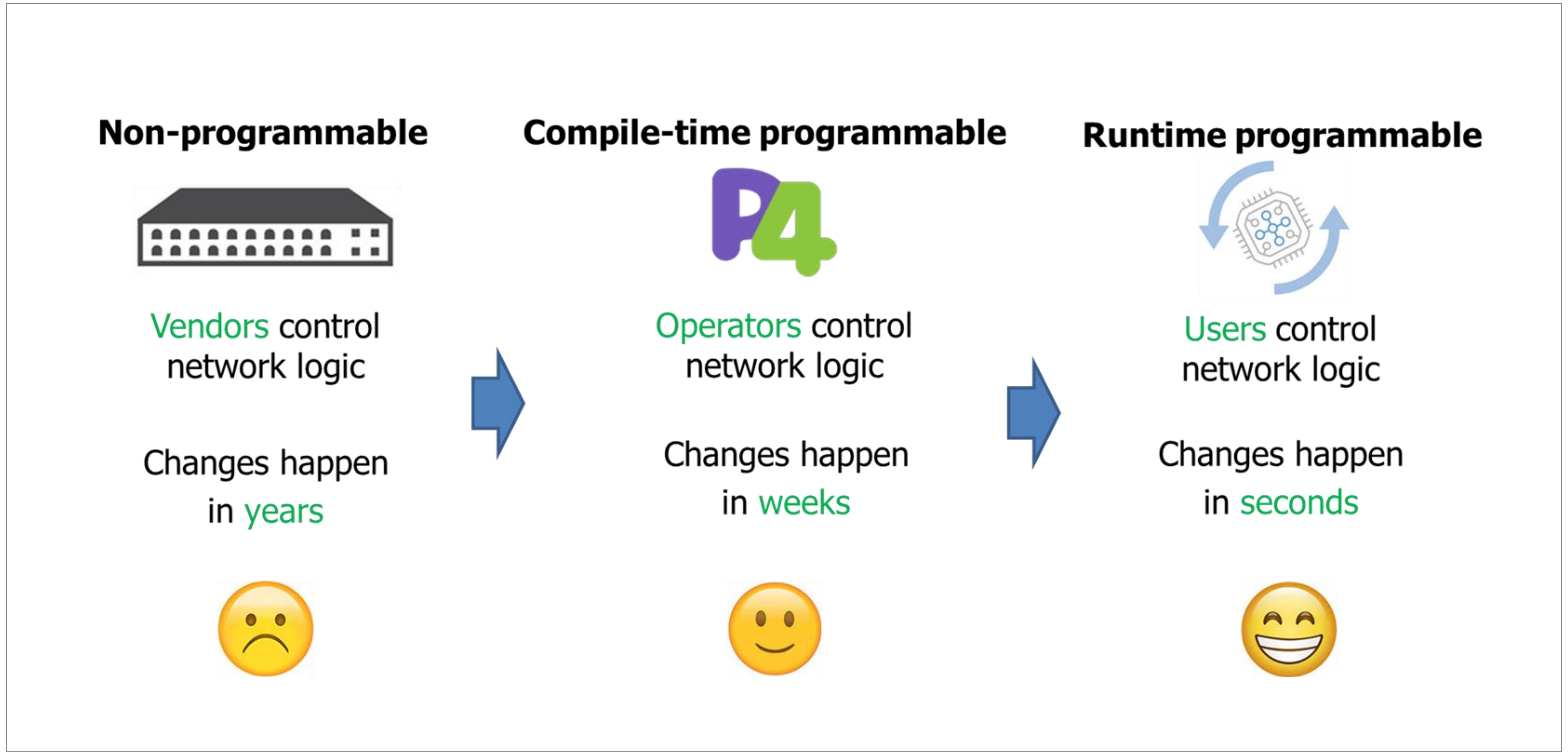
NVIDIA’s Resource Transmutable Network Processing ASIC

Kevin Deierling, VP Networking | August 29, 2023

From Programmability to Transmutability



- Decline of Moore's law → Need for domain-specific architectures
- Goal → Hardware as flexible as software

Current focus on programmability

- Flexibility to perform a wide range of tasks
- Portability where possible

Future focus on resource transmutability

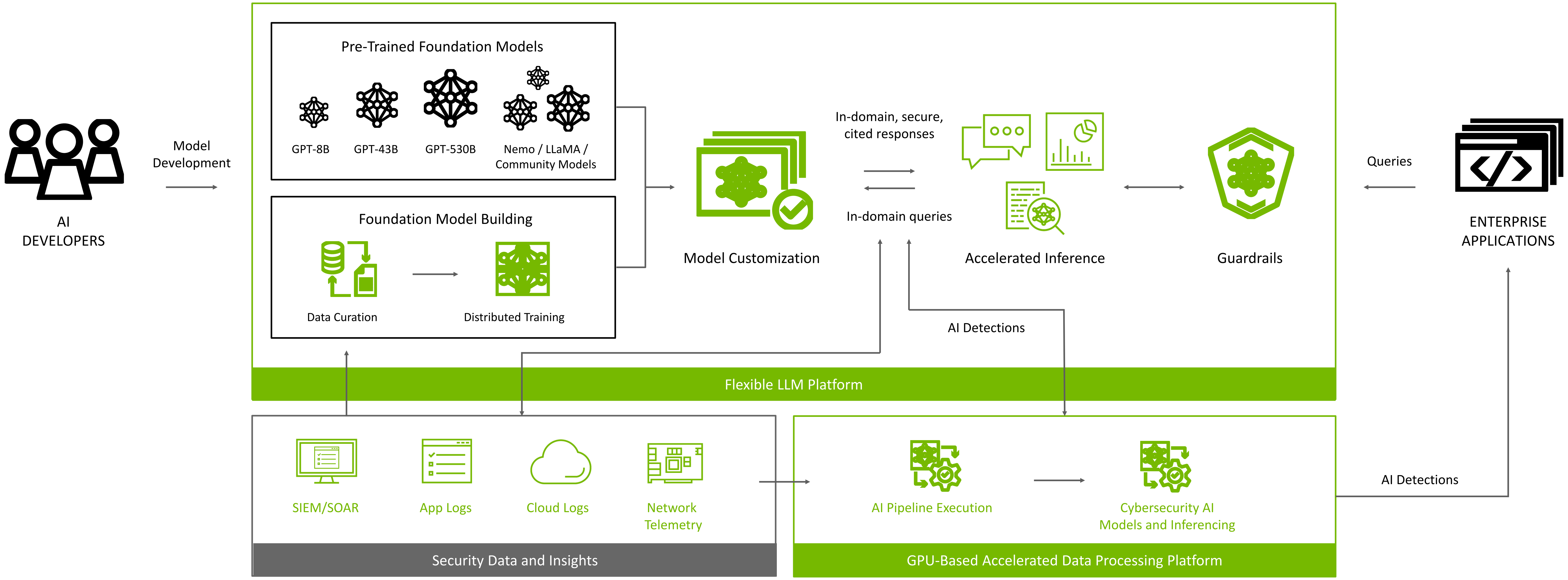
- Dynamic reprogramming of tasks
- Fungible resource allocation

Existing Challenges

- Traditional programmable ASICs: Fixed functions are limited in-runtime modification
- Current process: Risky, complex, not agile
  - Network level: Drain network flows and rerouting traffic, update, then bring back online
  - Device level: Prepare new program in scratch area, then switch over when complete
- Comparison to software data planes where:
  - Upgrades are straightforward
  - New functionality is easy to deploy
  - Programmability is flexible
  - Resource allocation is fungible

Conclusion — Transmutability is a must

Dynamic Workloads Require Transmutability



- Generative AI and Real-time AI cybersecurity frameworks are dynamic and evolving
  - Generative LLM AI and retrieval augmented generation
  - Real time Mitigation: Precise threat response by injecting mitigation modules.
  - Monitoring of traffic patterns and digital fingerprinting of devices, users, and machines
  - Smart telemetry/filtering/sampling and real-time deep data analytics allows GPU to detect anomalous or divergent behavior
  - Dynamic automated quarantining, deep packet inspection, mitigation and restoration
- Just-in-time Network Optimizations: Quick detection, incorporation, and removal of policy
- Scenario-specific Network Extensions: Direct tenant program extensions and integrations

NVIDIA's Solution: Transmutable ASICs

- Based on NVIDIA's BlueField and Spectrum network ASICs
  - Dynamic resource allocation & reclamation
- Reprogram without packet drops, no down time
  - Low level primitives "add", "remove", "update"
  - Indirection - tables referenced by HW "pointers"
  - Full resource utilization - shared memory across all HW match-action processing units
- NVIDIA software stack + runtime changes ⇒ transmutable
  - *BlueField DPU*: NVIDIA P4, DOCA Flow, DPDK
  - *Spectrum Switch*: NVIDIA P4, SAI, Switch SDK
- Programmable throughout deployment with a new set of control plane APIs
  - P4Runtime extensions, backwards compatible
  - DOCA APIs

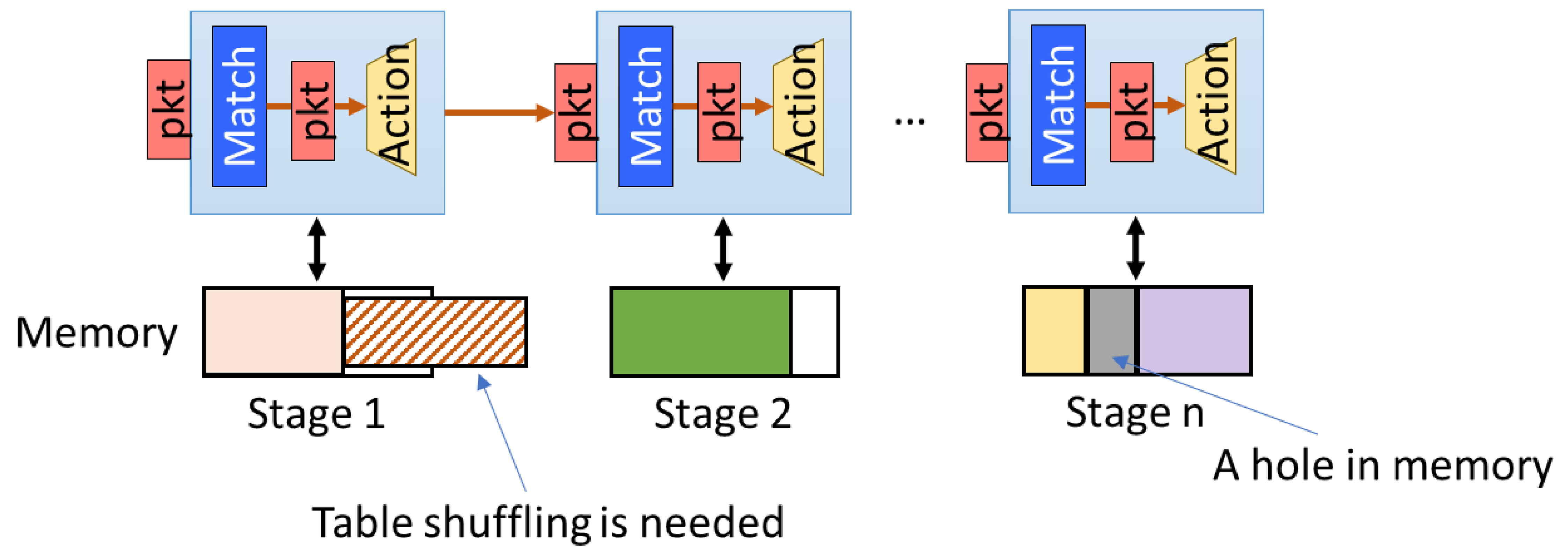
NVIDIA's Disaggregated Architecture

Reconfigurable Match-Action Tables (RMT)

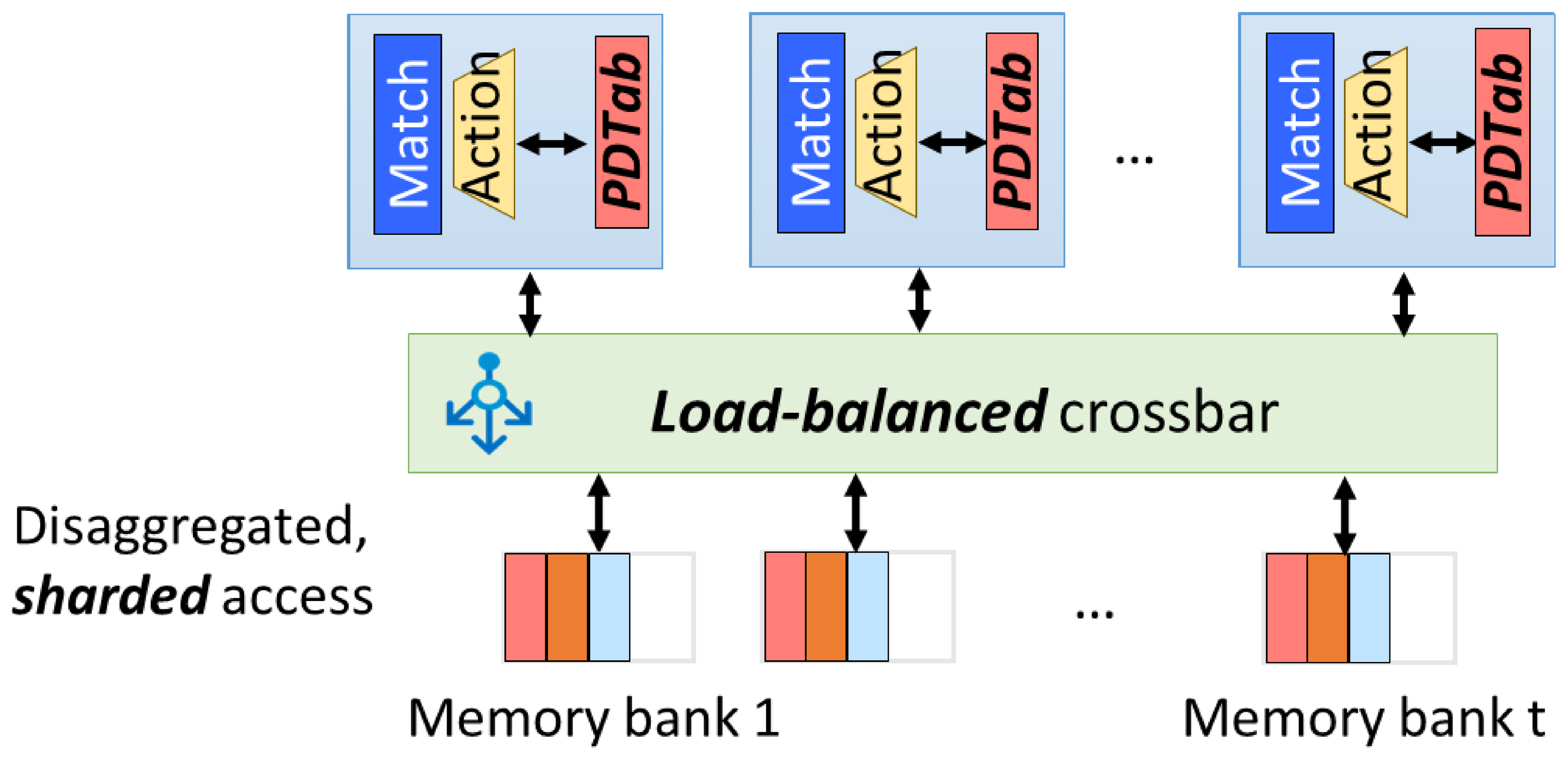
- Programmable pipeline architecture for packet processing
- Apply action "instructions" to a packet by matching keywords in the packet header vector
- Match can be exact, ternary, range or longest prefix match (LPM)

NVIDIA's Enhanced Disaggregated RMT (dRMT)

- Compute and memory are disaggregated
- Shared memory is sharded, and accesses are load-balanced
- Match-action processors handle packets in parallel with run-to-completion model
- Enables granular reconfiguration and transmutability



RMT architecture



dRMT architecture

DPU Transmutable Pipeline SDKs

Transmutable Pipeline

- Runtime loadable
- Hybrid Pipelines
- Plug-n-Play

NVIDIA P4

- High level packet processing programming language
- Domain Specific compiler + open source P4Runtime API

DOCA Flow

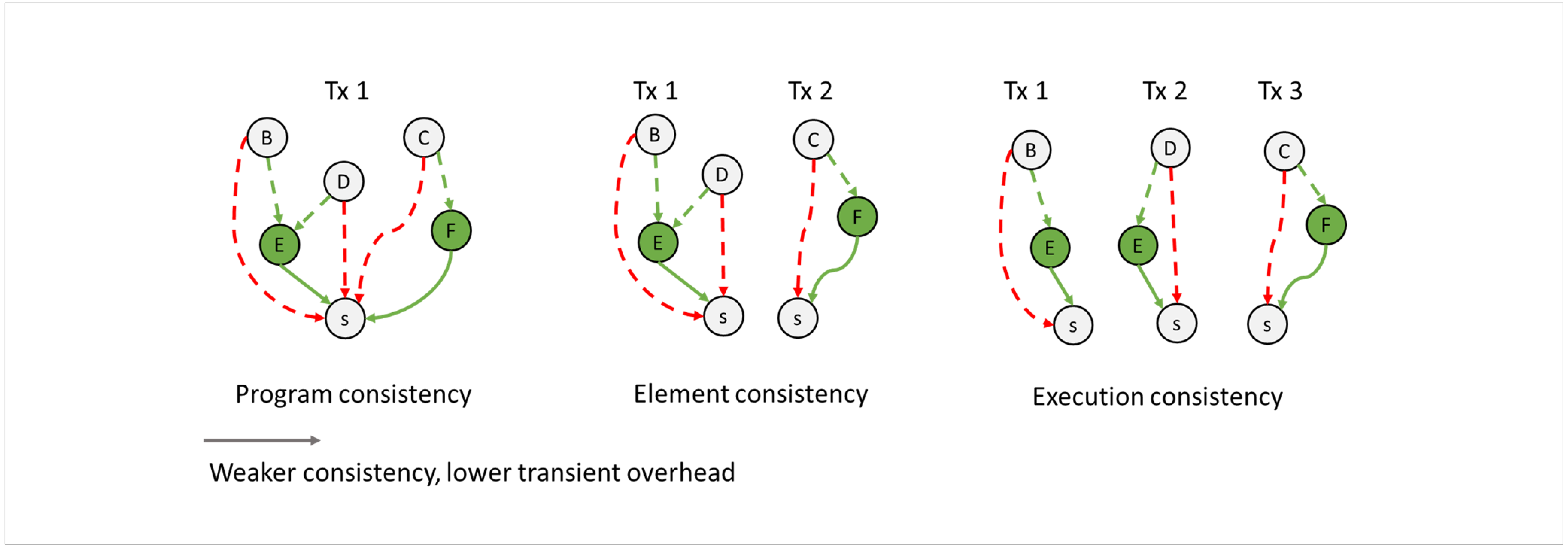
- High level accelerated networking pipeline API

DPDK

- Low level polled packet processing API

ASIC Design and Architecture Features

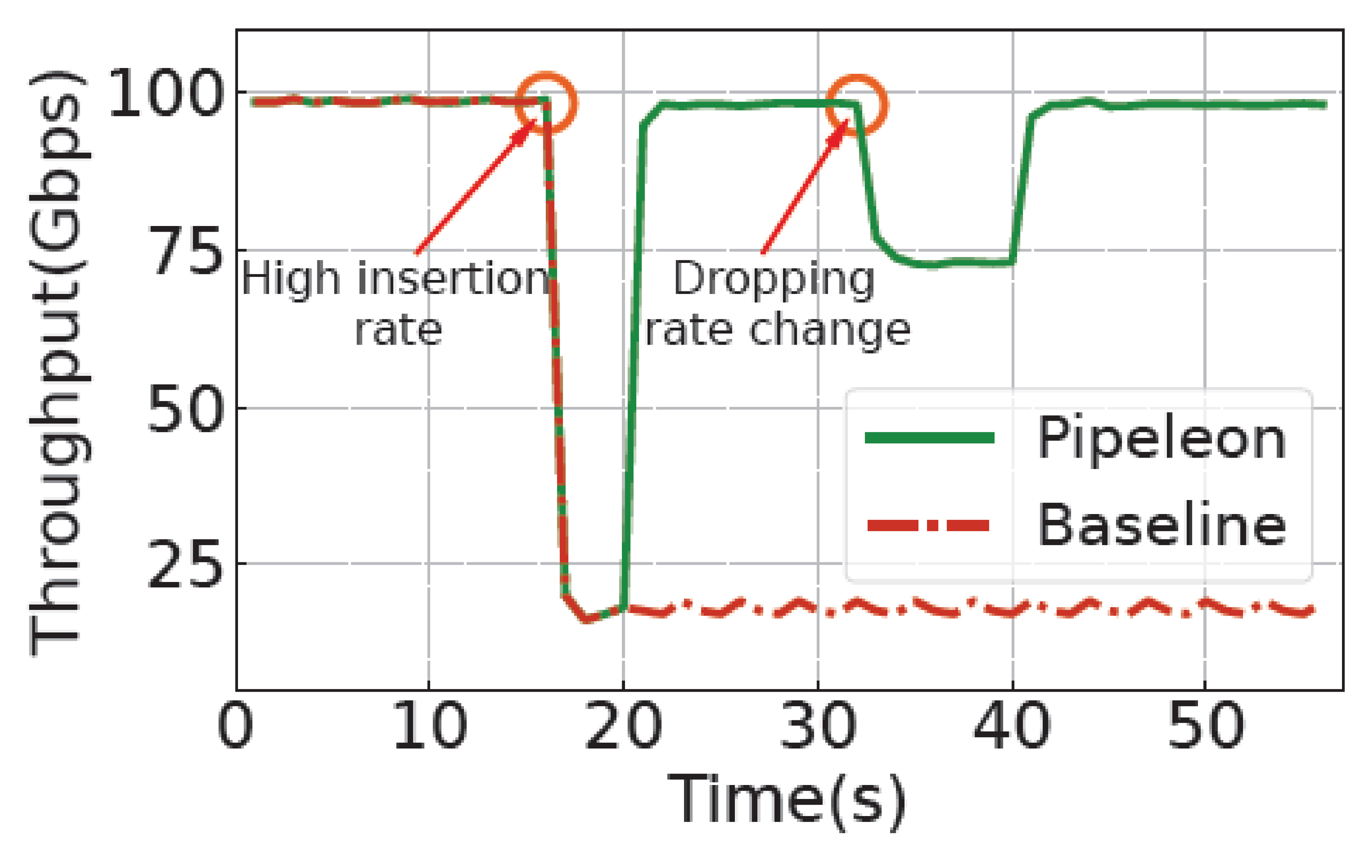
- Disaggregated Architecture → Breaks resource allocation boundaries for partial reconfiguration
- Sharded Resource Allocation → Balances loads, avoids contention
- Hybrid Programmability → Efficient fixed modules + customization
- Indirection → Low-latency, efficient reconfigurations
- Extended Control Plane → Modify elements, 3 consistency guarantees

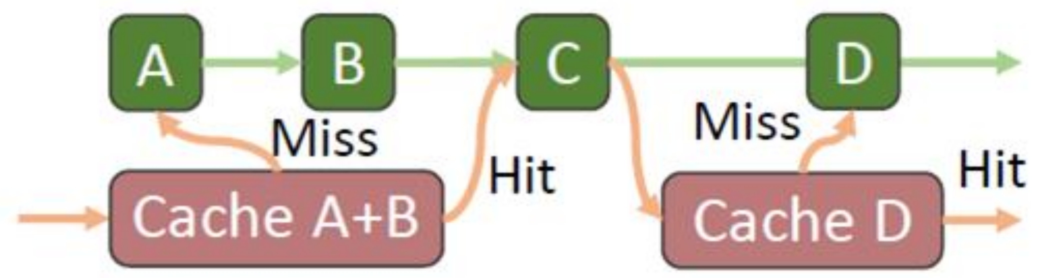


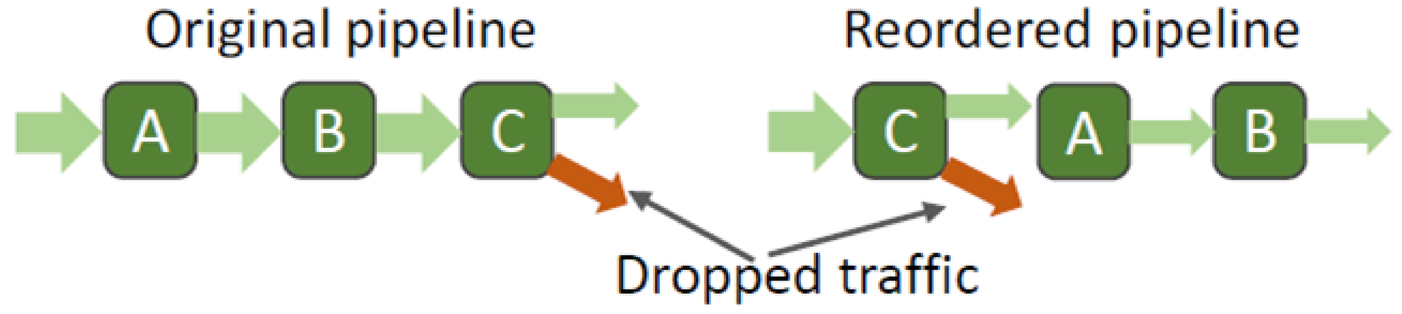
Real-World Use Cases

- Benchmarks performed on NVIDIA Bluefield DPU and Spectrum switch
- Demonstrated scalability and adaptivity
- Server Load Balancer (SLB)
  - Perform optimizations at runtime to maximize throughput
- Source Based Routing and Telemetry
  - Pipeline extensions and chaining of P4 services
  - Dynamically extend pipeline with new functionality
  - Temporarily add in-situ network visibility

Server Load Balancer on BlueField

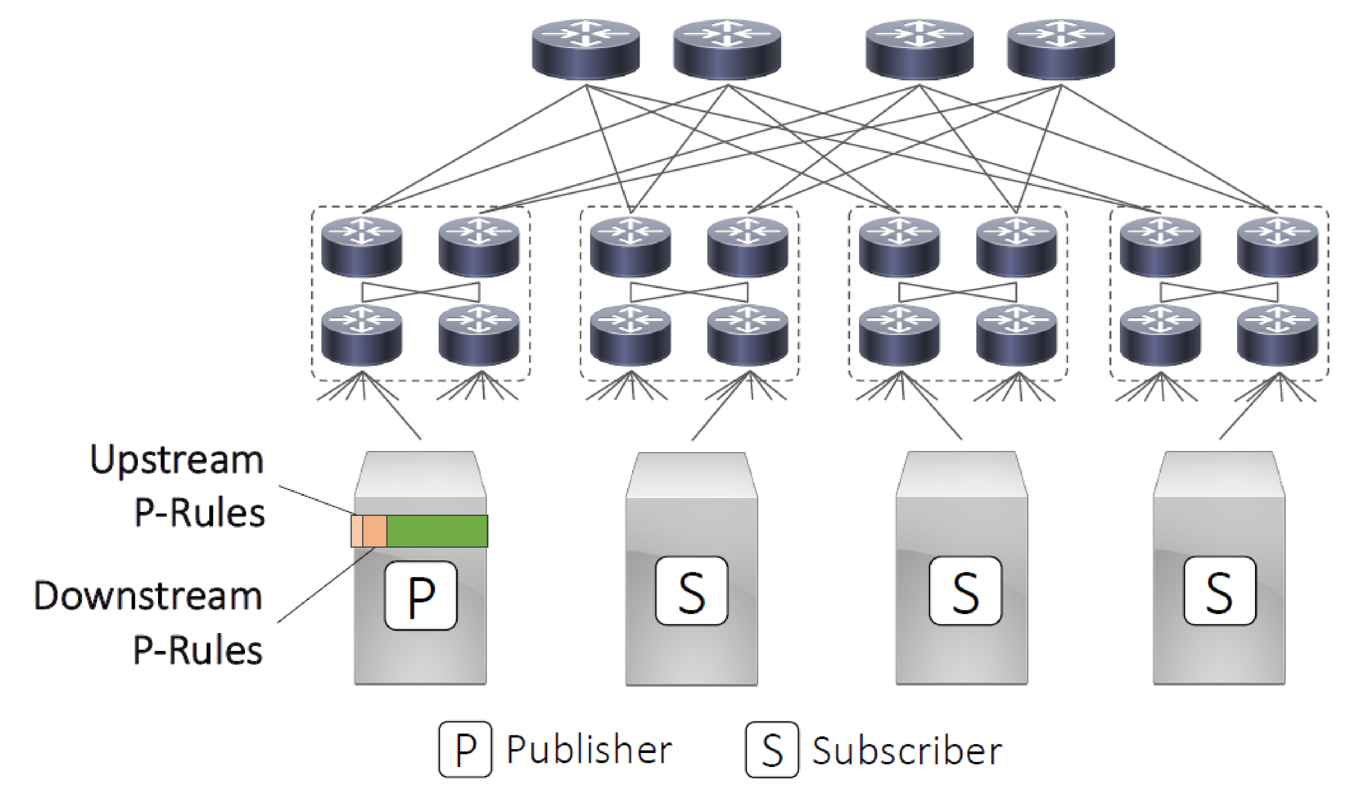


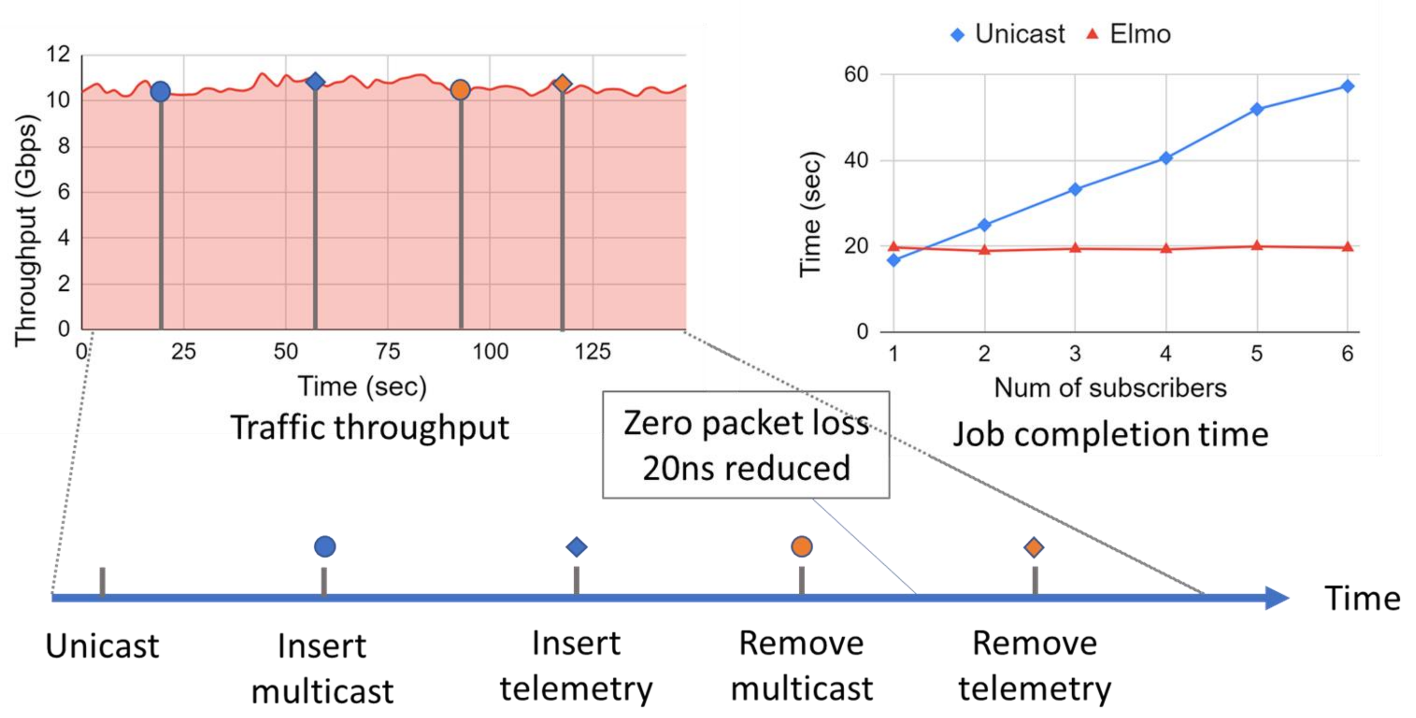




- "Pipeleon" runtime monitoring of rules/entries
  - High insertion rate event causes the cache table to "miss"
  - Miss counter threshold triggers a dynamic table reordering → throughput returns to line rate
- "Pipeleon" runtime monitoring of traffic and drops
  - Traffic pattern changes, causing a large number of policy driven packet drops
  - Drop counter threshold triggers a dynamic table reordering → throughput returns to line rate

Accelerated Multicast on Spectrum





- "ELMO" source routed multicast
  a. Enhancement to standard switch multicast table management
  b. Encodes multicast group information inside packets → scale improvement
- Postcard telemetry
  a. Dynamically load a pipeline module to send telemetry data
  b. Dynamically remove module once visibility no longer required

Conclusion & Next Steps

- NVIDIA’s innovation enables a truly adaptive network core, enabling network processing with resource transmutability
- Bridging the gap between hardware and software
- Transmutability as the future of network ASIC design
- Roadmap
  - Design the right APIs needed to load, control, update transmutable pipelines
  - Consistency guarantees and atomicity requirements
  - End to end solutions across multiple programmable network devices
  - Provide frameworks for performance and flexibility, but also complexity and scale

References

Runtime Programmable Switches

Jiarong Xing, Kuo-Feng Hsu, Matty Kadosh, Alan Lo, Yonatan Piasetzky, Arvind Krishnamurthy, and Ang Chen

NSDI 2022

https://www.usenix.org/conference/nsdi22/presentation/xing

Unleashing SmartNIC Packet Processing Performance in P4

Jiarong Xing, Yiming Qiu, Kuo-Feng Hsu, Songyuan Sui, Khalid Manaa, Omer Shabtai, Yonatan Piasetzky, Matty Kadosh, Arvind Krishnamurthy, T. S. Eugene Ng, Ang Chen

ACM SIGCOMM'23, New York, NY, September 2023

https://www.cs.rice.edu/~eugeneng/papers/SIGCOMM23-Pipeleon.pdf

A Vision for Runtime Programmable Networks

Jiarong Xing, Yiming Qiu, Kuo-Feng Hsu, Hongyi Liu, Matty Kadosh, Alan Lo, Aditya Akella, Thomas Anderson, Arvind Krishnamurthy, T. S. Eugene Ng, and Ang Chen

HotNets'21

https://dl.acm.org/doi/pdf/10.1145/3484266.3487377

Elmo: Source Routed Multicast for Public Clouds

M. Shahbaz, L. Suresh, J. Rexford, N. Feamster, O. Rottenstreich and M. Hira

IEEE/ACM Transactions on Networking, vol. 28, no. 6, Dec. 2020

https://www.cs.princeton.edu/~jrex/papers/elmo19.pdf

Realizing Source Routed Multicast Using Mellanox's Programmable Hardware Switches

Matty Kadosh, Yonatan Piasetzky, Barak Gafni, Lalith Suresh, Muhammad Shahbaz, Sujata Banerjee

https://opennetworking.org/wp-content/uploads/2020/04/Yonatan-Piasetzky-and-Muhammad-Shahbaz-Slide-Deck.pdf

NVIDIA