LOBIN: In-Network Machine Learning for Limit Order Books

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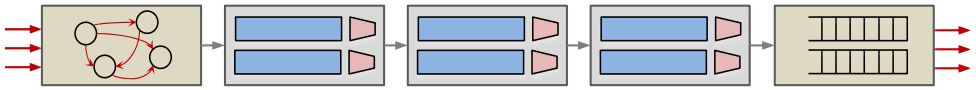
Motivation


In-network Machine Learning (ML)
Higher Intelligence
Lower Latency
Programmable Network Devices
High-frequency Traders
Algorithmic Traders

Concept of In-network ML

General Machine Learning	vs	*In-Network Machine Learning*
Local PC, Servers, …	Location	*Network Infrastructures*
CPU, GPU, …	Device	 **PISA**
C, Python, MATLAB, …	Language	*P4*
Training & Inference	Manner	*Offline Training Online Inference*

Concepts of MBO and LOB

- **Market-by-order (MBO):** an order-based market data feed, specifying the price for a certain security at which the trader is willing to trade as well as the quantity of shares.
- **Limit order book (LOB):** a real-time summary of unmatched orders for a certain security that are used to trade it at specific prices or better prices.

Graphical Representation of A LOB

Problem Setup

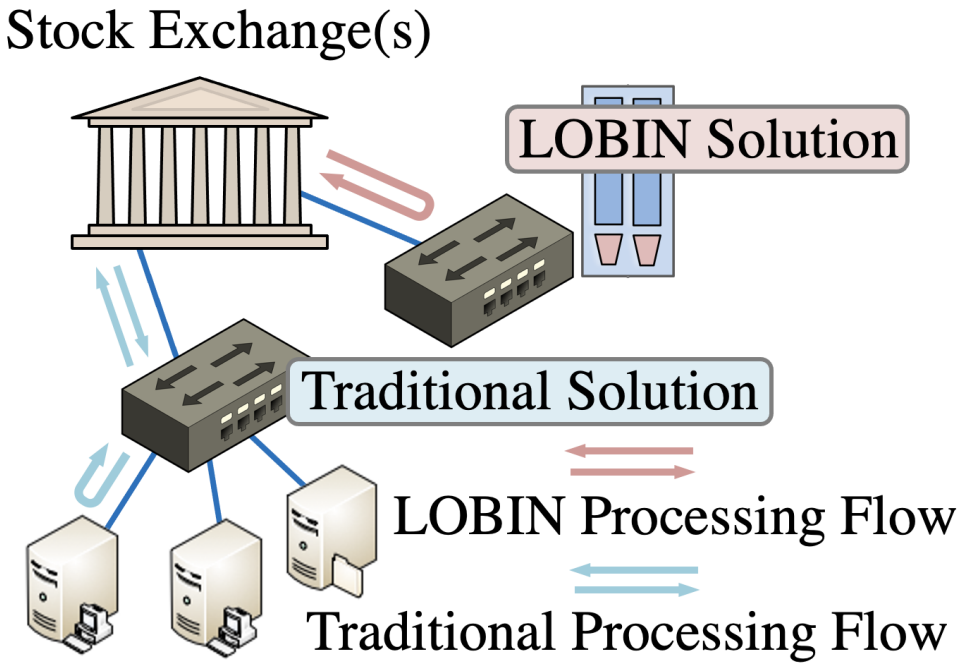
- ML-based future price movement forecasting: ***up, down, and stationary***.

Information Sources	Stateful?	Ideal ML Features?
MBO	No	No
LOB	Yes	Yes

	Switch (M)		Server (H)	
Model	ACC	F1	ACC	F1
SVM	46.19	21.06	46.19	21.06
DT_{EB}	37.09	31.00	37.19	31.61
DT_{DM}	37.09	31.00	37.19	31.61
RF_{EB}	35.55	28.47	39.99	31.03
RF_{DM}	37.29	28.30	39.89	30.30
$XGB^{\dagger}$	43.17	20.66	43.65	20.94
$IF^{\dagger\diamond}$	—-	—-	32.98	16.53
NB	47.35	33.90	47.35	33.90
KM_{LB}	34.76	31.20	34.76	31.20
KM_{EB}	20.83	11.49	34.76	31.20
KNN	32.98	16.53	34.21	23.59
$NN^{\ddagger}$	31.92	30.39	46.19	21.14

LOBIN: LOB In Network

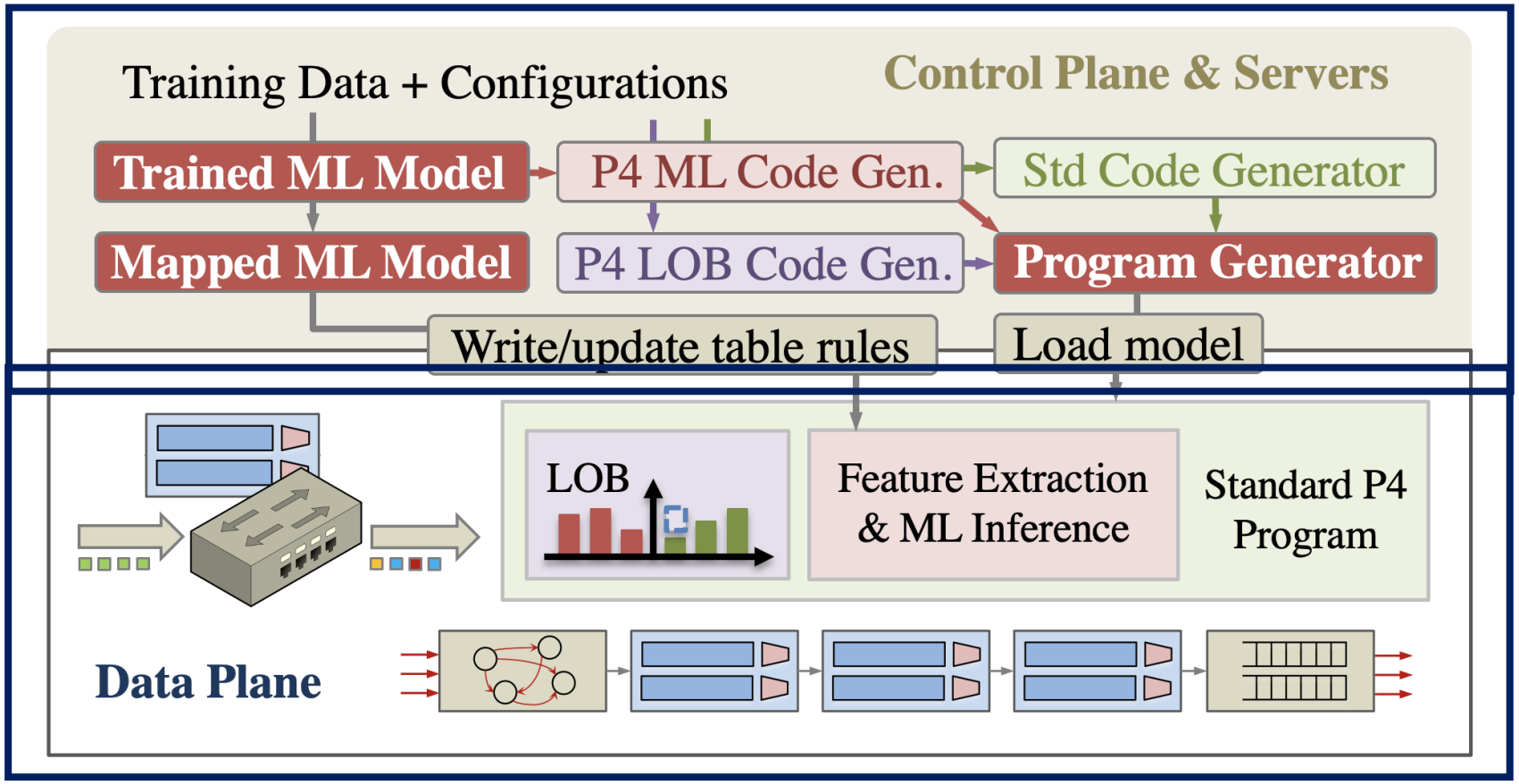
- A prototype for predicting stock price movement by building LOBs in programmable switches based on high-frequency market data feeds.



The General Working Scenario of LOBIN

System Design

- LOBIN consists of components on ***server, control plane, and data plane***.



Implementation in Switches

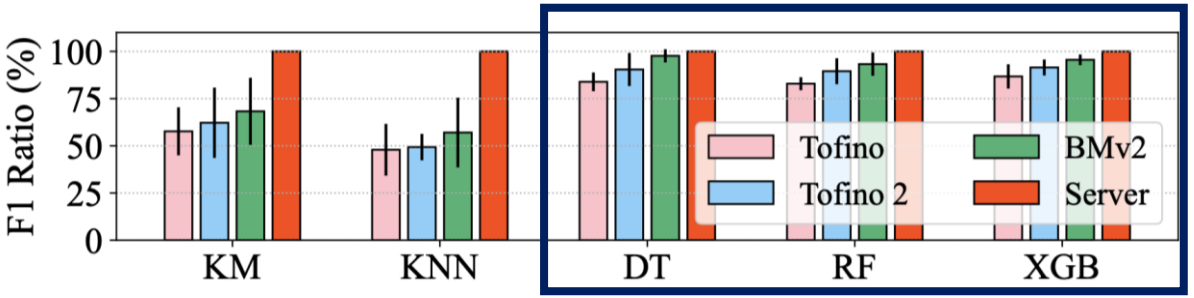
- LOBIN is implemented using ***P4*** (a programming language for controlling data planes in network devices) on ***BMv2*** (software switch), ***Tofino, and Tofino2*** (hardware switches).
- **Challenges:** lack of loops, cost of comparisons, limited access to registers, cost of if-else conditions, etc.
- **Novelty:** Construction of a new data structure within the data plane.

A Tofino Programmable Switch

ML Performance

- Dataset: ***NASDAQ's historical data feeds***.
- LOBIN runs on switches with ***limited-size*** models while the benchmark runs on a server using Sklearn with ***unlimited-size*** models.
- **Among the tested ML models, tree-based ensemble methods perform the best.**

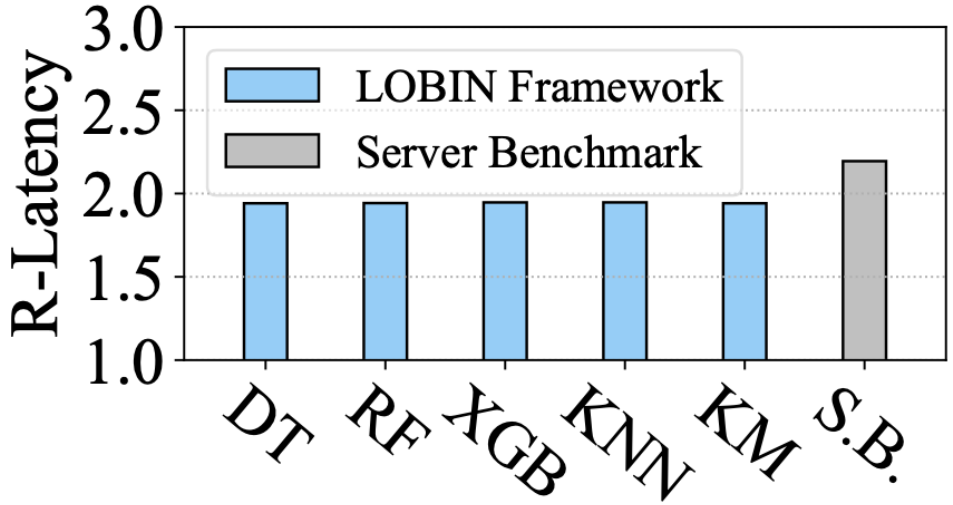
PYPL (Financials)								
	Tofino		Tofino 2		BMv2		Server (Sklearn)	
Model	ACC	F1	ACC	F1	ACC	F1	ACC	F1
KM	31.15	26.55	45.25	31.15	60.97	25.25	65.00	37.59
KNN	49.32	22.02	52.47	28.83	68.44	27.09	70.25	53.55
DT	51.13	50.29	65.40	57.67	73.98	57.77	73.98	57.77
RF	54.51	50.54	62.36	56.38	74.10	57.84	74.43	58.25
XGB	55.42	55.85	62.36	56.28	73.76	58.54	74.55	59.32



* ACC (Accuracy) / F1 Ratio: ML evaluation metrics (considered perfect when being 100%). Models: KM (k-means), KNN (k-nearest neighbors), DT (decision tree), RF (random forest), XGB (extreme gradient boosting).

Latency & Throughput

- LOBIN achieves sub-microsecond latency **even under resource constraints and with packet recirculation.**
- LOBIN achieves 3.2 Terabit/second throughput, meaning 1.45 billion messages/second.
- **LOBIN uses fewer features and smaller ML models, but it provides latency benefits.**

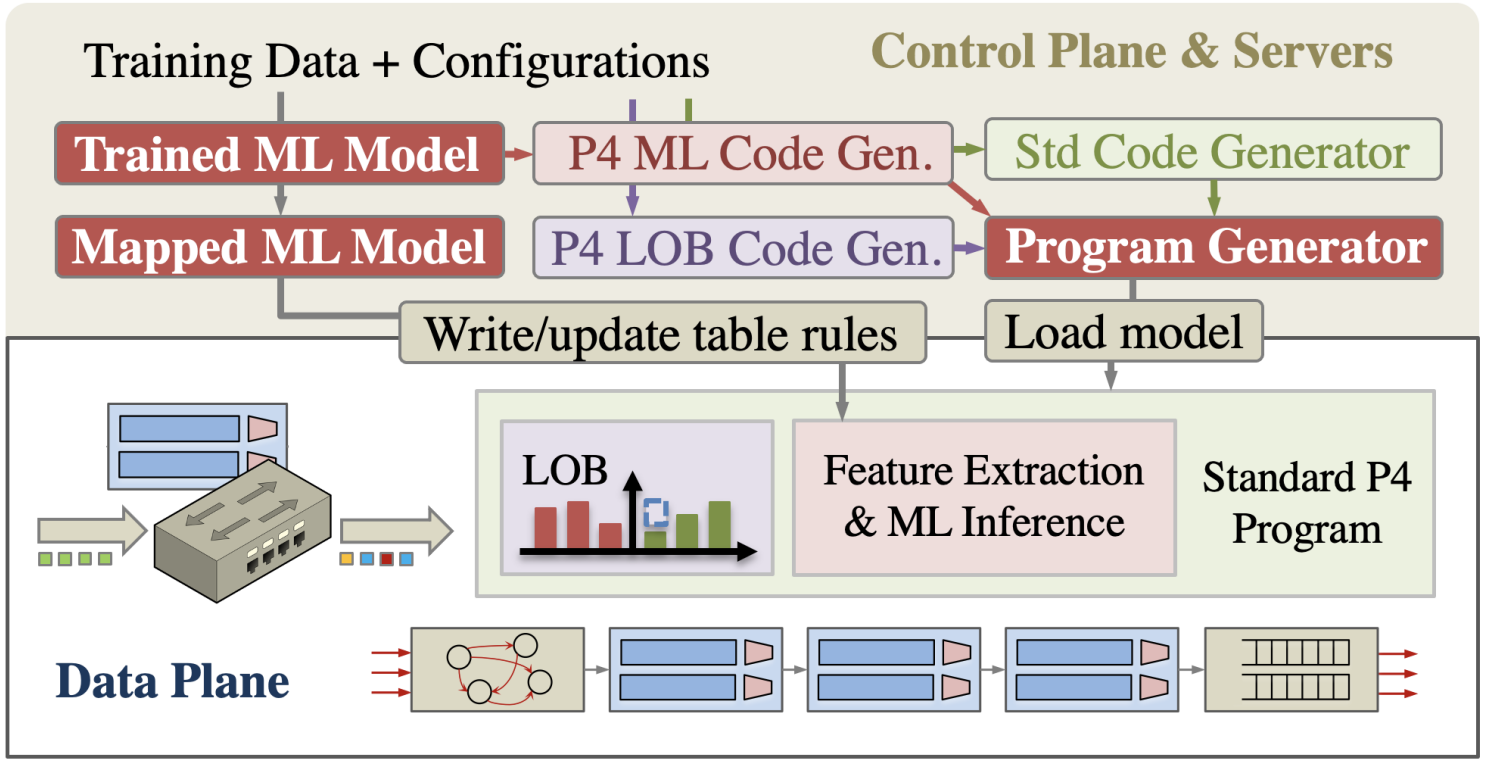


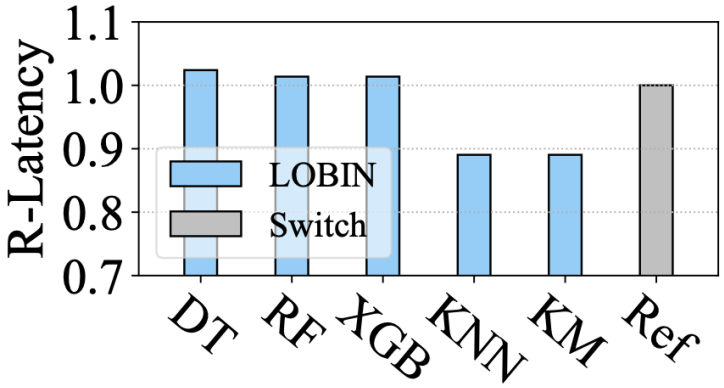
Relative Framework Latencies of LOBIN with Different Models and Benchmark (Nasdaq's Order-Matching Engine)

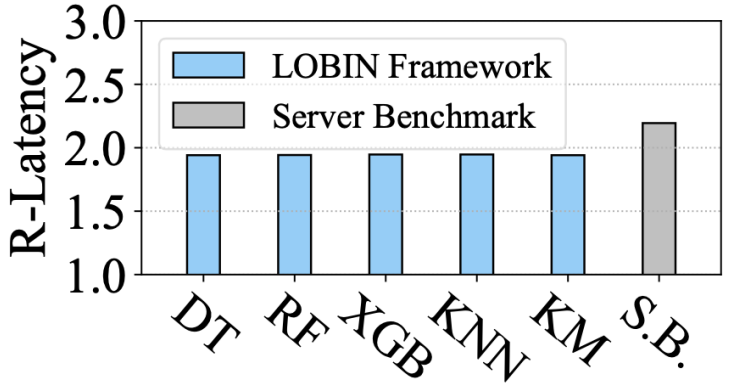
Summary

- **Contributions**
  - Novel data structure and new application to HFT.
  - High accuracy and sub-microsecond latency.
- **Future Directions**
  - Hybrid ML deployment.
  - Hand-crafted features.
  - More types of hardware (e.g., DPUs, SmartNICs).

Questions and Answers







Thank you for listening!

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