BigDataBench:
A Scalable Big Data and AI Benchmark Suite

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& BenchCouncil

HPCA 2019, Washington D.C., USA
BigDataBench Tutorial, Part 1: Challenges in characterizing modern workloads

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A New Golden Age for Computer Architecture—Domain-specific co-design

- Only path left is Domain Specific Architectures
  - *(Forrest Gump)* Just do a few tasks, but extremely well

- Fundamental Changes in Technology
  - Ending of Moore’s Law
  - End of Dennard Scaling
  - ILP limitation and inefficiency
  - Amdahl’s Law

John Hennessy and David Patterson
A.M. TURING AWARD WINNERS
Domain-specific co-design is totally not new!

- The first computer is domain-specific
  - not general-purpose
  - Few specific tasks
    - Indeed use benchmarks
  - Machine language
  - Even without an OS
HPC: domain-specific co-design flagship

- FLOPS
- Benchmarks
  - HPCC (Linpack)
- OS
  - Eliminate OS noises
- Communication
  - RDMA
- Programming: MPI
Co-designing everything is brand-new!

- A big application can afford the co-design cost
  - Google, Alibaba, Facebook, WeChat ……

- Open-source software and chip
  - Amortize and accelerate co-design
The landscape of modern workloads

- Ideal target for co-design

- Big Data
- Machine learning (AI)
- Internet services
- Edge service

- IoT, Edge, Datacenter, HPC
HPC only takes 20% market share

Big Data, ML, Internet Service
Bad news!

- Abstractions are abandoned

- Ad-hoc solutions everywhere!
Big Data landscape

Big Data landscape 2017

Hadoop on-premise
- cloudera
- Hortonworks
- Pivotal
- Microsoft
- IBM
- Teradata

Hadoop in the cloud
- Amazon
- Microsoft
- IBM
- Google
- Red Hat

Streaming / In-memory
- Apache Spark
- Apache Kafka
- Apache Storm

Data analyst platforms
- Tableau
- Qlik
- SAS
- MicroStrategy

Data science platforms
- IBM
- SAS
- Knime
- Alteryx

BI platforms
- Microsoft PowerBI
- Tableau
- Qlik
- Alteryx

Machine learning
- TensorFlow
- PyTorch
- Scikit-learn

Horizontal AI
- Google
- Amazon Web Services
- IBM

Speech & NLP
- IBM Watson
- Google Cloud Speech

Search
- Google
- Amazon

Social analytics
- Facebook
- Twitter

Web / mobile / commerce analytics
- Adobe
- IBM

Data sources
- LinkedIn
- Twitter
- Facebook

Business intelligence
- Tableau
- Qlik

Data visualization
- Tableau
- Qlik

Cloud
- Microsoft Azure
- Google Cloud
- Amazon Web Services

IoT
- Amazon IoT
- IBM Watson IoT

Health
- Apple
- Fitbit

Financial & economic
- Bloomberg
- Eikon

Air / space / sea
- NASA

Location intelligence
- Foursquare

People / entities
- LinkedIn

Other
- Enigma

Cloud services
- AWS
- Google Cloud
- Azure

Cloud storage
- Amazon S3
- Google Cloud Storage

Data resources
- Data.gov
- Data.gov.tw

Open data
- Data.gov

Security
- AWS CloudFront
- Google Cloud Security

Customer service
- Salesforce
- Zendesk

Marketing - B2B
- Marketo
- Salesforce

Marketing - B2C
- Adobe
- Salesforce

Insurance
- MetLife
- Allstate

Healthcare
- Cedars-Sinai
- Mayo Clinic

Energy
- Shell
- BP

Transportation
- Uber
- Lyft

Retail
- Amazon
- Walmart

Government
- NASA
- DOE

Social media
- Twitter
- Facebook

Research
- MIT
- Stanford

IoT
- Amazon
- Google

IoT devices
- Raspberry Pi
- Arduino

Big DataBench

HPCA 2019

© Matt Turk (mattturck), Jim Hao (jinhao), & FirstMark (firstmarkcap) mattturck.com/bigdata2017
Bad news

- Find a workload (from Google), just do it.

- Architecture conferences become accelerator ones.

- Engineers have to put more (1000) accelerators in one node.
Fundamental Challenges

- Lack simple but elegant abstractions that help achieve both efficiency and general-purpose!
  - Single-purpose is a structure obstacle to resource sharing
Looking back at History!
Database - Relational Algebra

- Relational Algebra
  - Five primitive and fundamental operators
    - Theoretical foundation of database
    - Strong expression power
      - Compose complex queries

From E. F. Codd, A relational Model of Data for Large shared data banks. Communication of ACM, vol 13. no.6, 1970
Numerical Method

Seven motifs would be important for the next decade

7 “Motifs”

- Phillip Colella proposed
- Simulation in the physical sciences is done out using various combinations of the following core algorithms

Parallel Computing

Landscape of Parallel Computing Research

13 dwarfs
• Berkeley research group
• Define building blocks for creating libraries & frameworks
• A pattern of computation and communication

Other Challenges (1)

- Totally isolated
  - Isolation among industry and academia
  - Isolation among different Internet service providers.
Other Challenges (2)

- Workload churns
  - Software as a services
  - Hot spot functions keep changing
Other Challenges (3)

- Open-source components are not the best!
Outline

- The challenges and motivation of characterizing modern workloads
- What is BigDataBench?
- Tutorial schedule
- Benchmarking methodology, model and metrics
- The summary of BigDataBench 5.0
Understand essentials of modern workloads

- Specify the common requirements of Big Data and AI only algorithmically in a **paper-and-pencil** approach
  - Reasonably divorced from individual implementations

- **NAS parallel benchmarks**
Complexity of modern workloads

- The common requirements are handled differently or even collaboratively by datacenter, HPC, edge, and devices.

- Capture the differences and collaborations among IoT, edge, datacenter and HPC in handling Big Data and AI workloads.
A scalable big data and AI benchmark suite

- Treat big data, AI and Internet service workloads as a pipeline of units of computation handling (input or intermediate) data

- Target: find the main abstractions of time-consuming units of computation (data motifs)
  - The combination of data motifs = complex workloads
    - Similar to Relational Algebra
  - Data motifs-based scalable benchmarking methodology

Scalable Benchmark Methodology

- **Traditional**: create each benchmark or proxy for every possible workload
- **Our**: Data motif-based (Scalable)
  - Micro Benchmark---**Single** data motif
  - Component Benchmark---**Data motif combination with different weights**
  - Application Benchmark---**End-to-end** application
BigDataBench 5.0

Scalable Big Data and AI Benchmark Suite

Large scale system-level benchmarks

Micro Benchmark  Component Benchmark  Application Benchmark

100X Runtime Speedup  90%+ Average Accuracy

Data Adaptability  Configuration Adaptability  Cross Architecture

Proxy benchmarks for simulation

Real-world dataset and data generation tools

Table  Text  Graph  Matrix  Image  Audio

Structured  Semi-structured  Un-structured

AI  Graph  Offline Analytics  Online Service

Streaming  Data Warehouse  NoSQL

44 Workloads covering 7 types

16 Software stack

Flink  GraphX  Spark  MVAPICH  DataMPI  NoSql  MPI  Caffe

Hive  Lightning-Fast Cluster Computing  Alibaba  JStorm  TensorFlow

Impala  Shark  Hadoop RDMA  hadoop  GraphLab

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100X Runtime Speedup
Representative Domains in
BigDataBench 5.0

Search Engine
Social Network
Electronic Commerce

Taking up 80% of internet services according to page views and daily

Internet Service
Search engine, Social network, E-commerce

Top 20 websites

Recognition Science
(AI)


100’s of new
VIDEOS on YouTube
every minute

600+ new
MUSIC streaming on
PANDORA every minute

13000+ hours
PHOTOS on FLICKR every
minute

6600+ new
data growth
IMAGES, VIDEOS,
documents, ...

Medical science

DDBJ/EMBL/GenBank database Growth

http://www.ddbj.nig.ac.jp/breakdown_stats/dbgrowth-e.html#dbgrowth-graph
BigDataBench Evolution

- **2013.7**
  - BigDataBench 1.0
    - Search engine
    - 6 workloads

- **2013.12**
  - BigDataBench 2.0
    - Typical Internet service domains
    - An architectural perspective
    - 19 workloads & data generation tools

- **2014.4**
  - BigDataBench 3.0
    - Multidisciplinary effort
    - 32 workloads: diverse implementations

- **2014.12**
  - BigDataBench 3.1
    - 5 application domains: 14 data sets and 33 workloads
    - Same specifications: diverse implementations
    - Multi-tenancy version
    - BigDataBench subset and simulator version

- **2015.12**
  - BigDataBench 3.2
    - New software stack: Flink, JStorm, GraphX, GraphLab
    - New workload type: Streaming, Graph processing
    - New dataset and workloads

- **2018.03**
  - BigDataBench 4.0
    - Data motif-based benchmarking methodology
    - Micro, component, application benchmark specification
    - 13 real-world data sets, 47 benchmarks, 7 workload types

- **2014.12**
  - BigDataBench 2.0
    - 11 data analytics workloads
    - Mixed data analytics workloads

**New software stack:** Flink, JStorm, GraphX, GraphLab
**New workload type:** Streaming, Graph processing
**New dataset and workloads**

**Multidisciplinary effort**
32 workloads: diverse implementations

**Typical Internet service domains**
An architectural perspective
19 workloads & data generation tools

**Data motif-based benchmarking methodology**
Micro, component, application benchmark specification
13 real-world data sets, 47 benchmarks, 7 workload types
Moves to BenchCouncil since V5.0

- BenchCouncil (international Open Benchmarking Council)
  - Non-profit organization

- http://www.benchcouncil.org

- Everyone can join BenchCouncil and contribute to BigDataBench
BigDataBench Publications

- Data Motifs: A Lens Towards Fully Understanding Big Data and AI Workloads. **PACT’18.**
- Data Motif-based Proxy Benchmarks for Big Data and AI Workloads. **IISWC 2018.**
- CVR: Efficient Vectorization of SpMV on X86 Processors. **CGO’18.**
- **Auto-tuning Spark Big Data Workloads on POWER8: Prediction-Based Dynamic SMT.** **PACT’16**
- Understanding Big Data Analytics Workloads on Modern Processors. **TPDS’16**
- Characterizing and subsetting big data workloads. **IISWC 2014**
- BigDataBench: a Big Data Benchmark Suite from Internet Services. **HPCA’14**
- Characterizing data analysis workloads in data centers. **IISWC 13 best paper award.**
- BDGS: A scalable big data generator suite in big data benchmarking. **WBDB 2013.**
BigDataBench Users

- [http://prof.ict.ac.cn/BigDataBench/users/](http://prof.ict.ac.cn/BigDataBench/users/)
- Industry users
  - Accenture, BROADCOM, SAMSUMG, Huawei, IBM
- About 600+ published papers using or citing BigDataBench
  - VLDB/SIGMOD, SC, FAST, ASPLOS, ISCA/Micro/HPCA and etc.
Industry Standard: BigDataBench-DCA

- China’s first industry-standard big data benchmark suite
  - http://prof.ict.ac.cn/BigDataBench/industry-standard-benchmarks/
  - Telecom Research Institute of Ministry of Industry and Information Technology, ICT, CAS, Huawei, China Mobile, Sina, ZTE, Intel (China), Microsoft (China), IBM CDL, Baidu, INSPUR, ZTE, 21vianet and UCloud
Outline

- The challenges and motivation of characterizing modern workloads
- What is BigDataBench?
- Tutorial introduction
- Benchmarking methodology, model and metrics
- The summary of BigDataBench 5.0
Main topics (1)

(1) The challenges and motivation for characterizing modern Big Data and AI workloads.

(2) Why scalable benchmarking methodology matters? What is a data motif? How many data motifs can characterize and compose modern comprehensive Big Data and AI workloads?

(3) Micro benchmarks of Modern Big Data and AI workloads.
Main topics (2)

- The essentials of modern big data and AI workloads (component benchmarks)
  - Image classification, Image generation, Text-to-Text Translation, Image-to-text, Image-to-image, Speech-to-text, Word embedding, Face embedding, Object detection, Recommendation, Graph Model, clustering, classification, PageRank, Feature extraction, Search engine indexing. Their data sets, algorithms, and involved data motifs.
Main topics （3）

(4) Two end-to-end application benchmarks: Mixed data center workloads, and E-commerce search (Joint work with Alibaba).

(5) The proxy benchmarks for modern Big Data and AI workloads that shorten the execution time by 100s times.
Main topics (4)

(6) How to use BigDataBench 5.0?

(7) How to contribute to BigDataBench? How to join BenchCouncil (http://www.benchcouncil.org).
## Schedule (1)

<table>
<thead>
<tr>
<th>Time</th>
<th>Session Description</th>
<th>Speaker</th>
<th>Slides</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30-09:00</td>
<td>Challenges and motivation for characterizing modern Big Data and AI workloads</td>
<td>Jianfeng Zhan</td>
<td>[Slides]</td>
</tr>
<tr>
<td>09:00-09:30</td>
<td>Benchmarking Methodology, models, and metrics</td>
<td>Jianfeng Zhan</td>
<td>[Slides]</td>
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<tr>
<td>09:30-10:00</td>
<td>Summary of Benchmarks</td>
<td>Jianfeng Zhan</td>
<td>[Slides]</td>
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<tr>
<td>10:00-10:30</td>
<td>Micro benchmarks</td>
<td>Wanling Gao</td>
<td>[Slides]</td>
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<td>10:30-10:50</td>
<td>Coffee Break</td>
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<tr>
<td>10:50-12:00</td>
<td>Essentials of modern big data and AI workloads</td>
<td>Wanling Gao</td>
<td>[Slides]</td>
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<tr>
<td>14:00-14:30</td>
<td>Two end-to-end application benchmarks</td>
<td>Jianfeng Zhan</td>
<td>[Slides]</td>
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<tr>
<td>14:30-15:40</td>
<td>How to use BigDataBench</td>
<td>Chen Zheng</td>
<td>[Slides]</td>
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<tr>
<td>15:40-16:00</td>
<td>Coffee Break</td>
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<tr>
<td>16:00-16:50</td>
<td>Big Data and AI proxy benchmarks</td>
<td>Wanling Gao</td>
<td>[Slides]</td>
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<tr>
<td>16:50-17:00</td>
<td>How to contribute to BigDataBench?</td>
<td>Chen Zheng</td>
<td>[Slides]</td>
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<td></td>
<td>How to join BenchCouncil (<a href="http://www.benchcouncil.org">http://www.benchcouncil.org</a>)</td>
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<tr>
<td>17:00-17:10</td>
<td>Wrap-Up</td>
<td>Jianfeng Zhan</td>
<td>[Slides]</td>
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Web resources

- http://www.benchcouncil.org/BigDataBench

- http://prof.ict.ac.cn/BigDataBench

- Slides will be available from

- http://www.benchcouncil.org/benchmarks.html