# DECIDABLE VARIABLE-RATE DATAFLOW FOR HETEROGENEOUS SIGNAL PROCESSING SYSTEMS

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# Motivation

- PRUNE (PSM Runtime Environment, Boutellier et al. 2018): A high-performance, dynamic, decidable dataflow model of computation and associated design framework for signal processing applications

- Variable-Rate Dataflow (VRDF, Wiggers et al. 2008): modeling of data-dependent communication behavior
  - VRDF can improve model analyzability due to the pre-indicated token rate limits and maintain sufficient expressiveness for adaptive behavior at the same time

- In previous work[1], PRUNE with adaptations for variable token rates has been preliminarily demonstrated to have performance and expressiveness benefits

[1] J. Boutellier and S. S. Bhattacharyya (2017) "Low-power heterogeneous computing via adaptive execution of dataflow actors", IEEE SiPS

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# Introduction

- This work: VR-PRUNE – a high-performance, flexible, dynamic decidable dataflow model of computation
  - Formalization of the preliminary work[1]
  - Elaboration of PRUNE Model of Computation and framework

- VR-PRUNE
  - is a hybrid between the PRUNE MoC  and the VRDF MoC: VR-PRUNE keeps the decidability of PRUNE, but adds to it support for variable token rates
  - is a Linux-based dataflow computing framework
  - supports OpenCL devices such as GPUs and multicore CPUs

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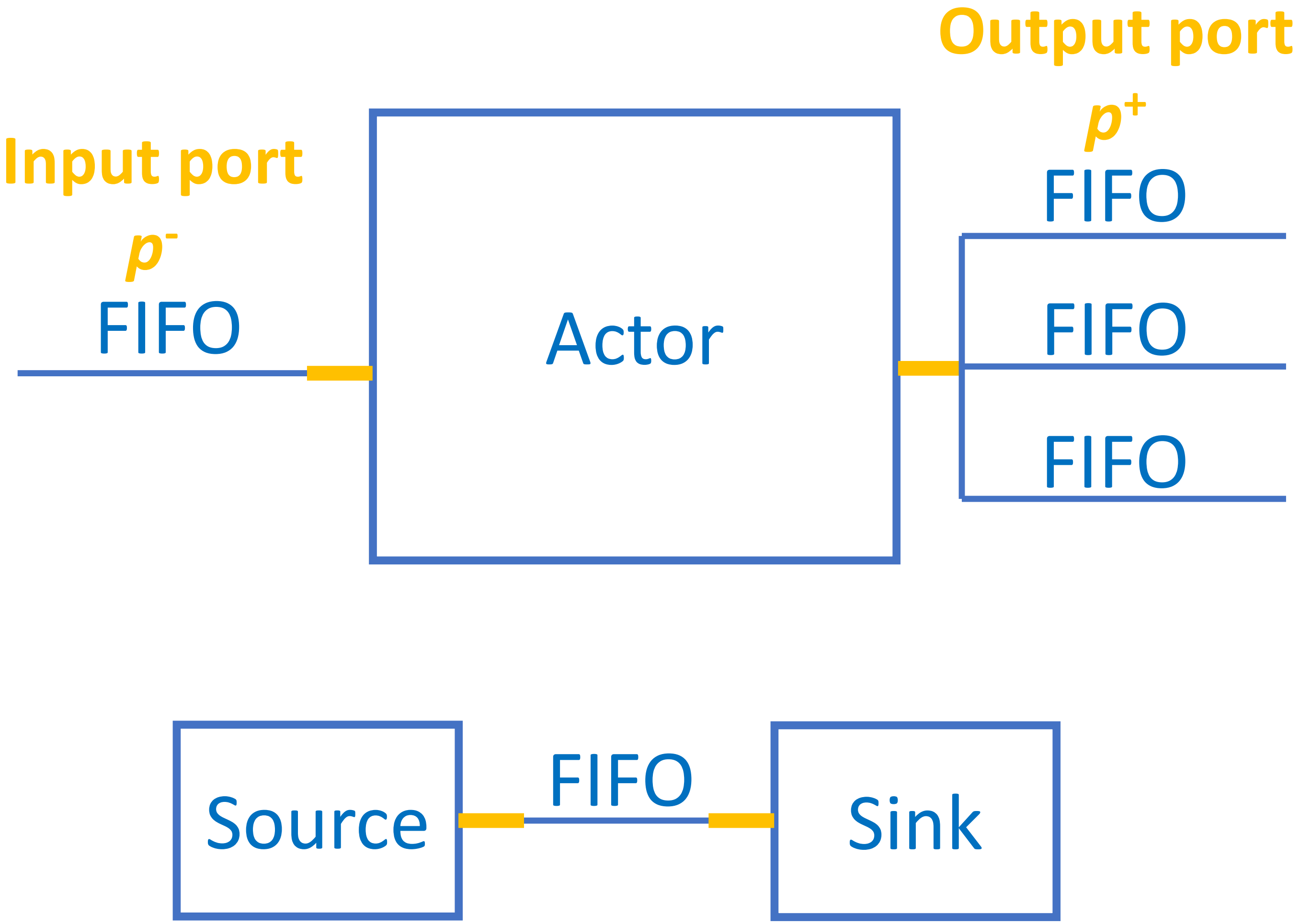
# Background: Model of Computation




- A FIFO channel is connected to an actor through an actor port
- An output port $p^+$ can be connected to multiple FIFOs, but every input port $p^-$ has only one FIFO connected to it
- Each FIFO has unique source and sink ports.

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# VR-PRUNE: MoC

## VR-PRUNE Port Types

1) Static regular ports (SRP): Fixed token consumption/production rate
2) Dynamic regular ports (DRP): Two fixed token rates, which are called *active token rate* `atr`(*p*) and *inactive token rate* `itr`(*p*) respectively

## VR-PRUNE Actor Types

1) Static processing actor:
   - All ports have just one token rate, the `atr`
2) Configuration actor:
   - Have one or multiple control output ports, which must be connected to the control input port of a dynamic actor or a dynamic processing actor
   - The control output ports must be SRPs with a token rate of unity

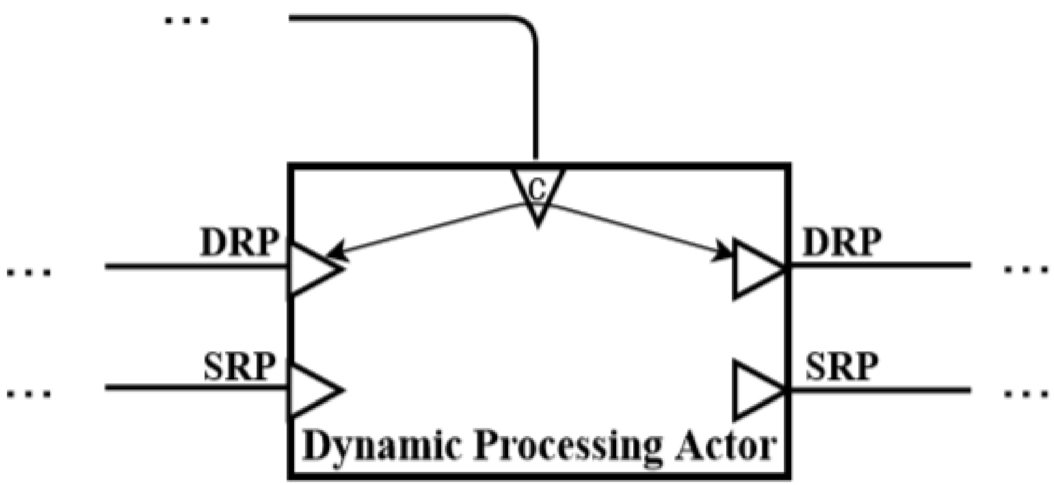
# VR-PRUNE: MoC

## VR-PRUNE Actor Types (cont'd)

3) Dynamic Actor (DA)
   - At least one control port (1,2,…)
   - At least one dynamic rate port (DRP) (1,2,…)
   - Any number of static rate ports (SRPs) (0,1,2,…)

4) Dynamic Processing Actor (DPA)
   - At least one control port (1,2,…)
   - At least one dynamic rate port (DRP) on both input and output side (2,…)
   - Any number of static rate ports (SRPs) (0,1,2,…)

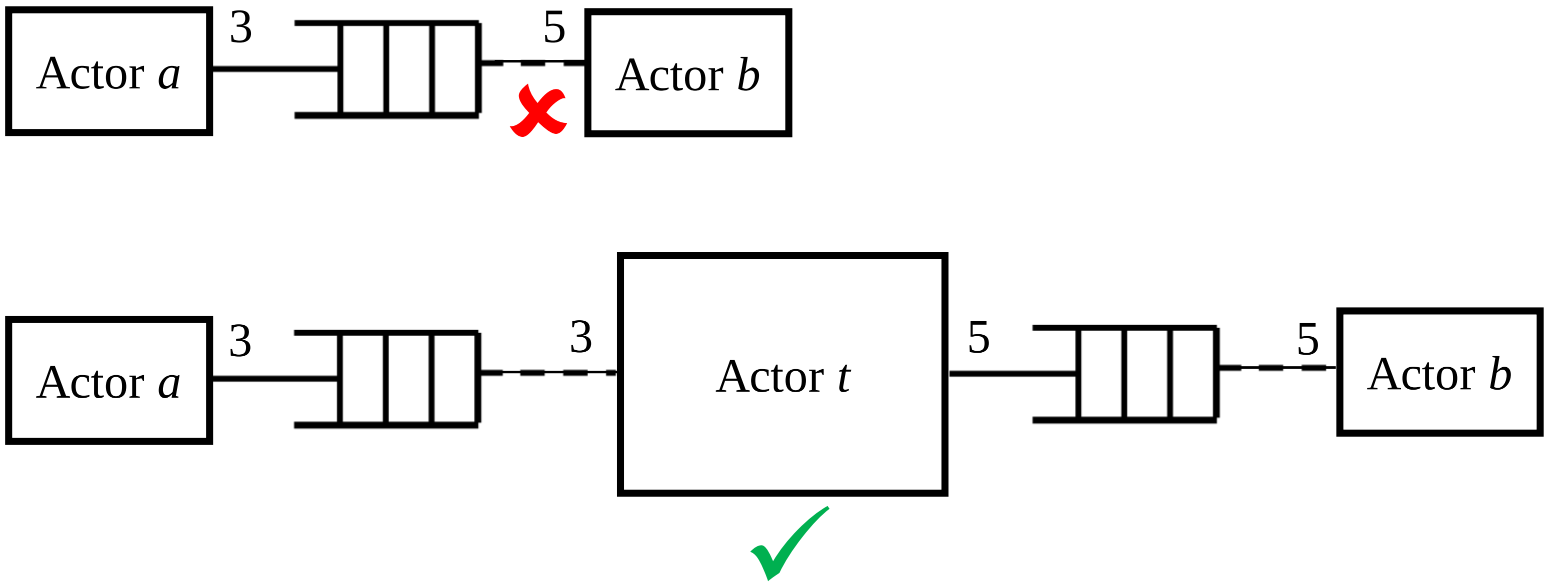
Note: For VR-PRUNE, the token rates of DRPs in DA and DPA can be set to any integer value between 0 and `atr`(*p*).



# VR-PRUNE: MoC

## Other constraints

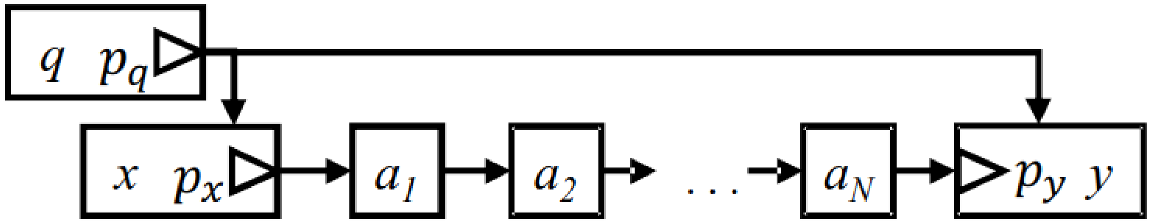
- Symmetric-rate dataflow behavior:  The token consumption rate equal the production rate for every FIFO



# VR-PRUNE: Design Rules

- **Linked port control rule**

For each pair $\{p_x, p_y\}$ of linked DRPs, the ports must be controlled by the same control output port $p_q$, and by the same element of the associated control token

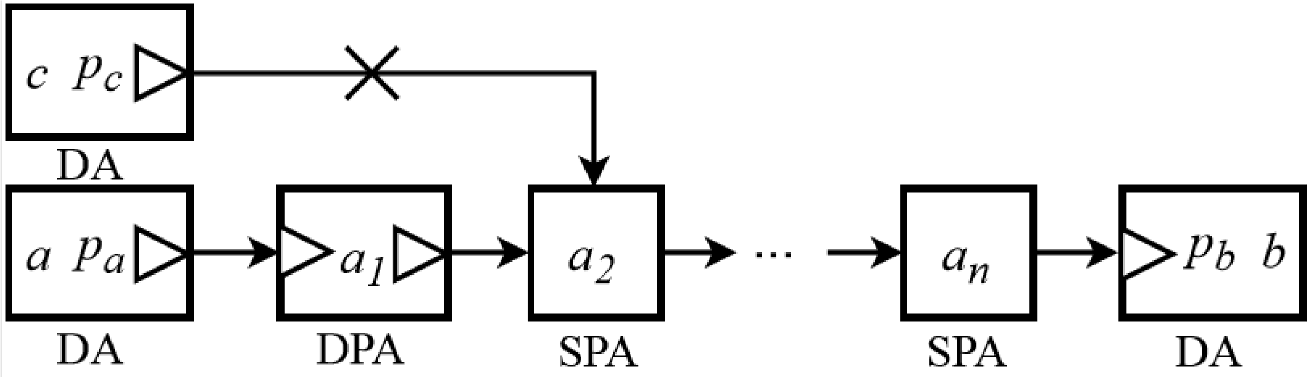



| | $p_x$ | $p_y$ |
|---|---|---|
| $p_q$ | 1 | 1 |

# VR-PRUNE: Design Rules

- **Connecting subchain rule:**

  1) Actor $a_i$ must be a SPA or DPA
  2) Each connecting subchain, to which actor $a_i$ belongs, must be associated with the two dynamic actors *a* and *b*




- In total, VR-PRUNE has five design rules – the rest are specified in the paper

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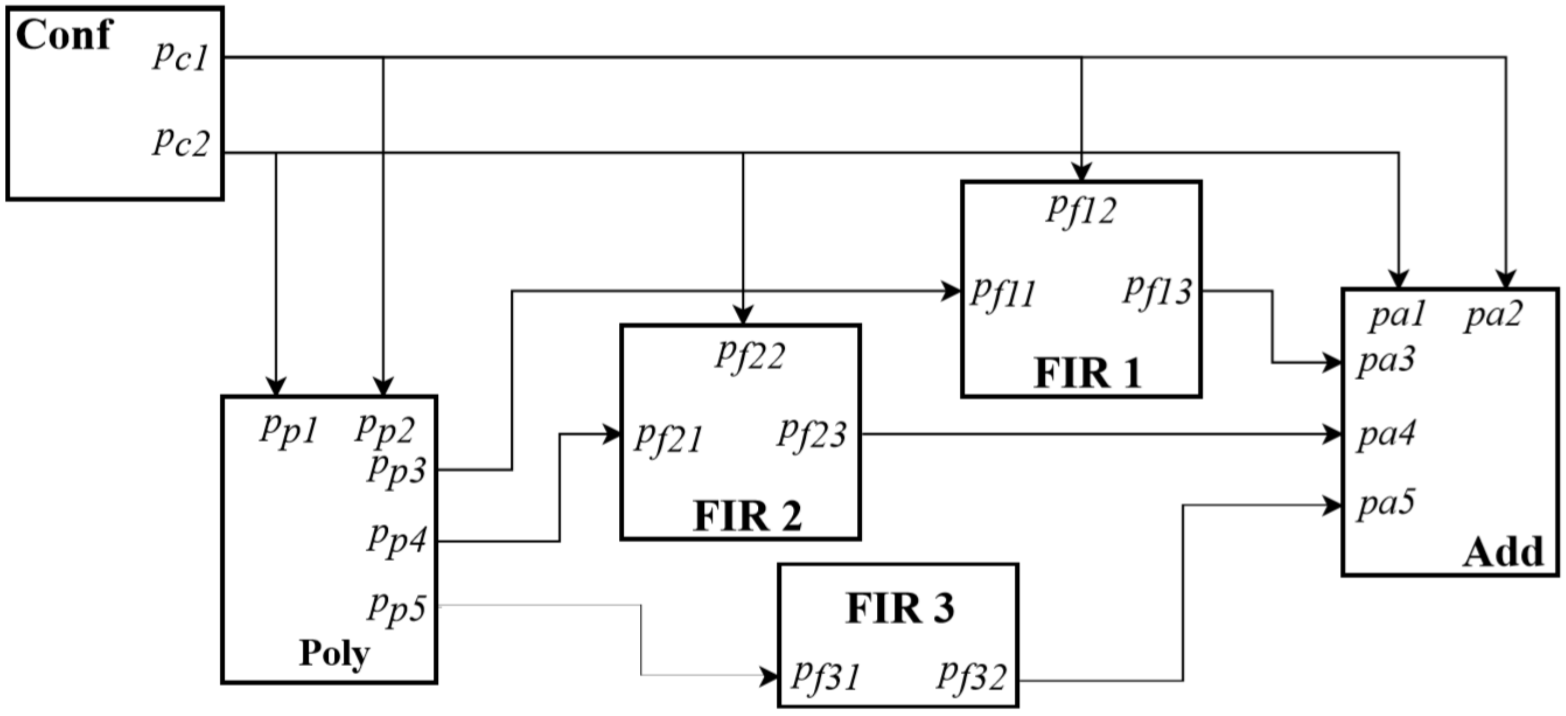
# VR-PRUNE: Dynamic Processing Graph




- A DPG consists of one configuration actor, two dynamic actors and any number of DPAs or SPAs
- FIR1 and FIR2 are dynamic processing actors, Poly and Add actors are DAs with DPRs on output and input side each

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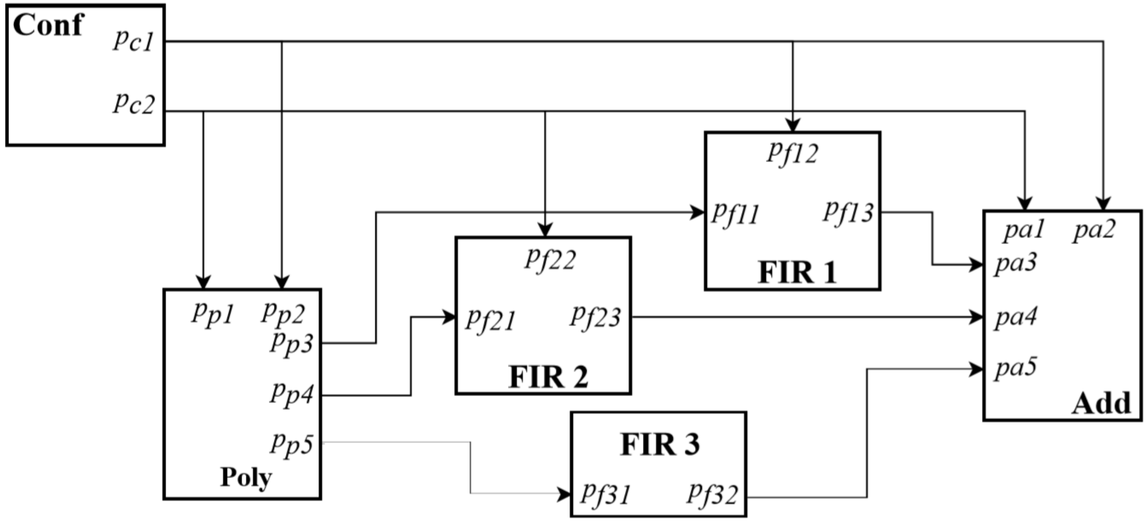
# VR-PRUNE: Control Table

**Table 1**. Control table for the graph in Fig. 2.

| | $p_{p3}$ | $p_{p4}$ | $p_{f11}$ | $p_{f13}$ |
|---|---|---|---|---|
| $p_{c1}$ | [0 .. 2] | - | [0 .. 2] | [0 .. 2] |
| $p_{c2}$ | - | [0 .. 3] | - | - |
| | $p_{f21}$ | $p_{f23}$ | $p_{a3}$ | $p_{a4}$ |
| $p_{c1}$ | - | - | [0 .. 2] | - |
| $p_{c2}$ | [0 .. 3] | [0 .. 3] | - | [0 .. 3] |




- Rows are indexed by control output ports
- Columns are indexed by dynamic regular ports (DRPs)
- Blank entries indicate the absence of any control relationship
- Positive-valued entries specify indices into *control*

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# VR-PRUNE: Experiments

**Table 2**. Platforms used for experiments.

| Tag | GPPs | GPU | Operating System |
|---|---|---|---|
| i7-940MX | Intel i7-6700HQ @ 2.60 GHz | NVidia GeForce 940MX | Ubuntu 18.04, g++ 7.0.0 |
| i7-GTX1080 | Intel i7-8700K @ 3.70GHz | NVidia Geforce GTX1080 | Ubuntu 18.04, g++ 7.0.0 |

The designer provides actor descriptions in C or OpenCL, based on which the VR-PRUNE compiler generates a top level file that realizes inter-actor communication

# VR-PRUNE: Experiments

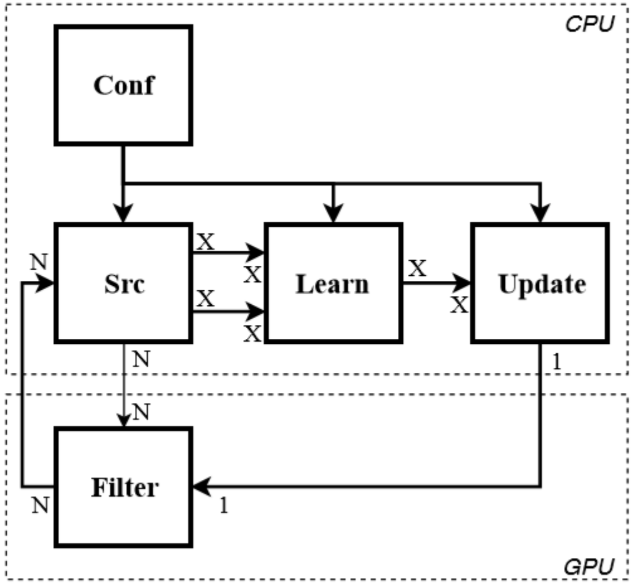


**Fig. 3**. VR-PRUNE model for the DU-DPD use case.

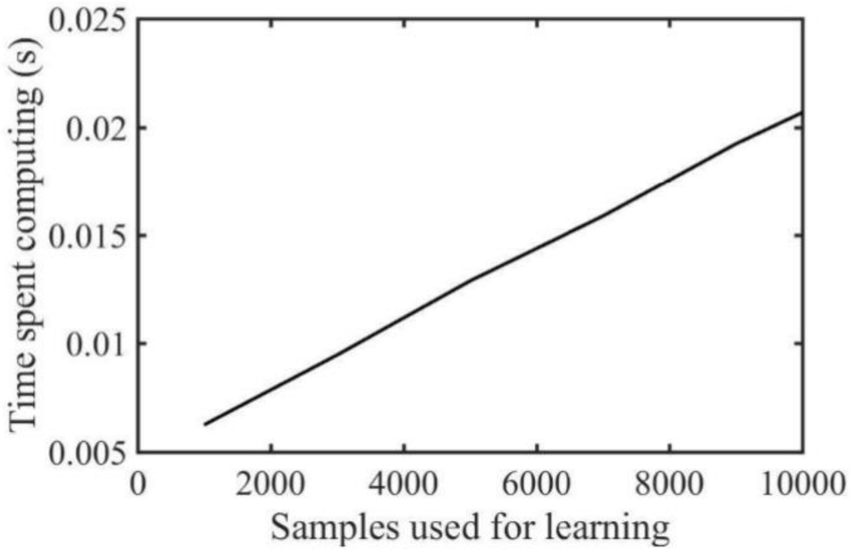


**Fig. 4**. Time spent in DU-DPD under VR-PRUNE on i7-GTX1080, as a function of samples used for learning.

Dynamic-token rate feature allows any number of samples between 1 and X

VR-PRUNE allows reducing the number of samples used for runtime learning

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# VR-PRUNE: Experiments

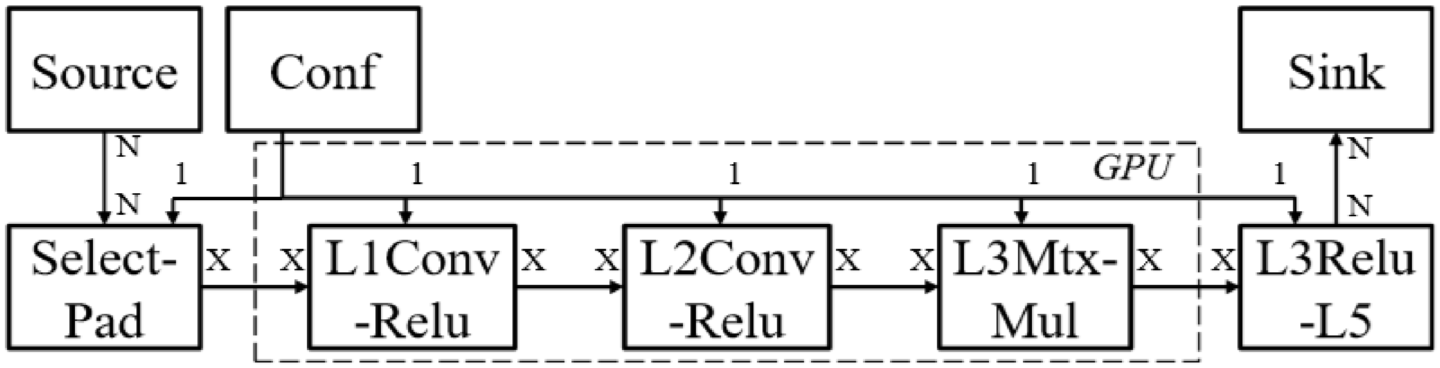


**Fig. 5**. The adaptive CNN application.

Components: two GPU-accelerated convolution layers followed by a GPU-accelerated dense layer and two more dense layers that have been combined into a single actor

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# VR-PRUNE: Performance

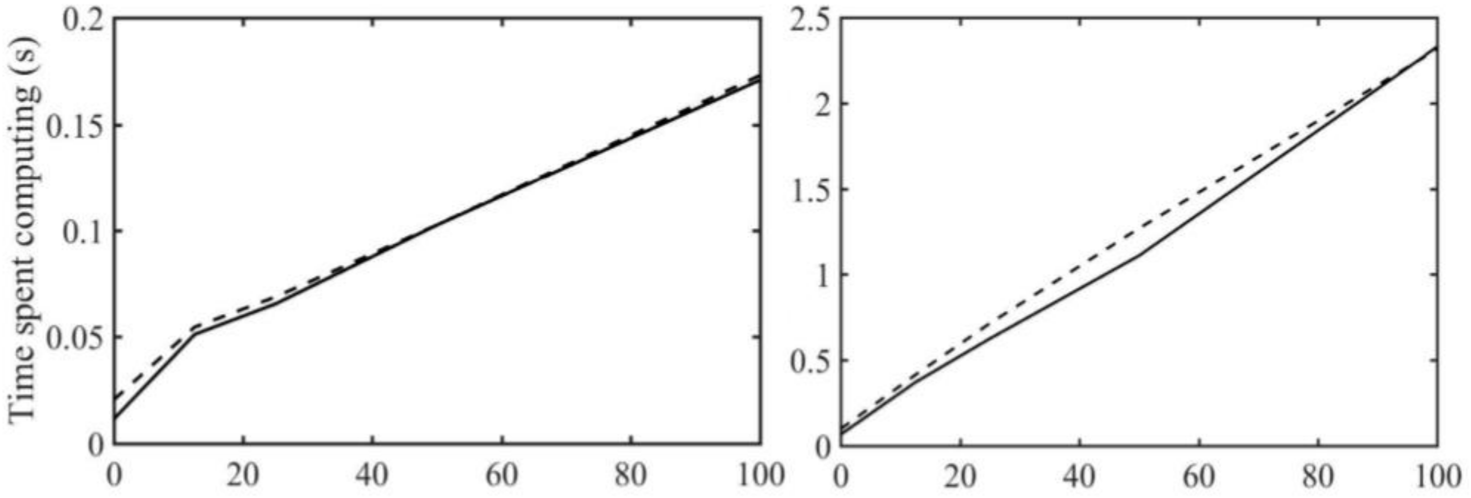


**Fig. 6**. Time spent in the CNN application as a function of % of frames processed: PRUNE (dashed line) vs. VR-PRUNE (solid line) on i7-GTX1080 (left) and i7-940MX (right).

The CNN inference (on/off) for each frame was randomly varied at runtime achieving the average percentage of frames processed for 0%, 12.5%, 25.0%, 50.0% and 100%, measuring the execution time for each percentage value

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# Conclusion

- VR-PRUNE is a high-performance, flexible, dynamic decidable dataflow model of computation
  - Combines the high-performance, decidable PRUNE Model of Computation with some features of the VRDF Model of Computation
- The experiments show that the variable token rate feature of VR-PRUNE does not impose any overhead compared to conventional PRUNE – in contrast, VR-PRUNE is computationally slightly more efficient than conventional PRUNE

# More sources

- PRUNE is introduced in more detail in the following paper

J. Boutellier, J. Wu, H. Huttunen, and S. S. Bhattacharyya. PRUNE: Dynamic and decidable dataflow for signal processing on heterogeneous platforms. *IEEE Transactions on Signal Processing*, 66 (3), 654-665, 2018

https://ieeexplore.ieee.org/document/8106744

- The main PRUNE repository:

https://gitlab.com/jboutell/Prune