# A Distributed Timing Analysis Framework for Large Designs


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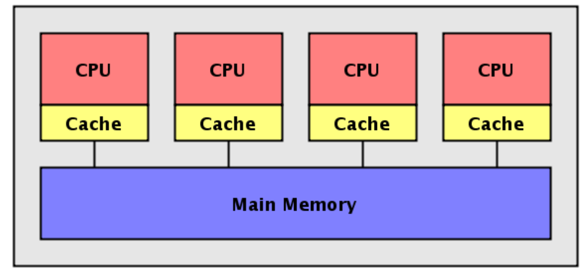
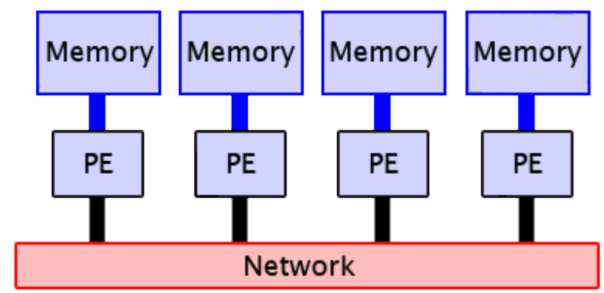
# Distributed Timing – Motivation and Goal

- ❑ **Motivation**
  - ❑ Ever increasing design complexity
    - Hierarchical partition
    - Abstraction
    - Multi-threading timing analysis
  - ❑ Too costly to afford high-end machines




Multi-threading in a single machine

- ❑ **Create a distributed timing engine**
  - ❑ Explore a feasible framework
  - ❑ Prototype a distributed timer
  - ❑ Scalability
  - ❑ Performance




Distributed computing on a machine cluster

# State-of-the-art Distributed System Packages

- **Open-source cloud computing platforms ([https://hadoop.apache.org/](https://hadoop.apache.org/))**
  - Hadoop
    - Reliable, scalable, distributed MapReduce platform on HDFS
  - Cassandra
    - A scalable multi-master database with no single points of failure
  - Chukwa
    - A data collection system for managing large distributed systems
  - Hbase
    - A scalable, distributed database that supports structured data storage
  - Zookeeper
    - Coordination service for distributed application
  - Mesos
    - A high-performance cluster manager with scalable fault tolerance
  - Spark
    - A fast and general computing engine for iterative MapReduce

## The Questions Are

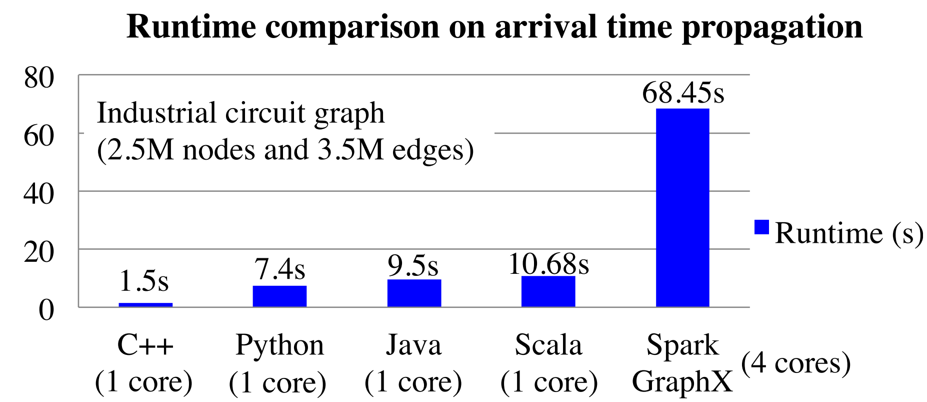
- ***Are these packages really suitable for our applications?***
  - Google/Hadoop MapReduce programming paradigm
  - Spark in-memory iterative batch processing

- ***What are the potential hurdles for EDA to use big-data tools?***
  - Big-data tools are majorly written in JVM languages
  - EDA applications highly rely on high-performance C/C++
  - Rewrites of numbers of codes

- ***What are the differences between EDA and big data?***
  - Computation intensive vs Data intensive
  - EDA data is more connected than many of social network

# An Empirical Experiment on Arrival Time Propagation

- ❑ **Bebchmark**
  - ❑ Timing graph from ICCAD 2016 CAD contest (*superblue18*)
    - 2.5M nodes
    - 3.5M edges
- ❑ **Implementation**
  - ❑ Spark – 4 cores
  - ❑ Java, Scala, etc. – 1 core
  - ❑ C++ – 1 core



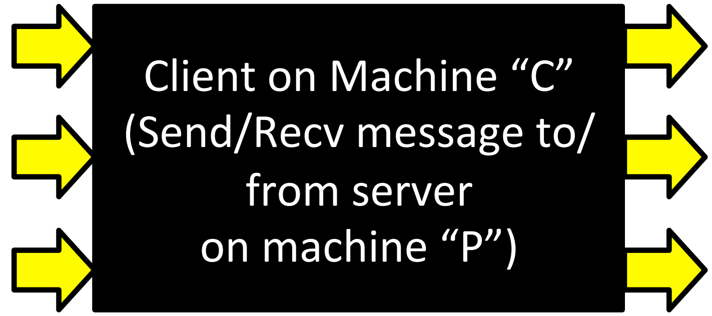

| Implementation | Spark 1.4 (RDD + GraphX Pregel) | Scala (Dijkstra) | C++ (Dijkstra) |
|---|---|---|---|
| Runtime (s) | 68.45 | 10.68 | **1.50** |

*Overhead of GraphX and message passing*

*Overhead of JVM*

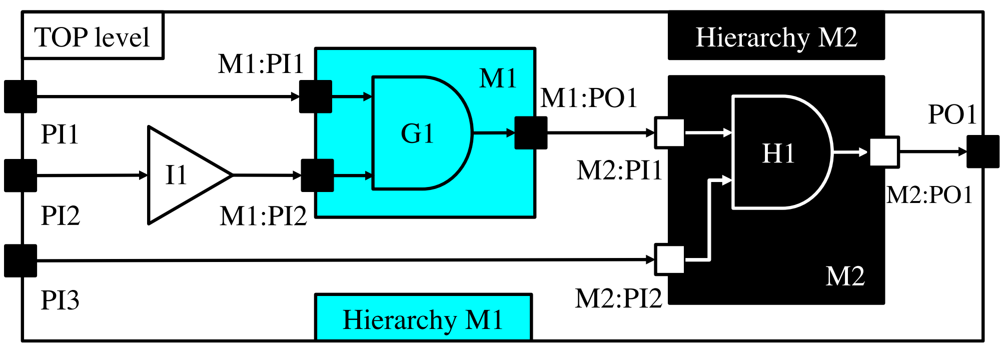
# The Proposed Framework for Distributed Timing

- ❑ **Focus on general design partitions**
  - ❑ Logical, physical, and hierarchies
  - ❑ Across multiple machines (DFS)

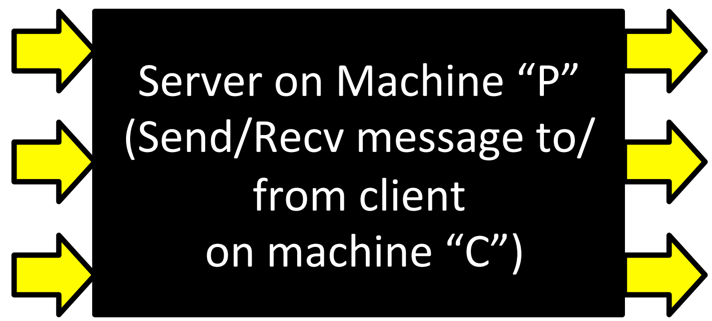



Client machine IP: 1.23.456.789

- ❑ **Single-server multiple-client model**
  - ❑ Server is the centralized communicator
  - ❑ Client exchange boundary timing with server




*An example design with three partitions*




Server machine IP: 140.110.44.32

# Key Components in our Framework

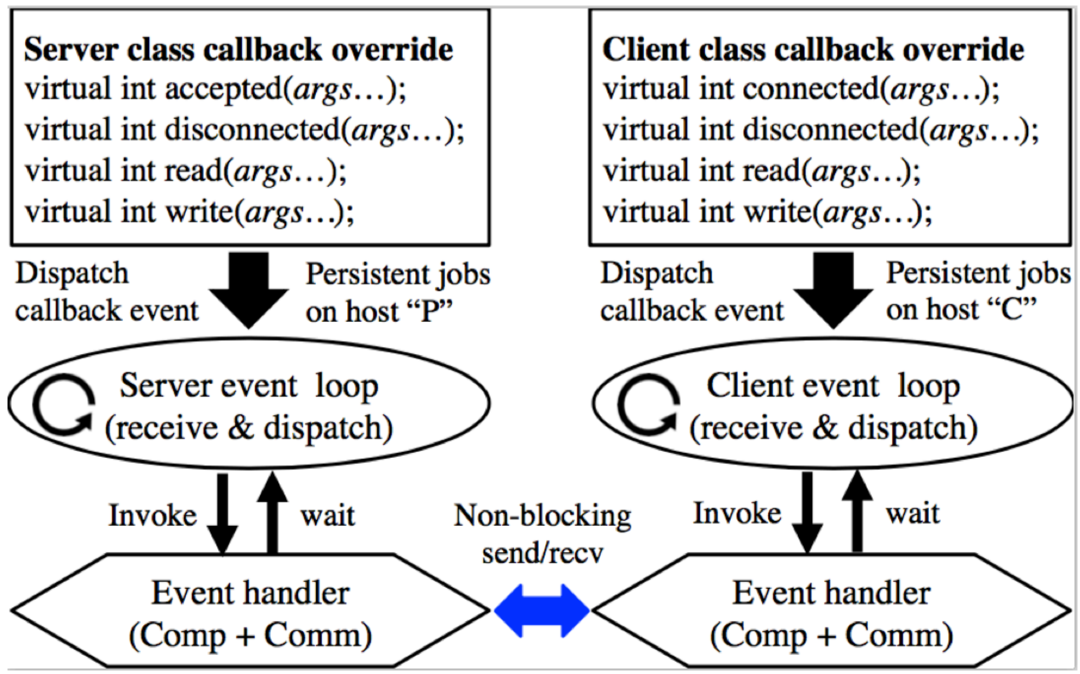
- **Multiple-program multiple-data paradigm**
  - Different programs for clients and server
  - Better scalability and work distribution
- **Non-blocking socket IO**
  - Program returns to users immediately
  - Overlap communication and computation
- **Event-driven environment**
  - Callback for message read/write events
  - Persistent in memory for efficient data processing
- **Efficient messaging interface**
  - Network see bytes only
  - Serialization and deserialization of timing data

# Non-blocking IO and Event-driven Loop with Libevent

- Libevent ([http://libevent.org/](http://libevent.org/))
  - Open-source under BSD license
  - Actively maintained
  - C-based library
  - Non-blocking socket
  - Reactor model

```
// Magic inside dispatch call
while (!event_base_empty(base)) {
  // non-block IO by OS kernel
  active_list ← get_active_events
  foreach(event e in active_list) {
    invoke the callback for event e
  }
}
```

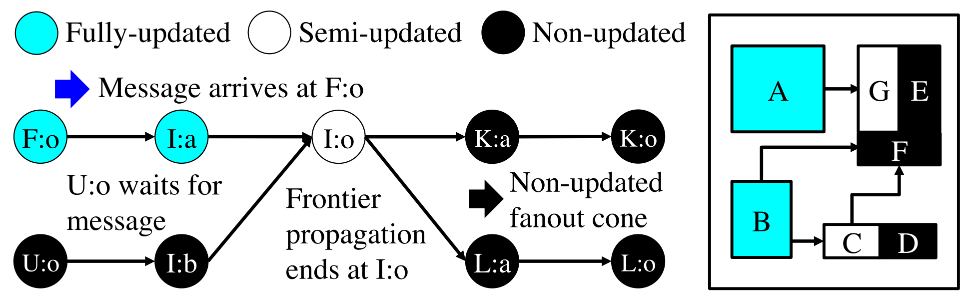
*An example event-driven code*



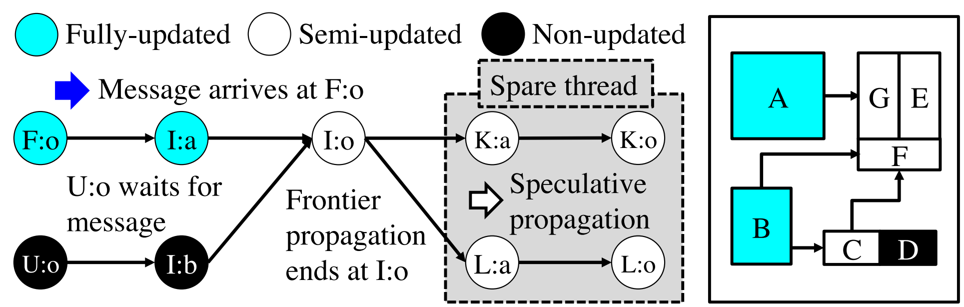

*Interface class in our framework (override virtual methods for event callback)*

# Callback Implementation

- ❑ **Client read callback**
  - ❑ Receive boundary timing
  - ❑ Propagate timing
  - ❑ Send back to the server
- ❑ **Server read callback**
  - ❑ Keep boundary mapping
  - ❑ Receive boundary timing
  - ❑ Propagate timing
  - ❑ Send to the client
- ❑ **Timing propagation**
  - ❑ Frontier vs Speculative



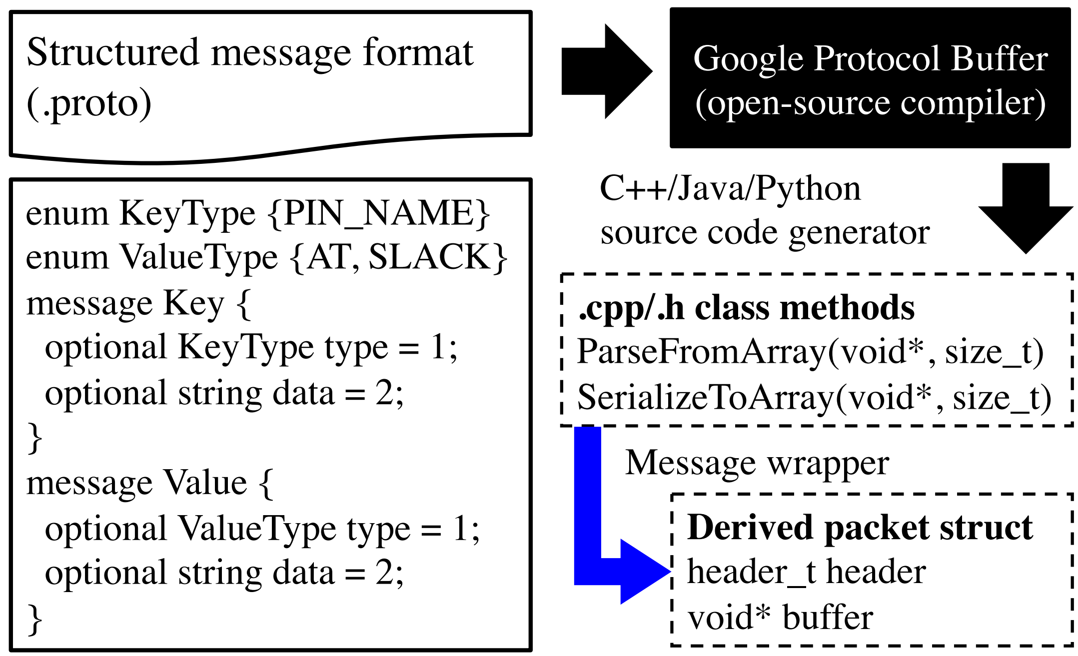

*Frontier timing propagation follows the topological order of the timing graph*




*If multi-threading is available, spare thread performs speculative propagation in order gain advanced saving of frontier work*

# Efficient Messaging Interface based on Protocol Buffer

- ❑ **Message passing**
  - ❑ Expensive
  - ❑ TCP byte stream
  - ❑ Unstructured
- ❑ **Data conversion**
  - ❑ Serialization
  - ❑ Deserialization
- ❑ **Protocol buffer**
  - ❑ Customized protocol
  - ❑ Simple and efficient
  - ❑ Built-in compression




*Integration of Google's open-source protocol buffer into our messaging interface greatly facilitates the data conversion between application-level developments and socket-level TCP byte streams.*

# Evaluation – Software and Hardware Configuration

- **Written in C++ language on a 64-bit Linux machine**
- **3rd-party library**
  - Libevent for event-driven network programming
  - Google's protocol buffer for efficient messaging
- **Benchmarks**
  - 250 design partitions generated by IBM EinsTimer
  - Millions-scale graphs generated by TAU and ICCAD contests
- **Evaluation environment**
  - UIUC campus cluster (https://campuscluster.illinois.edu/)
  - Each machine node has 16 Intel 2.6GHz cores and 64GB memory
  - 384-port Mellanox MSX6518-NR FDR InfiniBand (gigabit Ethernet)
  - Up to 250 machine nodes

# Evaluation – Results and Performance

## ❑ Overall performance

| Circuit | $\lvert G\rvert$ | $\lvert N\rvert$ | $\lvert V\rvert$ | $\lvert E\rvert$ | $\lvert P\rvert$ | $L$ | W/o speculation | | | | W/ speculation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | cpu | mem | msg | usage | cpu | mem | msg | usage |
| DesignA | 2.2M | 1.1M | 7.3M | 12.4M | 250 | 436 | 63s | 1.6GB | 0.7MB | 17.3% | 76s | 1.7GB | 1.6MB | 64.2% |
| DesignB | 14.5M | 9.3M | 39.0M | 117.0M | 37 | 3216 | 392s | 2.9GB | 2.0MB | 9.1% | 346s | 3.1GB | 5.7MB | 73.1% |
| DesignC | 23.3M | 11.3M | 76.9M | 107.0M | 30 | 2023 | 478s | 4.7GB | 2.3MB | 19.5% | 473s | 4.8GB | 8.1MB | 57.8% |
| DesignD | 42.7M | 20.8M | 128.1M | 178.4M | 50 | 5741 | 1239s | 5.1GB | 4.9MB | 20.1% | 1107s | 5.1GB | 9.7MB | 69.4% |

$\lvert G\rvert$: # of gates. $\lvert N\rvert$: # of nets. $\lvert V\rvert$: # of nodes. $\lvert E\rvert$: # of edges. $\lvert P\rvert$: # of partitions. $L$: # of levels. cpu: runtime. mem: peak memory on a program. msg: amount of message passing. usage: avg cpu utilization on a program.

## ❑ Scalability

- ❑ Scale to 250 machines (DesignA)

## ❑ Runtime efficiency

- ❑ Less than 1 hour on large designs (DesignC and DesignD)

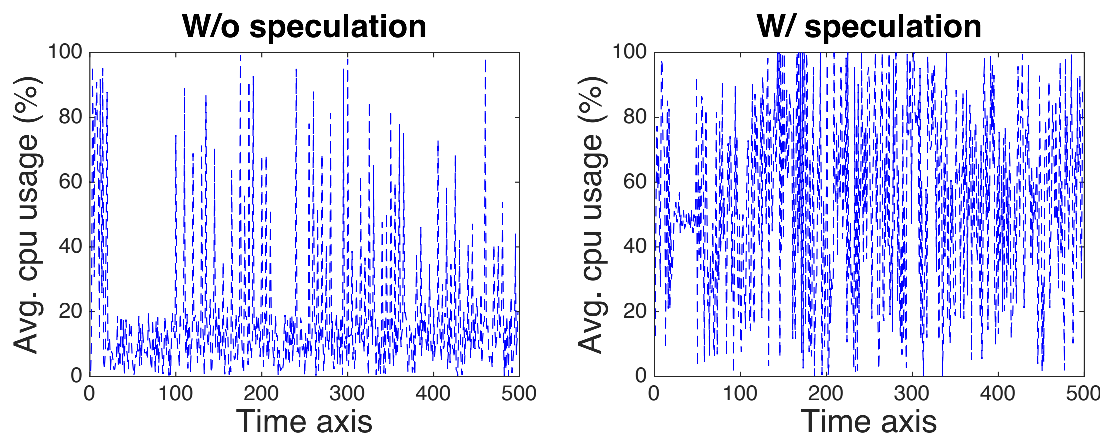
## ❑ Memory usage

- ❑ Peak usage is only about 5GB on a machine (DesignD)

# Evaluation – A Deeper Look

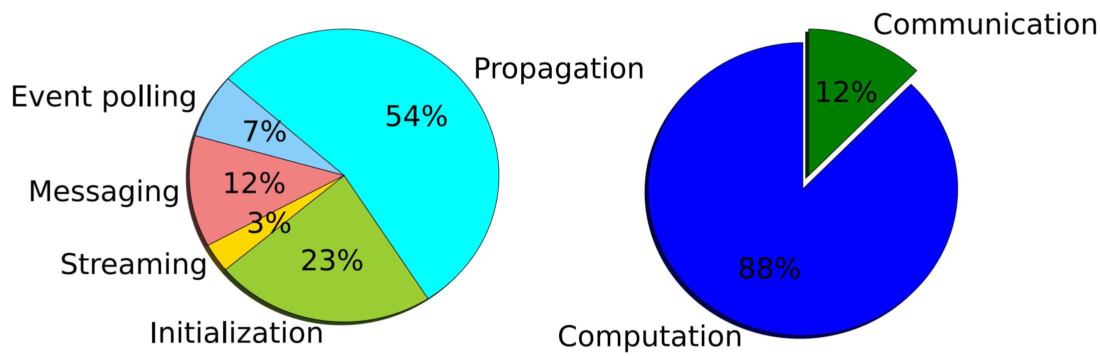
- ❑ **CPU utilization**
  - ❑ W/o speculation
  - ❑ W speculation

*W/ speculation on DesignD*
*+49% cpu rate*
*+4.8MB on message passing*




*Average cpu utilization over time across all machines.*

- ❑ **Runtime profile**
  - ❑ 7% event polling
  - ❑ 3% streaming
  - ❑ 23% initialization
  - ❑ 54% propagation
  - ❑ 12% communication




*Runtime profile of our framework (12% on communication and 88% on computation)*

# Conclusion and Future Work

- **Prototype a distributed timing analysis framework**
  - Server-client model
  - Non-blocking socket IO (overlap communication and computation)
  - Event-driven loop (autonomous programming)
  - Efficient messaging interface (serialization and deserialization)

- **Future work**
  - A system for distributed timing analysis
  - Fault tolerance
  - Distributed common path pessimism removal (CPPR)


- **Acknowledgment**
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