A Distributed Timing Analysis Framework for Large Designs

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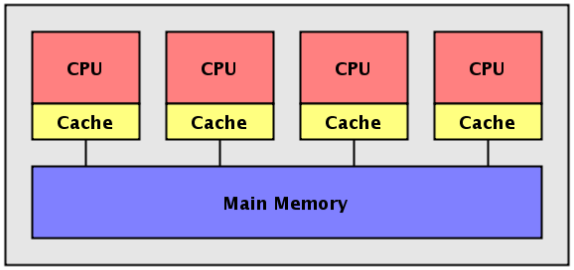
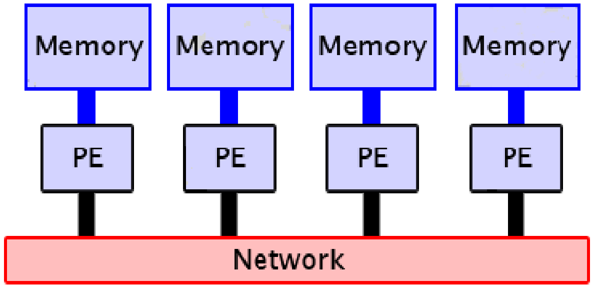
Distributed Timing – Motivation and Goal

- **Motivation**
  - Ever increasing design complexity
    - Hierarchical partition
    - Abstraction
    - Multi-threading timing analysis
  - Too costly to afford high-end machines
- **Create a distributed timing engine**
  - Explore a feasible framework
  - Prototype a distributed timer
  - Scalability
  - Performance



Multi-threading in a single machine



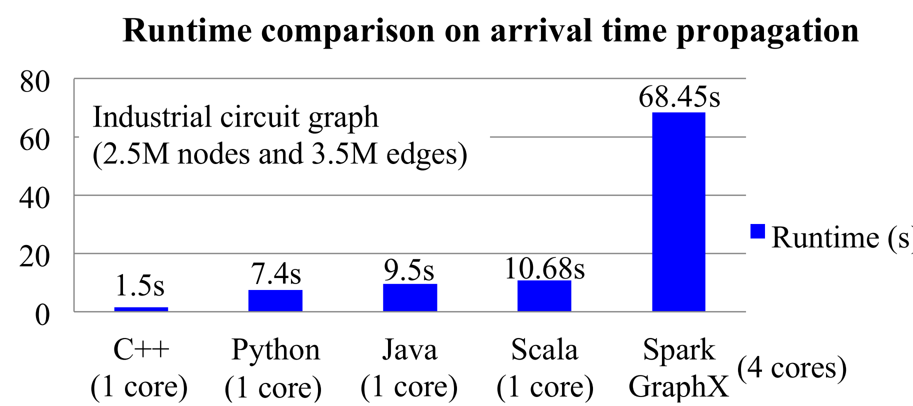
Distributed computing on a machine cluster

State-of-the-art Distributed System Packages

- **Open-source cloud computing platforms (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

An Empirical Experiment on Arrival Time Propagation

- **Benchmark**
  - 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



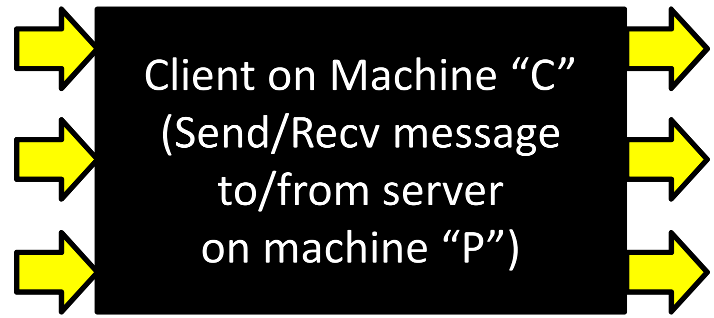
Implementation	Spark 1.4 (RDD + GraphX Pregel)	Scala (Dijkstra)	C++ (Dijkstra)
Runtime (s)	68.45	10.68	**1.50**

Overhead of GraphX and message passing

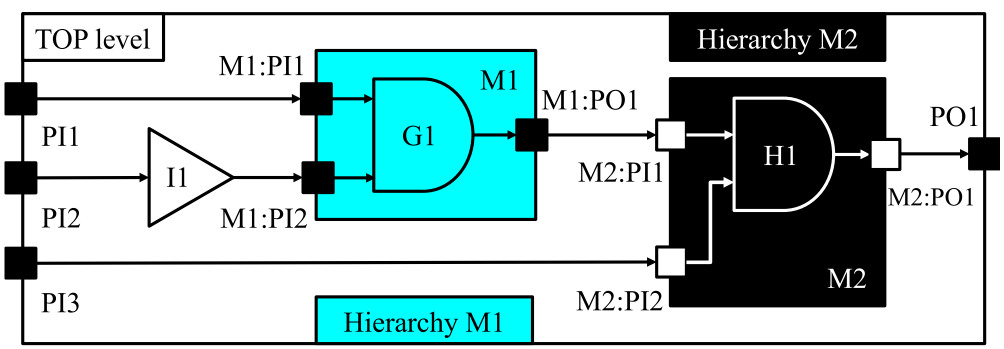
Overhead of JVM

The Proposed Framework for Distributed Timing

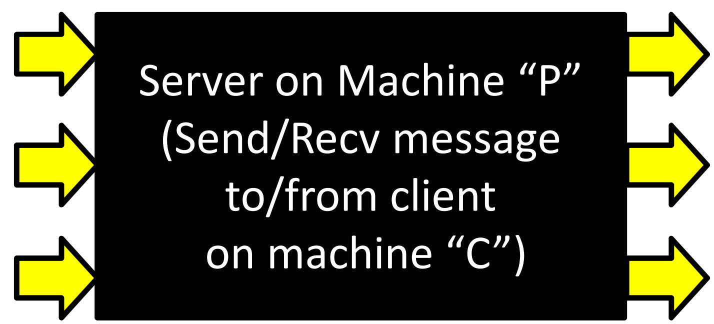
- **Focus on general design partitions**
  - Logical, physical, and hierarchies
  - Across multiple machines (DFS)
- **Single-server multiple-client model**
  - Server is the centralized communicator
  - Client exchange boundary timing with server



Client machine IP: 1.23.456.789



An example design with three partitions



Server machine IP: 140.110.44.32

Key Components in our Framework

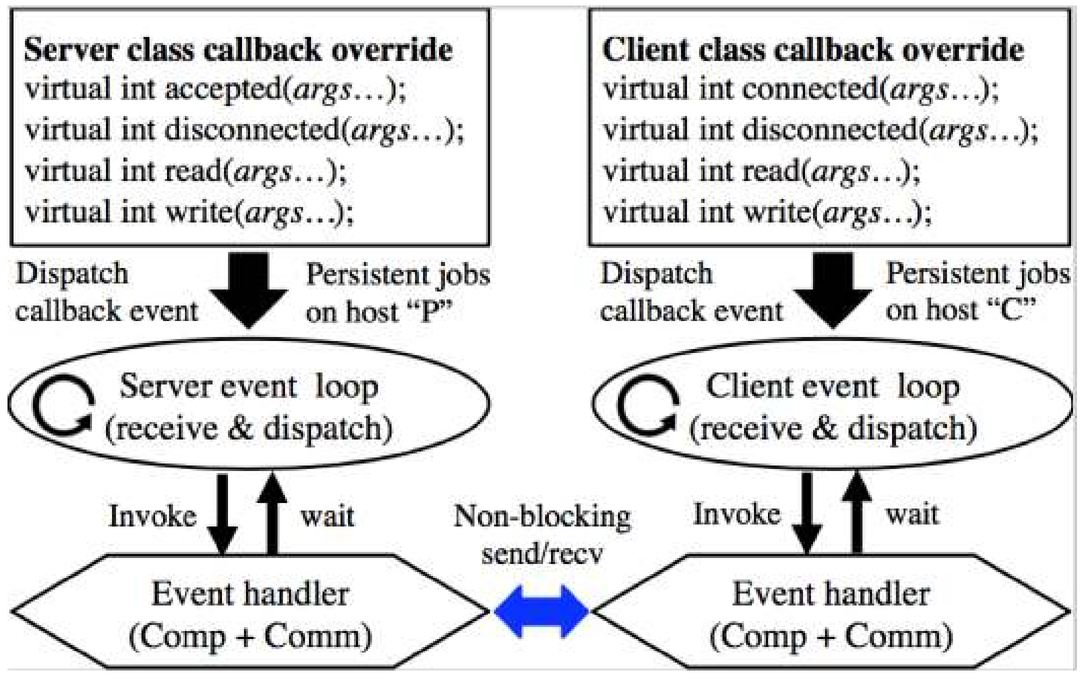
- **Multiple-program multiple-data paradigm**
  - Different programs for clients and server
  - Better scalability and work distribution
- **Non-blocking socket IO**
  - Program returns to users immediately
  - Overlap communication and computation
- **Event-driven environment**
  - Callback for message 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/)**
  - 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
  }
}
```

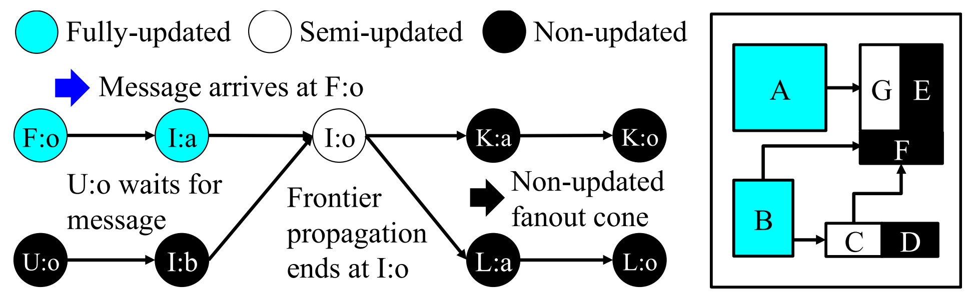
An example event-driven code



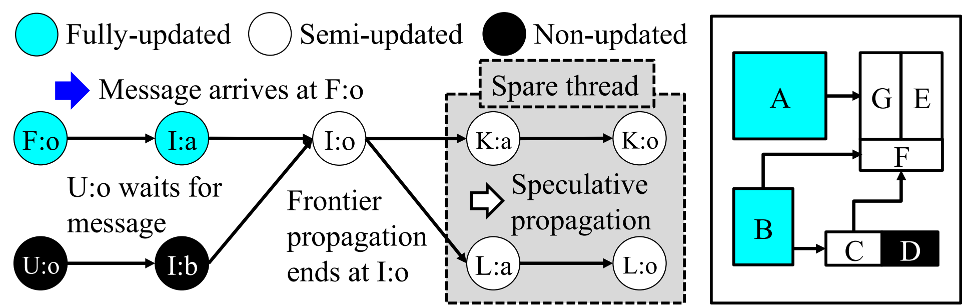
Interface class in our framework (override virtual methods for event callback)

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



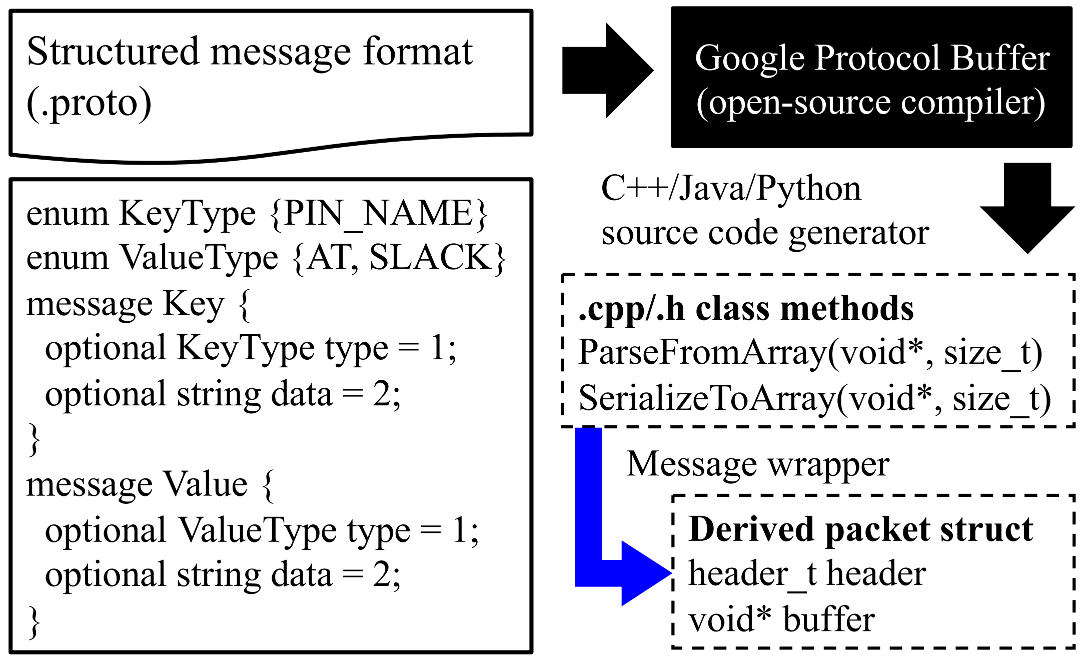
Frontier timing propagation follows the topological order of the timing graph



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	$\|G\|$	$\|N\|$	$\|V\|$	$\|E\|$	$\|P\|$	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%

$|G|$: # of gates. $|N|$: # of nets. $|V|$: # of nodes. $|E|$: # of edges. $|P|$: # 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)

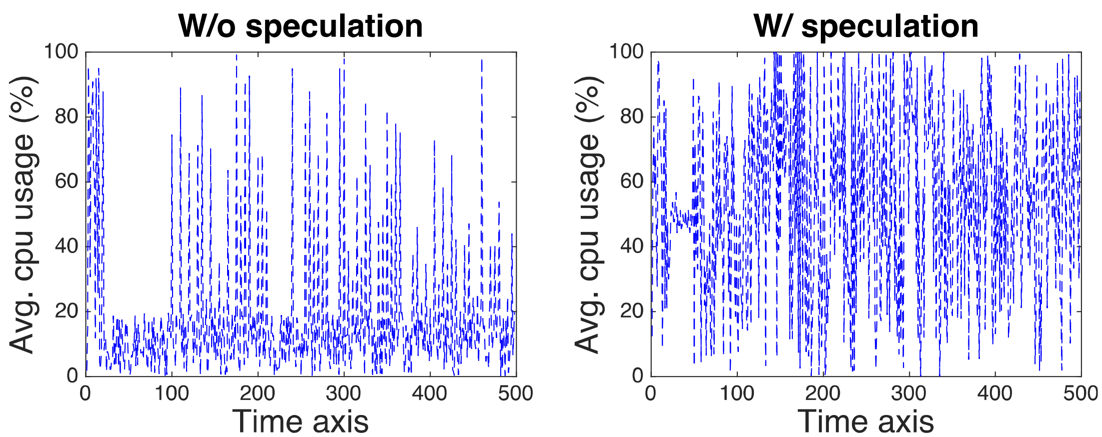
❑ Memory usage

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

Evaluation – A Deeper Look

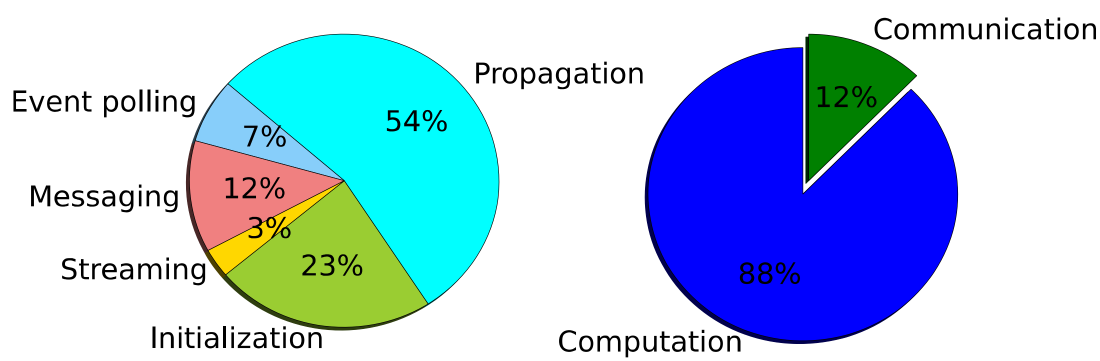
- ❑ **CPU utilization**
  - ❑ W/o speculation
  - ❑ W speculation

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**
  - UIUC CAD group
  - EinsTimer team (Debjit, Kerim, Natesan, Hemlata, Adil, Jin, Michel, etc.)

THANK YOU!

Backup Slides

- ***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