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Efficiency + Scalability = High-Performance Data Computing

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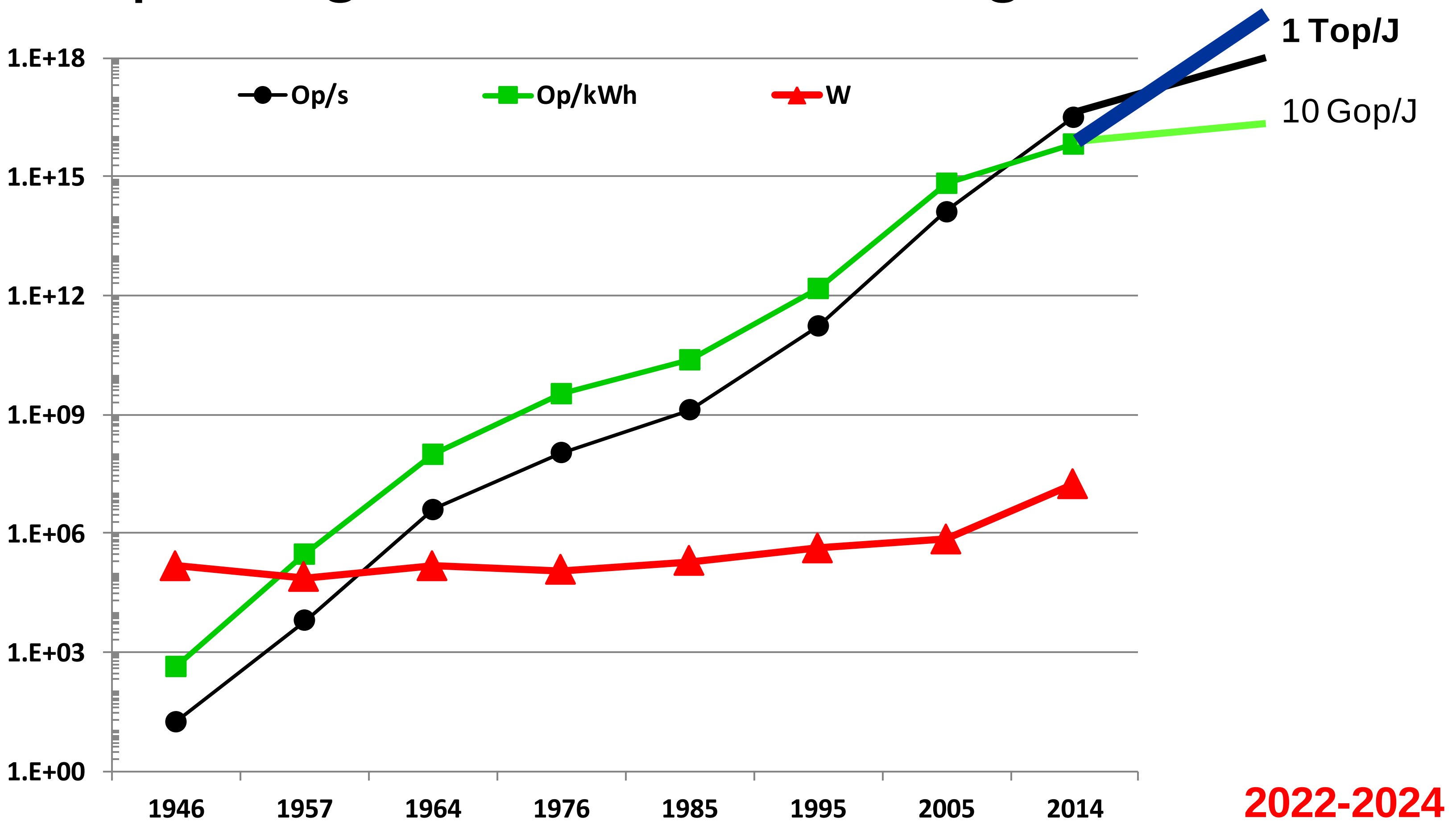
Fundamental Challenge: First time in 70 years

- Energy efficiency improvement lags behind speed growth → research goal: **1000 Gop/J**

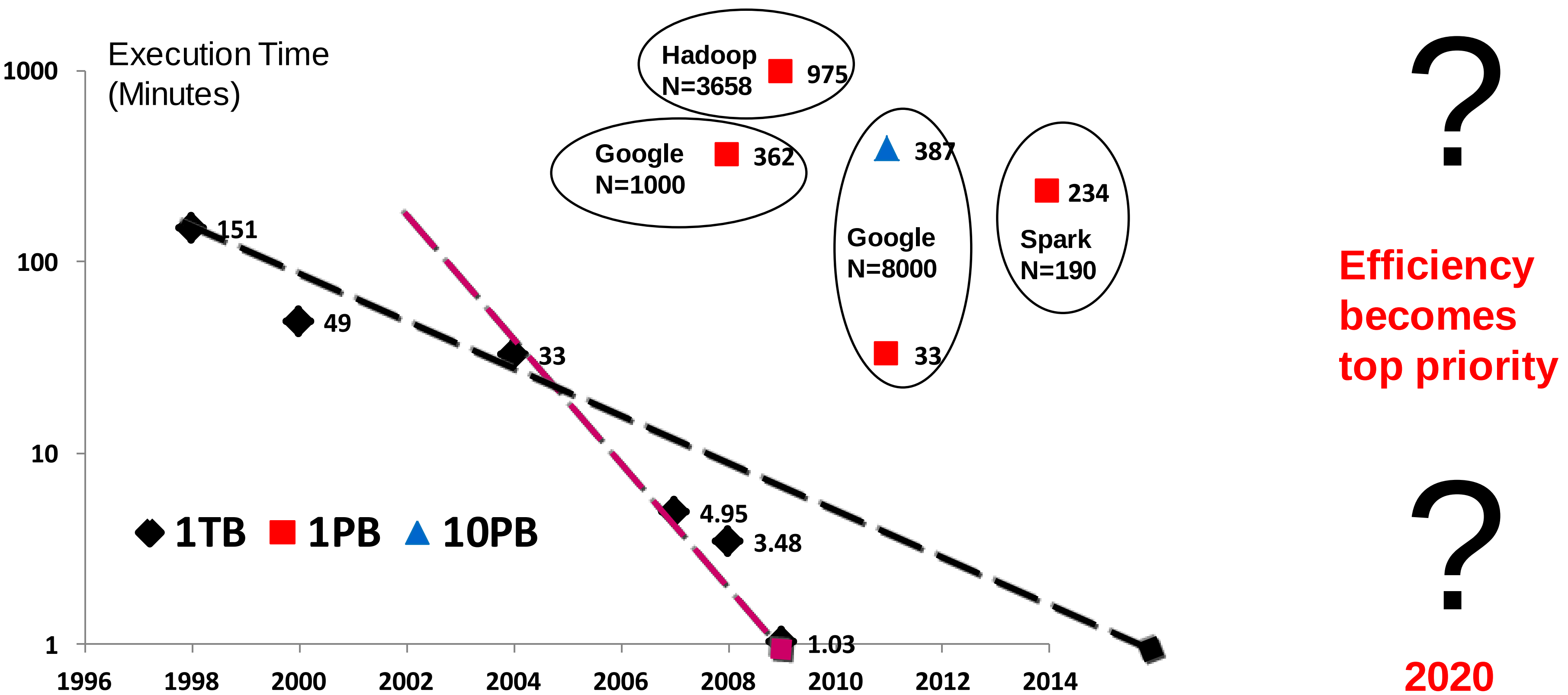


Big Data Computing Does Not Emphasize Efficiency

- Big data computing cares about five nonfunctional metrics
  - **Fault tolerance**: how well are faults handled
    - Now provides good-enough availability for 100 PB of data
  - **Usability**: how easy is it to write a scalable application
    - Now a sort program on Hadoop only needs a few dozens of lines of code, and need not change with data size (1GB, 1TB, 1PB) or system size (1 node, 100 nodes)
  - Performance metrics
    - **Scalability**: how much data can be handled
      - Now 10 PB data can be sorted in hours; EB data managed
    - **Speed**: 1 / seconds for a given data size
    - Speed **Efficiency**: (sustained) speed / peak speed
      Or **Energy Efficiency**: **speed / W** = **operations / Joule**

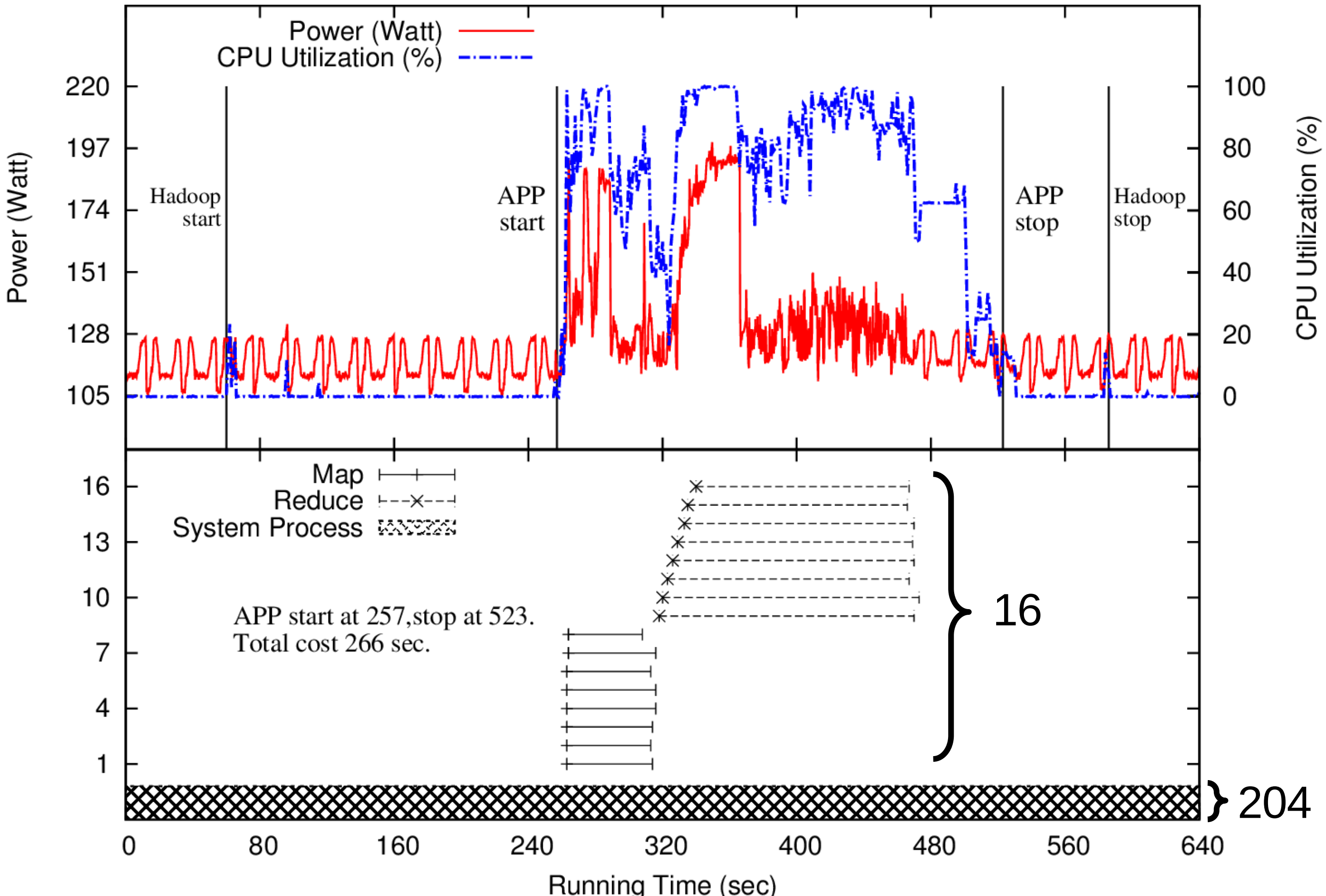
Four Stages of Jim Gray's Data Challenge

1. Terasort challenge raised (sort 1TB in 1 minute)
2. Speed growth: TB/minute in 2009 (ad hoc methods)
3. Data size growth: TB→PB→10PB (Map-Reduce)
4. Efficiency: 1PB sorted on 190 AWS instances in 2014



Data Computing Efficiency Is Bad

- Sort 4GB: performance & power consumption
  - SW: Hadoop 0.20.2 over CentOS 5.3
  - HW: one cluster node (2 4-core E5620 CPUs, 16GB mem, 150GB disk)



Speed Efficiency

(Sustained/Peak)

Payload:	**0.002%**
Linpack:	**94.5%**
Total op:	4.22%
Instruction:	4.72%

Energy Efficiency

(Operations per Joule)

Payload:	**1.55×10^4**
Linpack:	**7.26×10^8**
Total op:	2.20×10^7
Instruction:	2.45×10^7

Three Ways to Increase Efficiency

- Functional sensing
  - Significantly reduce amounts of data collected
- Acceleration by elastic processors
  - Dynamically transform hardware to match applications characteristics
- DataMPI
  - Transfer HPC knowledge to data computing
    - Buffer-to-buffer to key-value communication

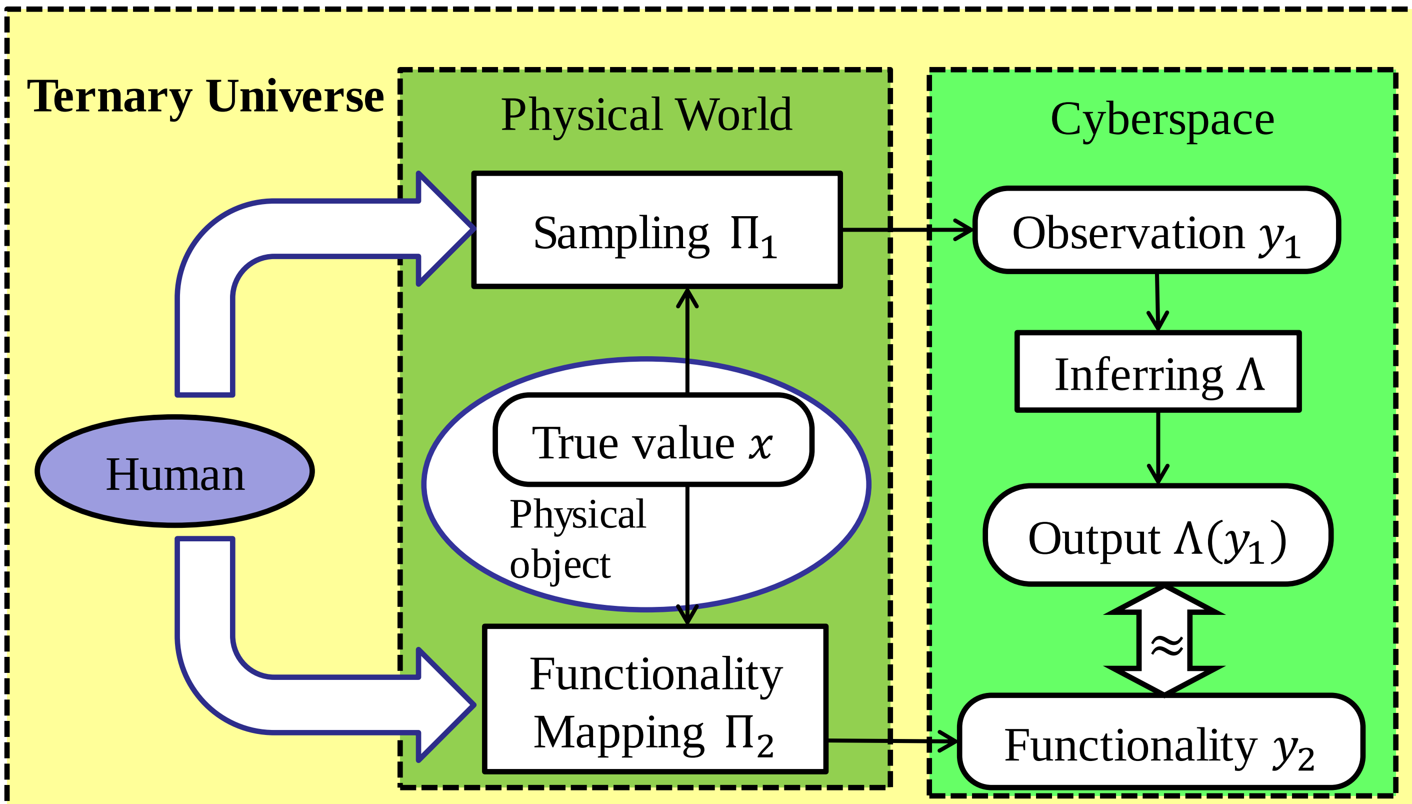
Functional Sensing Model in the Ternary Universe

Human decides the functionality according to the needs, and defines it with a functionality mapping Π_2

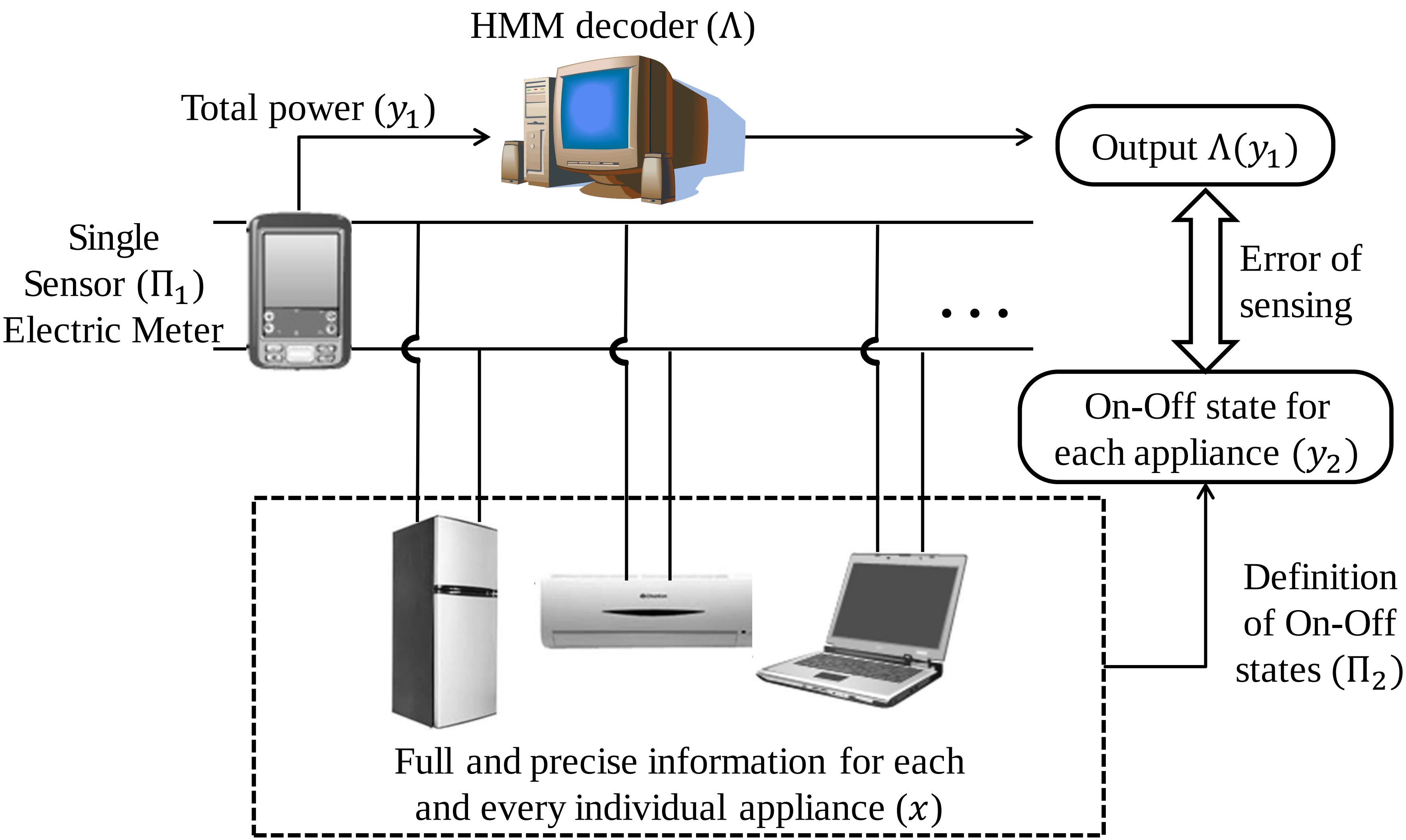
$$\Lambda(y_1) \qquad \begin{aligned} y_1 &= \Pi_1(x) \\ y_2 &= \Pi_2(x) \end{aligned}$$

We cannot get true value x, but only an observation y_1

Build an inferring algorithm Λ to calculate an approximate value of y_2, i.e., $\Lambda(y_1)$



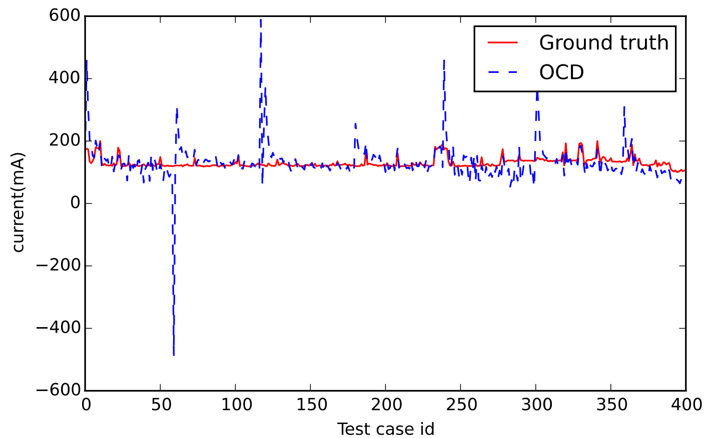
On-Off State Sensing of *N* Appliances in a Household with 1 Sensor



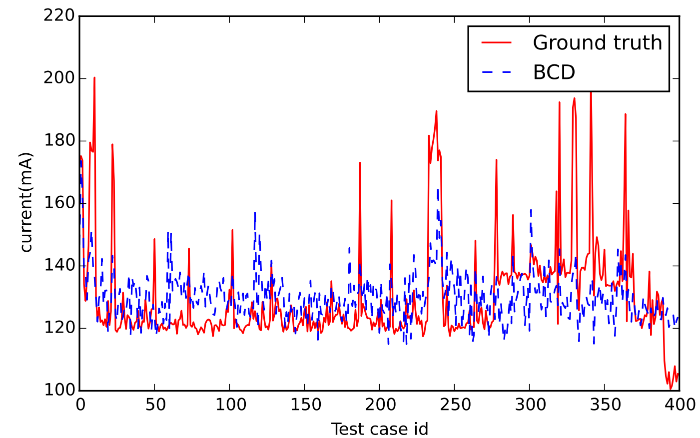
Bayesian Current Disaggregating (BCD)

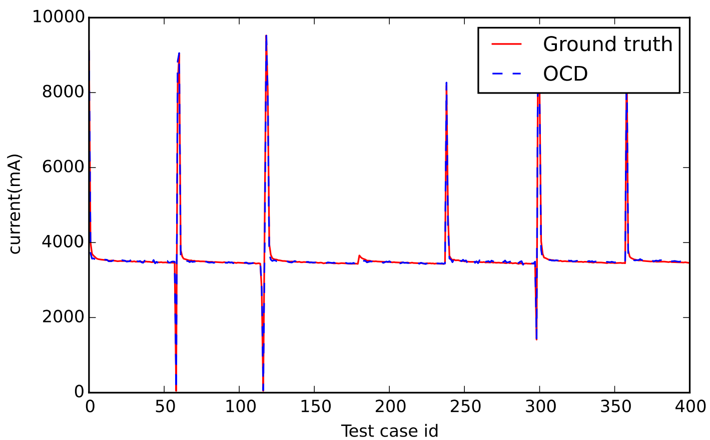
Results for a Laptop and a Fridge

	RMSE of OCD	**RMSE of BCD**	**Standard Deviation**
Laptop	42.01 mA	11.86 mA	14.58 mA
Fridge	50.43 mA	34.49 mA	603.07 mA

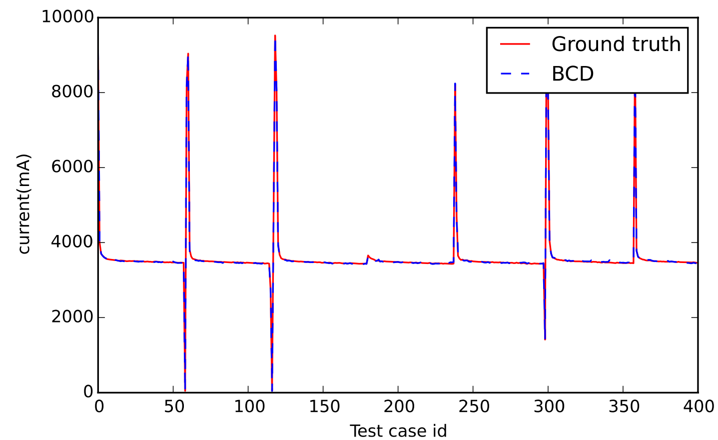


Laptop

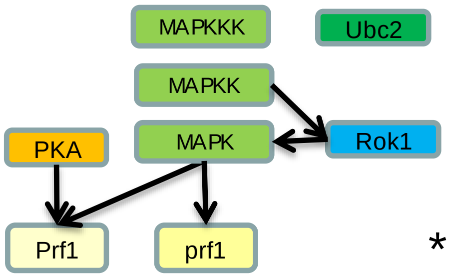




Fridge



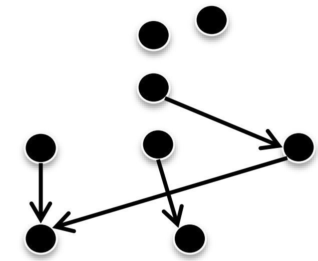
Inferring Cell-scale Signaling Representational Networks



*

Cell-scale signaling network (x)

Define the representational network over a specific timescale (Π_2)

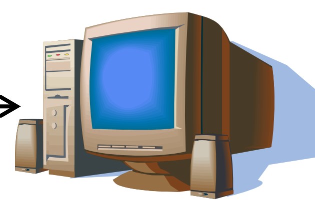


The representational network over a specific timescale (y_2)

Measurements over a specific timescale(Π_1)

**

Concentrations of proteins (y_1)



The CCELL algorithm (Λ)

RMSE

$$\begin{bmatrix} 0.8 & \cdots & 0.1 \\ \vdots & \ddots & \vdots \\ 0.0 & \cdots & 0.9 \end{bmatrix}$$

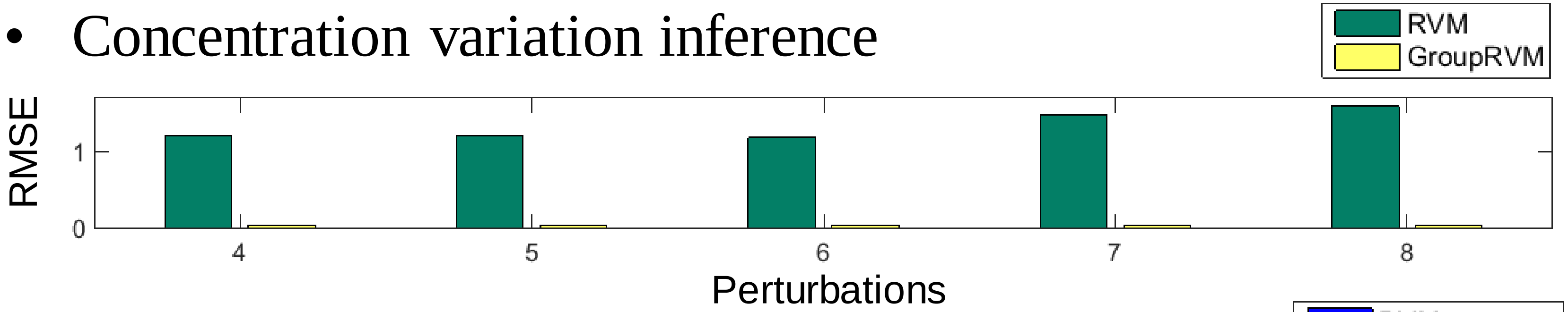
The inferred transition matrix of the representational network ($\Lambda(y_1)$)

* Vollmeister et al. 2012

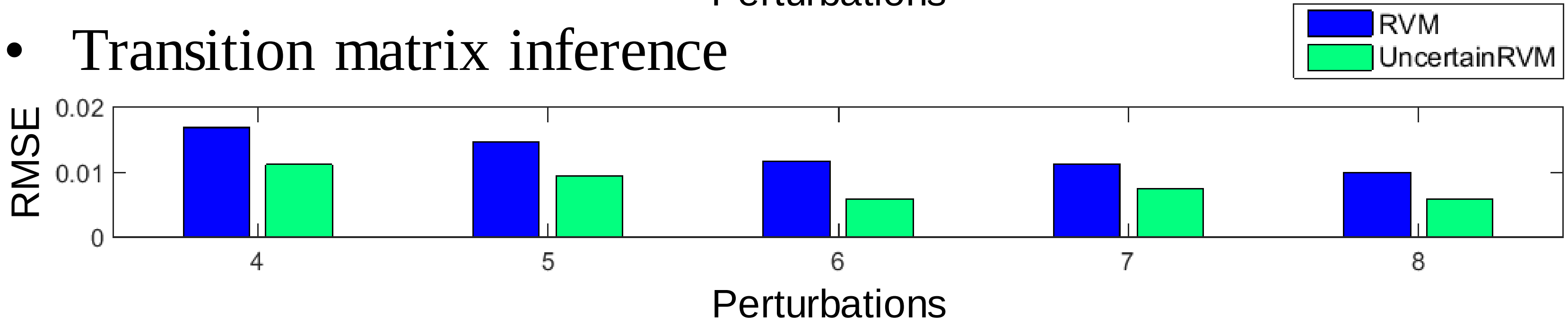
** en.wikipedia.org/wiki/ELISA

The Experimental Results of CCELL

- The synthetic cell-scale signaling network
  - JAK-STAT, GR, ERK and p38
  - **300 proteins**
- **150 antibodies** (tried 30~300 antibodies)
- Concentration variation inference



- Transition matrix inference



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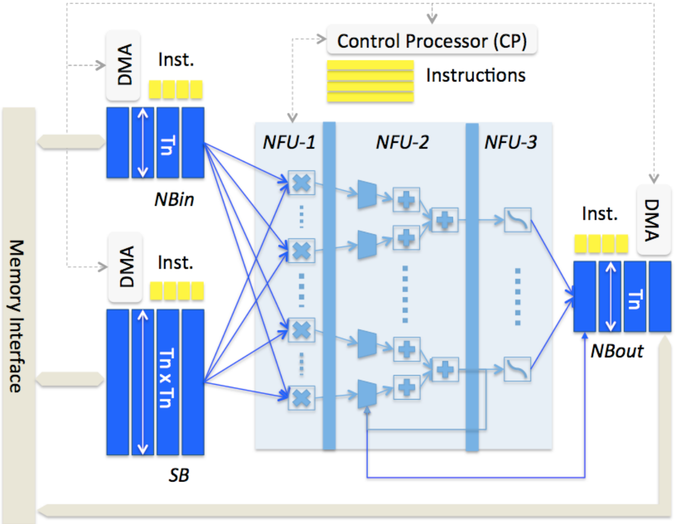
Nie Lei. Research on the model and perceiving methods for representational networks of biological systems [D]. Beijing: Institute of Computing Technology, Chinese Academy of Sciences, 2015 (In Chinese)

Elastic Processor

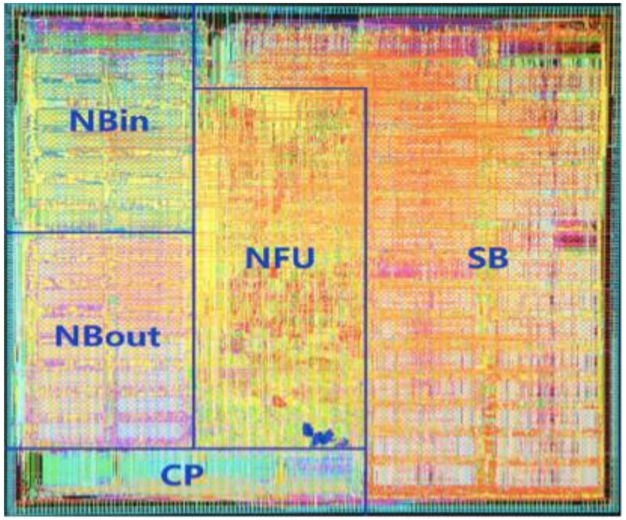
- A new architecture style (FISC)
  - Featuring **function instructions** executed by **programmable ASIC** accelerators
  - Targeting 1000 GOPS/W = 1 Top/J

	CISC Intel X86	RISC ARM	FISC Function Instruction Set Computer
Chip types:	**10s**	**1K**	**10K**
Power:	**10~100W**	**1~10W**	**0.1~1W**
Apps/chip:	**10M**	**100K**	**10K**

DianNao: A Neural Network Accelerator

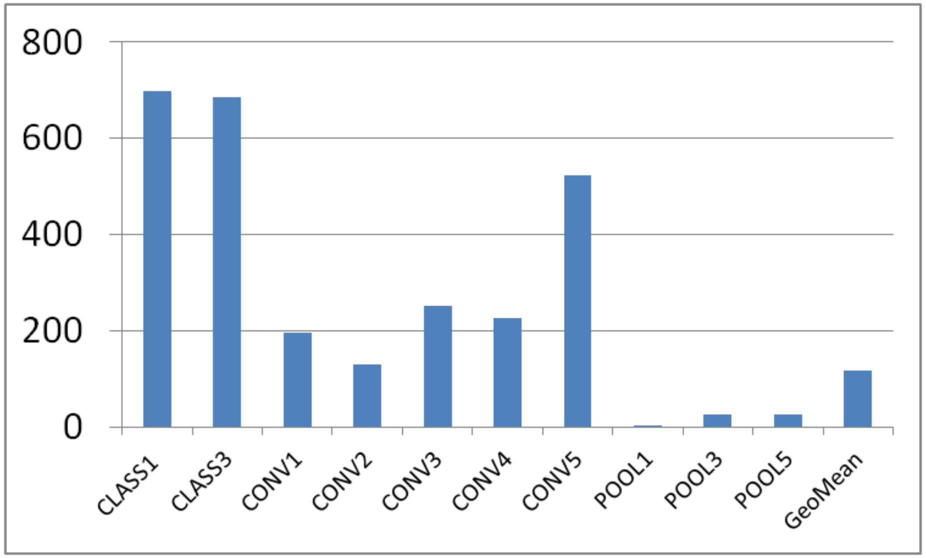


Architecture



IC Layout in GDSII

- Support multiple neural network algorithms, such as DNN, CNN, MLP,SOM
- Pre-tape-out simulation results:
  0.98GHz, 452 GOPS, 0.485W
  931.96 GOPS/W @ 65nm
- **ASPLOS 2014 Best Paper**

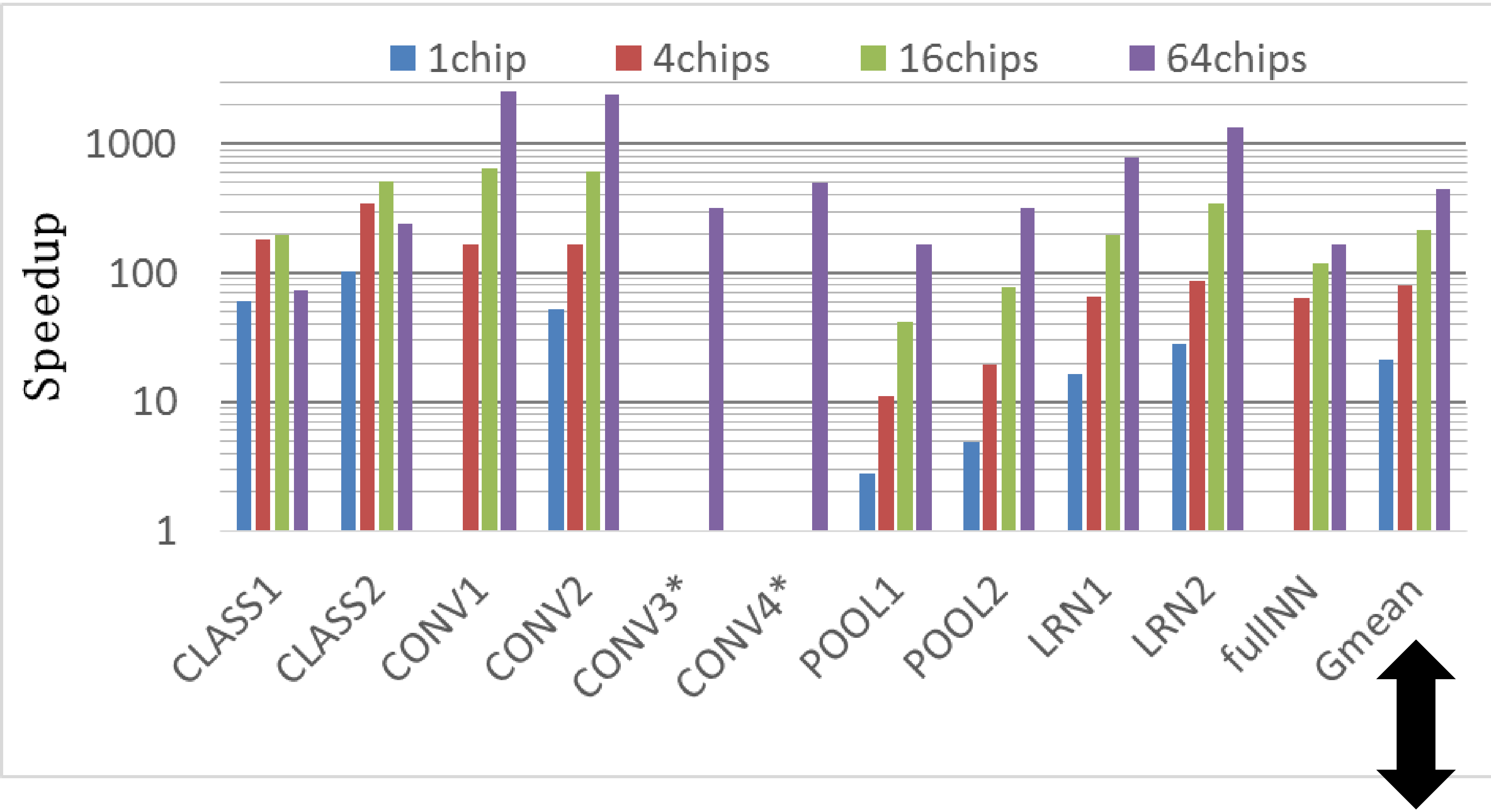


700 speedup over Intel Core i7

Three More Accelerators

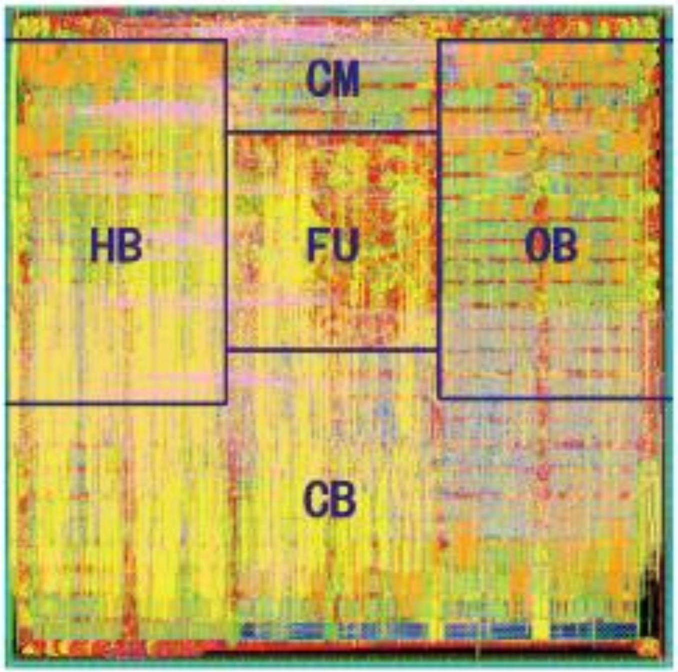
- **DaDianNao**: An NN supercomputer containing up to 64 chips
  - MICRO’14 best paper
  - **100-250 GOPS/W (@28nm)**
- **PuDianNao**: A polyvalent machine learning accelerator
  - ASPLOS’15
  - **300-1200 GOPS/W**
- **ShiDianNao**: A vision accelerator for embedded devices (cameras)
  - ISCA’15
  - **2000-4000 GOPS/W (16-bit)**
- Compared to **931 GOPS/W @65nm** for **DianNao**

DaDianNao: An NN Supercomputer



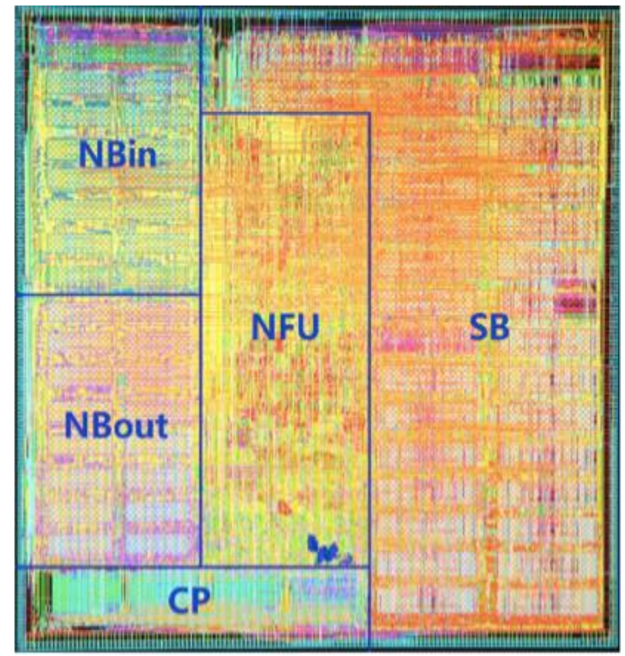
- In average, 450x speedup and 150x energy saving over K20 GPU for a 64-chip system

PuDianNao



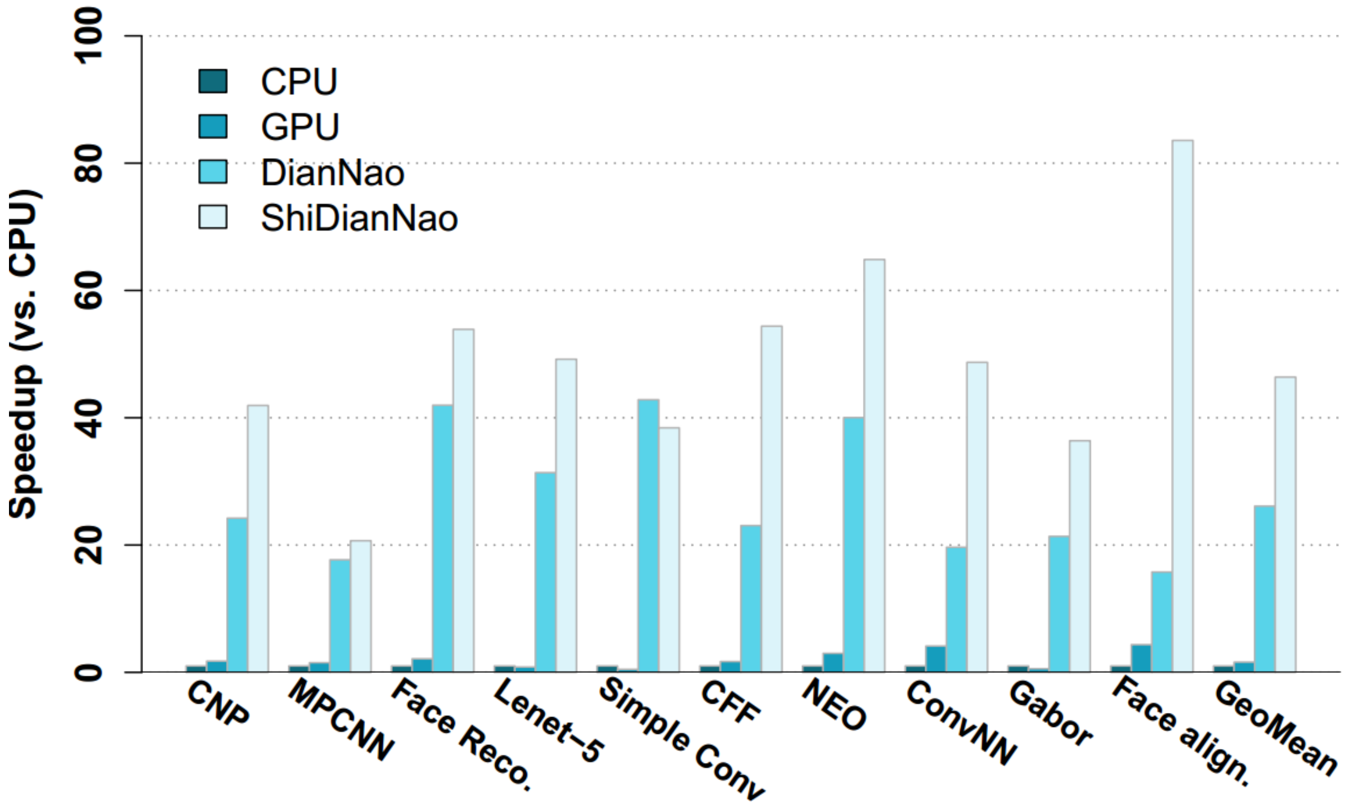
- Area: 3.51 mm^2
- Power: 596 mW
- Freq: 1 GHz
- Supporting a dozen types of ML algorithms: CNN/DNN, LR, Kmeans, SVM, NB, KNN, CT, …

DianNao



- Area: 3.02 mm2
- Power: 485 mW
- Freq: 0.98 GHz
- Supporting CNN/DNN

ShiDianNao: An vision accelerator for embedded devices

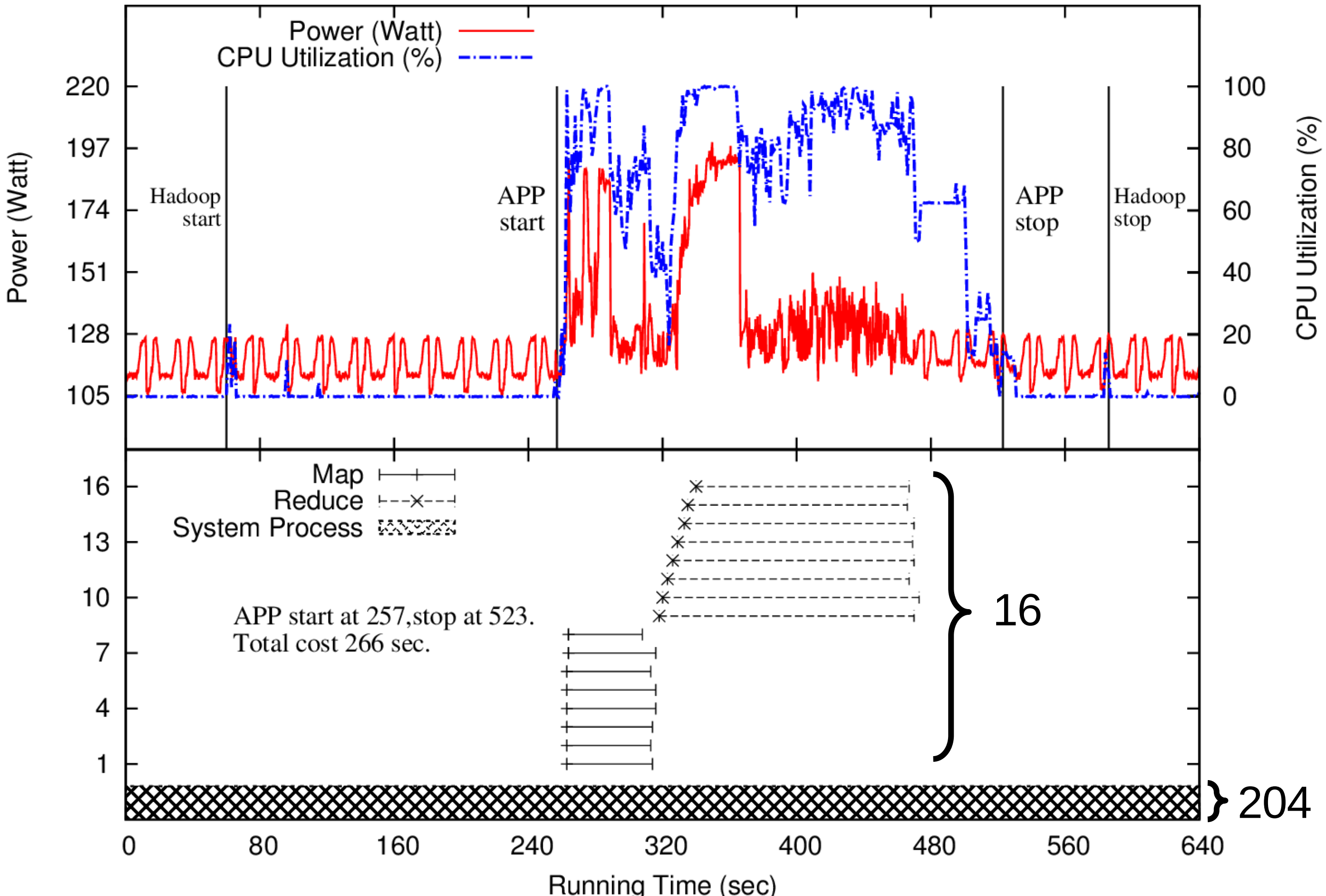


Speedup
46.38x vs. CPU
28.94x vs. GPU
1.87x vs. DianNao

Energy saving
4688.13x vs. GPU
63.48x vs. DianNao

Hadoop Efficiency Is Low

- Lacks a high-performance communication substrate
  - Use HTTP, RPC, direct Sockets over TCP/IP to communicate
  - Can MPI be used for big data?



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Direct MPI Use not Easy or Scalable

//MapReduce
map (String lineno, String contents) {
for each word w in contents {
EmitIntermediate(w, 1);
}
}

reduc) {
incre a);
}

LOC : 110

//MPI
process mapper:
1st> load input
2nd> parse token
3rd> MPI_Send (serialization)
…

process
1st>
(De
2nd> inc t
3rd> save output
…

LOC: 850

WordCount via MapReduce：Scalable over 1GB, 1TB, 1PB …

Desired Sort Code via DataMPI: Scalable and Easy to Write

```
public class Sort {
    public static void main(String[] args) {
        try {
            int rank, size;
            Map<String, String> conf = new HashMap<String, String>();
            conf.put(MPI_D_Constants.KEY_TYPE, java.lang.String.class.getName());
            conf.put(MPI_D_Constants.VALUE_TYPE, java.lang.String.class.getName());
            MPI_D.Init(args, MPI_D.Mode.Common, conf);
            if (MPI_D.COMM_BIPARTITE_O != null) {
                rank = MPI_D.Comm_rank(MPI_D.COMM_BIPARTITE_O);
                size = MPI_D.Comm_size(MPI_D.COMM_BIPARTITE_O);
                String[] keys = loadKeys(rank, size);
                if (keys != null) {
                    for (int i = 0; i < keys.length; i++) {
                        MPI_D.Send(keys[i], "");
                    }
                }
            } else {
                rank = MPI_D.Comm_rank(MPI_D.COMM_BIPARTITE_A);
                size = MPI_D.Comm_size(MPI_D.COMM_BIPARTITE_A);
                Object[] keyValue = MPI_D.Recv();
                while (keyValue != null) {
                    System.out.println("Task " + rank + " of " + size + " [illegible] key is "
                        + ((String) keyValue[0]) + ", valu[illegible] is " + (([illegible]g) keyValue[1]));
                    keyValue = MPI_D.Recv([illegible]
                }
            }
            MPI_D.Finalize();
        } catch (MPI_D_Exception e) {
            e.printStackTrace[illegible]
        }
    }
}
```

init

rank/size

send

recv

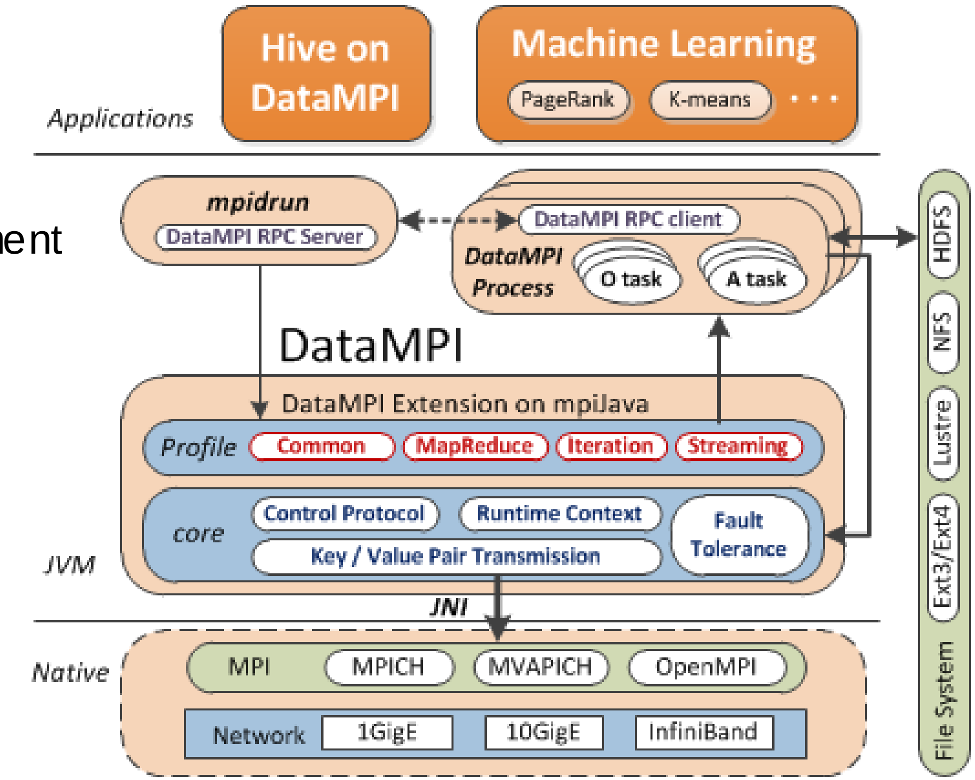
finalize

33 lines of code

1 GB, 1 TB, 1PB

DataMPI.ORG

- **Core**
  - Execution pipeline
  - Key-value communication
  - Native direct IO for buffer management
  - Key-value based checkpoint
- **Profiles**
  - Additional code sets
  - Each profile for a typical mode
- **mpidrun**
  - Communicator creation
  - Dynamic process management
  - Data-centric task scheduling



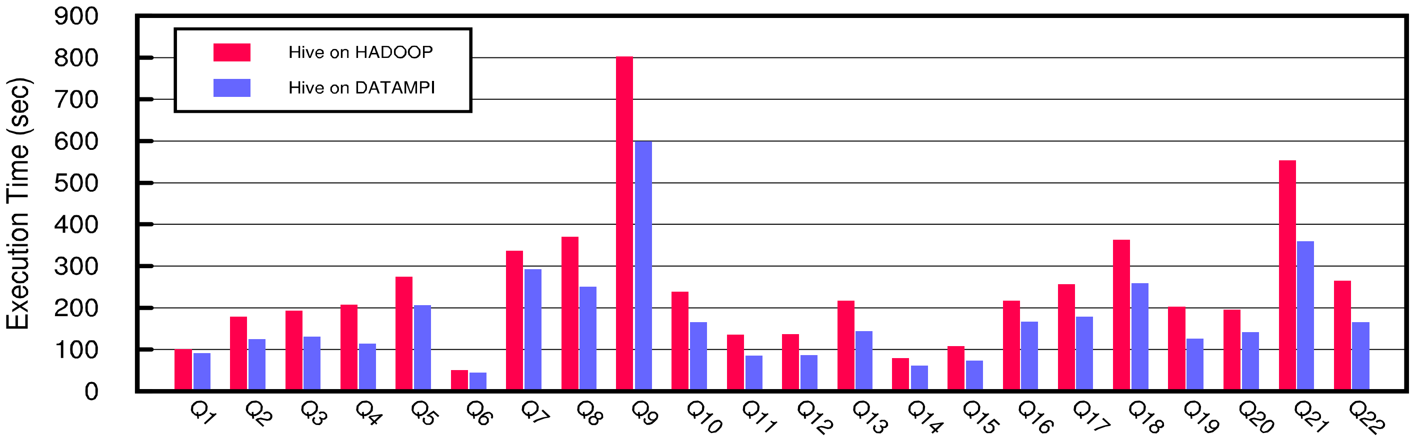
Command: *$ mpidrun -f <hostfile> -O <n> -A <m> -M <mode> -jar <jarname> <classname> <params>*

Example: *$ mpidrun -f ./conf/hostfile -O 64 -A 64 -M COMMON -jar ./benchmark/dmb-benchmark.jar dmb.Sort /text/64GB-text /text/64GB-output*

Hive on DataMPI

A first attempt to propose a general design for fully supporting and accelerating data warehouse systems with MPI

- **Functionality & Productivity & Performance**
  - Support Intel **HiBench** (2 micro benchmark queries) & **TPC-H** (22 app queries)
  - Only **0.3K** LoC modified in Hive
  - HiBench: **30%** performance improvement on average
  - TPC-H: **32%** improvement on average, up to **53%**



Performance Benefits with 40 GB data for 22 TPC-H queries

Lu Chao, Chundian Li, Fan Liang, Xiaoyi Lu, Zhiwei Xu. *Accelerating Apache Hive with MPI for Data Warehouse Systems*. ICDCS 2015, Columbus, Ohio, USA, 2015

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