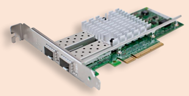
Taurus: An Intelligent Data Plane

Muhammad Shahbaz

Tushar Swamy, Alex Rucker, and Kunle Olukotun

Taurus: An Intelligent Data Plane

Programmable Data Plane



fused with

Machine Intelligence

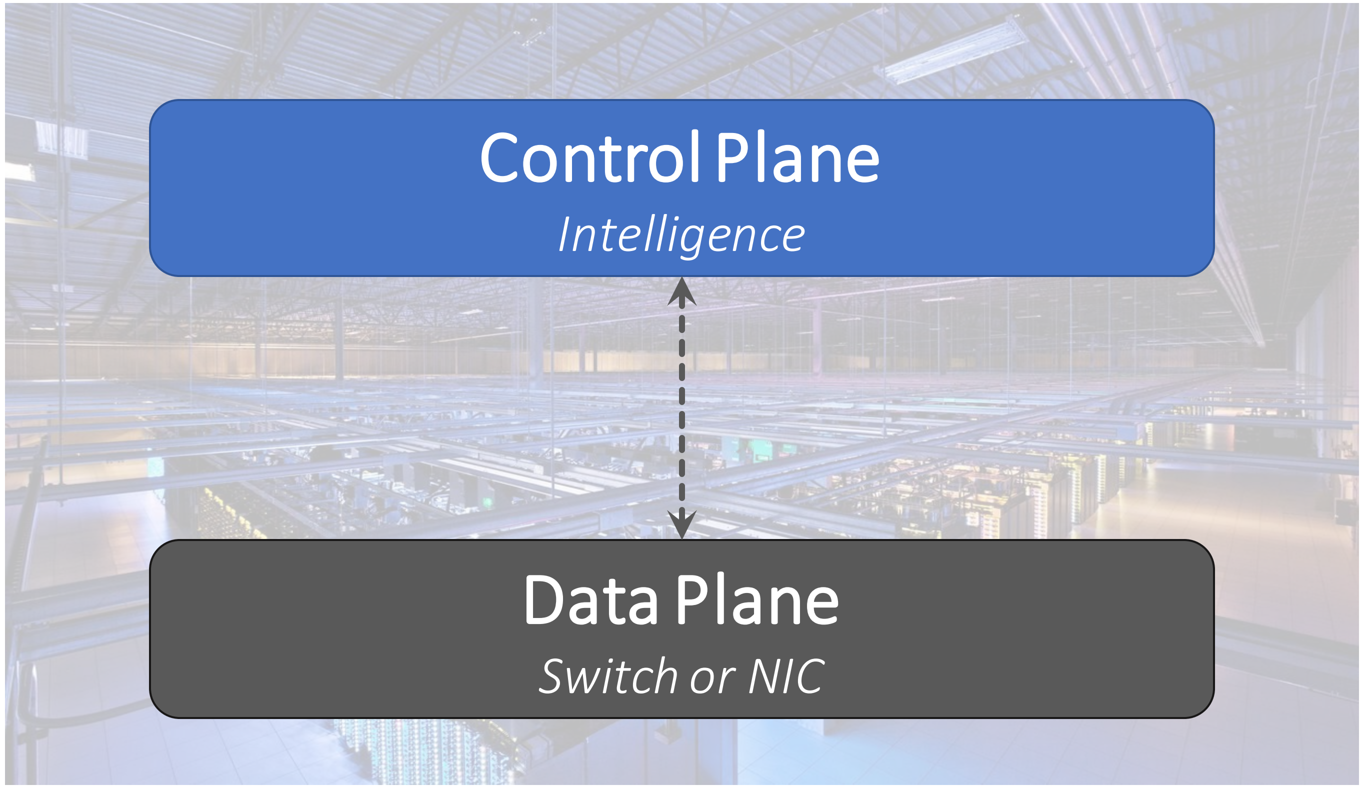
Deep Learning

Managing Networks is Hard!

amazon Google Microsoft

- Cloud Computing
- Internet of Things (IoT)
- Augmented and Virtual Reality (AR/VR)

Approaches to Manage Networks are …



amazon Google Microsoft

Slow but *intelligent*

Fast yet *dumb*

Approaches to Manage Networks are …

Examples:

- Congestion control
- Load balancing (ECMP, RSS)
- Queue scheduling
- and more

Characteristics:

- Operates on packets or flowlets (*i.e.*, bursts of packets)
- **Uses heuristics … hash, etc.**
- Low latency … ≤ sub µs
- High throughput … Tbps

Data Plane

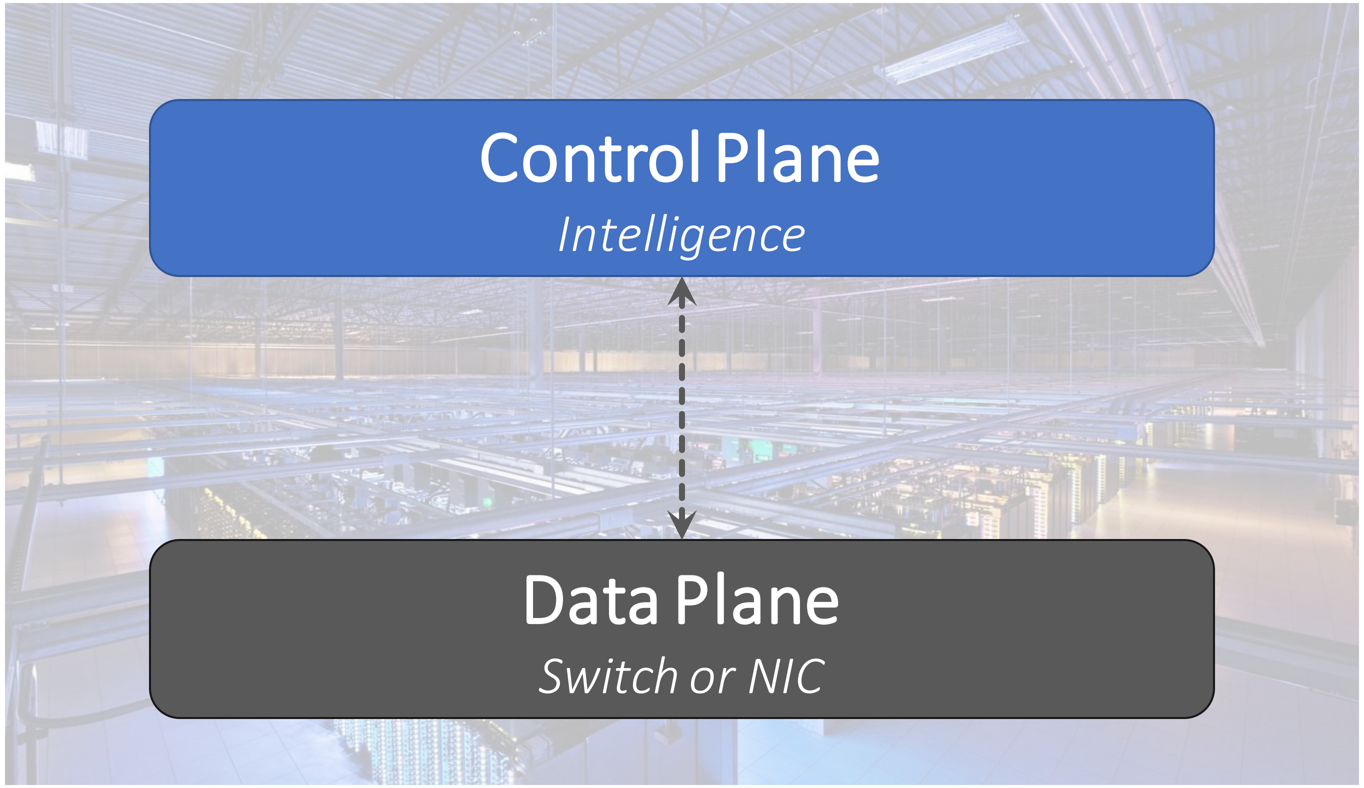
Switch or NIC

Packets In

Packets Out

Fast yet ***dumb***

Approaches to Manage Networks are …



Control Plane

Intelligence

Data Plane

Switch or NIC

Slow but *intelligent*

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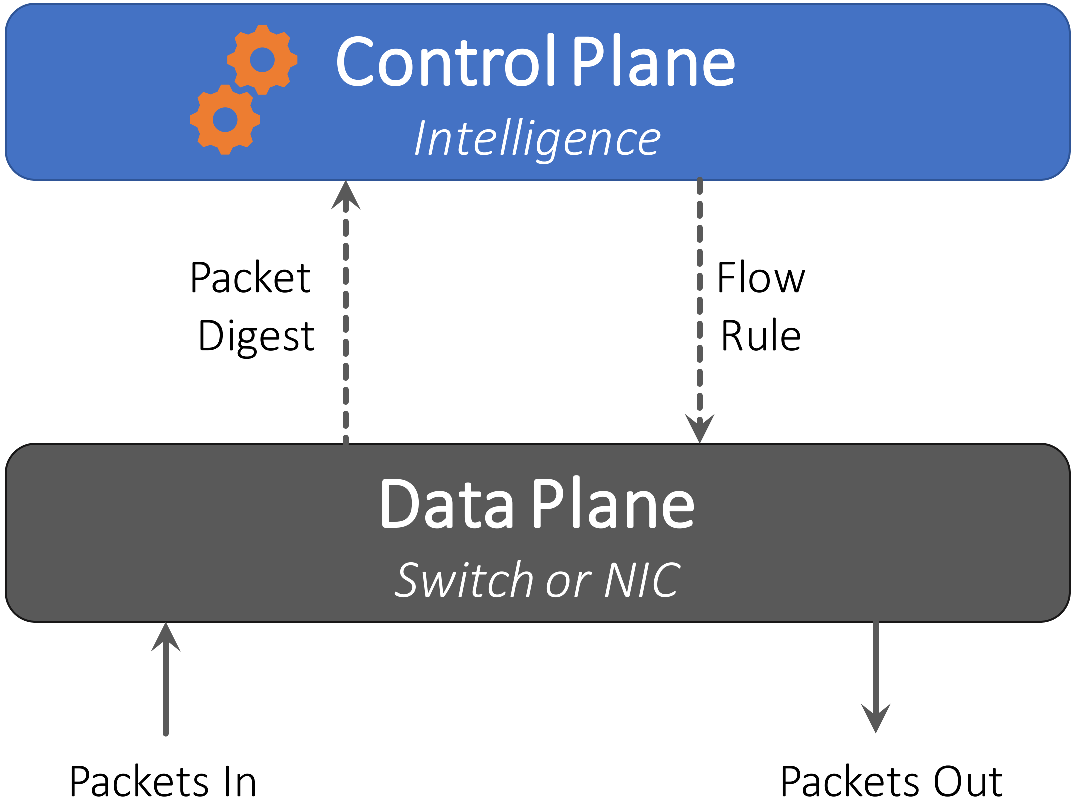
Approaches to Manage Networks are …



Slow but ***intelligent***

Examples:

- Anomaly detection
- Automation
- Recommendation

Characteristics:

- Operates on flows
- Performs complicated tasks
- Sub-second latency
- Low throughput

Approaches to Manage Networks are …

Control Plane

Intelligence

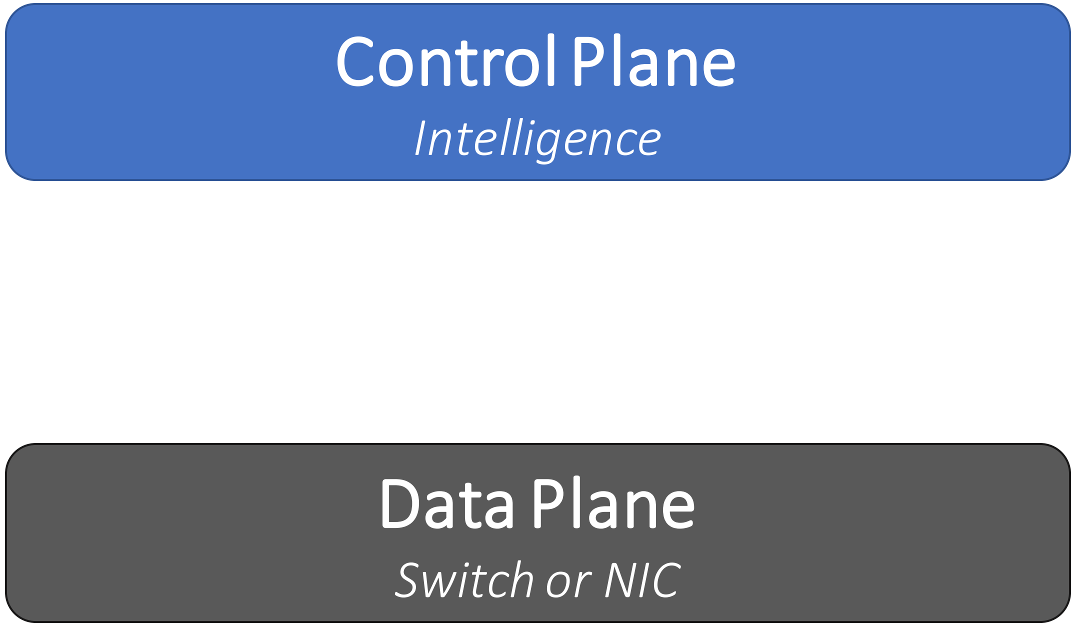
Slow but *intelligent*

Data Plane

Switch or NIC

Fast yet *dumb*

Approaches to Manage Networks are …



Control Plane

Intelligence

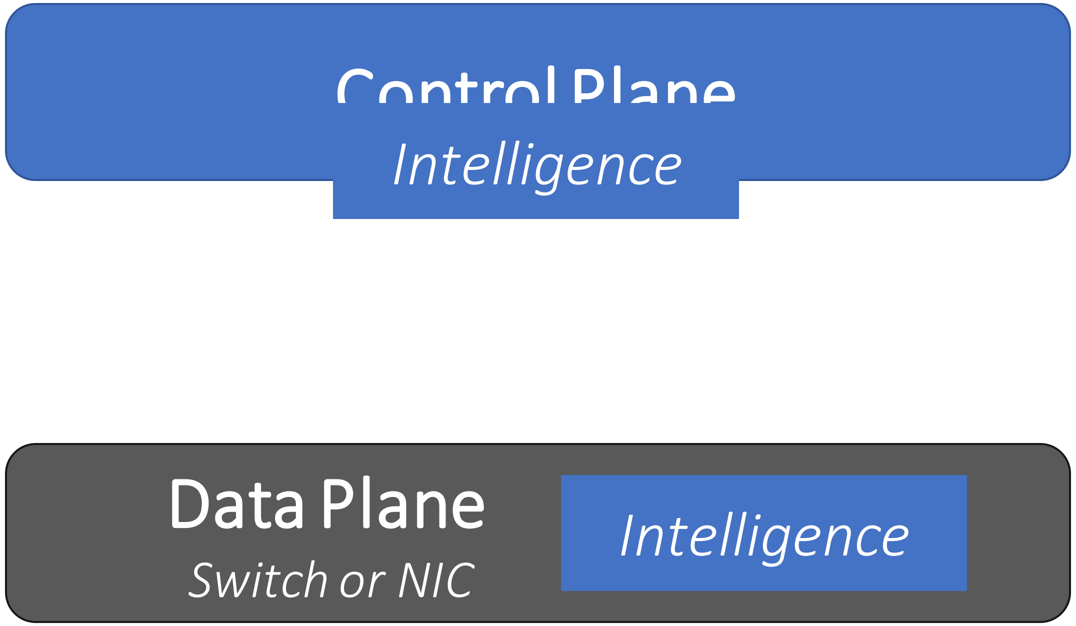
Data Plane

Switch or NIC

~~*Slow*~~ but *intelligent*

Fast yet ~~*dumb*~~

Approaches to Manage Networks are …



Control Plane

Intelligence

intelligent

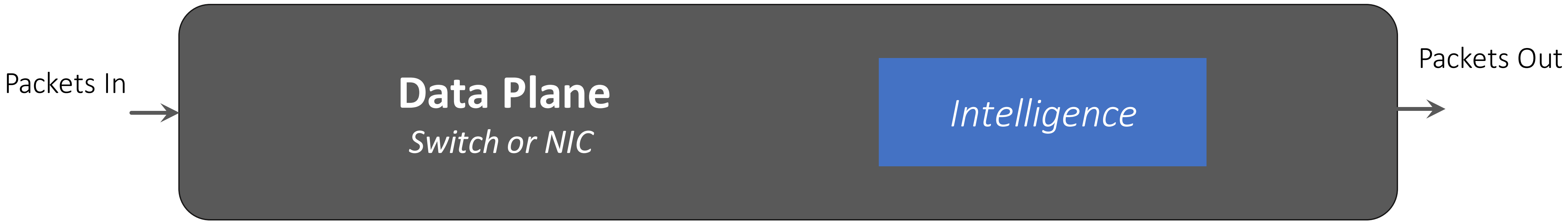
Data Plane

Switch or NIC

Intelligence

Fast and ***intelligent***

Taurus: An Intelligent Data Plane



What does “intelligence” mean?

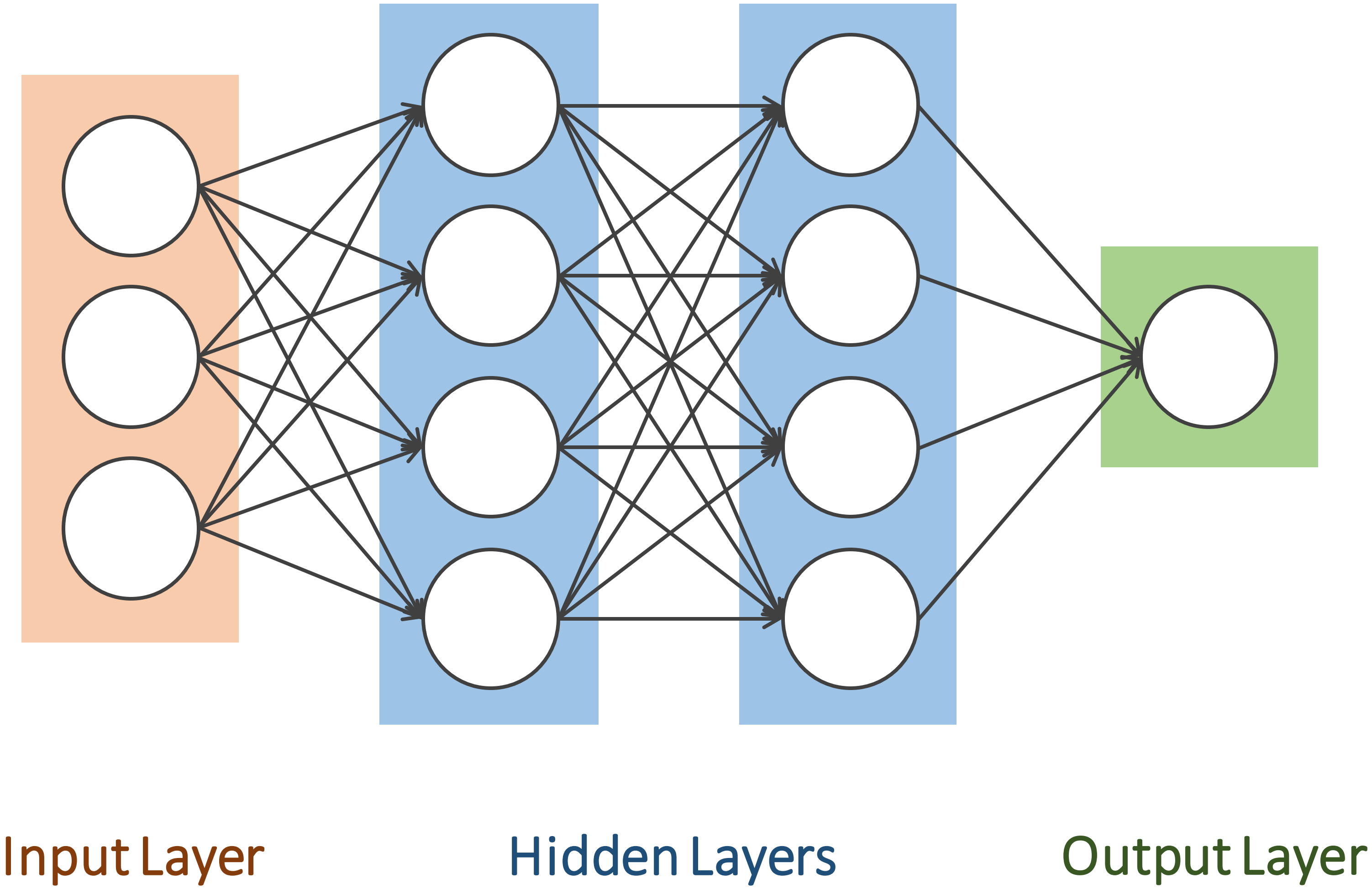
- Networks are becoming autonomous, ***Self-Driving Networks***.
- **Machine learning (ML)** will play a key role in the future of networks.

Security

Control

Analytics

ML Inference: Neural Networks

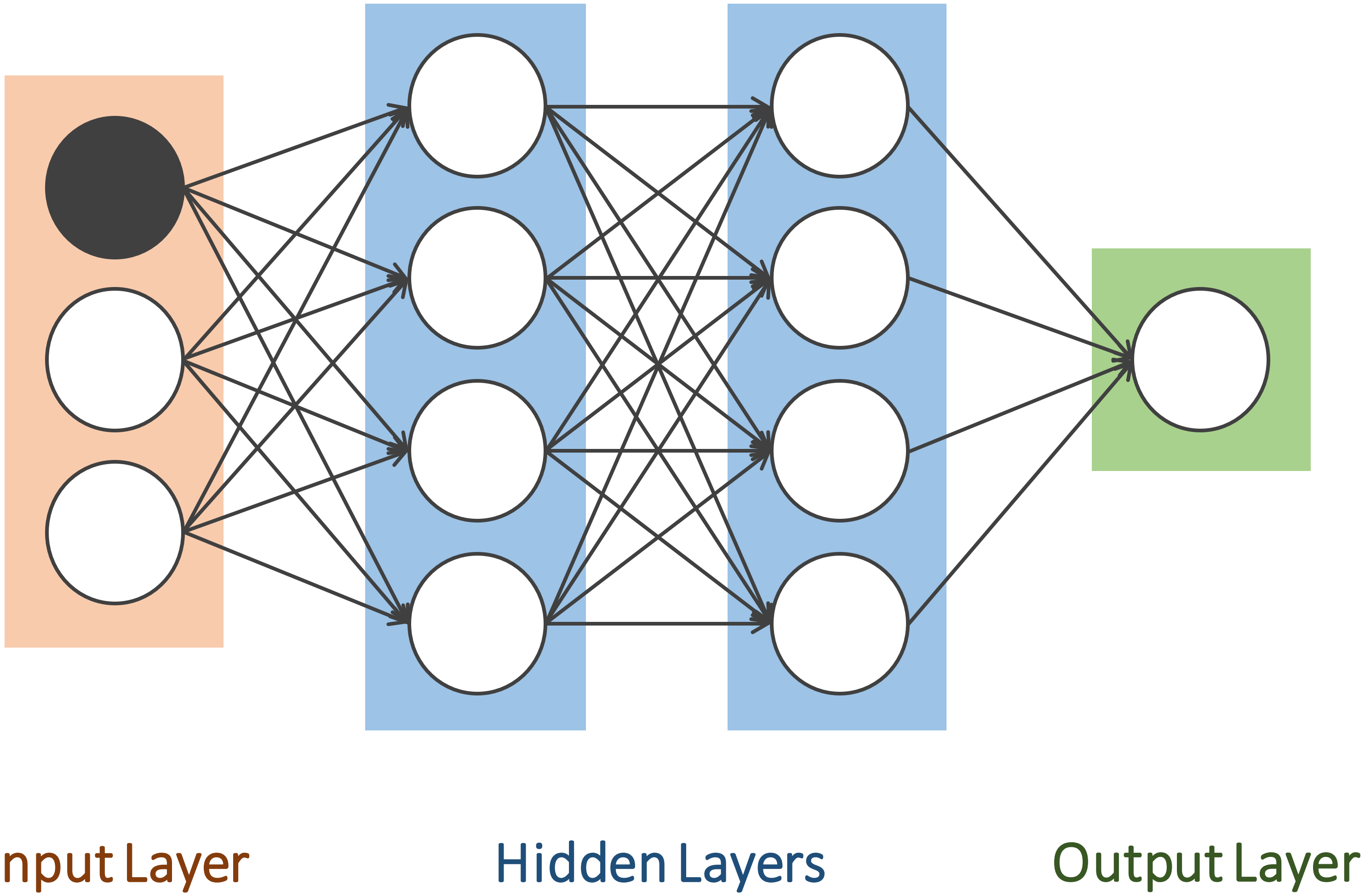


Input Layer

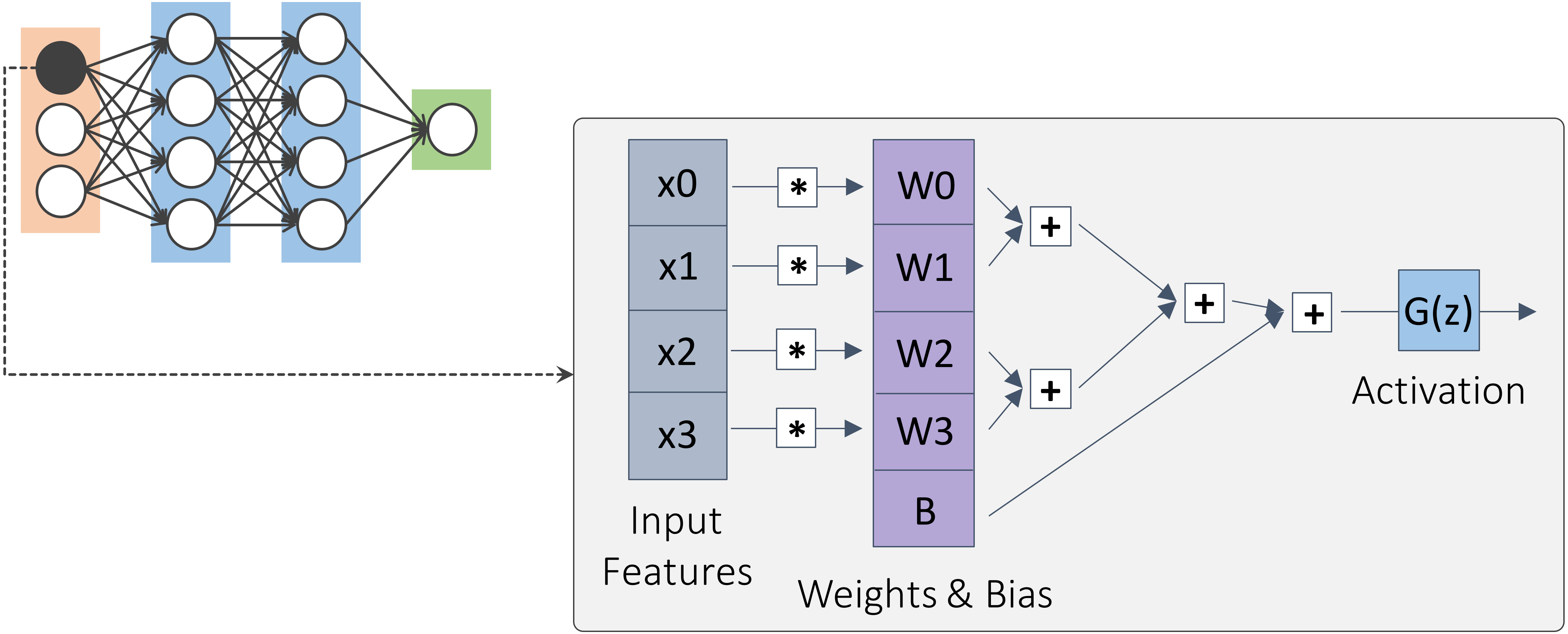
Hidden Layers

Output Layer

ML Inference: Neural Networks



ML Inference: Neural Networks



x0

x1

x2

x3

*

W0

W1

W2

W3

B

+

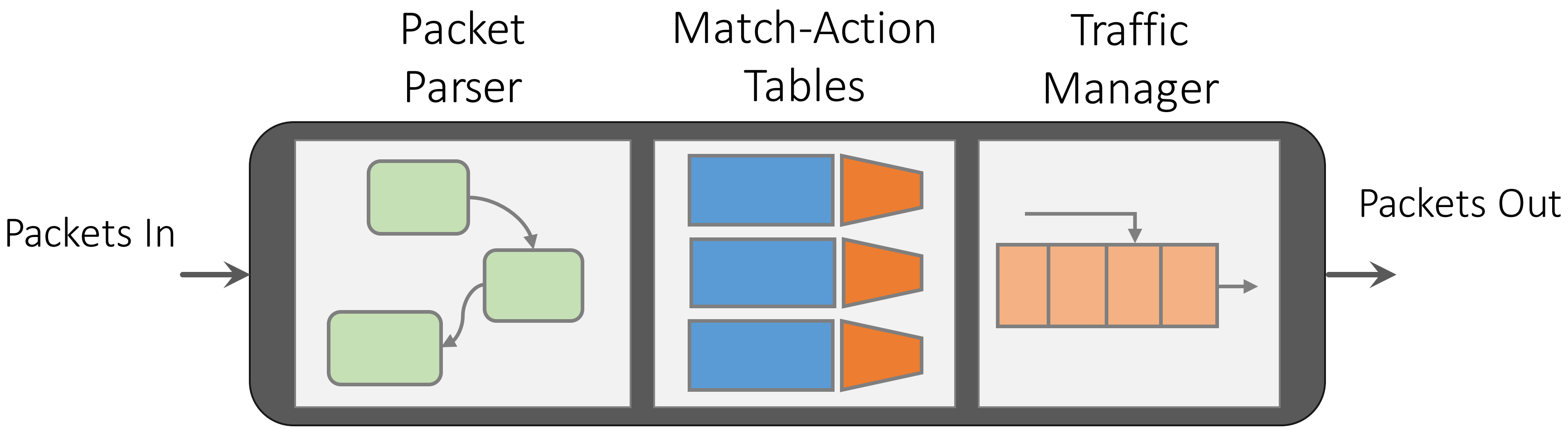
G(z)

Input Features

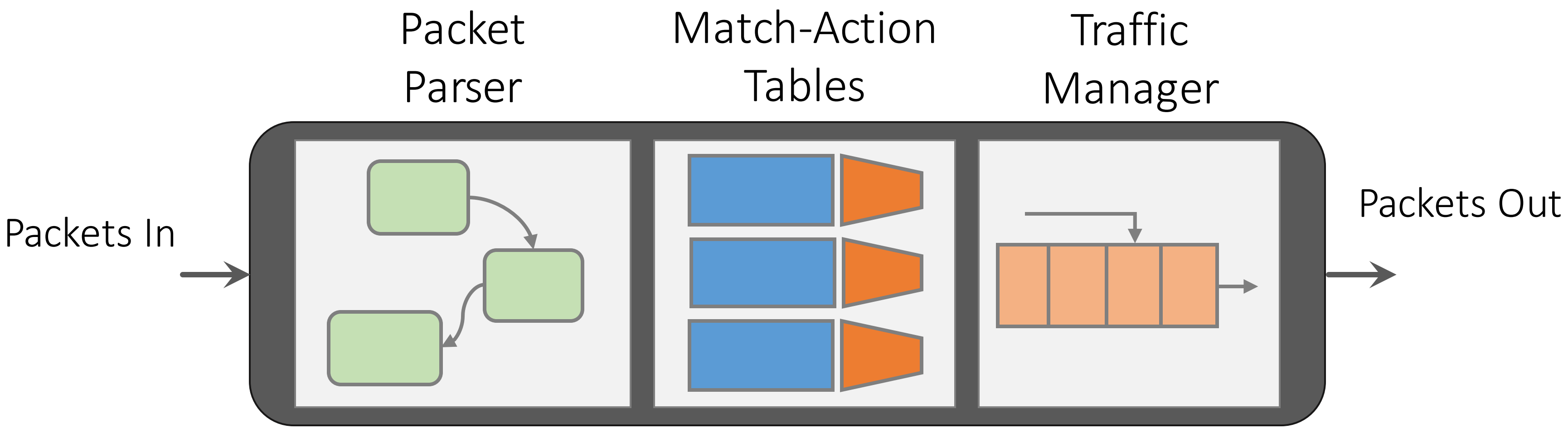
Weights & Bias

Activation

Modern Network Data Plane

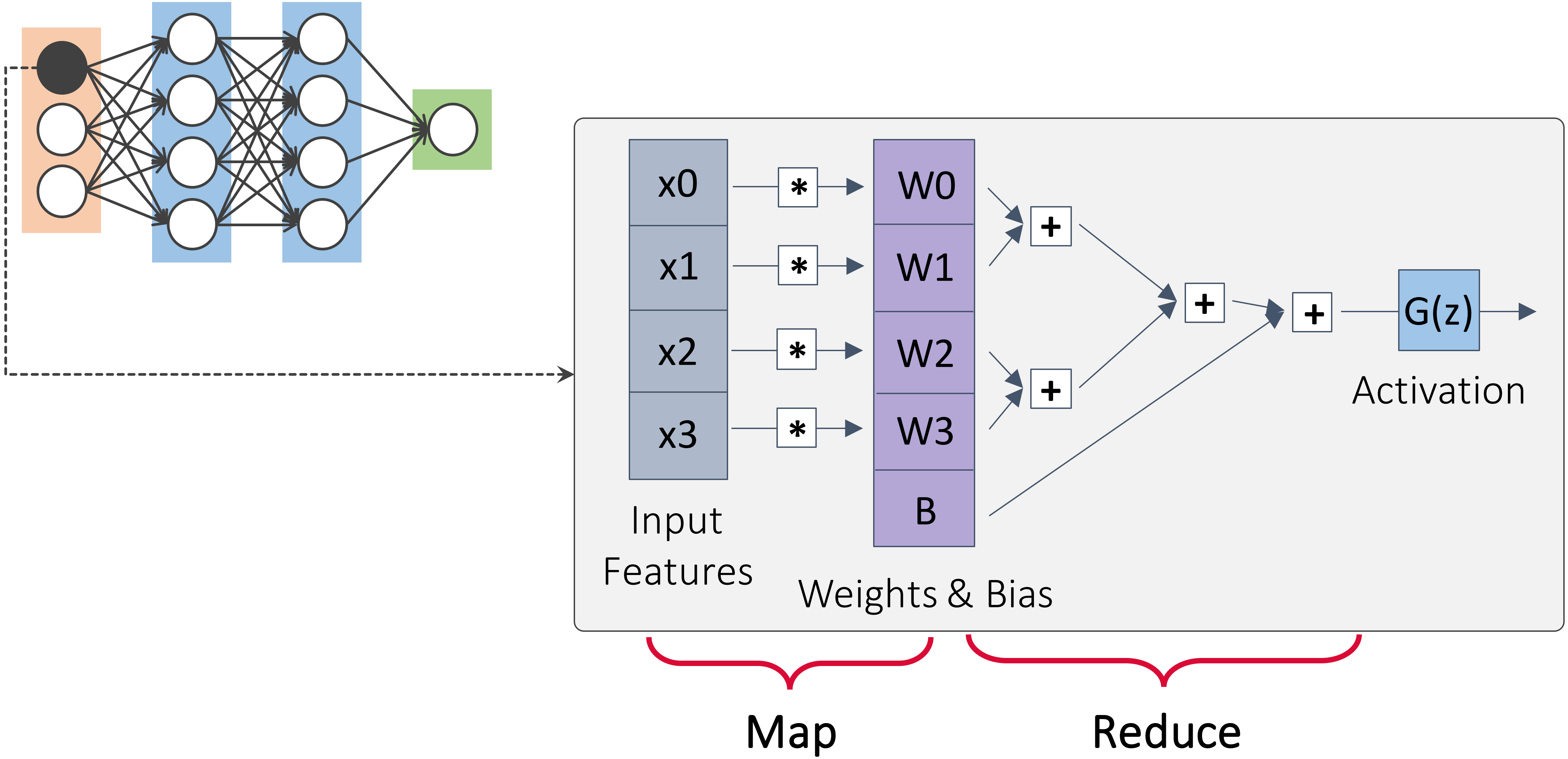


Modern Network Data Plane



- It’s **not suitable** for **learned operations:**
  - Arithmetic intensity is too low to perform ML operations
  - Not enough intermediate storage to carry feature and state
  - and more …

ML Inference: Neural Networks



x0

x1

x2

x3

Input Features

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B

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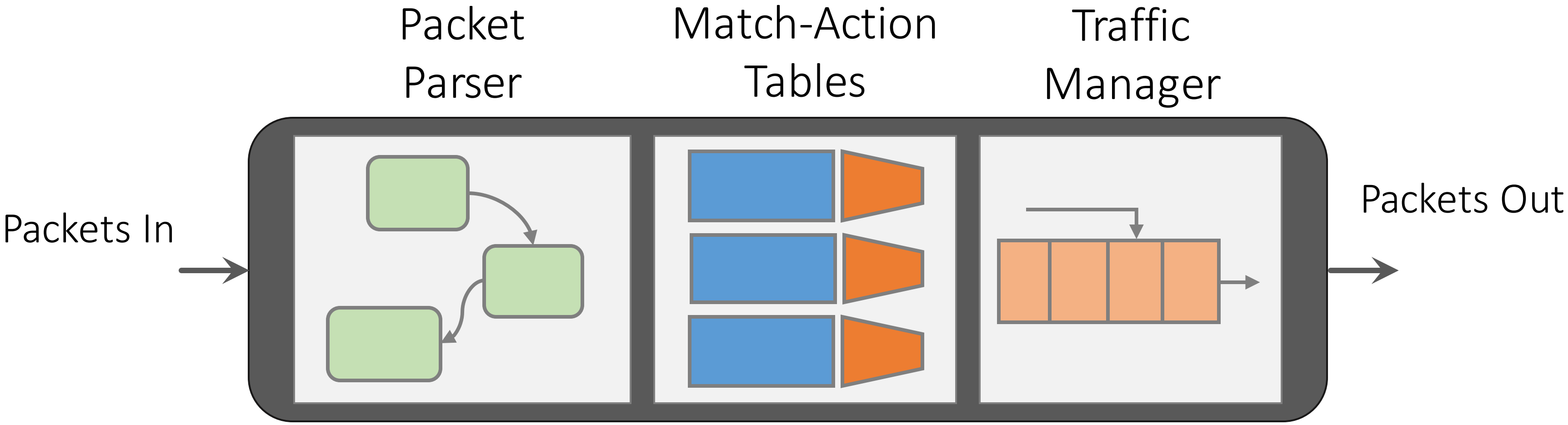
G(z)

Activation

Map

Reduce

Modern Network Data Plane



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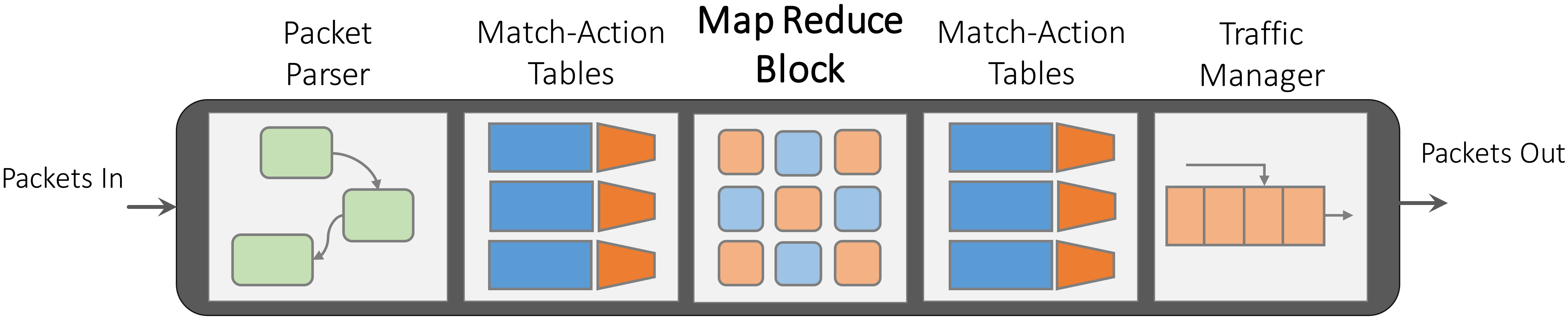


Packets In

Packet Parser

Match-Action Tables

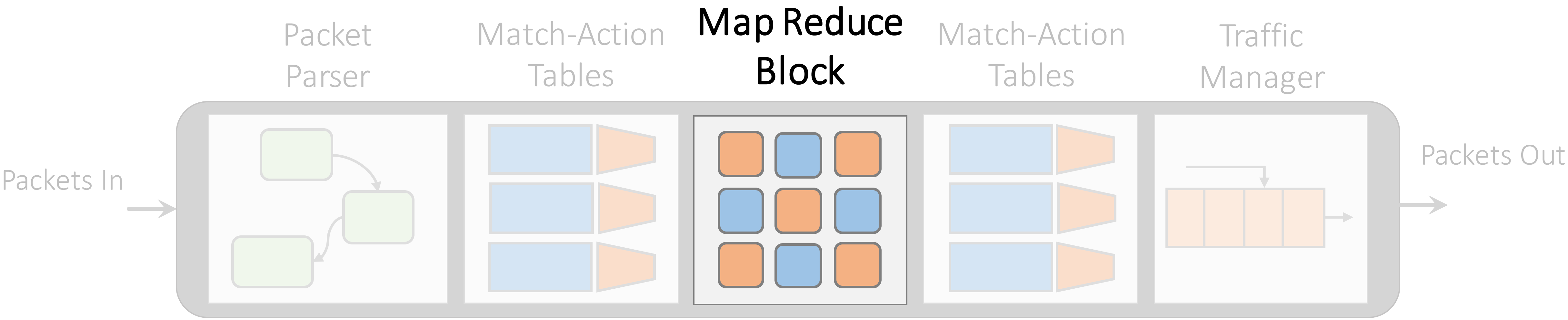
Map Reduce Block

Match-Action Tables

Traffic Manager

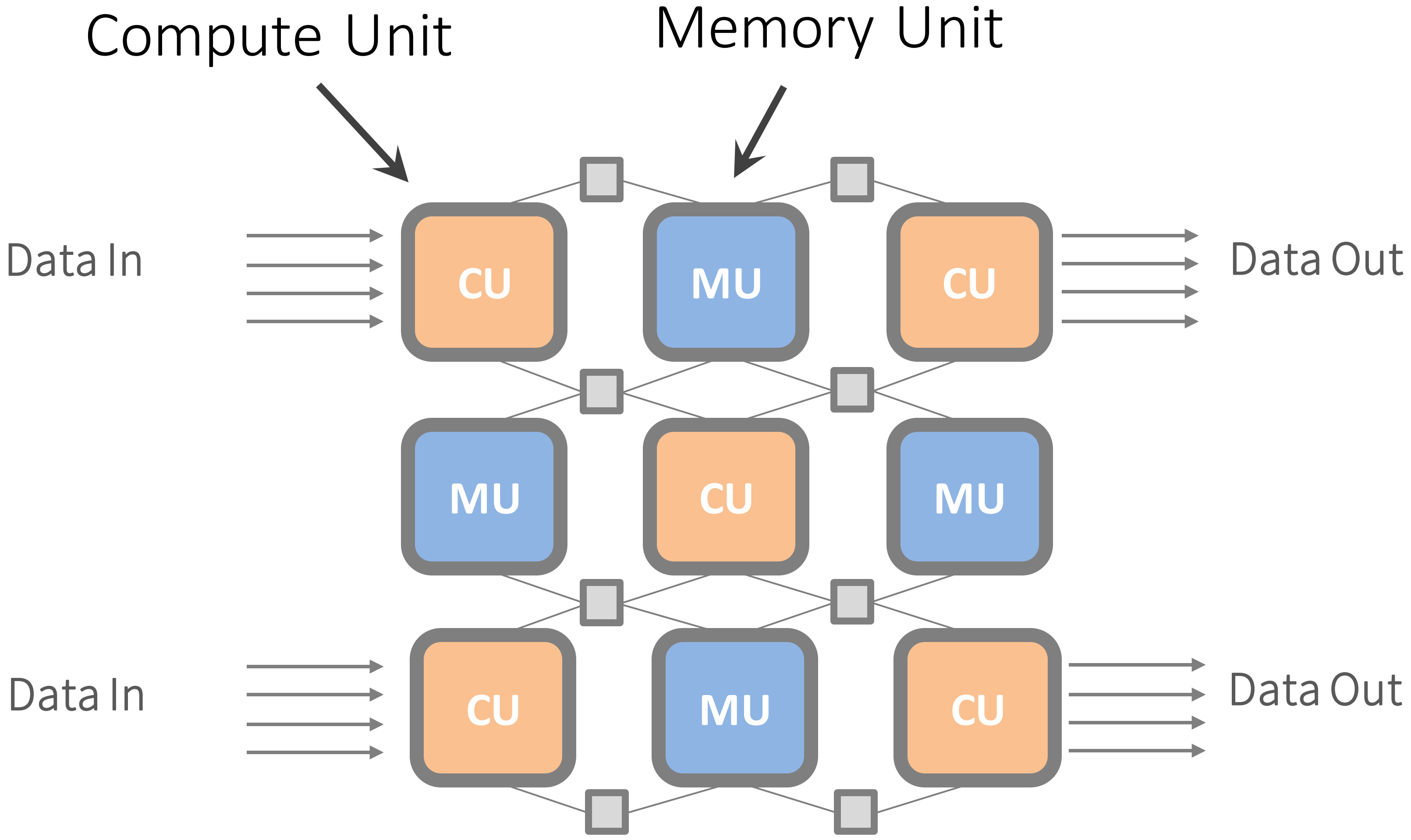
Packets Out

Taurus: An Intelligent Data Plane

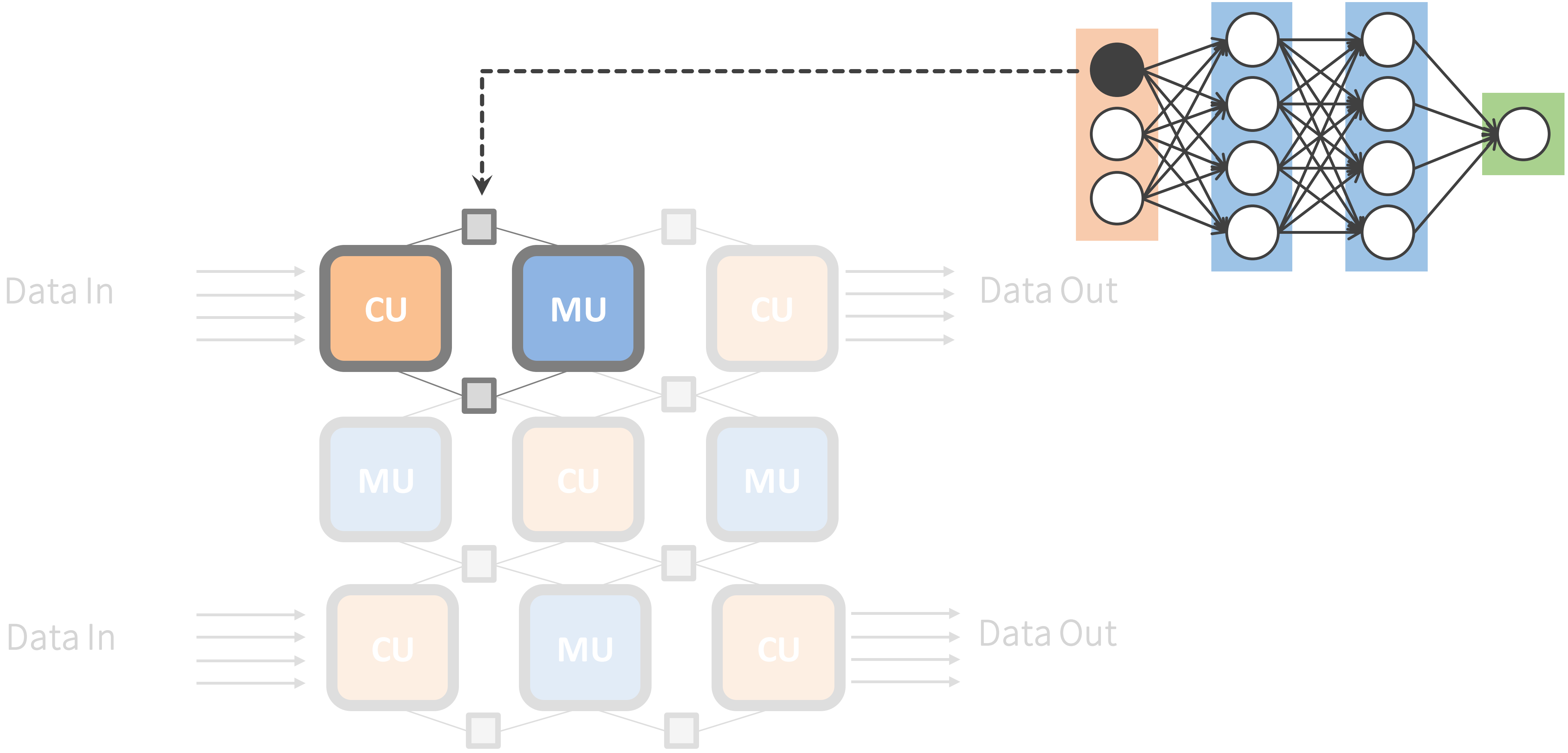


- Implements a **spatial SIMD architecture**

Taurus: Map Reduce Block

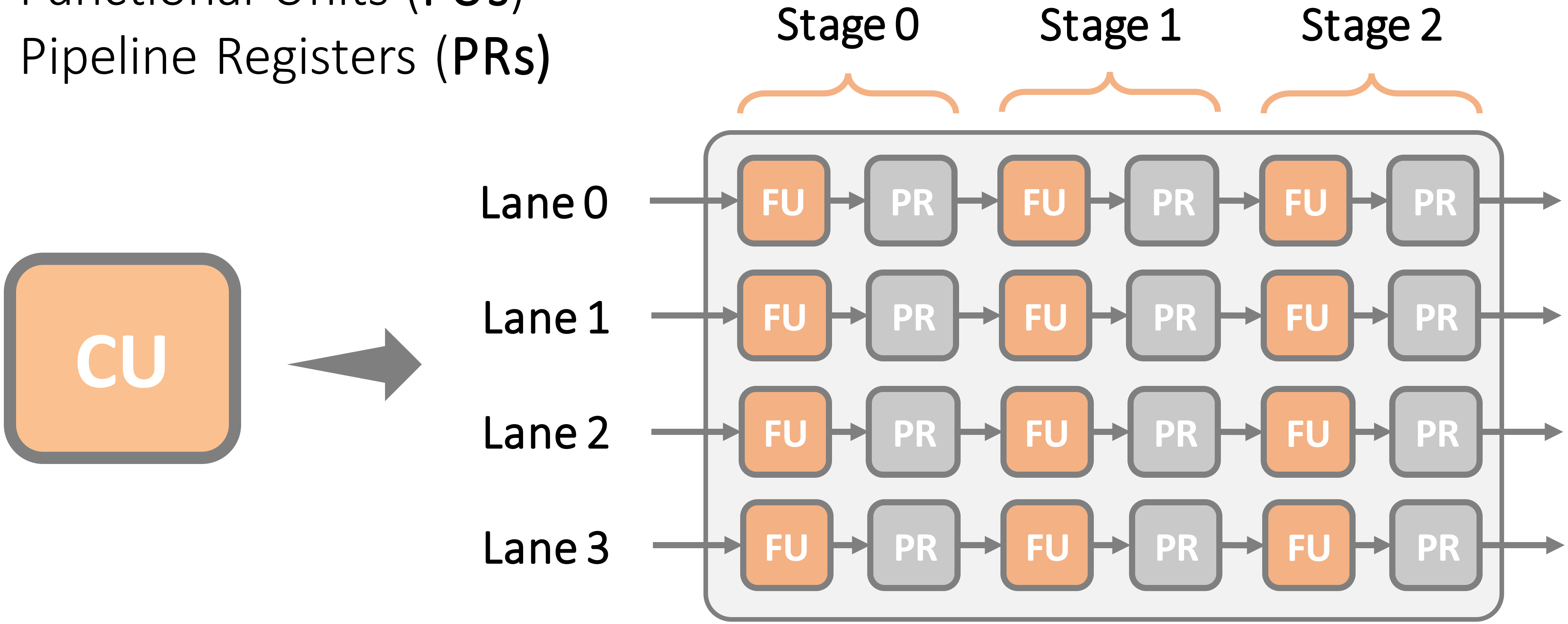


Taurus: Map Reduce Block

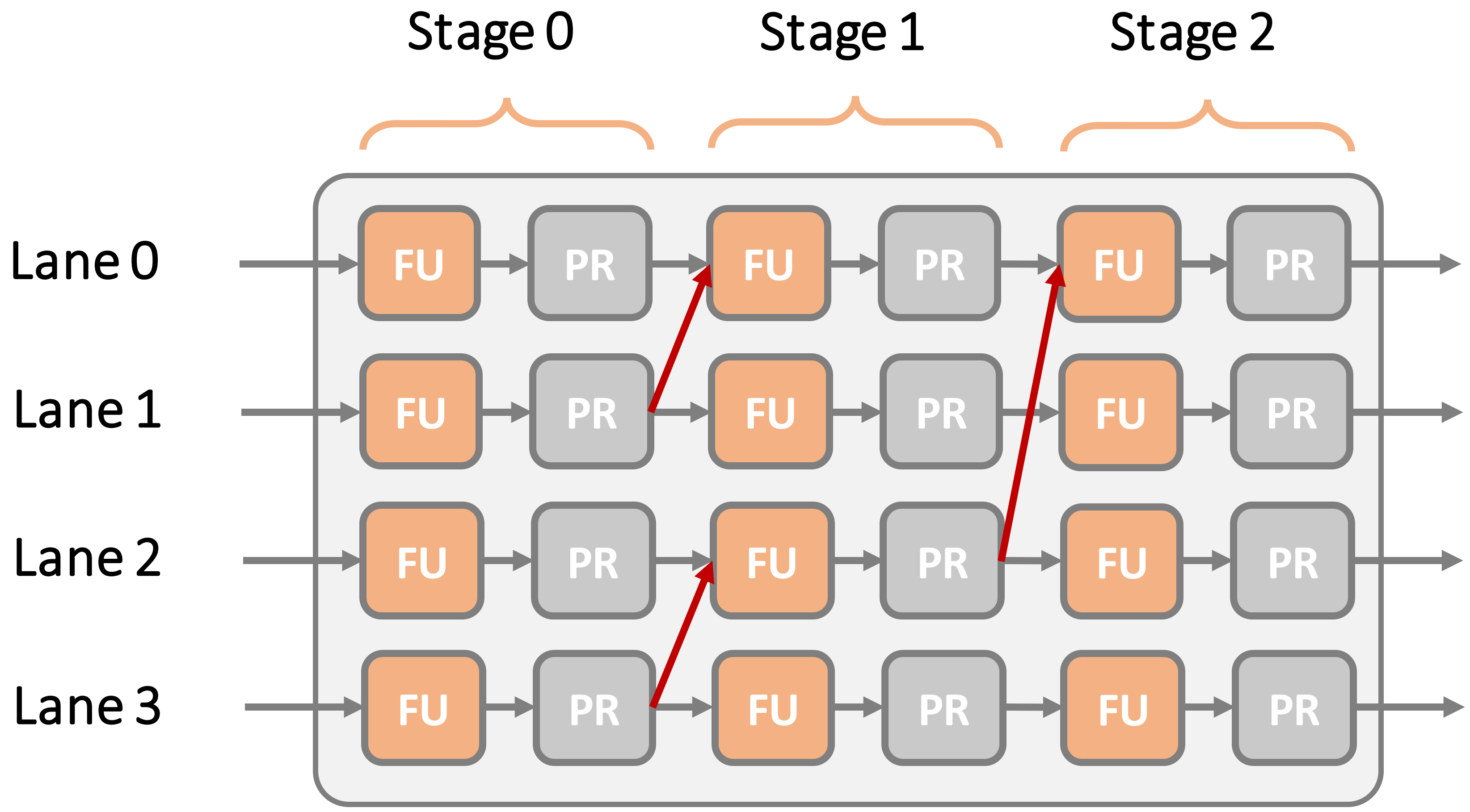


Map Reduce Block: Compute Unit (CU)

- Taurus **CUs** are array-based:
  - Functional Units (**FUs**)
  - Pipeline Registers (**PRs**)



Map Reduce Block: Compute Unit (CU)



Reduction network condenses **vectors to scalars**

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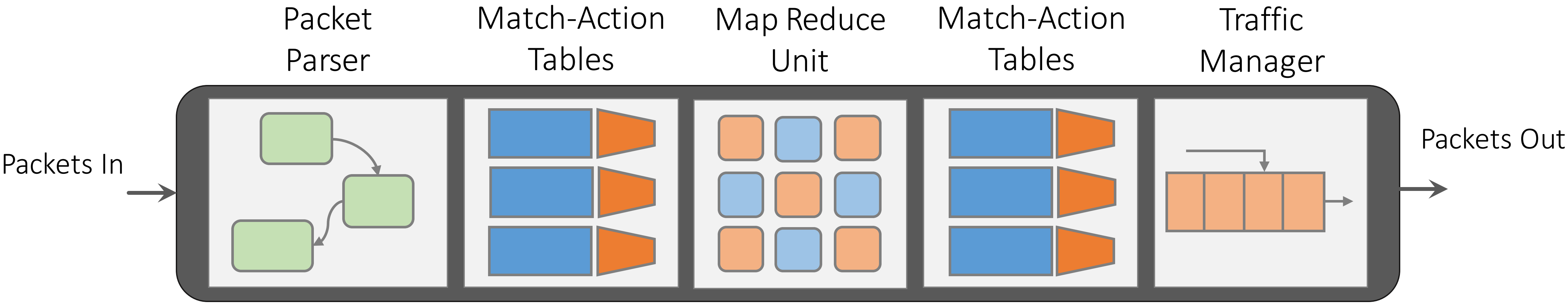
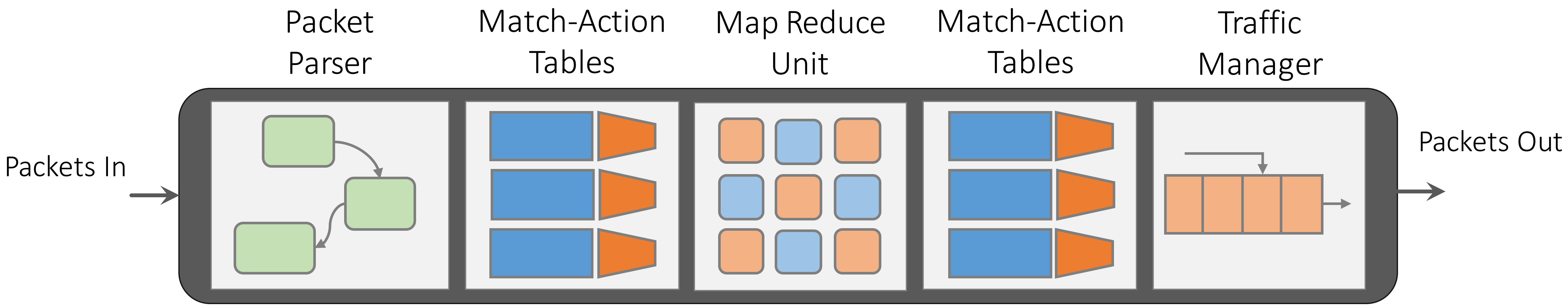


Example: Anomaly Detection



Packets In

Packet Parser

Match-Action Tables

Map Reduce Unit

Match-Action Tables

Traffic Manager

Packets Out

Parse packets and **read local features** (e.g., IP address)

Retrieve **out of network events** (e.g., failed logins per IP)

Apply **learned functions** to mark anomalous packets

Select a port or **action** (drop if score == 1)

Send packets out the selected port

Evaluation: Anomaly Detection in Switches

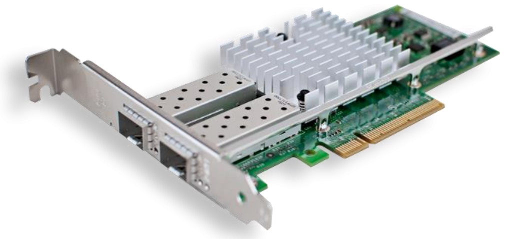
- Taurus examines **every** packet at **line rate**

- Added **latency** is **less** than **port-to-port** latency

			Area	Power
Model	Throughput	Latency	+%	+%
SVM	1 GPkt/s	**68** ns	6.1	1.1
DNN	1 GPkt/s	**362** ns	11.7	2.0

**Overheads are calculated relative to a 300 mm^2 chip with 4 reconfigurable pipelines, each drawing an estimated 25 W*

Evaluation: Congestion Control at the NICs

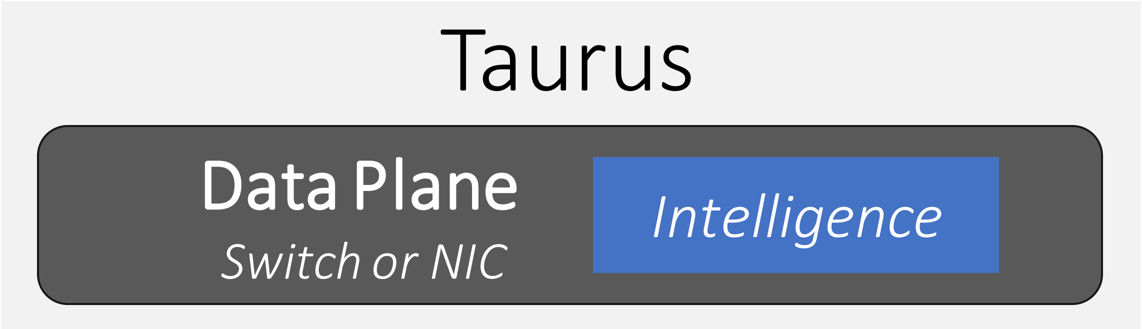


- **Indigo** is a **congestion control** LSTM network
- Taurus updates **every 12.5 ns** (software updates every 10 ms)

			Area	Power
Model	Throughput	Latency	+%	+%
LSTM	**0.08** GPkt/s	**380** ns	23.6	4.1

**Overheads are calculated relative to a 300 mm^2 chip with 4 reconfigurable pipelines, each drawing an estimated 25 W*

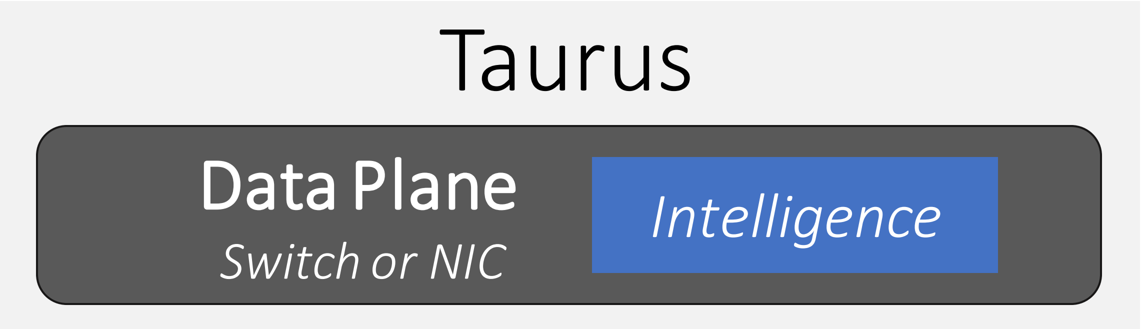
Conclusion



Fast and *intelligent*

- Designed to **run machine-learning inference** inside a data plane
- Provides **orders of magnitude improvement** over existing approaches

Conclusion



dataplane.ai

Fast and ***intelligent***

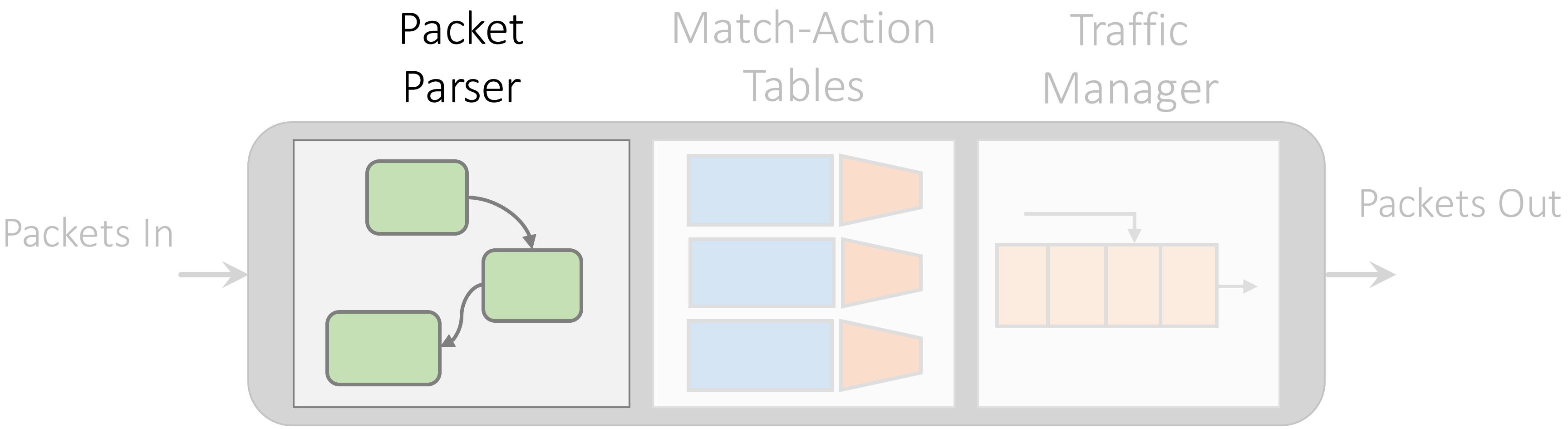
?

Muhammad **Shahbaz**

http://cs.stanford.edu/~mshahbaz

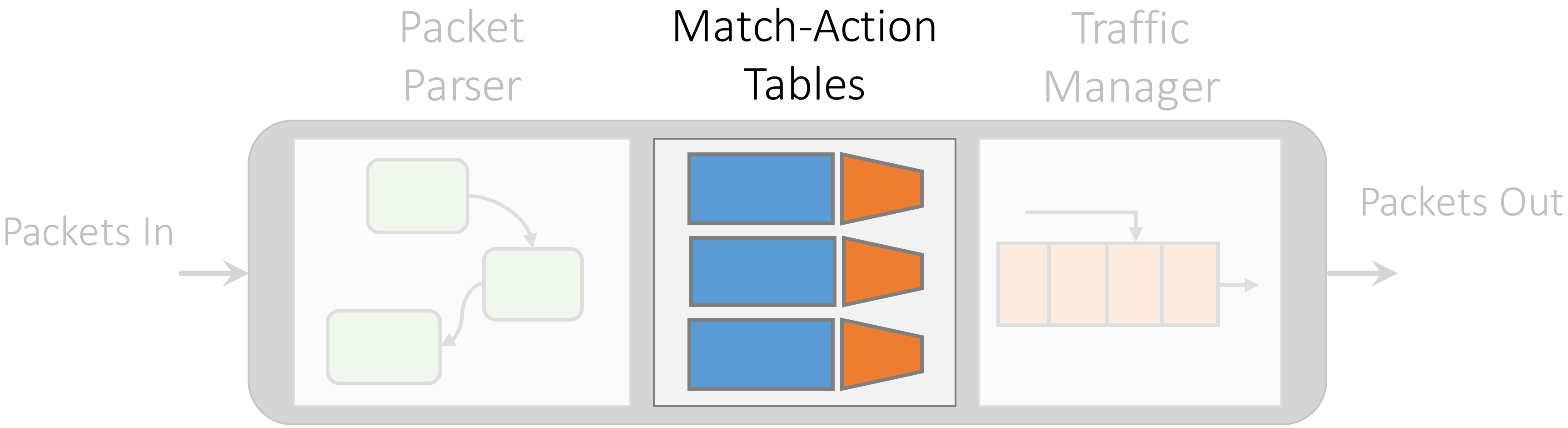
Backup slides …

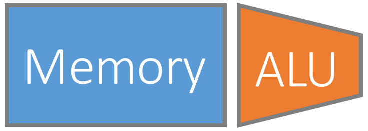
Modern Network Data Plane



- Implements a **finite state machine (FSM)** that operates on a user-defined **parse graph**
- Converts the **incoming packet bit stream into vectors**, *e.g.*,
  - headers (IP or TCP)

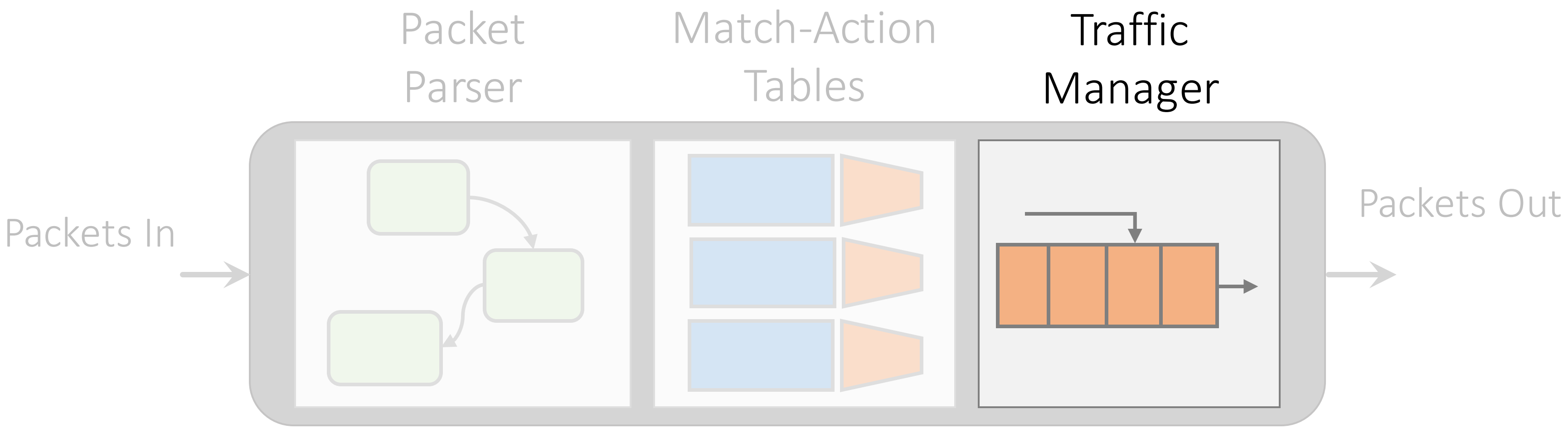
Modern Network Data Plane





- A **match-action table:**
  - Memory for **exact** (SRAM) and **ternary** (TCAM) match
  - ALU for basic single-cycle **VLIW operations** (no loops or multiplication)\

Modern Network Data Plane



- Responsible for **storing** and **forwarding** packets off of the chip:
  - **Queuing**: buffer incoming packet
  - **Replication**: clone packets across multiple egress ports (*e.g.*, multicast)
  - **Scheduling**: forward packets based on a queuing discipline (*e.g.*, PIFO) or instructions from the match-action tables