PARSEC

['pär-''sek] A unit of measure

The PARSEC Benchmark Suite Tutorial

- PARSEC 3.0 -

By

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Princeton University

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Part 1

Understanding PARSEC

What is PARSEC?

- Princeton Application Repository for Shared-Memory Computers
- Benchmark Suite for Chip-Multiprocessors
- Started as a cooperation between Intel and Princeton University, many more have contributed since then
- Freely available at:

  http://parsec.cs.princeton.edu/

  Other Resources:

  http://wiki.cs.princeton.edu/index.php/PARSEC

  parsec-users@lists.cs.princeton.edu
- You can use it for your research

PARSEC

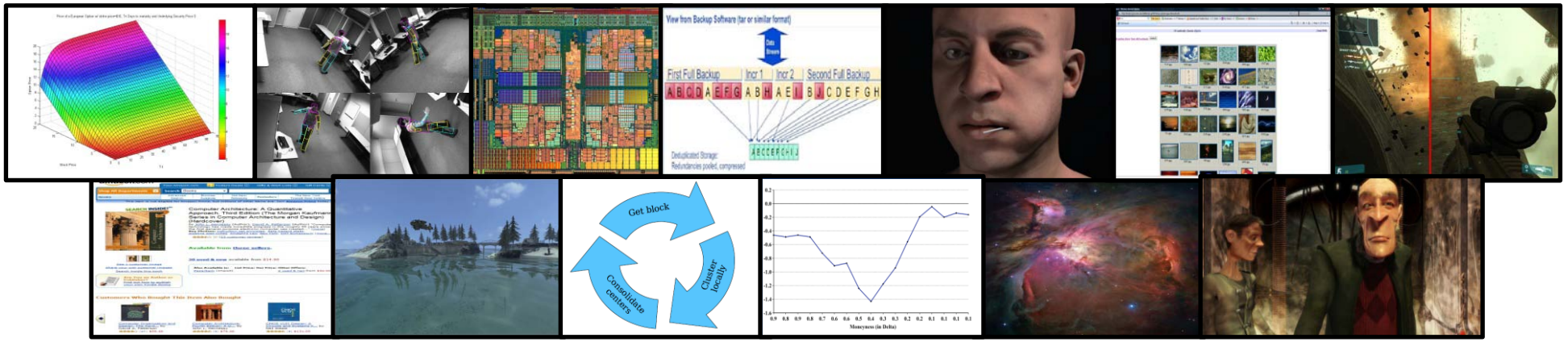
['pär-''sek] A unit of measure

Goal: An open-source parallel benchmark suite of emerging applications for evaluating multi-core and multiprocessor systems

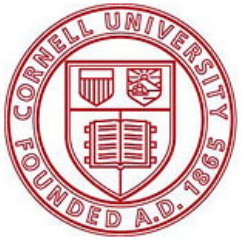
Application domains: financial, computer vision, physical modeling, future media, content-based search, deduplication

Current release:

PARSEC 2.1 (13 applications)



Contributors



Cornell University

The first version of PARSEC was created by Intel and Princeton University.

We would like PARSEC to be a community project.

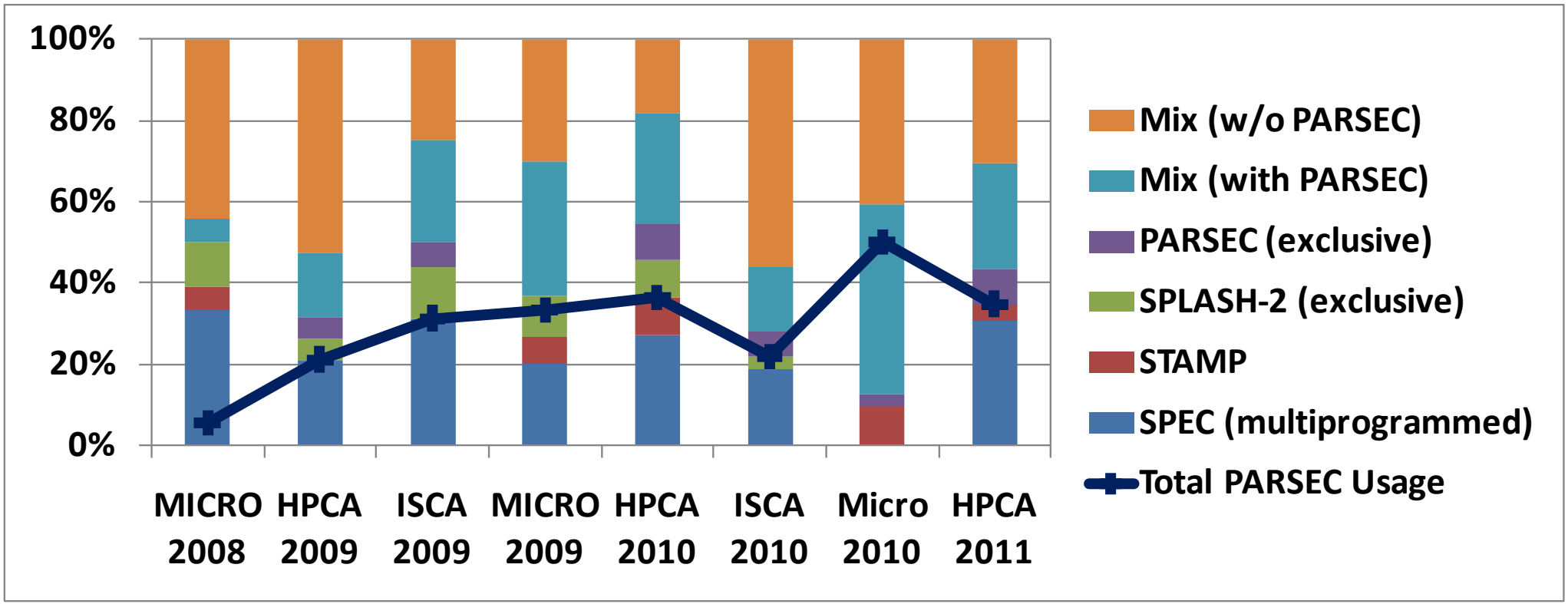
Many people and institutions have already contributed.

Interest in PARSEC

- 6000+ Downloads

Impact of PARSEC

- Google Scholar Citations: 400+
- Citation in top conferences (~40%)



History of PARSEC

- Jan 2008 PARSEC 1.0
  - 12 workloads
- Feb 2009 PARSEC 2.0
  - One new workload, raytrace
- Aug 2009 PARSEC 2.1
  - Bugfix

- **PARSEC 3.0**
  - **Summer 2011**

PARSEC 3.0 is coming soon

- New framework
  - Support network workloads
  - Support citations to encourage contribution
  - Be more convenient to add new workloads
- Much improved workloads
  - blackscholes, bodytrack, canneal, dedup, facesim, ferret, fluidanimate, freqmine, vips,
- SPLASH-2 and SPLASH-2x
  - Existing SPLASH-2 using the same framework
    - Use parsecmgmt to manage, build, and run
  - SPLASH-2x (joint work with Prof. JP Singh)
    - Multiple input sets at different scales

Objectives of PARSEC

- Multithreaded Applications
  Future programs must run on multiprocessors
- Emerging Workloads
  Increasing CPU performance enables new applications
- Diverse
  Multiprocessors are being used for more and more tasks
- State-of-Art Techniques
  Algorithms and programming techniques evolve rapidly
- Support Research
  Our goal is insight, not numbers

Workloads

Program	Application Domain	Parallelization		Working Set	Data Usage	
		Model	Granularity		Sharing	Exchange
blackscholes	Financial Analysis	data-parallel	coarse	small	low	low
bodytrack	Computer Vision	data-parallel	medium	medium	high	medium
canneal	Engineering	unstructured	fine	unbounded	high	high
dedup	Enterprise Storage	pipeline	medium	unbounded	high	high
facesim	Animation	data-parallel	coarse	large	low	medium
ferret	Similarity Search	pipeline	medium	unbounded	high	high
fluidanimate	Animation	data-parallel	fine	large	low	medium
freqmine	Data Mining	data-parallel	medium	unbounded	high	medium
raytrace	Rendering	data-parallel	medium	unbounded	high	low
streamcluster	Data Mining	data-parallel	medium	medium	low	medium
swaptions	Financial Analysis	data-parallel	coarse	medium	low	low
vips	Media Processing	data-parallel	coarse	medium	low	medium
x264	Media Processing	pipeline	coarse	medium	high	high

There aren't any two workloads with the same combinations

Blackscholes Overview

- Prices a portfolio of options with the Black-Scholes PDE

- Computational finance application (Intel)
- Synthetic input based on replication of 1,000 real options
- Coarse-granular parallelism, static load-balancing
- Small working sets, negligible communication

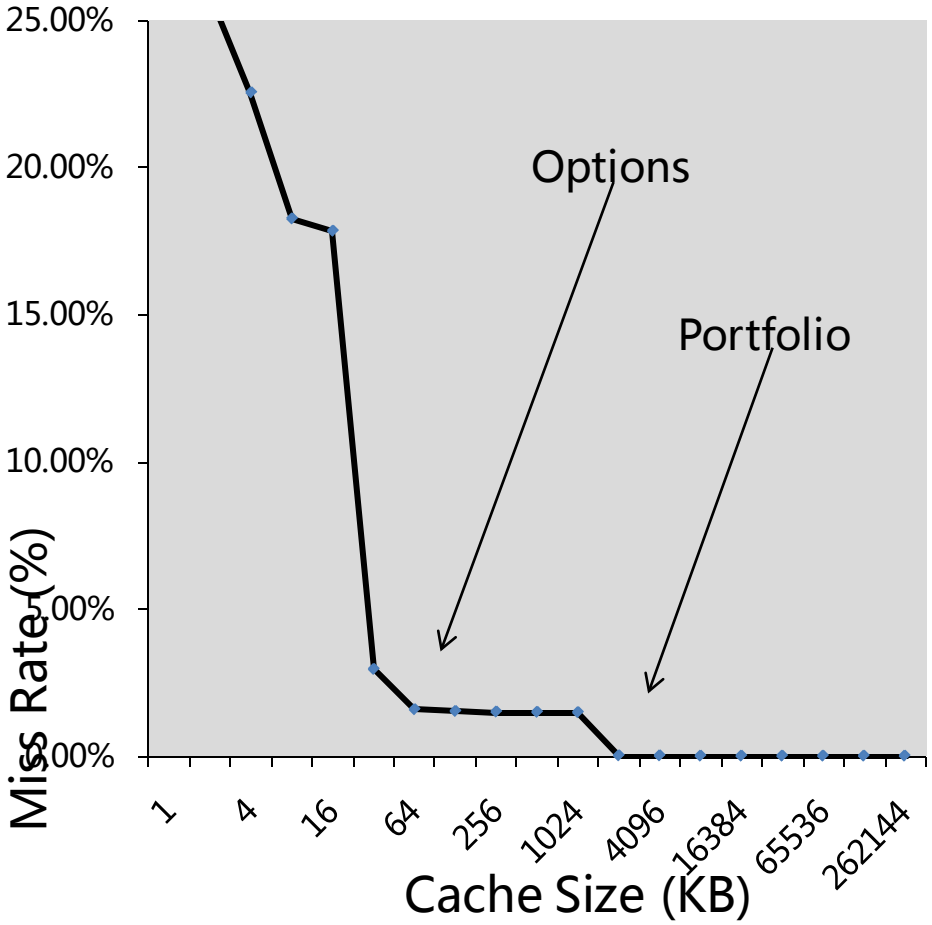
Blackscholes is the simplest of all PARSEC workload

Blackscholes Rationale

- Computers have become key technology for trading
- Derivatives are financial instrument with one of highest analytical requirements
- Blackscholes formula fundamental description of option behavior
- High demand for performance: Saving few milliseconds can earn lots of money

Blackscholes Characteristics

Working Sets



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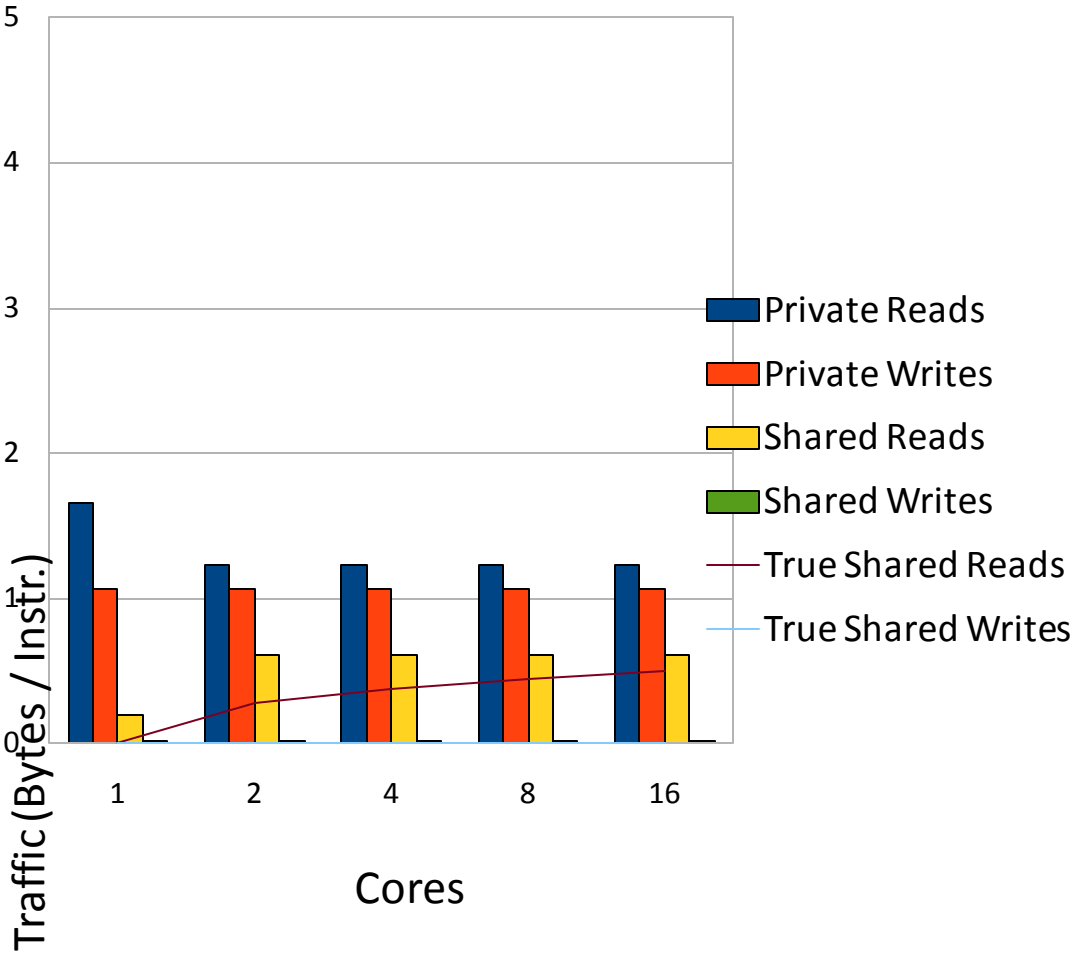
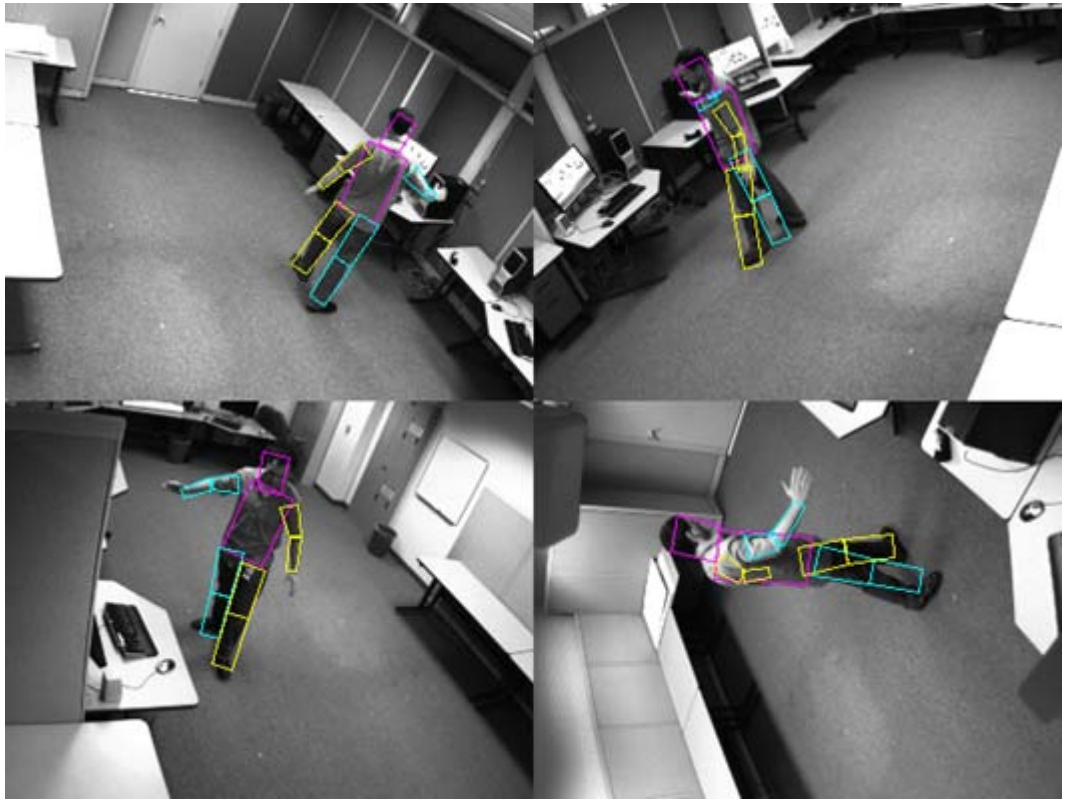


Small working sets, negligible communication

Bodytrack Overview

- Tracks a markerless human body
- Computer vision application (Intel)
- Input is video feed from 4 cameras
- Medium-granular parallelism, dynamic load-balancing
- Pipeline and asynchronous I/O
- Medium working sets, some communication



Output of Bodytrack (Frame 1)

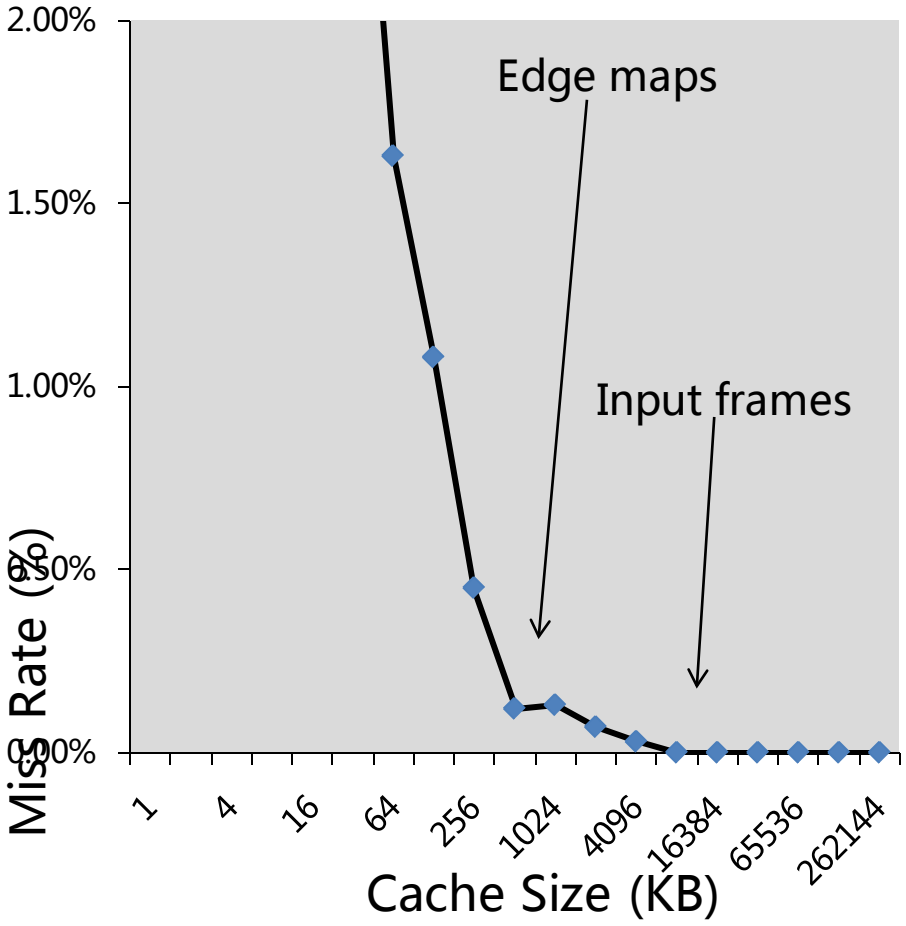
Bodytrack Rationale

- Machines increasingly rely on computer vision to interact with environment
- Often no aid available (e.g. Markers, constrained behavior)
- Must usually happen in real-time

Stanley, Winner of the DARPA Challenge 2005. Autonomous vehicle navigation requires real-time computer vision.

Bodytrack Characteristics

Working Sets



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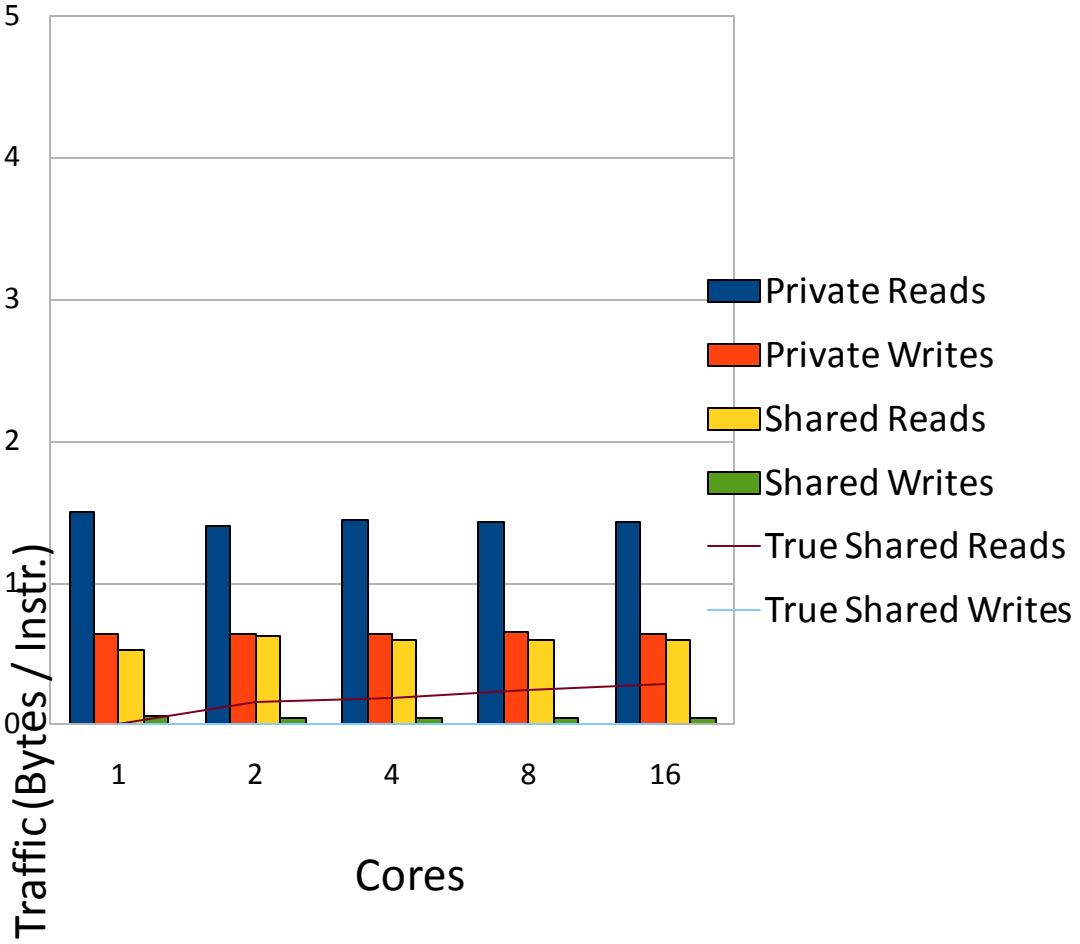


Medium working sets, some communication

Canneal Overview

- Minimizes the routing cost of a chip design with cache-aware simulated annealing
- Electronic Design Automation (EDA) kernel (Princeton)
- Input is a synthetic netlist
- Fine-grainr parallelism, no problem decomposition
- Uses atomic instructions to synchronize
- Synchronization strategy based on data race recovery rather than avoidance
- Huge working sets, communication intensity only constrained by cache capacity.

Workload with most demanding memory behavior

Canneal Rationale

- Optimization is one of the most common types of problems.
- Place & Route is a difficult EDA challenge.
- Transistor counts continue to increase at an exponential rate.
- Simulated annealing allows to scale optimization cost by allowing incremental performance investments.

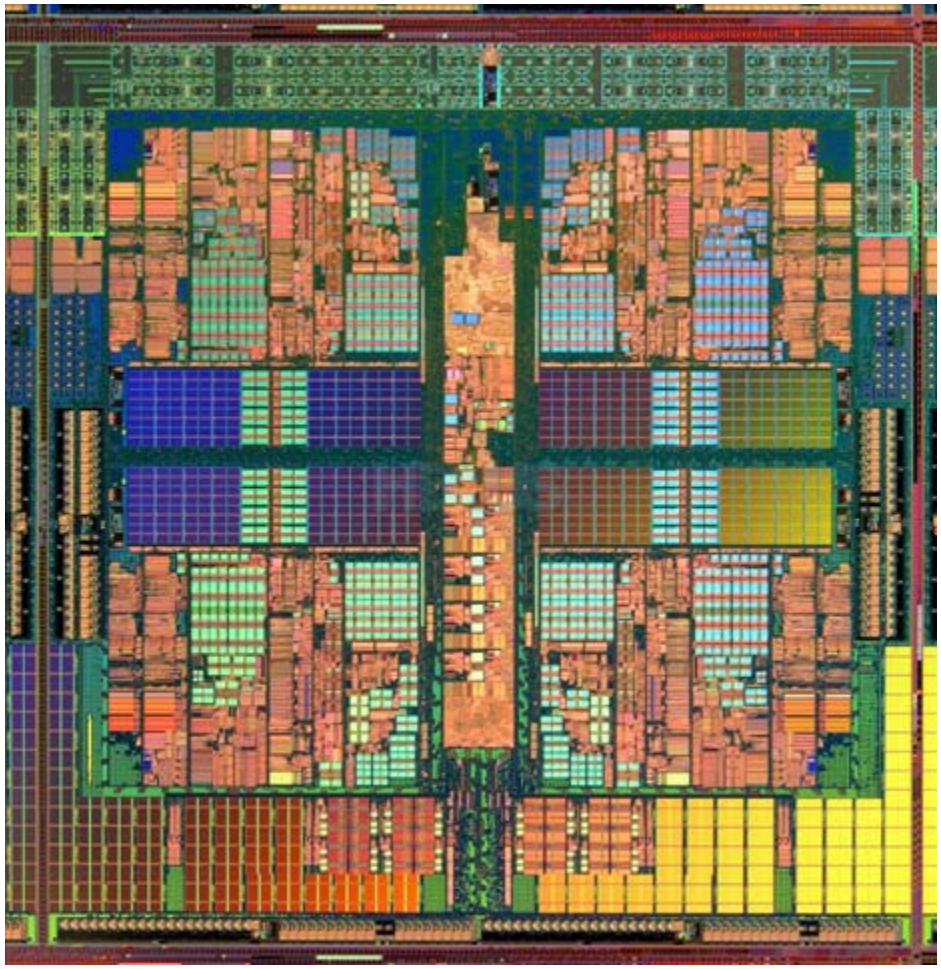
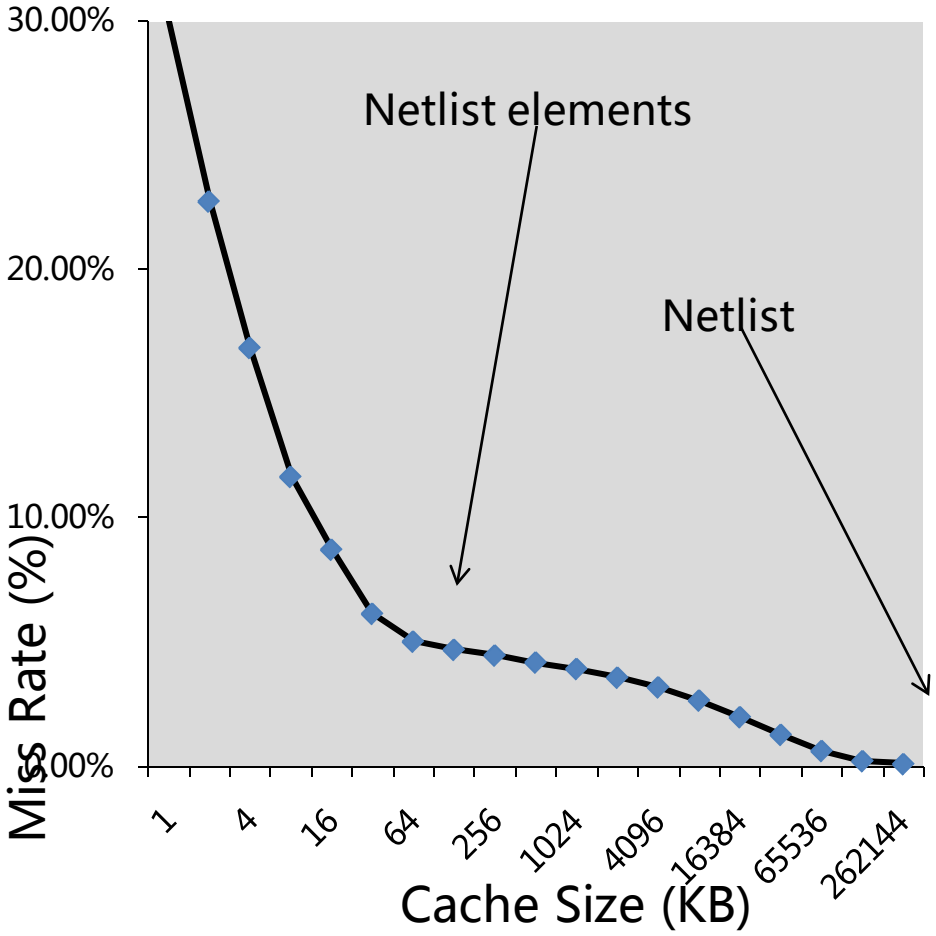


Photo of AMD's Barcelona quad-core CPU. It consists of about 463 million transistors.

Canneal Characteristics

Working Sets



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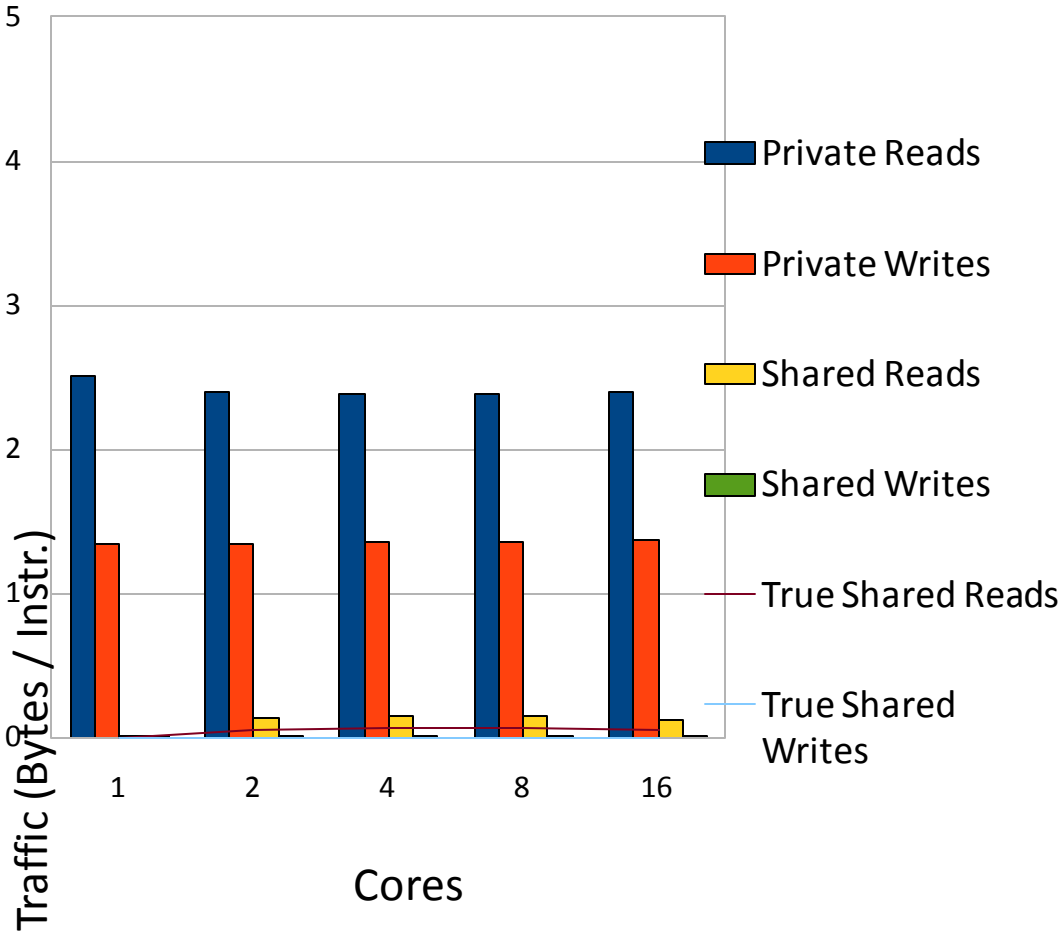


Huge working sets, communication limited by capacity

Dedup Overview

- Detects and eliminates redundancy in a data stream with a next-generation technique called 'deduplicaton'
- Enterprise storage kernel (Princeton)
- Input is an uncompressed archive containing various files
- Improved, more computationally intensive deduplication methods
- More cache-efficient serial version
- Pipeline parallelism with multiple thread pools
- Huge working sets, significant communication

Dedup Rationale

- Growth of world data keeps outpacing growth of processing power.
- This data has to be stored and transferred.
- Use cheap resources (processing power) to make more efficient use of scarce resources (storage & bandwidth).
- Already in use in commercial products.

datadomain

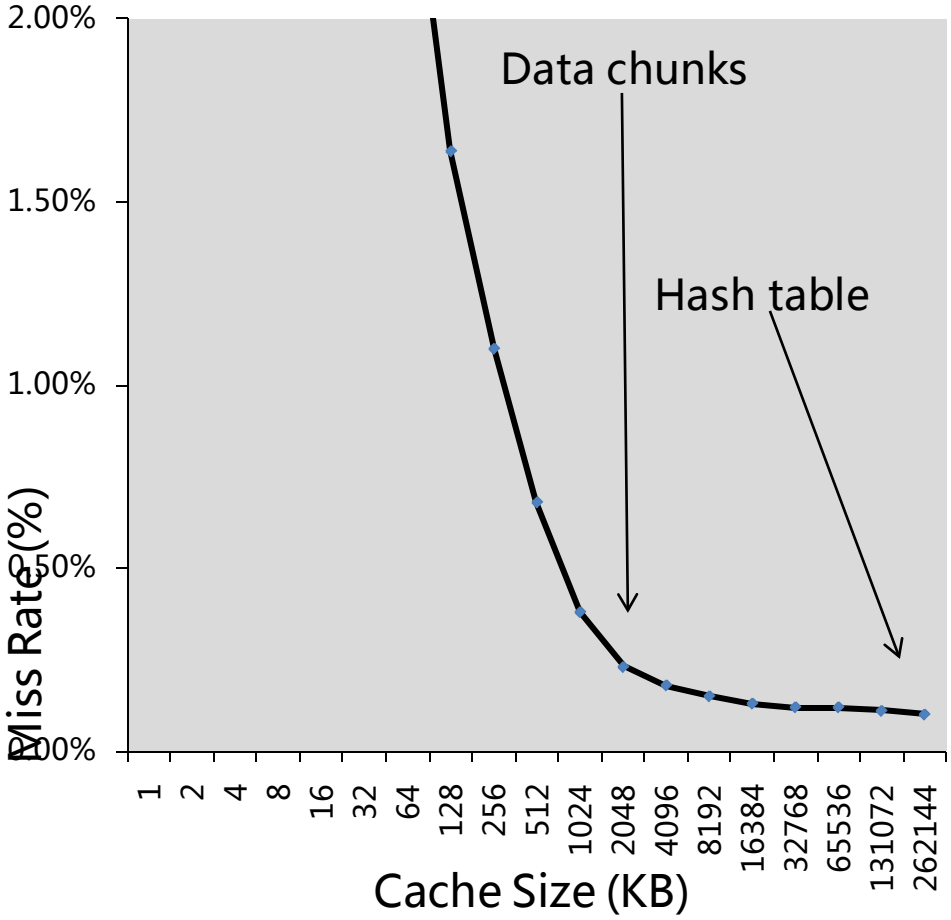
NetApp

EXAGRID
SYSTEMS

Next-generation storage and networking products already use data deduplication.

Dedup Characteristics

Working Sets



Cache Hits

Huge working sets, some communication

Facesim Overview

- Simulates motions of a human face for visualization purposes
- Computer animation application (Intel + Stanford)
- Input is a face model and a series of muscle activations
- Coarse-grained parallelism, similarities to HPC programs
- Large working sets, some sharing

Source: Eftychios Sifakis et al.

Facesim creates visually realistic animations of a human face

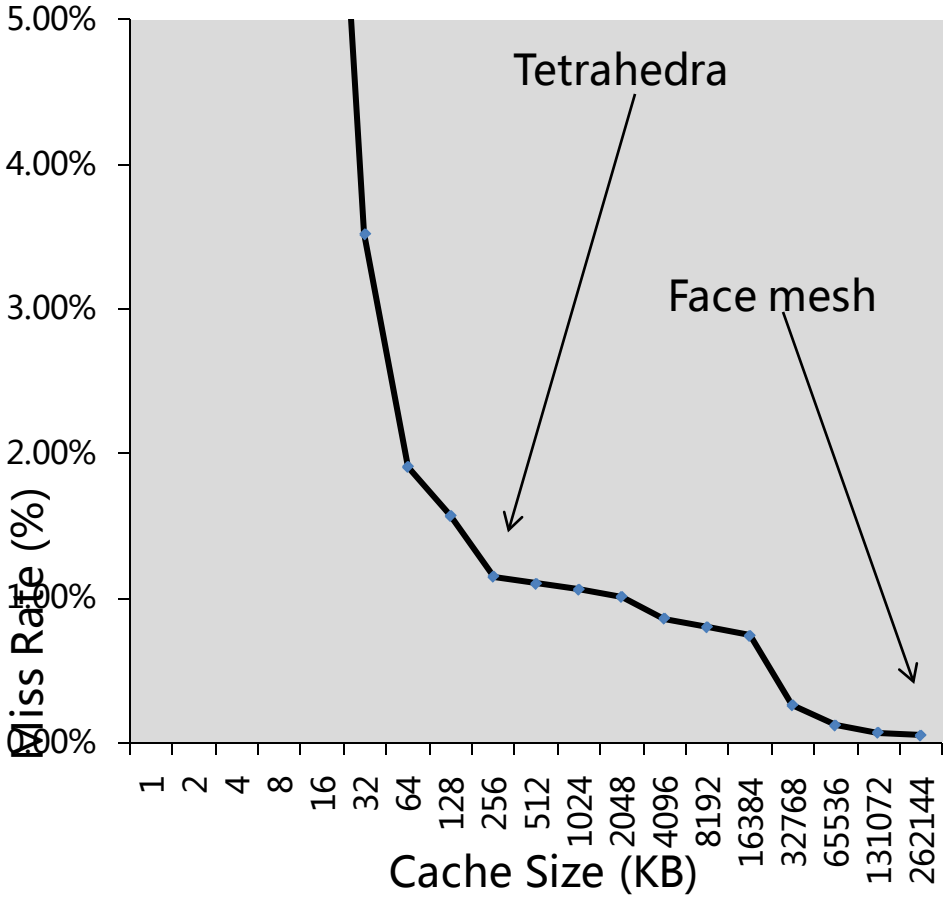
Facesim Rationale

- Video games and other interactive animations require visualization of realistic faces in realtime
- Challenging problem, humans evolved to perceive finest details in a face
- Physical simulation gives excellent results, but is computationally very challenging
- Technology already in use for movie productions (e.g. Pirates of the Caribbean 3)

Faces are an integral part of contemporary games. Screenshot of Codemasters' "Overlord: Raising Hell" (2008).

Facesim Characteristics

Working Sets



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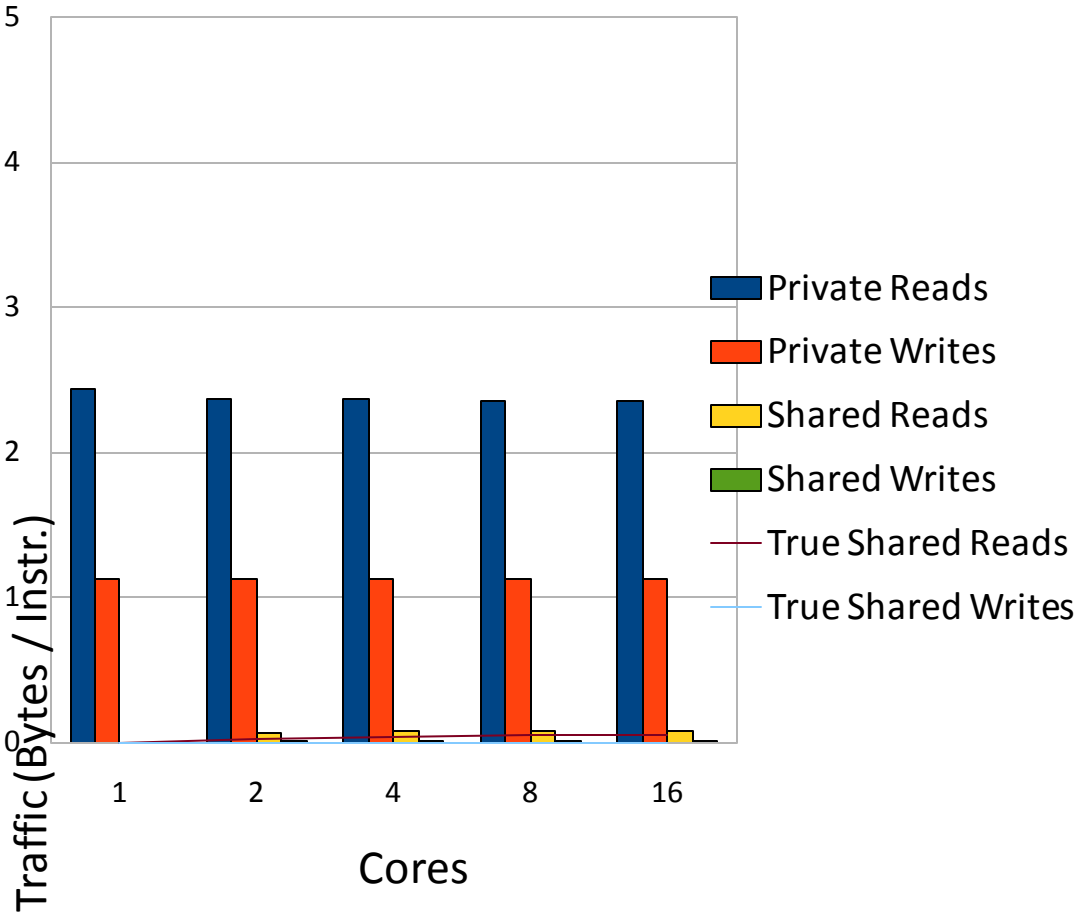


Large working sets, some sharing

Ferret Overview

- Search engine which finds a set of images similar to a query image by analyzing their contents
- Server application for content-based similarity search of feature-rich data (Princeton)
- Input is an image database and a series of query images
- Pipeline parallelism with multiple thread pools
- Huge working sets, very communication intensive

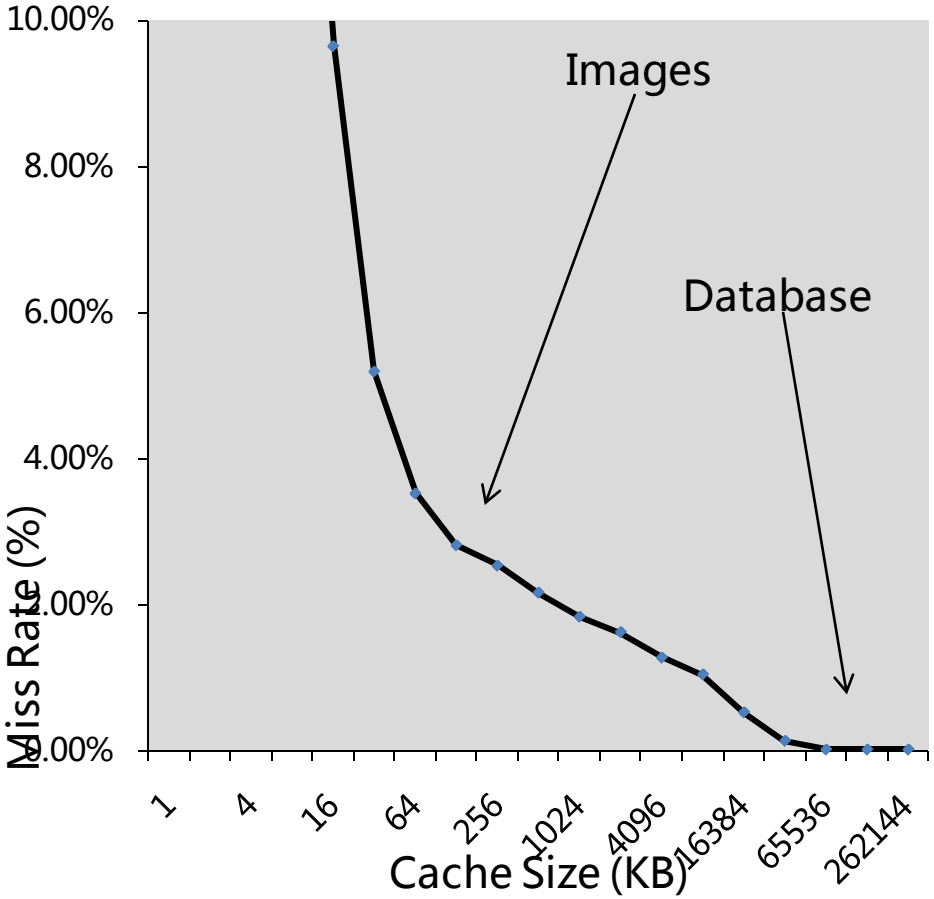
Ferret Rationale

- Growth of world data requires methods to search and index it
- Noise and minor variations frequently make same content appear slightly different
- Traditional approaches using key words are inflexible and don't scale well
- Computationally expensive

A web interface for image similarity search.

Ferret Characteristics

Working Sets



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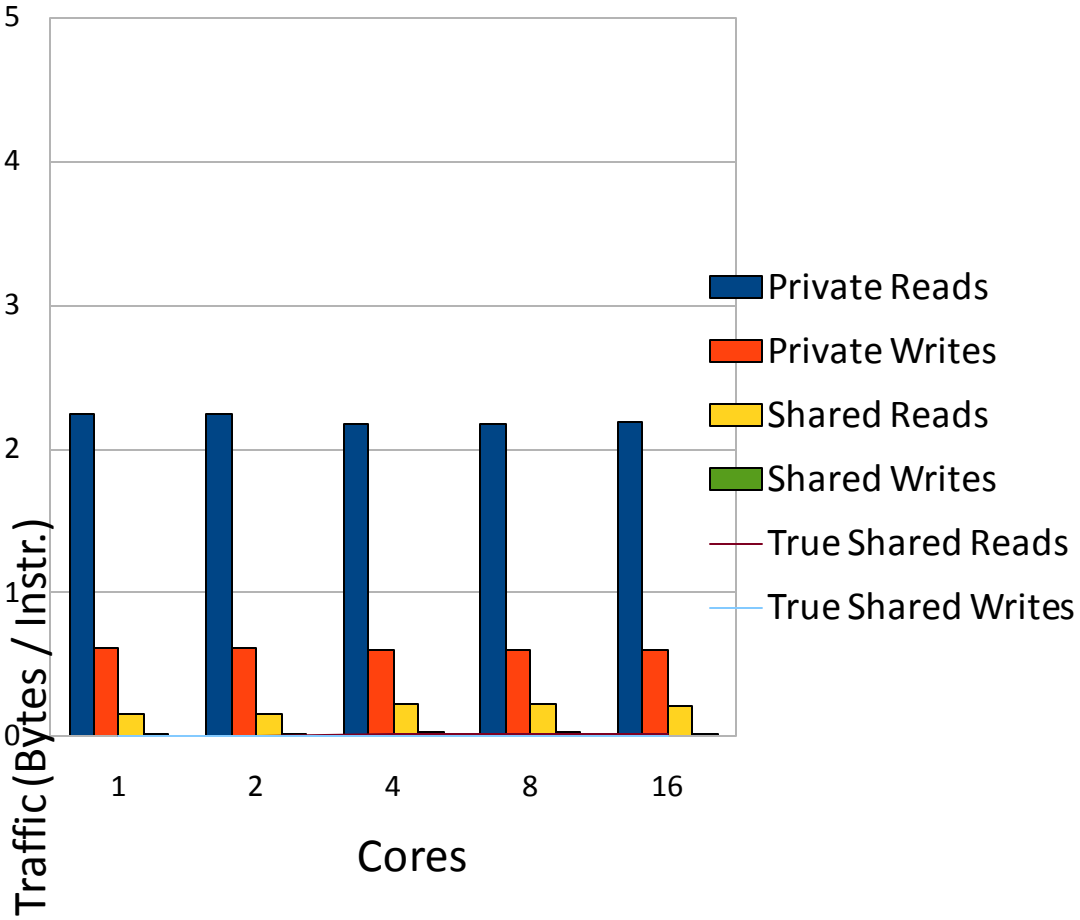


Huge working sets, very communication intensive

Fluidanimate Overview

- Simulates the underlying physics of fluid motion for realtime animation purposes with SPH algorithm
- Computer animation application (Intel)
- Input is a list of particles
- Coarse-granular parallelism, static load balancing
- Large working sets, some communication

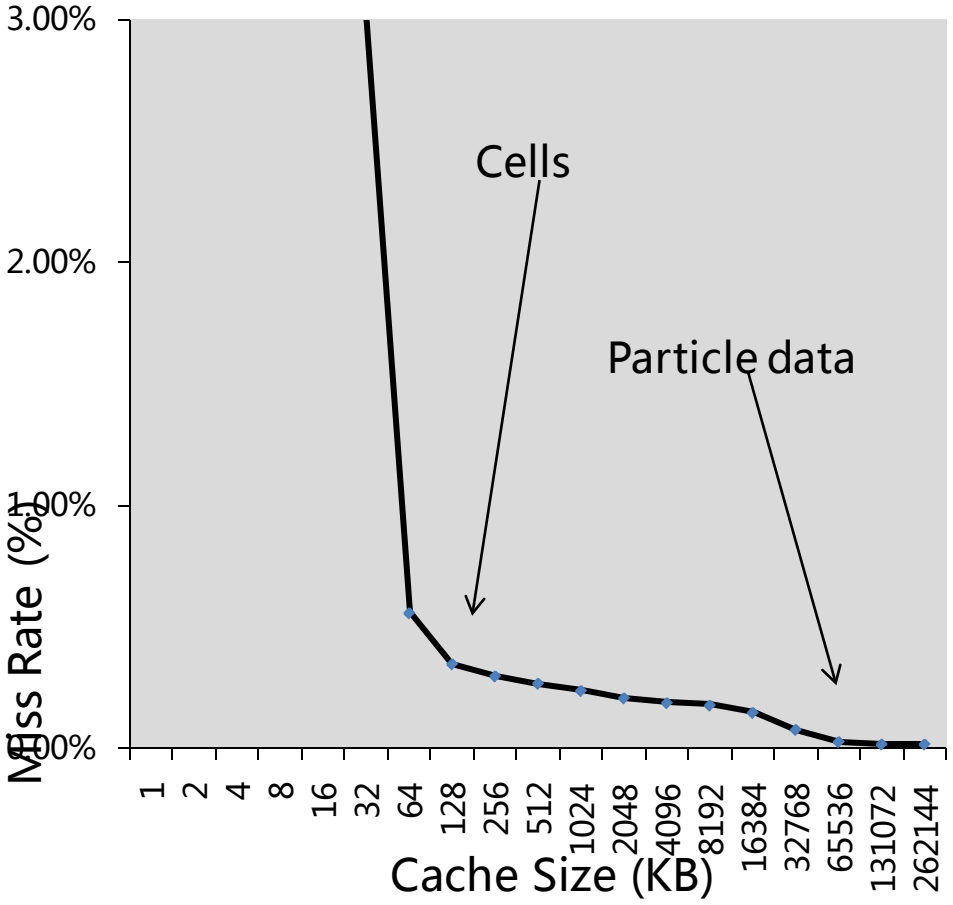
Fluidanimate Rationale

- Physics simulations allows significantly more realistic animations
- Highly demanded feature for games
- Fluid animation one of most challenging effects
- Already beginning to get used in games

Advanced physics effects are already starting to get used in games: Tom Clancy's Ghost Recon Advanced Warfighter (2006) with (left) and without (right) PhysX effects.

Fluidanimate Characteristics

Working Sets



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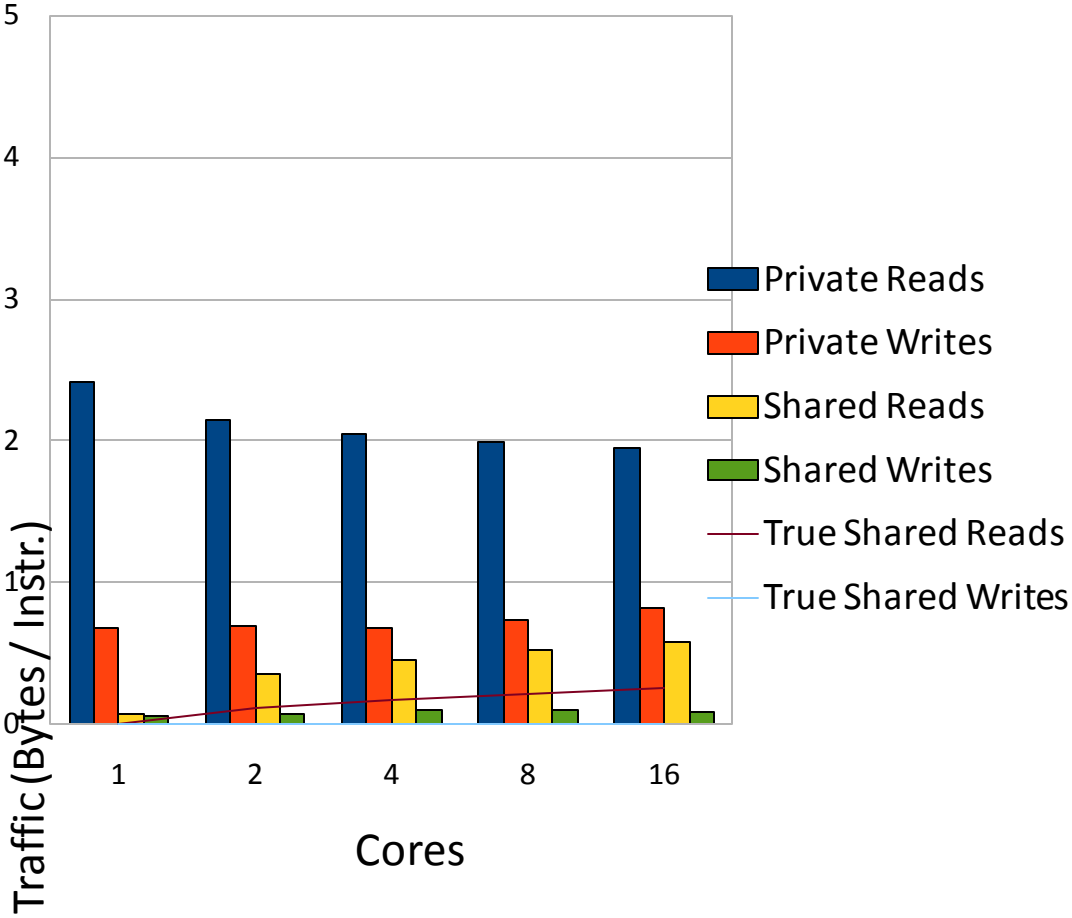


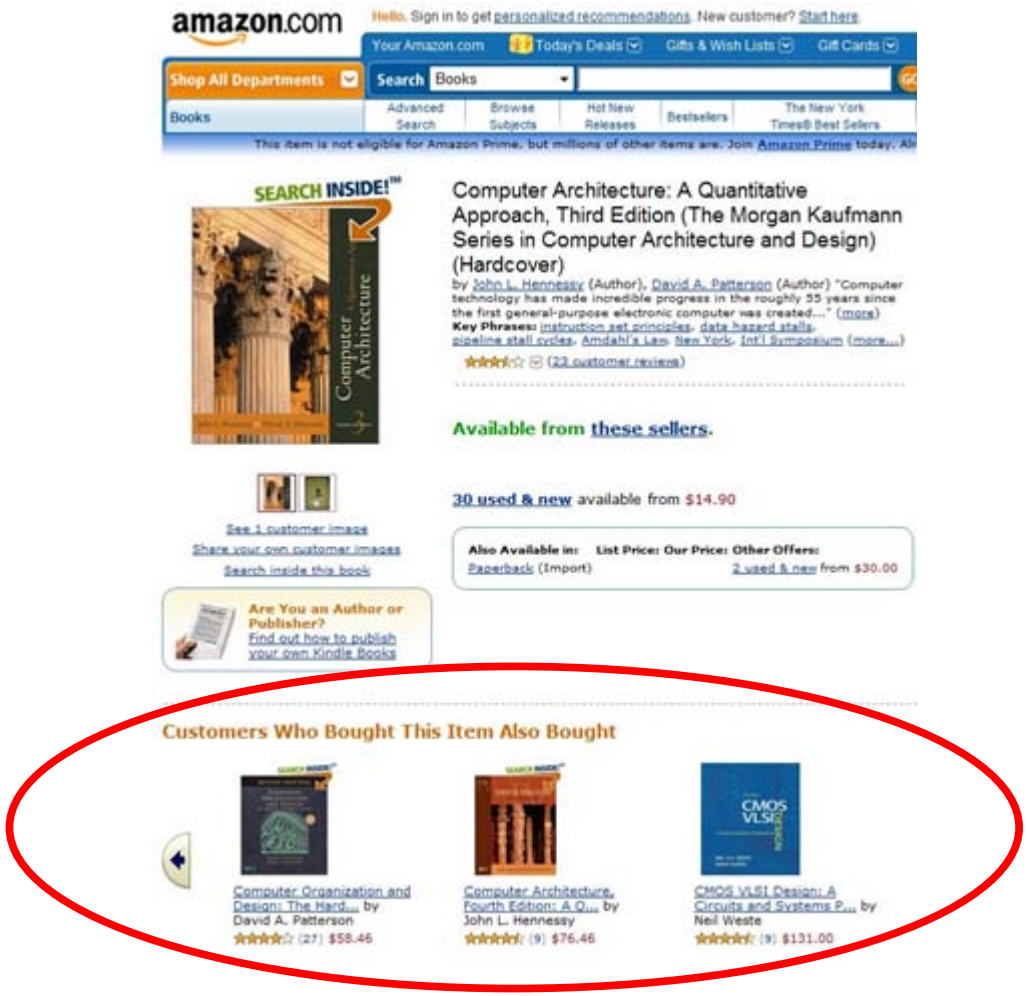
Large working sets, some communication

Freqmine Overview

- Identifies frequently occurring patterns in a transaction database
- Data mining application (Intel + Concordia)
- Input is a list of transactions
- Medium-granular parallelism, parallelized with OpenMP
- Huge working sets, some sharing

Freqmine Rationale

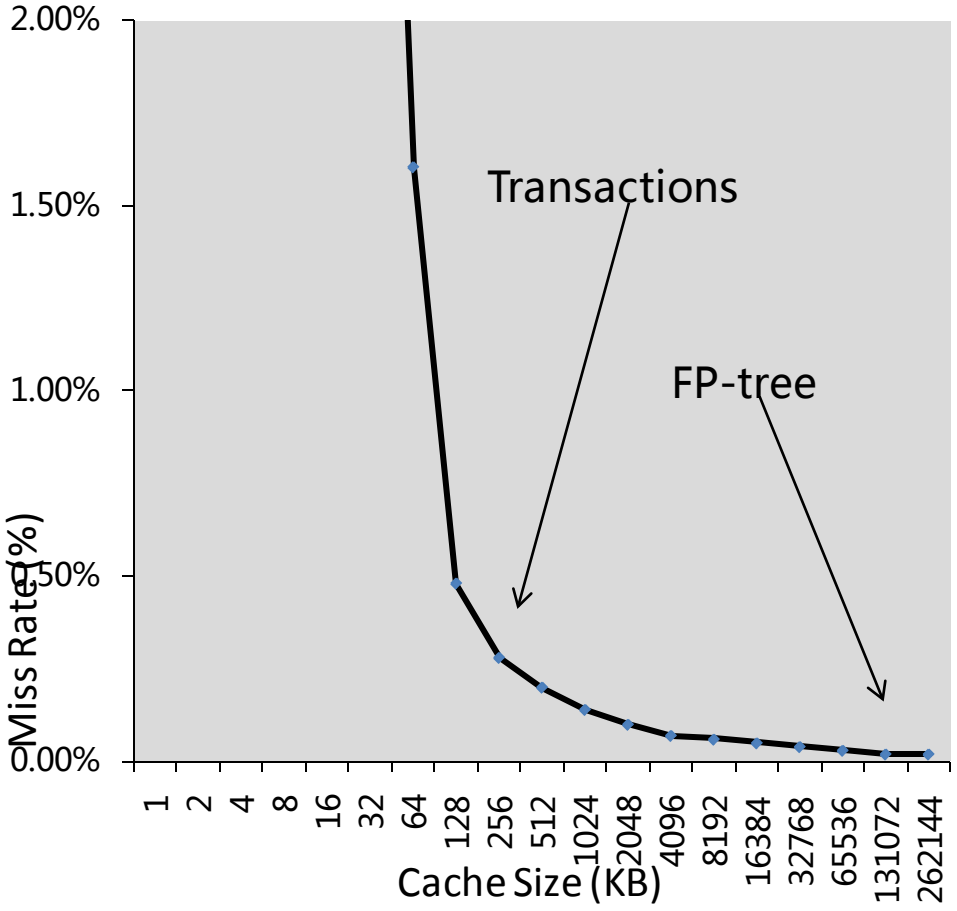
- Increasing amounts of data need to be analyzed for patterns
- Applies to many different areas such as marketing, computer security or computational biology
- Requirements for computational processing power virtually unlimited in practice



Frequent Itemset Mining is already used e.g. for e-commerce (Screenshot: Amazon.com).

Freqmine Characteristics

Working Sets



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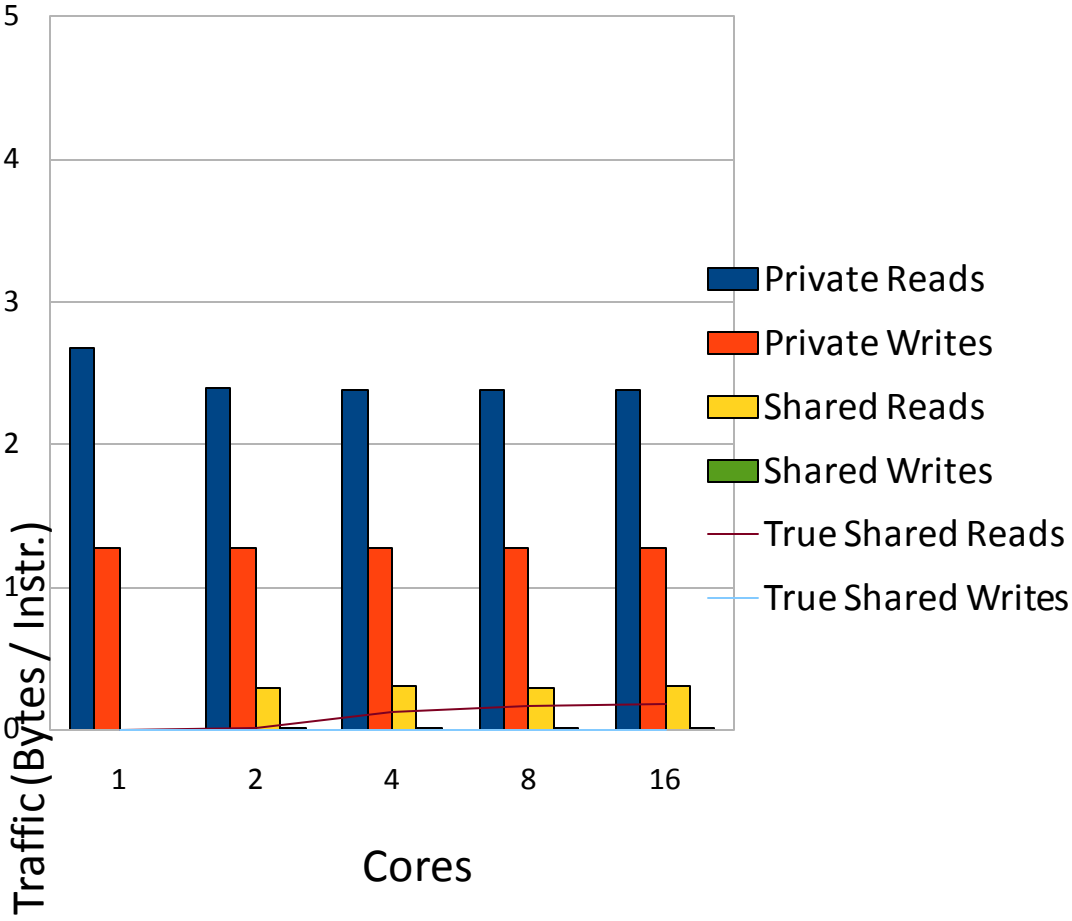


Huge working sets, some sharing

Raytrace Overview

- Uses physical simulation for visu
- Computer animation application (Intel)
- Input is a complex object composed of many triangles
- Fine-granular parallelism, dynamic load balancing
- Large working sets, little communication, significant data sharing

Source: Stanford University

Native input for raytrace. (10 million polygons)

Raytrace Rationale

- Physics simulations allows accurate visualizations with realistic 3D graphics
- Realistic effects possible without tricks (shadows, reflections, refractions, etc.)
- Simpler development of games at the cost of more expensive computations

May 23, 2008 10:12 AM PDT

Nvidia buys ray-tracing tech company RayScale

Posted by Brooke Crothers

Font size Print E-mail Share Post a comment

Nvidia confirmed Friday that it has acquired RayScale, a small company that develops ray-tracing technology. Financial terms of the deal have not been disclosed.

rayscale

Ray tracing has been mentioned frequently by Intel over the last six months. An Intel blog titled "**Real Time Ray-Tracing: The End of Rasterization?**" and later comments by Intel executives that the company **is looking at doing ray tracing on its processors** set the stage for debate on the viability of ray tracing in mainstream gaming.

PC graphics technology today uses **rasterization**. (**A discussion of ray tracing vs. rasterization**.)

Ray Tracing is a technique for rendering three-dimensional graphics with extremely complex light interactions, allowing the creation of transparent surfaces and shadows, for example, with stunning photorealistic results.

Ray tracing is a highly parallel process. And the GPU (graphics processing unit) provides high level of parallelism, according to Nvidia officials speaking at a conference on Thursday. The GPU has special function units that were desgined for doing graphics operations that are perfect for ray tracing, said Nvidia Chief Scientist David Kirk.

At the conference, Kirk and RayScale scientists discussed "GPU ray tracing." It's not clear how soon this technology would be used commercially by Nvidia.

RayScale, which provides interactive ray tracing and photo-realistic rendering solutions, says its technologies "dramatically increase the speed and realism at which graphics professionals can produce high quality three-dimensional computer graphics and photorealistic computer images."

RayScale is a product of the decade-long interactive ray-tracing research at the University of Utah, **according to RayScale**.

At the Intel Developer Forum in Shanghai in April, Senior Intel Vice President Patrick Gelsinger spelled out Intel's

Major companies have started to invest into ray tracing (Source: cnet, May 2008)

Raytrace Characteristics

- Huge working sets containing the whole scene
- Exact working set sizes are data-dependent
- Entire scene is shared among all threads
- Memory bandwidth main issue for good speedups

Large working sets, little communication

Streamcluster Overview

- Computes an approximation for the optimal clustering of a stream of data points
- Machine learning application (Princeton)
- Input is a stream of multidimensional points
- Coarse-granular parallelism, static load-balancing
- Medium-sized working sets of user-determined size

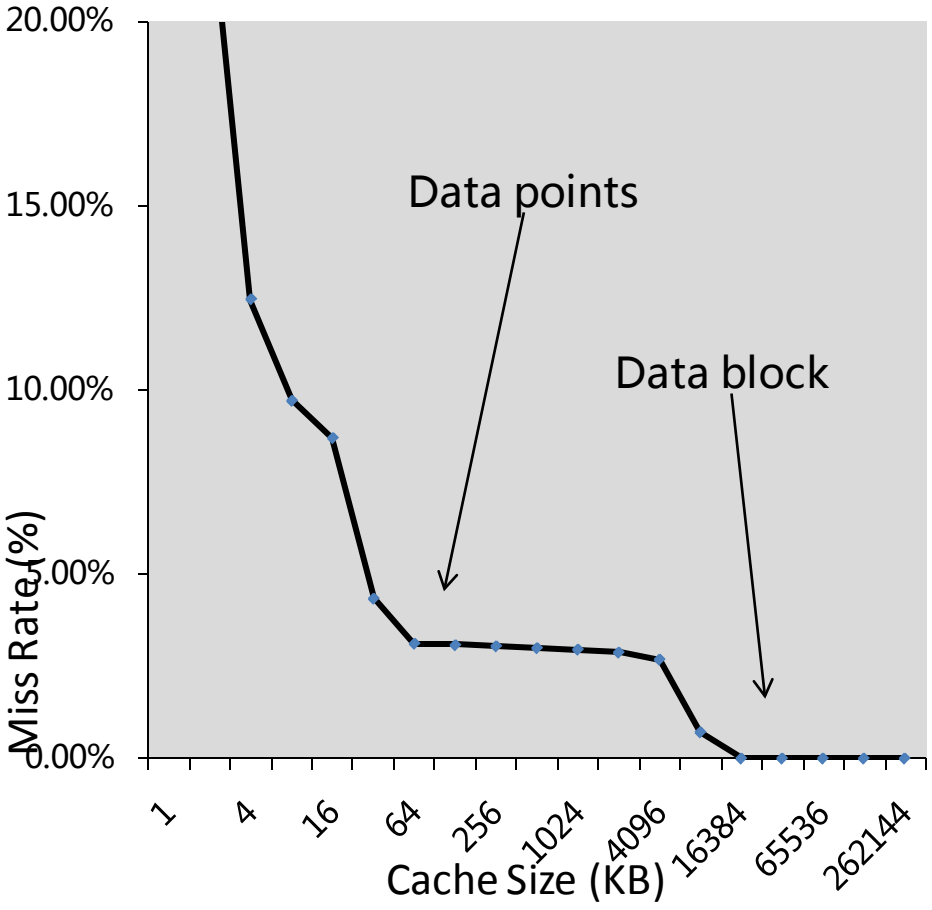
Working set size can be determined at the command line

Streamcluster Rationale

- Clustering is a common problem in many fields like network security or pattern recognition
- Often input data is only available as a data stream, not as a data set (e.g. huge data set that has to be processed under real-time conditions, continuously produced data, etc).
- Approximation algorithms have become a popular choice to handle problems which are intractable otherwise

Streamcluster Characteristics

Working Sets



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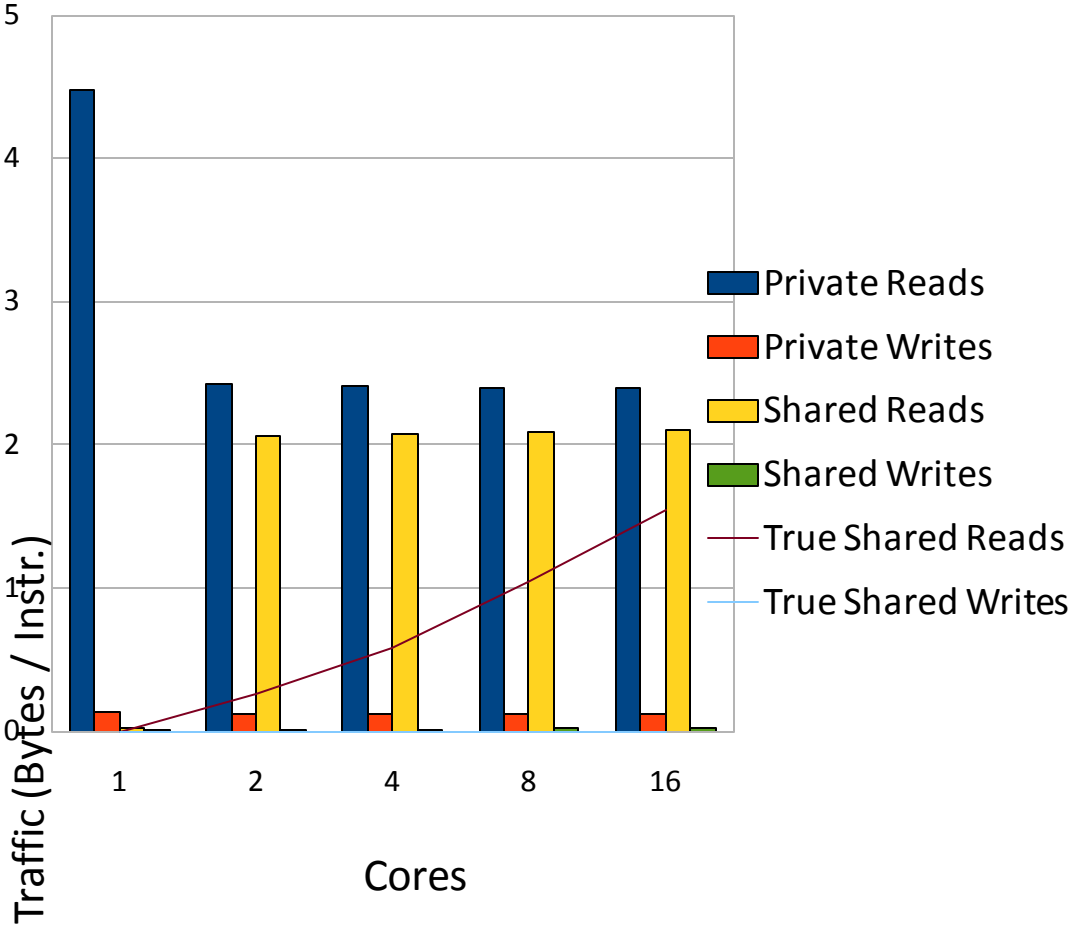


Medium-sized working sets of user-determined size

Swaptions Overview

- Prices a portfolio of swaptions with the Heath-Jarrow-Morton framework
- Computational finance application (Intel)
- Input is a portfolio of derivatives
- Coarse-granular parallelism, static load-balancing
- Medium-sized working sets, little communication

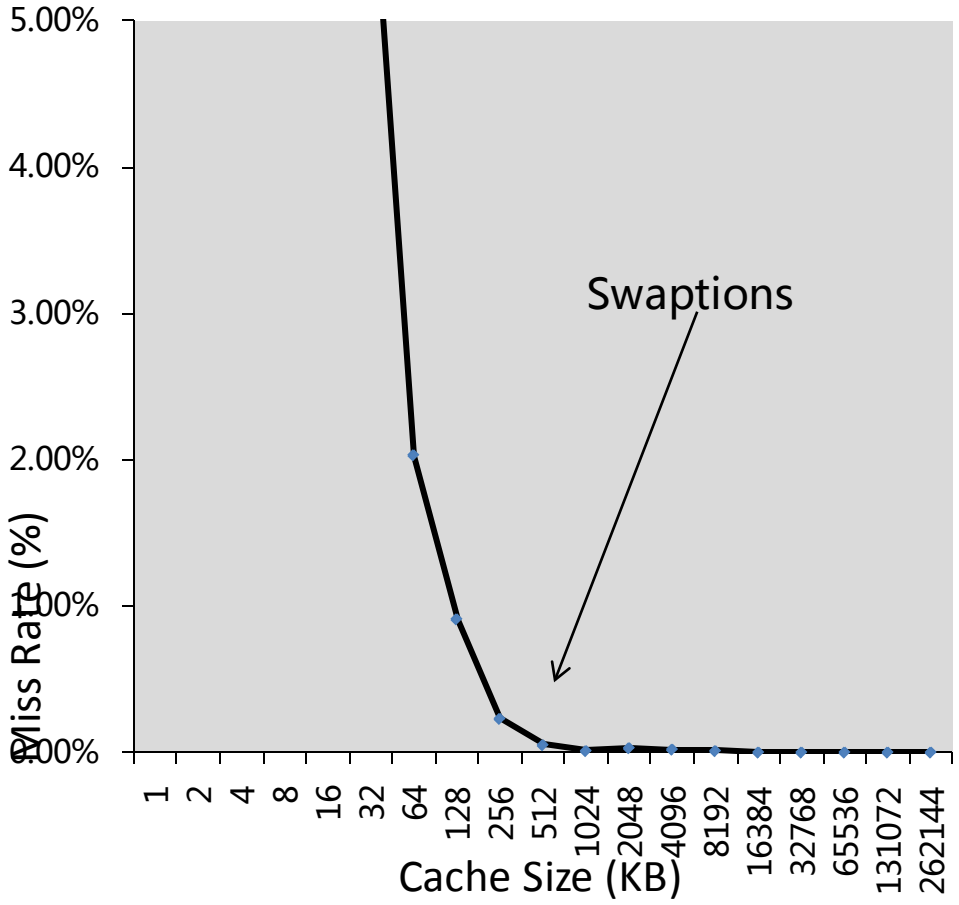
Employs Monte Carlo simulation

Swaptions Rationale

- Computerized trading of derivatives has become wide-spread
- High demand for performance: Saving few milliseconds can earn lots of money
- Monte Carlo simulation is a common approach in many different fields

Swaptions Characteristics

Working Sets



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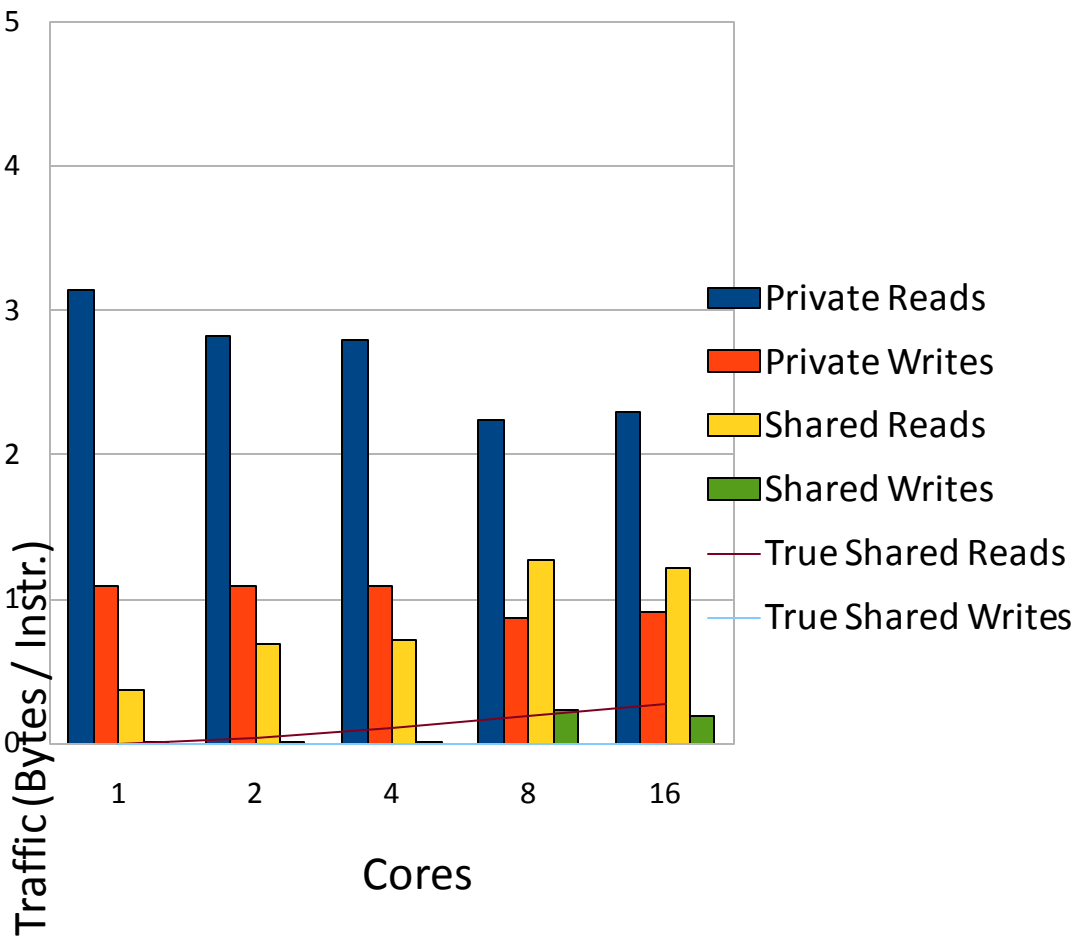


Medium-sized working sets, little communication

Vips Overview

- Applies a series of transformations to an image
- Media application (Princeton + National Gallery of London)
- Input is an uncompressed image
- Medium-granular parallelism, dynamic load-balancing
- Medium-sized working sets, some sharing

http://www.vips.ecs.soton.ac.uk/

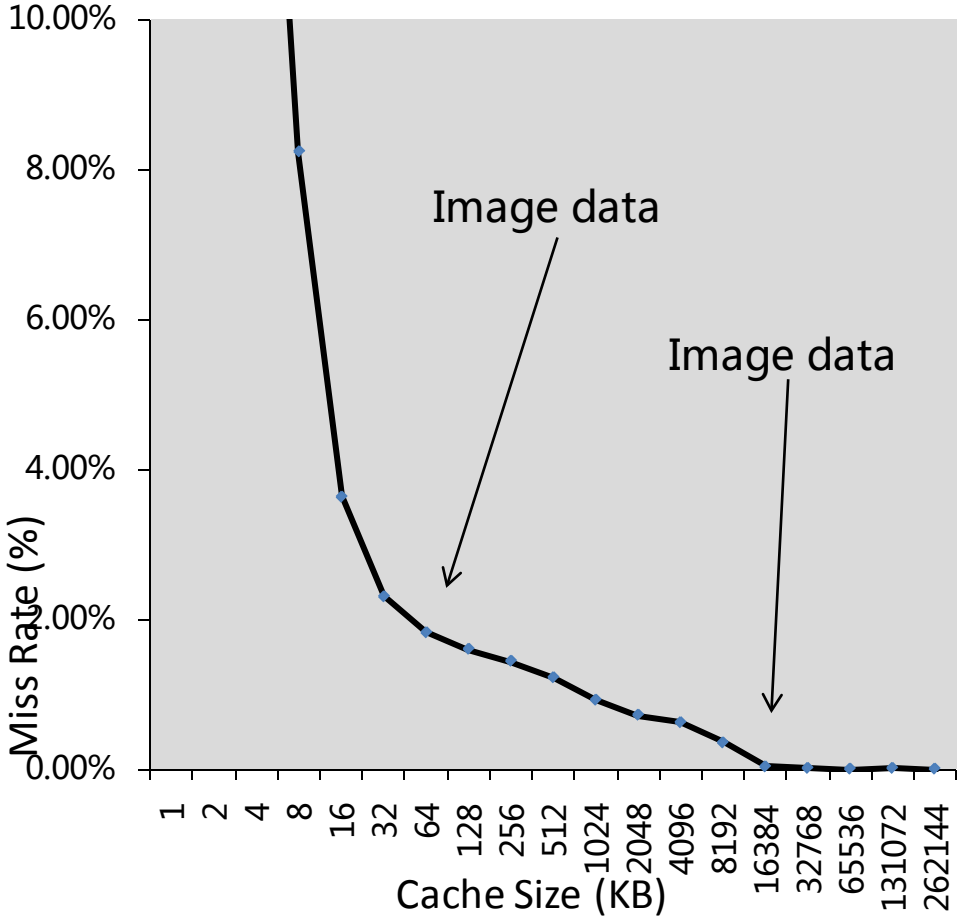
Vips Rationale

- Image processing is one of most common operations for desktops and workstations
- Amount of digital photos grows exponentially
- Professional images can become huge but still need to be handled quickly
- Benchmark based on real print-on-demand service at National Gallery of London

The native input set for vips is a picture of the Orion galaxy with 18,000 x 18,000 pixels.

Vips Characteristics

Working Sets



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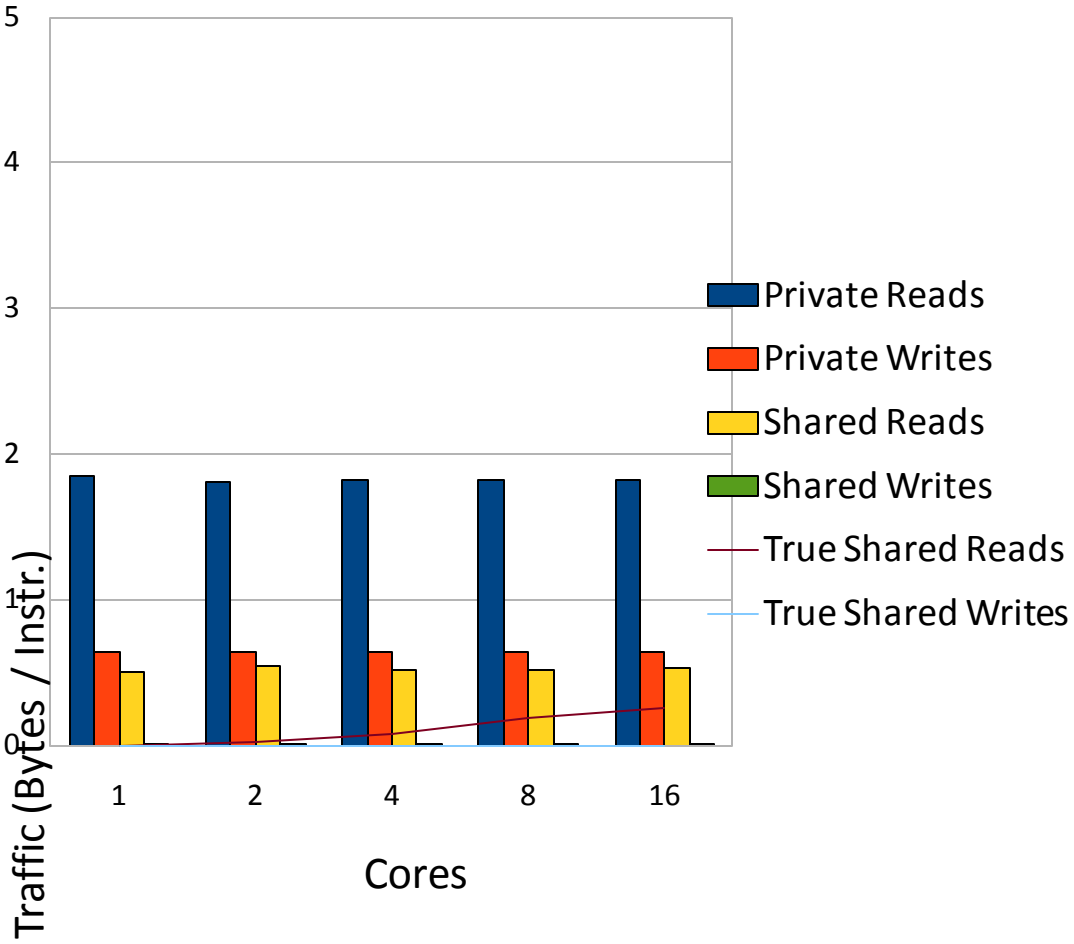


Medium-sized working sets, some sharing

X264 Overview

- MPEG-4 AVC / H.264 video encoder
- Media application (Princeton + Open Source Community)
- Input is a sequence of uncompressed image
- Coarse-granular pipeline parallelism
- Medium-sized working sets, very communication intensive

http://www.videolan.org/developers/x264.html

X264 Rationale

- Increasing storage and network capacity have made videos popular

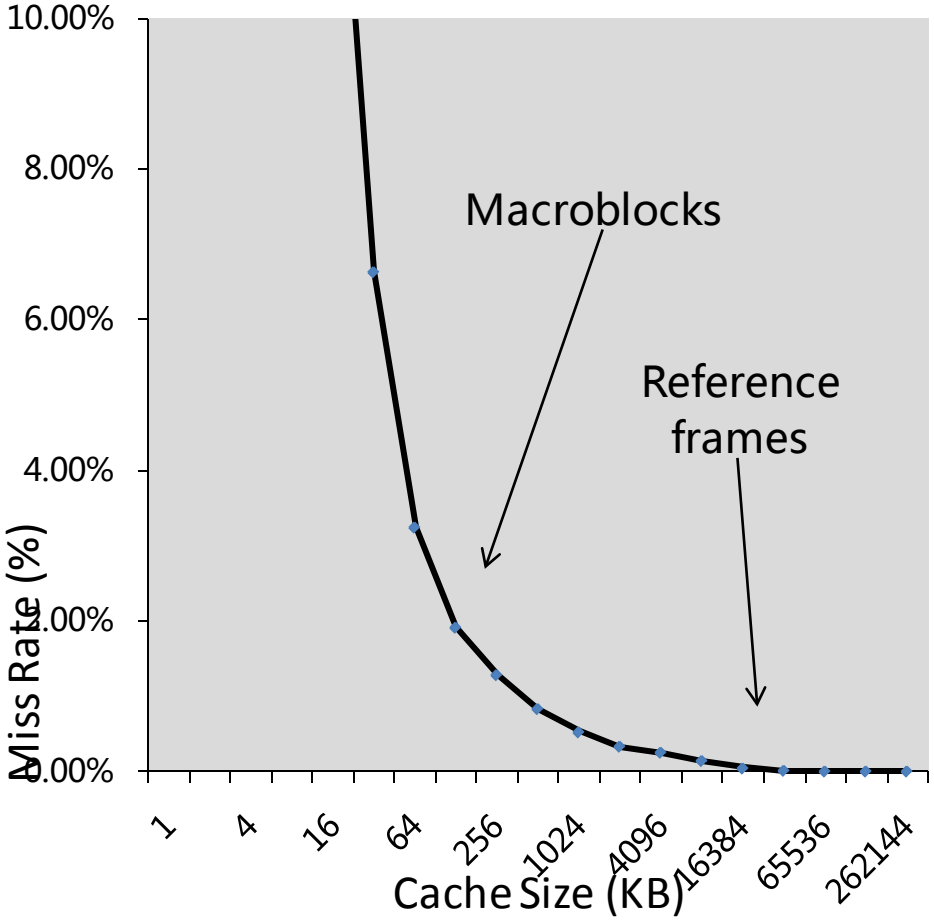
- Shift towards digital TV
- MPEG-4 AVC / H.264 is the standard for next-generation video compression

The input frames for x264 were taken from the open source movie "Elephants Dream" (2006).

More processing power enables better compression quality

X264 Characteristics

Working Sets



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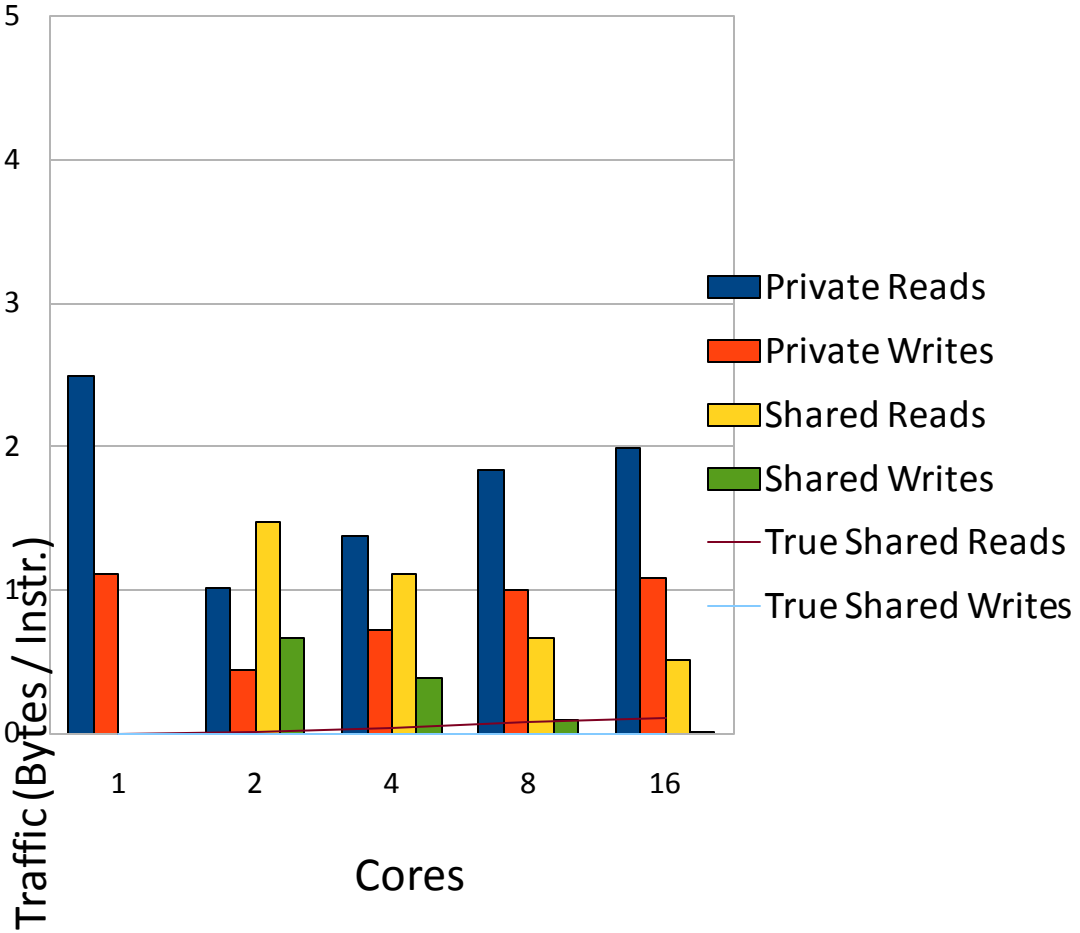


Medium-sized working sets, very communication intensive

Workloads Summary

Program	Application Domain	Parallelization		Working Set	Data Usage	
		Model	Granularity		Sharing	Exchange
blackscholes	Financial Analysis	data-parallel	coarse	small	low	low
bodytrack	Computer Vision	data-parallel	medium	medium	high	medium
canneal	Engineering	unstructured	fine	unbounded	high	high
dedup	Enterprise Storage	pipeline	medium	unbounded	high	high
facesim	Animation	data-parallel	coarse	large	low	medium
ferret	Similarity Search	pipeline	medium	unbounded	high	high
fluidanimate	Animation	data-parallel	fine	large	low	medium
freqmine	Data Mining	data-parallel	medium	unbounded	high	medium
raytrace	Rendering	data-parallel	medium	unbounded	high	low
streamcluster	Data Mining	data-parallel	medium	medium	low	medium
swaptions	Financial Analysis	data-parallel	coarse	medium	low	low
vips	Media Processing	data-parallel	coarse	medium	low	medium
x264	Media Processing	pipeline	coarse	medium	high	high

There aren't any two workloads with the same combinations

Comparing Program Behavior

- **Question:** How to quantify and compare program behavior

- **A Principle-Component-Analysis (PCA) based Benchmark Analysis Methodology**
- **PCA**: a mathematical procedure (wikipedia)

  A set of possibly correlated characteristics

  → A set of uncorrelated principle components (PC)
- **Steps**:

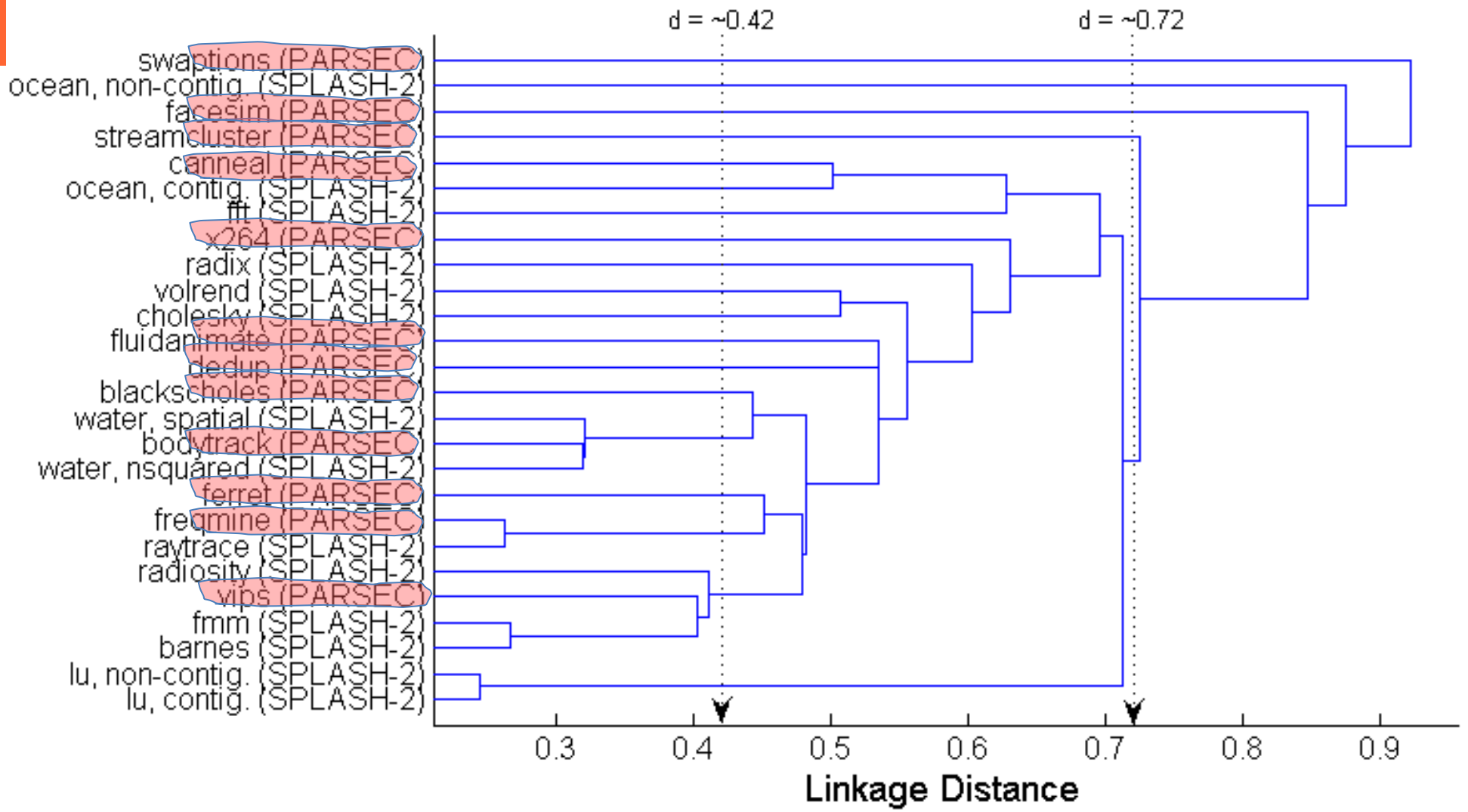
  ❶Collect characteristics by simulations or real executions

  ❷Run the PCA procedure → several PCs → vectors in PCA space

  ❸Evaluate the similarity of programs by computing the Euclidean Distance of the vectors in PCA space

  ❹Visualize similarity with scatter plots and dendrograms

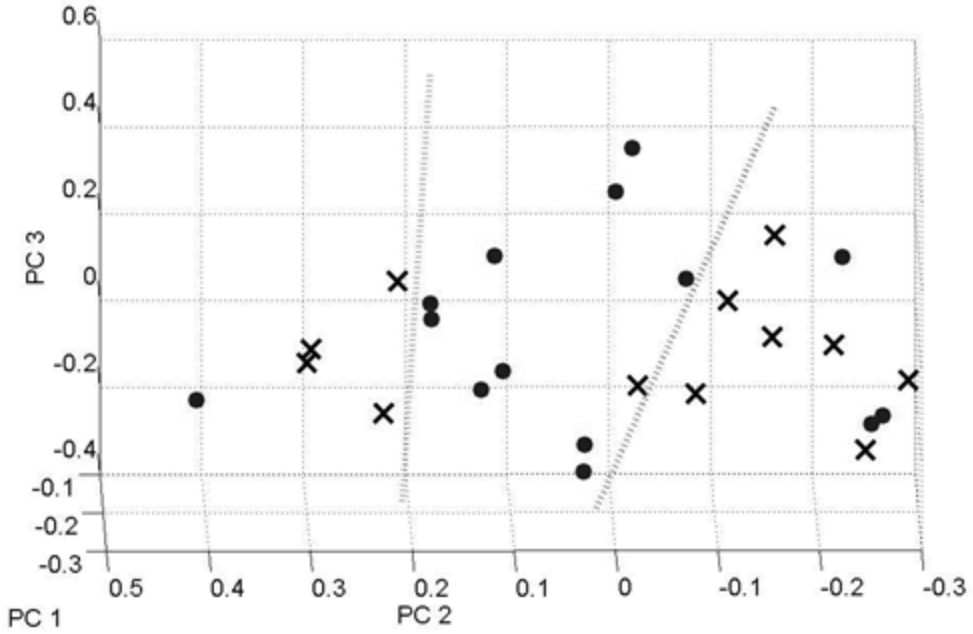
Redundancy & Similarity



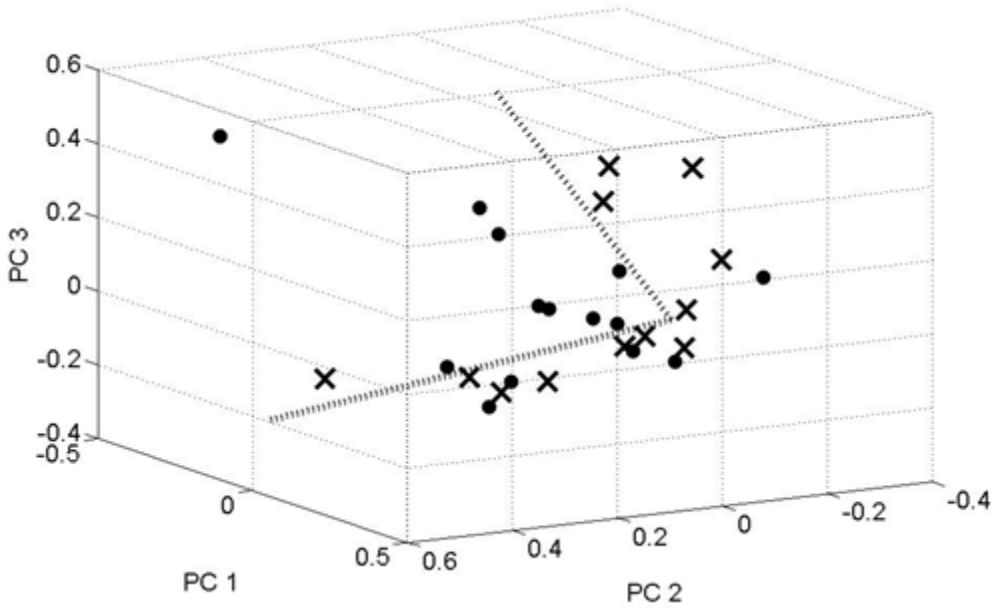
The PARSEC workloads are unique and representative

PARSEC vs. SPLASH-2

Instruction Mix



Sharing

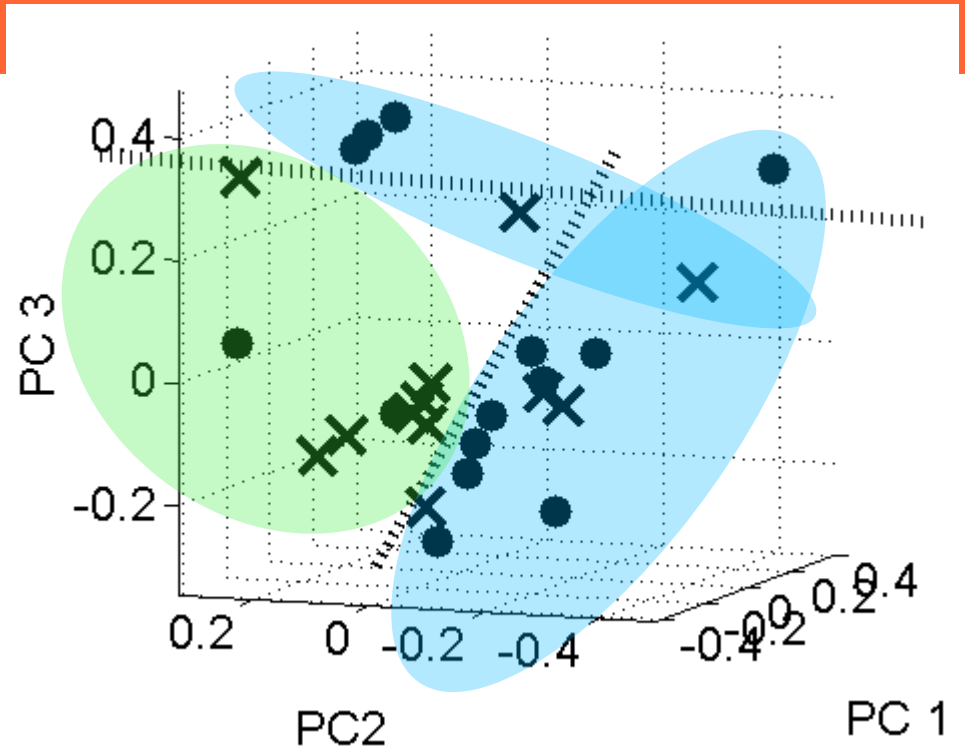


× PARSEC ● SPLASH-2

Statistical analysis shows significant differences.

You should expect different results

Systematic Differences



× PARSEC ● SPLASH-2

Benchmark suites cluster in different areas, little overlap

Integrate SPLASH-2 into PARSEC framework

PARSEC and SPLASH-2 complement each other well

PARSEC vs. SPLASH-2: A Quantitative Comparison of Two Multithreaded Benchmark Suites on Chip-Multiprocessors, *In Proceedings of the IEEE International Symposium on Workload Characterization, September 2008*

Input Set Selection/Evaluation

- **Question:** How to choose input sets with multiple scales to meet various demands, e.g., simulation, real machine?

- **Linear**
  - Linear impact on runtime / loops
  - Typically does not change working set sizes

- **Complex**
  - Frequently affects multiple kernels at the same time
  - Often impacts working set sizes, can change the ratio of the kernel execution time

- **Greedy Heuristic Rules:**
  - ❶ Use linear scaling
  - ❷ Use combination of linear and complex scaling

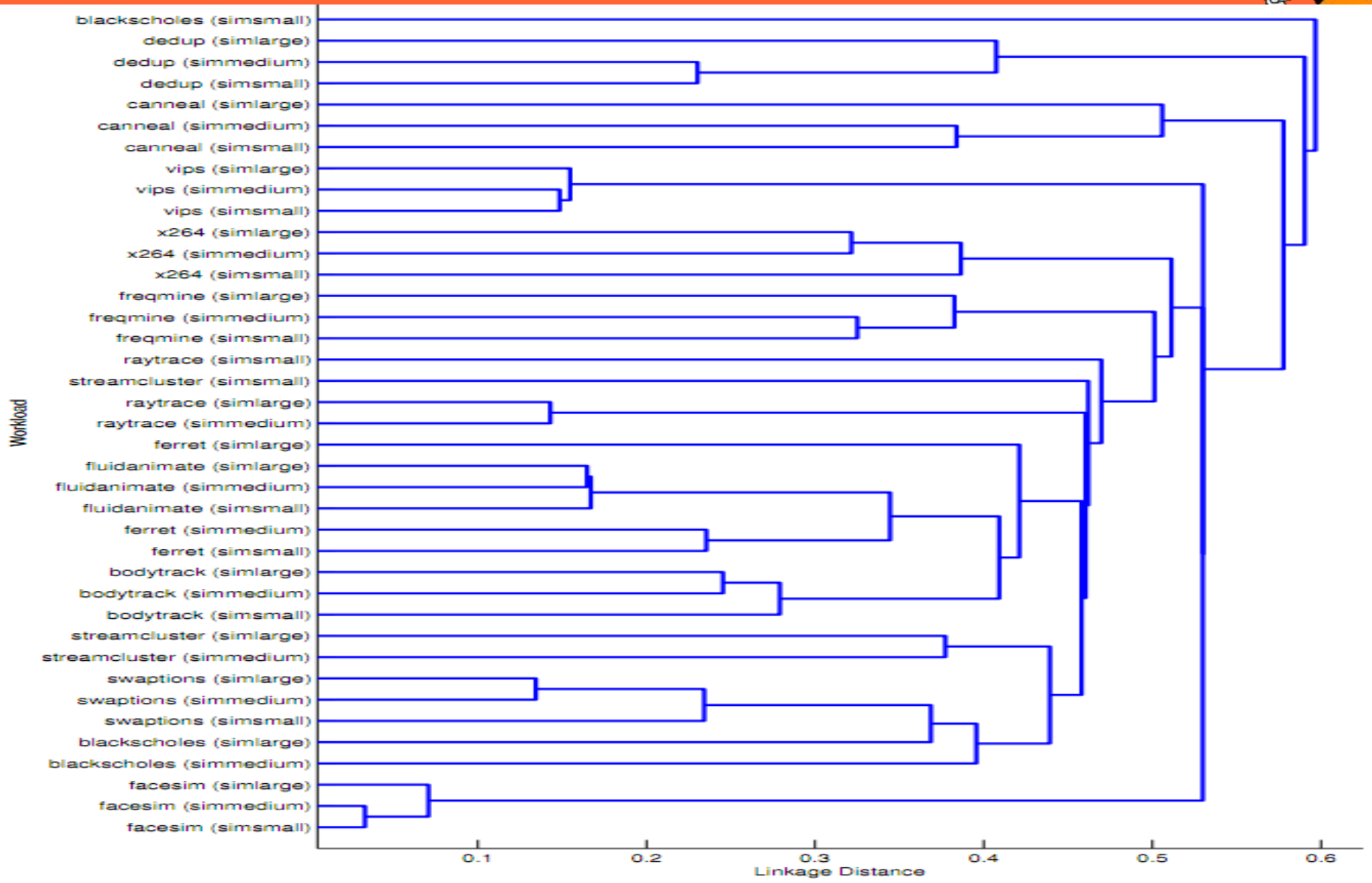
Input Set Evaluation

Program	Input Set	Problem Size	
		Complex Component	Linear Component
blackscholes	simsmall		4,096 options
	simmedium		16,384 options
	simlarge		65,536 options
	native		10,000,000 options
bodytrack	simsmall	4 cameras, 1,000 particles, 5 layers	1 frame
	simmedium	4 cameras, 2,000 particles, 5 layers	2 frames
	simlarge	4 cameras, 4,000 particles, 5 layers	4 frames
	native	4 cameras, 4,000 particles, 5 layers	261 frames
canneal	simsmall	100,000 elements	10,000 swaps per step, 32 steps
	simmedium	200,000 elements	15,000 swaps per step, 64 steps
	simlarge	400,000 elements	15,000 swaps per step, 128 steps
	native	2,500,000 elements	15,000 swaps per step, 6,000 steps
dedup	simsmall		10 MB data
	simmedium		31 MB data
	simlarge		184 MB data
	native		672 MB data

- **Four reference input scales**
- **Both Linear and Complex impacts are included**

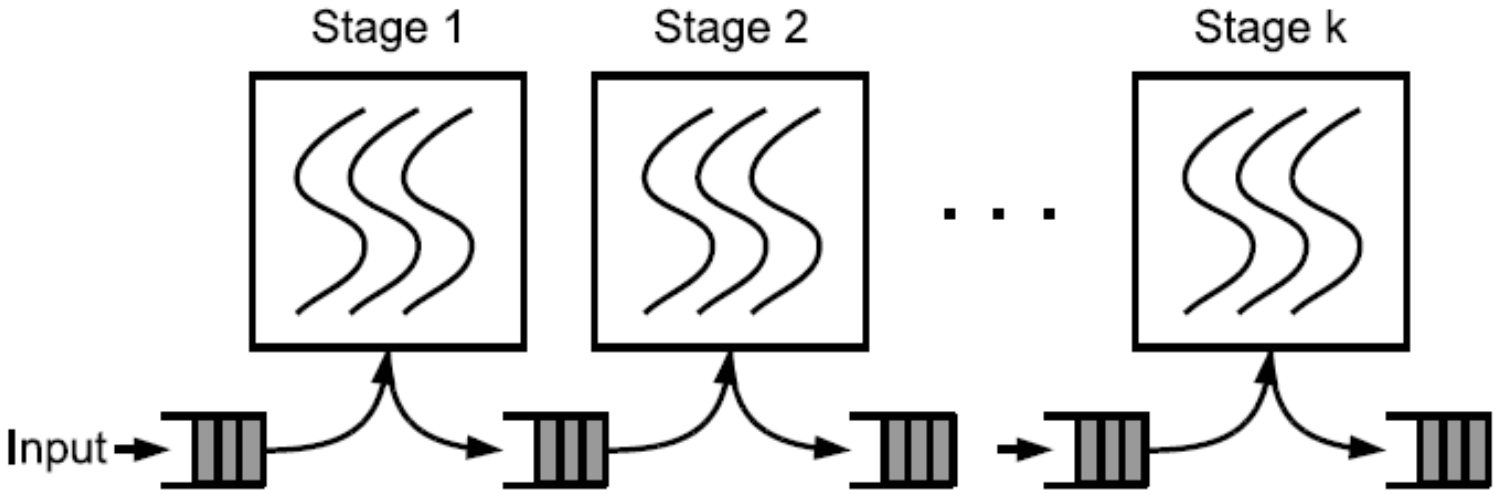
Fidelity and Scaling of the PARSEC Benchmark Inputs, ***In Proceedings of the IEEE International Symposium on Workload Characterization, December 2010***

Input Set Similarity



Most workloads form local cluster → linear

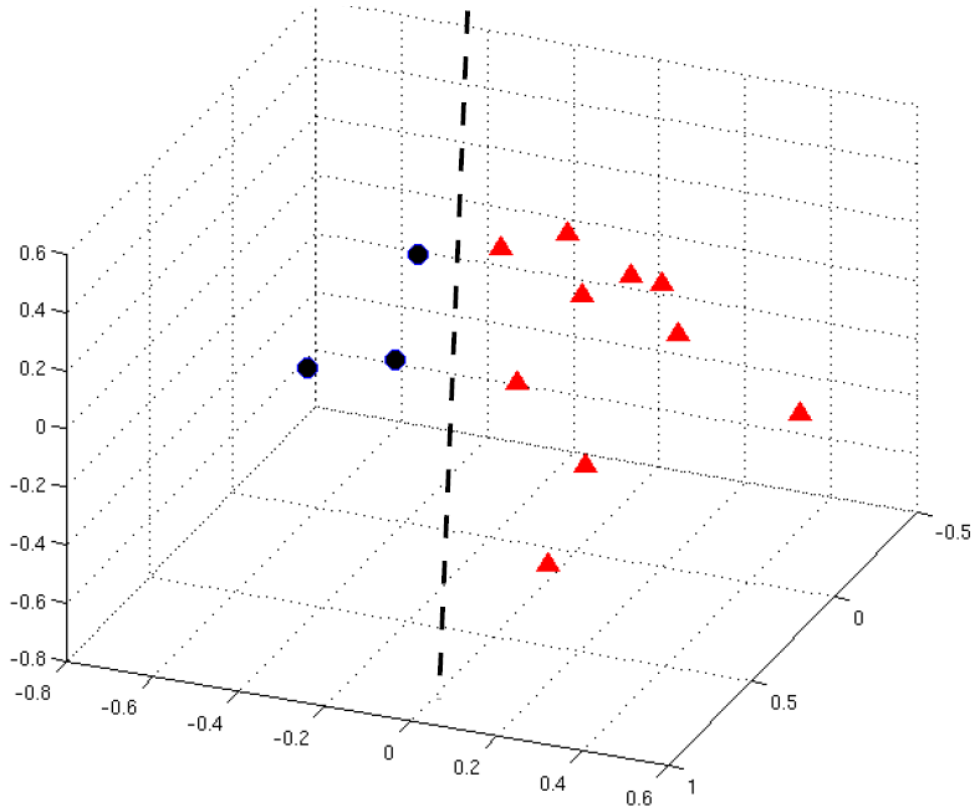
Pipelined Programming Model



- Pipelined programming model is the most common model used in products
  - Clean interfaces and modules
  - Parallel programming

Characteristics

Workload	Parallelism			Dependency Modeling
	Pipeline	Data	I/O	
bodytrack	N	Y	Y	N
dedup	Y	Y	Y	N
ferret	Y	Y	Y	N
x264	Y	N	N	Y



Significant systematic differences between the two types of programs

Characteristics of Workloads Using the Pipeline Programming Model, *In Proceedings of the 3rd Workshop on Emerging Applications and Many-core Architecture, June 2010.*

Research by PARSEC

- "Does Cache Sharing on Modern CMP Matter to the Performance of Contemporary Multithreaded Programs?", Eddy Z. Zhang, Yunlian Jiang, Xipeng Shen, PPoPP, 2010. (Best Paper Award)
- "Characterizing the TLB Behavior of Emerging Parallel Workloads on Chip Multiprocessors", Abhishek Bhattacharjee, Margaret Martonosi. PACT 2009, (Best paper Finalist)
- …

Part 2

Working with PARSEC

Framework Directory Structure

- PARSEC is composed of the framework and packages

```
.
|-- bin
|   `-- ...
|-- config
|   |-- bibliography
|   |   |-- bienia11parsec.bibconf
|   |   `-- woo95splash.bibconf
|   `-- packages
|       |-- parsec.blackscholes.pkgconf
|       |-- ...
|       |-- parsec.zlib.pkgconf
|       |-- splash2x.barnes.pkgconf
|       |-- ...
|       `-- splash2x.water_spatial.pkgconf
|-- ext
|   |-- user-defined
|   |-- splash2
|   `-- splash2x
|       |-- apps
|       `-- kernels
`-- pkgs
    |-- apps
    |   |-- ...
    |   `-- x264
    |-- kernels
    |   |-- ...
    |   `-- streamcluster
    |-- libs
    |   |-- ...
    |   `-- zlib
    `-- tools
        `-- yasm
```

Framework executable files

Global configuration files

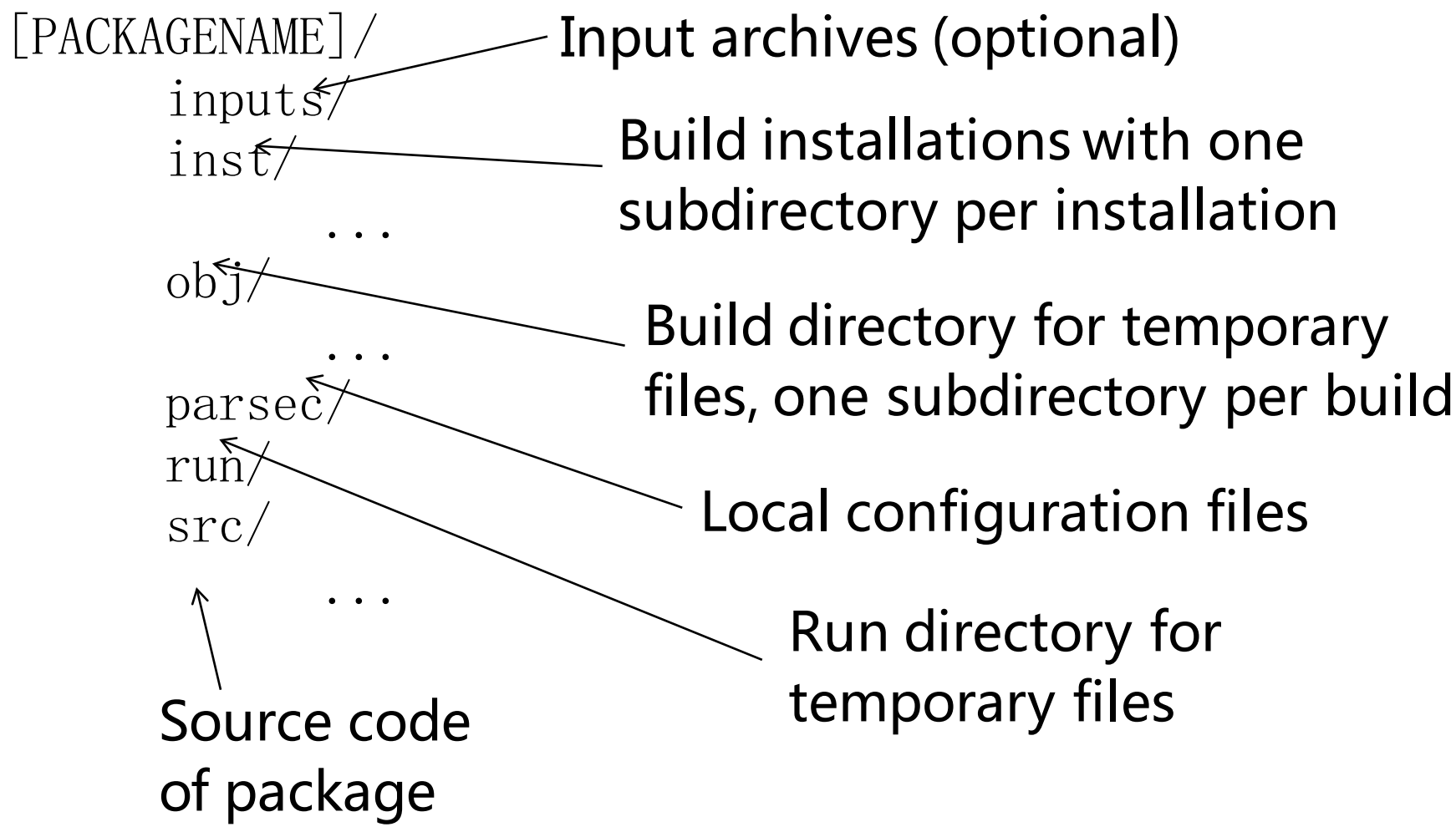
Extended benchmark directory

PARSEC benchmark directory

Each group directory contains one directory per package in that group

Package Directory Structure

- Each package directory is structured as follows:



Configuration Files

- Global configuration files (in `config/` directory of framework):
  - PARSEC main configuration file: `parsec.conf`
    - `3.0` → `package`
  - System configurations: `[OSNAME].sysconf`
  - Global build configurations: `[BUILDCONF].bldconf`
  - Global run configurations: `[INPUT].runconf`
- Local configuration files (in `parsec/` directory of each package):
  - Local build configurations: `[BUILDCONF].bldconf`
  - Local run configurations: `[INPUT].runconf`

Hello World (1)

Run the following command:

```
parsecmgmt -a status –p parsec
```

Hello World (2)

Run the following command:

```
parsecmgmt -a status –p parsec
```

You should see some information similar to the following one:

```
[PARSEC] Installation status of selected packages:
[PARSEC] parsec.blackscholes:
[PARSEC]   amd64-linux.gcc
[PARSEC]   amd64-linux.gcc-hooks
[PARSEC]   amd64-linux.gcc-tbb
[PARSEC] parsec.bodytrack:
[PARSEC]   amd64-linux.gcc
[PARSEC]   amd64-linux.gcc-serial
[PARSEC] parsec.canneal:
[PARSEC]   amd64-linux.gcc
[PARSEC]   amd64-linux.gcc-pthreads
[PARSEC]   amd64-linux.gcc-serial
```

Workload/package name

suite name

Hello World (3)

Run the following command:

```
parsecmgmt -a status –p all
```

parsecmgmt

- A script to help you manage your PARSEC installation
- Can build and run PARSEC workloads for you
- Only there for convenience, you can also do the same tasks manually
- Uses information in configuration files to do its job
- Use the following command to get some help:

```
parsecmgmt -h
```

Building Workloads

- You can build a PARSEC workload as follows:

```
parsecmgmt -a build -p [suite].[PACKAGE]
```

- Flag '`-a`' specifies the desired action, flag '`-p`' gives one or more packages
- A package can be a workload, library or anything else that comes with PARSEC and can be compiled
- '`parsecmgmt -a info`' gives you a list of all available packages
- `Parsecmgmt` will automatically handle dependencies between packages correctly

Building Workloads

Q: How do you build workload `canneal`?

Q: How do you build workload `raytrace` in parsec suite?

Q: How do you build workload `raytrace` in splash2x suite?

Building Workloads Answer (1)

Q: How do you build package canneal?

A: You can use the following command:

```
> parsecmgmt -a build -p canneal
[PARSEC] Packages to build:  canneal

[PARSEC] [========== Building package canneal ==========]
[PARSEC] [---------- Analyzing package canneal ----------]
[PARSEC] canneal depends on: hooks
[PARSEC] [---------- Analyzing package hooks ----------]
[PARSEC] hooks does not depend on any other packages.
[PARSEC] [---------- Building package hooks ----------]
[PARSEC] Copying source code of package hooks.
[PARSEC] Running 'env make':
/usr/bin/gcc -O3 -funroll-loops -fprefetch-loop-arrays
-DPARSEC_VERSION=2.0 -Wall -std=c99 -D_GNU_SOURCE
-D_XOPEN_SOURCE=600 -c hooks.c
ar rcs libhooks.a hooks.o
ranlib libhooks.a
[PARSEC] Running 'env make install':
...
```

Building Workloads Answer (2)

Q: How do you build package canneal?

A: You can use the following command:

```
> parsecmgmt -a build -p parsec.canneal
[PARSEC] Packages to build:  canneal

[PARSEC] [========== Building package canneal ==========]
[PARSEC] [---------- Analyzing package canneal ----------]
[PARSEC] canneal depends on: hooks
[PARSEC] [---------- Analyzing package hooks ----------]
[PARSEC] hooks does not depend on any other packages.
[PARSEC] [---------- Building package hooks ----------]
[PARSEC] Copying source code of package hooks.
[PARSEC] Running 'env make':
/usr/bin/gcc -O3 -funroll-loops -fprefetch-loop-arrays
-DPARSEC_VERSION=2.0 -Wall -std=c99 -D_GNU_SOURCE
-D_XOPEN_SOURCE=600 -c hooks.c
ar rcs libhooks.a hooks.o
ranlib libhooks.a
[PARSEC] Running 'env make install':
...
```

Building Workloads Answer (3)

Q: How do you build workload `raytrace` in parsec suite?
Q: How do you build workload `raytrace` in splash2x suite?

A: You can use the following command:

- `parsecmgmt -a build -p parsec.raytrace`
- `parsecmgmt -a build -p splash2x.raytrace`

Suite, Groups & Aliases

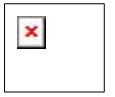
- Each package belongs to exactly one group
- `Parsecmgmt` also understands aliases
- You can use group names and aliases instead of package names
- Example:

```
parsecmgmt -a build -p all
parsecmgmt -a build –p parsec
parsecmgmt -a build –p splash2x
```

- Current Suites are `parsec, splash2x`
- Possible aliases are `kernels`, `apps`, `bench`, `libs`, `tools` and `all`
- **`User-defined aliases [demo]`**

Build Configurations

- Build configurations determine how `parsecmgmt` is to build a package
- Specifies compiler, compiler flags, optimizations, etc.
- Use flag '`-c`' with `parsecmgmt` to select a build configuration
- You should create your own build configurations according to your needs
- Default build configurations are `gcc`, `gcc-hooks`, `gcc-serial` and `icc`
- PARSEC build configurations to enable specific parallelizations are `gcc-openmp`, `gcc-pthreads` and `gcc-tbb`



Build Configurations Quiz

Q: How do you build workload `canneal` with build configuration `gcc-serial`?

Build Configurations Answer

Q: How do you build workload `canneal` with build configuration `gcc-serial`?

A: You can use the following command:

```
> parsecmgmt -a build -p canneal -c gcc-serial
[PARSEC] Packages to build:  canneal

[PARSEC] [========== Building package canneal ==========]
[PARSEC] [---------- Analyzing package canneal ----------]
[PARSEC] canneal depends on: hooks
[PARSEC] [---------- Analyzing package hooks ----------]
[PARSEC] hooks does not depend on any other packages.
[PARSEC] [---------- Building package hooks ----------]
[PARSEC] Copying source code of package hooks.
[PARSEC] Running 'env make':
/usr/bin/gcc -O3 -funroll-loops -fprefetch-loop-arrays
-DPARSEC_VERSION=2.0 -Wall -std=c99 -D_GNU_SOURCE
-D_XOPEN_SOURCE=600 -c hooks.c
ar rcs libhooks.a hooks.o
ranlib libhooks.a
[PARSEC] Running 'env make install':
```

Multiple Builds

- You can have more than one build of every package installed
- `Parsecmgmt` will create a platform description string to distinguish builds as follows:

```
[ARCHITECTURE]-[OSNAME].[BUILDCONF]
```

- You can override this string by defining environment variable `PARSECPLAT`
- PARSEC 2.0 also allows you to append an extension to further distinguish builds

Show Available Installations

- You can see a list of all installed builds if you run:

```
parsecmgmt -a status –p all
```

- `Parsecmgmt` will list the platform description strings of all installed builds for each workload:

```
[PARSEC] Installation status of selected packages:
[PARSEC] blackscholes:
[PARSEC]   -no installations-
[PARSEC] bodytrack:
[PARSEC]   -no installations-
...
[PARSEC] canneal:
[PARSEC]   x86_64-linux-gnu.gcc
[PARSEC]   x86_64-linux-gnu.gcc-serial
...
```

Cleanup

- Remove all temporary directories (used e.g. for building):

```
parsecmgmt -a fullclean -p all
```

- Uninstall a specific installation:

```
parsecmgmt -a uninstall -p [PACKAGE] -c [BUILDCONF]
```

- Uninstall everything:

```
parsecmgmt -a fulluninstall -p all
```

Running Benchmarks

- You can run a PARSEC benchmark as follows:

```
parsecmgmt -a run -p [PACKAGE] -c [BUILDCONF]
           -i [INPUT] -n [THREADS]
```

- Like building workloads, but you can also specify an input and the number of threads

Flag '`-n`' specifies the *minimum* number of threads. The actual number can be higher. You must use other techniques to limit the number of CPUs.

- Default inputs are `test`, `simdev`, `simsmall`, `simmedium`, `simlarge` and `native`

Input Sets

- `Test`
  Execute program, as small as possible, best-effort execution path as real inputs
- `Simdev`
  Stresses all machine parts required by larger input sets, same execution path as real inputs
- `Simsmall`
  Like real inputs, runtime ~1s
- `Simmedium`
  Like real inputs, runtime ~5s
- `Simlarge`
  Like real inputs, runtime ~15s
- `Native`
  Like real inputs, runtime ~15min

Running Benchmarks Quiz

Q: How do you run the serial version of workload `canneal` with input `simsmall`?

Running Benchmarks Answer

Q: How do you run the serial version of workload `canneal` with input `simsmall`?

A: You can use the following command:

```
> parsecmgmt -r run -p canneal -c gcc-serial -i simsmall
[PARSEC] Benchmarks to run:  canneal

[PARSEC] [========== Running benchmark canneal ==========]
[PARSEC] Setting up run directory.
[PARSEC] Unpacking benchmark input 'simsmall'.
100000.nets
[PARSEC] Running '...':
[PARSEC] [---------- Beginning of output ----------]
PARSEC Benchmark Suite Version 2.0
Threadcount: 1
10000 moves per thread
Start temperature: 2000
...
[PARSEC] [----------    End of output    ----------]
[PARSEC] Done.
```

Log Files

- `Parsecmgmt` stores all output of builds and runs in log files
- All log files are kept in the `log/` directory of the framework
- Naming convention:

`build_[DATE]_[TIMESTAMP].log`

and

`run_[DATE]_[TIMESTAMP].log`

Documentation

- Comprehensive documentation shipped with PARSEC
- Full set of man pages available in the `man/` directory
- Add it to the `MANPATH` environment variable to access it (example assumes bash shell):

```
MANPATH=${MANPATH}:${PARSECDIR}/man
```

- We provide a script `env.sh` which does that for you (see next slide)
- Then you can start browsing the documentation as follows:

```
man parsec
```

Environment Setup

- You can modify your environment to make the PARSEC tools and its man pages available at the command line (without full path)
- The `env.sh` script in the PARSEC root directory will do that for you
- Source it as follows (example assumes bash shell):

```
source env.sh
```

- If you use PARSEC a lot you can add that to your login scripts to have it always available

Managing Build Configurations

- Create a new build configuration:

```
bldconfadd -n [NAME]
```

- In most cases you will want to create a copy of an existing build configuration
- Use flag '-c' for a hard copy and flag '-s' for a soft copy
- Delete a build configuration:

```
bldconfdel -n [NAME]
```

- Use flag '-h' with both tools to get more detailed usage information

Modifying Build Configurations

- You should adapt build configurations to your needs
- Each build configuration has to define:
  - Default environment variables for makefiles (CC, CXX, CFLAGS, …)
  - Build tool version numbers (CC_ver, CXX_ver, …)
  - It should define macro `PARSEC_VERSION`
- The global configuration files define all parameters, the local ones adapt them and add additional variables as needed by each package

Build Configuration Quiz

Q: Create a new build configuration `gcc-debug` based on `gcc` that compiles all packages without optimization but with debugging support. Test it on workload `canneal`.

Build Configuration Answer

Q: Create a new build configuration `gcc-debug` based on `gcc` that compiles all packages without optimization but with debugging support. Test it on workload `canneal`.

A: First, create a copy of build configuration '`gcc` ':

```
configadd -n gcc-debug -s gcc
```

Next, edit `gcc-debug.bldconfig` in directory `config/` to use the new flags:

```
#!/bin/bash

source ${PARSECDIR}/config/gcc.bldconf

CFLAGS="${CFLAGS} -O0 -g"
CXXFLAGS=" ${CXXFLAGS} -O0 -g"
```

Build Information

- `Parsecmgmt` creates a special file '`build-info`' with information about the build in each build installation directory

- File contains details about build configuration and environment at the time of compilation:
  - Exact location and version of all compilers
  - Compiler flags specified by build configuration
  - Modifications of environment variables

- Makes it a lot easier to figure out what was going on if build configurations were modified

Build Information Quiz

Q: How did `parsecmgmt` modify the environment to build the serial version of workload `canneal`?

Build Information Answer

Q: How did `parsecmgmt` modify the environment to build the serial version of workload `canneal`?

A: It's in `build-info` for the `gcc-serial` configuration:

```
PARSEC Compile Information
==========================
Package 'canneal'
Built on Wed May 7 20:24:59 EDT 2008

Configure arguments:  --prefix=/home/cbienia/parsec/parsec-2.0/pkgs/
kernels/canneal/inst/x86_64-linux-linux.gcc-serial

Environment modifications: version=serial

CC: /usr/bin/gcc
Version: gcc (GCC) 4.1.2 20070626 (Red Hat 4.1.2-14)
Copyright (C) 2006 Free Software Foundation, Inc.
This is free software; see the source for copying conditions.  There is
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURP
CFLAGS: -O3 -funroll-loops -fprefetch-loop-arrays -DPARSEC_VERSION=2.0
...
```

How to add a workload

- Add a “hello” workload
- cd “ext” directory
- create your suite “ext/user”
- Copy template workload to your suite
- change config file

Part 3

Roadmap of PARSEC

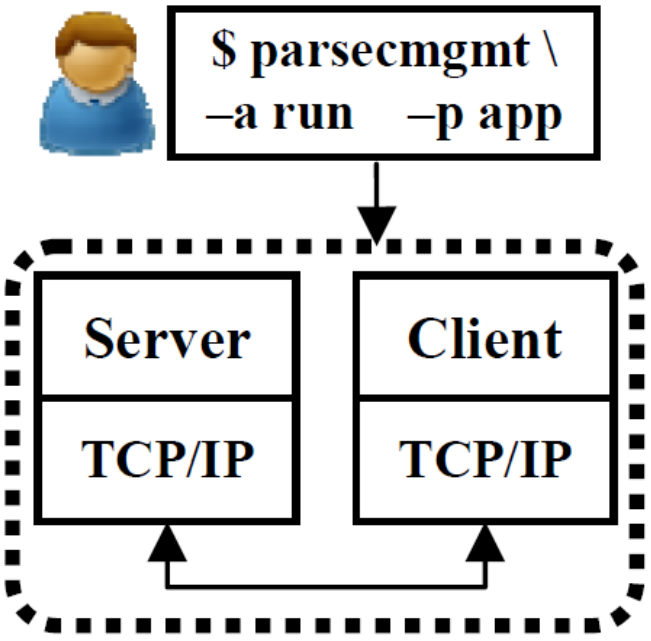
Network Workloads

- Network workloads are ubiquitous
- TCP/IP stack is CPU intensive
  - Rule-of-thumb: 1Gbits/sec ~1Ghz Pentium CPU
- 10 Gbits are here and CPUs are multicores
  - Need parallelized TCP/IP stack
- No TCP/IP stack in existing benchmarks

Framework

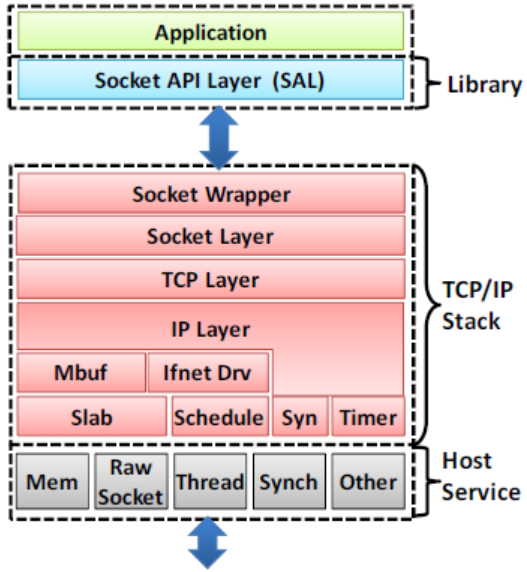
- **Goal: A framework easily run network workloads on real machine and simulators**

- A user-level, parallelized TCP/IP stack
  - Easy to run on a simulator
- **Environment**
  - Run client and server workloads together

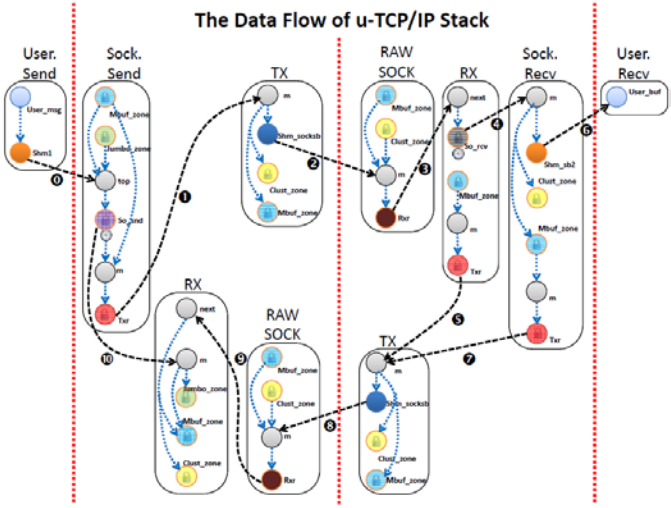


Approach

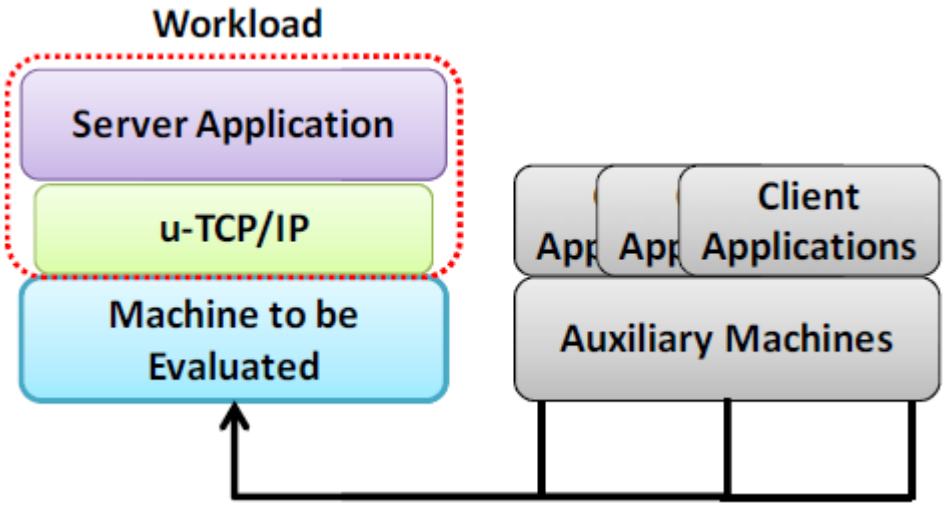
- User-level TCP/IP Stack (u-TCP/IP)
  - Extract the TCP/IP Stack from FreeBSD kernel
  - Keep u-TCP/IP' s behavior similar



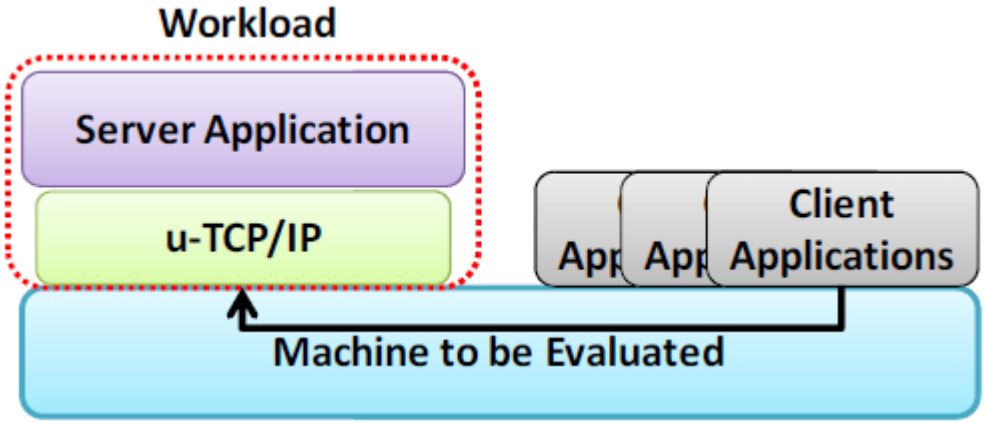
- Parallelized u-TCP/IP → up-TCP/IP
  - Use multiple methods to parallelize u-TCP/IP
    - Pipelined model
    - Data parallel



Two Modes



- Inter-Node



- Intra-Node

GPGPU Workloads

- Many emails asking if we provide GPGPU workloads
- Need Huge Efforts
- Our Plan
  - Encourage people to port PARSEC to GPGPU
  - Submit your GPU-version PARSEC
  - Credits given by the new framework

Part 4

Concluding Remarks

- PARSEC 3.0
  - Release planned for summer 2011

- We need your contribution
  - Network Workloads
  - Porting PARSEC to GPGPU

We are looking for contributions

References

[1] Christian Bienia. **Benchmarking Modern Multiprocessors** Ph.D. Thesis. Princeton University, January 2011.

[2] Christian Bienia and Sanjeev Kumar and Jaswinder Pal Singh and Kai Li. **The PARSEC Benchmark Suite: Characterization and Architectural Implications**. InProceedings of the 17th International Conference on Parallel Architectures and Compilation Techniques, October 2008.

[3] Christian Bienia and Kai Li. **Fidelity and Scaling of the PARSEC Benchmark Inputs**.. In *Proceedings of the IEEE International Symposium on Workload Characterization, December 2010.*

[4] Christian Bienia and Kai Li. **Characteristics of Workloads Using the Pipeline Programming Model**. In *Proceedings of the 3rd Workshop on Emerging Applications and Many-core Architecture, June 2010.*

[5] Christian Bienia, Sanjeev Kumar and Kai Li. **PARSEC vs. SPLASH-2: A Quantitative Comparison of Two Multithreaded Benchmark Suites on Chip-Multiprocessors**. In *Proceedings of the IEEE International Symposium on Workload Characterization*, September 2008.

[6] Yungang Bao, Christian Bienia and Kai Li. A Framework for Benchmarking Network Workloads. TR_110415, 2011.

Open Discussion

Where do you think PARSEC should go?

What has to change?

Questions?

PARSEC

['pär-''sek] A unit of measure

The PARSEC Benchmark Suite Tutorial

- PARSEC 3.0 -

by

Yungang Bao, Christian Bienia, Kai Li

Princeton University

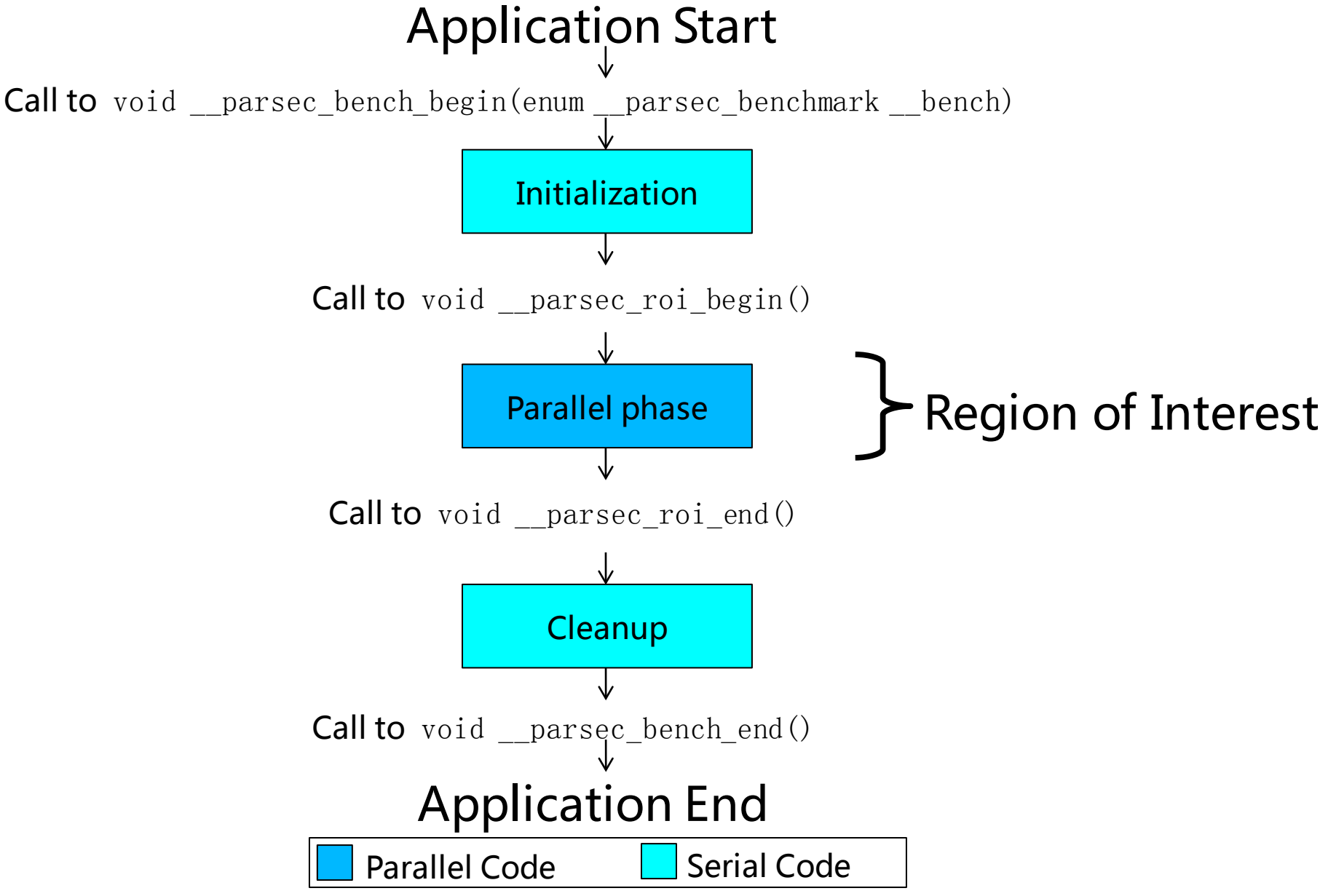
PARSEC Hooks

- Write code once, automatically insert into all workloads simply by rebuilding them
- The hooks API functions are called at specific, predefined locations by all workloads
- Implemented as a library
- Comes with several useful features already implemented (see `config.h` in hooks package)
- Read the man pages for detailed explanations

Enabling PARSEC Hooks

- Define macro ENABLE_PARSEC_HOOKS (and tell the compiler and linker to use the hooks header files and library)
- The following flags work with gcc:
  - For CFLAGS: `-DENABLE_PARSEC_HOOKS -I${PARSECDIR}/pkgs/hooks/inst/${PARSECPLAT}/include`
  - For LDFLAGS: `-L${PARSECDIR}/pkgs/libs/hooks/inst/${PARSECPLAT}/lib`
  - For LIBS: `-lhooks`
- The build configuration gcc-hooks does this already by default

PARSEC Hooks API



PARSEC Hooks Features

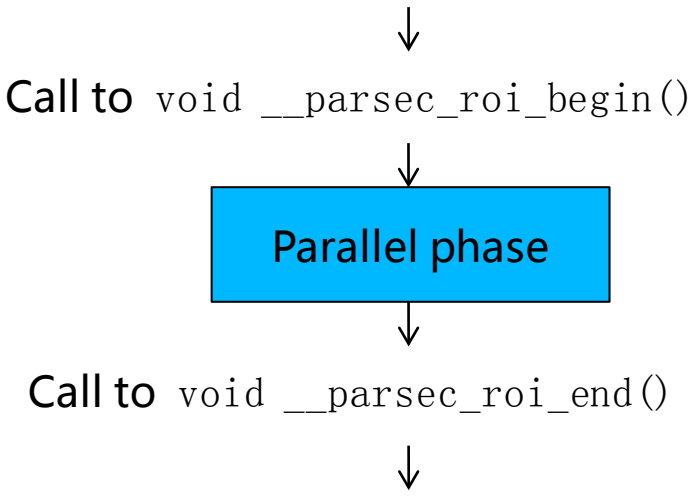
- Measure execution time of ROI
  Define ENABLE_TIMING in config.h (enabled by default)

- Control thread affinity via environment variables
  Define ENABLE_SETAFFINITY in config.h (enabled by default, Linux only)

- Execute Simics "Magic Instruction" before and after ROI
  Define ENABLE_SIMICS_MAGIC in config.h (disabled by default, Simics simulations only)

Assisting Simulations with PARSEC Hooks

You can use PARSEC Hooks to eliminate unnecessary simulation time:



Possible actions:
- Create checkpoint
- Switch from fast-forward to detailed simulation

Possible actions:
- Terminate simulation
- Switch to fast-forward
- Analyze simulation results

PARSEC Hooks Quiz

Q: Use PARSEC hooks to print out "Entering ROI" if build configuration `gcc-debug` is used. Test it with `canneal`.

PARSEC Hooks Answer (1)

Q: Use PARSEC hooks to print out "I like PARSEC" if build configuration `gcc-debug` is used. Test it with `canneal`.

A: Add a print statement to `__parsec_roi_begin()`:

```
#ifdef ENABLE_MY_OUTPUT
printf(HOOKS_PREFIX " I like PARSEC\n");
#endif //ENABLE_MY_OUTPUT
```

Define macro for build configuration `gcc-debug`:

```
#!/bin/bash

source ${PARSECDIR}/config/gcc.bldconf

CFLAGS="${CFLAGS} -O0 -g -DENABLE_MY_OUTPUT"
CXXFLAGS=" ${CXXFLAGS} -O0 -g -DENABLE_MY_OUTPUT"
```

PARSEC Hooks Answer (1)

Q: Use PARSEC hooks to print out "I like PARSEC" if build configuration gcc-debug is used. Test it with canneal.

A: Remove any existing installations of gcc-debug:

```
parsecmgmt -a uninstall -c gcc-debug
  -p hooks canneal
```

Build and run canneal:

```
parsecmgmt -a build -c gcc-debug -p canneal
parsecmgmt -a run -c gcc-debug -p canneal
```