WP4 Safety and security

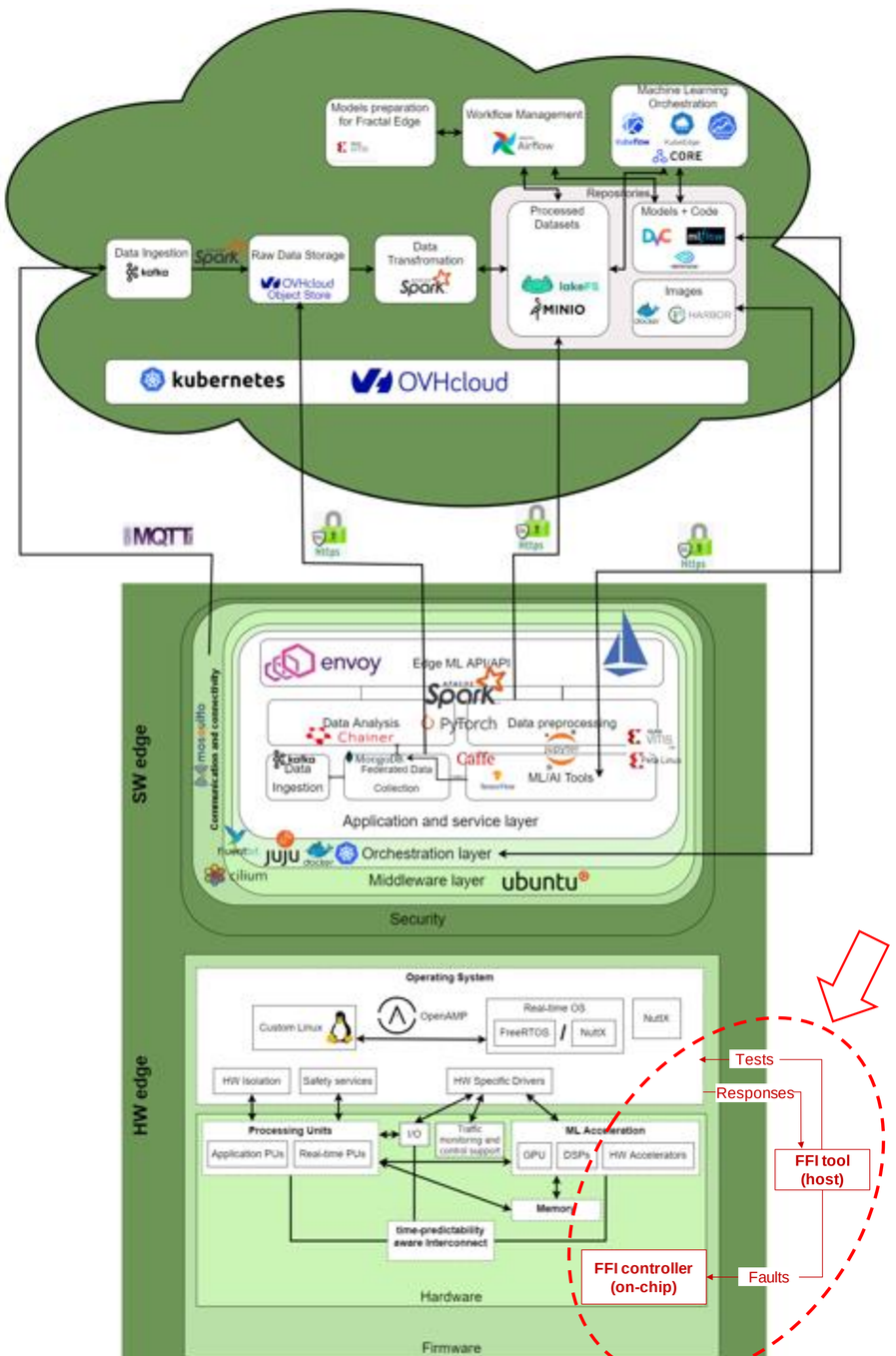
WP4T43-06: FPGA Fault Injection Tool (DAVOS FFI)

Developed by: UPV

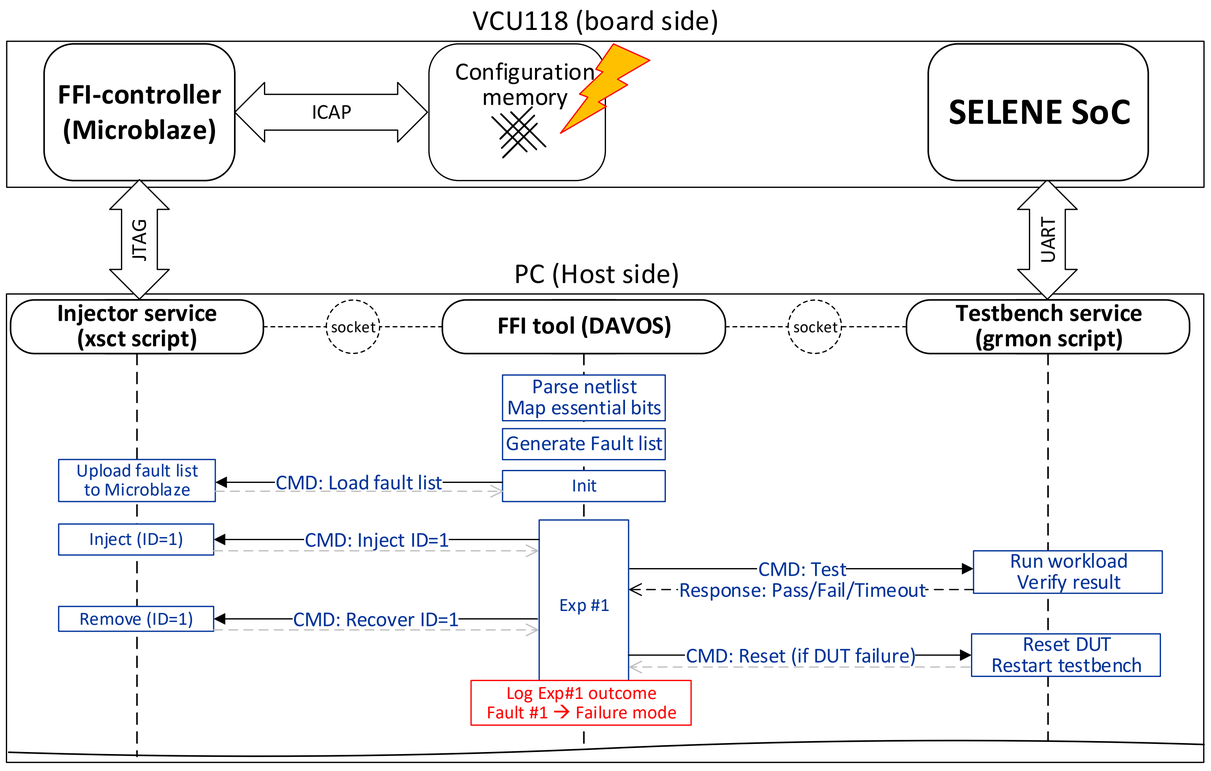
FFI tool description:

- **Objective:**
  - ✓ Automated robustness assessment of FPGA prototype against hardware faults
  - ✓ Identification of dependability bottlenecks and fault propagation paths
  - ✓ Verification of fault-tolerance and dependability-related components (RootVoter, PMU, etc.)
- **Fractal features associated:** Safety, Redundancy, Self-monitoring
- **Inputs:** FPGA design under test (DUT), workload/testbench, configuration of faultload
- **Outputs:** Robustness report describing DUT behavior in presence of faults, rate of observed failure modes for each targeted component, critical/weak points of the DUT
- **Integration:** NOEL-V SoC and GRMON debugger (DUT side), DAVOS toolkit (host side)
- **Fault injection approach:** Dynamic partial reconfiguration – altering configuration memory (CM) content at runtime, statistical sampling of fault space, essential bits
- **Fault models:**
  - ✓ Bit-flips in configuration memory – permanent faults in logic and routing (ready to use)
  - ✓ Bit-flips in registers and on-chip user memories – transients (ongoing work)

Component location



Structure and operation of FFI tool



Get started

1. Customize FFI configuration (config.xml file):

```
<FFI   dut_scope          = "cpu/core0/gpp0/noelv0/cpuloop[2].core/"
       pblock             = "tiles:X2Y302:X90Y359"
       target_logic       = "LUT"
       sample_size        = "5000"
       fault_multiplicity = "1"
       dut_script         = "grmon -u -uart /dev/ttyUSB2 -c host_grmon.do" />
```

- Filter fault targets by design hierarchy
- Filter fault targets by FPGA floorplan
- Filter fault targets by logic type (LUT / BRAM /...)
- Number of sampled fault configurations
- Number of fault targets per configuration
- Link testbench script to FFI configuration

2. Adapt testbench service to the used workload (SW):

- ✓ Customize “host_grmon.do” for baremetal SW,
- ✓ OR define custom testbench with the same interface (commands received via socket):

```
CMD ← SOCKET RECEIVE:
IF CMD=1:   Test( ) {…} → return status: Pass / Failure Mode
IF CMD=2:   Reset( ){…} → return status: OK
```

3. Run fault injection experiment: DAVOS/> python FFI_tool.py config.xml

```
Injector FFIHostGrmon instantiated from /home2/tuil/DAVOS
layout loaded for device part: xcvu9p-flga2104-2L-e
Bitstream parsed: /home2/tuil/selene_axi4/selene-hardware/selene-soc/selene-xilinx-vcu118/vivado/noelv-xilinx-vcu118/DavosGenerated/Bitstream.bit
FFI Design Model initialized in 57.1 seconds

Mapped LUTS in dut_scope = "cpu/core0/gpp0/noelv0/cpuloop[2].core/", pblock = None: 48388
Sampled faults: 5000 (population size = 3096832)

Faultlist loaded: /home2/tuil/selene_axi4/selene-hardware/selene-soc/selene-xilinx-vcu118/vivado/noelv-xilinx-vcu118/DavosGenerated/Faultlist_0.bin

Exp: 3619, Target: cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][0][op1][9]_i_9/bit_02
        Injection status    : Ok
        Injection result    : ReplicaFail:f=00000010:t=00000000
        Fault removal       : Ok
        DUT recovery check (post-SEU-remove): Ok
        Exp. Time           : 0.3 seconds (Total: 2763.8 seconds), Statistics:
                              Masked: 3549 (98.04% ± 0.45%), Fail:   0 (0.00% ± 0.00%), Hang:  14 (0.39% ± 0.20%),
                              ReplicaFail:  36 (0.99% ± 0.32%), ReplicaFail:   8 (0.22% ± 0.15%), ReplicaHang:  13 (0.36% ± 0.19%)

Experimental result: Masked: 4906 (98.12% ± 0.38%), Fail:   0 (0.00% ± 0.00%), Hang:  22 (0.44% ± 0.18%),
                     ReplicaFail:  45 (0.90% ± 0.26%), ReplicaFail:   8 (0.16% ± 0.11%), ReplicaHang:  19 (0.38% ± 0.17%)
FFI summary exported: LOG_2022-06-09_17-53-26.csv
Completed in 4045.1 seconds
```

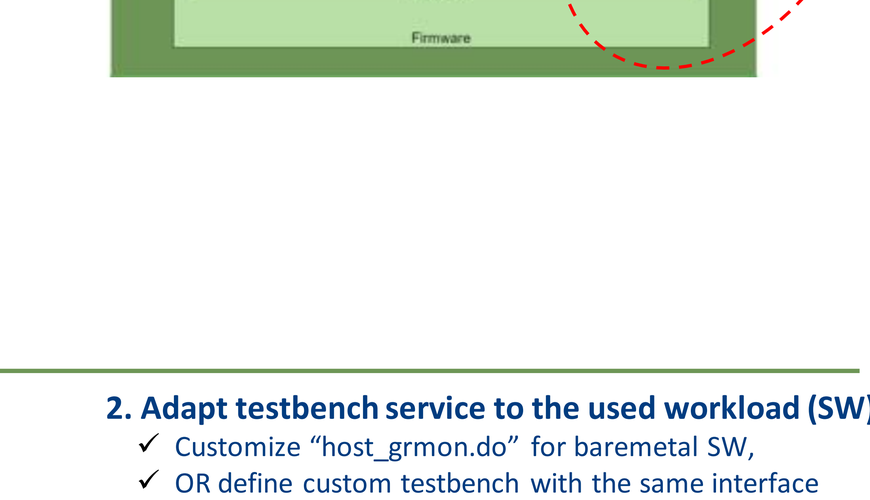
4. Examine logged critical bits (bit-flips that lead to data corruption/timeout/hang failures)

	A	C	D	E	F	G	H	I	J	K	L	M
1	Id	Ce	Mu	FailureMod	Offset	DesignNode	SLR	FAR	Word	Bit	Mask	Time
177	175	1	1	ReplicaFail	175	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][1][op1][41]_i_5/bit_57	0x000	0x00084a08	73	25	0x02000000	0
231	229	1	1	ReplicaFail	229	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/mmu0/dco[data][0][55]_INST_0/bit_26	0x000	0x0008aa06	27	10	0x00000400	0
392	390	1	1	ReplicaFail	390	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][1][op2][23]_i_2/bit_22	0x000	0x00084102	54	22	0x00400000	0
419	417	1	1	ReplicaFail	417	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[m][result][0][30]_i_8/bit_55	0x000	0x00083208	80	23	0x00800000	0
422	420	1	1	ReplicaFail	420	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][1][op1][7]_i_2/bit_57	0x000	0x00086408	44	25	0x02000000	0
510	508	1	1	ReplicaFail	508	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][0][op1][0]_i_6/bit_38	0x000	0x00085501	59	6	0x00000040	0
537	535	1	1	ReplicaFail	535	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/dci[edata][55]_INST_0/bit_59	0x000	0x00087e08	42	11	0x00000800	0
659	657	1	1	ReplicaFail	657	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/ramrf.rf0/rdata1[3]_INST_0/bit_12	0x000	0x00087907	40	12	0x00001000	0
666	664	1	1	ReplicaFail	664	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alupreforw1][0][1]_i_7/bit_18	0x000	0x00087306	25	2	0x00000004	0
696	694	1	1	ReplicaFail	694	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[m][result][1][17]_i_4/bit_35	0x000	0x00081c05	53	19	0x00080000	0
840	838	1	1	ReplicaFail	838	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/rfi[wdata1][22]_INST_0/bit_14	0x000	0x00086a03	56	14	0x00004000	0
873	871	1	1	ReplicaFail	871	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[e][alui][1][op1][53]_i_4/bit_29	0x000	0x00085d06	86	13	0x00002000	0
1056	1054	1	1	ReplicaFail	54	cpu/core0/gpp0/noelv0/cpuloop[2].core/u0/iu0/syncrregs.r[m][result][1][23]_i_3/bit_34	0x000	0x00082801	54	18	0x00040000	0

LOG_2022-06-09_17-53-26

Listo Se encontraron 45 de 5000 registros

5. Visualize statistical results (rate of observed failure modes)



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