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Systematic Evaluation of the European NG-LARGE FPGA & EDA Tools for On-Board Processing

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Outline

1. Introduction
2. Evaluation Methodology
3. Evaluation Results
4. Conclusion and Future Work

Introduction

❑ On-Board Data Processing

- applications → increased computational & I/O demands, multiple algorithms, …
- platforms → reliability, re-programmability, low-power, fast I/O, …

❑ Embedded Platforms

- space-grade **CPUs** → never reach "very high-performance"
- space-grade **FPGAs** → limited pool, even smaller for European high-density chips
- **high-density EU space-grade FPGAs** → *NanoXplore BRAVE FPGAs*

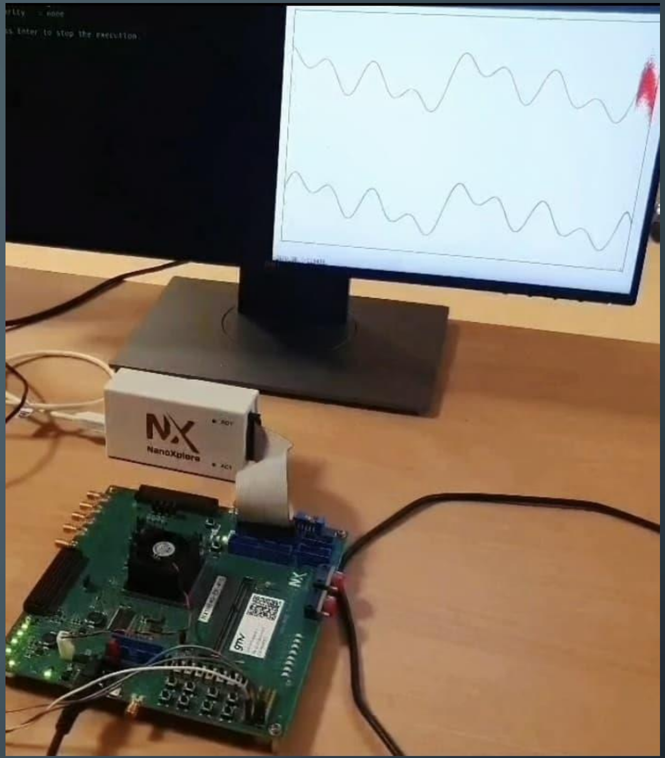
❑ NG-LARGE FPGA

- 2nd European high-density FPGA → successor of NG-MEDIUM
- to be used in ESA missions → *Navigation*, *Exploration*, …
- competitive → radiation-hardness, resources, reconfiguration

INTRODUCTION

❑ NG-LARGE Features

- SRAM-based, 65nm, rad-hard by design
- logic/arithmetic → 137K LUTs, 32K CYs, 384 DSPs
- memory/register → 129K DFFs, 192 RAMBs
- I/O → SpaceWire @400Mbps (also for configuration)



❑ "QUEENS2" ESA Activity

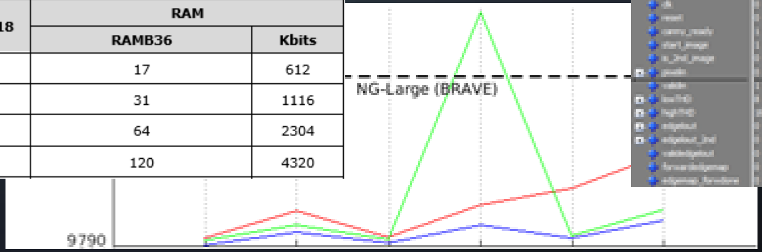
➢ "QUality Evaluation of European New SW for BRAVE II"

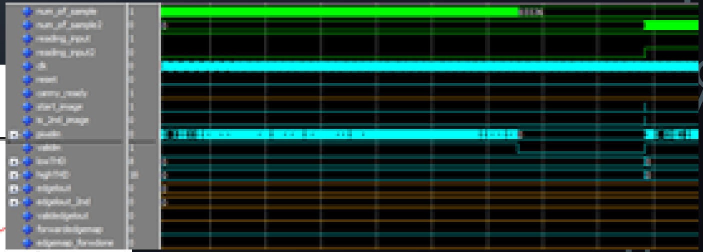
- assessment of the **SW programming tool** (*NXmap*)
- intensive DSP benchmarking on the HW chip (*NG-LARGE*)

based on our evaluation methodology!

Xilinx ISE (Virtex-5QV xqr5vfx130) with SIFT Descr benchmark

Config.	LUT6	DFF	DSP25x18	RAM	
				RAMB36	Kbits
c1	10099	7386	32	17	612
c2	10108	7388	32	31	1116
c3	10093	7411	32	64	2304
c4	10248	7416	32	120	4320





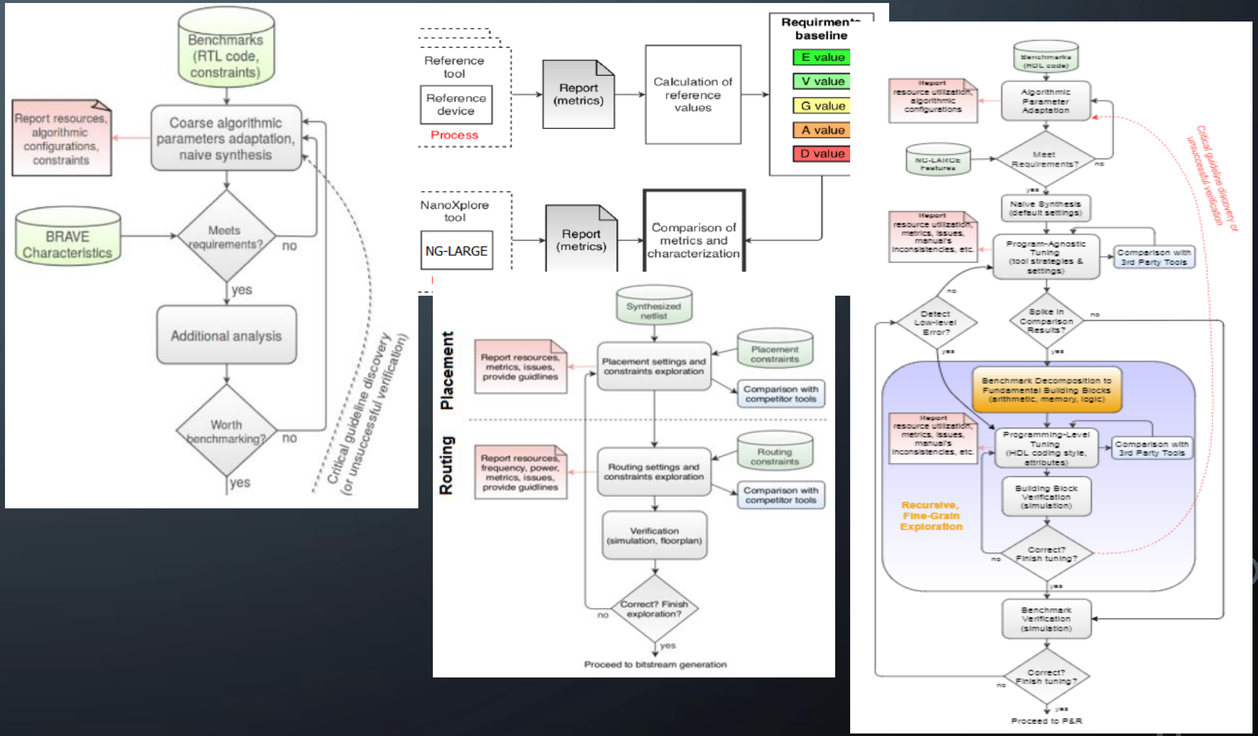
Proposed Evaluation Methodology

❑ Systematic Assessment Approach

- enhanced vs QUEENS1 activity (NG-MEDIUM evaluation)
- involves feedback loops
- performs comparisons vs. state-of-the-art tools/devices → COTS & space-grade FPGAs

❑ Methodology Steps

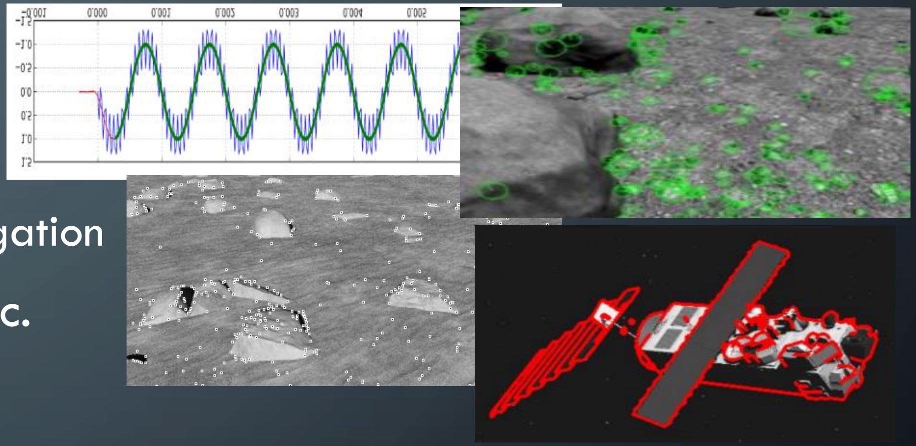
1. selection of benchmarks
2. definition of rating method
3. assessment of synthesis
4. assessment of placement & routing
5. assessment of bitstream generation



Steps 1-2: Benchmarks and Rating Method

❑ Benchmark Selection

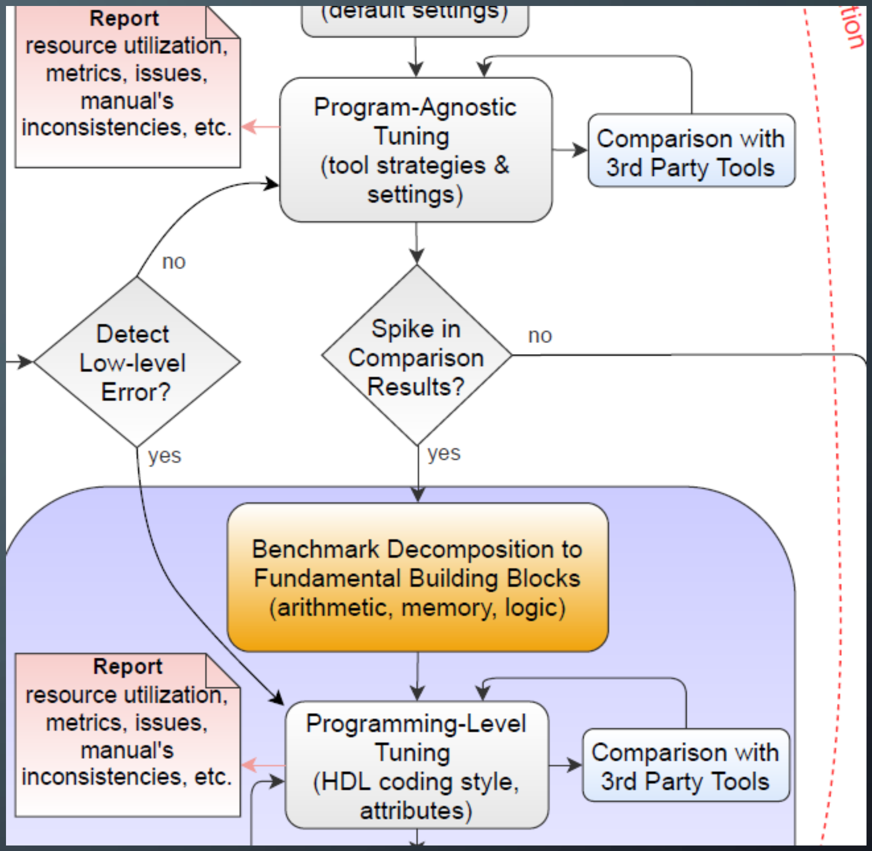
- goal → stress the tool/device with diverse algorithms (computations, I/O, resources, etc.)
- categories:
  - DC1: low-complexity → FSM, RAM, MULT, ADD
  - DC2: medium-complexity → LEON3, VGA controller
  - DC3: high-performance DSP → image processing, navigation
- selection criteria → scalability, diversity, throughput, etc.



❑ Rating Method

- goal → define the evaluation process and comparison to 3rd party tools
- metrics → resource utilization, frequency, power, tool runtime, etc.
- reference value → average of all the 3rd party results

Step 3: Assessment of Synthesis



❑ Assessment Targets

- NXmap settings (strategies and synthesis options)
- mapping efficiency
- quality of results (resources, correctness)
- quality of NXmap reports

❑ Testing in 2 Stages

1. program-agnostic tuning → tool settings
2. programming-level tuning → HDL coding

❑ Assessment Mechanisms

- report records → systematic comparison with 3rd party tools
- functional verification → post-synthesis netlist simulation
- issues resolving → benchmark decomposition to small blocks + feedback loop

Steps 4-5: Assessment of P&R and Bitstream

❑ Placement & Routing

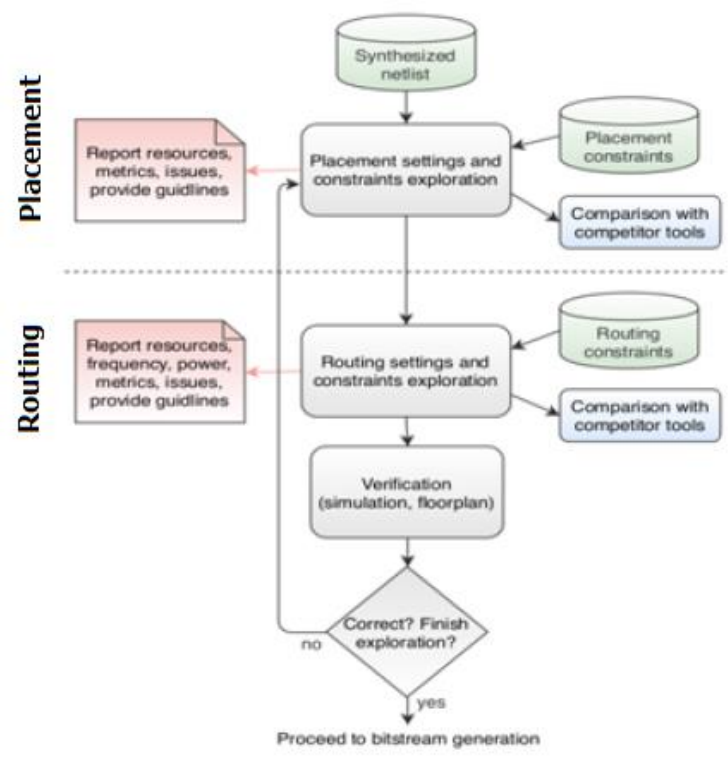
- exploration of physical constraints & place/route settings
- assessment of STA, power consumption, reports
- functional & timing verification → post-P&R netlist simulation

❑ Bitstream Generation

- configuration interfaces & speed
- reconfiguration tests
- bitstream validation

❑ HW Verification

- comparison to ground-truth data



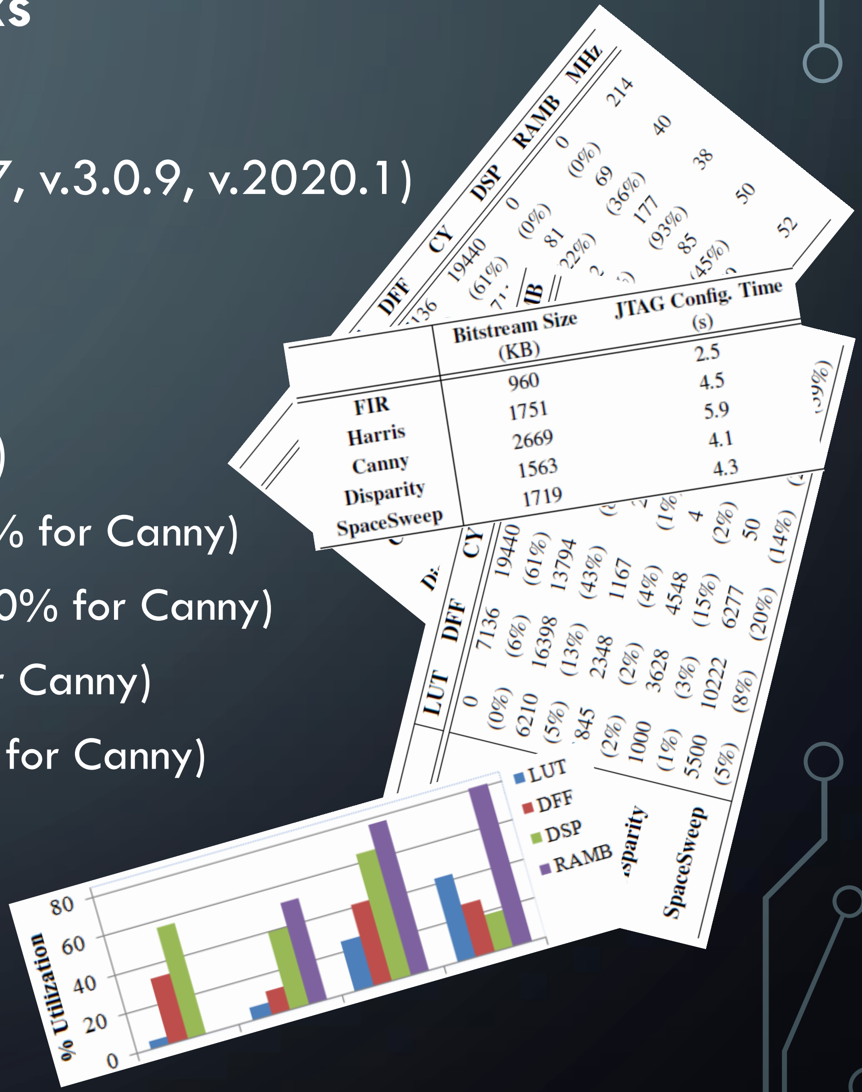
Evaluation Results (1/2)

❑ Implementation of High-Performance Benchmarks

- benchmarks → FIR, Harris, Canny, Disparity, SpaceSweep
- SW tool → NXmap3 v.2020.3 (also tested v.2.9.6, v.2.9.7, v.3.0.9, v.2020.1)

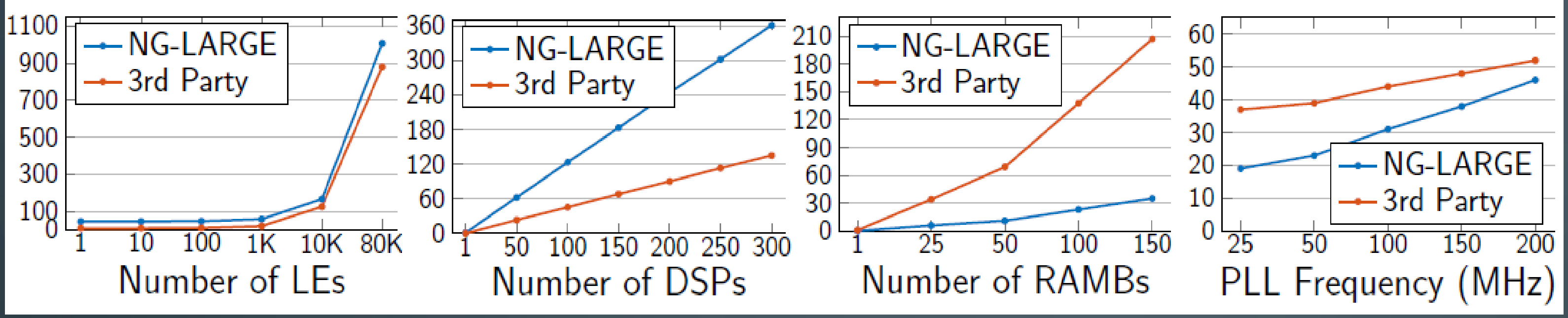
❑ Resource Utilization

- competitive vs 3rd party tools (compare absolute numbers)
  - RAMB → **excellent** (-56% for Harris, -39% for Disparity, 0% for Canny)
  - DSP → excellent (-30% for Harris, -20% for SpaceSweep, 0% for Canny)
  - LUT → good (-6% for Harris, -57% for Disparity, +48% for Canny)
  - DFF → good (-2% for Harris, -5% for SpaceSweep, +46% for Canny)
- significant improvement vs QUEENS1
  - NXmap3 → more mature vs earlier versions (NXmap2)



EVALUATION RESULTS (2/2)

❑ Power Consumption



- worse w.r.t. LE/DSP (5x-1.5x)
- better w.r.t. RAMB/PLL (up to 6x)
- similar static power (diff. 0.08W)

❑ Performance

	Frequency (MHz)	Runtime (s)	Throughput (*)
FIR	214	continuous	214 MSPS
Harris	40	0.19 / frame	5.3 FPS
Canny	38	0.10 / frame	10 FPS
Disparity	50	6.7 / frame	18 MPDS
SpaceSweep	52	10.8 / frame	29 MPDS

- **Disparity/SpaceSweep** (1024x1024)
  - improve depth extraction by 1 order
- **Harris/Canny** (1024x1024)
  - sufficient: VBN → 1-10 FPS
- Frequency Improvement **vs Nxmap2**

System-Level Evaluation: "SPARTAN VBN2"

Implementation of Entire VBN System (I/O + Processing, past ESA activity)

- algorithms on HW → Harris Corner Detector + SIFT Descriptor/Matching
- architecture → GR740 (processor) + NG-LARGE (accelerator)
- I/O → SpaceWire @100Mbps for 512x512 stereo pair + HW output

Comparative Evaluation

	LE	LUT	DFF	DSP	RAMB	MHz
NG-LARGE	98279 (76%)	98279 (71%)	56296 (44%)	250 (65%)	113 (58%)	22
3rd Party	14894 (73%)	50427 (62%)	39008 (48%)	129 (40%)	228 (77%)	30

	Harris Time[1]	SIFT Time[1]	SpW I/O Time[1]	Total System Time[2]	Total System Throughput[2]
NG-LARGE	208ms	395ms	28ms	1251ms	0.8 FPS
3rd Party	104ms	196ms	28ms	624ms	1.6 FPS

[1] refers to one 512×512 image.
[2] refers to a localization step with one 512×512 stereo pair.

- results vs competitor
  - LE, LUT, DFF → 6.5x, 2x, 1.4x more (due to LE & LUT architecture)
  - DSP → 2x more (due to design choices)
  - RAMB → 2x less (due to bigger RAMB size)
  - Max MHz → > 2x less (improving among Nxmap versions)
  - system throughput → 2x less FPS
- **fully functional, correct execution!**

Conclusion and Future Work

- ❑ **NG-LARGE → Promising Space-Grade Solution**
  - successful HW execution of high-performance benchmarks
  - competitive resource utilization and power consumption
  - sufficient SW tool capabilities
  - improving throughput (already good for space applications)

- ✓ **Evaluation of NG-ULTRA (“QUEENS3”)**
  - assessment of SoC’s embedded processor
  - implementation of new benchmarks (e.g., telecom)

- ✓ **Implementation of New VBN Pipelines & AI Algorithms**
  - custom designs on BRAVE FPGAs
  - I/O via SpaceWire

Thank you!

Questions?

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“QUEENS2”

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