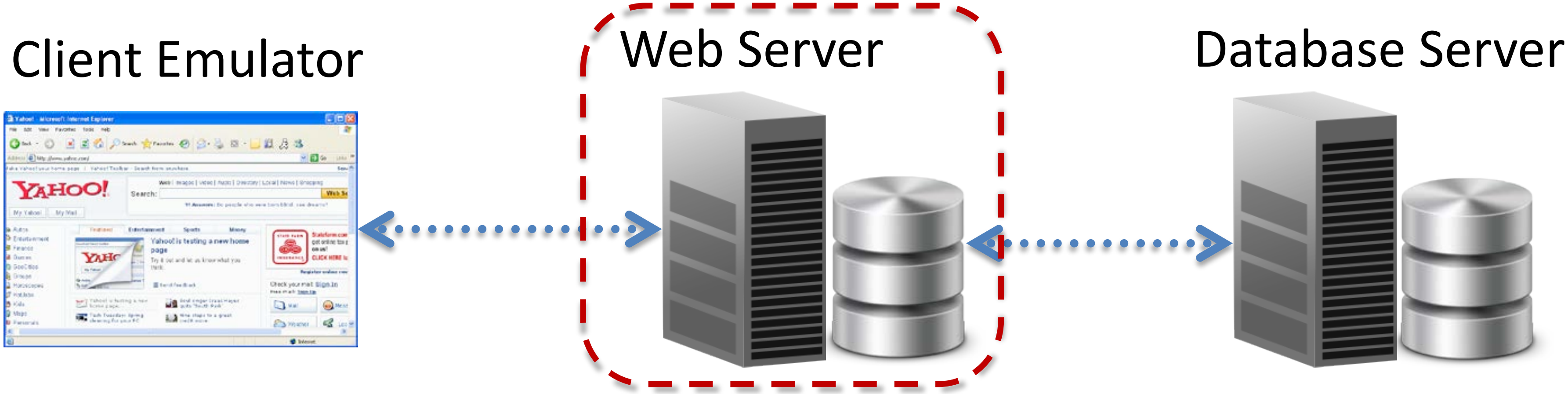


Web Serving Benchmark



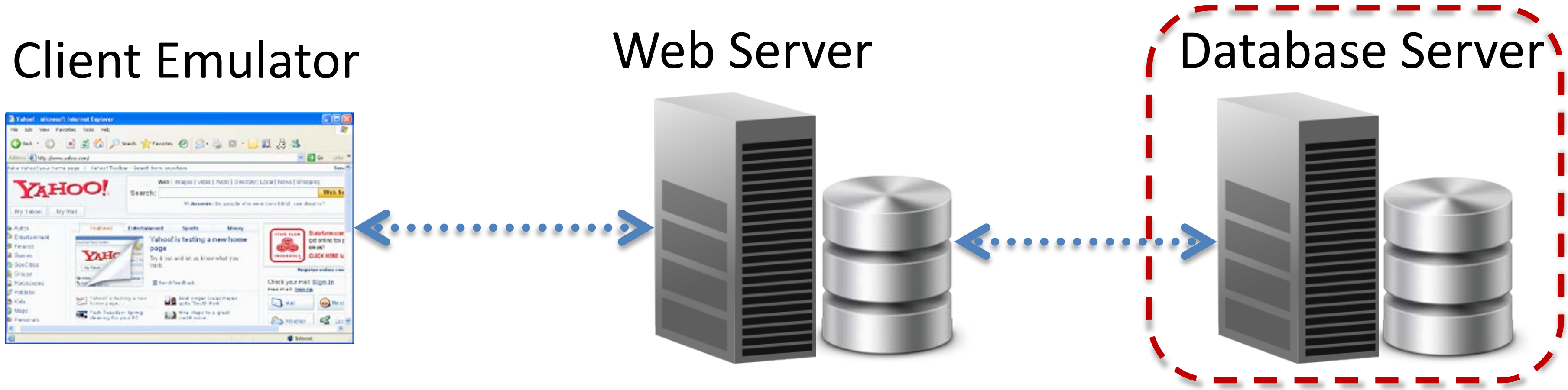
- Faban traffic generator
- Pre-configured page transition matrix (CloudStone)

Web Serving Benchmark



- Web server (Nginx)
- Application server (PHP)
  - Serves a social calendar application (Olio)
- File store (image files)

Web Serving Benchmark



- Database server (MySQL)

Download CloudSuite 2.0

parsa.epfl.ch/cloudsuite

CloudSuite: Hands-on

- Media Streaming
  - Installing the server
  - Installing client generator
  - Overview of the dataset
  - Running the benchmark
  - Checking quality of service

Hands-on Tutorial Page

http://parsa.epfl.ch/cloudsuite/CloudSuite-Flexus.html

Wifi password: isca40ta

CloudSuite
Full-System Simulation

Alexandros Daglis

CloudSuite Simulation Requirements

CloudSuite Workloads:

- Multi-threaded, multi-processor
- Data-intensive
- Multi-tier

⇒ Exercise OS and I/O extensively

⇒ OS and I/O are first-order performance determinants

Need full-system simulation

Flexus Framework

- Functional Full-System Simulation: Simics
- Detailed Microarchitectural Simulation: Flexus
- Fast Simulation: Statistical sampling

Flexus Framework

- Functional Full-System Simulation: Simics
- Detailed Microarchitectural Simulation: Flexus
- Fast Simulation: Statistical sampling

Full-System Simulation Requirements

Full-system functional simulator must support:

- Privileged-mode ISA
- I/O devices
- Networks of systems
- Saving/restoring architecturally-visible state

Simics provides these capabilities

Simics Configuration & CLI

- Configuration file defines system components
  - Motherboard, CPUs, memory, I/O devices

- Command-line interface (CLI) provides interface to simulation
  - Start and stop simulation
  - Save and restore target system checkpoints

Simics Checkpoints

- Contain full-system architectural state
- Are incremental - Require all files in chain
- Form the basis for Flexus simulation

Simics µArch Interface

- Simics does not provide timing details
  - But provides a Micro-Architectural Interface (MAI)
  - Allows a user module to take control over timing
- Simics feeds Flexus with instructions
- Flexus gives timing feedback to Simics

Simics Hands-On

Preparing a Workload for Simulation

1. Install OS
2. Reconfigure and reboot target machine
3. Install application & create dataset
4. Tune workload parameters
5. Run application

Preparing a Workload for Simulation

1. Install OS
2. Booting target machine
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Media Streaming in Simics Hands-on

1. Loading a freshly-installed OS checkpoint
2. Preparing target system
3. Running applications in Simics
4. Saving system checkpoints
5. Loading system checkpoints

Initial Checkpoint

- Freshly-installed OS: Solaris 10 u9
- Media Streaming binaries & datasets
  - Faban client on Client machine
  - Darwin Streaming Server on Server machine
  - Video dataset on Server machine
- Necessary libraries

Getting Started with Media Streaming

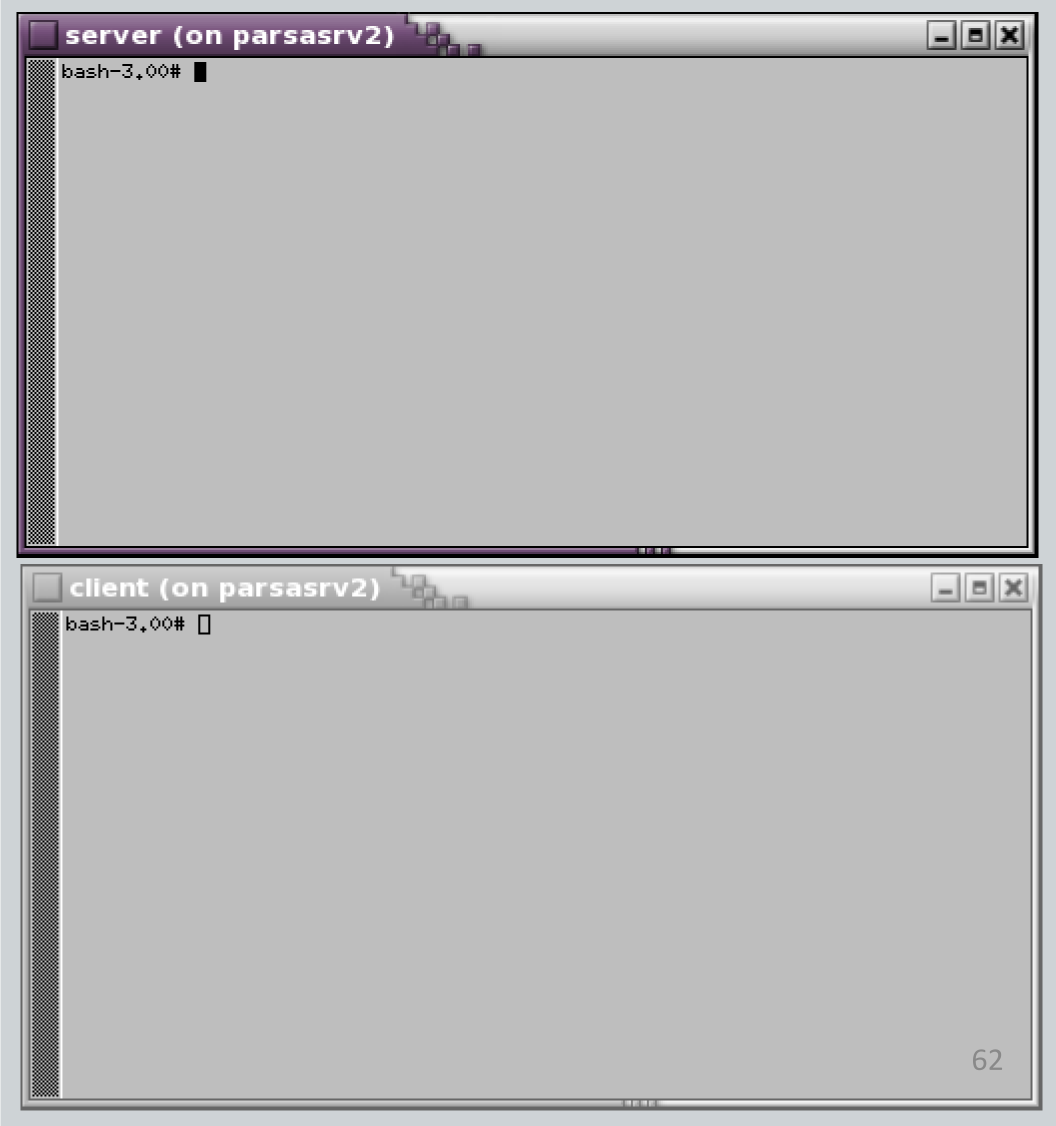
Simulated target system:

- Server (1 core)
- Client (1 core)

- Binaries:

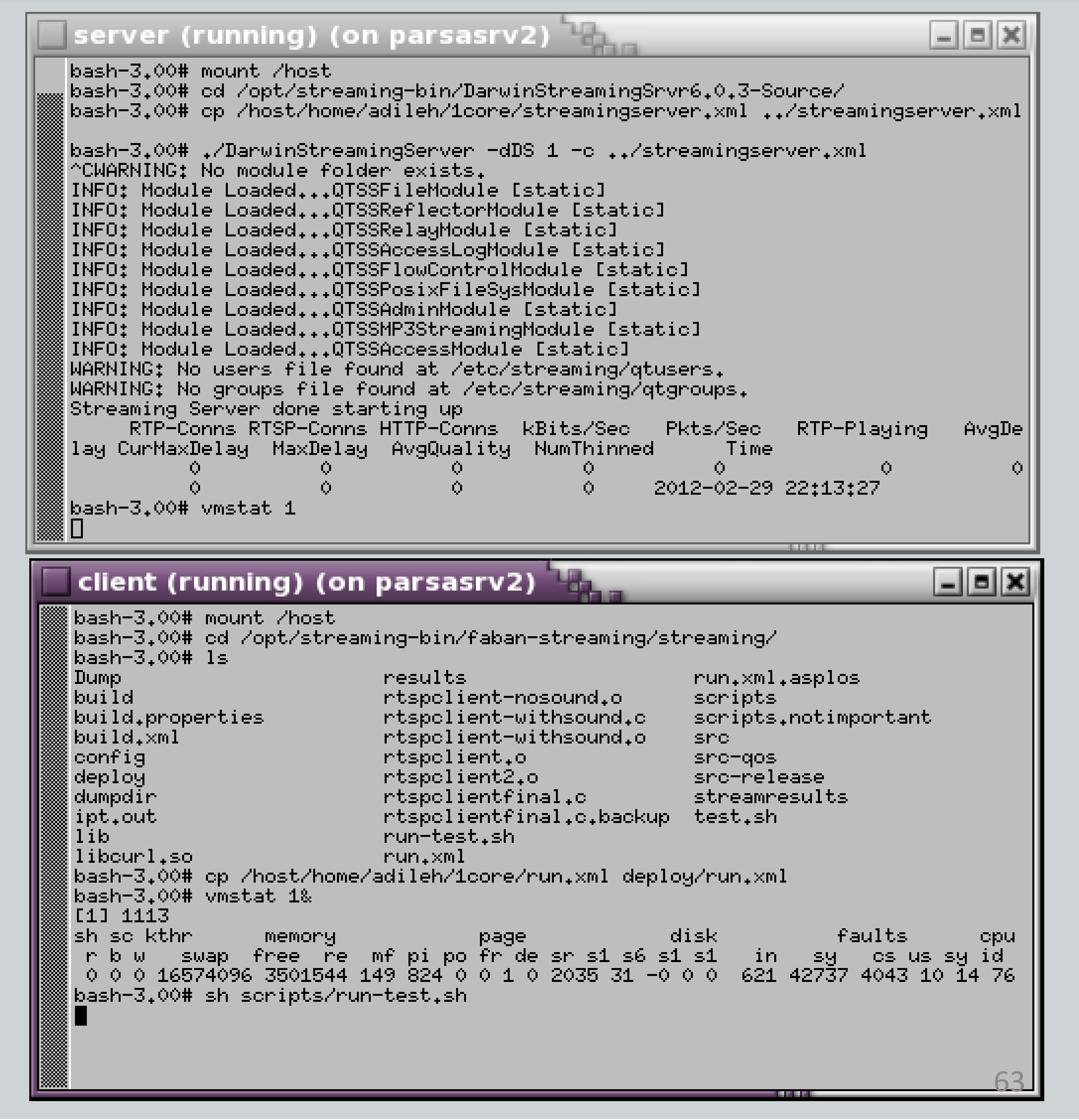
  /opt
- Dataset:

  /streaming_data



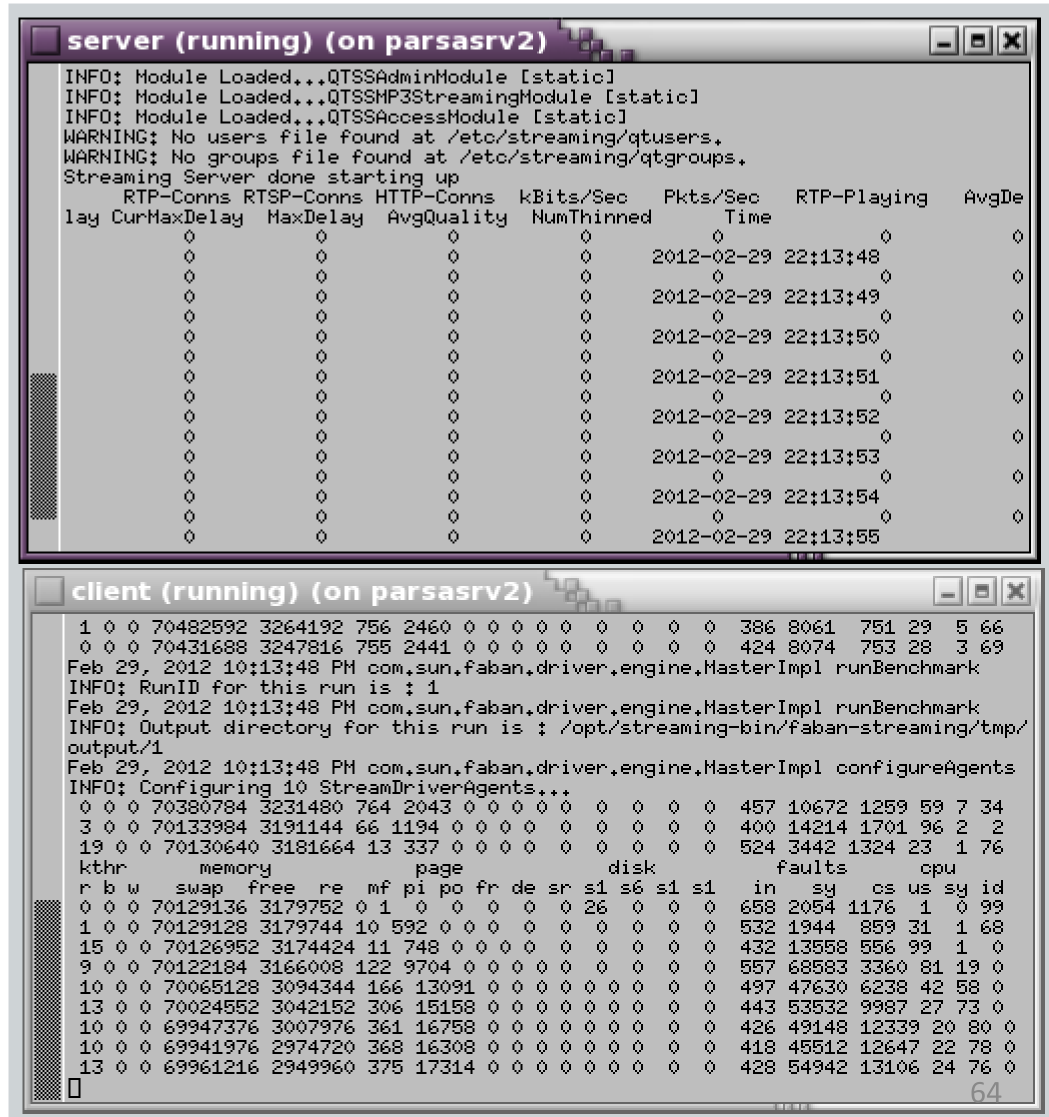
Preparing Target System

- Move configuration files
- Move experiment files
- Start experiment



Media Streaming in Action

- Monitoring
- QoS check



Flexus Simulator Toolset

Cansu Kaynak

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Software Simulation

- Allows for fast & easy evaluation of an idea
  - Minimal cost, simulator runs on your desktop
  - Reuse components, don't implement everything
- Enables various benchmarks (e.g., SPEC, CloudSuite)
  - Can execute real applications
  - Can simulate thousands of disks
  - Can simulate very fast networks

Main Idea

- Use existing system simulator (Simics)
  - Handles BIOS (booting, I/O, interrupt routing, etc.)
- Build a “plugin” architectural model simulator
  - Fast – read state of system from Simics
  - Detailed – interact with and throttle Simics

Developing with Flexus

- Flexus philosophy
- Fundamental abstractions
- Important support libraries
- Simulators and components in Flexus 4.1
- Hands-on

Flexus philosophy

- Component-based design
  - Compose simulators from encapsulated components
- Software-centric framework
  - Flexus abstractions are not tied to hardware
- Cycle-driven execution model
  - Components receive “clock-tick” signal every cycle
- SimFlex methodology
  - Designed-in fast-forwarding, checkpointing, statistics

Developing with Flexus

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- **Fundamental abstractions**
- Important support libraries
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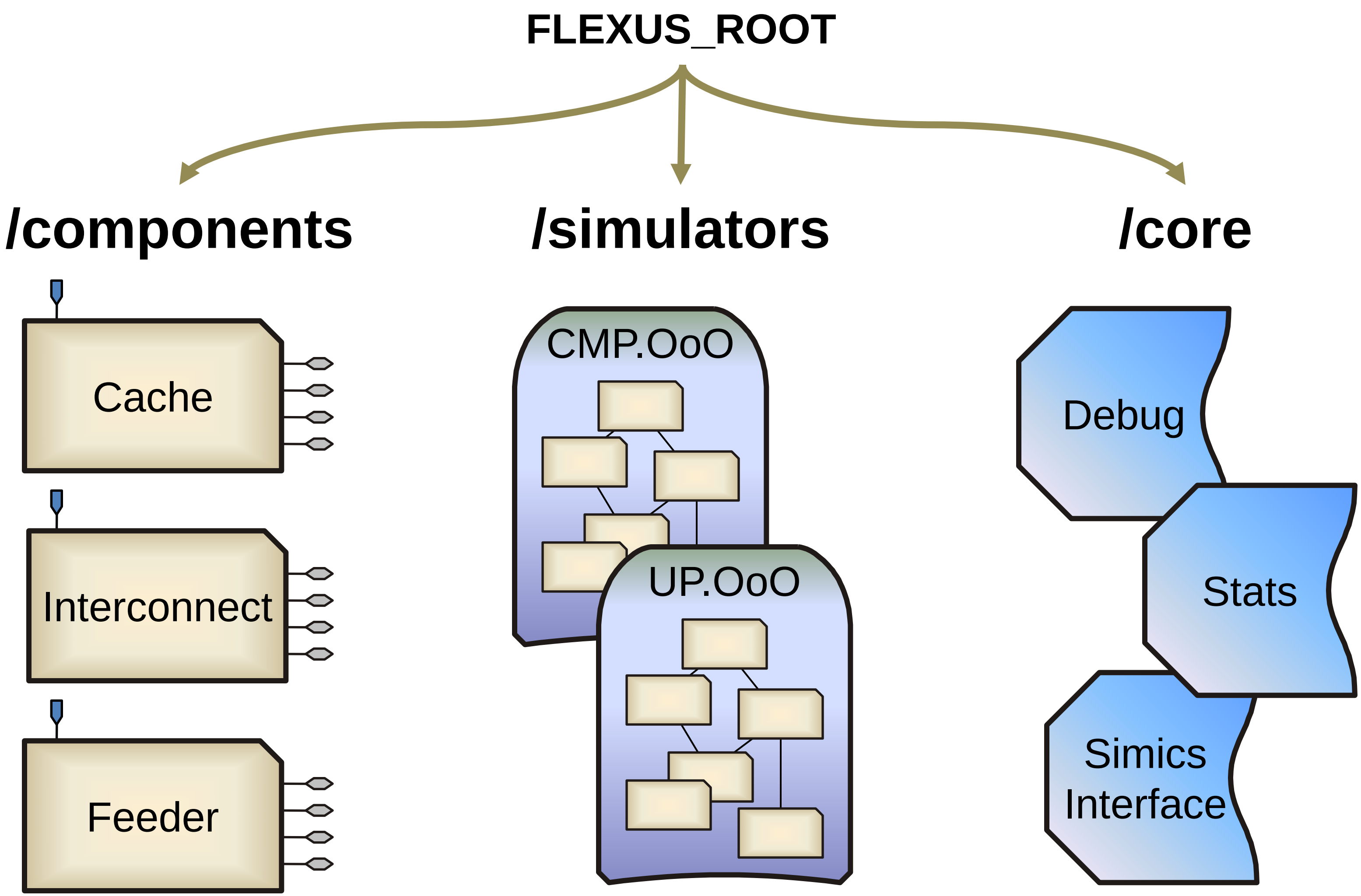
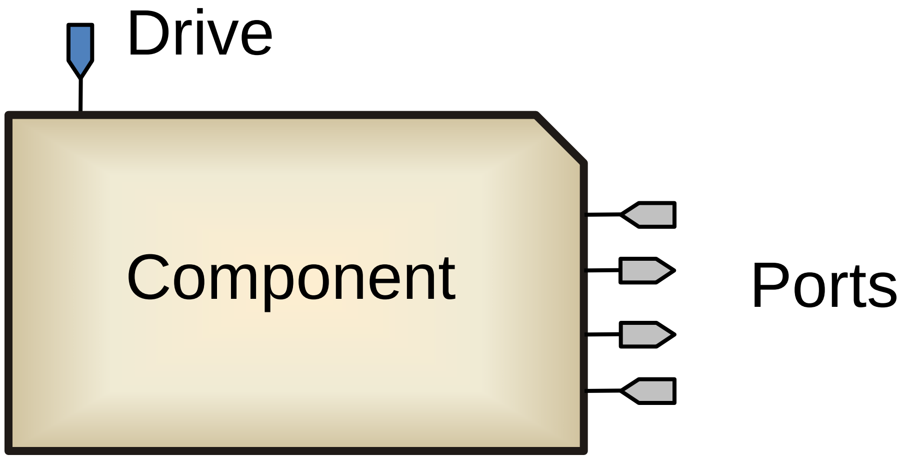
Flexus organization



Fundamental abstractions

- Component
  - Component interface
    - Specifies data and control entry points
  - Component parameters
    - Configuration settings available in Simics or cfg file
- Simulator
  - Wiring
    - Specifies which components and how to connect
    - Specifies default component parameter settings

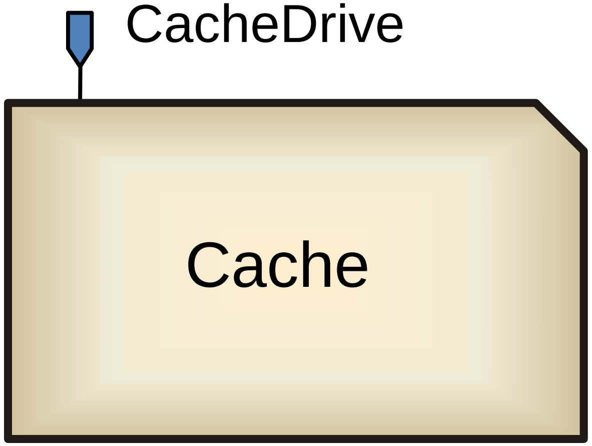
Component interface



- Component interface (terminology inspired by *Asim* [Emer 02])
  - Drive: “clock-tick” control entry point to component
  - Port: specifies data flow between components

Components w/ same ports are interchangeable

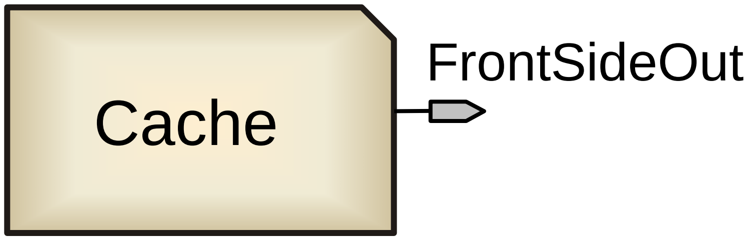
Abstractions: Drive




```
COMPONENT_INTERFACE(
  ...
  DRIVE (  Name )
  ...
);
```

- Control entry-point
- Function called once per cycle

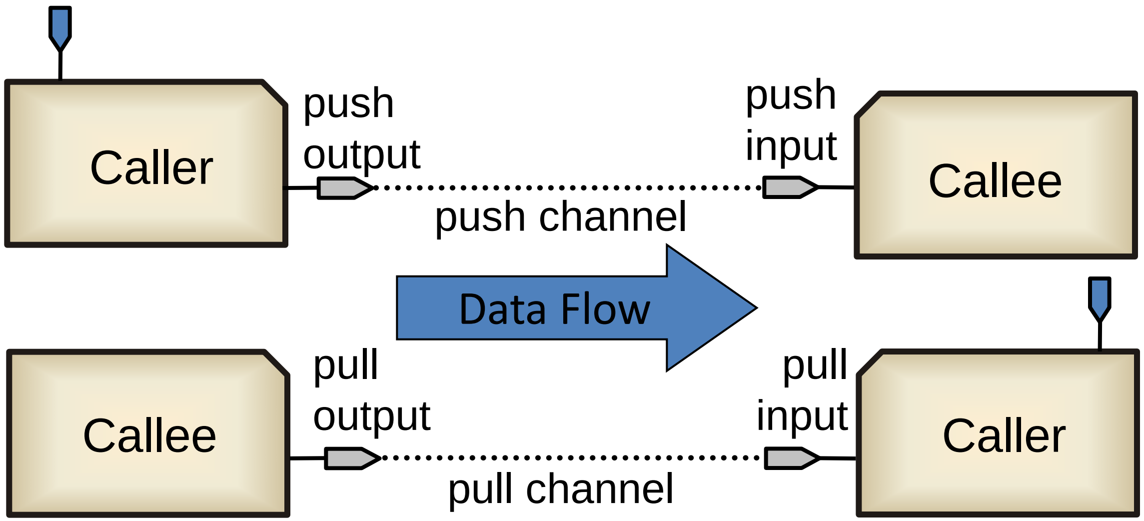
Abstractions: Port




```
COMPONENT_INTERFACE(
  ...
  PORT (  Type, Payload, Name )
  ...
);
```

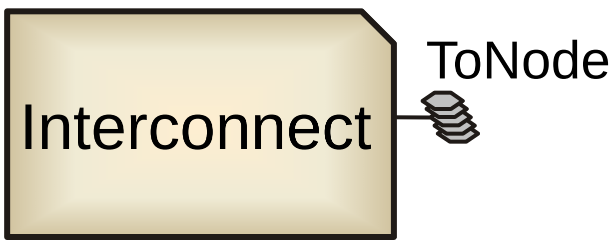
- Data exchange between components
- Ports connected together in simulator wiring

Types of ports and channels



- Type - direction of data and control flow
  - Control flow: Push vs. Pull
  - Data flow: Input vs. Output
- Payload - arbitrary C++ data type
- Type and payload must match to connect ports
- Availability - caller must check if callee is ready

Port and component arrays




```
COMPONENT_INTERFACE(
  ...
  DYNAMIC_PORT_ARRAY(...)
  ...
);
```

- 1-to-*n* and *n*-to-*n* connections
  - E.g., 1 interconnect -> *n* network interfaces
- Array dimensions can be dynamic

Example code using a port

SenderComponent.cpp

```
void someFunction() {
  Message msg;
  if ( FLEXUS_CHANNEL(Out).available() )   {
        FLEXUS_CHANNEL(Out) << msg;
  }
}
```

ReceiverComponent.cpp

```
bool available( interface::In )          {  return true;  }
void push( interface::In, Message & msg)  { … }
```

Configuring components

- Configurable settings associated with component
  - Declared in component specification
  - Can be std::string, int, long, long long, float, double, enum
  - Declaration:

    PARAMETER(BlockSize, int, “Cache block size", “bsize", 64)
  - Use: cfg.BlockSize
- Usage from Simics console
  - flexus.set “-L2:bsize” “64”
  - flexus.print-configuration   flexus.write-configuration “file”

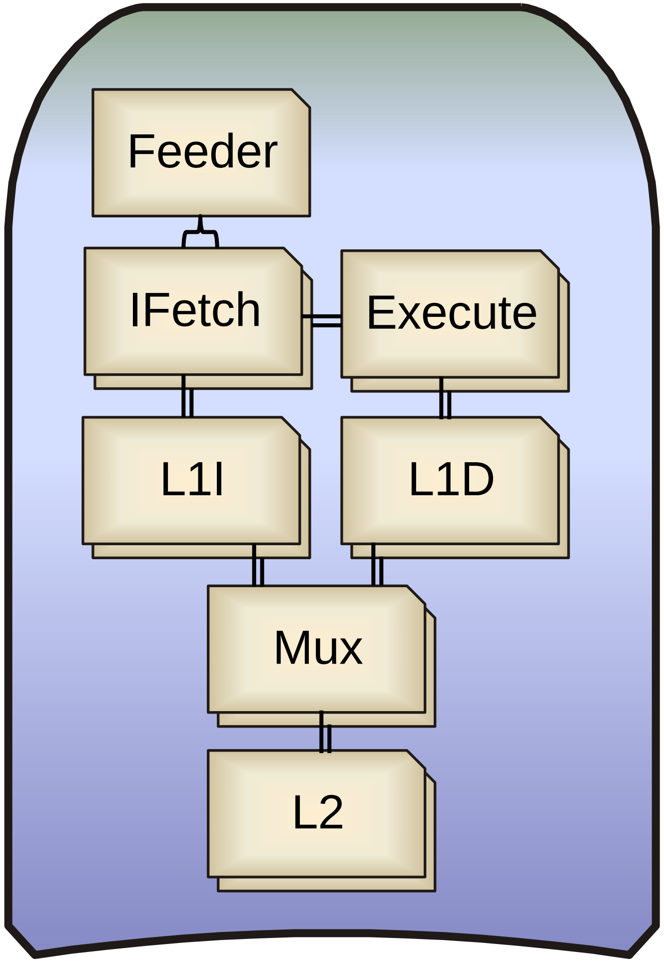
Simulator wiring

simulators/*name*/Makefile.*name*

- List components for link
- Indicate target support

simulators/*name*/wiring.cpp

1. Include interfaces
2. Declare configurations
3. Instantiate components
4. Wire ports together
5. List order of drives



Developing with Flexus

- Flexus philosophy
- Fundamental abstractions
- **Important support libraries**
- Simulators and components in Flexus 4.1
- Hands-on

Critical support libraries in /core

- Statistics support library
  - Record results for use with `stat-manager`
- Debug library
  - Control and view Flexus debug messages

Statistics support library

- Implements all the statistics you need
  - Histograms
  - Unique counters
  - Instance counters
  - etc.

- Example:

```
Stat::StatCounter  myCounter( statName() + “-count” );
++ myCounter;
```

A typical debug statement

```
DBG_(Iface,
  Comp(*this),
  AddCategory( Cache ),
  ( << "Received on FrontSideIn[0](Request): "
    << *(aMessage[MemoryMessageTag])
  ),
  Addr(aMessage[MemoryMessageTag]->address())
);
```

Severity level

Associate with this component

Put this in the “Cache” category

Text of the debug message

Add an address field for filtering

Debug severity levels

1.	Tmp	temporary messages (cause warning)
2.	Crit	critical errors
3.	Dev	infrequent messages, e.g., progress
4.	Trace	component defined – typically tracing
5.	Iface	all inputs and outputs of a component
6.	Verb	verbose output from OoO core
7.	Vverb	very verbose output of internals

Controlling debug output

- Compile time
  - `make` *target-severity*
  - *(e.g.* `make UP.Trace-iface`*)*
- Run time
  - `flexus.debug-set-severity` *severity*
- Hint – when you need a lot of detail…
  - Set severity low
  - Run until shortly before point of interest (or failure)
  - Set severity high
  - Continue running

Developing with Flexus

- Flexus philosophy
- Fundamental abstractions
- Important support libraries
- **Simulators and components in Flexus 4.1**
- Hands-on

Simulators in Flexus 4.1

• UP.Trace	fast memory system
• CMP.L2Shared.Trace	fast CMP memory system
• CMP.MT4.L2Shared.Trace	fast CMP memory system w/ 4-way MT support
• UP.OoO	1 CPU 2-level hierarchy
• CMP.L2SharedNUCA.OoO	private L1 / shared L2
• CMP.MT4.L2SharedNUCA.OoO	private L1 / shared L2 w/ 4-way MT support
• CMP.L2SharedNUCA.DRAMSim.OoO	private L1 / shared L2 w/ DRAMSim 2.0

Memory hierarchy

- “top”, “front” = closer to CPU
- Allows for high MLP
  - Non-blocking, pipelined accesses
  - Hit-under-miss within set
- Coherence protocol support
  - MESI and MOESI coherence protocols
  - Non-inclusive
  - Supports “Downgrade” and “Invalidate” messages
  - Request and snoop virtual channels for progress guarantees

Out-of-order execution

- Timing-first simulation approach [Mauer'02]
  - OoO components interpret SPARC ISA
  - Flexus validates its results with Simics
- Idealized OoO to maximize memory pressure
  - Decoupled front-end
  - Precise squash & re-execution
  - Configurable ROB, LSQ capacity; dispatch, retire rates
- Memory consistency models (SC, TSO, RMO)

Hands-on

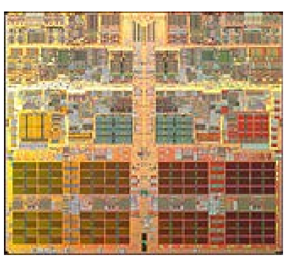
- Set up `.run_job.rc.tcl` file
- Launch Simics using the `run_job` script
- Build Flexus simulators
  - Examine Flexus directory structure and source files
- Launch trace-based simulation
- Launch cycle-accurate (OoO) simulation
  - Examine debug output and statistics

Boosting Simulation Speed with Statistical Sampling

Djordje Jevdjic

Simulation Speed Challenges

- Longer benchmarks
  - SPEC 2006: Trillions of instructions per benchmark
- Slower simulators
  - Full-system simulation: 1000× slower than SimpleScalar



- Multiprocessor systems
  - CMP: 2x cores every processor generation

1,000,000× slowdown vs. HW → years per experiment

Full-system simulation is slow

- Simulation slowdown per cpu

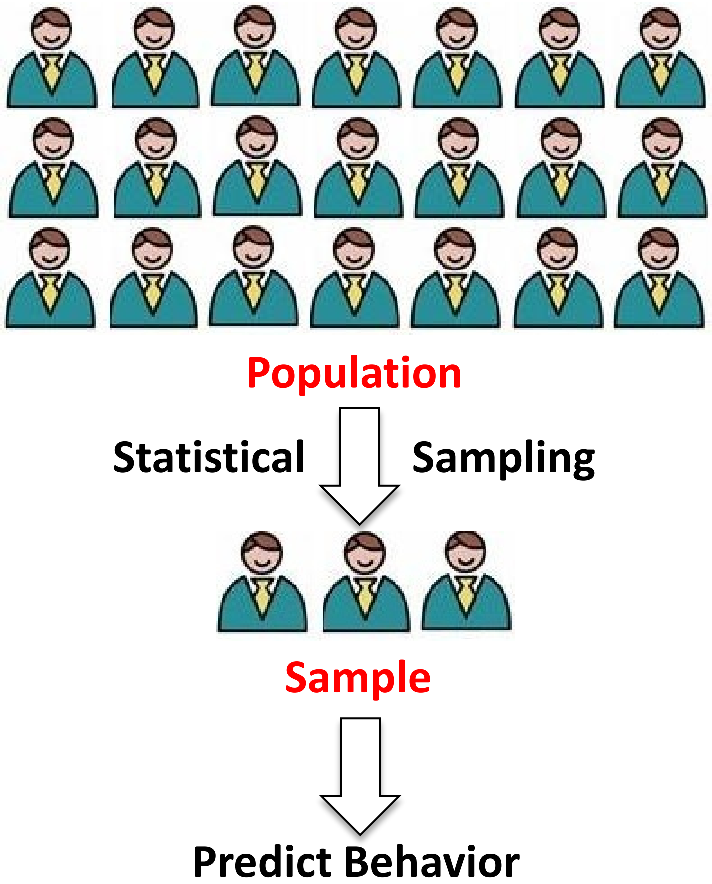
– Real HW:	~ 2 GIPS	1 s
– Simics:	~ 30 MIPS	66 s
– Flexus, no timing:	~ 900 KIPS	37 m
– Flexus, OoO:	~ 24 KIPS	23 h

2 years to simulate 10 seconds of a 64-core workload!

Statistical Sampling

- Random selection of population
  - E.g., 3000 out of 300 million
- Predict the behavior based on the selected sample

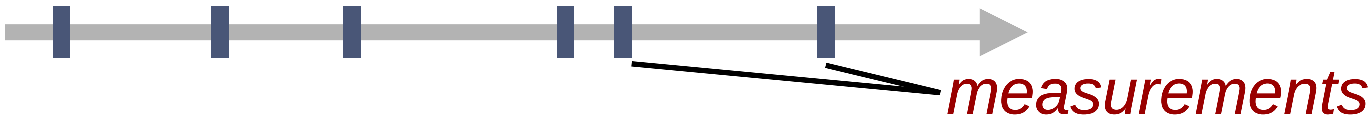
- Features:
  - High accuracy
  - Simple
  - Strong mathematical foundation



Power of a small part to predict behavior of a whole

Statistical Sampling for Simulation

- Measure uniform or random locations



- Each measurement is on a group of instructions

- ~10,000x reduction in turnaround time

Challenge: programs are sequential

Sampling of Sequential Programs

- Correctness
  - State of memory, registers, etc.
- Bias
  - State of cache, branch predictor, reorder buffer, etc.

Functional Simulation

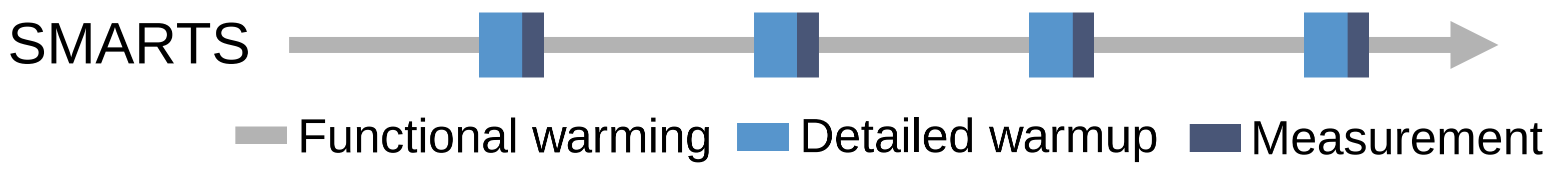
- Functional simulation is faster than detailed simulation
  - Flexus (no timing) is 38 times faster than Flexus (OoO)

- Use functional simulation for “warmup”
  - Memory (guarantees correctness)
  - Registers (guarantees correctness)
  - Cache hierarchy (avoids bias)
  - Branch predictor (avoids bias)

No state for core microarchitecture → Bias

Handling Bias

- Core micro-architecture can be warmed up rapidly
  - Detailed simulation to warmup core micro-architecture
- Perform warmup prior to measurement
  - Functional warming during fast-forwarding
  - Detailed warmup before each simulation window

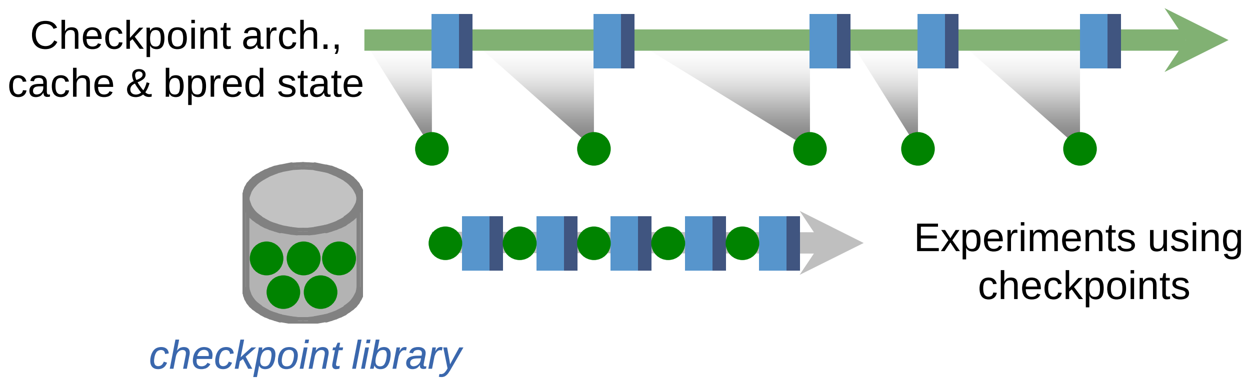


Simulation Speedup

- 10 seconds of a 64-core workload
  - Normal execution: 2 years
  - With sampling: 20 days

- 37x improvement in simulation speed but not enough
- Solution
  - Avoid functional simulation (17 days)
  - Accelerate detailed simulation (3 days)

Avoiding Functional Simulation

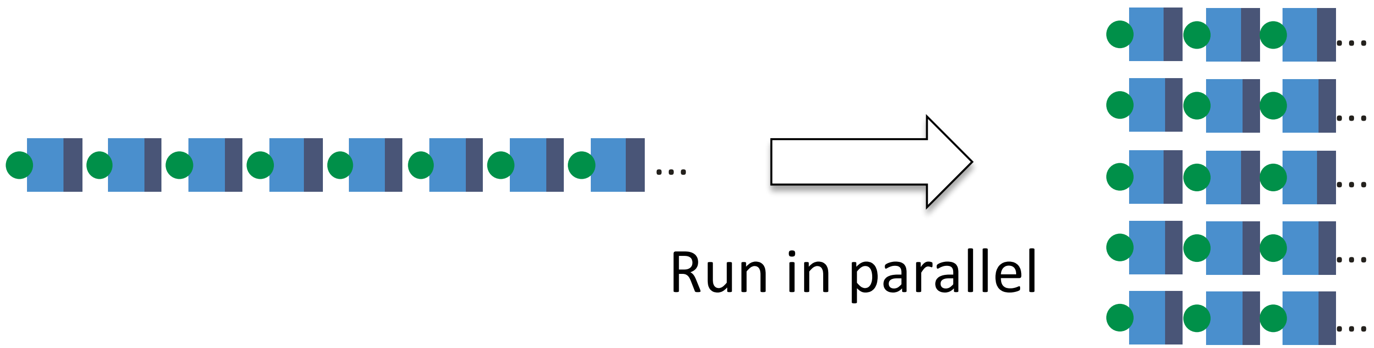


- Store warm cache & branch predictor state
  - Same sample design, accuracy, confidence
  - No warming length prediction needed

Works for any microarchitecture

Accelerating Detailed Simulation

- Checkpoint library makes measurement independent
- Run multiple measurements in parallel

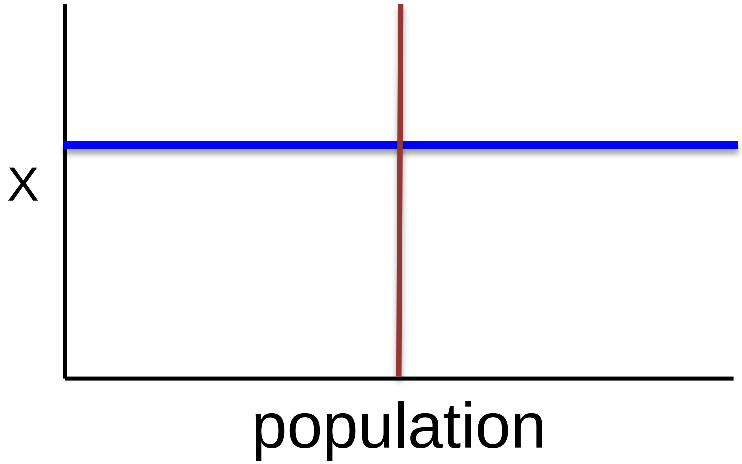


Simulation Speedup

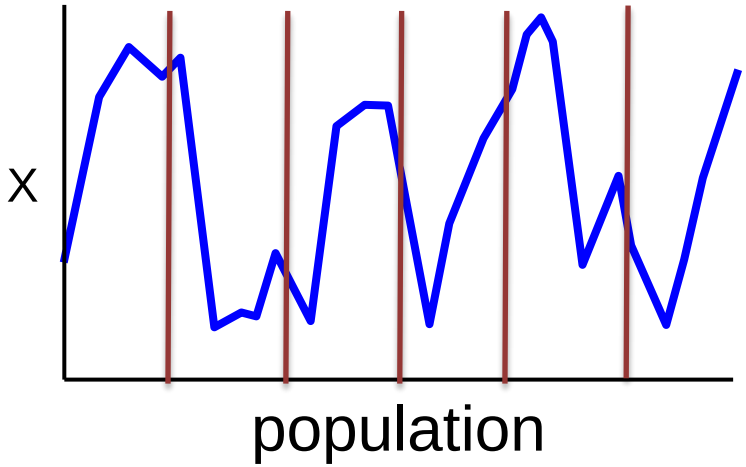
- Sampling without a checkpoint library:
  - 10 seconds of a 64-core workload: 20 days

- Sampling with a checkpoint library:
  - 10 seconds of a 64-core workload: 3 hours with 100 cores

How to Choose the Sample Size?



Low variability ➔ Small sample size



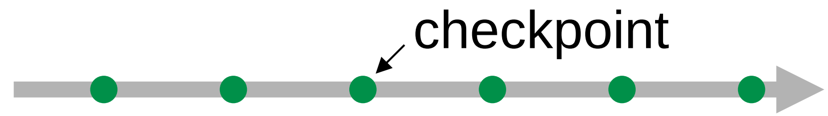
High variability ➔ Large sample size

Variability determines sample size

Steps for Timing Simulation

1. Prepare workload for simulation
   – Port workload into Simics
2. Measure baseline variance
   – Determine required library size

3. Collect checkpoints
   – Via functional warmup



4. Detailed Simulation
   – Estimate performance results

2. Determine Sampling Parameters

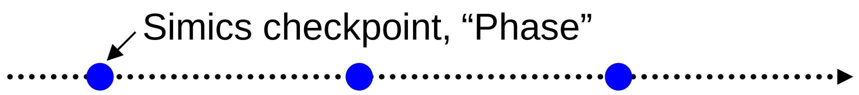
- Guess variability
- Generate flexpoints for the variability
- Run timing simulation
- Measure error and correct the guess

Typical Sampling Parameters

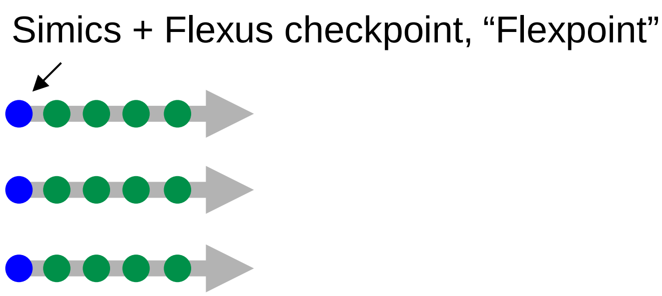
	Flexus (64-CPU CMP.OoO)
Warming	100k cycles
Measurement	50k cycles
Target confidence	95%
Sample size	800
Sim. time per checkpoint	~ 20 min

3. Checkpoint Creation

- Spread Simics checkpoints
  - Simics fast mode rapidly covers 10 seconds



- Collect flexpoints in parallel
  - Via CMP.L2Shared.Trace
  - From each Simics checkpoint



4. Detailed Simulation

- Run detailed simulation with OoO simulators
- Process all flexpoints, aggregate offline
- Manipulate results with *stat-manager*
  - Each run creates binary `stats_db.out` database
  - Offline tools to select subsets; aggregate
  - Generate text reports from simple templates
  - Compute confidence intervals for mean estimates

Matched-pair comparison [Ekman 05]

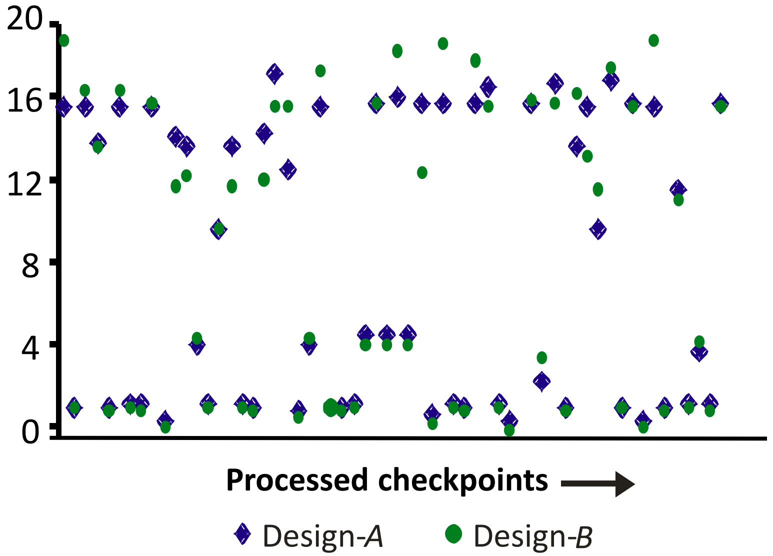
- Often interested in relative performance

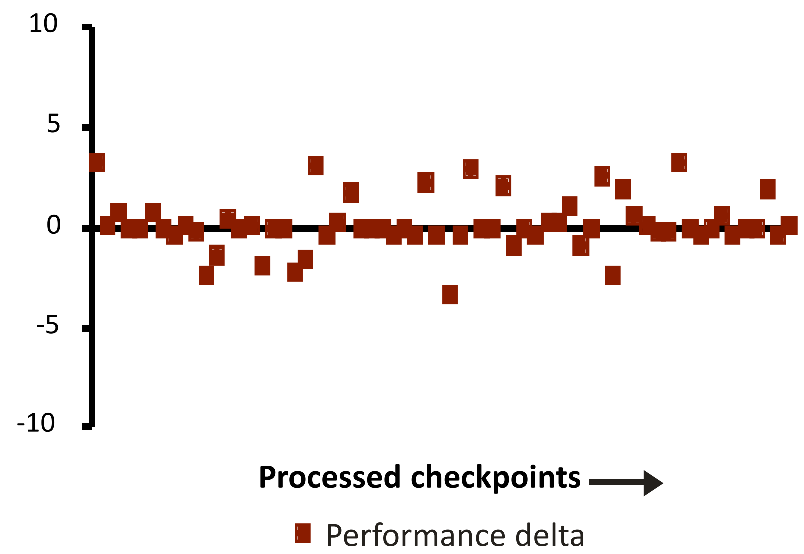
- Change in performance across designs varies less than absolute change

- Matched pair comparison
  - Allows smaller sample size
  - Reports confidence in performance change

Matched-pair example

Performance results for two microarchitecture designs
checkpoints processed in random order





Lower variability in performance delta reduces sample size by 3.5 to 150x

Matched-pair with Flexus

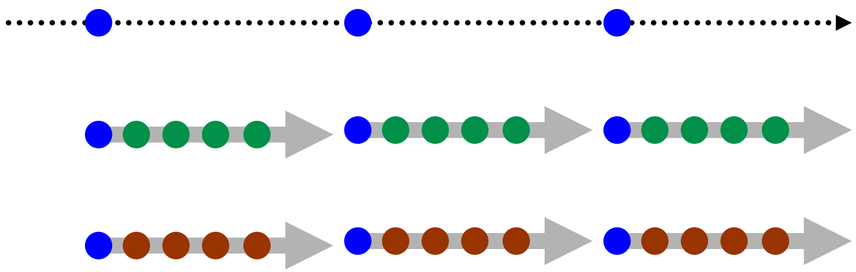
- Simple μArch changes (e.g., changing latencies)
  - use same flex-points

- Complex changes (e.g., adding components)

Simics checkpoints

Flex-points for design A

Flex-points for design B



Hands-on

- Generate Flexpoints
- Launch timing simulation for all flexpoints
- Aggregate stats with stat-collapse
- Examine aggregate statistics
  - Compute confidence
  - Plot timing breakdown

Thanks!

How to Use CloudSuite Images

Cansu Kaynak

CloudSuite Simics Release

Released images (phase_000) contain:

- CloudSuite binaries & necessary libraries
- Tuned workloads at steady state
- Ready to run

CloudSuite Images

From 1 core to 64 cores:

1. Data Analytics
2. Data Serving
3. Media Streaming (4, 8, 16 cores)
4. Software Testing
5. Web Search (1 to 32 cores) ~ SW scalability
6. Web Serving (1 to 8 cores)

Coming soon:

1. Data Caching
2. Graph Analytics

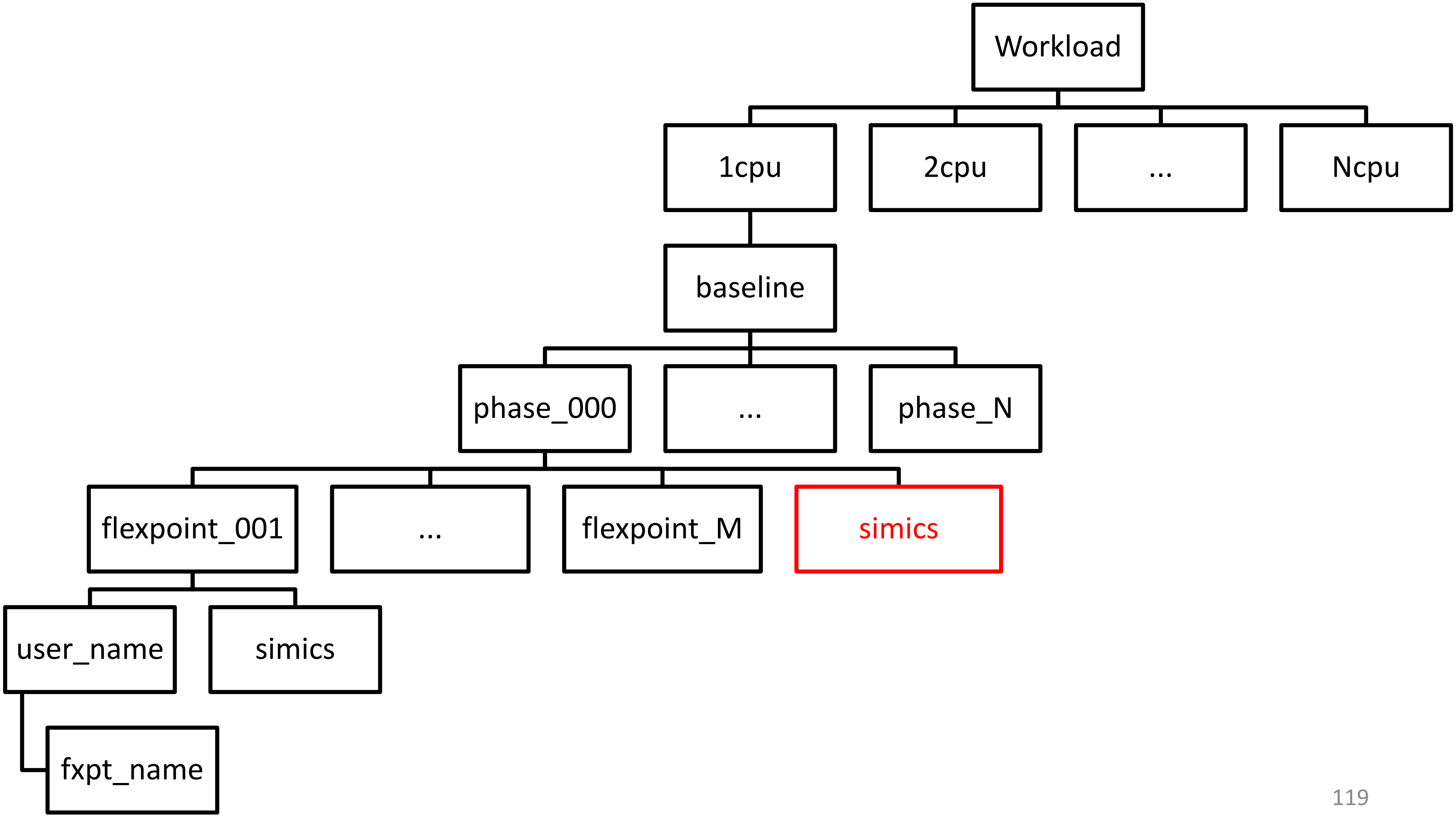
Deploying CloudSuite Images

- Paths for logical components in configuration files:
  - Binary disk
  - Data disk(s)

```
checkpoint_path: (  "/path/to/binary_disk",
                    "/path/to/data_disk")
```

- Load initial state & save it as phase_000
- Detailed instruction are in setup document…

Directory Hierarchy for Flexus



What We Release

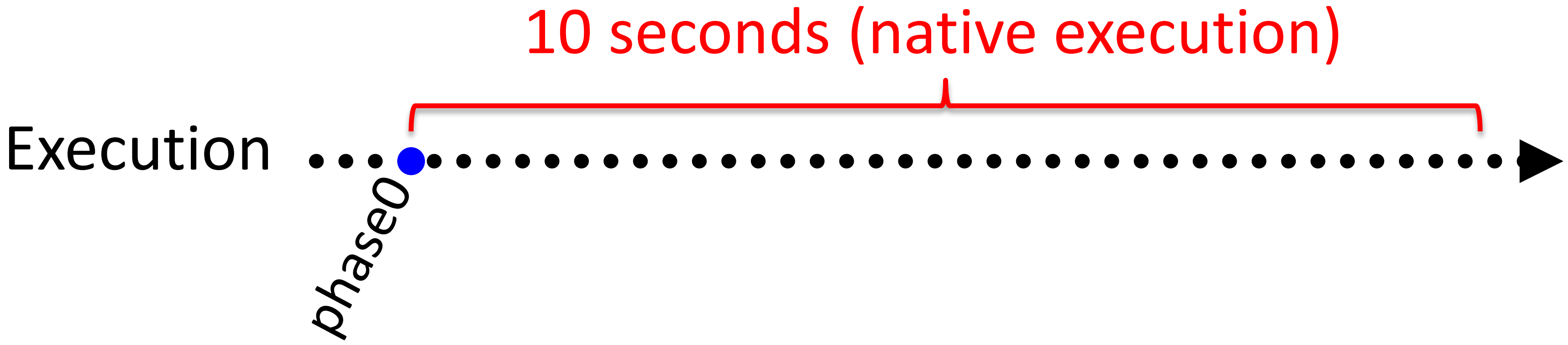
We provide phase_000:

- Steady state of workload execution

How Long To Simulate

Representative execution window of a workload:

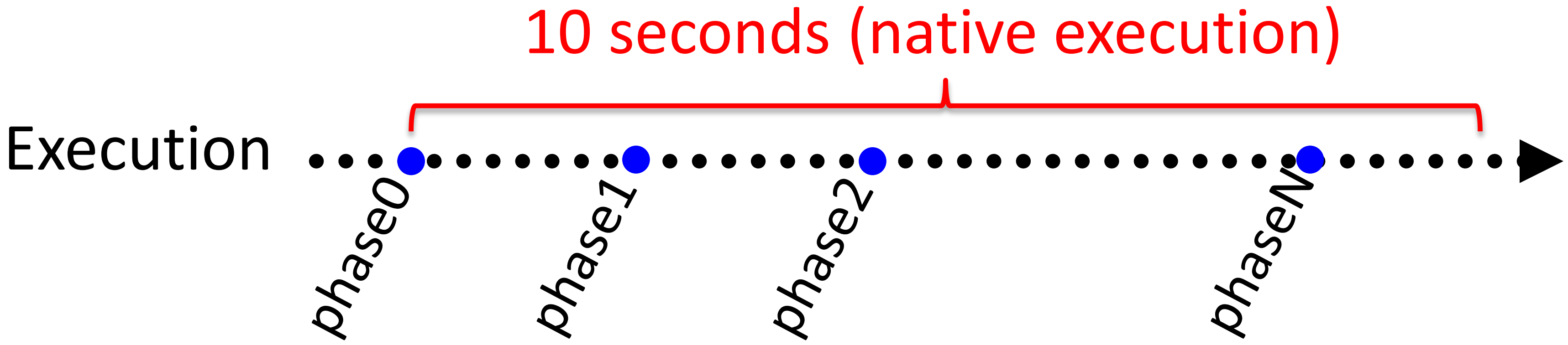
- Steady architectural behavior (measured on real HW)
- 10 sec. of native execution (25 sec. for media streaming)



Phase Generation

Divides the entire execution into phases

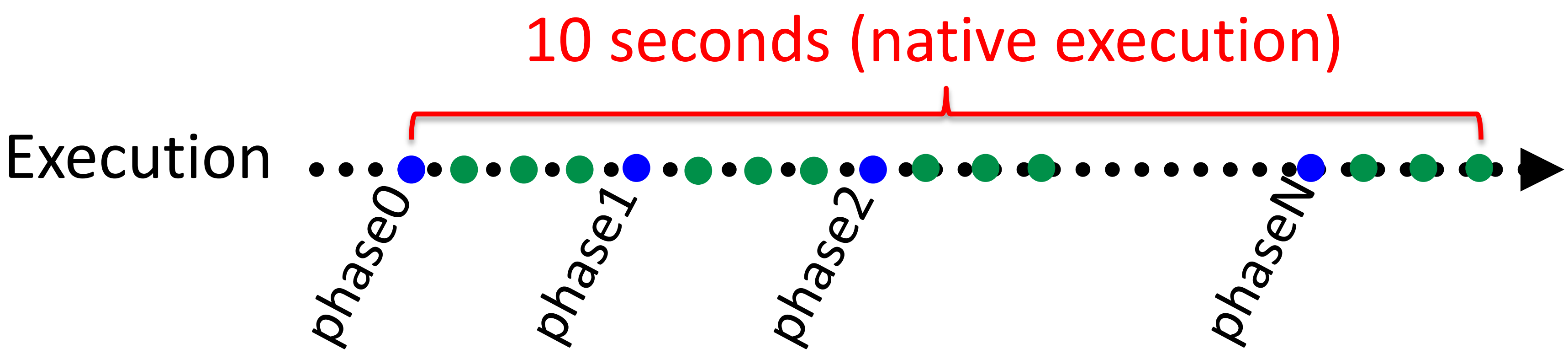
- Generates phases (Simics checkpoints) using Simics fast mode
- As many phases as necessary for desired parallelism
  - e.g., 10 phases



Flexpoint Generation

Divides every phase into flexpoints (parallel across phases)

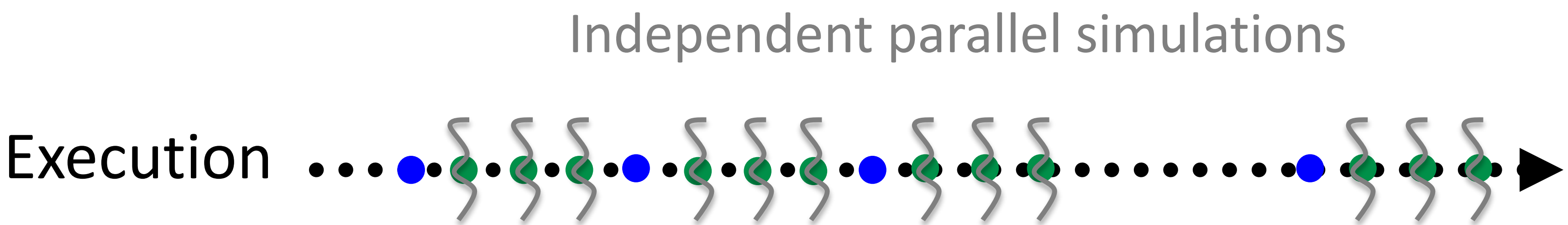
- Generates flexpoints using Flexus trace simulator
  - Functional warming of cache and branch predictor state
- As many flexpoints as necessary for desired degree of confidence
  - e.g., 80 flexpoints per phase



Timing Simulation

Cycle-accurate simulation in parallel across flexpoints

- First, detailed warm-up of microarchitectural state
- Then, takes measurements from the warmed state
  - e.g., 100K-cycle warm-up, 50K-cycle measurement
  - Longer warm-up necessary for Data Serving



Wrap-Up

- Two steps before cycle-accurate simulation:
  1. Phase generation
  2. Flexpoint generation

- Refer to .run_job.rc.tcl in Flexus 4.1 for workloads, phases, flex-points

Thanks!