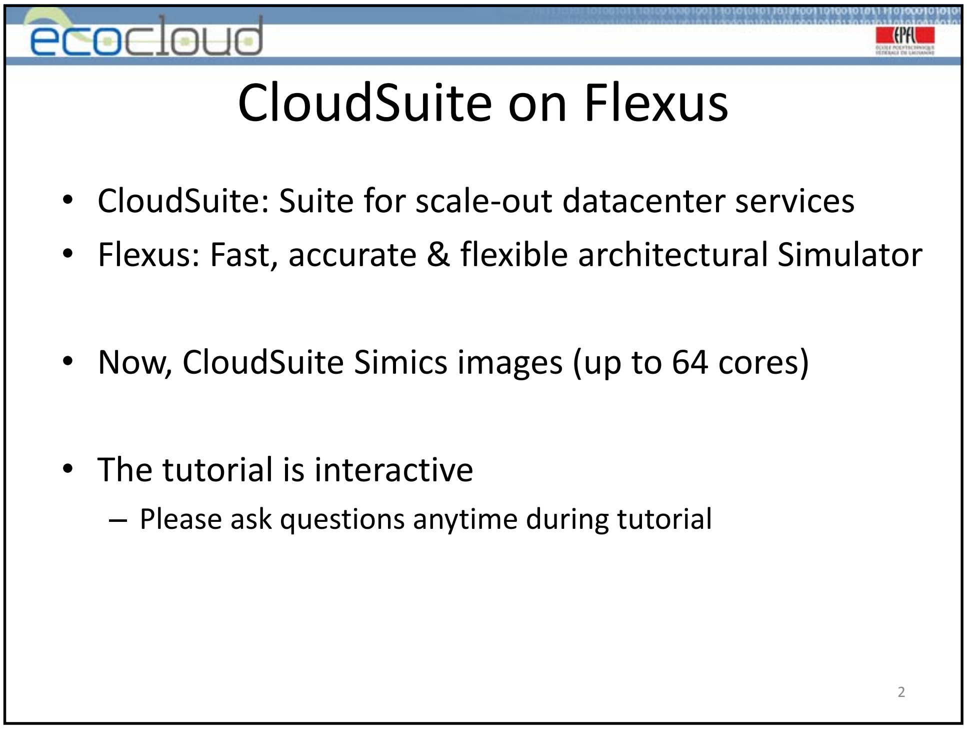
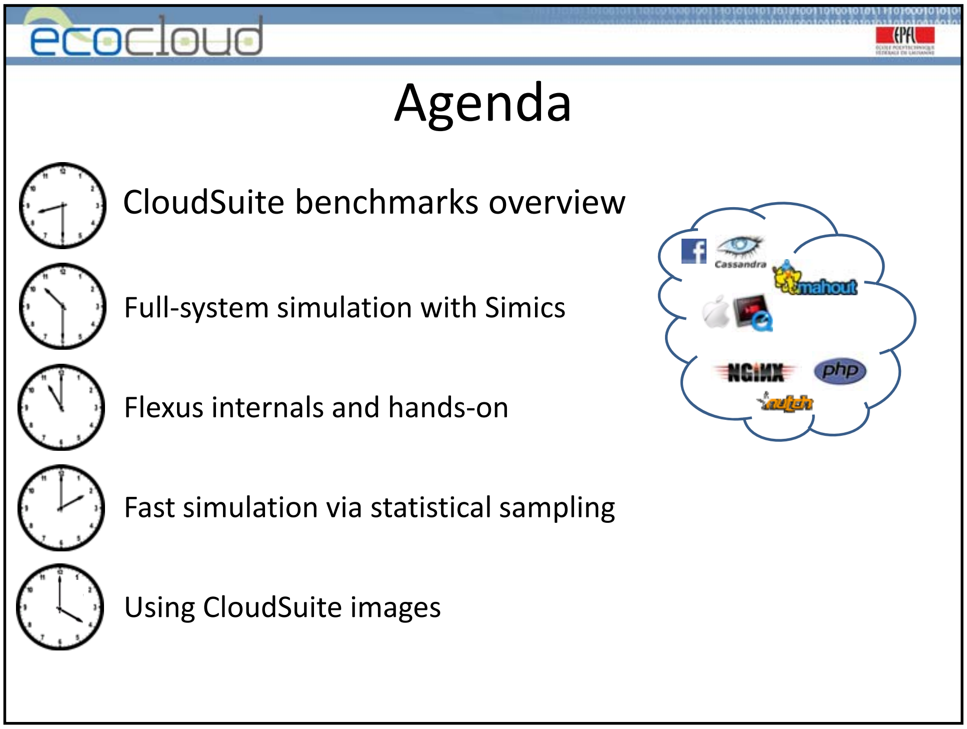
Welcome Everybody

Almutaz Adileh
Cansu Kaynak
Pejman Lotfi-Kamran
Stavros Volos



CloudSuite on Flexus

- CloudSuite: Suite for scale-out datacenter services
- Flexus: Fast, accurate & flexible architectural Simulator
- Now, CloudSuite Simics images (up to 64 cores)
- The tutorial is interactive
  - Please ask questions anytime during tutorial



Agenda

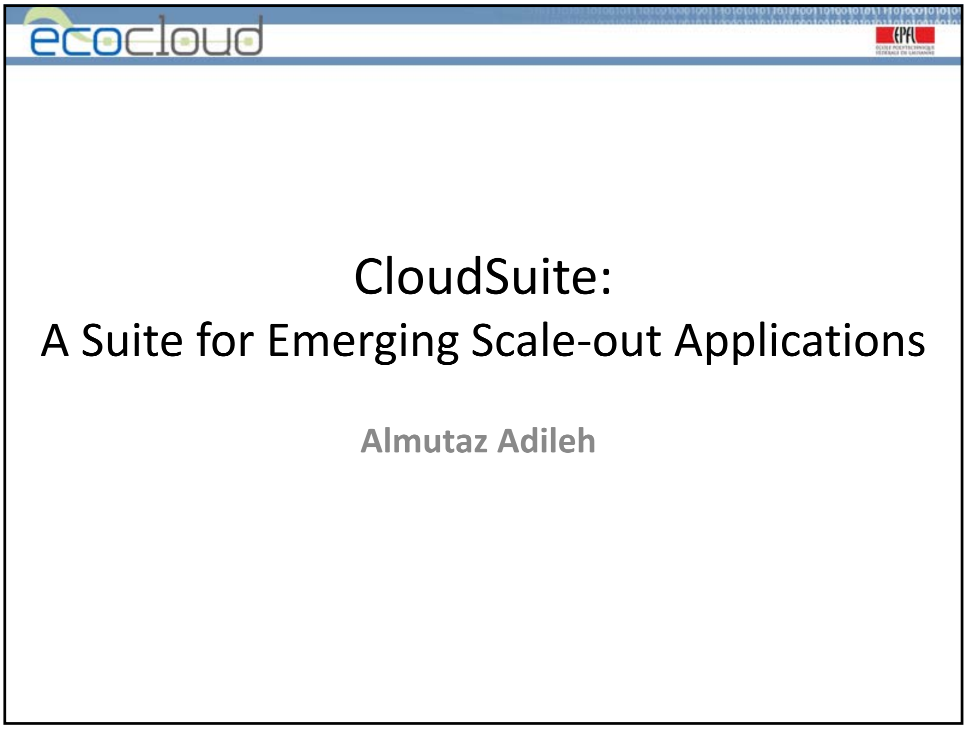
CloudSuite benchmarks overview

Full-system simulation with Simics

Flexus internals and hands-on

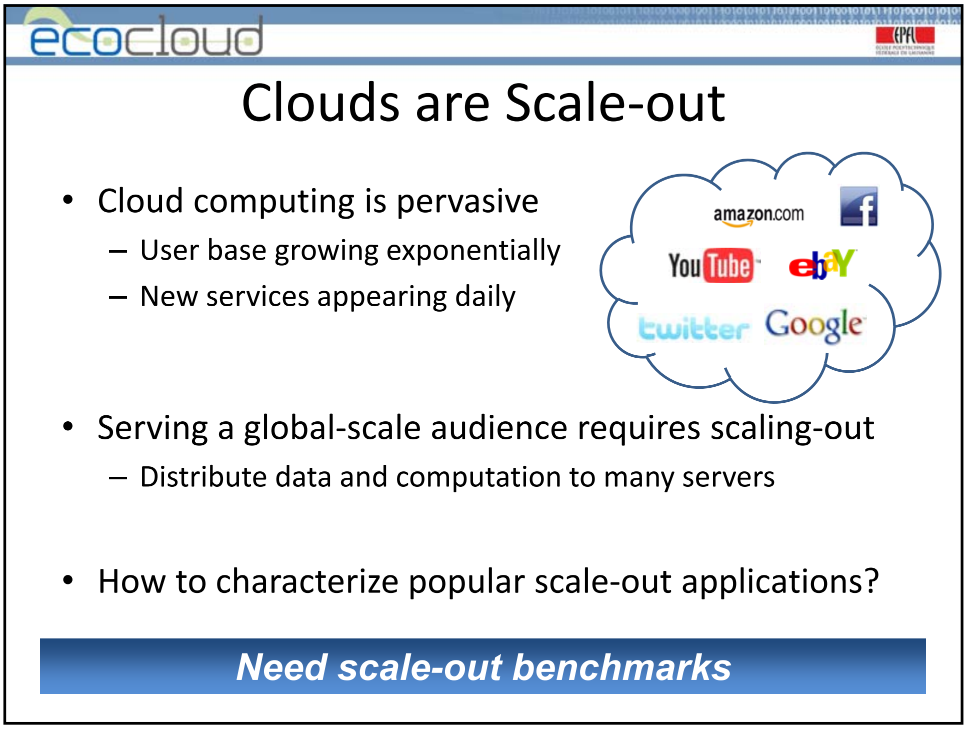
Fast simulation via statistical sampling

Using CloudSuite images



CloudSuite:
A Suite for Emerging Scale-out Applications

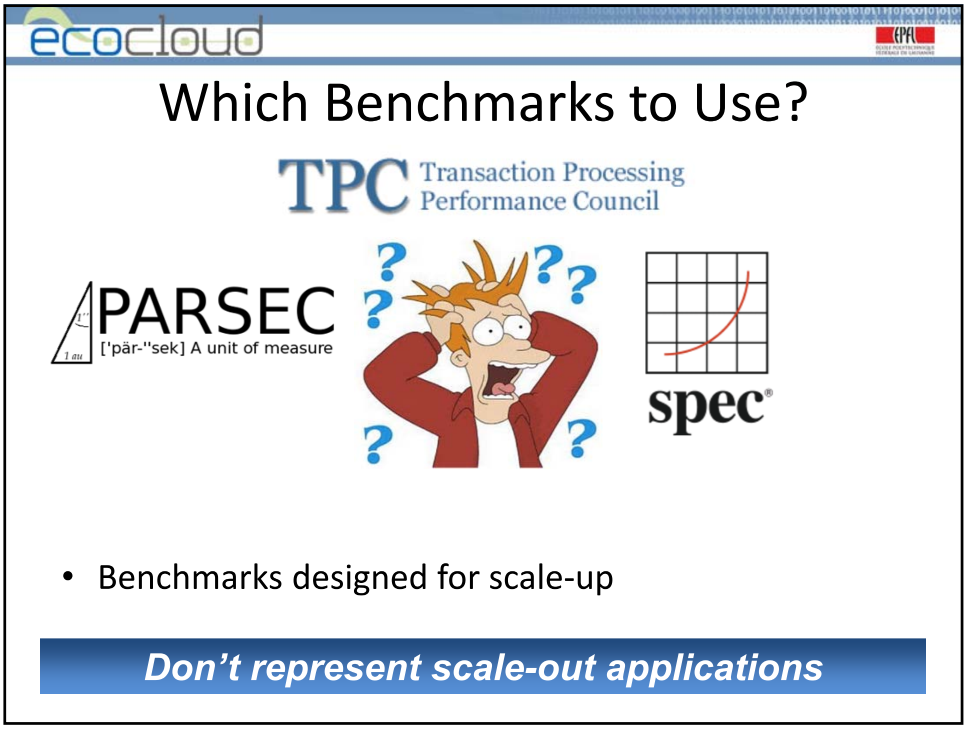
Almutaz Adileh


ecocloud
EPFL
amazon.com
YouTube
ebay
twitter
Google

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
- How to characterize popular scale-out applications?

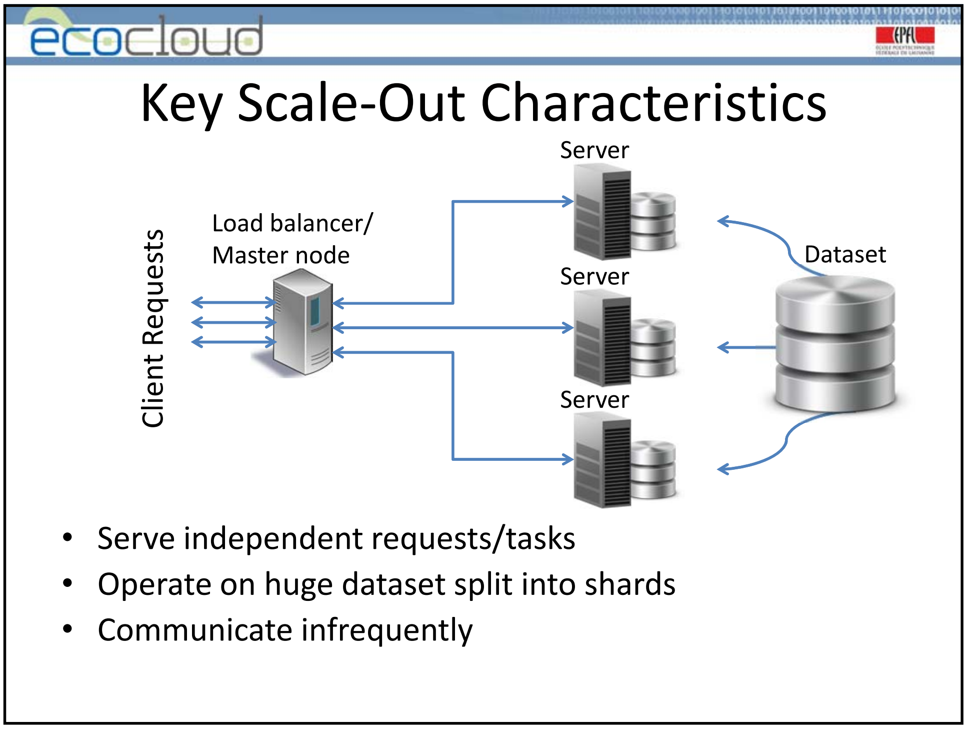
Need scale-out benchmarks


ecocloud
EPFL
TPC Transaction Processing Performance Council
PARSEC ['pär-"sek] A unit of measure
1 au
1''
? ? ? ? ? ?
spec

Which Benchmarks to Use?

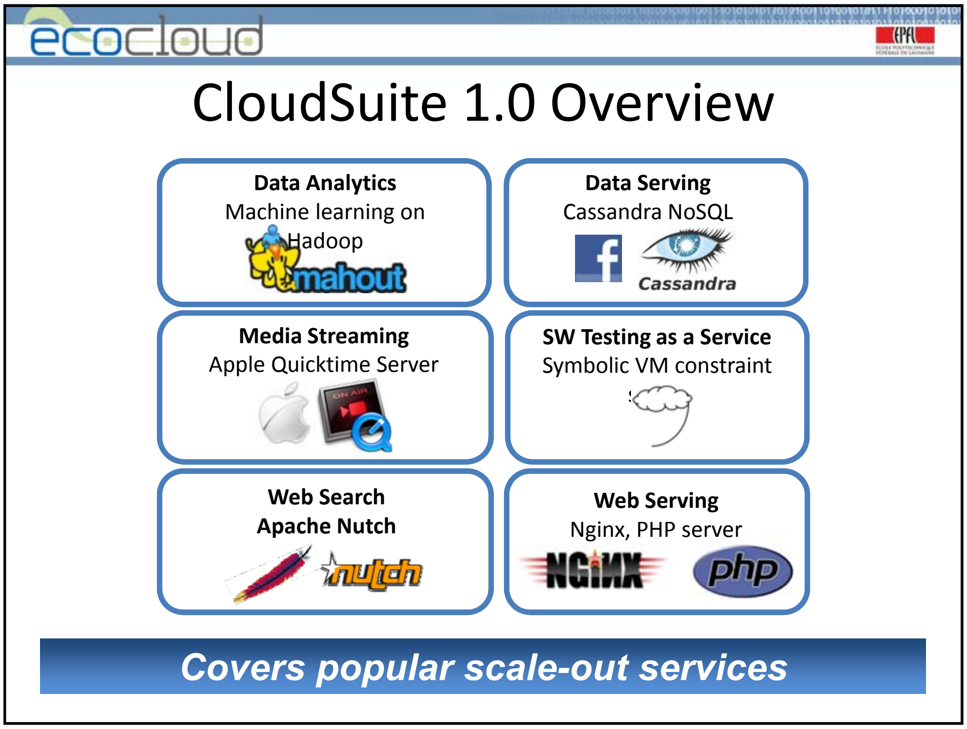
- Benchmarks designed for scale-up

Don't represent scale-out applications



Key Scale-Out Characteristics

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



CloudSuite 1.0 Overview

Data Analytics
Machine learning on
Hadoop

Data Serving
Cassandra NoSQL

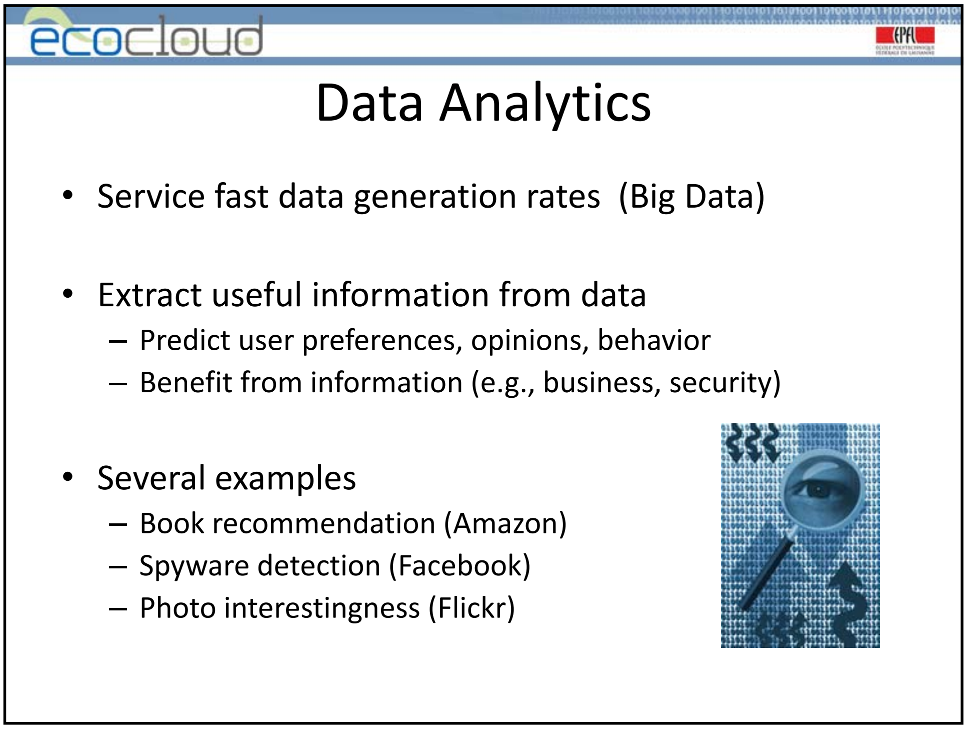
Media Streaming
Apple Quicktime Server

SW Testing as a Service
Symbolic VM constraint

Web Search
Apache Nutch

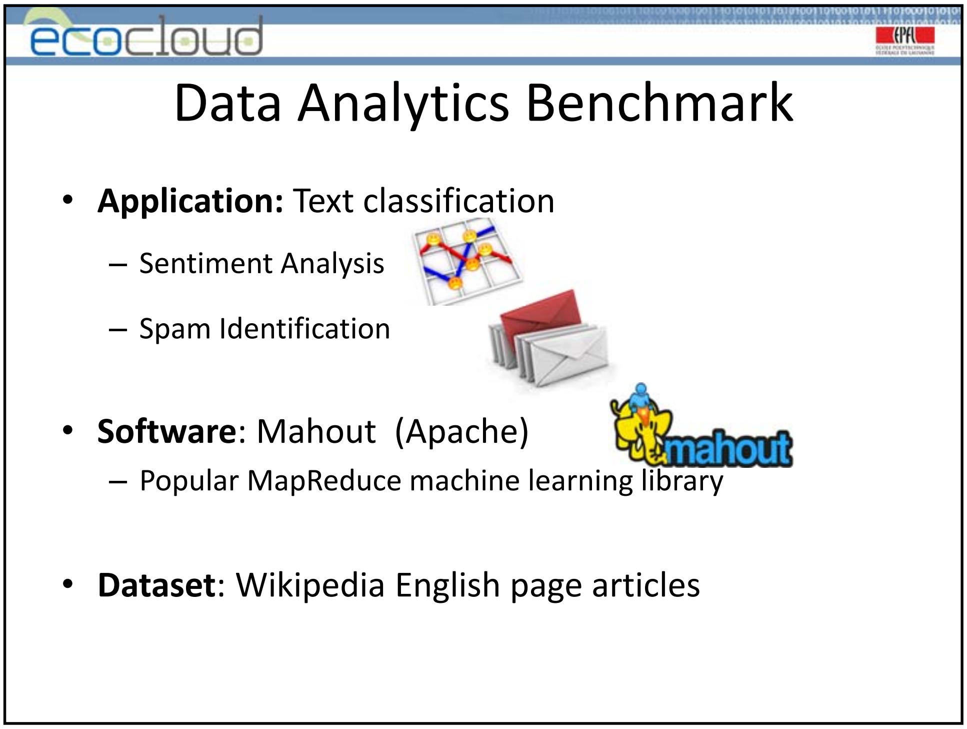
Web Serving
Nginx, PHP server

Covers popular scale-out services



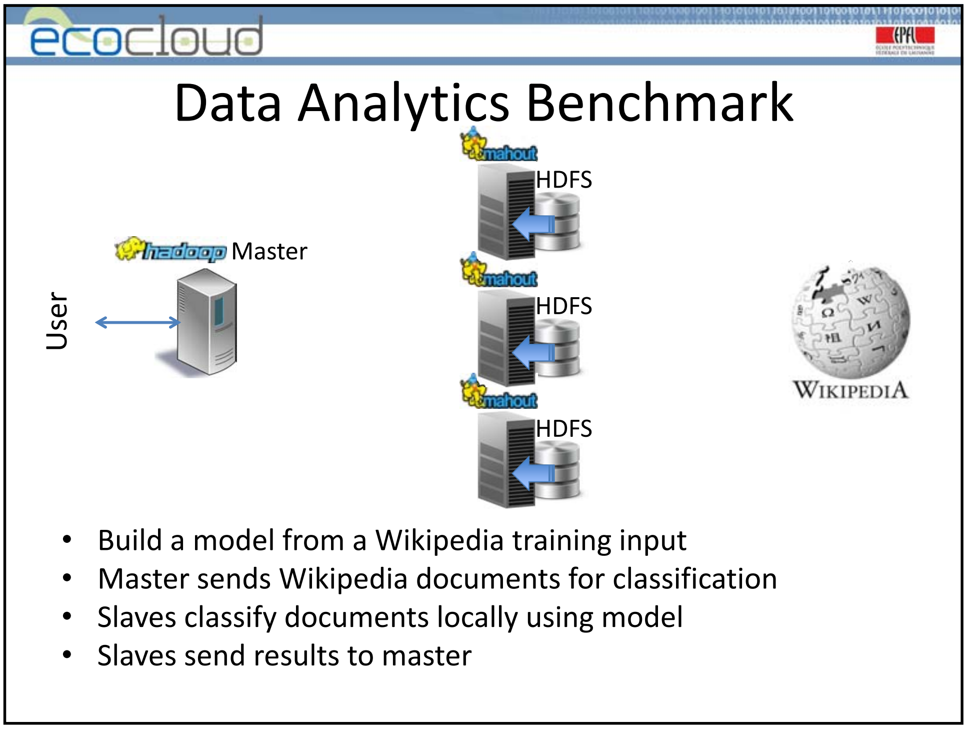
Data Analytics

- Service fast data generation rates (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)
  - Photo interestingness (Flickr)



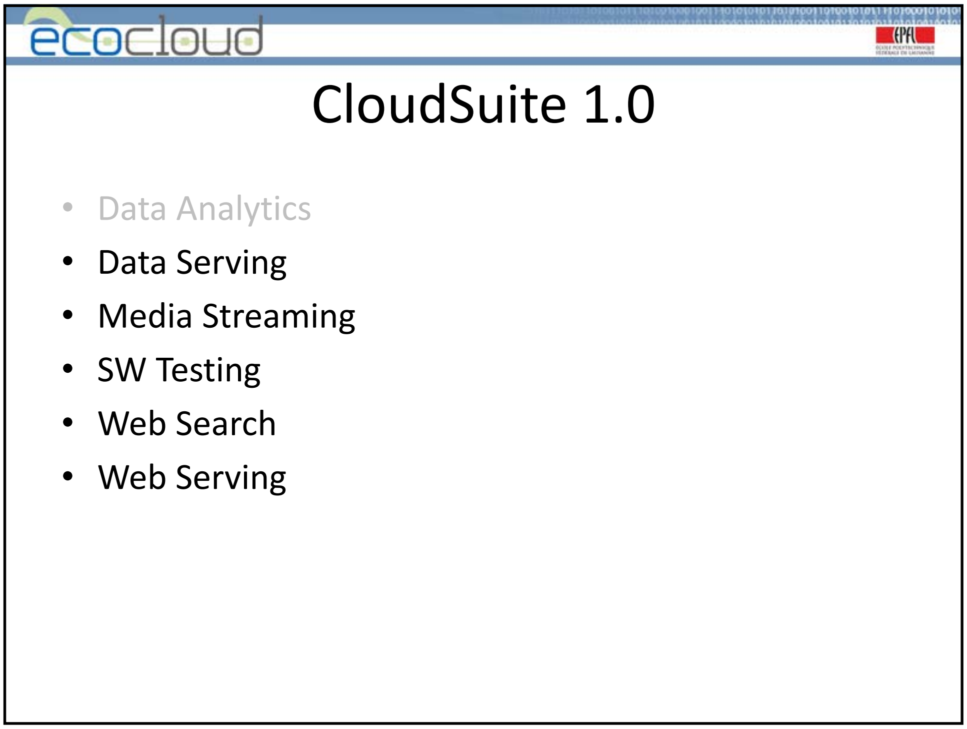
Data Analytics Benchmark

- **Application:** Text classification
  - Sentiment Analysis
  - Spam Identification
- **Software**: Mahout (Apache)
  - Popular MapReduce machine learning library
- **Dataset**: Wikipedia English page articles



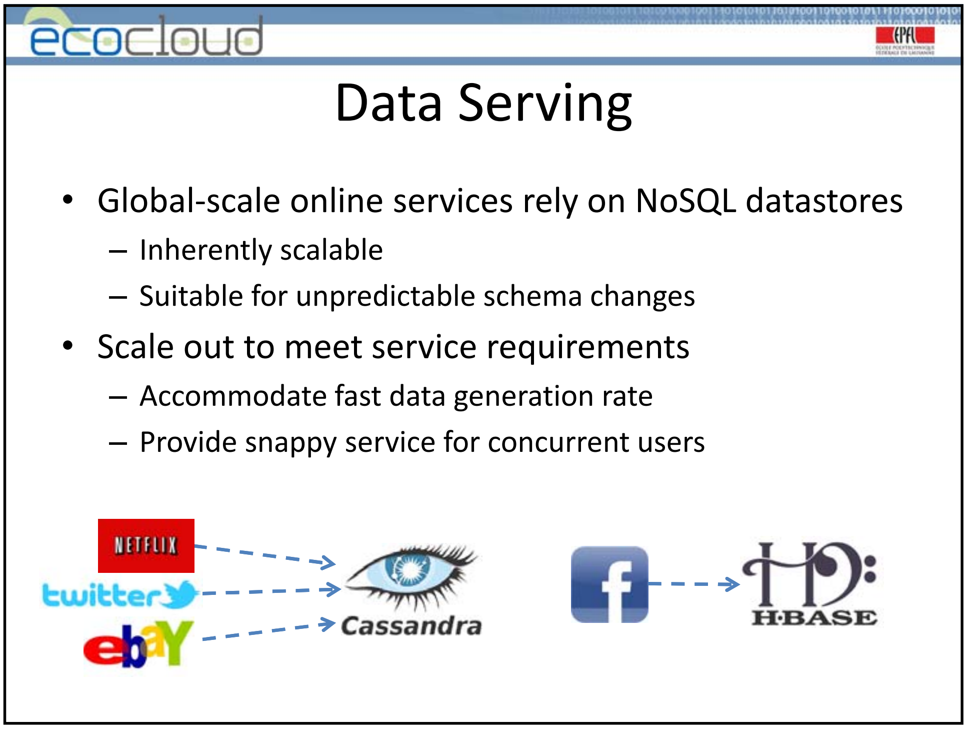
Data Analytics Benchmark

- 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 1.0

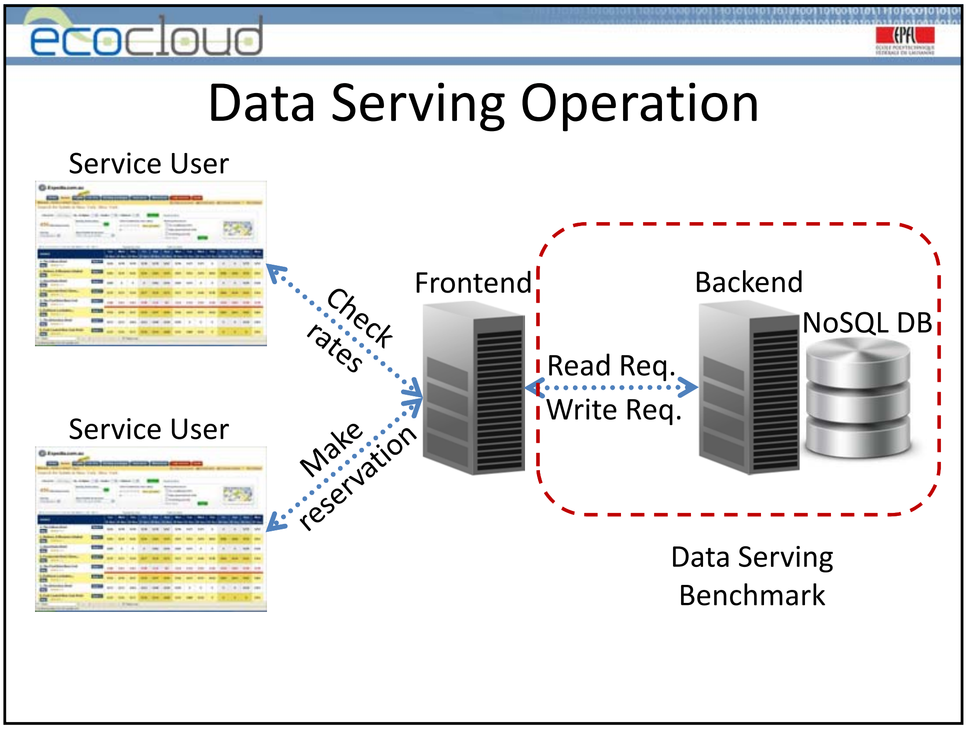
- Data Analytics
- Data Serving
- Media Streaming
- SW Testing
- Web Search
- Web Serving



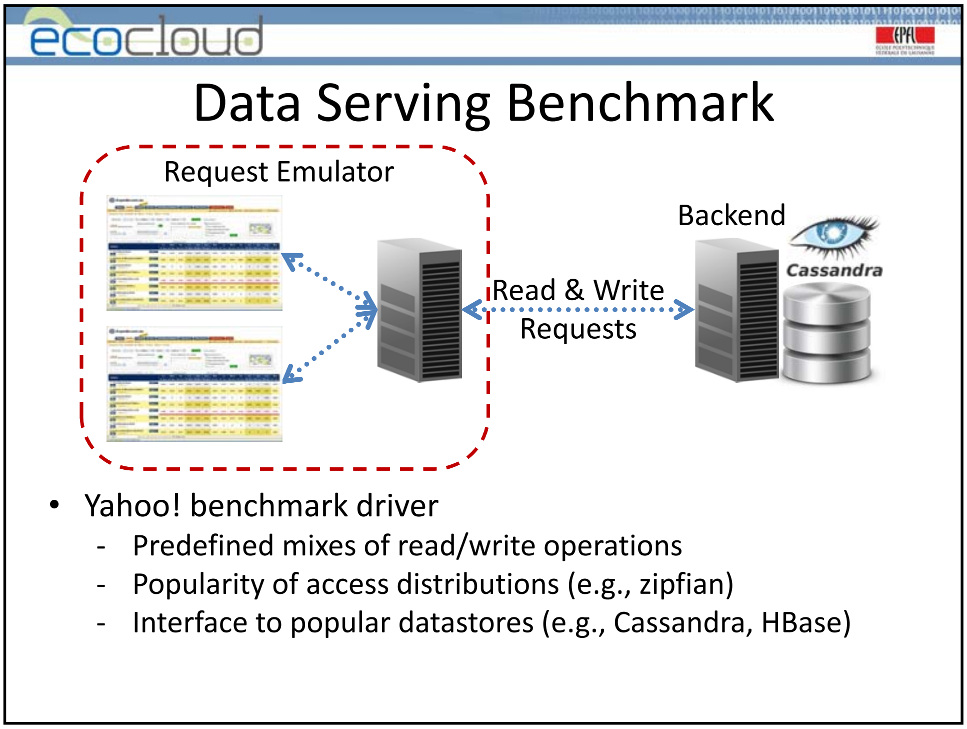
Data Serving

- 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
  - Provide snappy service for concurrent users

ecocloud
EPFL
NETFLIX
twitter
ebay
Cassandra
H·BASE

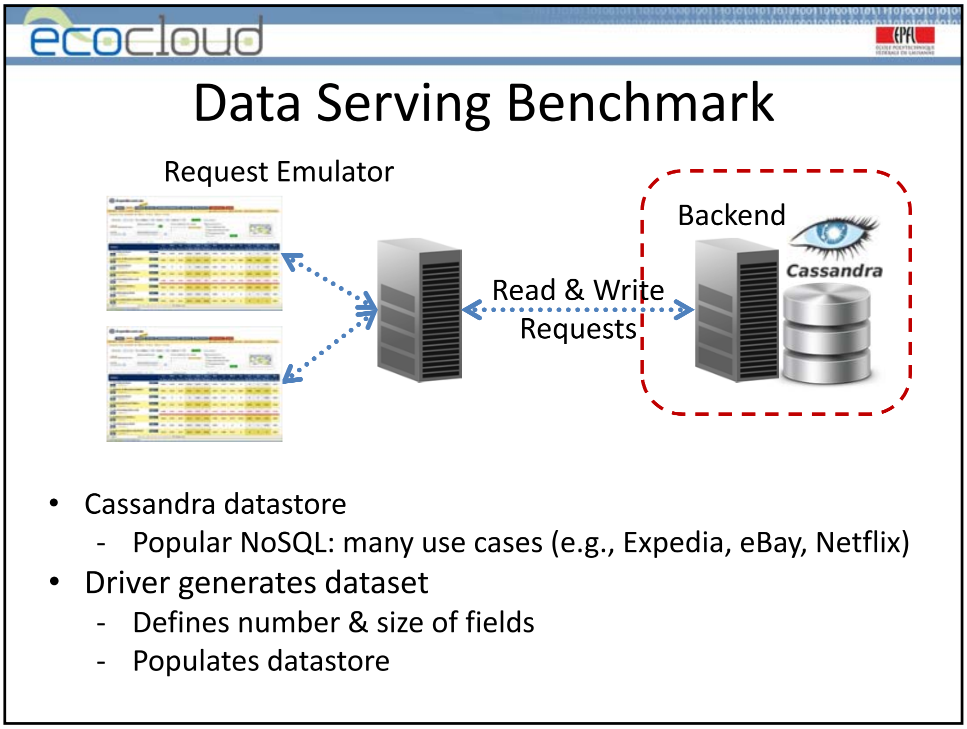


Data Serving Operation



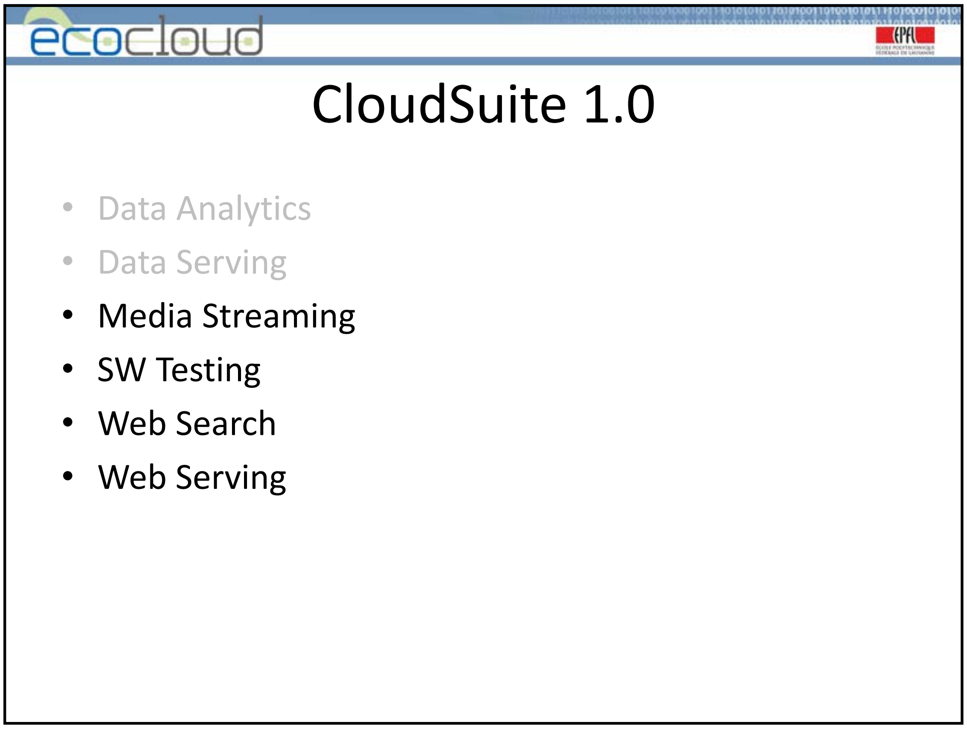
Data Serving Benchmark

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



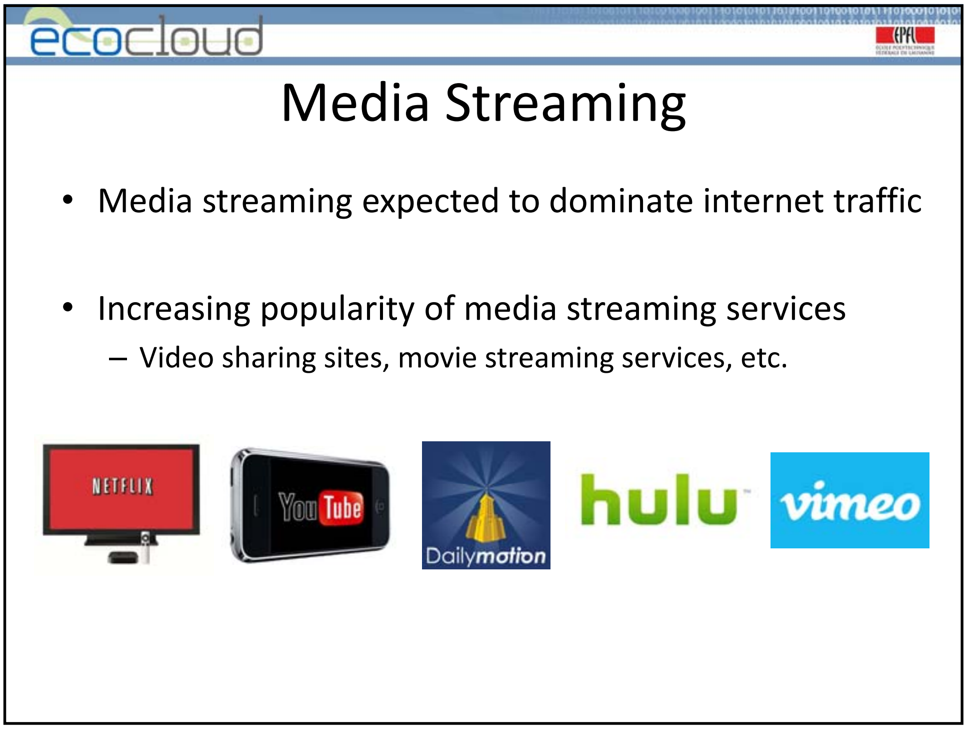
Data Serving Benchmark

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



CloudSuite 1.0

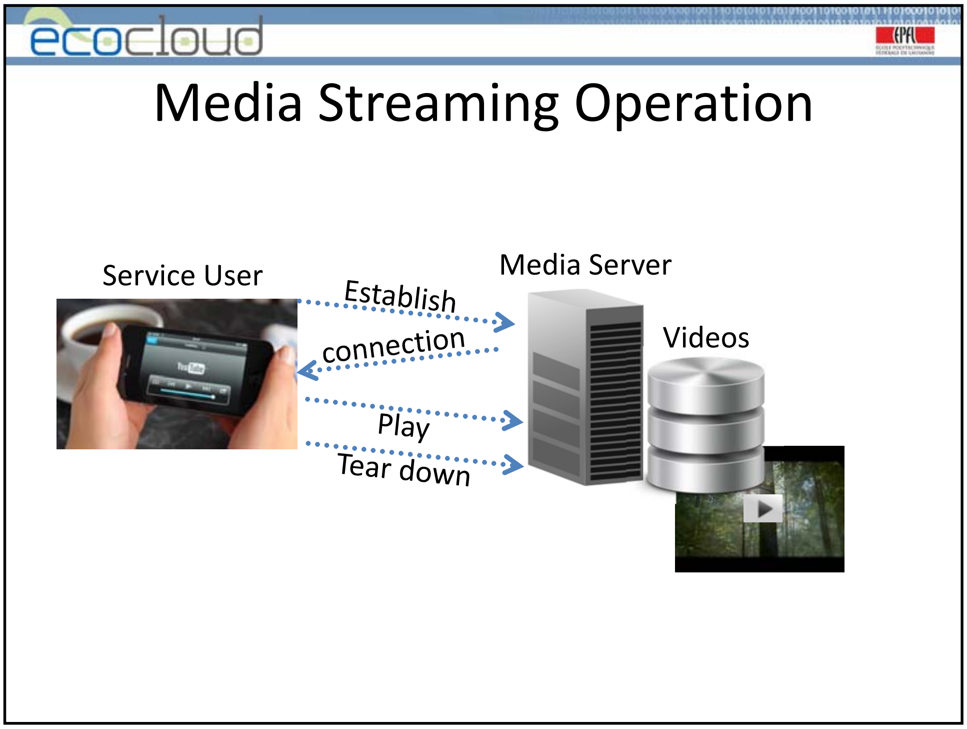
- Data Analytics
- Data Serving
- Media Streaming
- SW Testing
- Web Search
- Web Serving



Media Streaming

- Media streaming expected to dominate internet traffic
- Increasing popularity of media streaming services
  - Video sharing sites, movie streaming services, etc.

NETFLIX
YouTube
Dailymotion
hulu
vimeo



Media Streaming Operation

Service User

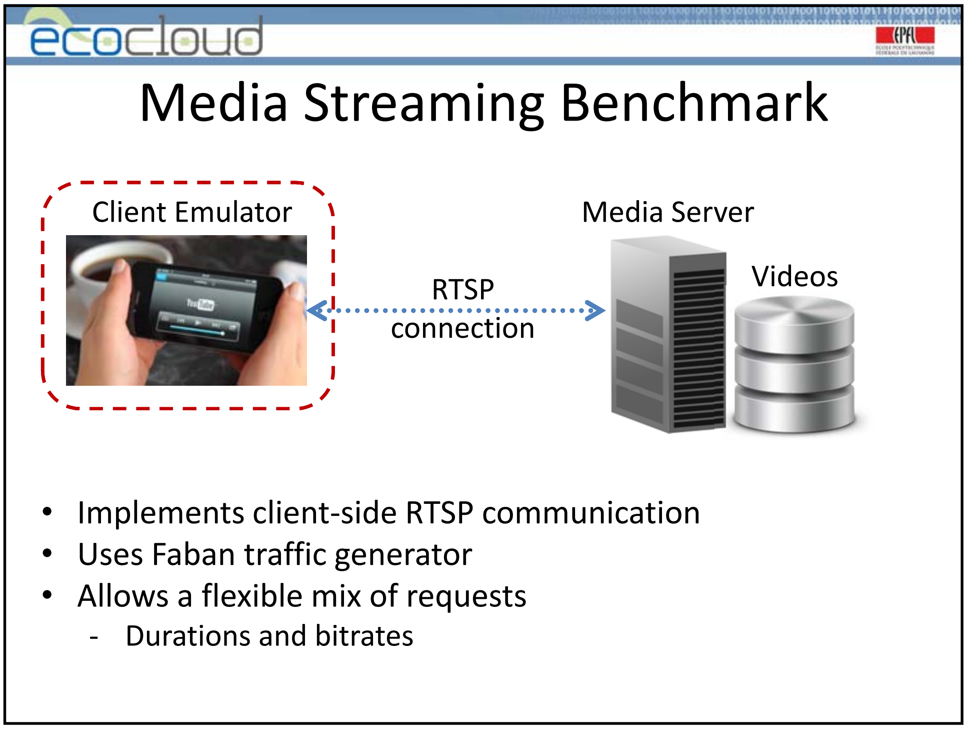
Establish connection

Play

Tear down

Media Server

Videos



Media Streaming Benchmark

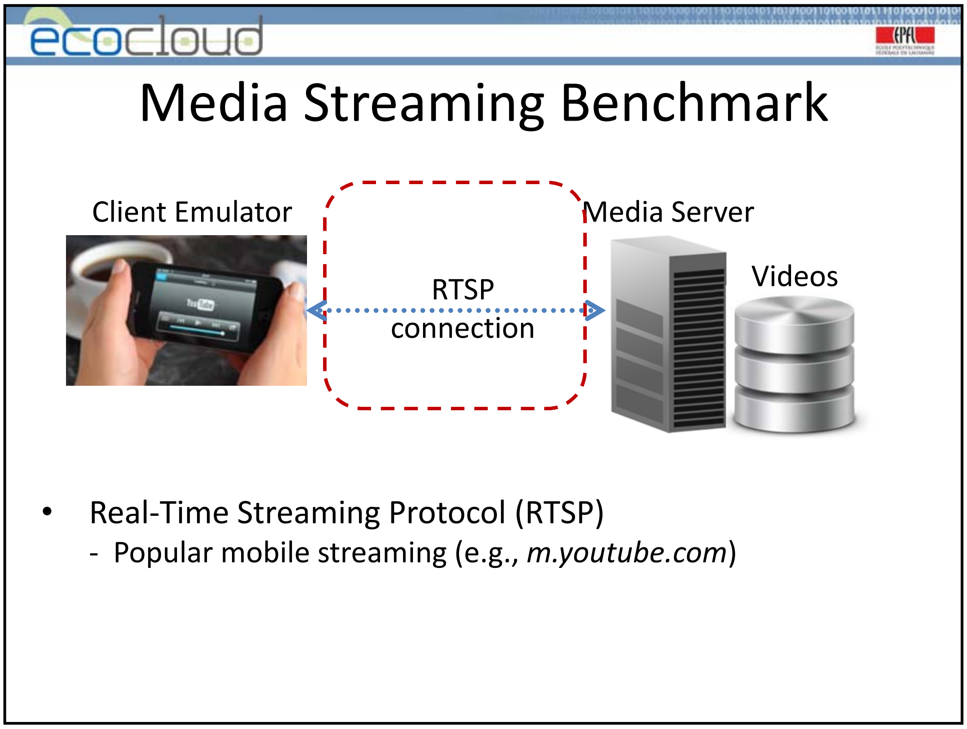
Client Emulator

RTSP connection

Media Server

Videos

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



Media Streaming Benchmark

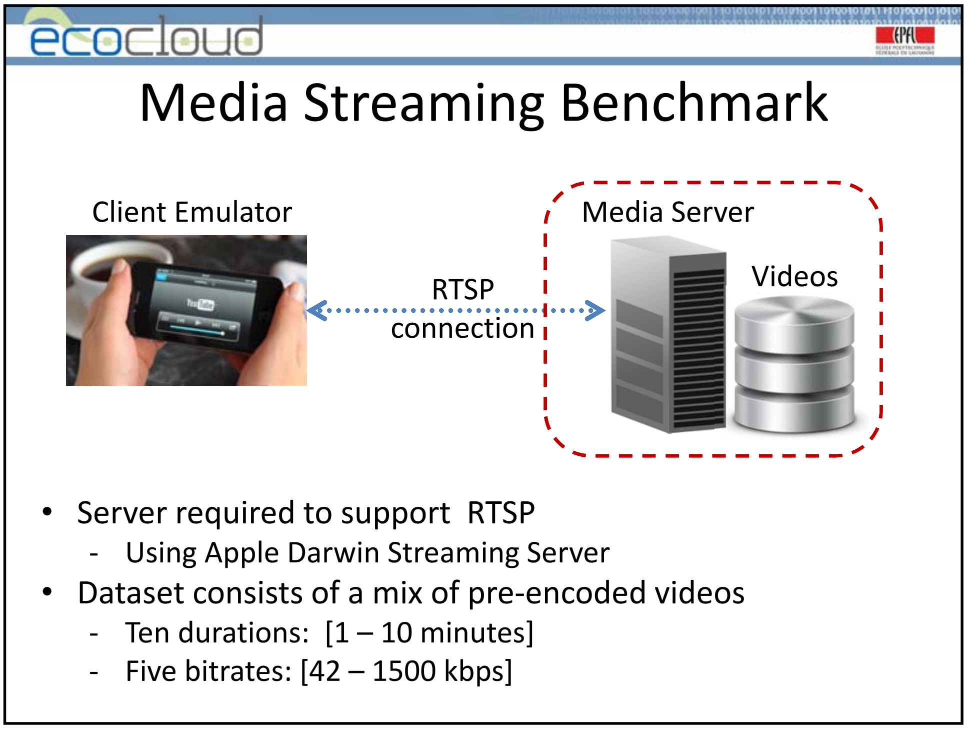
Client Emulator

RTSP connection

Media Server

Videos

- Real-Time Streaming Protocol (RTSP)
  - Popular mobile streaming (e.g., *m.youtube.com*)



Media Streaming Benchmark

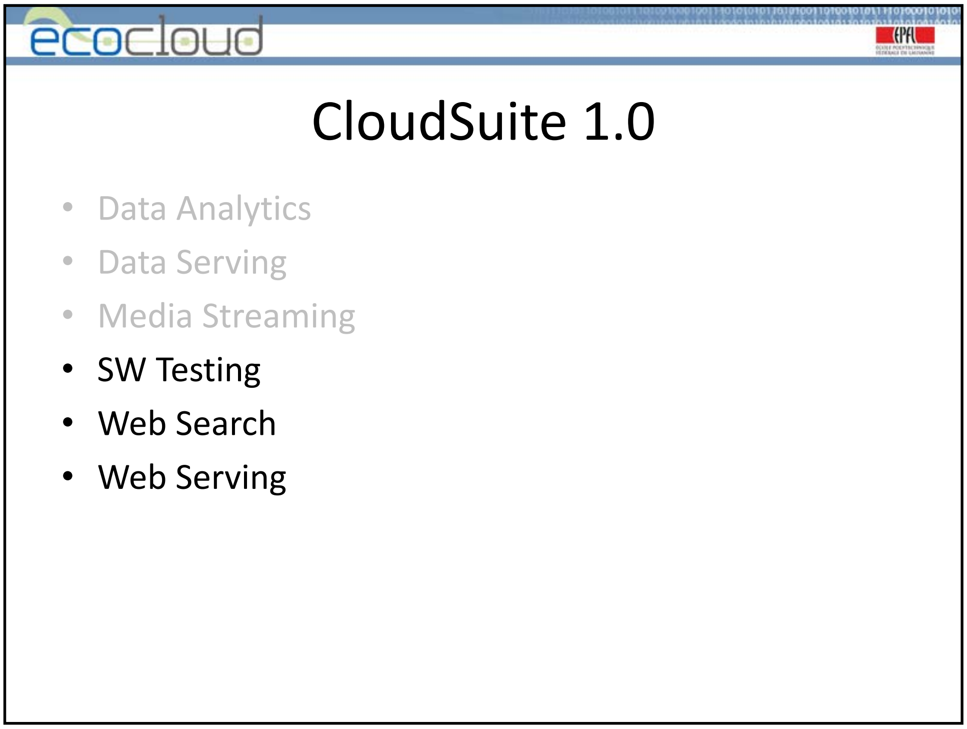
Client Emulator

RTSP connection

Media Server

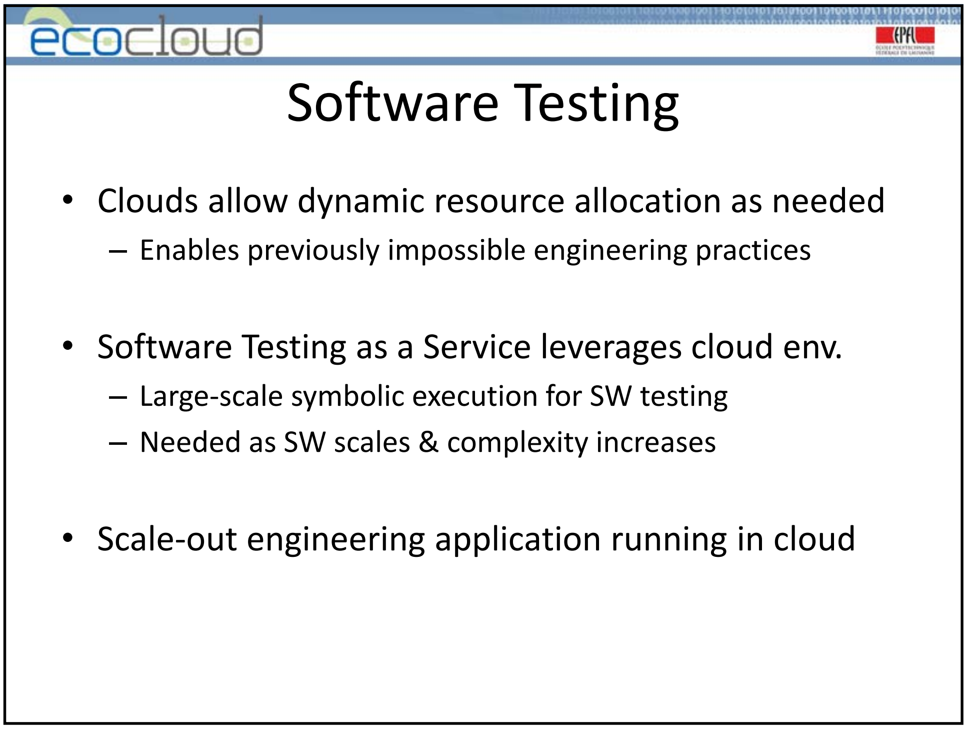
Videos

- 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]



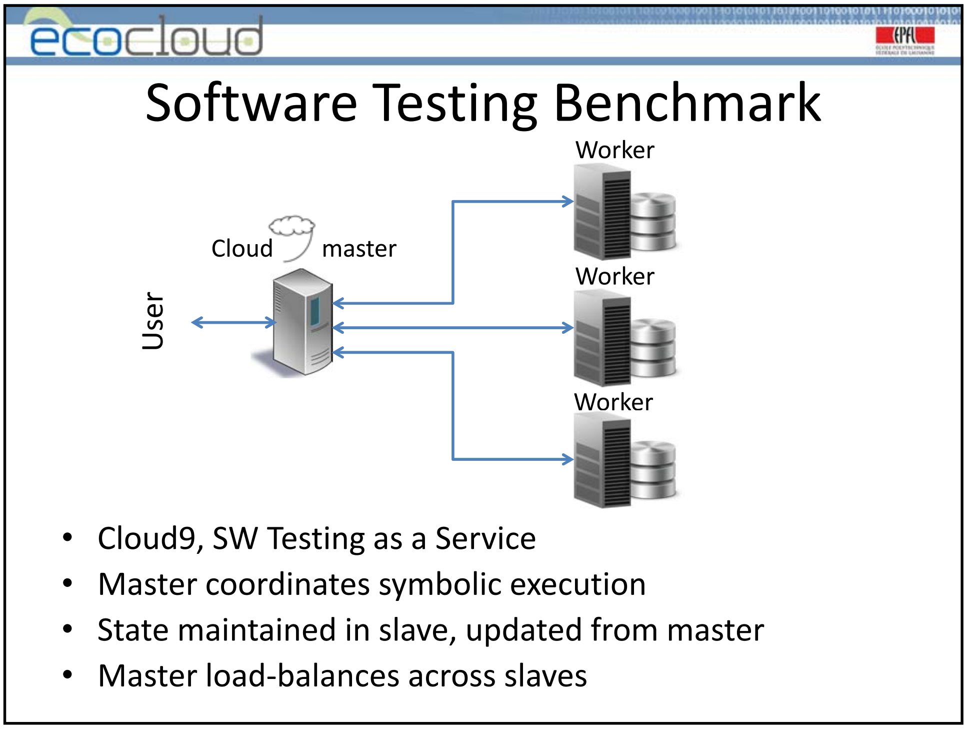
CloudSuite 1.0

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



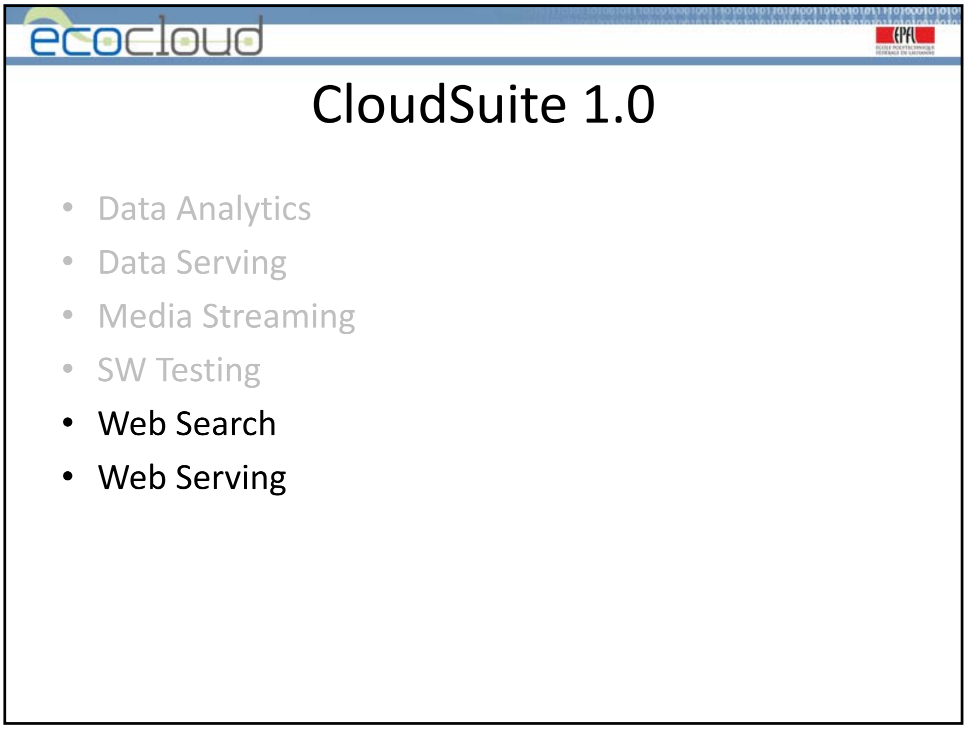
Software Testing

- Clouds allow dynamic resource allocation as needed
  - Enables previously impossible engineering practices
- Software Testing as a Service leverages cloud env.
  - 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



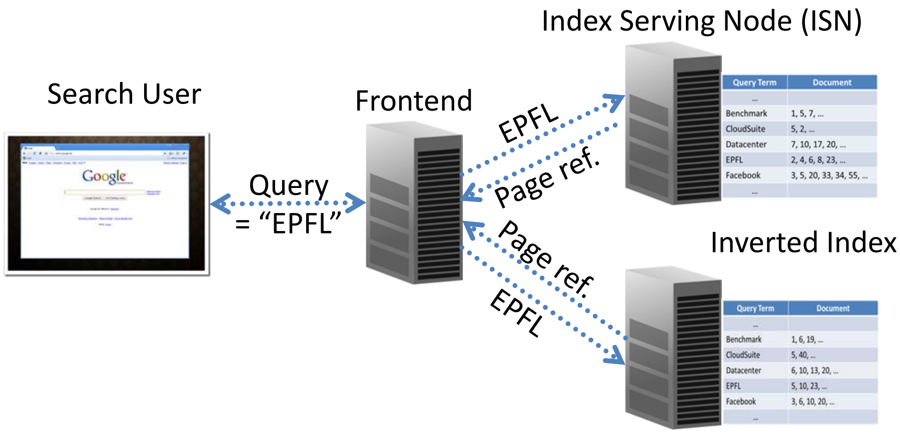
CloudSuite 1.0

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

Web Search

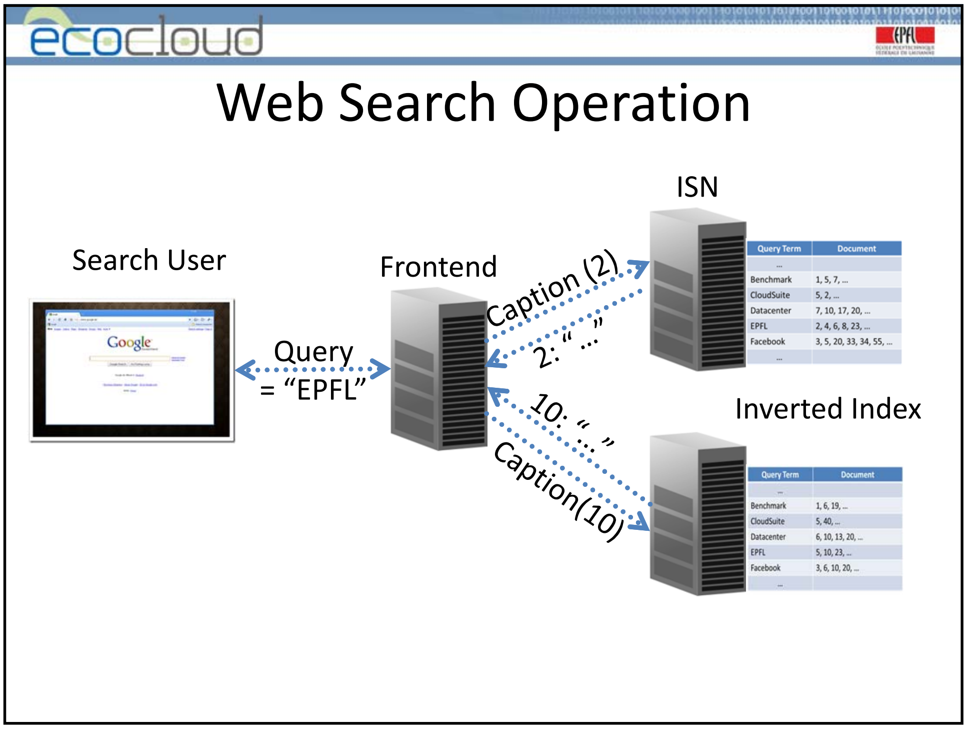
- Most popular online service
  - Numerous search clouds deployed by industry

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
…	
Benchmark	1, 6, 19, …
CloudSuite	5, 40, …
Datacenter	6, 10, 13, 20, …
EPFL	5, 10, 23, …
Facebook	3, 6, 10, 20, …
…	



Web Search Operation

Search User

Frontend

ISN

Query = “EPFL”

Caption (2)

2: “ … ”

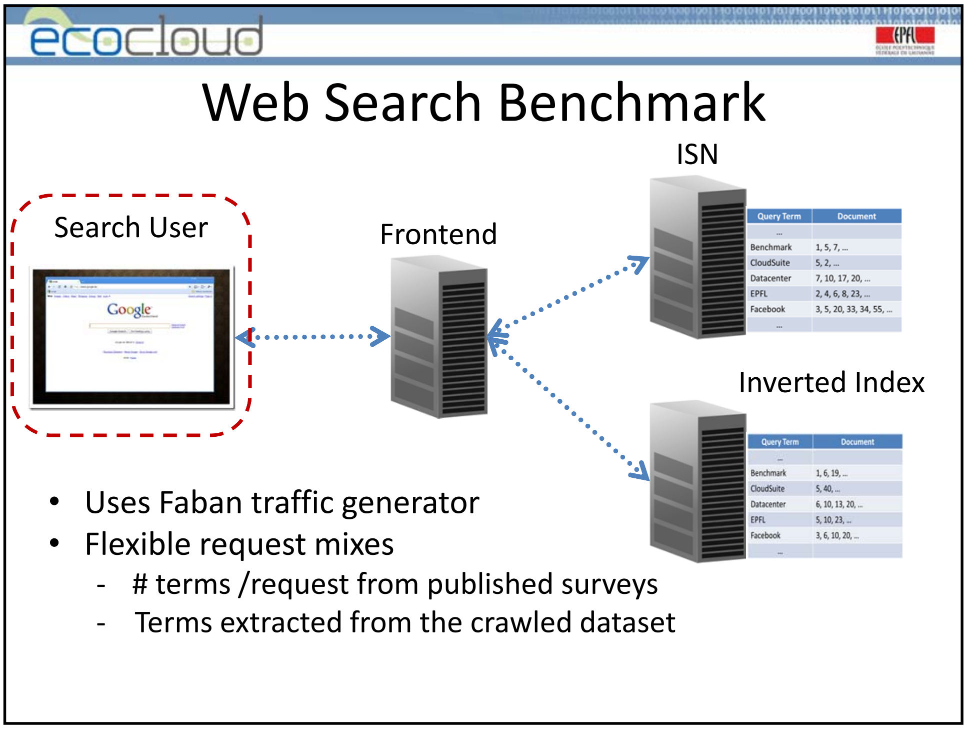
10: “ … ”

Caption(10)

Inverted Index

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
…	
Benchmark	1, 6, 19, …
CloudSuite	5, 40, …
Datacenter	6, 10, 13, 20, …
EPFL	5, 10, 23, …
Facebook	3, 6, 10, 20, …
…	



Web Search Benchmark

ISN

Search User

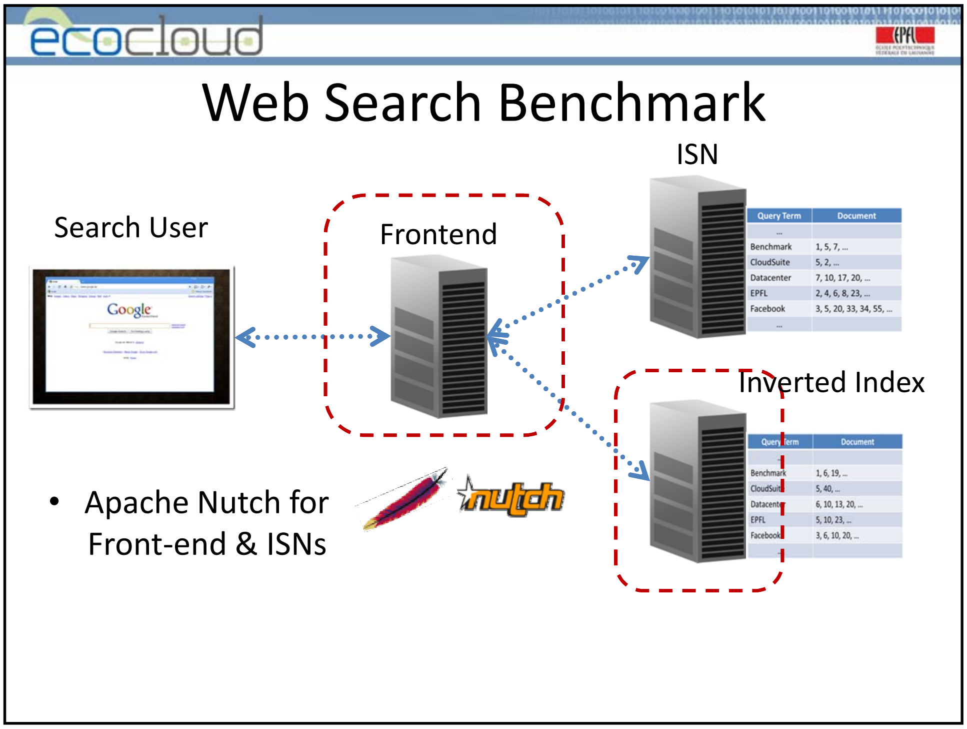
Frontend

Inverted Index

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
…	
Benchmark	1, 6, 19, …
CloudSuite	5, 40, …
Datacenter	6, 10, 13, 20, …
EPFL	5, 10, 23, …
Facebook	3, 6, 10, 20, …
…	

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



Web Search Benchmark

ISN

Search User

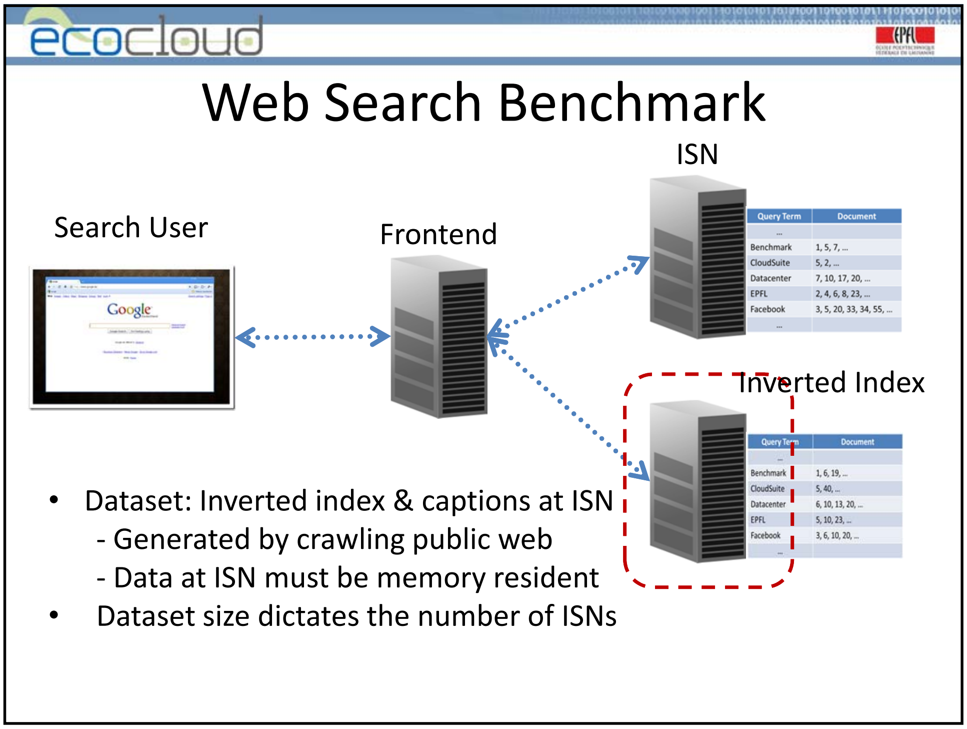
Frontend

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, …
…	

Inverted Index

Query Term	Document
…	
Benchmark	1, 6, 19, …
CloudSuite	5, 40, …
Datacenter	6, 10, 13, 20, …
EPFL	5, 10, 23, …
Facebook	3, 6, 10, 20, …
…	

- Apache Nutch for Front-end & ISNs



Web Search Benchmark

ISN

Search User

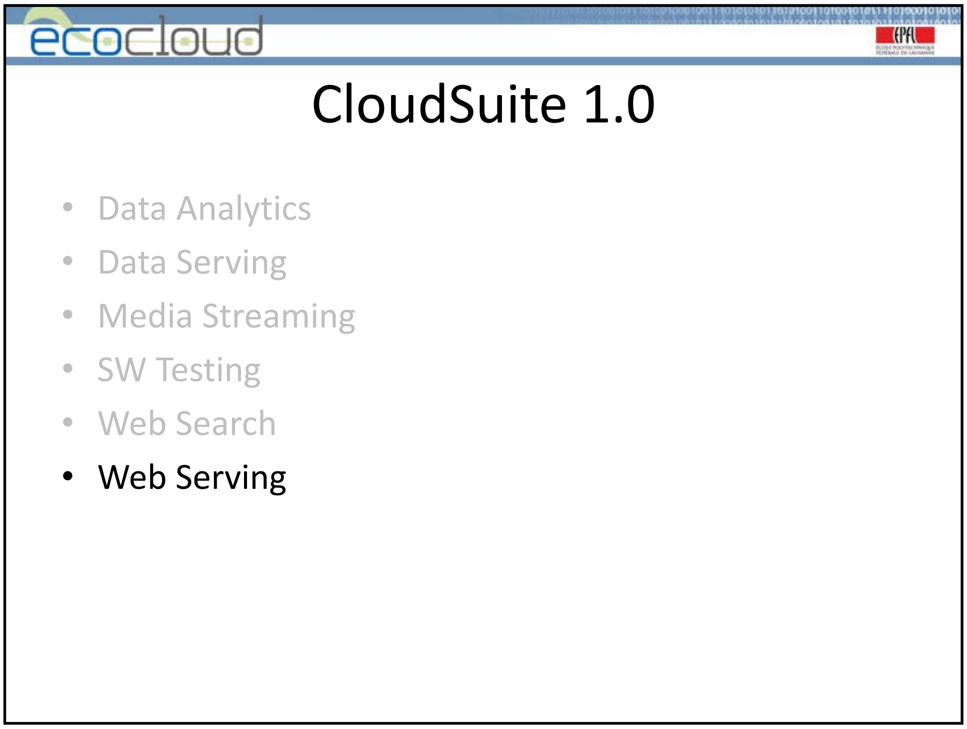
Frontend

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, …
…	

Inverted Index

Query Term	Document
…	
Benchmark	1, 6, 19, …
CloudSuite	5, 40, …
Datacenter	6, 10, 13, 20, …
EPFL	5, 10, 23, …
Facebook	3, 6, 10, 20, …
…	

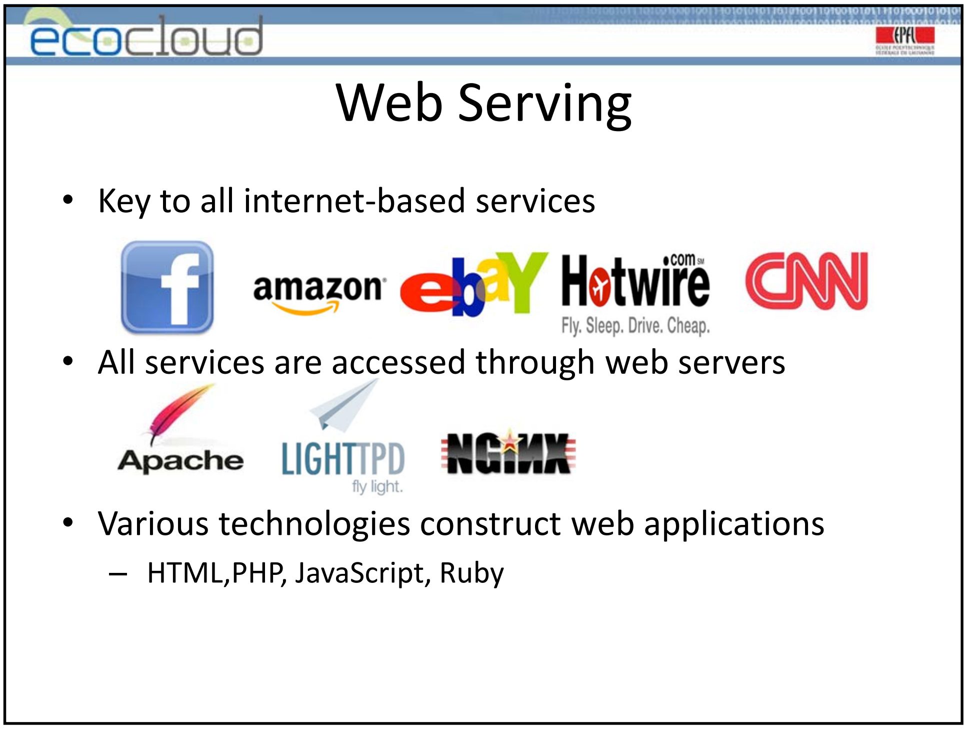
- Dataset: Inverted index & captions at ISN
  - Generated by crawling public web
  - Data at ISN must be memory resident
- Dataset size dictates the number of ISNs



ecocloud
EPFL

CloudSuite 1.0

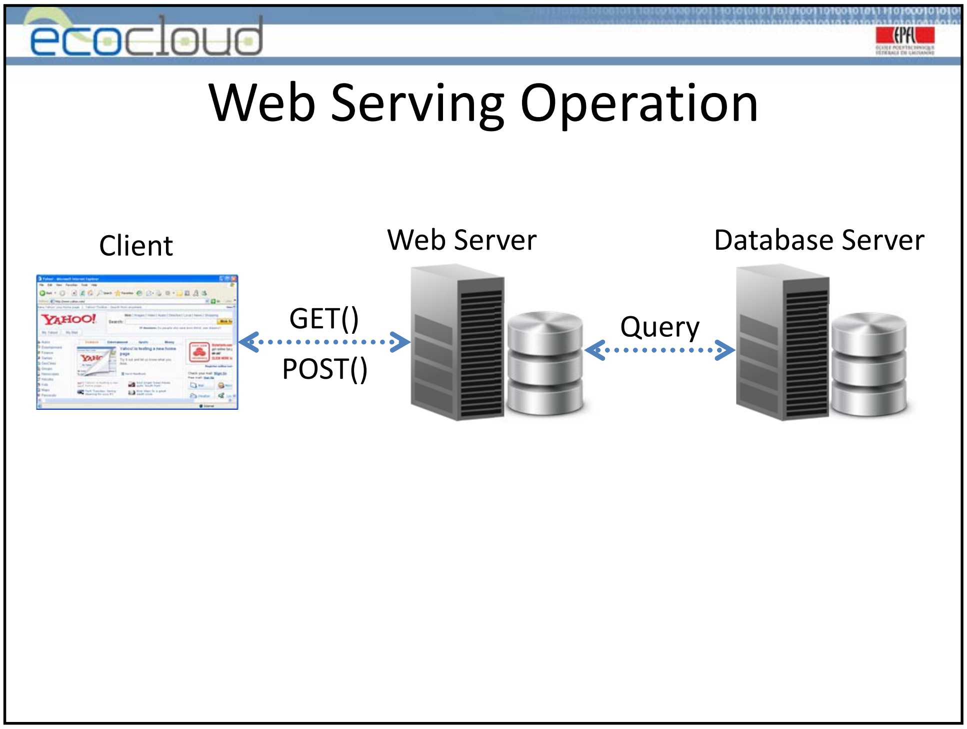
- Data Analytics
- Data Serving
- Media Streaming
- SW Testing
- Web Search
- Web Serving



ecocloud
EPFL
amazon
ebaY
Hotwire.com
Fly. Sleep. Drive. Cheap.
CNN
Apache
LIGHTTPD
fly light.
NGINX

Web Serving

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



Web Serving Operation

Client

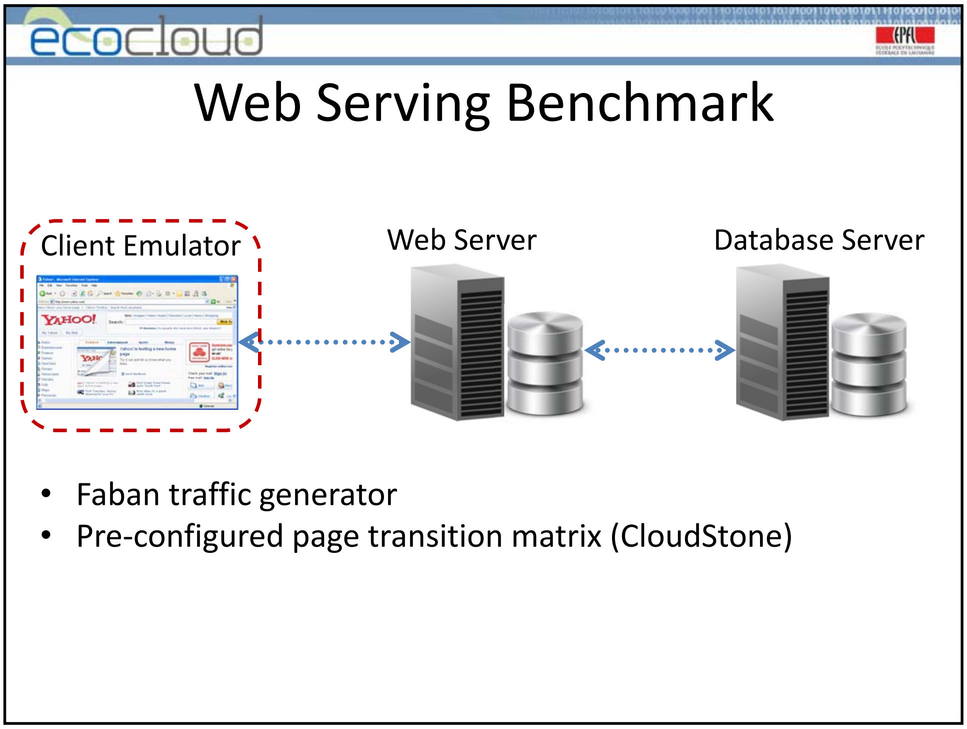
Web Server

Database Server

GET()

POST()

Query



Web Serving Benchmark

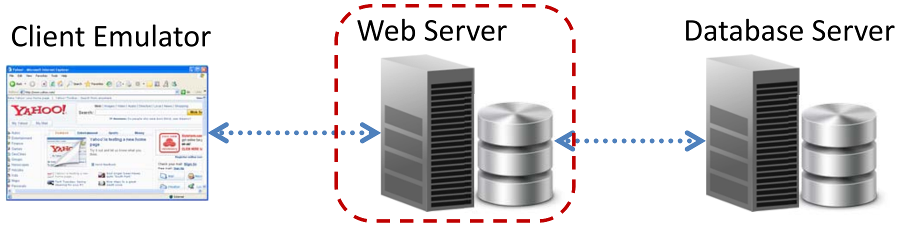
Client Emulator

Web Server

Database Server

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

Web Serving Benchmark



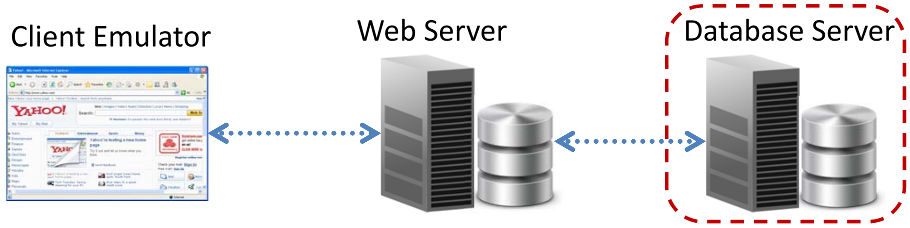
Client Emulator

Web Server

Database Server

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

Web Serving Benchmark

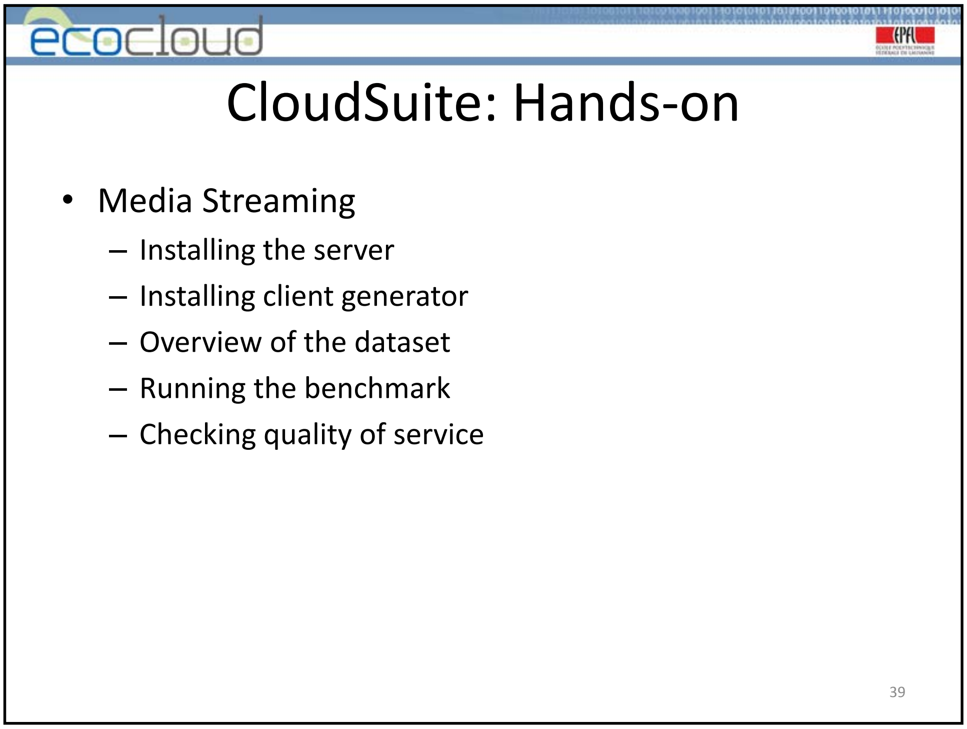


Client Emulator

Web Server

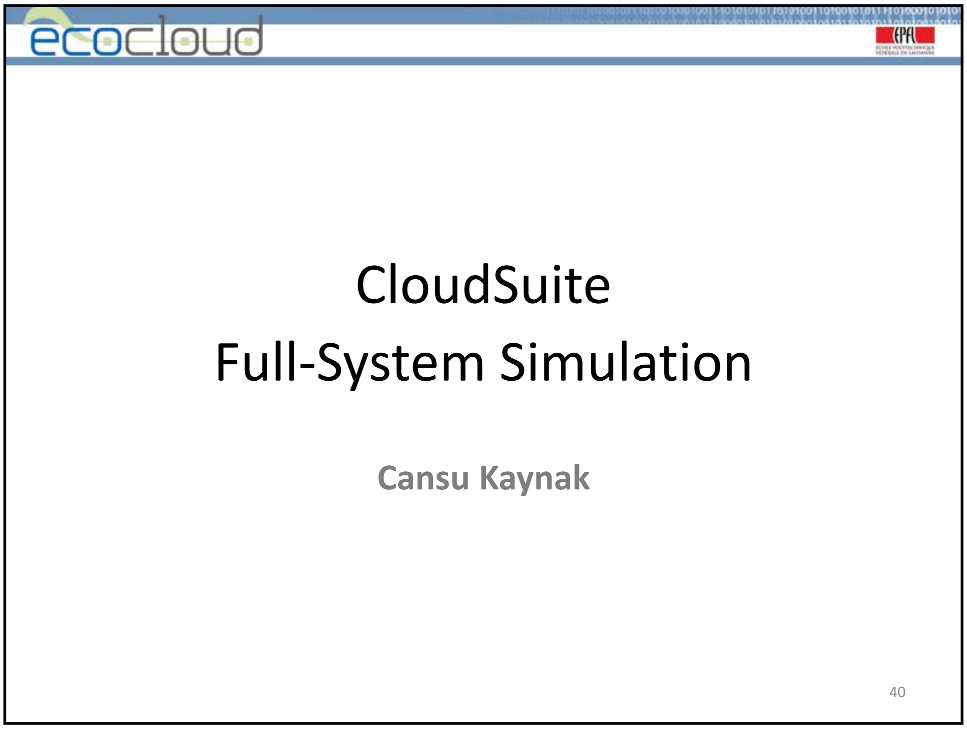
Database Server

- Database server (MySQL)



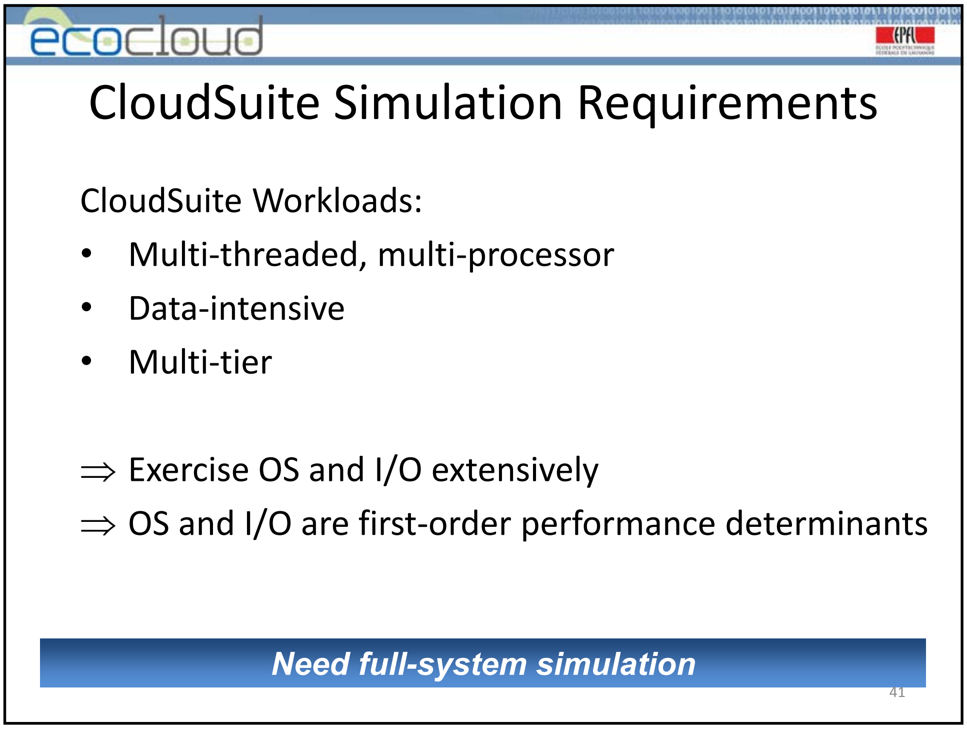
CloudSuite: Hands-on

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



CloudSuite
Full-System Simulation

Cansu Kaynak



CloudSuite Simulation Requirements

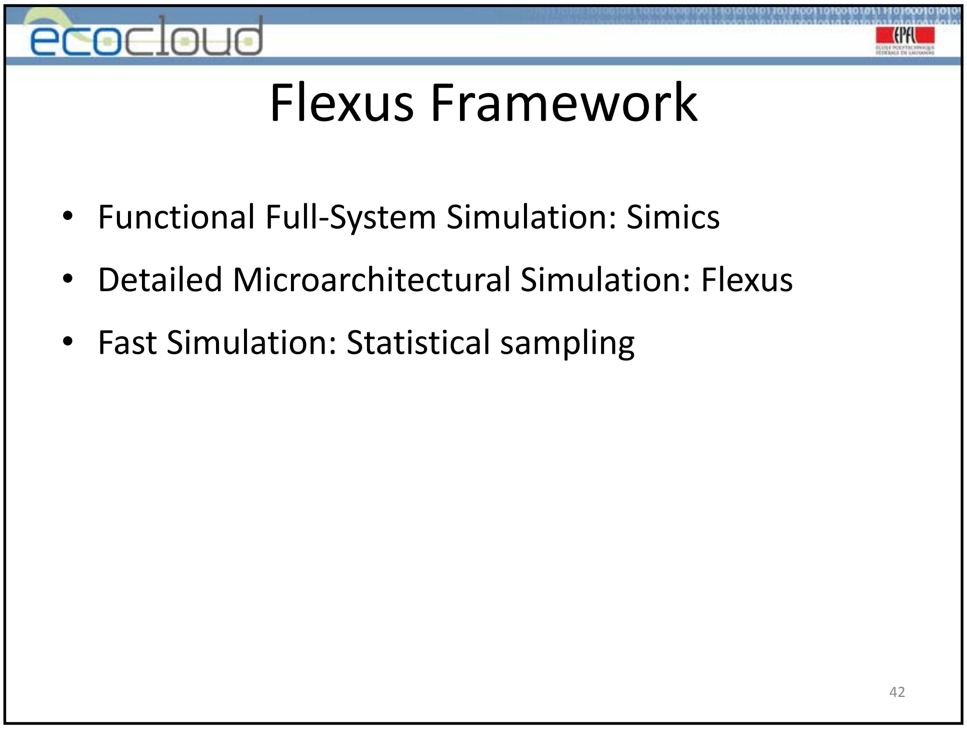
CloudSuite Workloads:

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

⇒ Exercise OS and I/O extensively

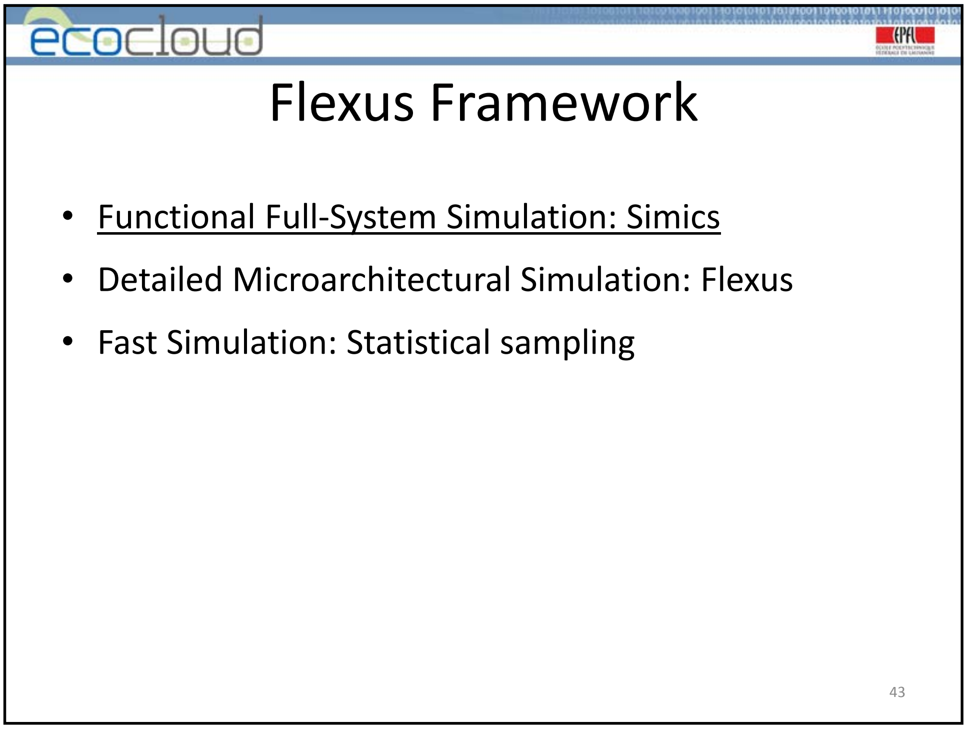
⇒ OS and I/O are first-order performance determinants

Need full-system simulation



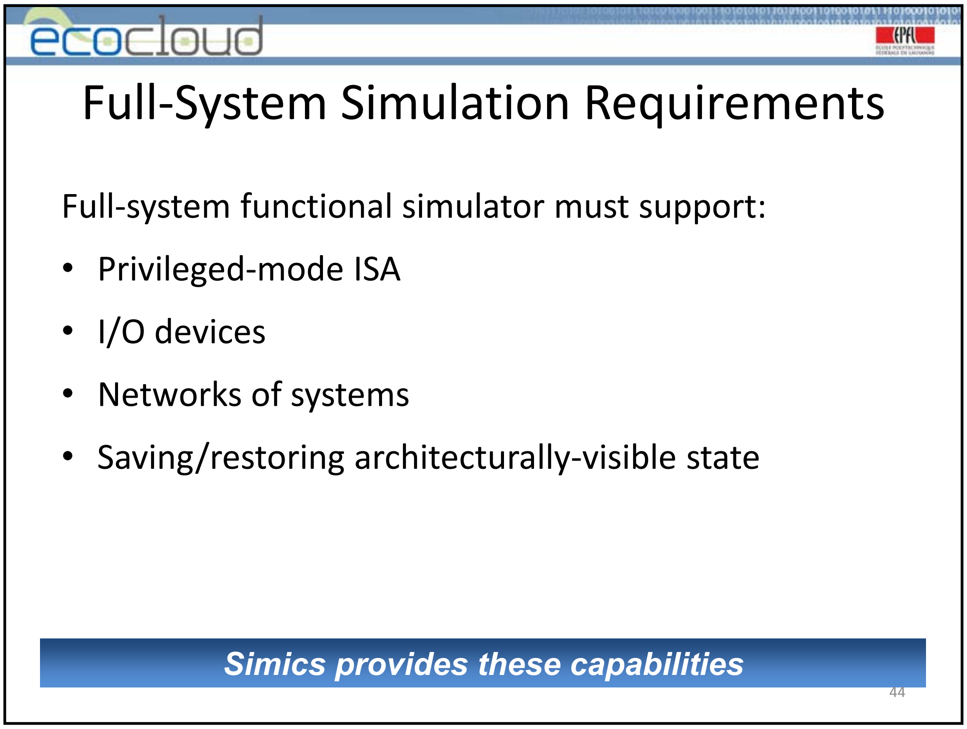
Flexus Framework

- 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

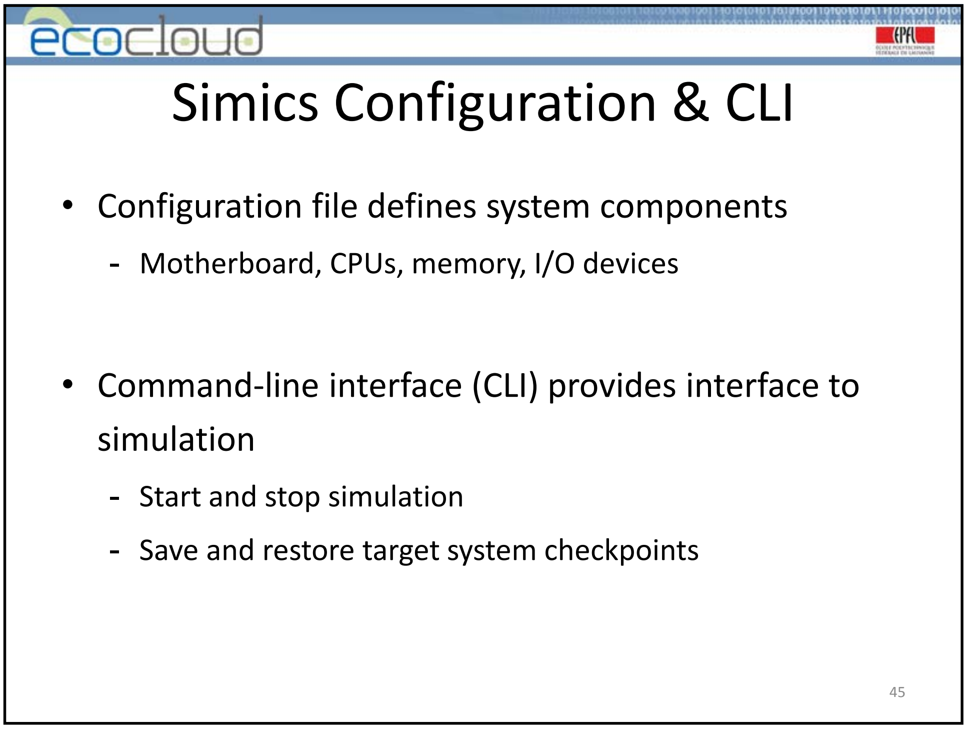


Full-System Simulation Requirements

Full-system functional simulator must support:

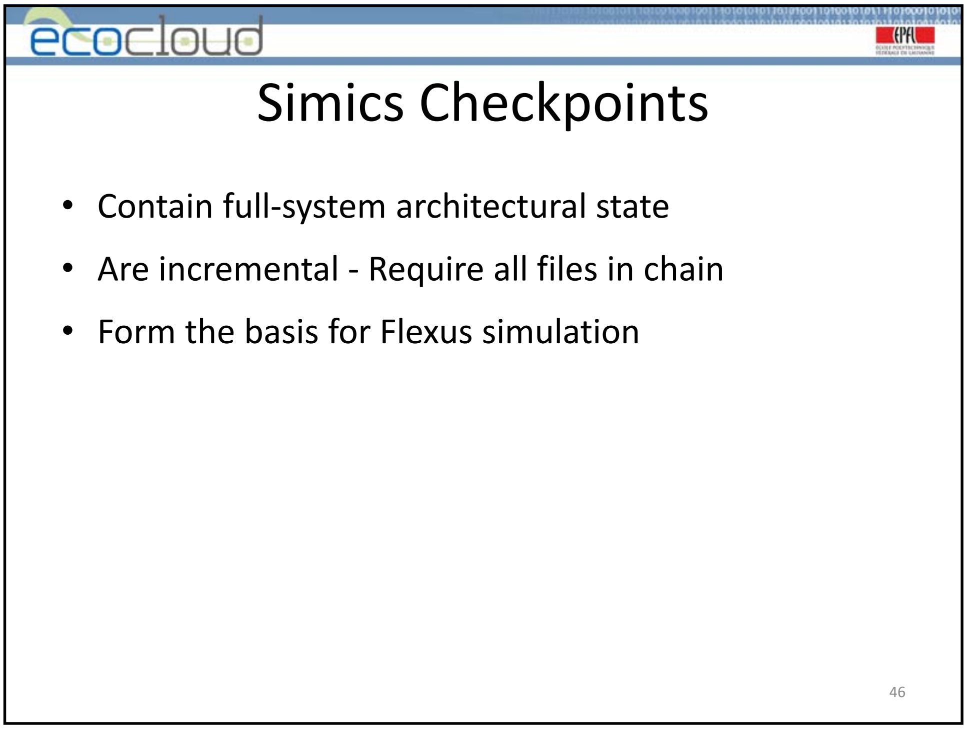
- Privileged-mode ISA
- I/O devices
- Networks of systems
- Saving/restoring architecturally-visible state

Simics provides these capabilities



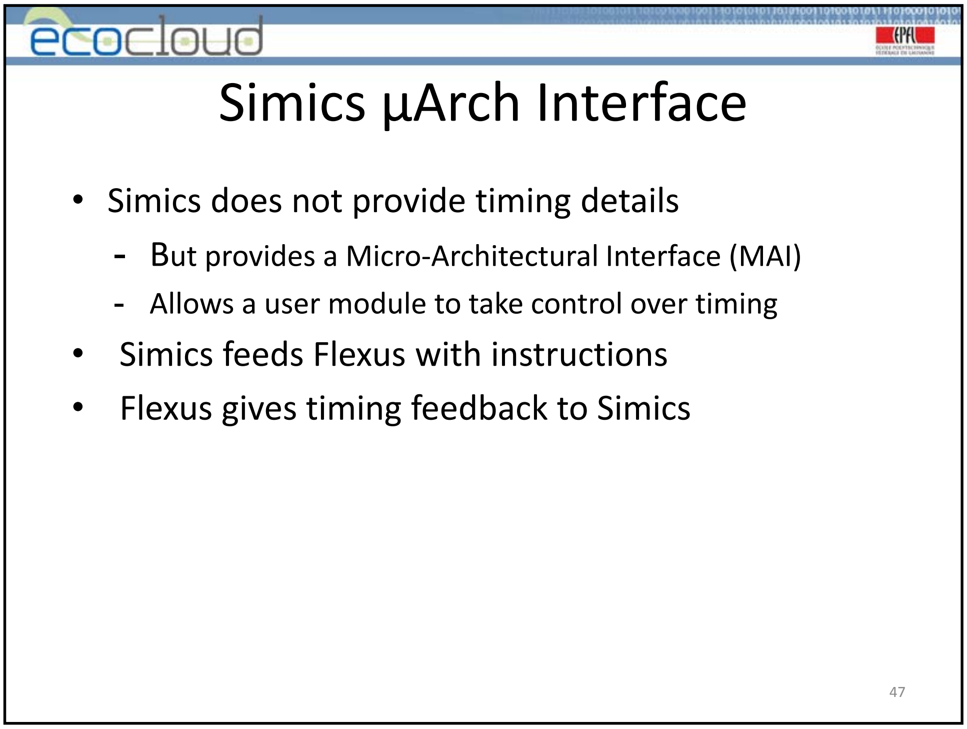
Simics Configuration & CLI

- 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



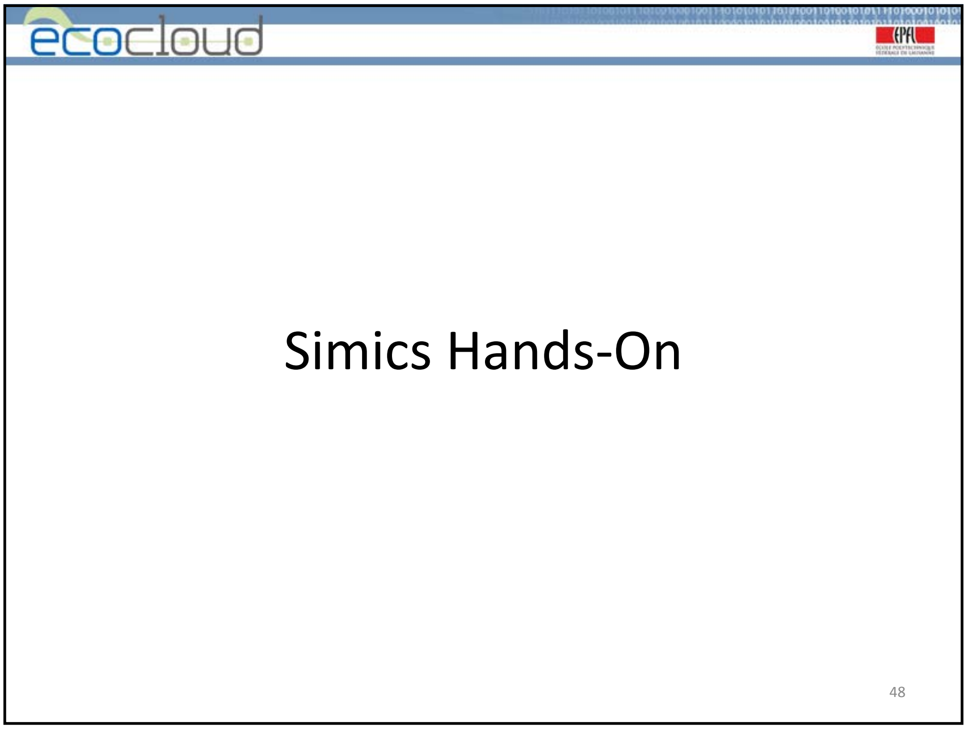
Simics Checkpoints

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

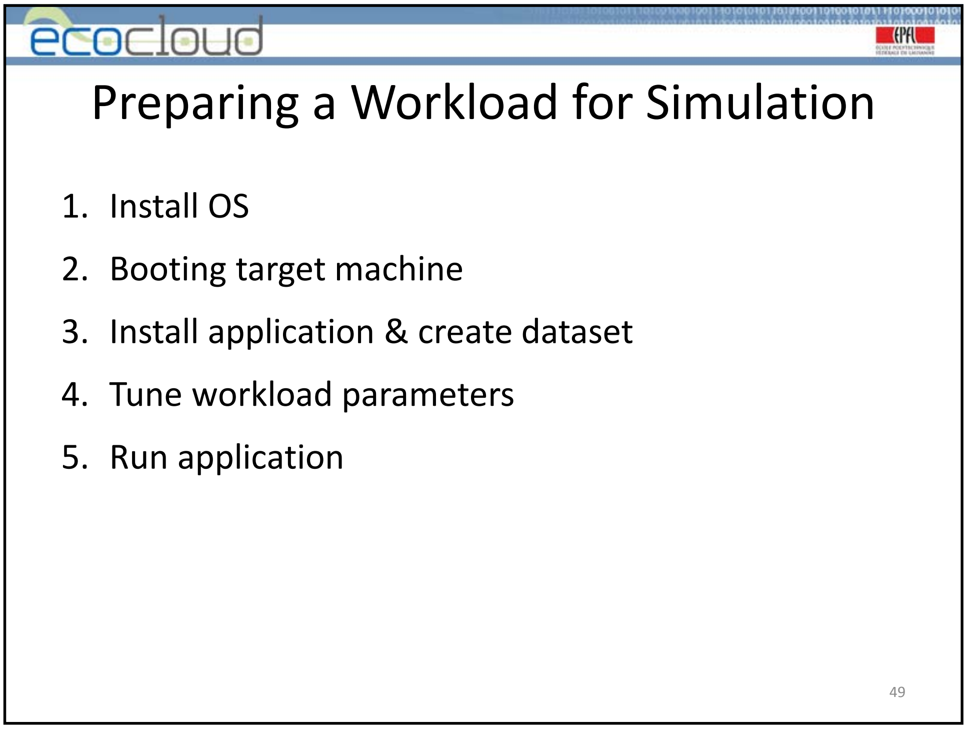


Simics µArch Interface

- 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



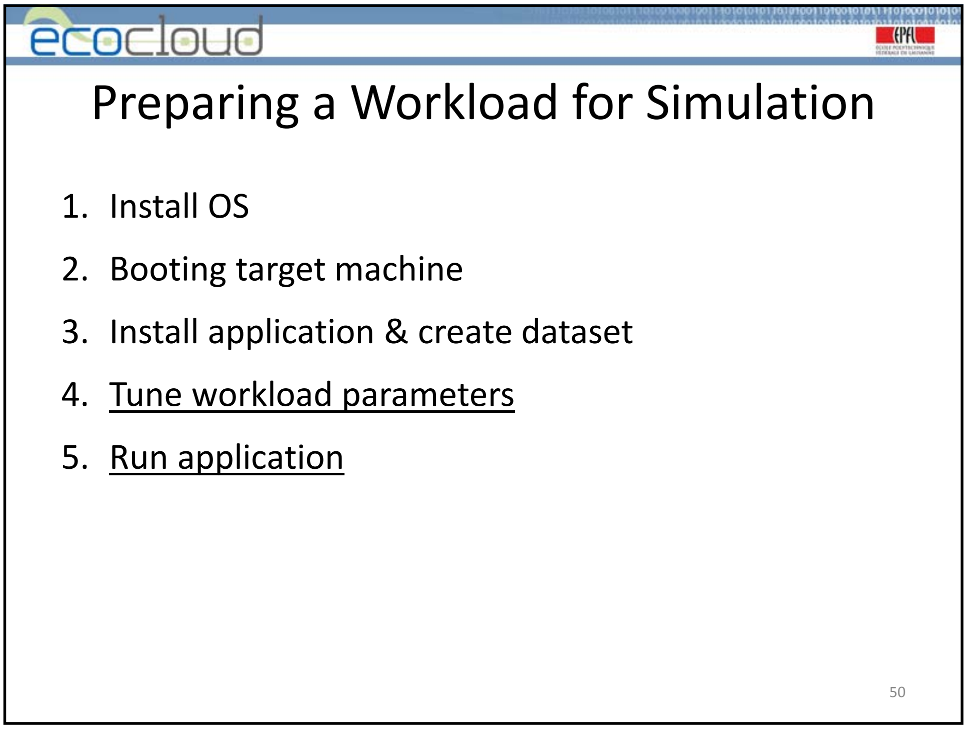
Simics Hands-On



Preparing a Workload for Simulation

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

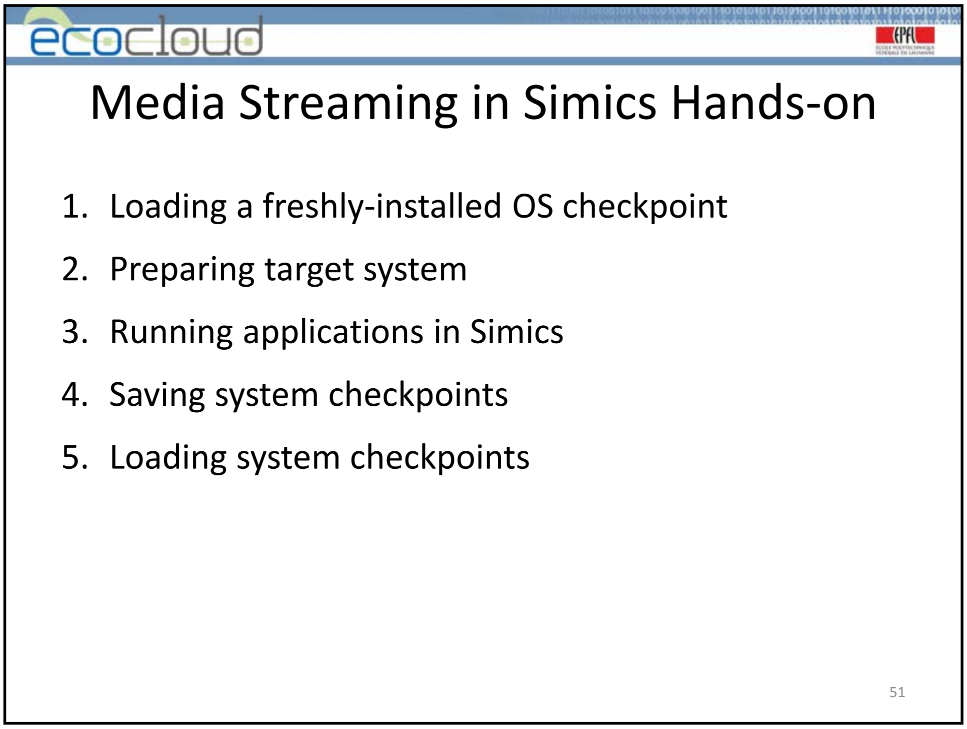
49



Preparing a Workload for Simulation

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

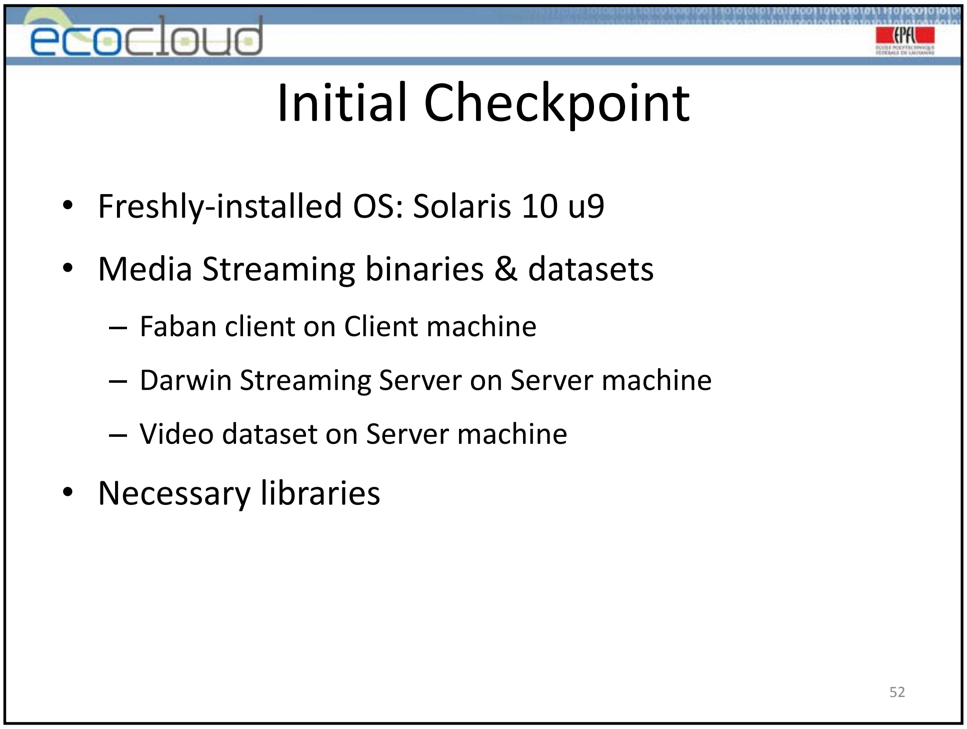
50



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

51



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

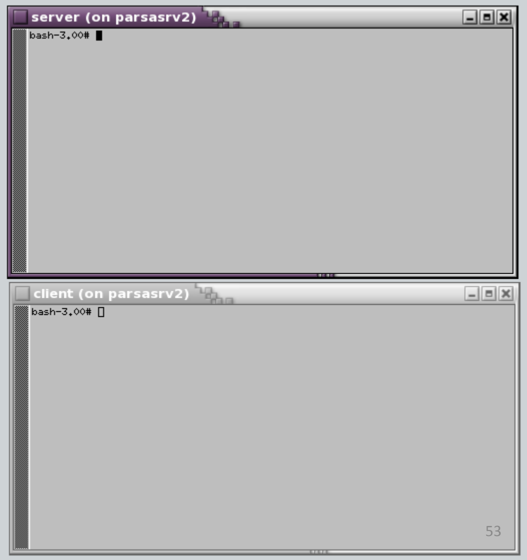
52

Getting Started with Media Streaming

Simulated target system:

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

- Binaries:
  /opt
- Dataset:
  /streaming_data

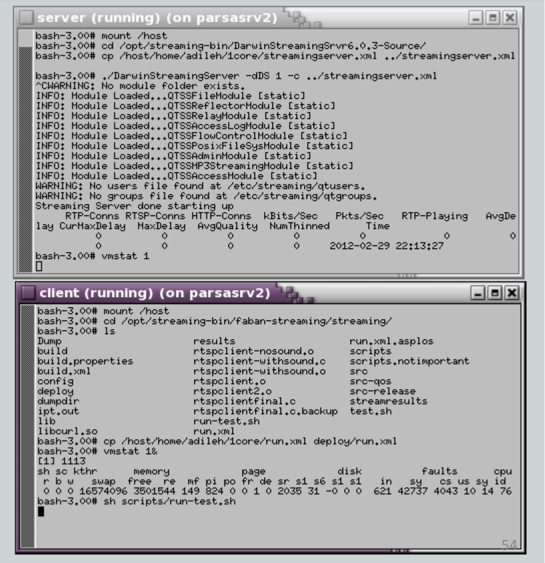


```
bash-3.00# 
```

```
bash-3.00# 
```

Preparing Target System

- Move configuration files
- Move experiment files
- Start experiment



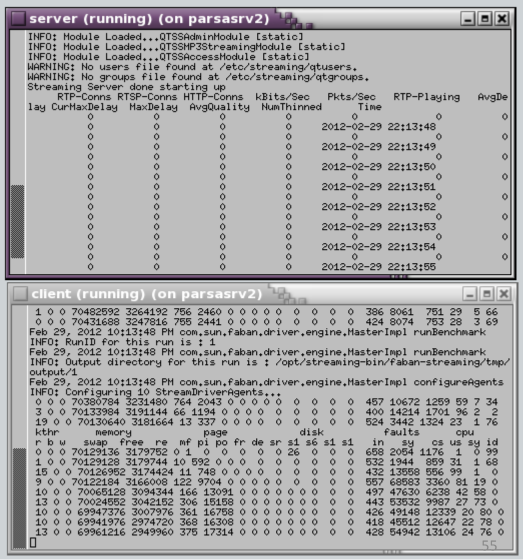
```
bash-3.00# mount /host
bash-3.00# cd /opt/streaming-bin/DarwinStreamingSrvr6.0.3-Source/
bash-3.00# cp /host/home/adileh/1core/streamingserver.xml ../streamingserver.xml

bash-3.00# ./DarwinStreamingServer -dDS 1 -c ../streamingserver.xml
^CWARNING: No module folder exists.
INFO: Module Loaded...QTSSFileModule [static]
INFO: Module Loaded...QTSSReflectorModule [static]
INFO: Module Loaded...QTSSRelayModule [static]
INFO: Module Loaded...QTSSAccessLogModule [static]
INFO: Module Loaded...QTSSFlowControlModule [static]
INFO: Module Loaded...QTSSPosixFileSysModule [static]
INFO: Module Loaded...QTSSAdminModule [static]
INFO: Module Loaded...QTSSMP3StreamingModule [static]
INFO: Module Loaded...QTSSAccessModule [static]
WARNING: No users file found at /etc/streaming/qtusers.
WARNING: No groups file found at /etc/streaming/qtgroups.
Streaming Server done starting up
     RTP-Conns RTSP-Conns HTTP-Conns  kBits/Sec   Pkts/Sec   RTP-Playing   AvgDe
lay CurMaxDelay  MaxDelay  AvgQuality  NumThinned      Time
          0          0          0          0          0             0          0
          0          0          0          0     2012-02-29 22:13:27
bash-3.00# vmstat 1
```

```
bash-3.00# mount /host
bash-3.00# cd /opt/streaming-bin/faban-streaming/streaming/
bash-3.00# ls
Dump                      results                   run.xml.asplos
build                     rtspclient-nosound.o      scripts
build.properties          rtspclient-withsound.c    scripts.notimportant
build.xml                 rtspclient-withsound.o    src
config                    rtspclient.o              src-qos
deploy                    rtspclient2.o             src-release
dumpdir                   rtspclientfinal.c         streamresults
ipt.out                   rtspclientfinal.c.backup  test.sh
lib                       run-test.sh
libcurl.so                run.xml
bash-3.00# cp /host/home/adileh/1core/run.xml deploy/run.xml
bash-3.00# vmstat 1&
[1] 1113
sh sc kthr      memory            page            disk          faults      cpu
 r b w   swap  free  re  mf pi po fr de sr s1 s6 s1 s1   in   sy   cs us sy id
 0 0 0 16574096 3501544 149 824 0 0 1 0 2035 31 -0 0 0  621 42737 4043 10 14 76
bash-3.00# sh scripts/run-test.sh
```

Media Streaming in Action

- Monitoring
- QoS check


server (running) (on parsasrv2)
client (running) (on parsasrv2)

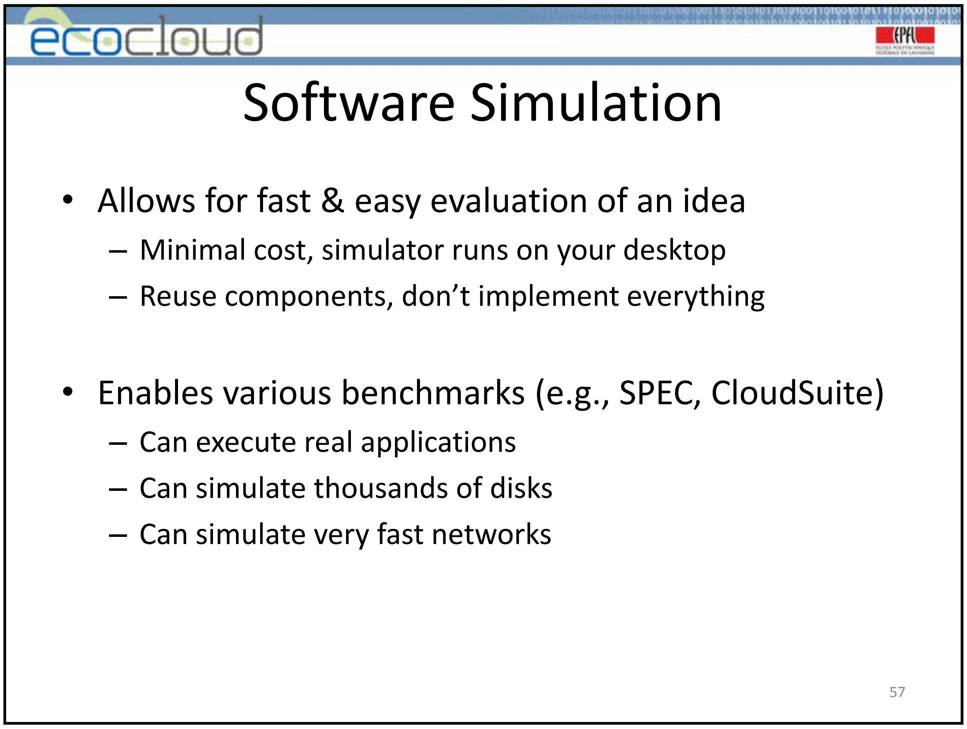
```
INFO: Module Loaded...QTSSAdminModule [static]
INFO: Module Loaded...QTSSMP3StreamingModule [static]
INFO: Module Loaded...QTSSAccessModule [static]
WARNING: No users file found at /etc/streaming/qtusers.
WARNING: No groups file found at /etc/streaming/qtgroups.
Streaming Server done starting up
     RTP-Conns RTSP-Conns HTTP-Conns  kBits/Sec   Pkts/Sec   RTP-Playing   AvgDe
lay CurMaxDelay  MaxDelay  AvgQuality  NumThinned       Time
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:48
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:49
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:50
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:51
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:52
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:53
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:54
          0          0          0          0          0            0         0
          0          0          0          0     2012-02-29 22:13:55
```

```
 1 0 0 70482592 3264192 756 2460 0 0 0 0 0  0  0  0  0  386 8061  751 29  5 66
 0 0 0 70431688 3247816 755 2441 0 0 0 0 0  0  0  0  0  424 8074  753 28  3 69
Feb 29, 2012 10:13:48 PM com.sun.faban.driver.engine.MasterImpl runBenchmark
INFO: RunID for this run is : 1
Feb 29, 2012 10:13:48 PM com.sun.faban.driver.engine.MasterImpl runBenchmark
INFO: Output directory for this run is : /opt/streaming-bin/faban-streaming/tmp/
output/1
Feb 29, 2012 10:13:48 PM com.sun.faban.driver.engine.MasterImpl configureAgents
INFO: Configuring 10 StreamDriverAgents...
 0 0 0 70380784 3231480 764 2043 0 0 0 0 0  0  0  0  0  457 10672 1259 59 7 34
 3 0 0 70133984 3191144 66 1194 0 0 0 0  0  0  0  0  0  400 14214 1701 96 2  2
 19 0 0 70130640 3181664 13 337 0 0 0 0  0  0  0  0  0  524 3442 1324 23  1 76
 kthr      memory            page            disk          faults      cpu
 r b w   swap  free   re  mf pi po fr de sr s1 s6 s1 s1   in   sy   cs us sy id
 0 0 0 70129136 3179752 0 1  0  0  0  0  0 26  0  0  0  658 2054 1176  1  0 99
 1 0 0 70129128 3179744 10 592 0 0 0  0  0  0  0  0  0  532 1944  859 31  1 68
 15 0 0 70126952 3174424 11 748 0 0 0 0  0  0  0  0  0  432 13558 556 99  1  0
 9 0 0 70122184 3166008 122 9704 0 0 0 0 0  0  0  0  0  557 68583 3360 81 19 0
 10 0 0 70065128 3094344 166 13091 0 0 0 0 0 0 0  0  0  497 47630 6238 42 58 0
 13 0 0 70024552 3042152 306 15158 0 0 0 0 0 0 0  0  0  443 53532 9987 27 73 0
 10 0 0 69947376 3007976 361 16758 0 0 0 0 0 0 0  0  0  426 49148 12339 20 80 0
 10 0 0 69941976 2974720 368 16308 0 0 0 0 0 0 0  0  0  418 45512 12647 22 78 0
 13 0 0 69961216 2949960 375 17314 0 0 0 0 0 0 0  0  0  428 54942 13106 24 76 0
▯
```

Flexus Simulator Toolset

Stavros Volos

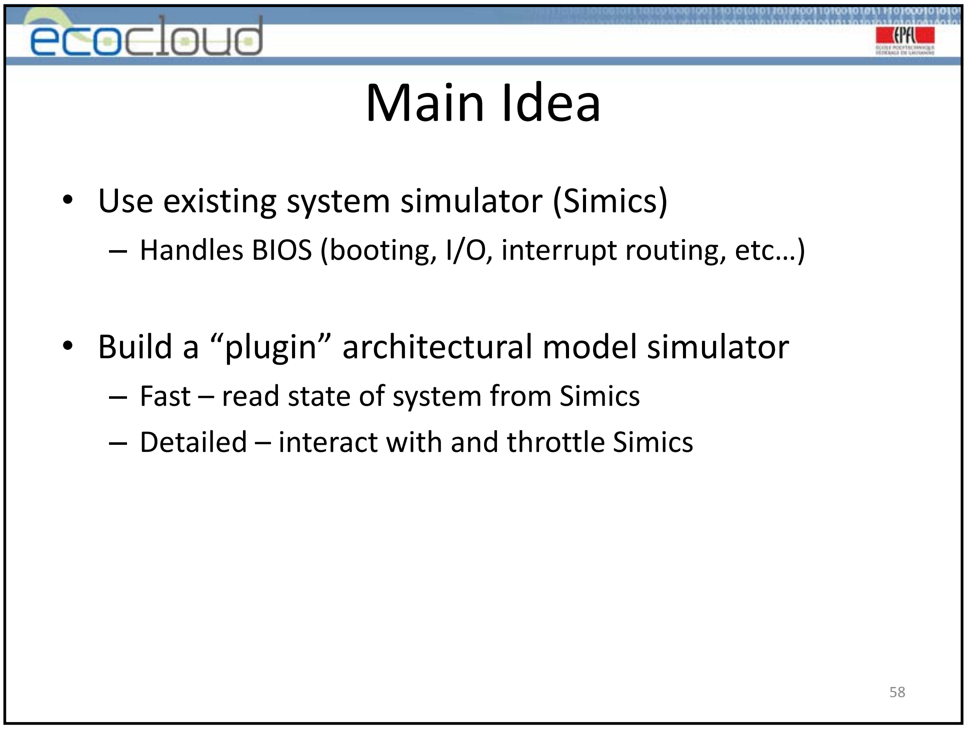
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE



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

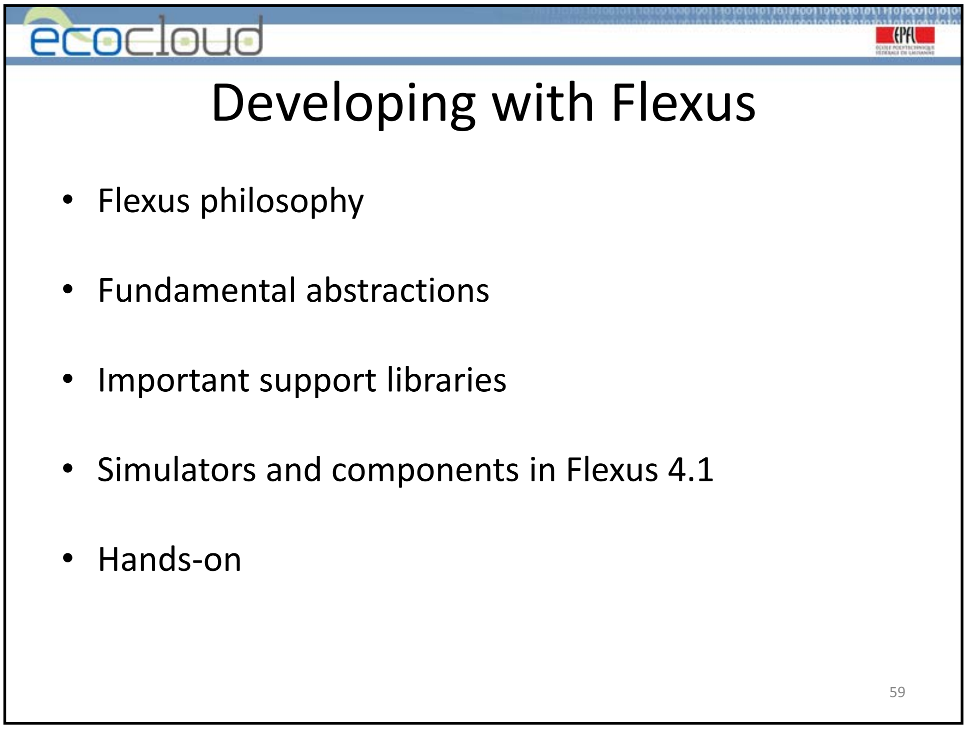
57



Main Idea

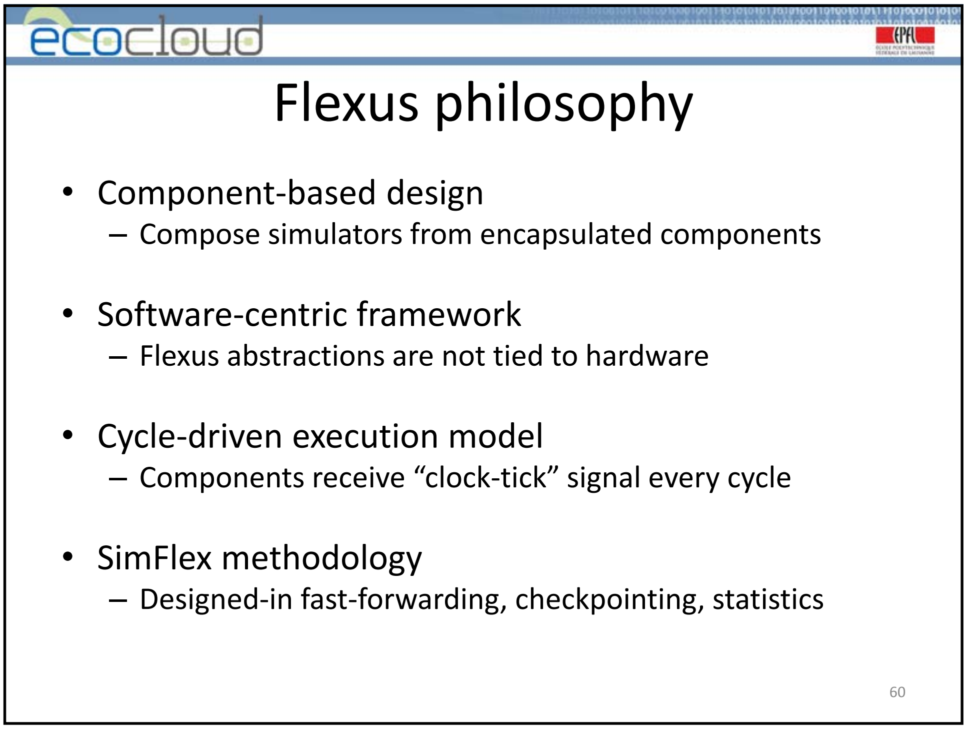
- Use existing system simulator (Simics)
  - Handles BIOS (booting, I/O, interrupt routing, etc…)
- Build a “plugin” architectural model simulator
  - Fast – read state of system from Simics
  - Detailed – interact with and throttle Simics

58



Developing with Flexus

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



Flexus philosophy

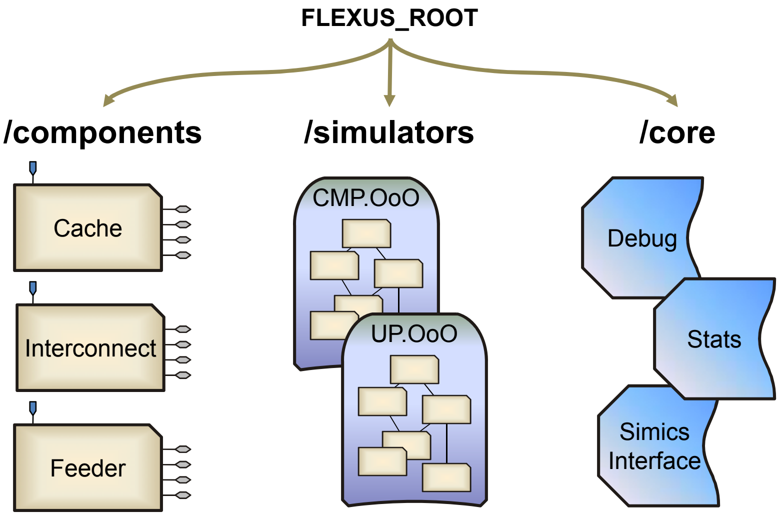
- Component-based design
  - Compose simulators from encapsulated components
- Software-centric framework
  - Flexus abstractions are not tied to hardware
- Cycle-driven execution model
  - Components receive “clock-tick” signal every cycle
- SimFlex methodology
  - Designed-in fast-forwarding, checkpointing,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

Developing with Flexus

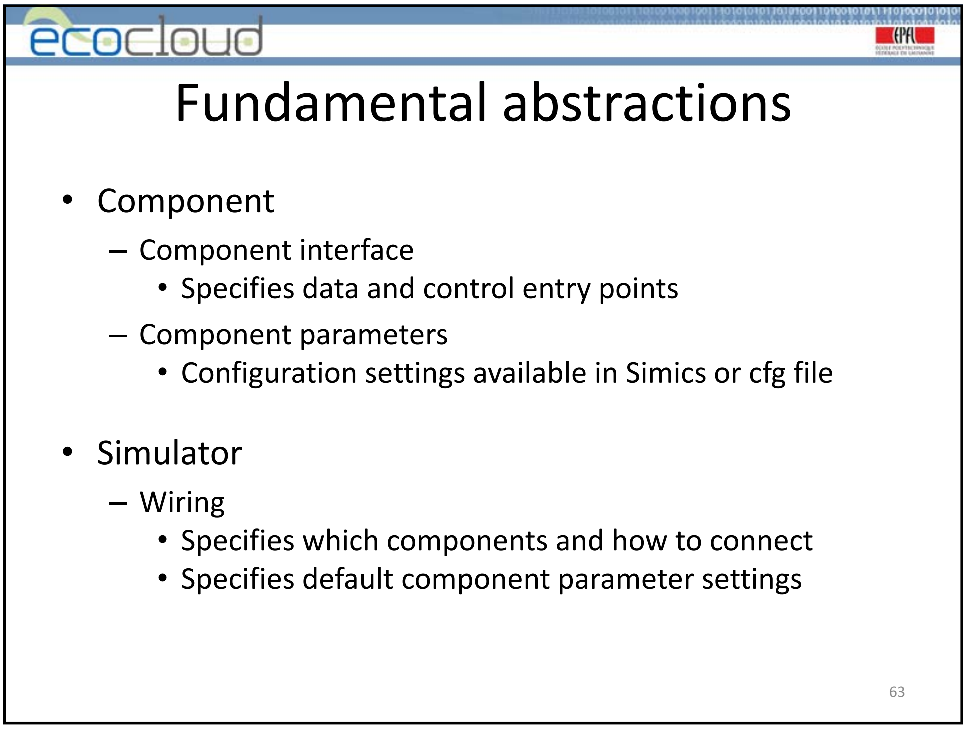
- Flexus philosophy
- **Fundamental abstractions**
- Important support libraries
- Simulators and components in Flexus 4.1
- Hands-on

61

Flexus organization

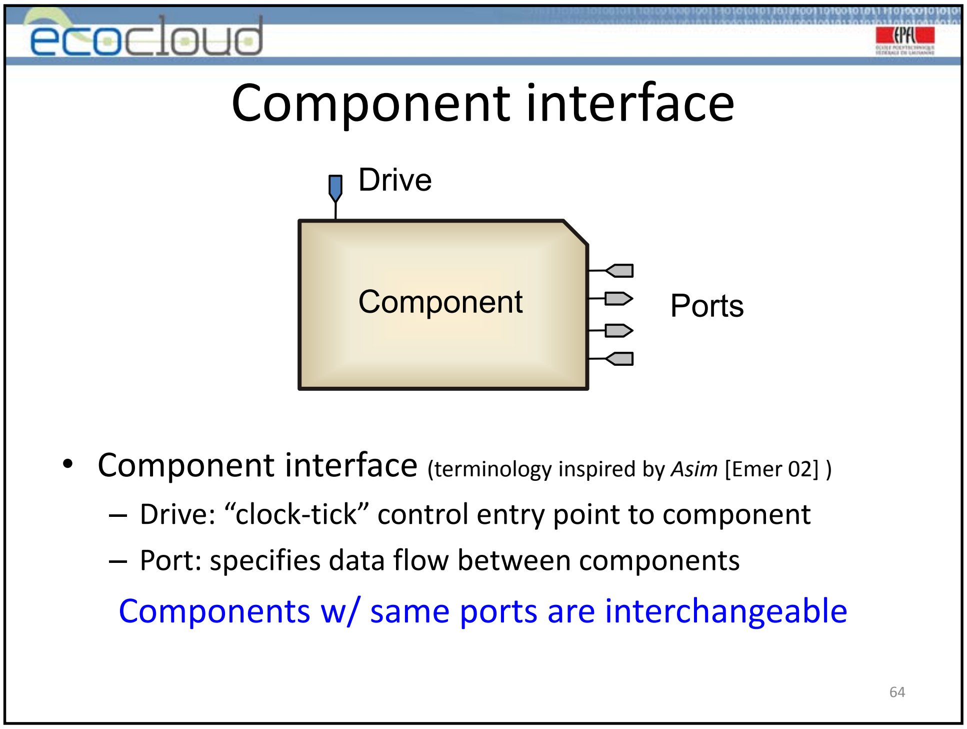


62



Fundamental abstractions

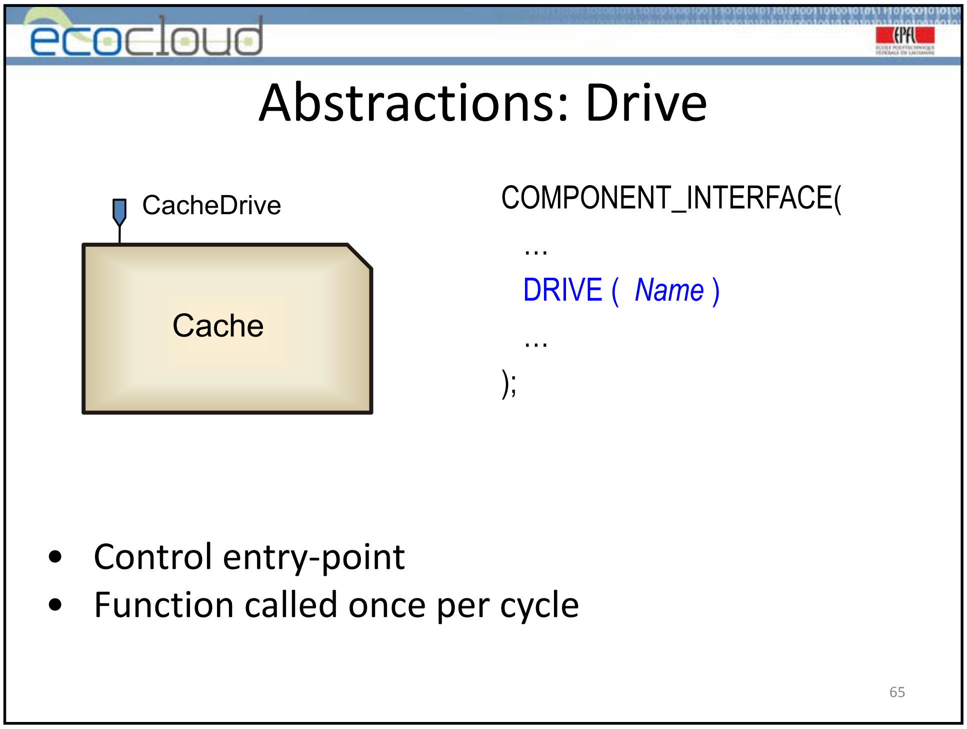
- Component
  - Component interface
    - Specifies data and control entry points
  - Component parameters
    - Configuration settings available in Simics or cfg file
- Simulator
  - Wiring
    - Specifies which components and how to connect
    - Specifies default component parameter settings



Component interface

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

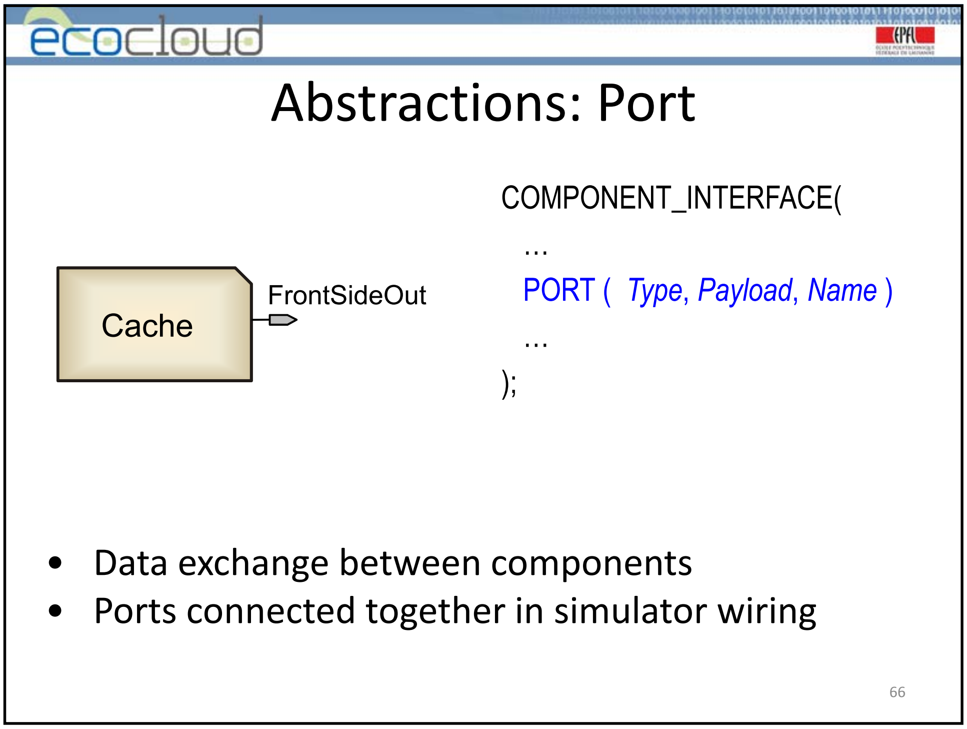
Components w/ same ports are interchangeable


CacheDrive
Cache

Abstractions: Drive

```
COMPONENT_INTERFACE(
  …
  DRIVE (  Name )
  …
);
```

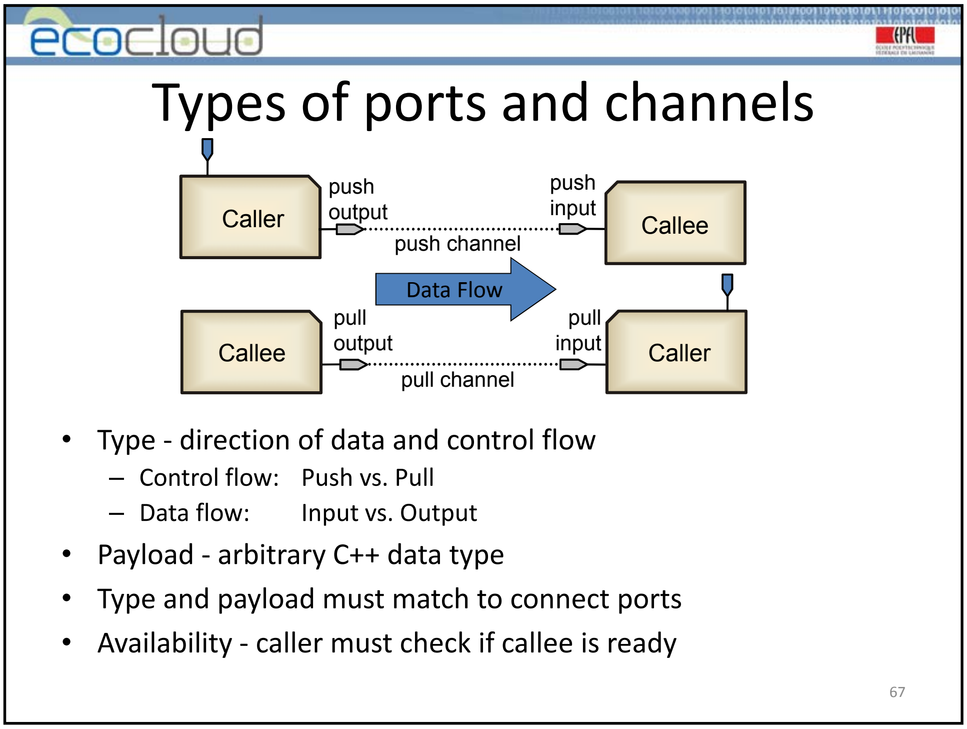
- Control entry-point
- Function called once per cycle


Cache
FrontSideOut

Abstractions: Port

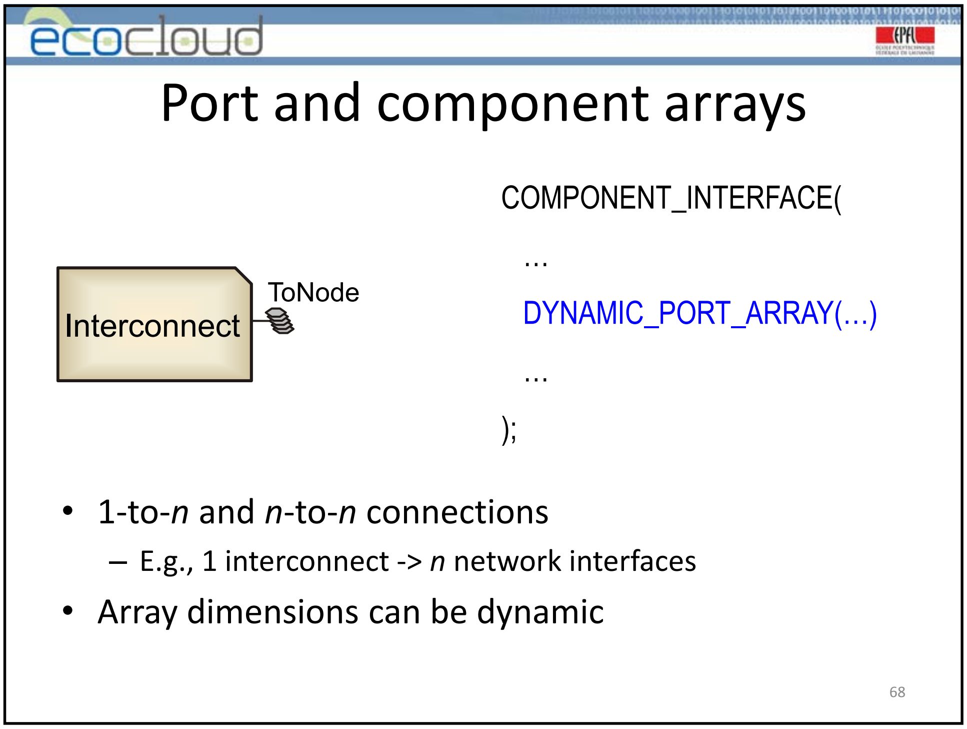
```
COMPONENT_INTERFACE(
  …
  PORT (  Type, Payload, Name )
  …
);
```

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



Types of ports and channels

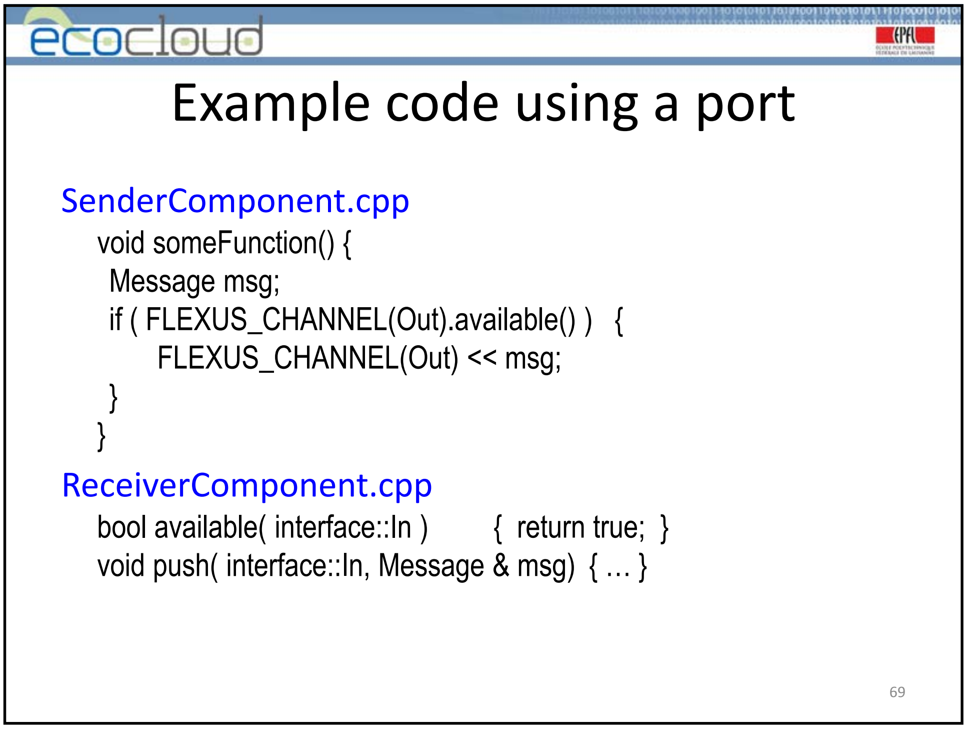
- Type - direction of data and control flow
  - Control flow: Push vs. Pull
  - Data flow: Input vs. Output
- Payload - arbitrary C++ data type
- Type and payload must match to connect ports
- Availability - caller must check if callee is ready



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

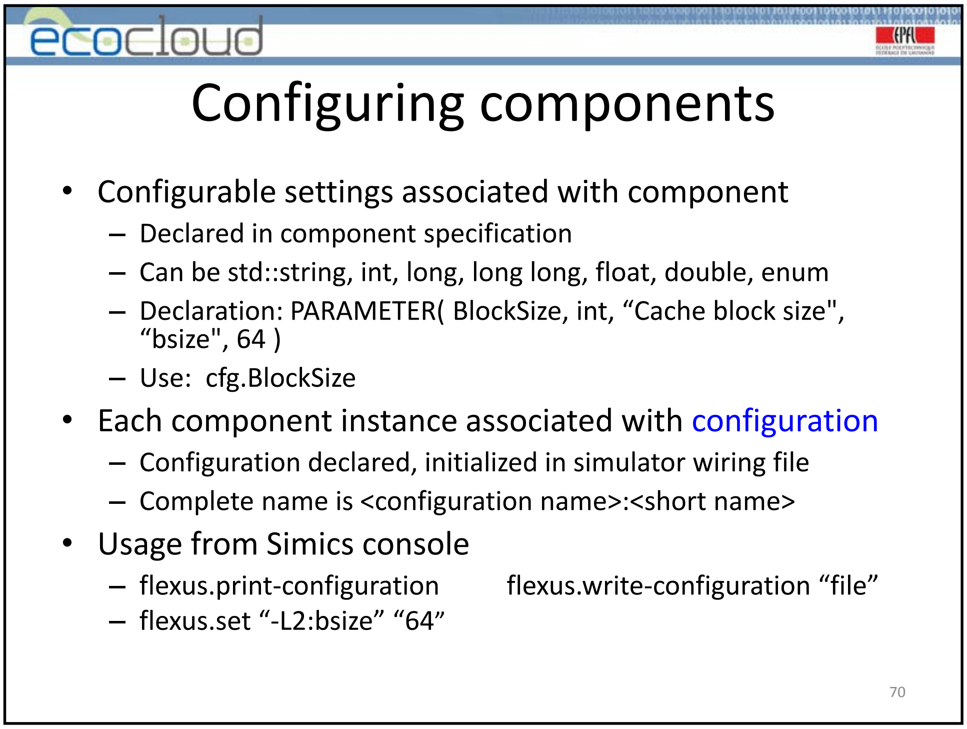
SenderComponent.cpp

```
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)  { … }
```

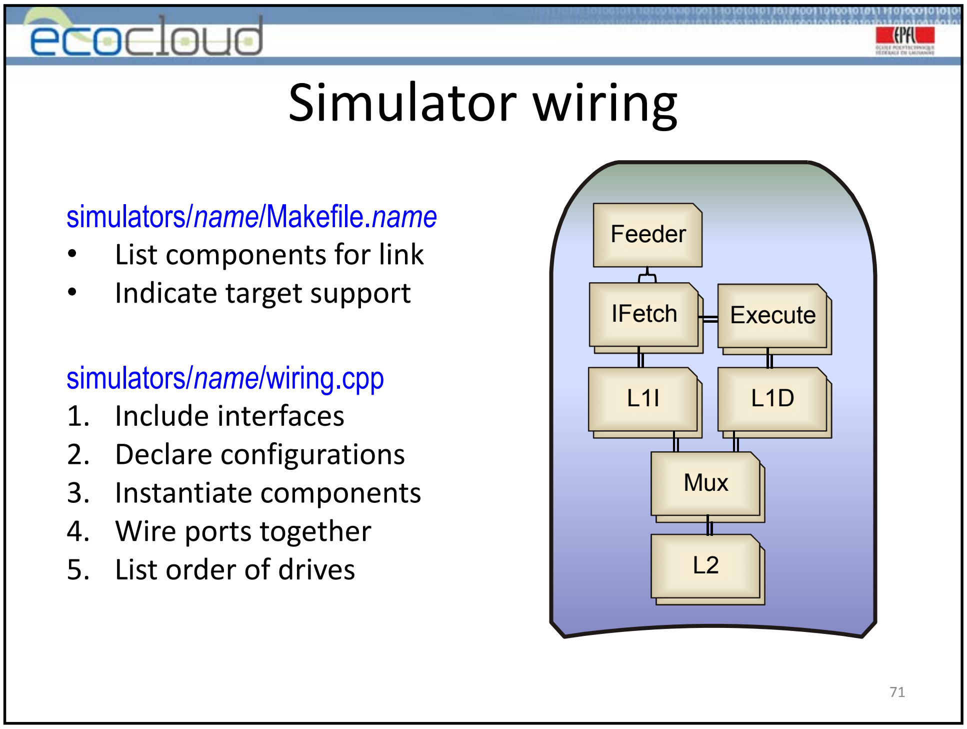
69



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
- Each component instance associated with configuration
  - Configuration declared, initialized in simulator wiring file
  - Complete name is <configuration name>:<short name>
- Usage from Simics console
  - flexus.print-configuration   flexus.write-configuration “file”
  - flexus.set “-L2:bsize” “64”

70



Simulator wiring

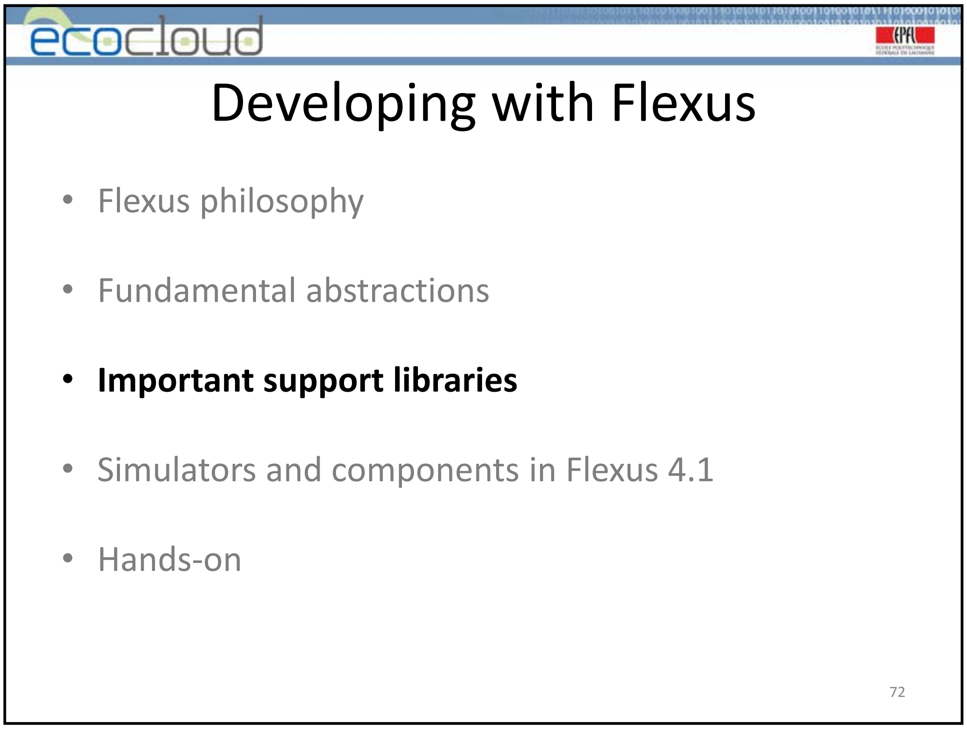
simulators/*name*/Makefile.*name*

- List components for link
- Indicate target support

simulators/*name*/wiring.cpp

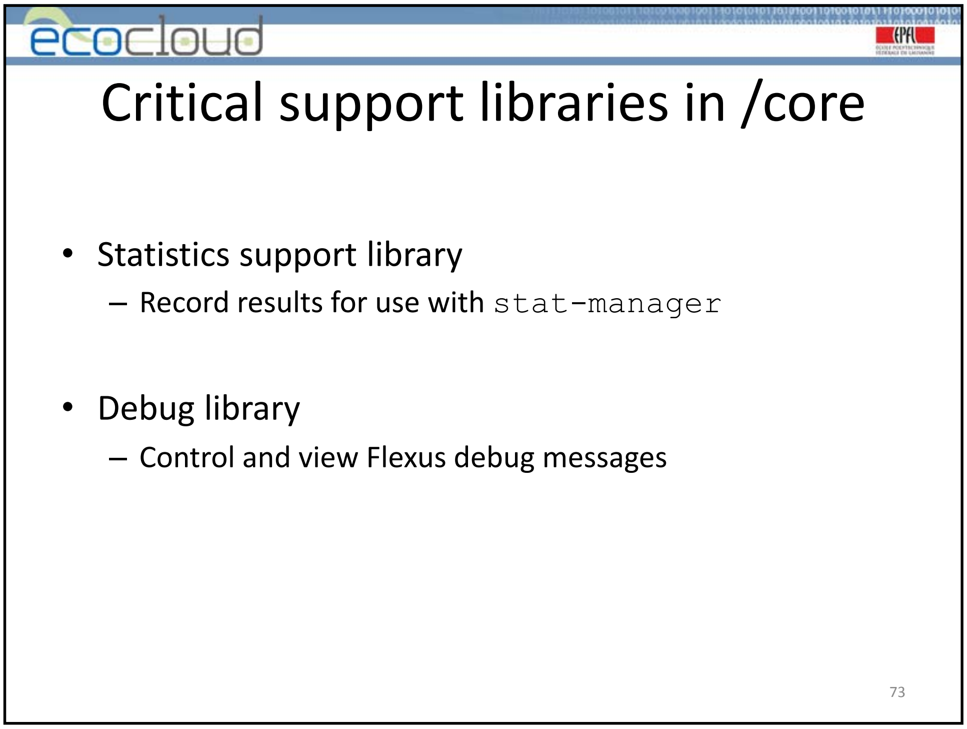
1. Include interfaces
2. Declare configurations
3. Instantiate components
4. Wire ports together
5. List order of drives

Feeder
IFetch
Execute
L1I
L1D
Mux
L2



Developing with Flexus

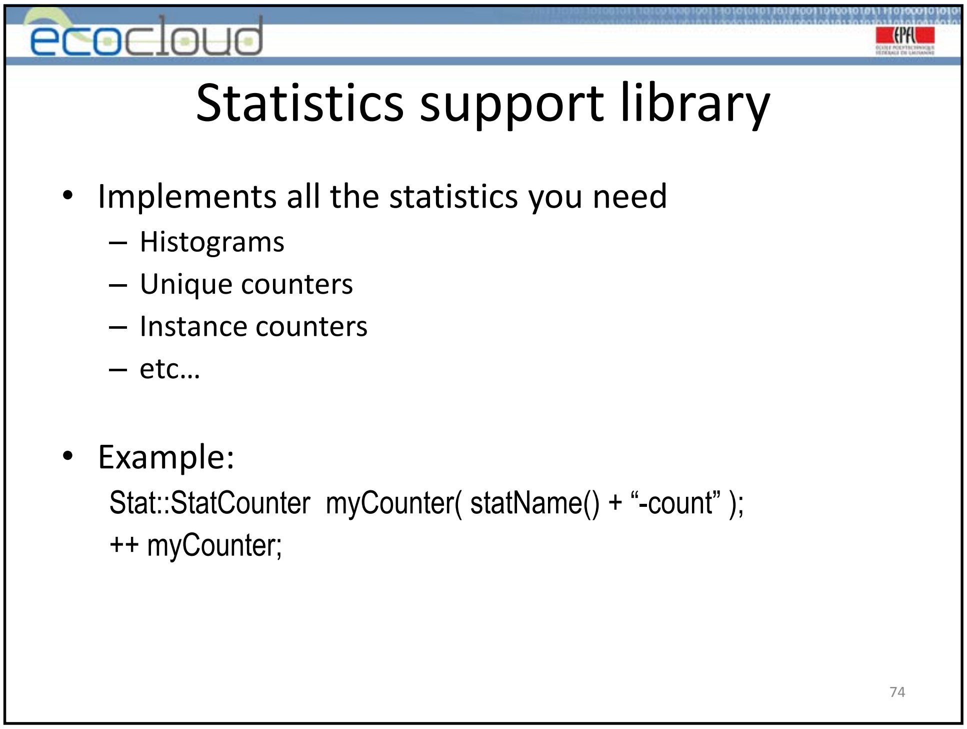
- Flexus philosophy
- Fundamental abstractions
- **Important support libraries**
- Simulators and components in Flexus 4.1
- Hands-on



Critical support libraries in /core

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

73

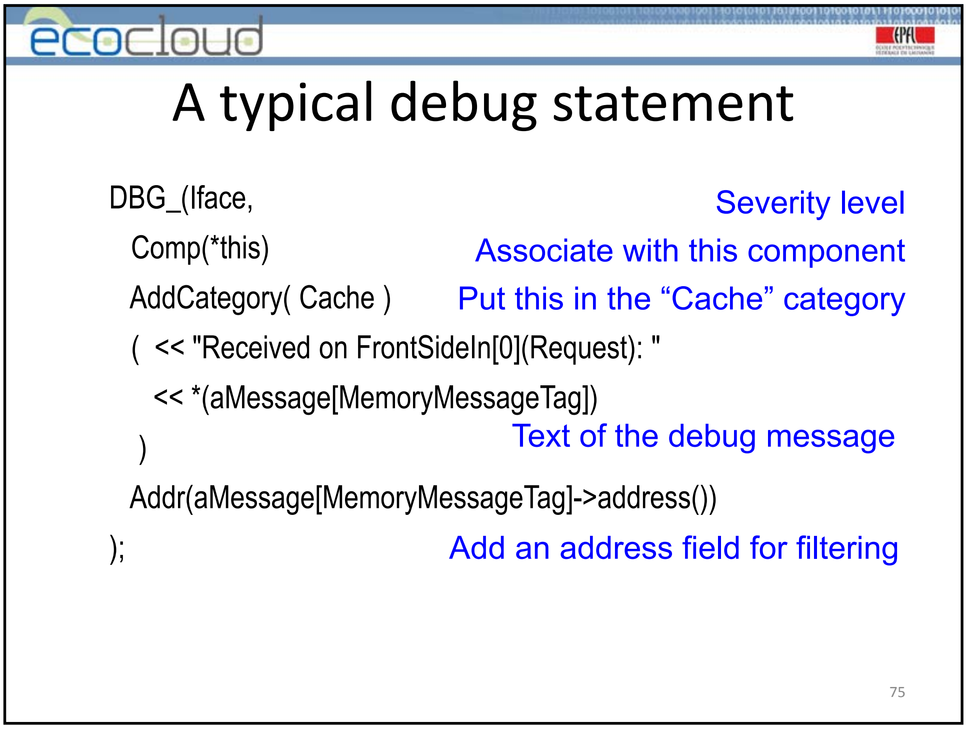


Statistics support library

- Implements all the statistics you need
  - Histograms
  - Unique counters
  - Instance counters
  - etc…
- Example:

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

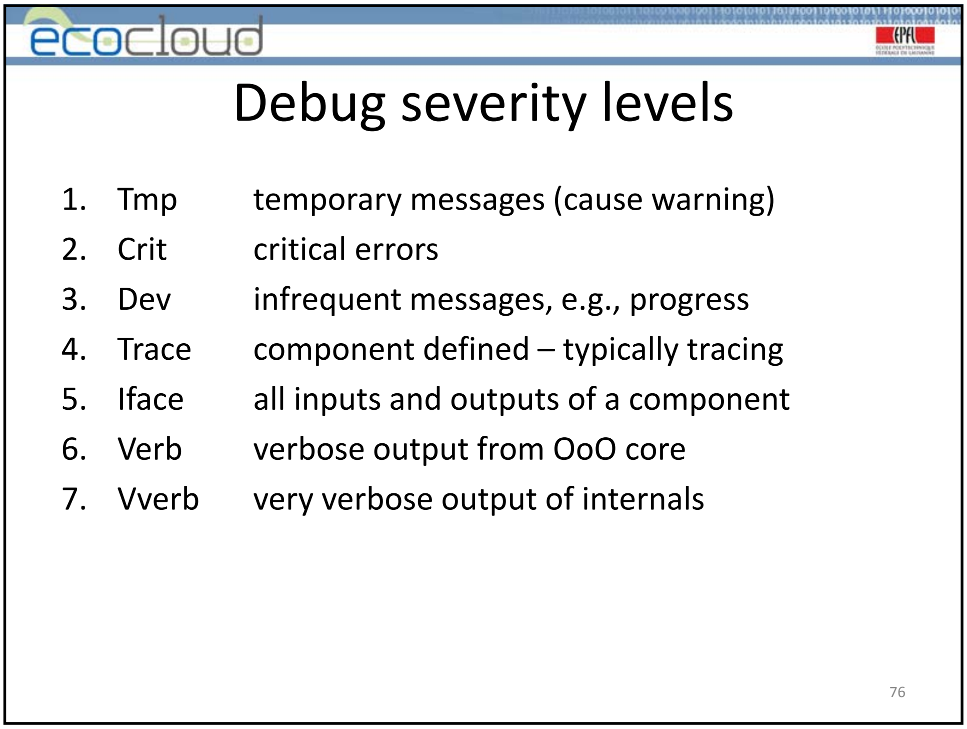
74



A typical debug statement

```
DBG_(Iface,                                              Severity level
  Comp(*this)                              Associate with this component
  AddCategory( Cache )                  Put this in the “Cache” category
  (  << "Received on FrontSideIn[0](Request): "
     << *(aMessage[MemoryMessageTag])
   )                                         Text of the debug message
  Addr(aMessage[MemoryMessageTag]->address())
);                                   Add an address field for filtering
```

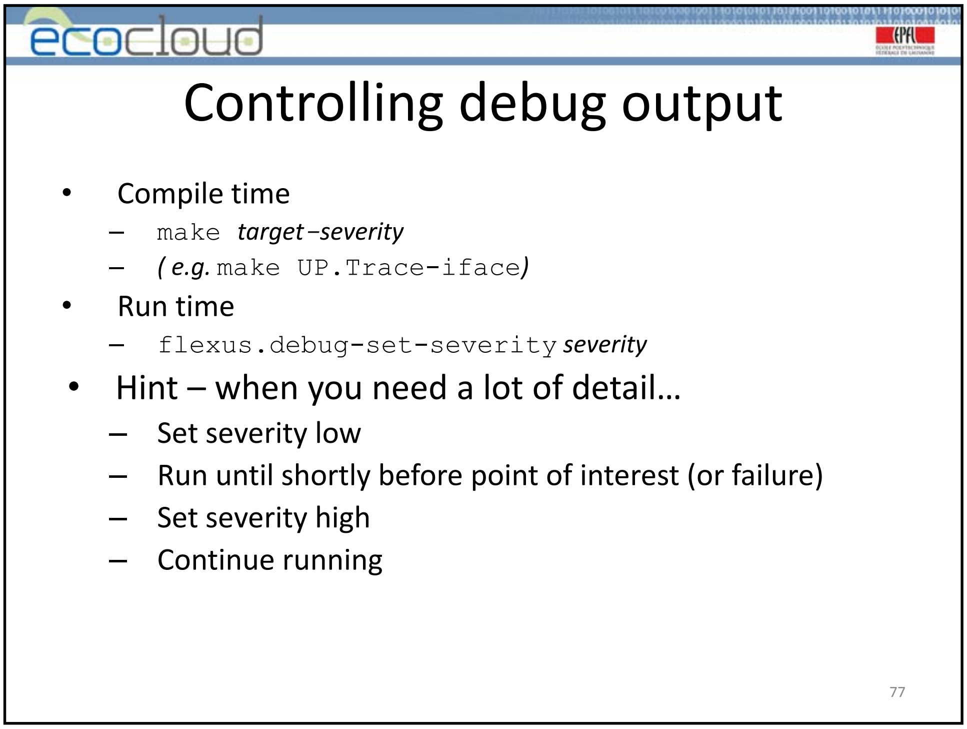
75



Debug severity levels

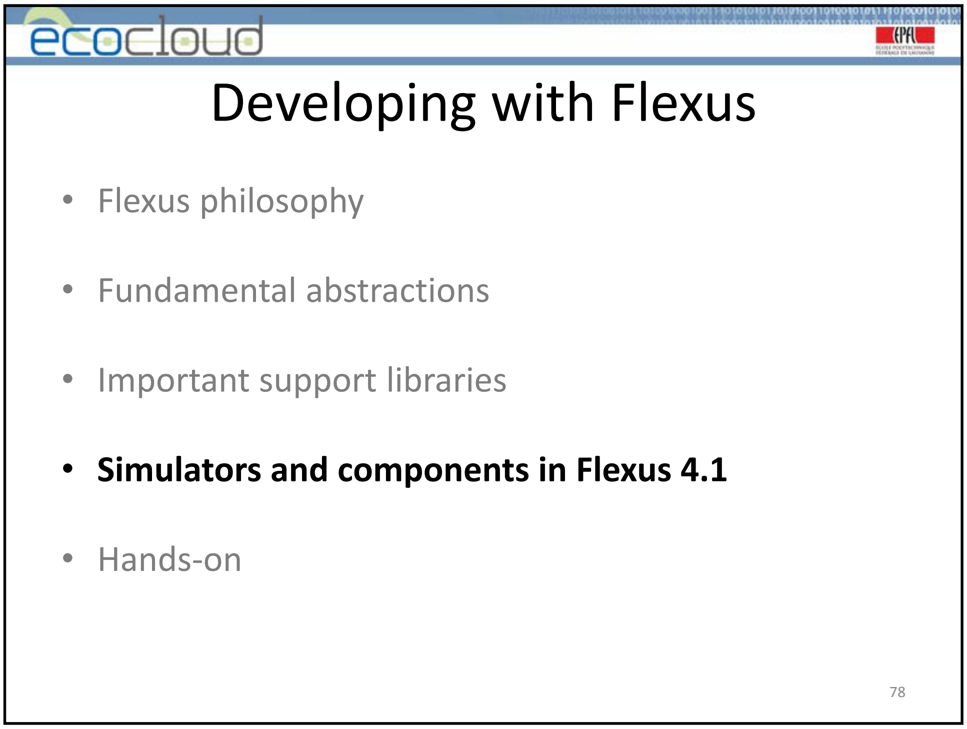
1.	Tmp	temporary messages (cause warning)
2.	Crit	critical errors
3.	Dev	infrequent messages, e.g., progress
4.	Trace	component defined – typically tracing
5.	Iface	all inputs and outputs of a component
6.	Verb	verbose output from OoO core
7.	Vverb	very verbose output of internals

76



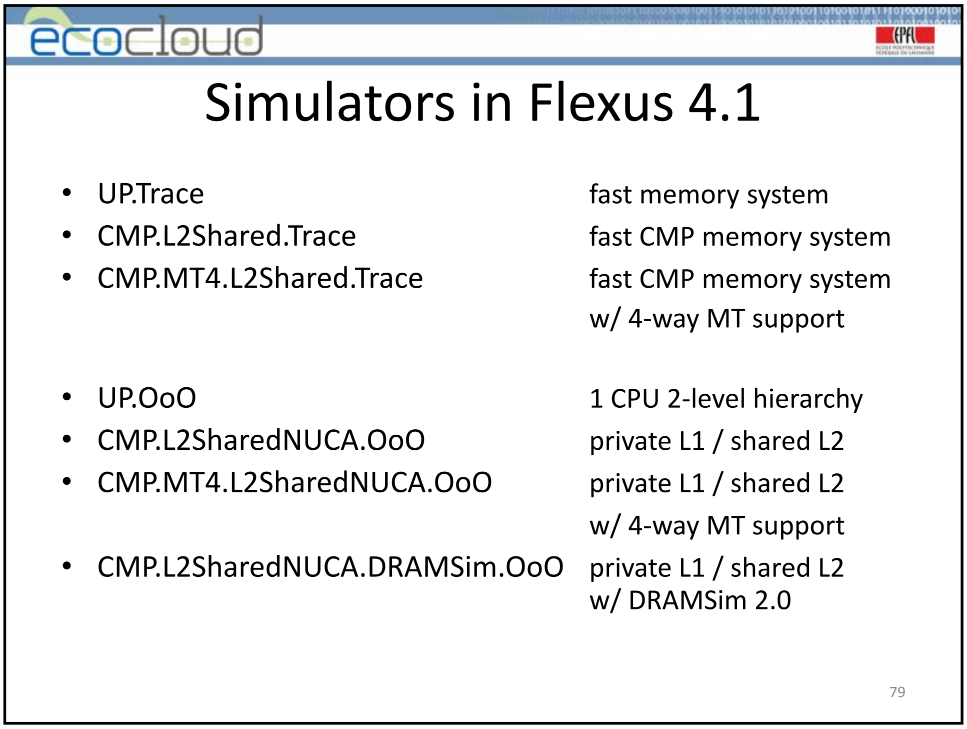
Controlling debug output

- 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

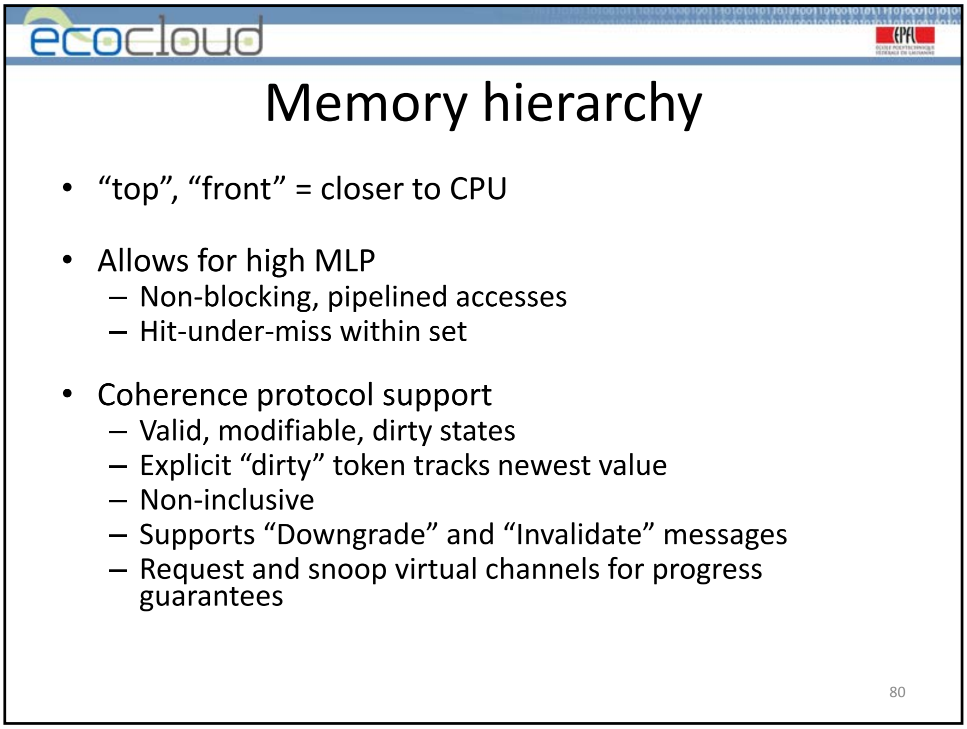
- Flexus philosophy
- Fundamental abstractions
- Important support libraries
- **Simulators and components in Flexus 4.1**
- Hands-on



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

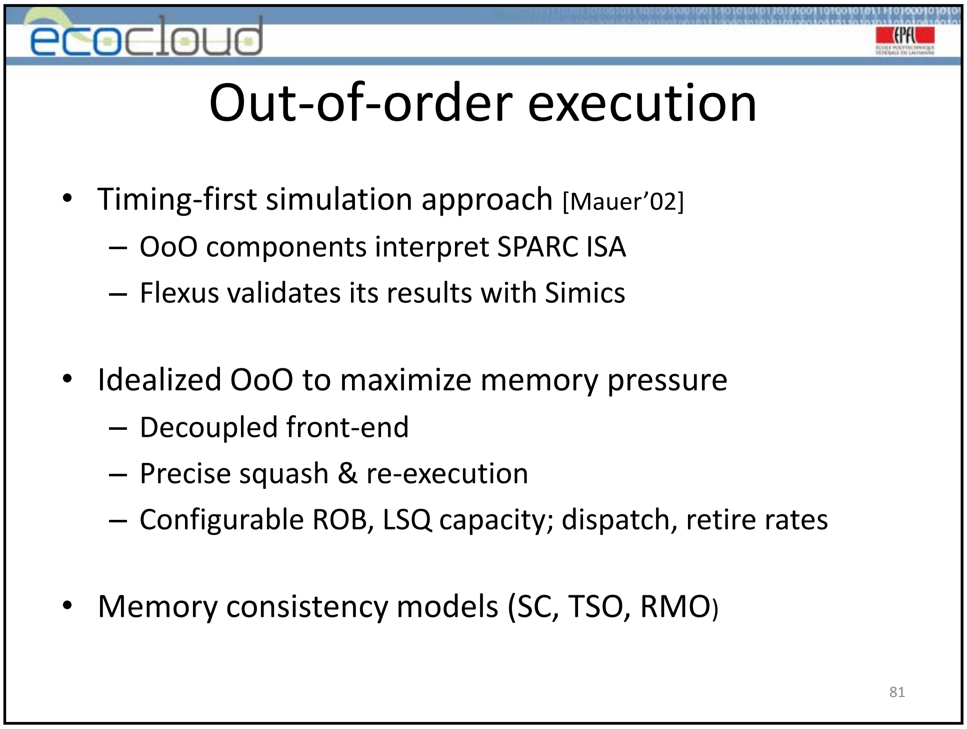
79



Memory hierarchy

- “top”, “front” = closer to CPU
- Allows for high MLP
  - Non-blocking, pipelined accesses
  - Hit-under-miss within set
- Coherence protocol support
  - Valid, modifiable, dirty states
  - Explicit “dirty” token tracks newest value
  - Non-inclusive
  - Supports “Downgrade” and “Invalidate” messages
  - Request and snoop virtual channels for progress guarantees

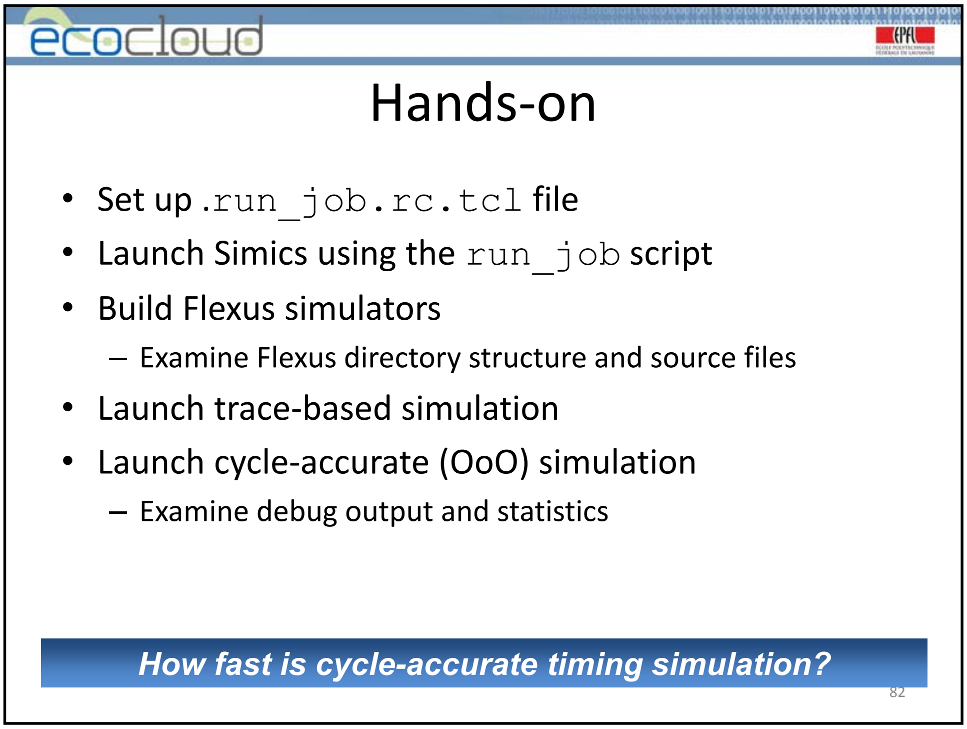
80



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)

81

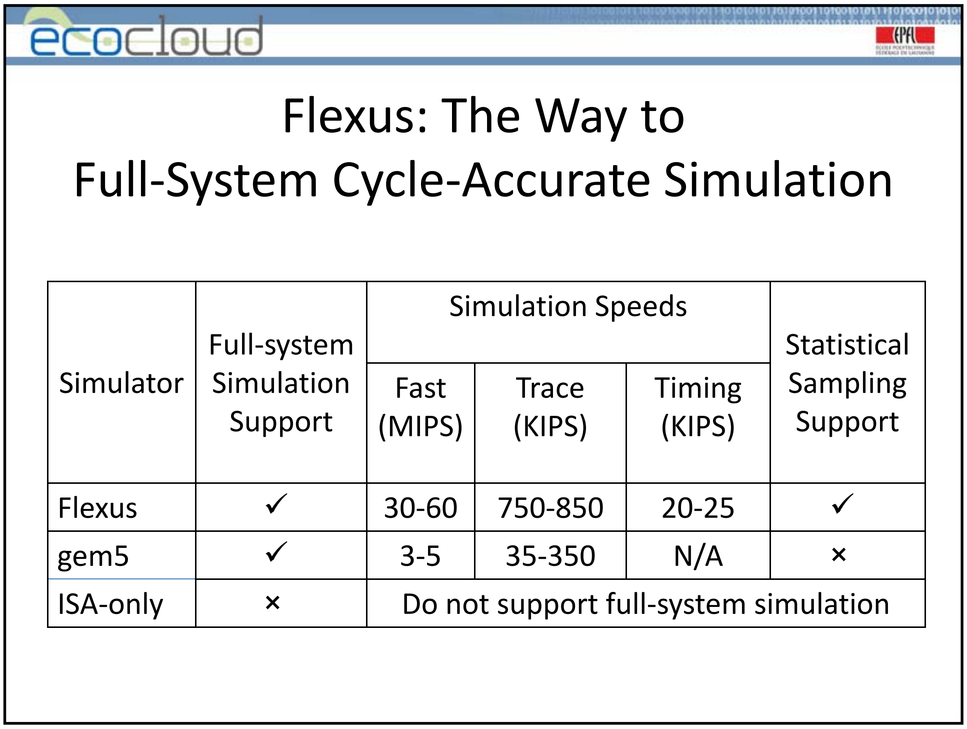


Hands-on

- 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

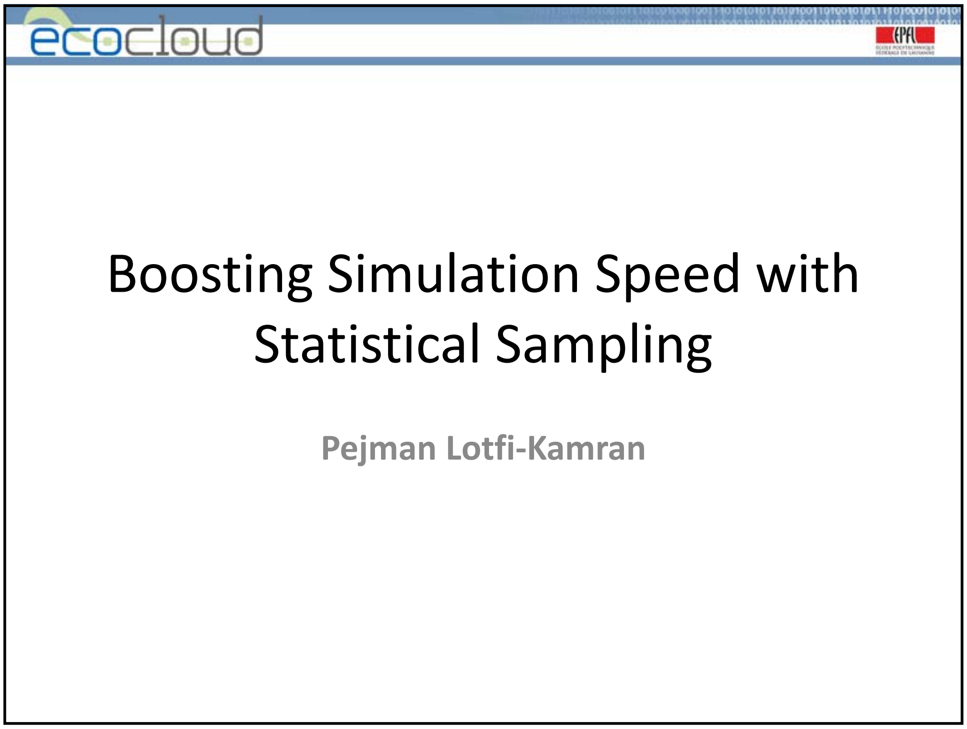
How fast is cycle-accurate timing simulation?

82



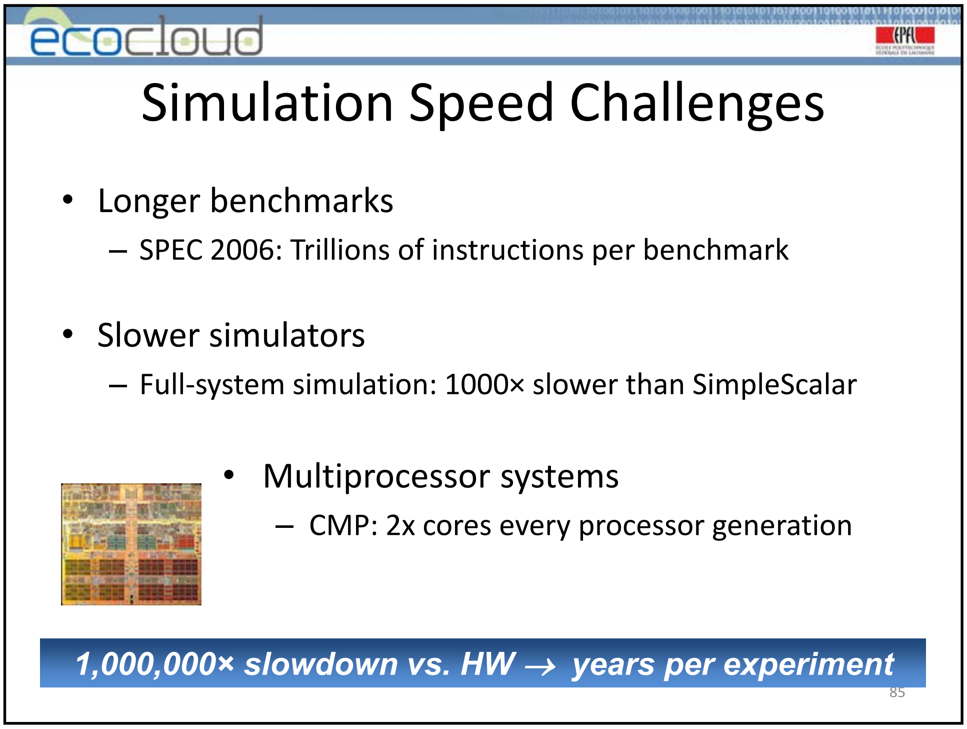
Flexus: The Way to Full-System Cycle-Accurate Simulation

Simulator	Full-system Simulation Support	Simulation Speeds			Statistical Sampling Support
		Fast (MIPS)	Trace (KIPS)	Timing (KIPS)	
Flexus	✓	30-60	750-850	20-25	✓
gem5	✓	3-5	35-350	N/A	×
ISA-only	×	Do not support full-system simulation			



Boosting Simulation Speed with Statistical Sampling

Pejman Lotfi-Kamran

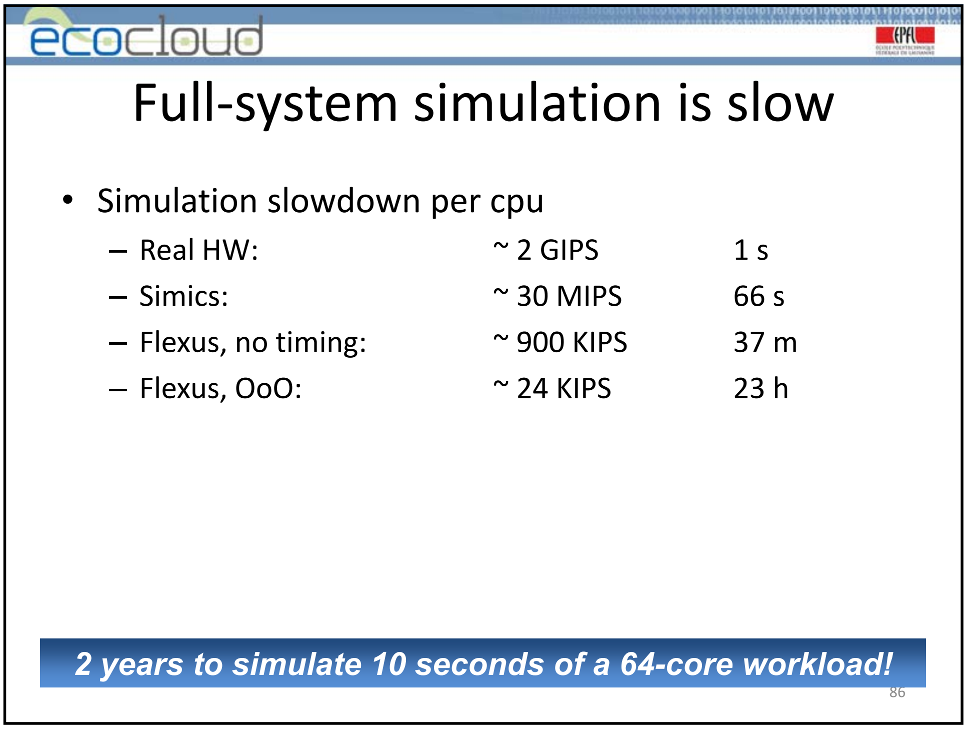


Simulation Speed Challenges

- 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

85



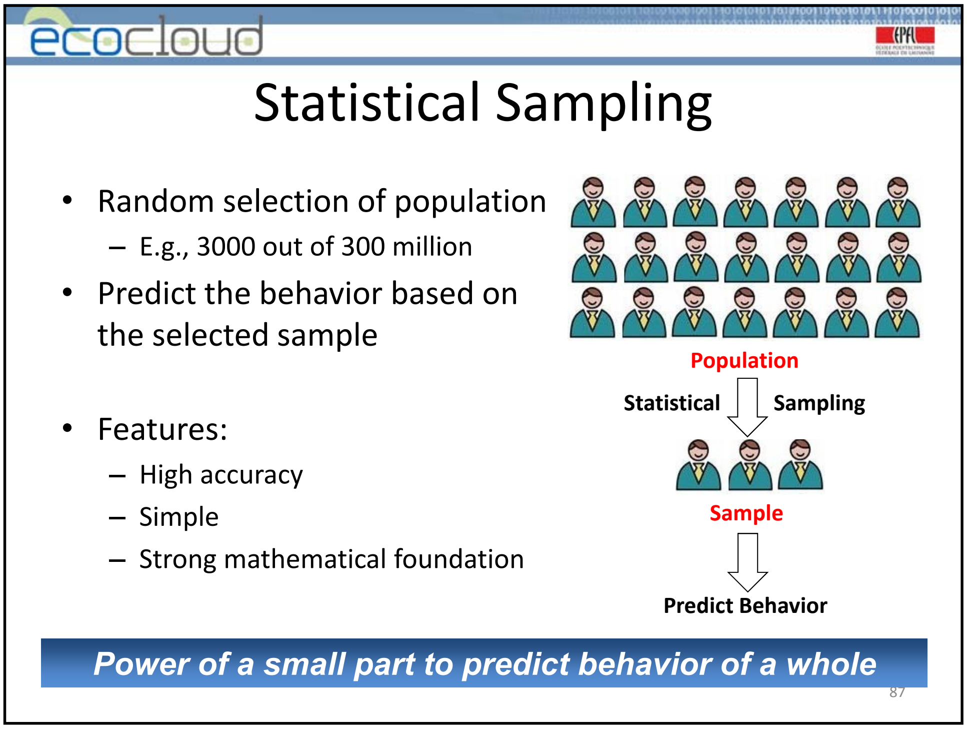
Full-system simulation is slow

- 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!

86



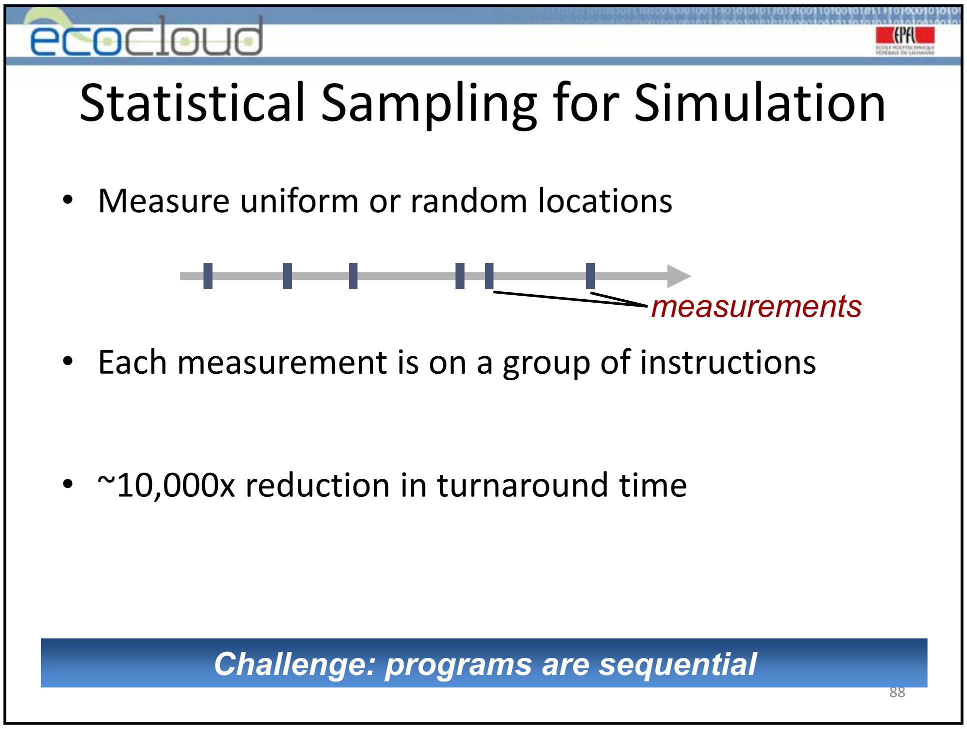
Statistical Sampling

- 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

Population
Statistical Sampling
Sample
Predict Behavior

Power of a small part to predict behavior of a whole

87



Statistical Sampling for Simulation

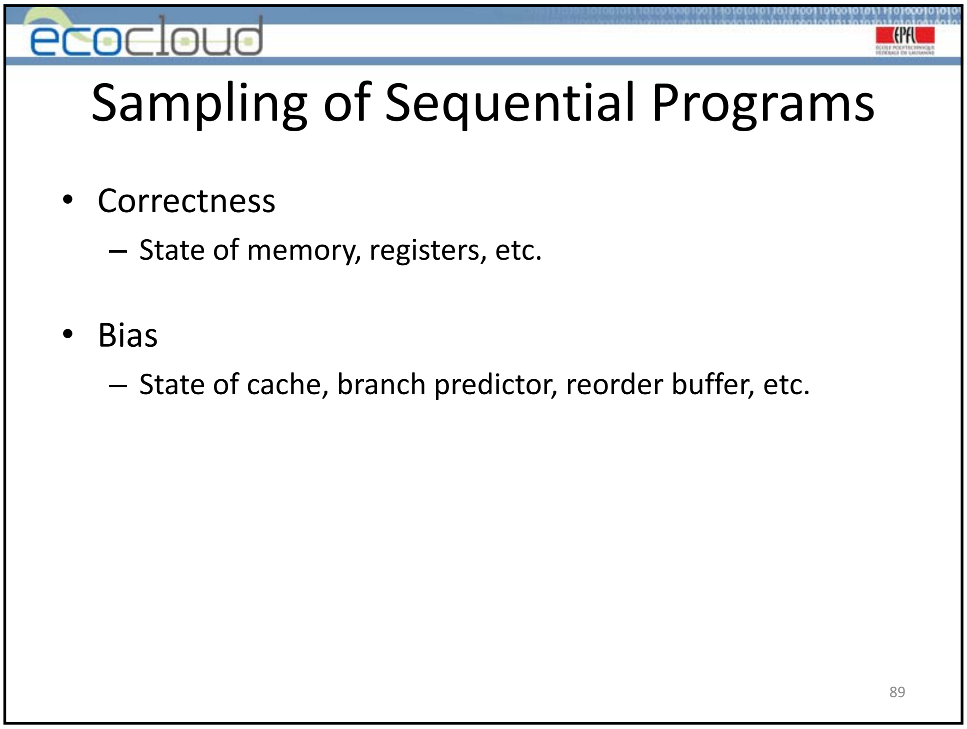
- Measure uniform or random locations

measurements

- Each measurement is on a group of instructions
- ~10,000x reduction in turnaround time

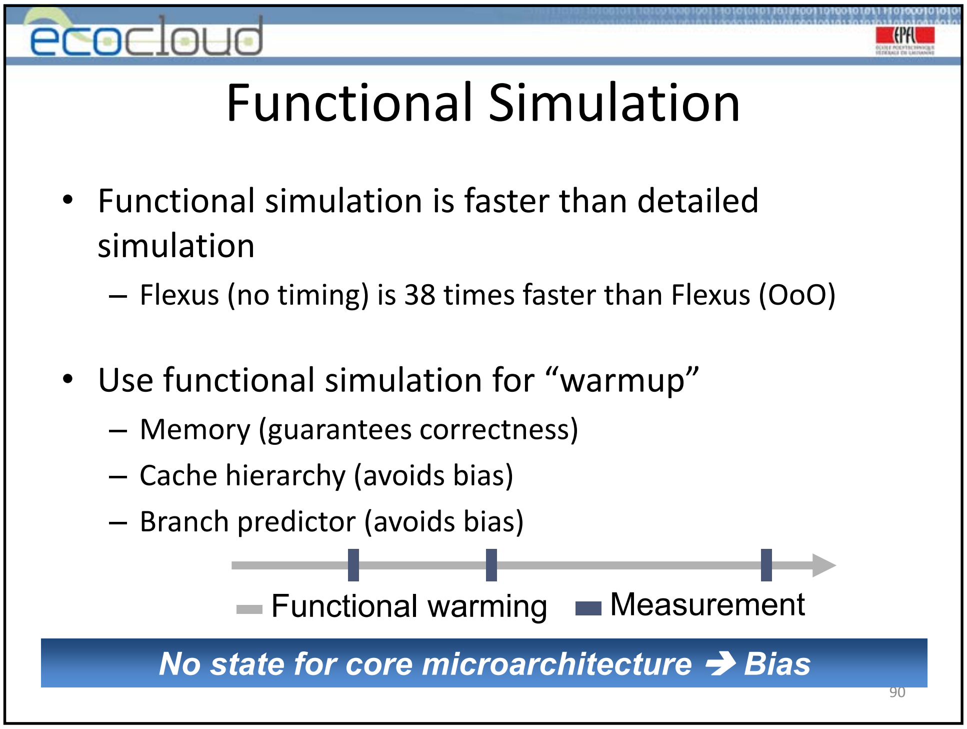
Challenge: programs are sequential

88



Sampling of Sequential Programs

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

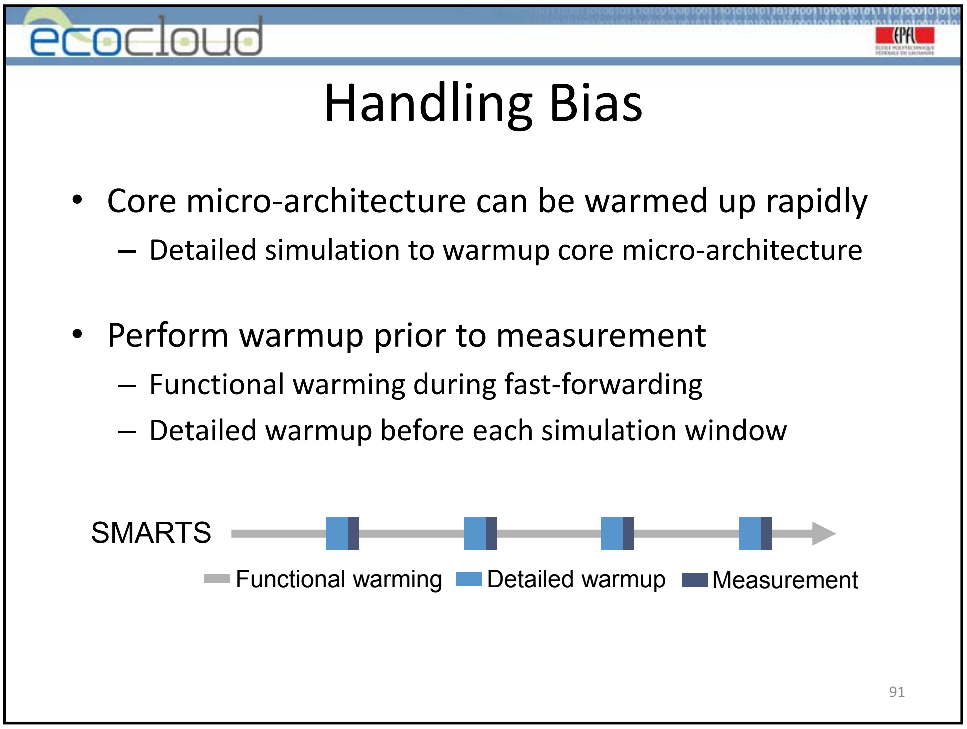


Functional Simulation

- 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)
  - Cache hierarchy (avoids bias)
  - Branch predictor (avoids bias)

▬ Functional warming ▬ Measurement

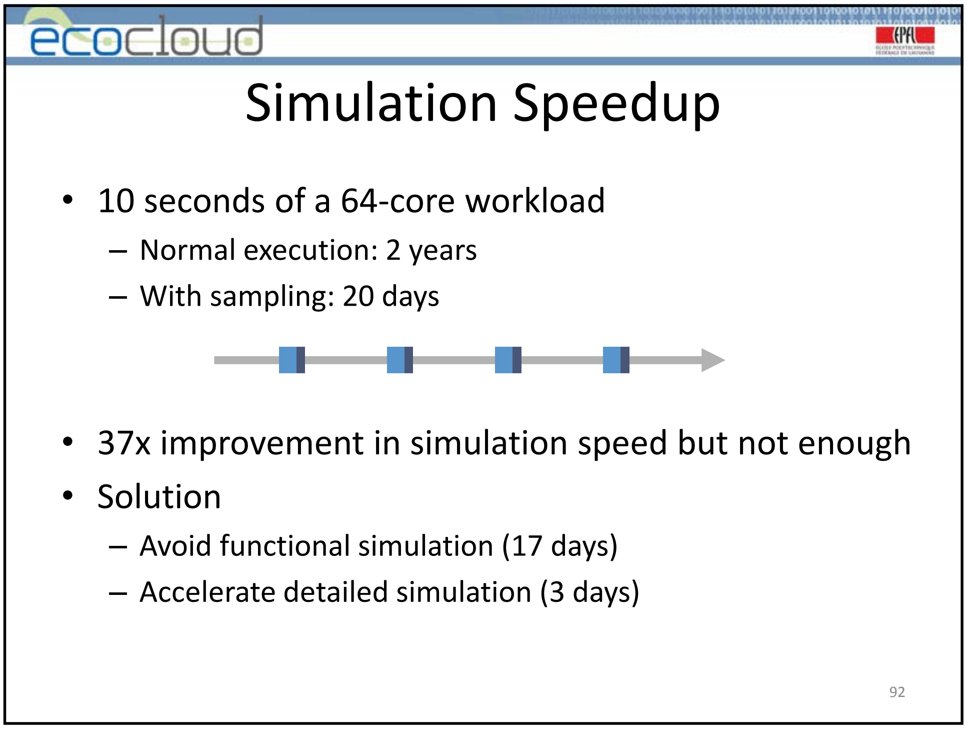
No state for core microarchitecture → Bias



Handling Bias

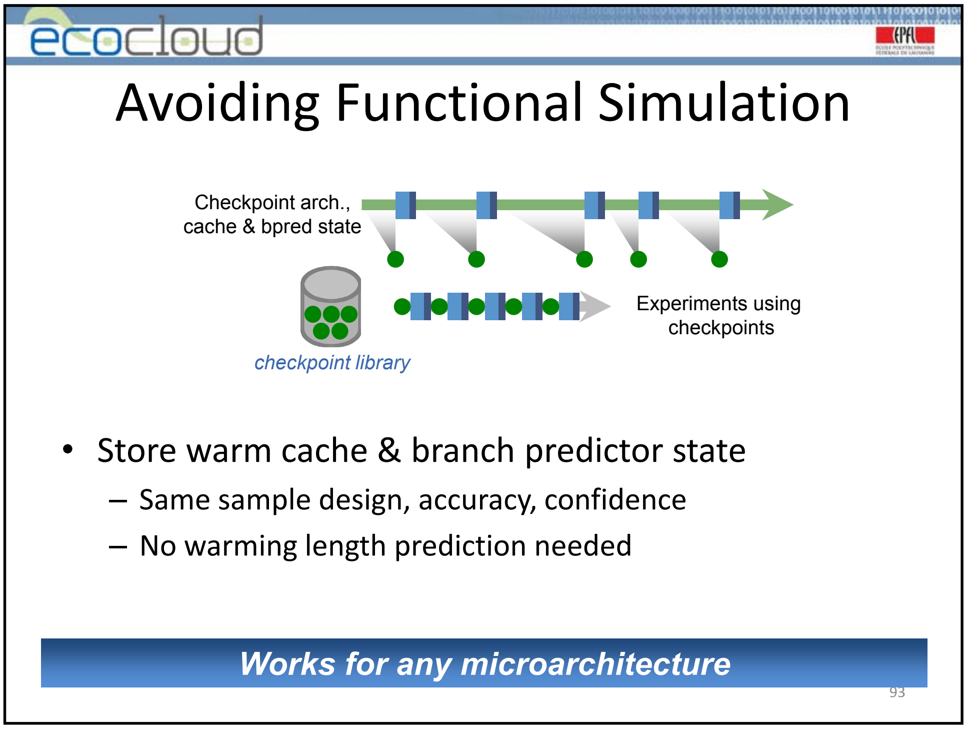
- Core micro-architecture can be warmed up rapidly
  - Detailed simulation to warmup core micro-architecture
- Perform warmup prior to measurement
  - Functional warming during fast-forwarding
  - Detailed warmup before each simulation window

SMARTS
Functional warming
Detailed warmup
Measurement



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

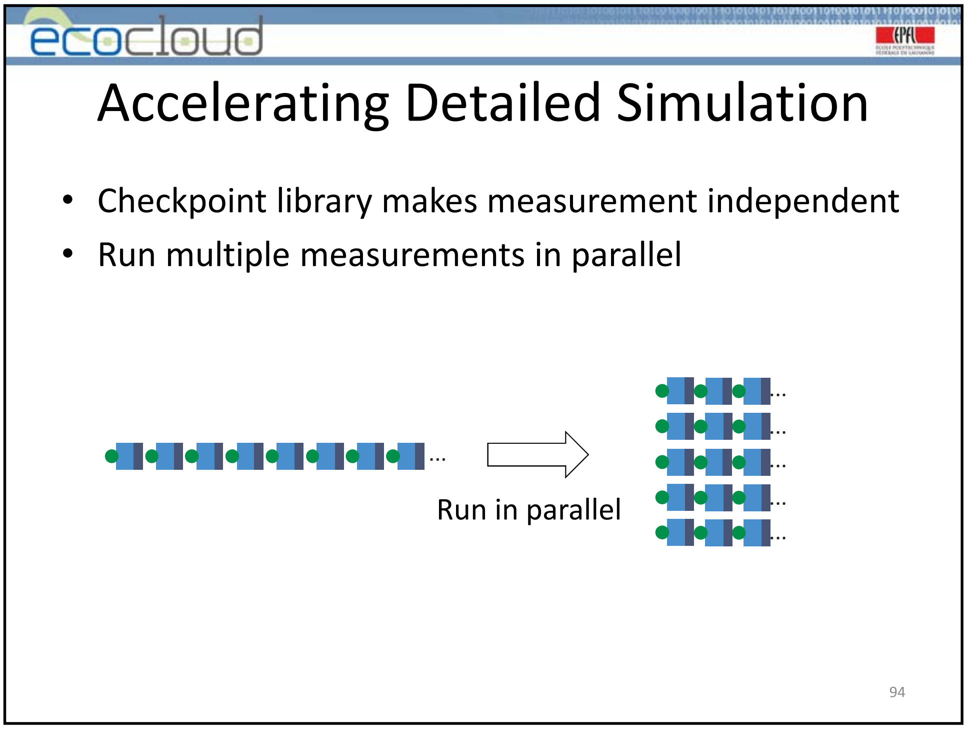
Checkpoint arch., cache & bpred state

checkpoint library

Experiments using checkpoints

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

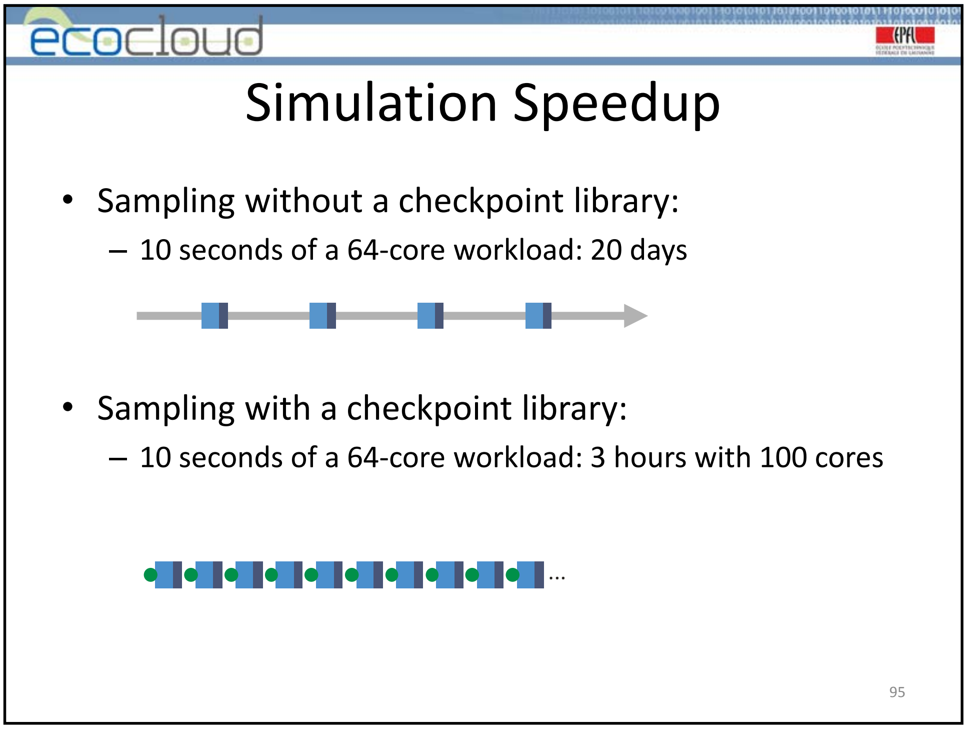
Works for any microarchitecture



Accelerating Detailed Simulation

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

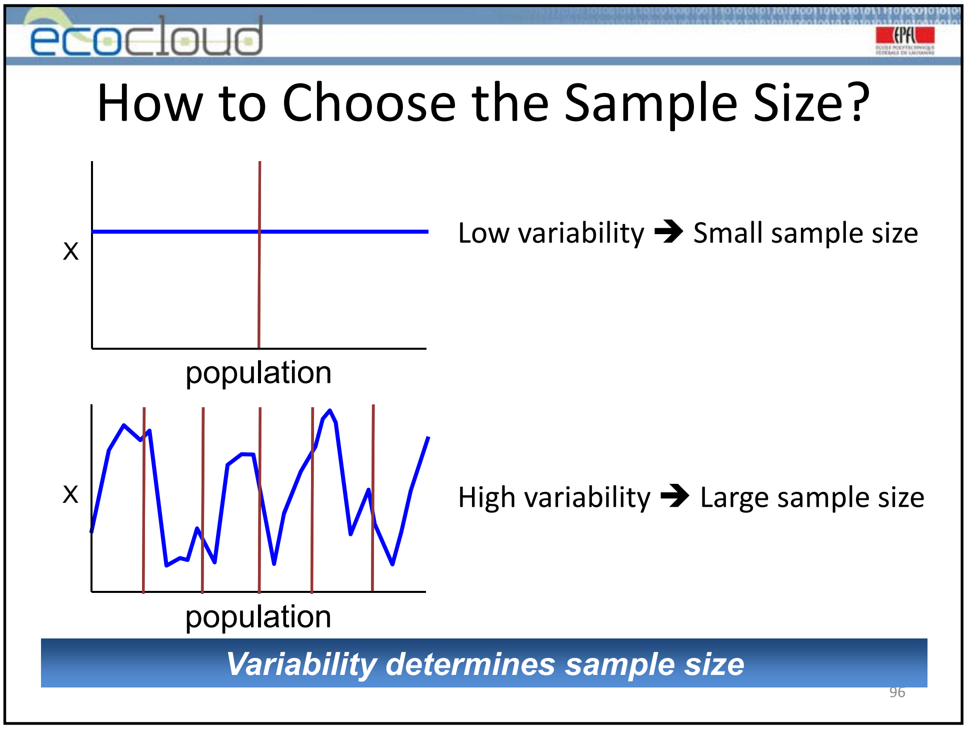
Run in parallel



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

95



How to Choose the Sample Size?

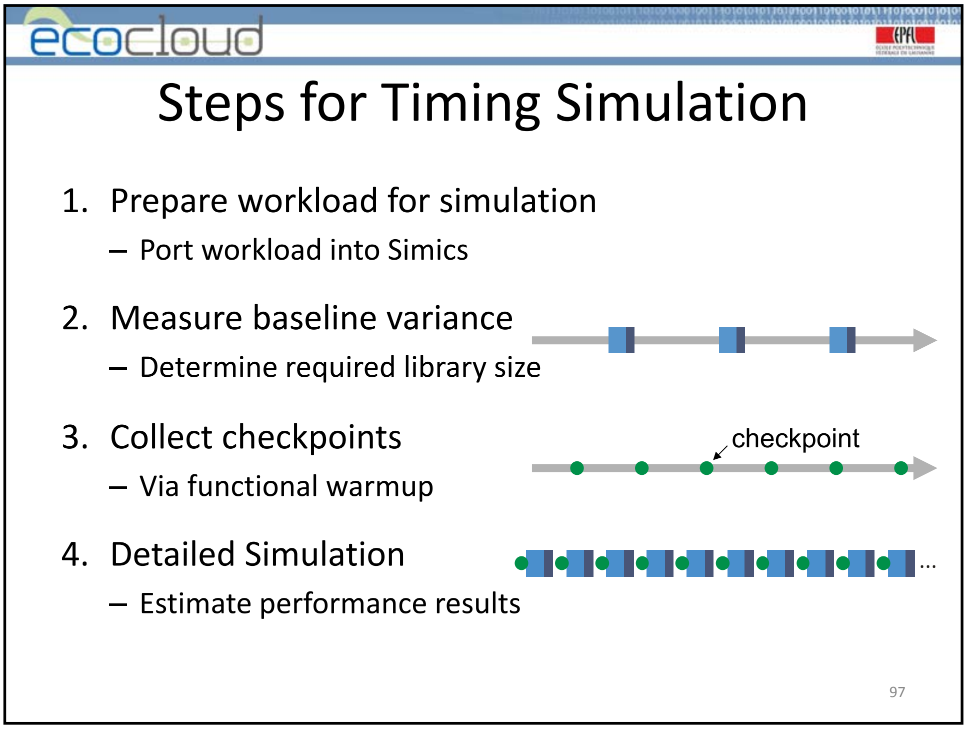
x
population
x
population

Low variability ➔ Small sample size

High variability ➔ Large sample size

Variability determines sample size

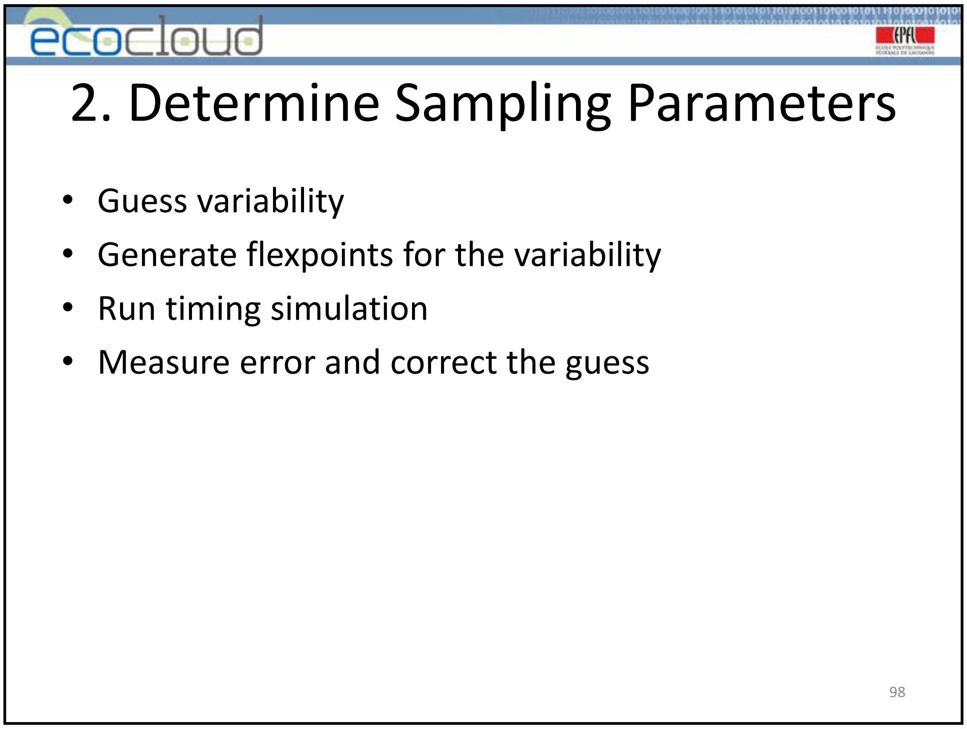
96



Steps for Timing Simulation

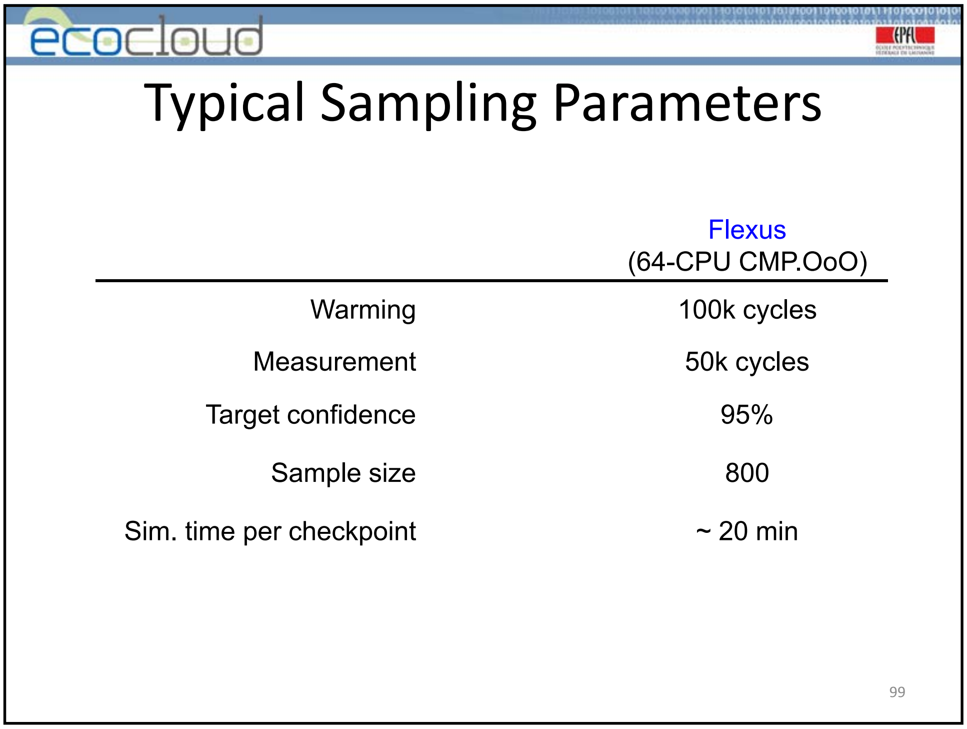
1. Prepare workload for simulation
   – Port workload into Simics
2. Measure baseline variance
   – Determine required library size
3. Collect checkpoints
   – Via functional warmup
4. Detailed Simulation
   – Estimate performance results

checkpoint
…



2. Determine Sampling Parameters

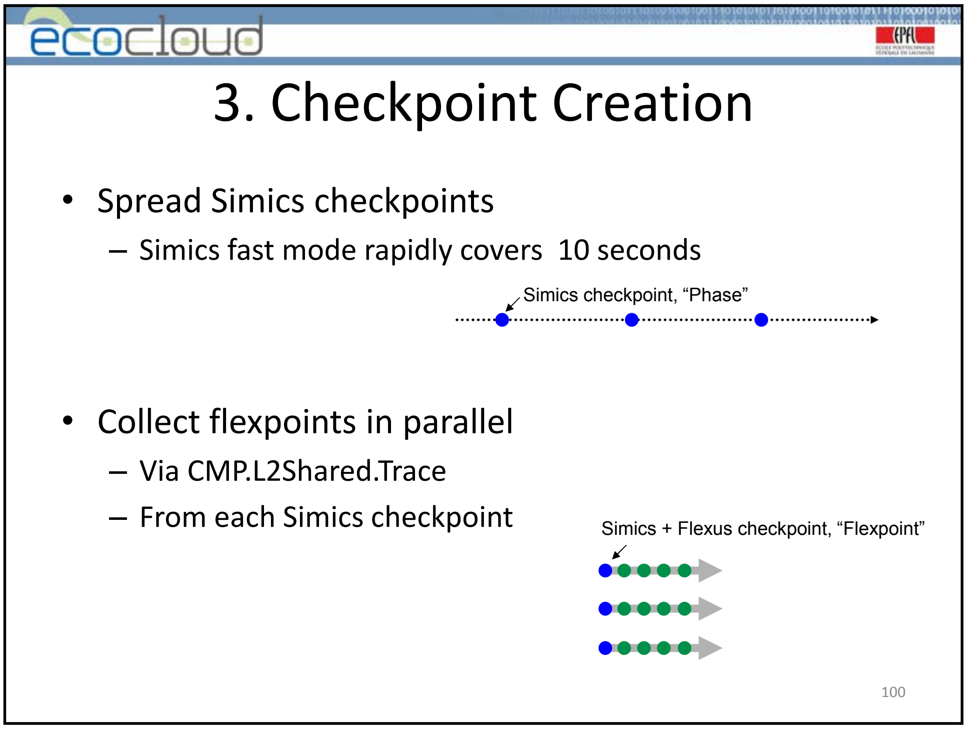
- Guess variability
- Generate flexpoints for the variability
- Run timing simulation
- Measure error and correct the guess



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

99



3. Checkpoint Creation

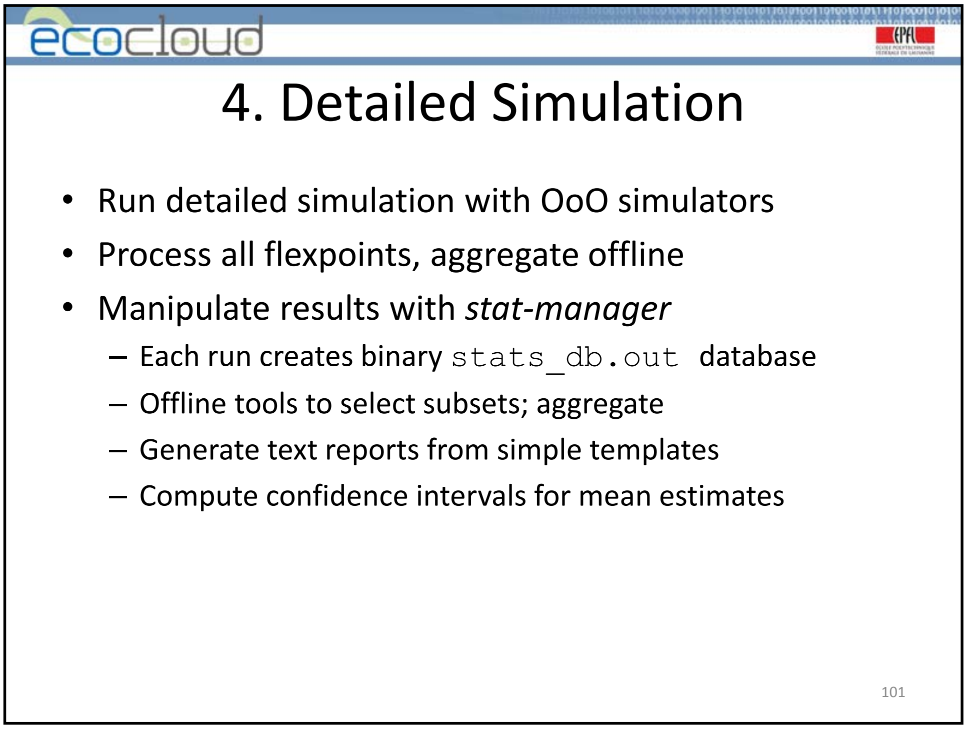
- Spread Simics checkpoints
  - Simics fast mode rapidly covers 10 seconds

Simics checkpoint, “Phase”

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

Simics + Flexus checkpoint, “Flexpoint”

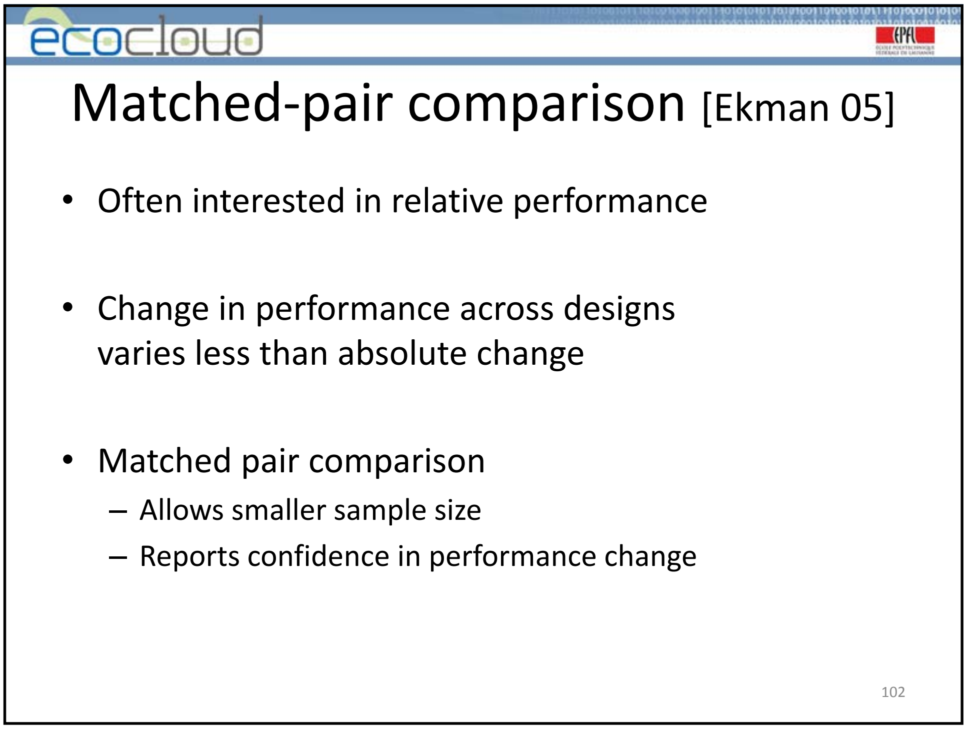
100



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

101



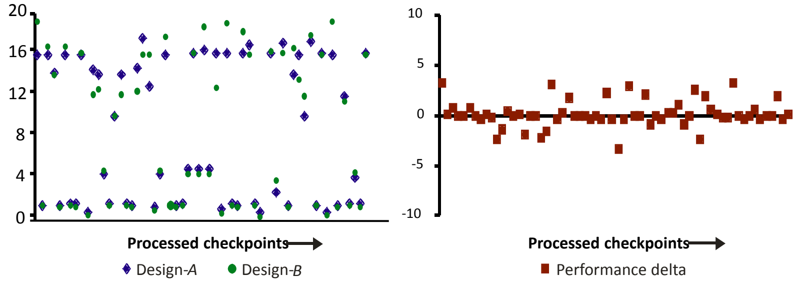
Matched-pair comparison [Ekman 05]

- 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

102

Matched-pair example

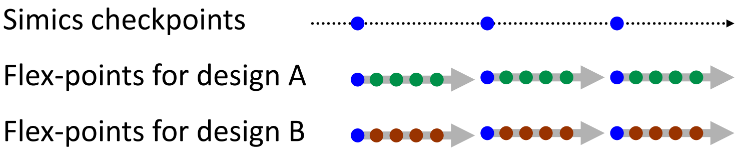
Performance results for two microarchitecture designs
checkpoints processed in random order



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

Matched-pair with Flexus

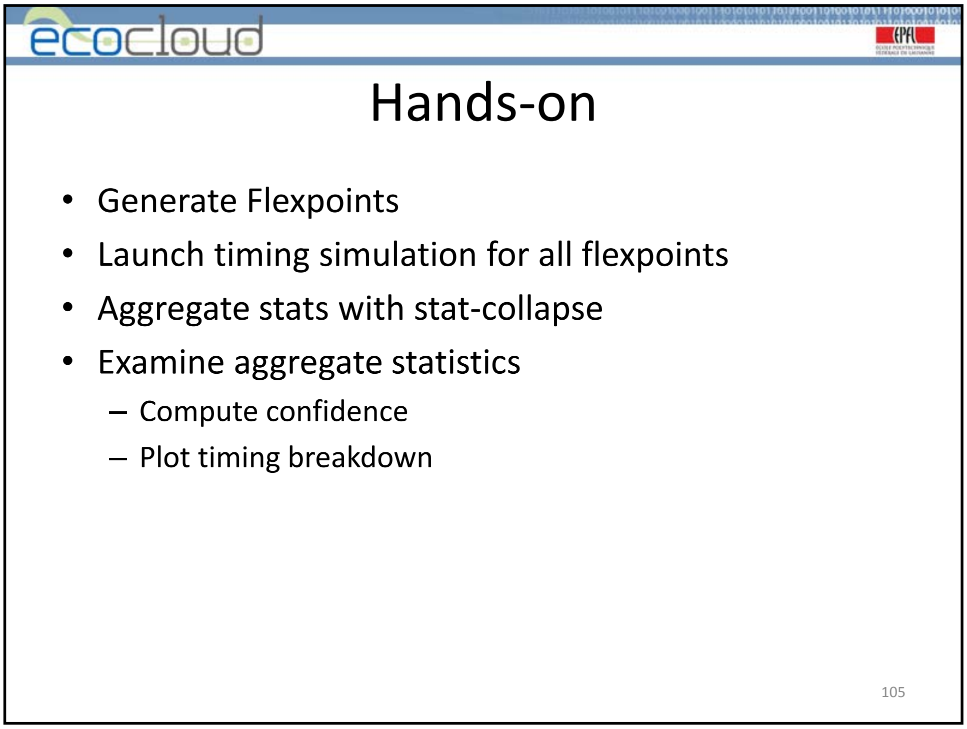
- Simple µArch changes (e.g., changing latencies)
  - use same flex-points
- Complex changes (e.g., adding components)



Simics checkpoints

Flex-points for design A

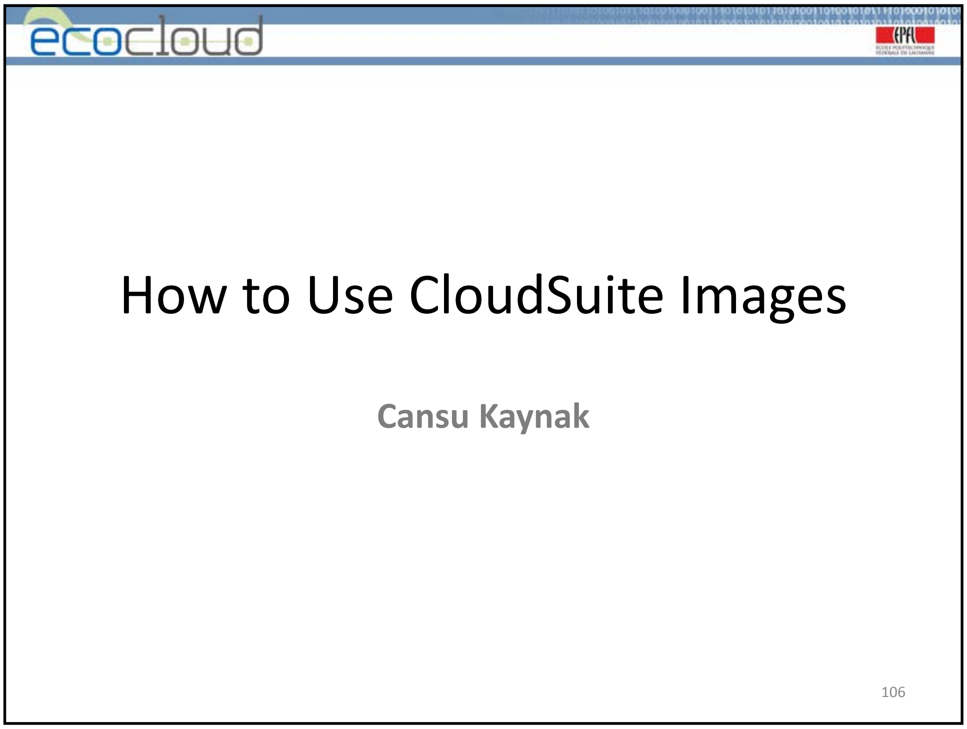
Flex-points for design B



Hands-on

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

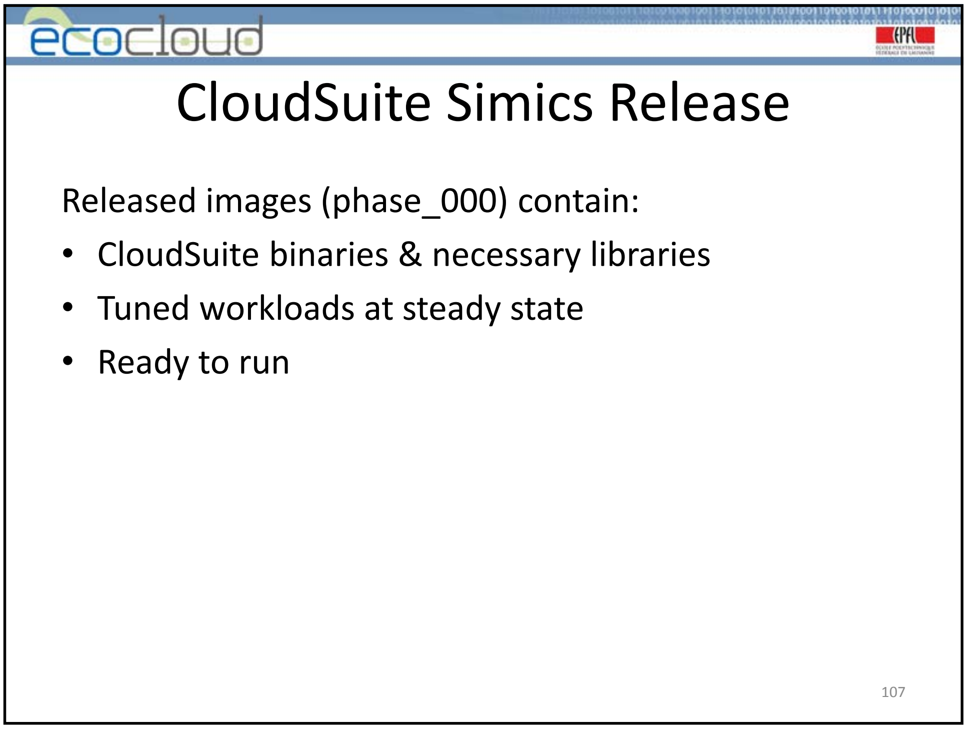
105



How to Use CloudSuite Images

Cansu Kaynak

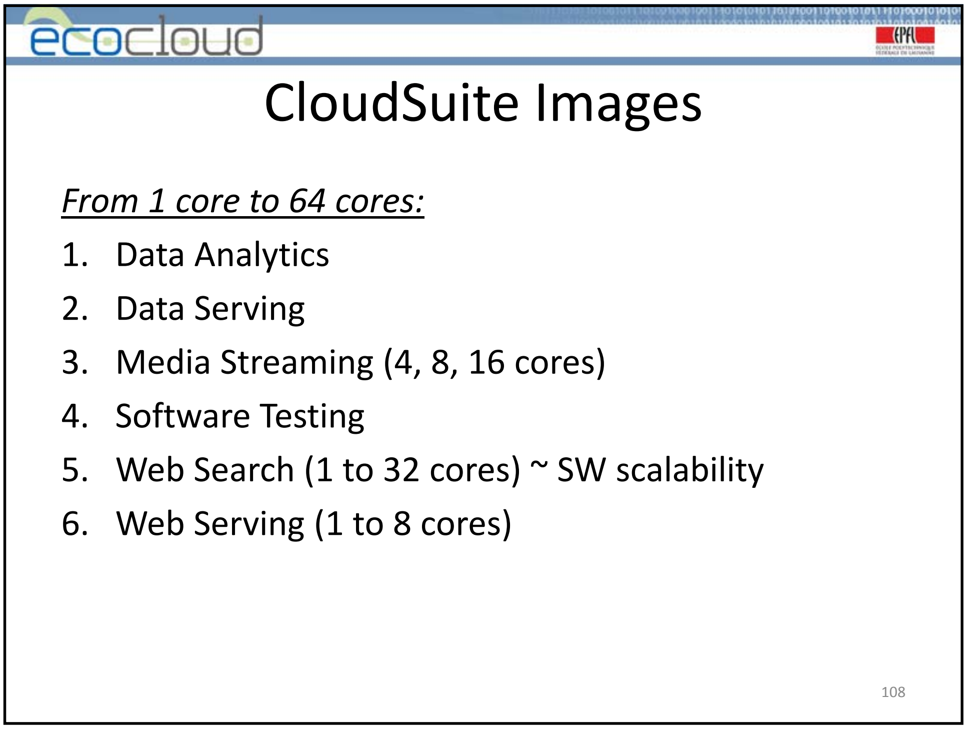
106



CloudSuite Simics Release

Released images (phase_000) contain:

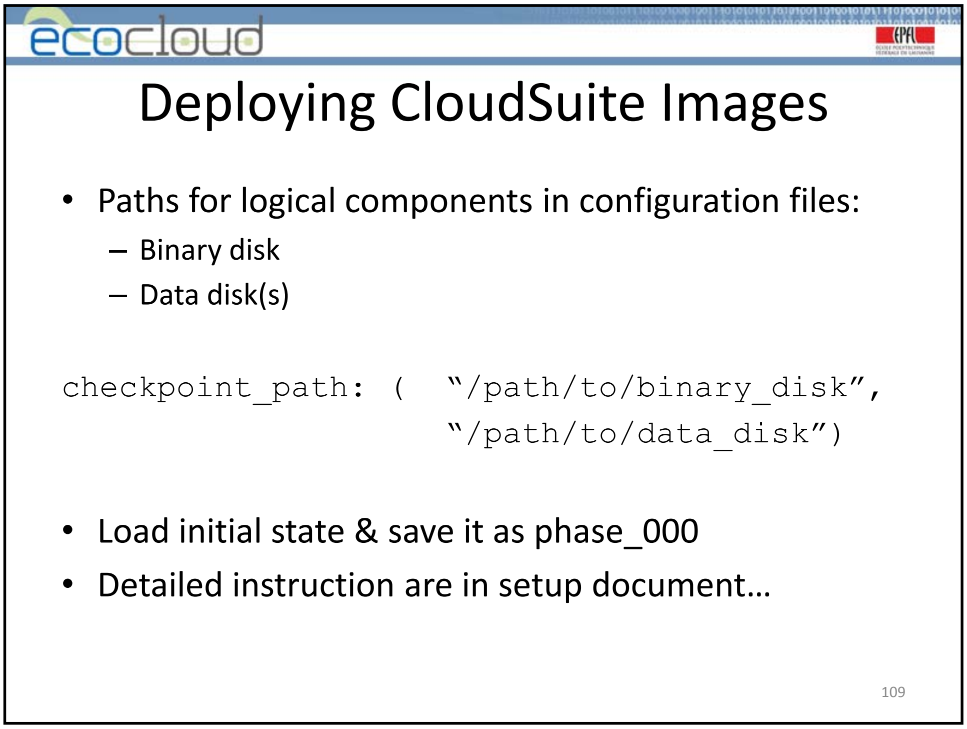
- CloudSuite binaries & necessary libraries
- Tuned workloads at steady state
- Ready to run



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)

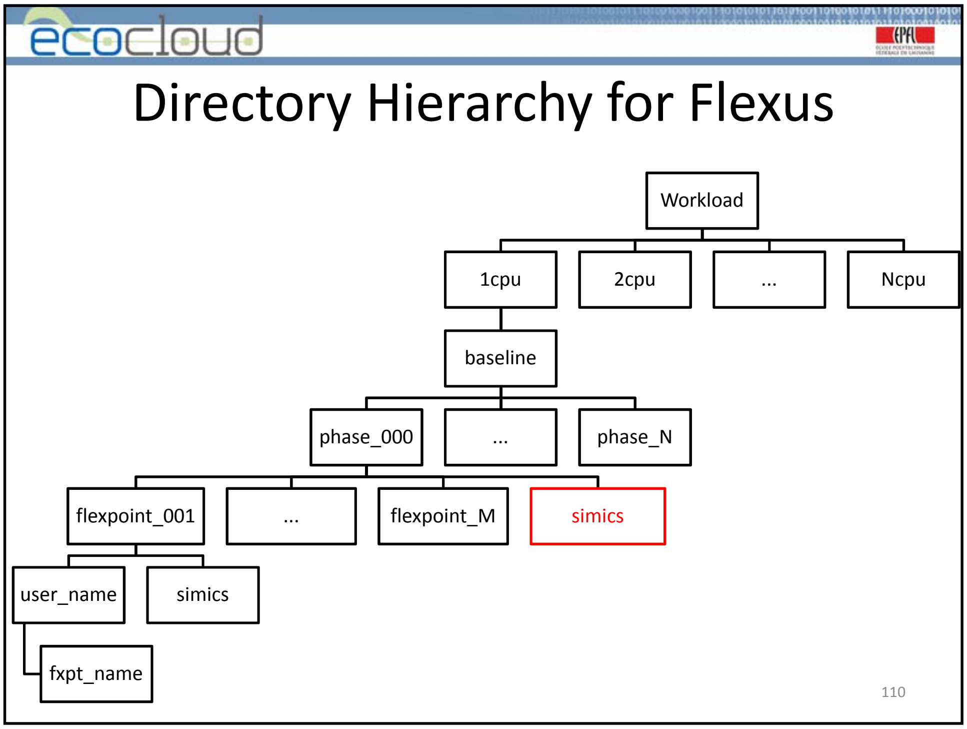


Deploying CloudSuite Images

- 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

Workload

1cpu
2cpu
...
Ncpu

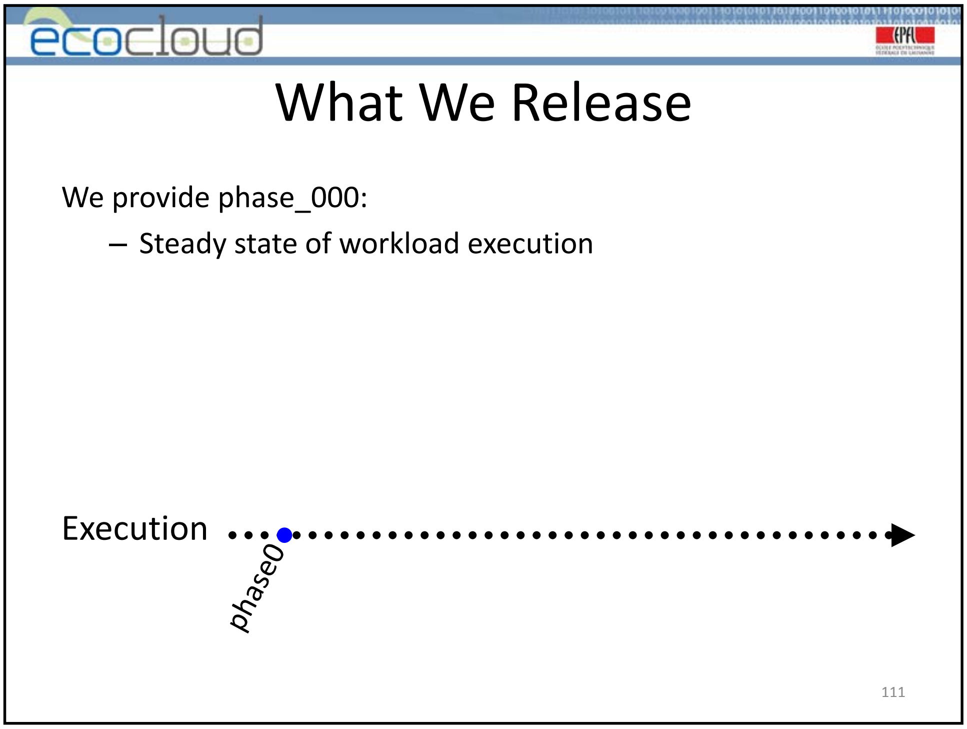
baseline

phase_000
...
phase_N

flexpoint_001
...
flexpoint_M
simics

user_name
simics

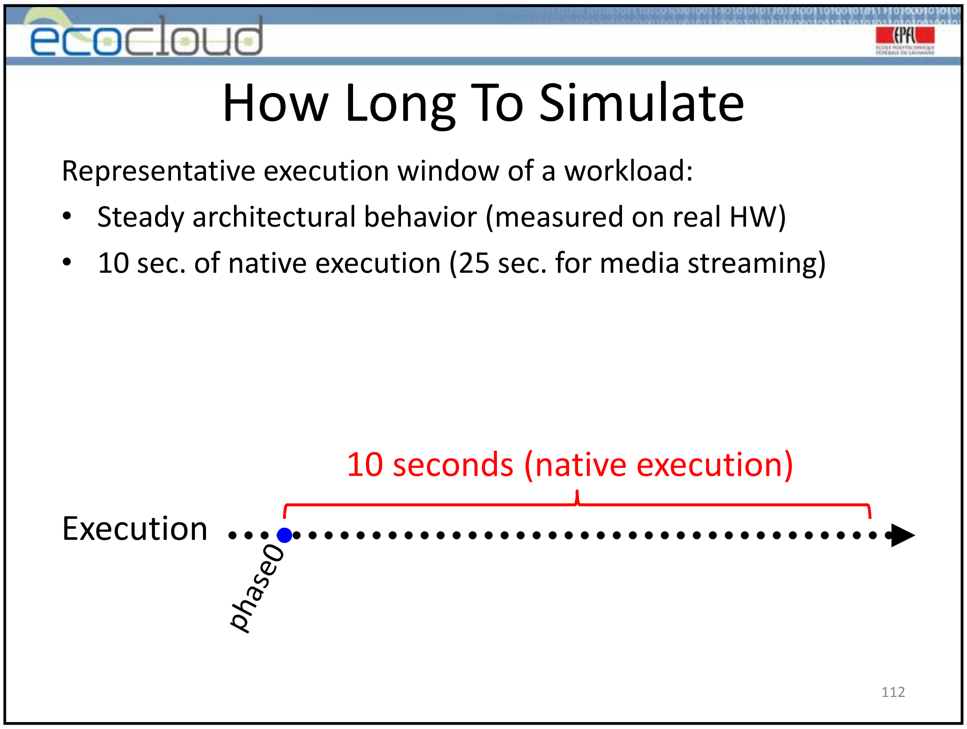
fxpt_name



What We Release

We provide phase_000:

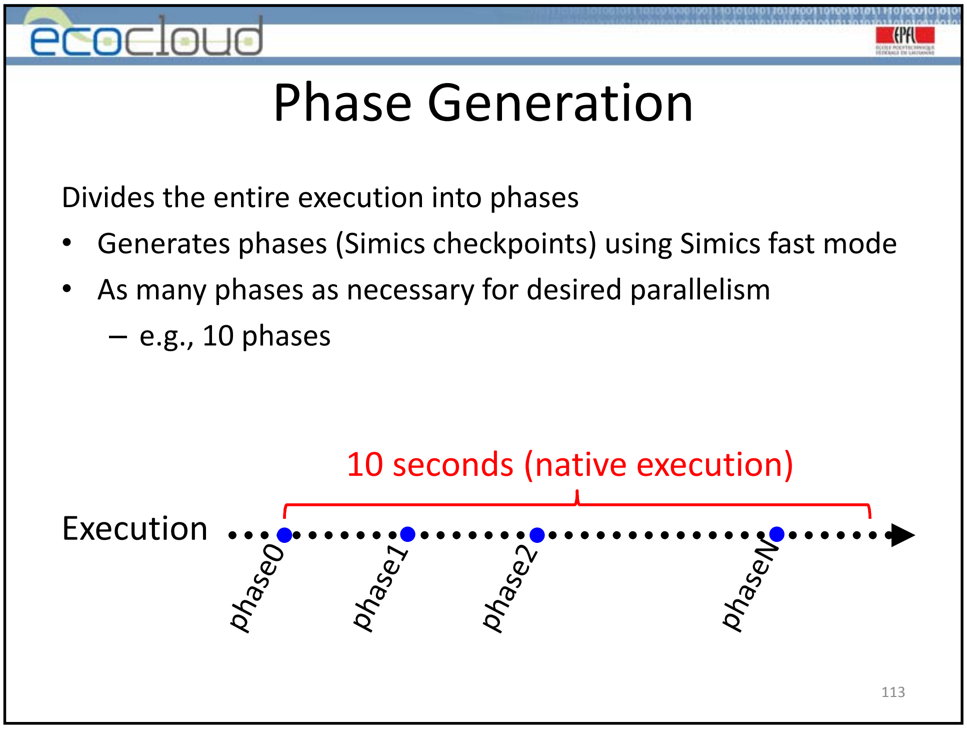
- Steady state of workload execution



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)

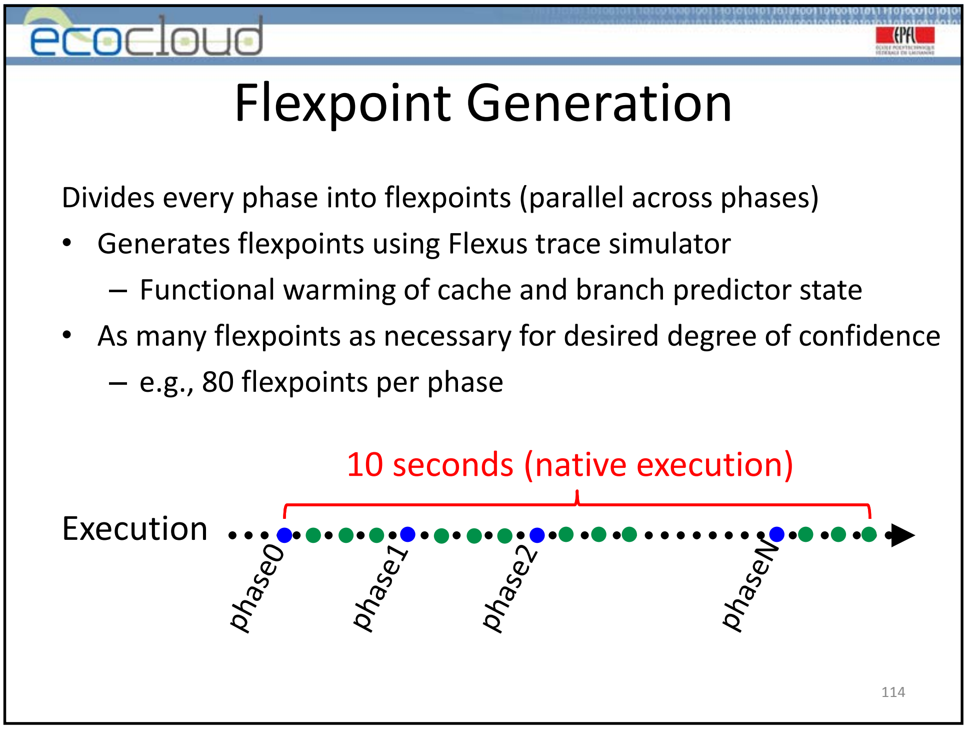


Phase Generation

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

10 seconds (native execution)
Execution
phase0
phase1
phase2
phaseN

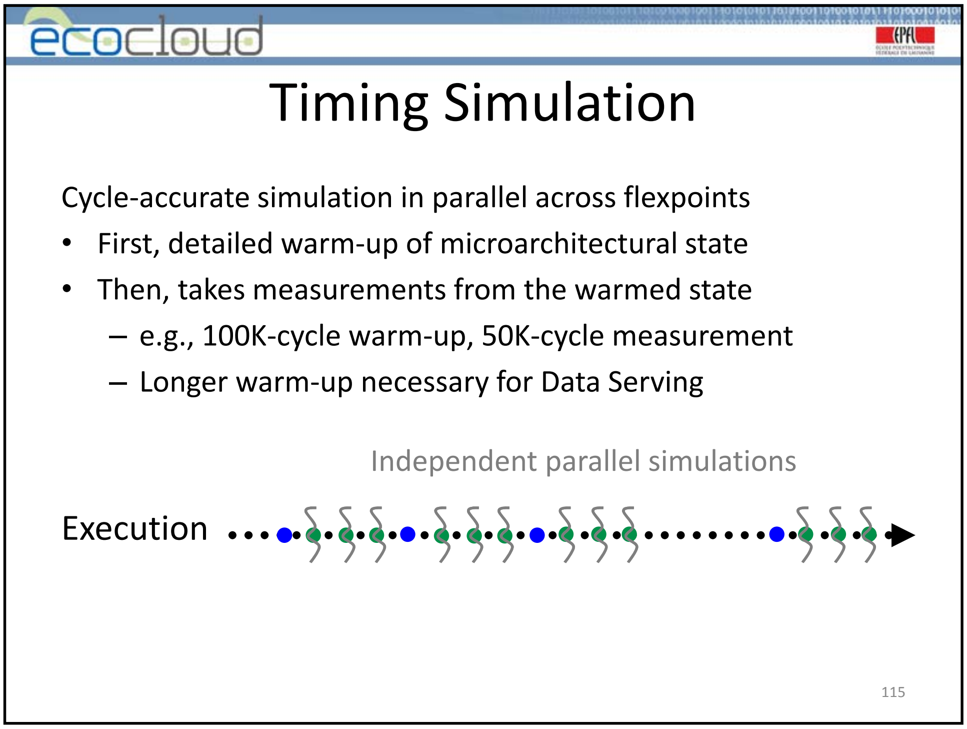


Flexpoint Generation

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

10 seconds (native execution)
Execution
phase0
phase1
phase2
phaseN



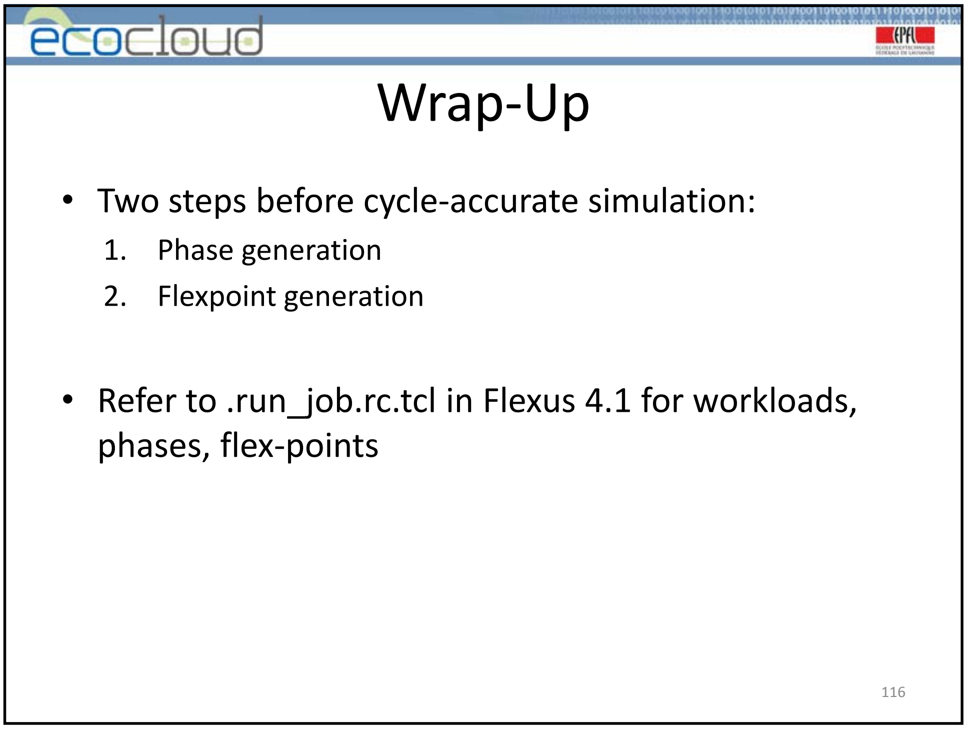
Timing Simulation

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

Independent parallel simulations

Execution



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!