2022 DESIGN AND VERIFICATION™ DVCON CONFERENCE AND EXHIBITION EUROPE

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Reusable Verification Environment for a RISC-V Vector Accelerator

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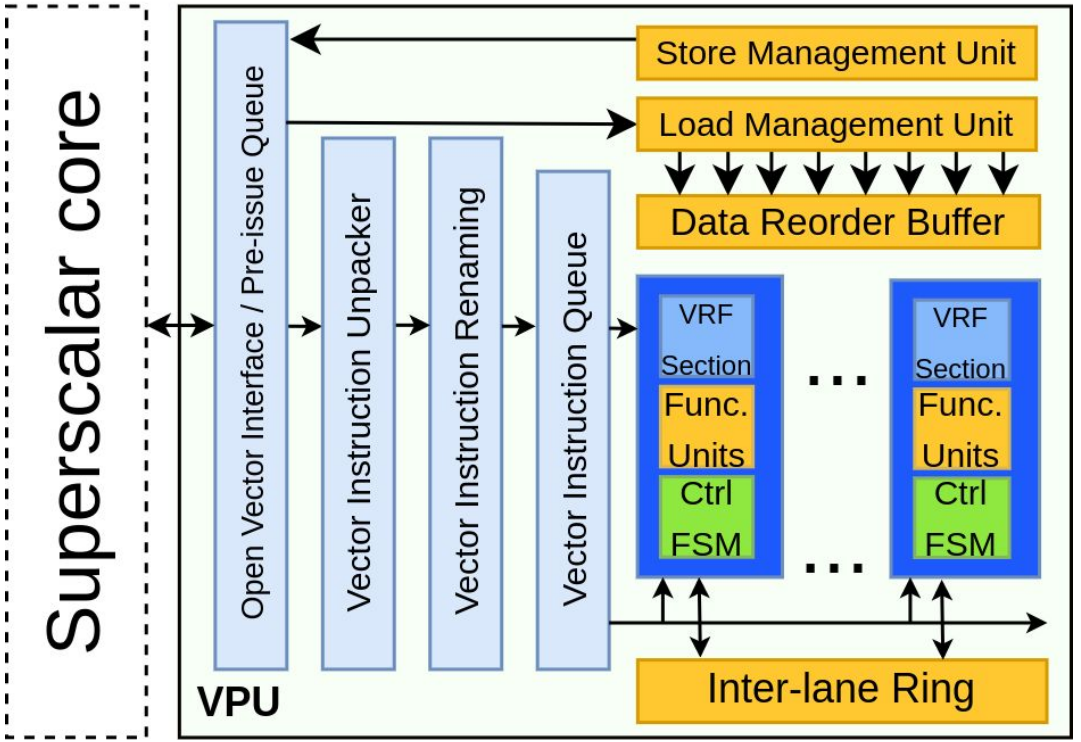
accellera SYSTEMS INITIATIVE

- Free and open Instruction Set Architecture
- Growing rapidly, open collaboration
- HPC, automotive, transportation, cloud, communications, consumer, IoT, etc.
- Modular ISA
  - Vector extension

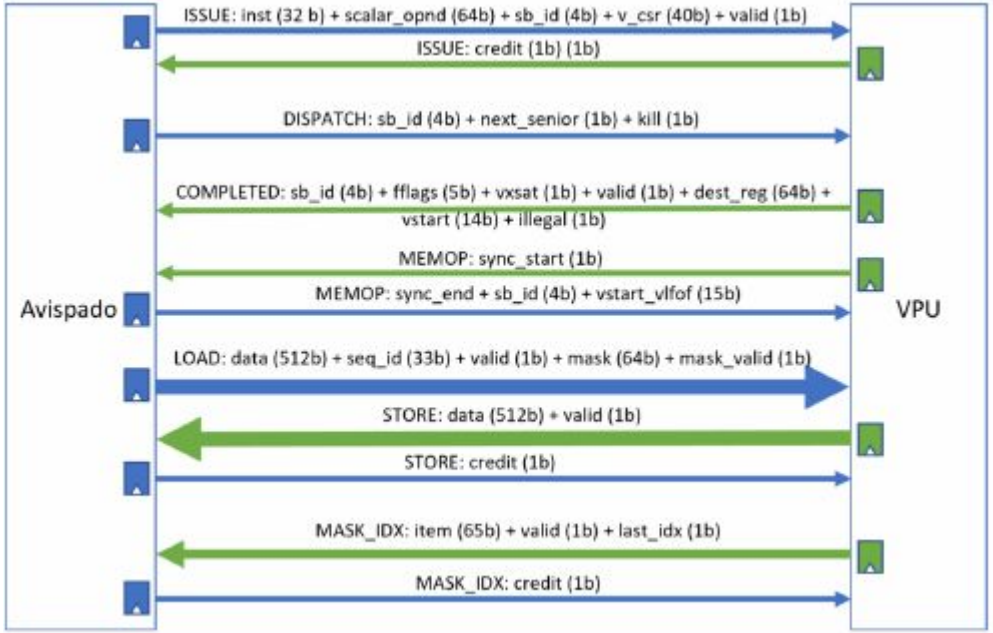
Vector Processing Unit (VPU)

- DUT
- Vector extension 0.7.1
  - Updating to 1.0
- Different “flavors”
  - EPI*
  - eProcessor*



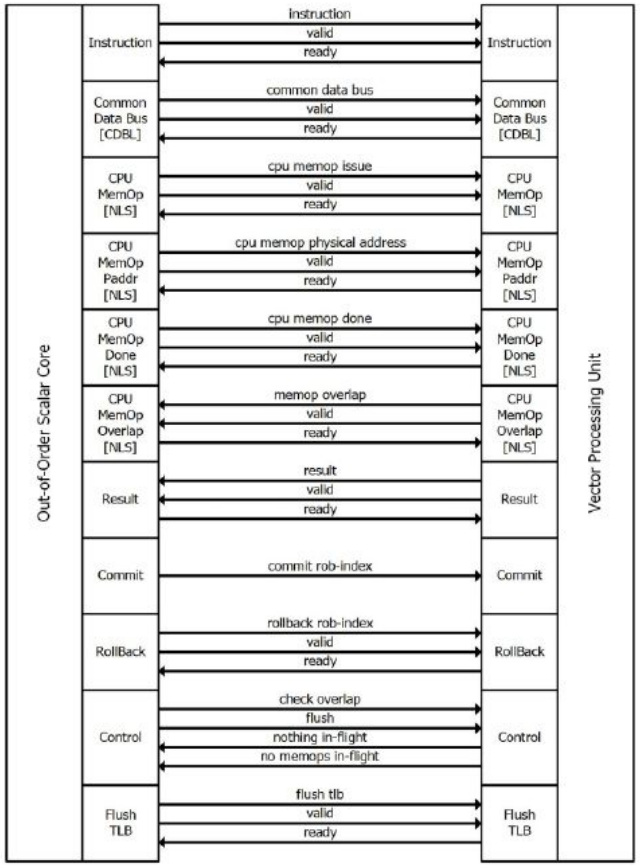
European Processor Initiative

- Core (Avispado) developed by partner (Semidynamics)
- Communicates with the VPU through OVI
- Vector memory accesses are performed by the core



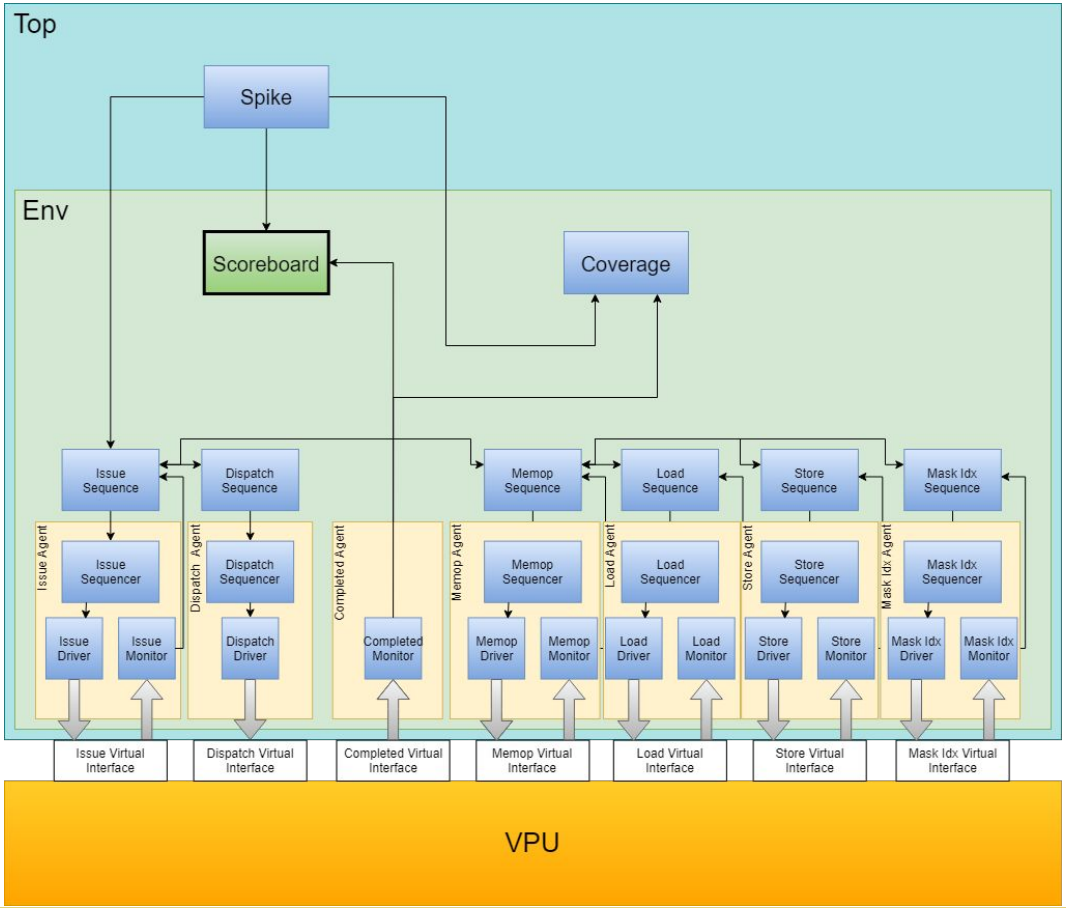
eProcessor

- Different interface for communicating with the core
- VPU access memory directly through AMBA5 CHI interface
- Interface needs signals to solve memory aliasing issues



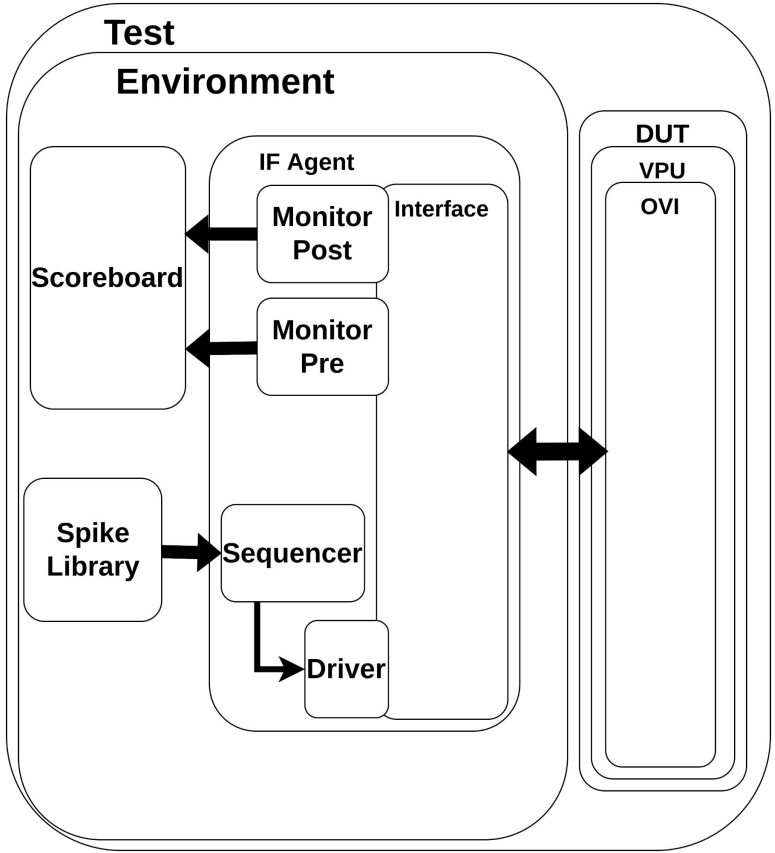
Previous environment

- One agent per each OVI channel
  - Massive interprocess communication
- Difficult to maintain, adapt and evolve

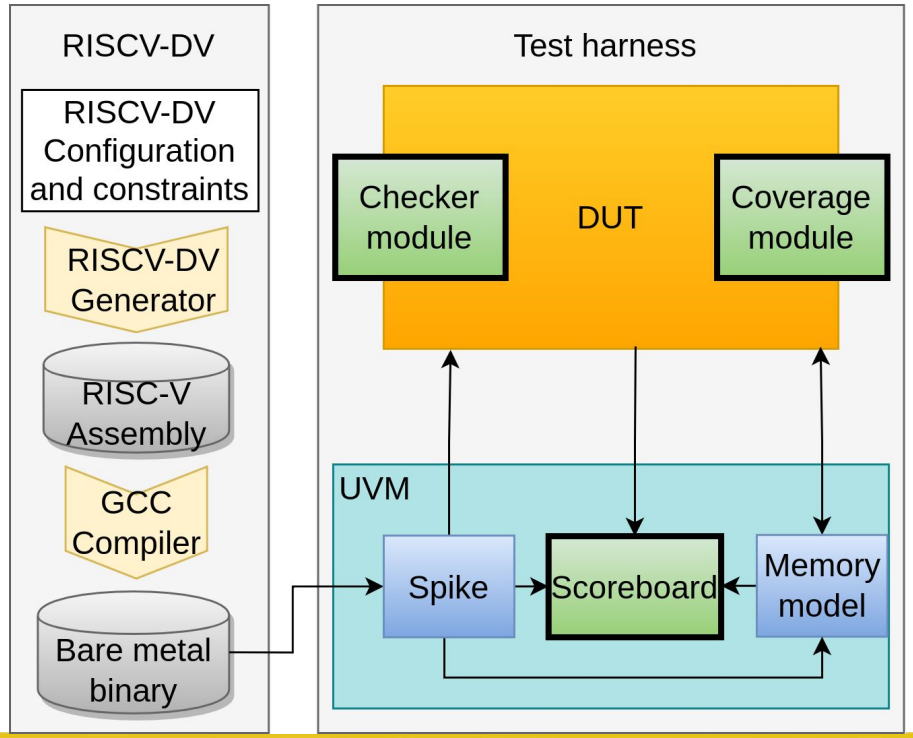


New UVM environment

- Common to all projects using the VPU
- Base interface-agnostic verification environment with common components (vpu-dv)
  - Test generation
  - Reference model usage
  - UVCs
  - Interface abstract class
  - Continuous integration
  - Coverage collection and reporting
- Project-specific environment
  - Interface implementation
  - Modified reference model library
  - Specific configurations



Verification environment flow

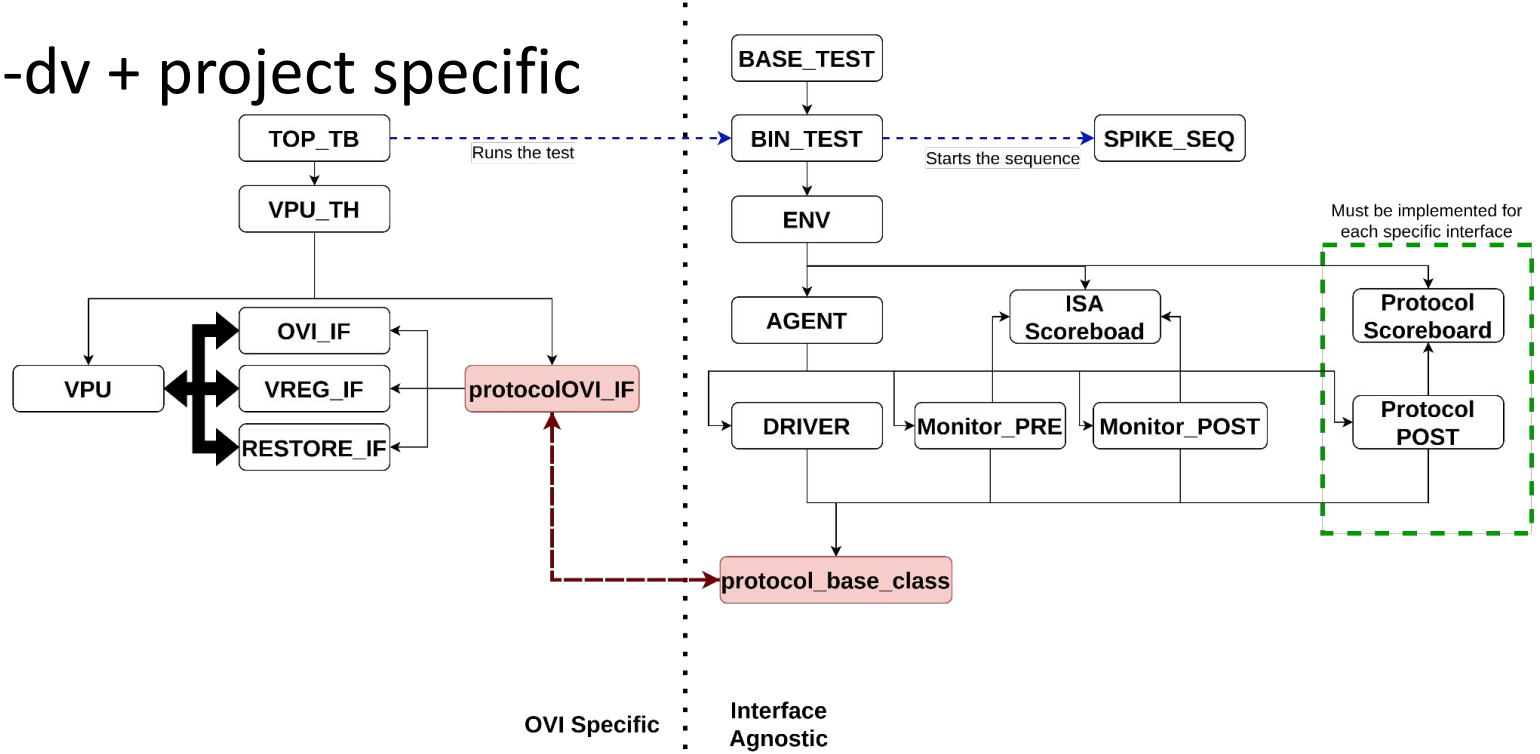


vpu-dv

- Interface base abstract class
  - With methods called by UVCs
  - Implemented in specific project environment

```
1.  pure virtual task do_protocol(); //Runs the specific protocol of the interface to stimulate the DUT
2.  pure virtual task wait_for_clk(int unsigned num_cycles = 1) ; //Waits for as many num_cycles cycles of the interface clock
3.  pure virtual function drive (ins_tx req); //Pushes the instruction inside the transaction into the pending instructions queue
4.  pure virtual function bit new_ins_tx(); //Returns whether or not there are new instructions received from the driver
5.  pure virtual function iss_state_t monitor_pre(); //Returns the first pending instruction received from the driver
6.  pure virtual function bit new_dut_tx(); //Returns whether or not there are new completed instructions
7.  pure virtual function dut_state_t monitor_post(); //Returns the first pending completed instruction's result
8.  pure virtual function bit new_protocol_tx(); //Returns whether or not there are new completed instructions
9.  pure virtual function protocol_instr_t monitor_protocol(); //Returns the first pending completed instruction
10. pure virtual function protocol_instr_t next_infl_instr(); //Returns the first inflight instruction
```

vpu-dv + project specific



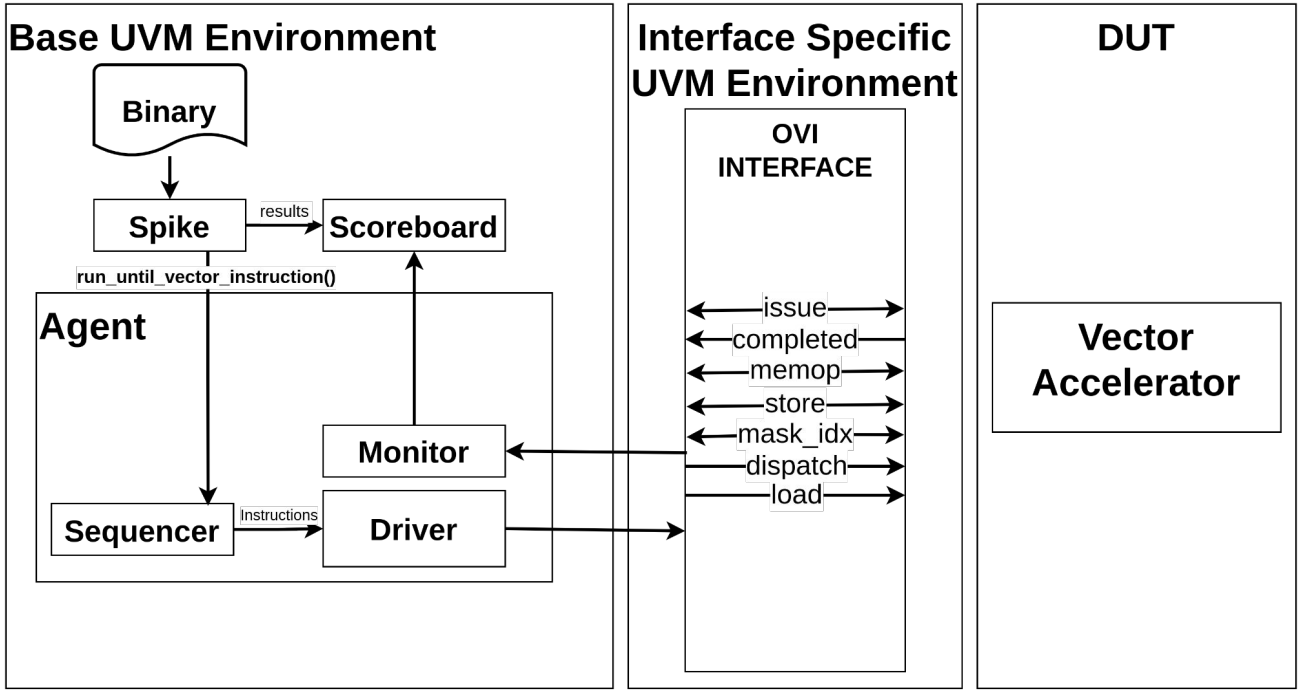
vpu-dv

- Reference model
  - Wrapper abstract class
    - Declares methods to be implemented by ISS.
    - Wrapper class overridden in build phase of uvm_test:
      - set_type_override_by_type(env_pkg::env::get_type(), eprocessor_env::get_type());
  - Derived class
    - Implements methods
- Spike
  - C++ implemented
  - Communication done using DPI.
  - Specific versions for each project, with different configurations

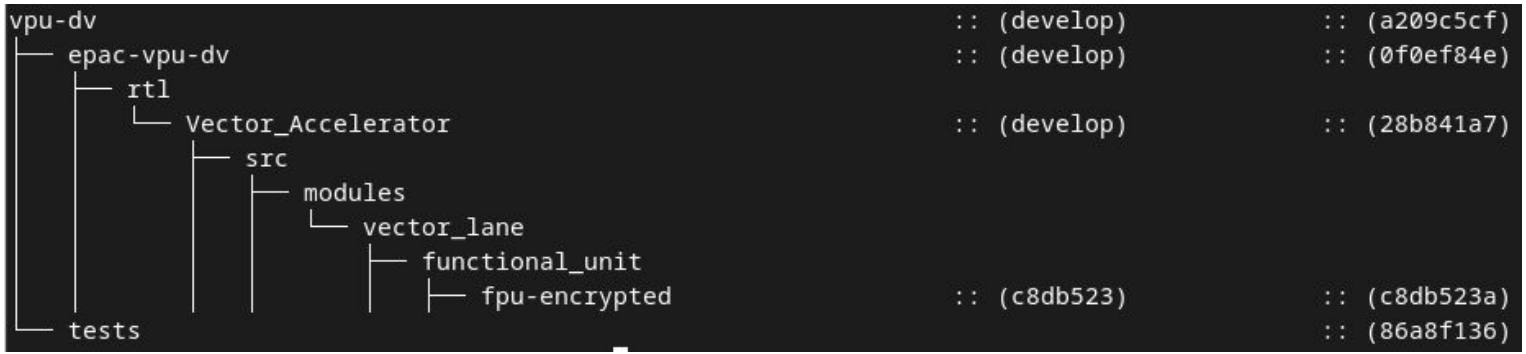
vpu-dv

- Test generation
  - tests repository as submodule
    - ISA tests with different configurations
    - Branch of submodule specified by project environment
  - RISCV-DV random binary generator
    - Modified according to our needs and for different projects.
    - Executed as first step in CI pipelines flow

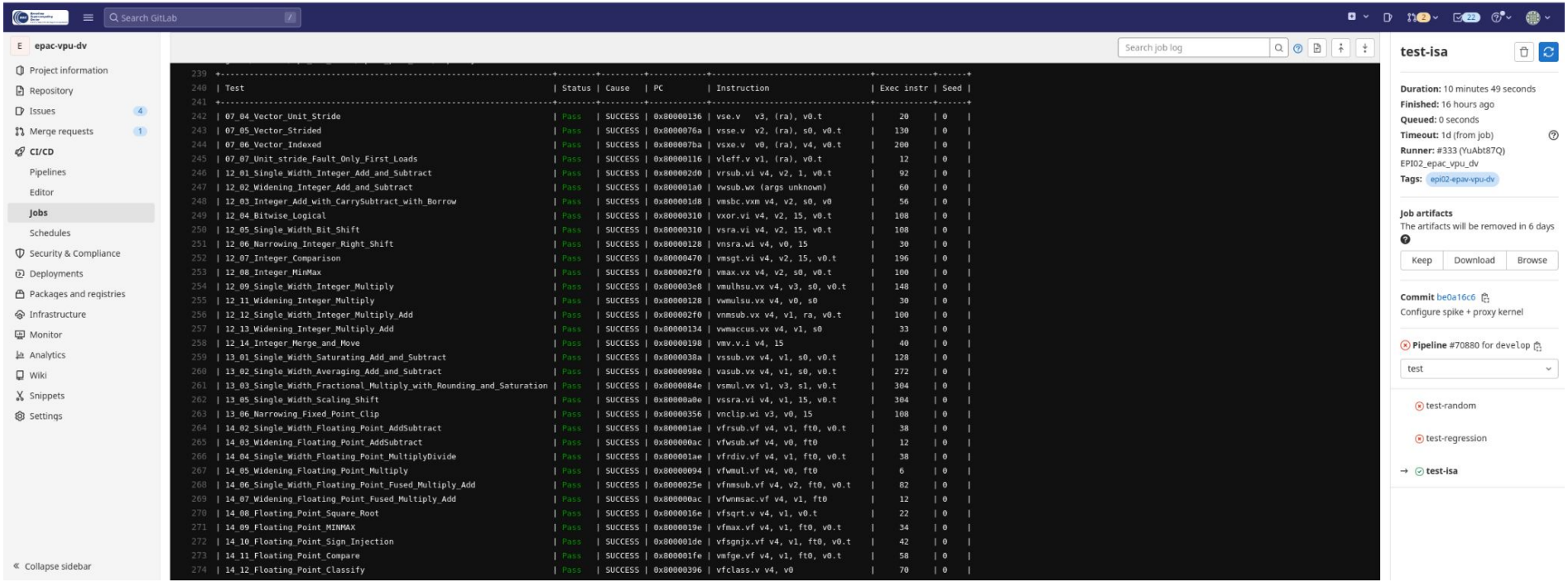
epac-vpu-dv


Base UVM Environment
Binary
Spike
results
Scoreboard
run_until_vector_instruction()
Agent
Monitor
Sequencer
Instructions
Driver
Interface Specific UVM Environment
OVI INTERFACE
issue
completed
memop
store
mask_idx
dispatch
load
DUT
Vector Accelerator

epac-vpu-dv

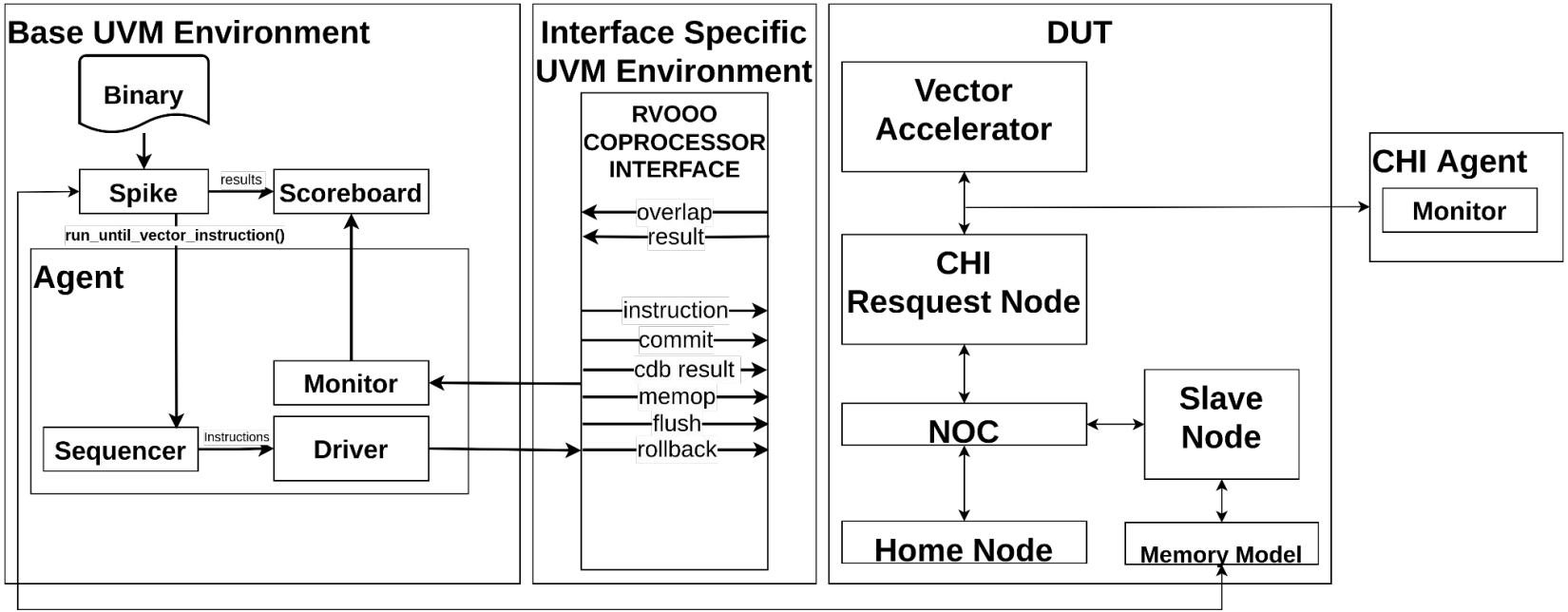

vpu-dv :: (develop) :: (a209c5cf)
epac-vpu-dv :: (develop) :: (0f0ef84e)
rtl
Vector_Accelerator :: (develop) :: (28b841a7)
src
modules
vector_lane
functional_unit
fpu-encrypted :: (c8db523) :: (c8db523a)
tests :: (86a8f136)

epac-vpu-dv



Test	Status	Cause	PC	Instruction	Exec instr	Seed
07_04_Vector_Unit_Stride	Pass	SUCCESS	0x80000136	vse.v v3, (ra), v0.t	20	0
07_05_Vector_Strided	Pass	SUCCESS	0x8000076a	vsse.v v2, (ra), s0, v0.t	130	0
07_06_Vector_Indexed	Pass	SUCCESS	0x800007ba	vsxe.v v0, (ra), v4, v0.t	200	0
07_07_Unit_stride_Fault_Only_First_Loads	Pass	SUCCESS	0x80000116	vleff.v v1, (ra), v0.t	12	0
12_01_Single_Width_Integer_Add_and_Subtract	Pass	SUCCESS	0x800002d0	vrsub.vi v4, v2, 1, v0.t	92	0
12_02_Widening_Integer_Add_and_Subtract	Pass	SUCCESS	0x800001a0	vwsub.wx (args unknown)	60	0
12_03_Integer_Add_with_CarrySubtract_with_Borrow	Pass	SUCCESS	0x800001d8	vmsbc.vxm v4, v2, s0, v0	56	0
12_04_Bitwise_Logical	Pass	SUCCESS	0x80000310	vxor.vi v4, v2, 15, v0.t	108	0
12_05_Single_Width_Bit_Shift	Pass	SUCCESS	0x80000310	vsra.vi v4, v2, 15, v0.t	108	0
12_06_Narrowing_Integer_Right_Shift	Pass	SUCCESS	0x80000128	vnsra.wi v4, v0, 15	30	0
12_07_Integer_Comparison	Pass	SUCCESS	0x80000470	vmsgt.vi v4, v2, 15, v0.t	196	0
12_08_Integer_MinMax	Pass	SUCCESS	0x800002f0	vmax.vx v4, v2, s0, v0.t	100	0
12_09_Single_Width_Integer_Multiply	Pass	SUCCESS	0x800003e8	vmulhsu.vx v4, v3, s0, v0.t	148	0
12_11_Widening_Integer_Multiply	Pass	SUCCESS	0x80000128	vwmulsu.vx v4, v0, s0	30	0
12_12_Single_Width_Integer_Multiply_Add	Pass	SUCCESS	0x800002f0	vnmsub.vx v4, v1, ra, v0.t	100	0
12_13_Widening_Integer_Multiply_Add	Pass	SUCCESS	0x80000134	vwmaccus.vx v4, v1, s0	33	0
12_14_Integer_Merge_and_Move	Pass	SUCCESS	0x80000198	vmv.v.i v4, 15	40	0
13_01_Single_Width_Saturating_Add_and_Subtract	Pass	SUCCESS	0x8000038a	vssub.vx v4, v1, s0, v0.t	128	0
13_02_Single_Width_Averaging_Add_and_Subtract	Pass	SUCCESS	0x8000098e	vasub.vx v4, v1, s0, v0.t	272	0
13_03_Single_Width_Fractional_Multiply_with_Rounding_and_Saturation	Pass	SUCCESS	0x8000084e	vsmul.vx v1, v3, s1, v0.t	304	0
13_05_Single_Width_Scaling_Shift	Pass	SUCCESS	0x80000a8e	vssra.vi v4, v1, 15, v0.t	304	0
13_06_Narrowing_Fixed_Point_Clip	Pass	SUCCESS	0x80000356	vnclip.wi v3, v0, 15	108	0
14_02_Single_Width_Floating_Point_AddSubtract	Pass	SUCCESS	0x800001ae	vfrsub.vf v4, v1, ft0, v0.t	38	0
14_03_Widening_Floating_Point_AddSubtract	Pass	SUCCESS	0x800000ac	vfwsub.wf v4, v0, ft0	12	0
14_04_Single_Width_Floating_Point_MultiplyDivide	Pass	SUCCESS	0x800001ae	vfrdiv.vf v4, v1, ft0, v0.t	38	0
14_05_Widening_Floating_Point_Multiply	Pass	SUCCESS	0x80000094	vfwmul.vf v4, v0, ft0	6	0
14_06_Single_Width_Floating_Point_Fused_Multiply_Add	Pass	SUCCESS	0x8000025e	vfnmsub.vf v4, v2, ft0, v0.t	82	0
14_07_Widening_Floating_Point_Fused_Multiply_Add	Pass	SUCCESS	0x800000ac	vfwnmsac.vf v4, v1, ft0	12	0
14_08_Floating_Point_Square_Root	Pass	SUCCESS	0x8000016e	vfsqrt.v v4, v1, v0.t	22	0
14_09_Floating_Point_MINMAX	Pass	SUCCESS	0x8000019e	vfmax.vf v4, v1, ft0, v0.t	34	0
14_10_Floating_Point_Sign_Injection	Pass	SUCCESS	0x800001de	vfsgnjx.vf v4, v1, ft0, v0.t	42	0
14_11_Floating_Point_Compare	Pass	SUCCESS	0x800001fe	vmfge.vf v4, v1, ft0, v0.t	58	0
14_12_Floating_Point_Classify	Pass	SUCCESS	0x80000396	vfclass.v v4, v0	70	0

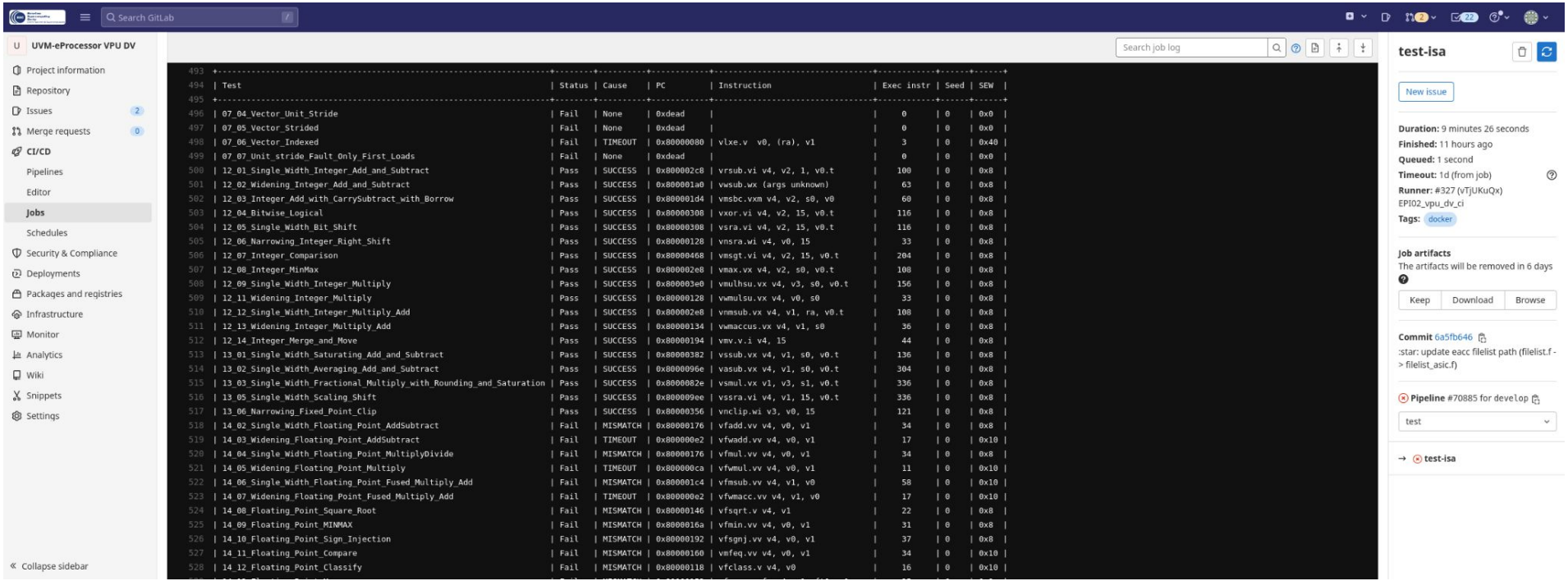
eprocessor-vpu-dv



eprocessor-vpu-dv

```
vpu-dv                                                  :: (develop)        :: (a209c5cf)
├── eprocessor-vpu-dv                                   :: (develop)        :: (473c2506)
│   ├── rtl
│   │   ├── eAccelerator                                :: (develop)        :: (06d011bc)
│   │   │   ├── docs
│   │   │   │   └── specs                               :: (d088cc5)        :: (d088cc5f)
│   │   │   ├── src
│   │   │   │   ├── package
│   │   │   │   │   └── riscv_pkg                                           :: (b2a90d84)
│   │   ├── epi_nocsim                                  :: (dev)            :: (b34c3283)
│   │   │   ├── modules
│   │   │   │   ├── ep-fake-snf                                             :: (57dea70a)
│   │   │   │   ├── ep-rni                                                  :: (15e118a2)
│   │   │   │   ├── l2hn                                                    :: (7f07a642)
│   │   │   │   ├── noc_ep0                                                 :: (29897d7a)
│   │   │   │   ├── ProNoC                                                  :: (7d728b19)
│   │   │   │   └── vpu_chi_interface                                       :: (e0ecafe1)
└── tests                                                                   :: (86a8f136)
```

eprocessor-vpu-dv



Test	Status	Cause	PC	Instruction	Exec instr	Seed	SEW
07_04_Vector_Unit_Stride	Fail	None	0xdead		0	0	0x0
07_05_Vector_Strided	Fail	None	0xdead		0	0	0x0
07_06_Vector_Indexed	Fail	TIMEOUT	0x80000080	vlxe.v v0, (ra), v1	3	0	0x40
07_07_Unit_stride_Fault_Only_First_Loads	Fail	None	0xdead		0	0	0x0
12_01_Single_Width_Integer_Add_and_Subtract	Pass	SUCCESS	0x800002c8	vrsub.vi v4, v2, 1, v0.t	100	0	0x8
12_02_Widening_Integer_Add_and_Subtract	Pass	SUCCESS	0x800001a0	vwsub.wx (args unknown)	63	0	0x8
12_03_Integer_Add_with_CarrySubtract_with_Borrow	Pass	SUCCESS	0x800001d4	vmsbc.vxm v4, v2, s0, v0	60	0	0x8
12_04_Bitwise_Logical	Pass	SUCCESS	0x80000308	vxor.vi v4, v2, 15, v0.t	116	0	0x8
12_05_Single_Width_Bit_Shift	Pass	SUCCESS	0x80000308	vsra.vi v4, v2, 15, v0.t	116	0	0x8
12_06_Narrowing_Integer_Right_Shift	Pass	SUCCESS	0x80000128	vnsra.wi v4, v0, 15	33	0	0x8
12_07_Integer_Comparison	Pass	SUCCESS	0x80000468	vmsgt.vi v4, v2, 15, v0.t	204	0	0x8
12_08_Integer_MinMax	Pass	SUCCESS	0x800002e8	vmax.vx v4, v2, s0, v0.t	108	0	0x8
12_09_Single_Width_Integer_Multiply	Pass	SUCCESS	0x800003e0	vmulhsu.vx v4, v3, s0, v0.t	156	0	0x8
12_11_Widening_Integer_Multiply	Pass	SUCCESS	0x80000128	vwmulsu.vx v4, v0, s0	33	0	0x8
12_12_Single_Width_Integer_Multiply_Add	Pass	SUCCESS	0x800002e8	vnmsub.vx v4, v1, ra, v0.t	108	0	0x8
12_13_Widening_Integer_Multiply_Add	Pass	SUCCESS	0x80000134	vwmaccus.vx v4, v1, s0	36	0	0x8
12_14_Integer_Merge_and_Move	Pass	SUCCESS	0x80000194	vmv.v.i v4, 15	44	0	0x8
13_01_Single_Width_Saturating_Add_and_Subtract	Pass	SUCCESS	0x80000382	vssub.vx v4, v1, s0, v0.t	136	0	0x8
13_02_Single_Width_Averaging_Add_and_Subtract	Pass	SUCCESS	0x8000096e	vasub.vx v4, v1, s0, v0.t	304	0	0x8
13_03_Single_Width_Fractional_Multiply_with_Rounding_and_Saturation	Pass	SUCCESS	0x8000082e	vsmul.vx v1, v3, s1, v0.t	336	0	0x8
13_05_Single_Width_Scaling_Shift	Pass	SUCCESS	0x800009ee	vssra.vi v4, v1, 15, v0.t	336	0	0x8
13_06_Narrowing_Fixed_Point_Clip	Pass	SUCCESS	0x80000356	vnclip.wi v3, v0, 15	121	0	0x8
14_02_Single_Width_Floating_Point_AddSubtract	Fail	MISMATCH	0x80000176	vfadd.vv v4, v0, v1	34	0	0x8
14_03_Widening_Floating_Point_AddSubtract	Fail	TIMEOUT	0x800000e2	vfwadd.vv v4, v0, v1	17	0	0x10
14_04_Single_Width_Floating_Point_MultiplyDivide	Fail	MISMATCH	0x80000176	vfmul.vv v4, v0, v1	34	0	0x8
14_05_Widening_Floating_Point_Multiply	Fail	TIMEOUT	0x800000ca	vfwmul.vv v4, v0, v1	11	0	0x10
14_06_Single_Width_Floating_Point_Fused_Multiply_Add	Fail	MISMATCH	0x800001c4	vfmsub.vv v4, v1, v0	58	0	0x10
14_07_Widening_Floating_Point_Fused_Multiply_Add	Fail	TIMEOUT	0x800000e2	vfwmacc.vv v4, v1, v0	17	0	0x10
14_08_Floating_Point_Square_Root	Fail	MISMATCH	0x80000146	vfsqrt.v v4, v1	22	0	0x8
14_09_Floating_Point_MINMAX	Fail	MISMATCH	0x8000016a	vfmin.vv v4, v0, v1	31	0	0x8
14_10_Floating_Point_Sign_Injection	Fail	MISMATCH	0x80000192	vfsgnj.vv v4, v0, v1	37	0	0x8
14_11_Floating_Point_Compare	Fail	MISMATCH	0x80000160	vmfeq.vv v4, v0, v1	34	0	0x10
14_12_Floating_Point_Classify	Fail	MISMATCH	0x80000118	vfclass.v v4, v0	16	0	0x10

Conclusions

- Developed a verification infrastructure reusable for many projects
  - Currently for EPI SGA1 and eProcessor
  - In development for EPI SGA2 (RVV 1.0)
- Easy to extend and maintain
- Ability to uncover more bugs

Acknowledgments

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Questions?

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