Isolation Mechanisms for High-Speed Packet-Processing Pipelines

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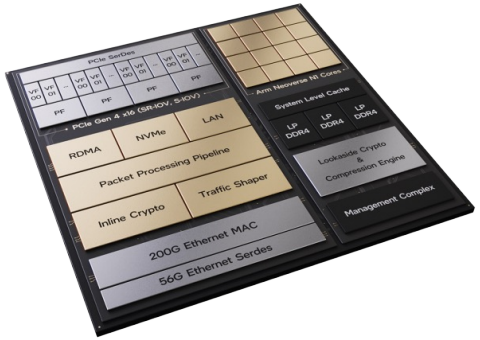
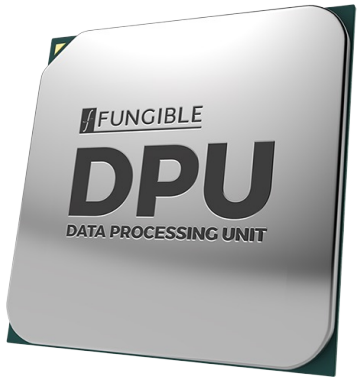
Data-plane programmability is mainstream

- Our focus: pipeline-based programmable networking devices with a Reconfigurable Match Table (RMT)-style architecture



Intel Mount Evans IPU



Fungible DPU

Pensando SmartNICs

Intel Barefoot Tofino Switches

Can improve performance for many systems

NetCache: Balancing Key-Value Stores with Fast In-Network Caching

Xin Jin[1], Xiaozhou Li[2], Haoyu Zhang[3], Robert Soulé[2,4],
Jeongkeun Lee[2], Nate Foster[2,5], Changhoon Kim[2], Ion Stoica[6]

Eris: Coordination-Free Consistent Transactions Using In-Network Concurrency Control

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HPCC: High Precision Congestion Control

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But **most systems** are now deployed on **shared** **cloud infrastructure**

Can multiple tenant programs share one programmable network device?

Not yet! Lack **isolation mechanisms**

What is isolation?

- Common requirements
  - One program cannot impact another's behavior or performance
  - Reconfiguring a program does not disrupt others
  - Maintain aggregate device throughput and latency

- RMT-specific requirement: **expressivity**
  - does not limit complexity of programs that can be executed

Why do existing works not suffice?

- Key challenge: **expressivity**
- Some approaches (e.g., NetVRM) focus on memory isolation
- Others partition processing resources between programs
  - Reduced stages and ALUs limit complexity of programs
- **Our goal**: Isolation should not limit what can run on RMT

How to implement isolation in RMT?

- **Time sharing**: mechanisms to switch between programs
  - Problem: context switching is too costly at high speeds
- **Space sharing**: split processing units between programs
  - Problem: limit expressivity by reducing number of instruction units
- Need a new approach: **Menshen**

Menshen's high-level approach

- Software mediation
  - Resource allocation
  - Compilation

- New hardware primitives enable
  - Switching between programs at packet timescales
  - Disruption-free reconfiguration

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Menshen's Hardware Primitives:

program ID + overlays + space partitioning

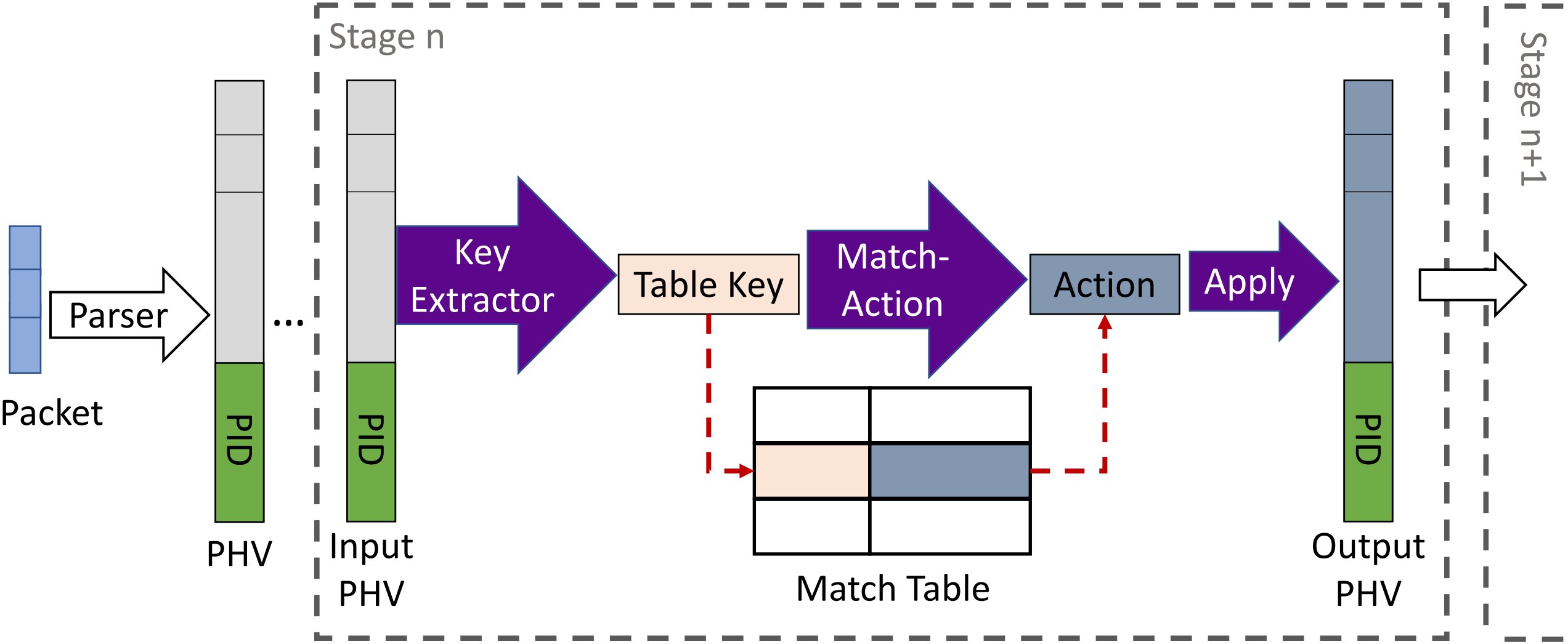
Menshen program IDs

- Menshen associates a PID with each tenant program
- Every packet specifies the program ID (PID)
  - In our current implementation: VLAN tag

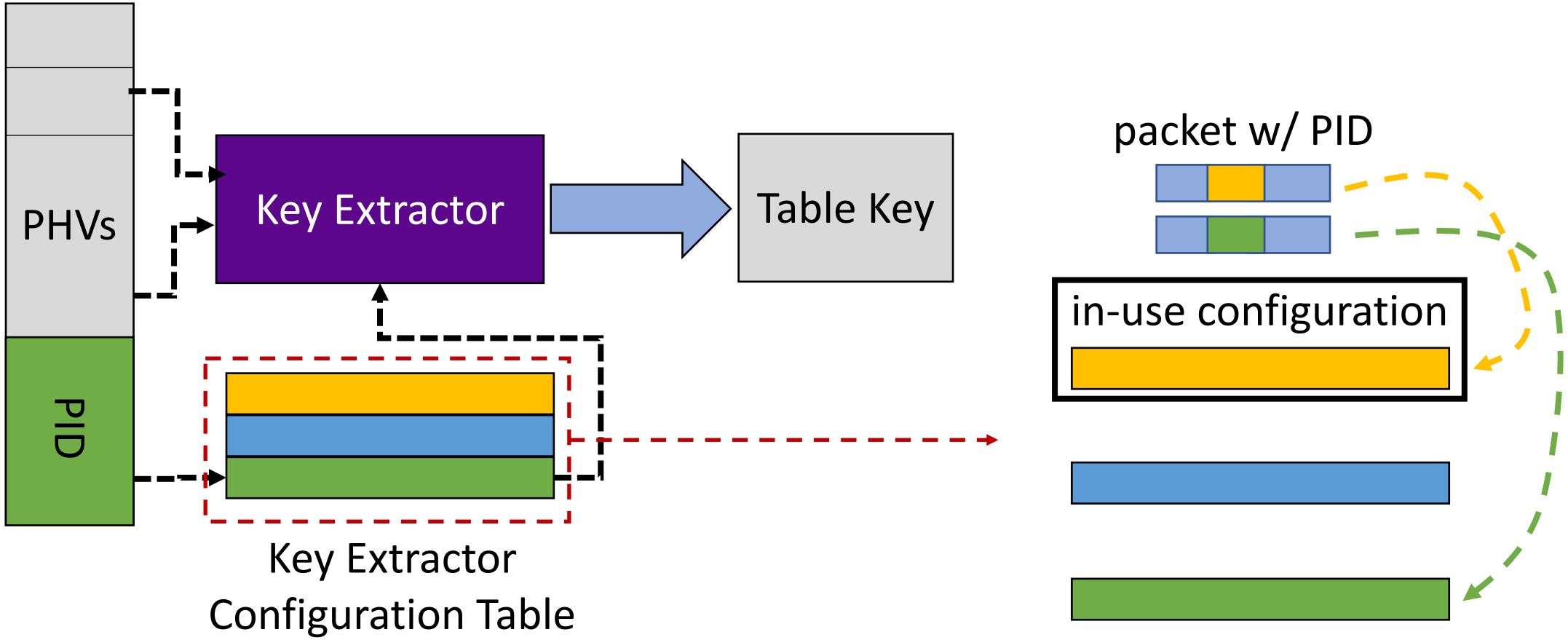
Packet format

Menshen uses PID to select program

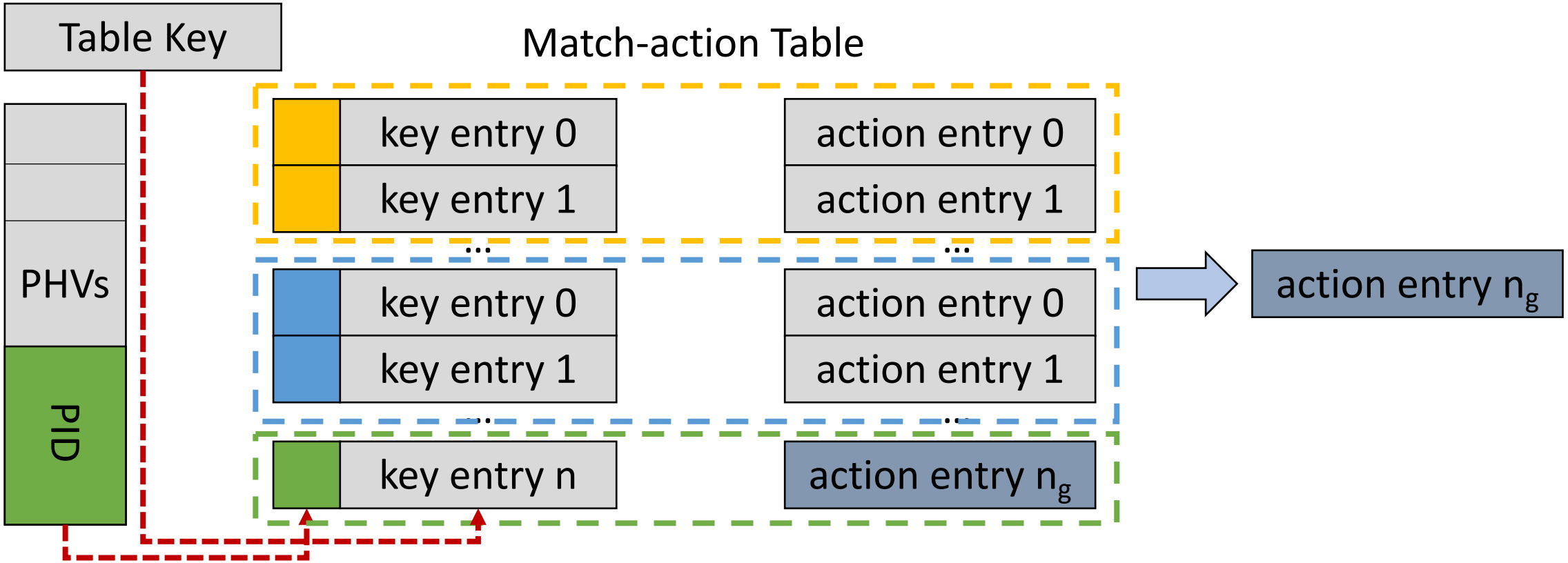
Review: How a RMT stage works



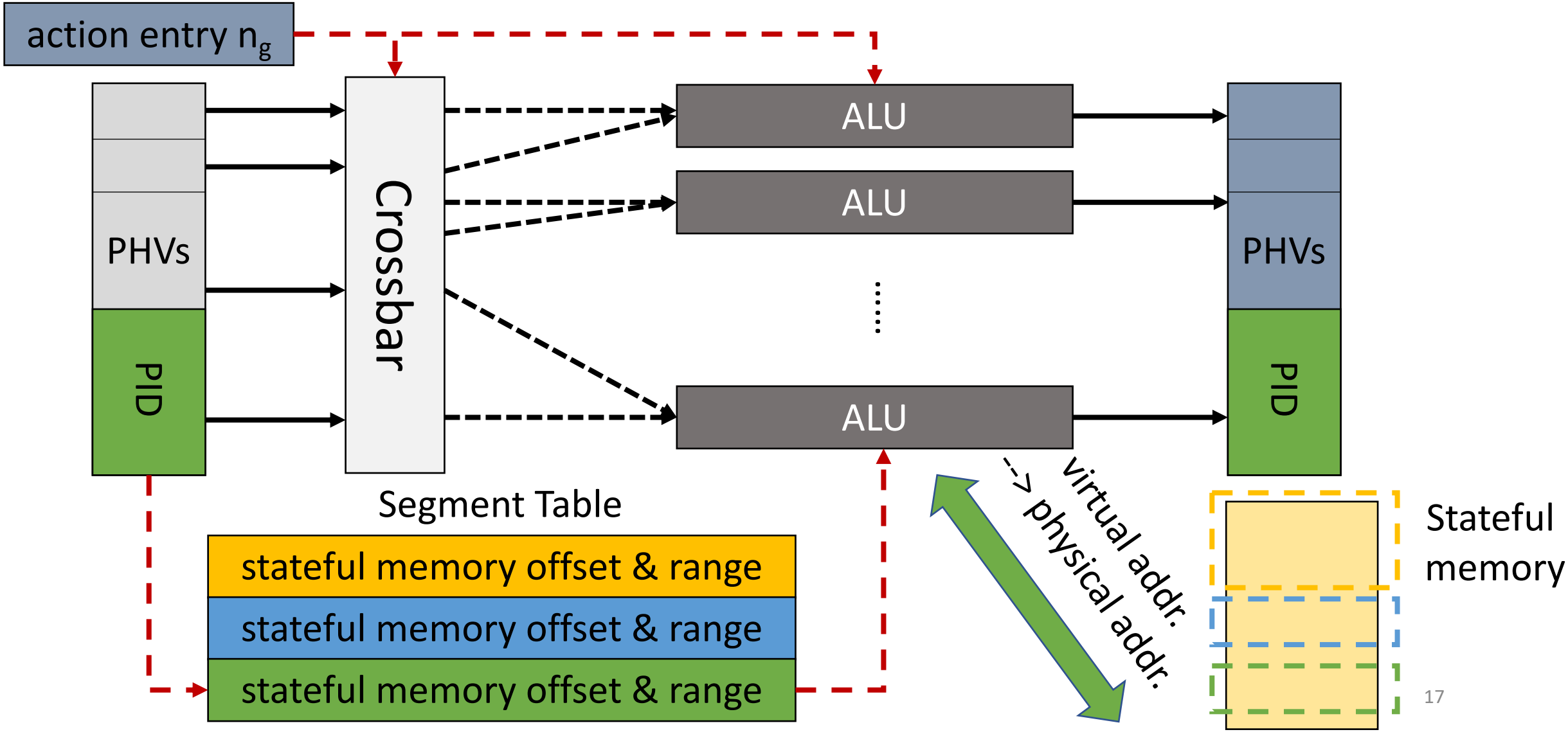
Menshen: How **overlays** work
Key extraction enhancements



Menshen: How **space partitioning** works
Match-action enhancement



Menshen: Action engine enhancements



Menshen's design principles: overlays + space partitioning

- Tables and memory are **partitioned** between programs
  - Large enough, negligible impact on expressivity
- Use **overlays** to share stages and actions between programs
  - Does not limit program length or complexity
- Configuration tables are in registers
  - Allows switching programs at per-packet timescales

Implementation

- We have an open-source implementation
  - Software extends P4 reference compiler
  - FPGA prototype integrated with NetFPGA and Corundum
- Also includes an open-source RMT pipeline implementation
  - Simplifies evaluation of proposed RMT extensions
- Menshen also has ASIC synthesis results
  - works at 1 GHz with FreePDK45nm library

Evaluation

- Does Menshen achieve isolation requirements?
  1. Can it support multiple programs while ensuring correctness?
  2. Does it hurt aggregate pipeline performance?
  3. Is it disruption-free?

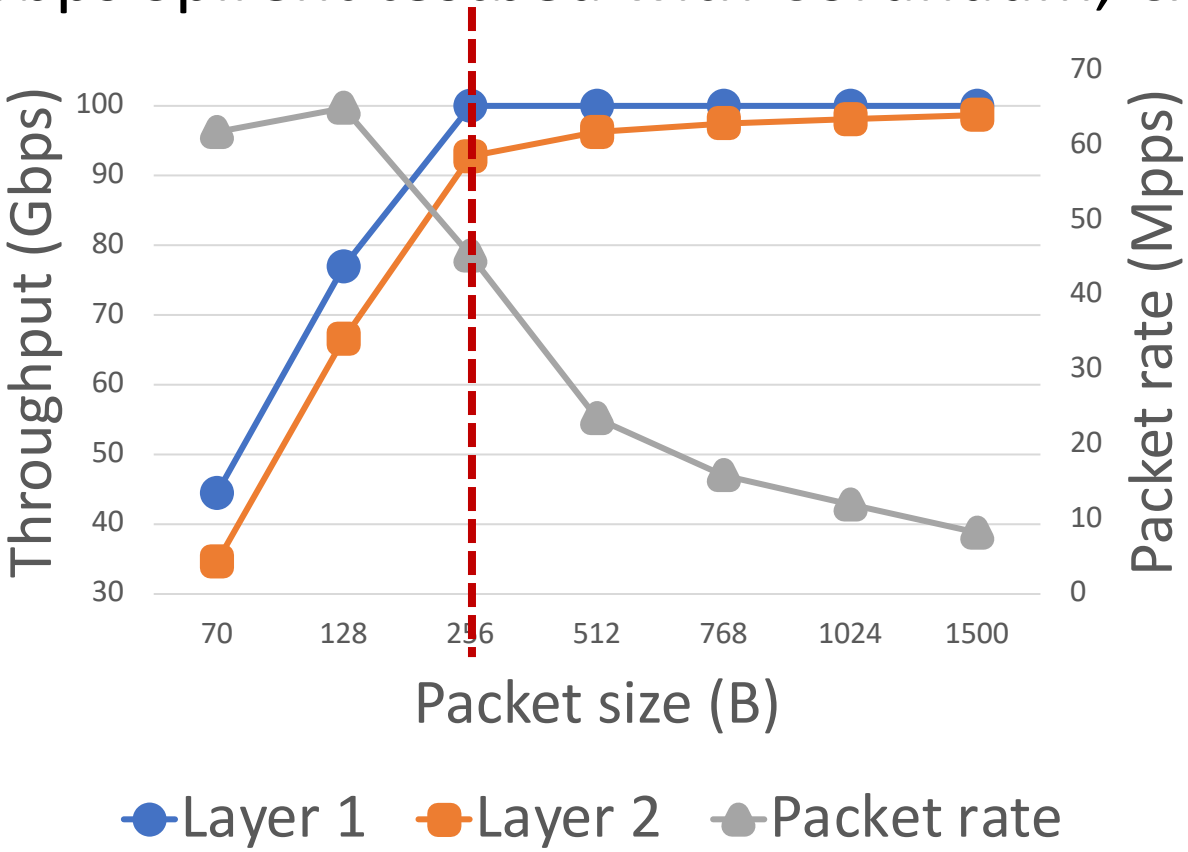
1. Can Menshen support multiple programs?

- 6 P4 tutorial programs
  - CALC, Firewall, Load balancing
  - QoS, Source routing, multicast
- + simplified NetChain and NetCache

- Tested program correctness using packet traces ✔

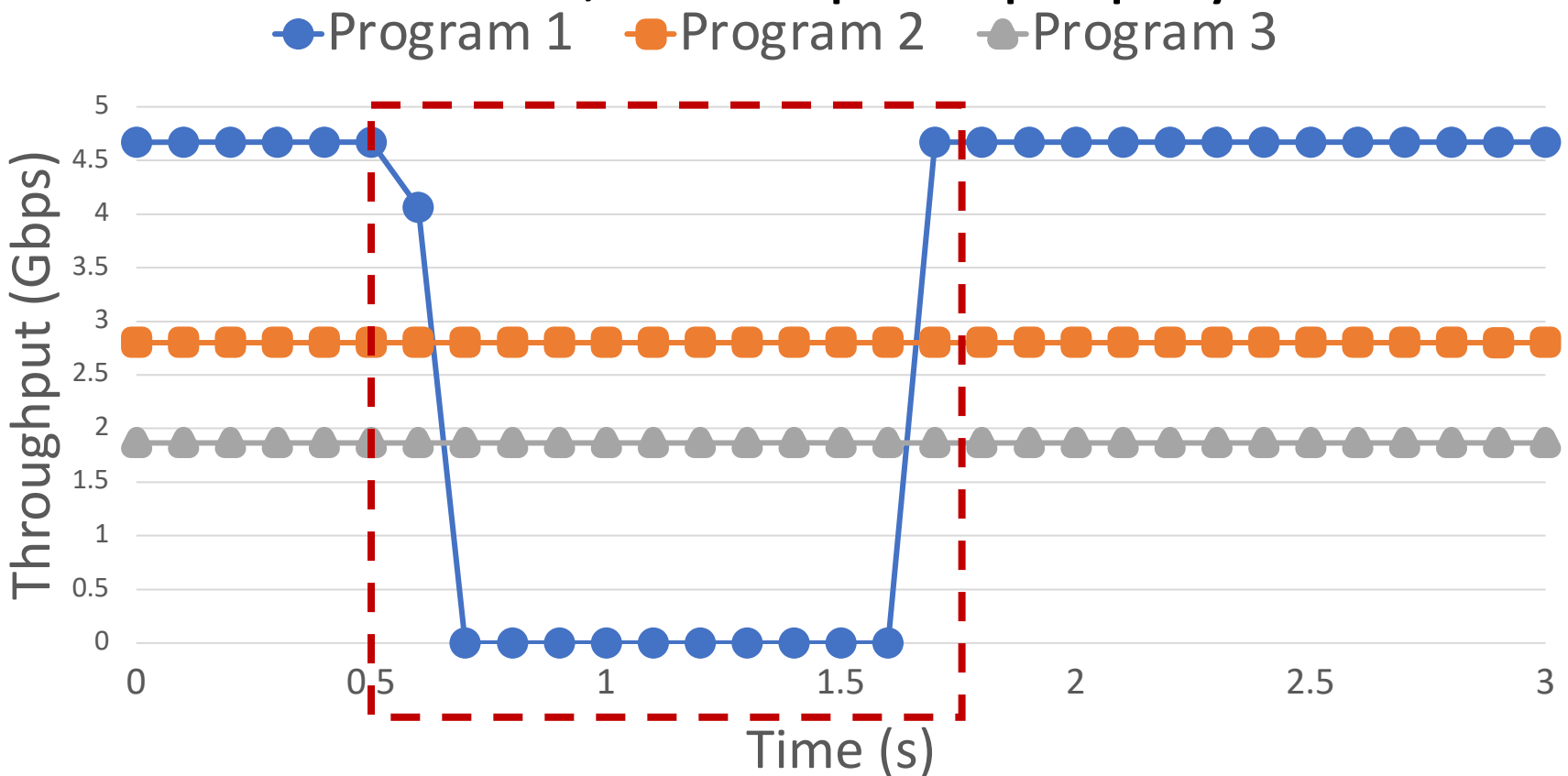
2. Menshen's overall throughput performance

- Menshen's pipeline throughput with varying packet sizes
  - setup: 100Gbps Spirent testbed with Corundum, CALC program loaded



3. Does reconfiguration disrupt other programs?

- 3 CALC programs send traffic with 5:3:2 ratio on 10Gbps link
- setup: NetFPGA testbed, netmap + tcpreplay



Conclusion --- the quest for isolation

- The lack of isolation is a barrier to the adoption of programmable networks

- Menshen: a proposal for how to provide isolation for RMT
  - Core idea: redesign how time and space sharing work in RMT

- Menshen: publicly available for use and extension

https://isolation.quest

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