POINT-CLOUD PROCESSING USING HDL CODER

SMART TECHNOLOGY FOR SMARTER CARS

AGENDA

Introduction

- LiDAR Sensors in Automotive Industry

Point Cloud Processing

- Classic processing pipeline

HDL-Coder Workflow

- Hardware structure
- Examples on the usage

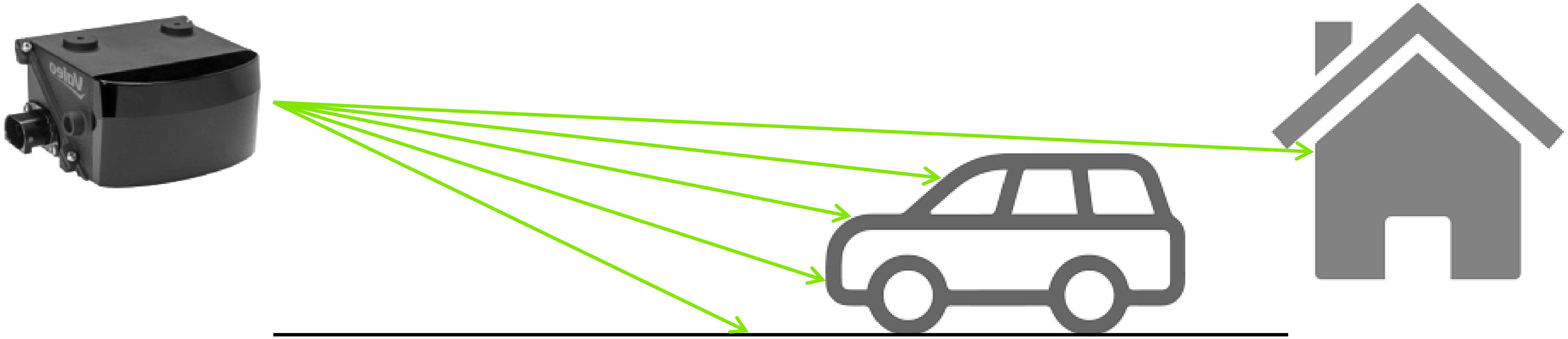
LIDAR SENSORS IN AUTOMOTIVE

Additional sensor technology offering

- High distance measurement
- Accurate point distance
- Working under bad circumstances (fog, night)
- Enhancing redundancy

Time of flight measurement for emmitted Laser Beam

$$d = \frac{\delta_t \cdot c}{2}, \quad \delta_t = \text{measured time till light is received}, c = \text{speed of light}$$



LIDAR SENSORS IN AUTOMOTIVE

Valeo SCALA first mass production LiDAR Sensor for automotive (2017)

- 58.000 points per second
- Next generation ~200.000 points per second

Research Utilities

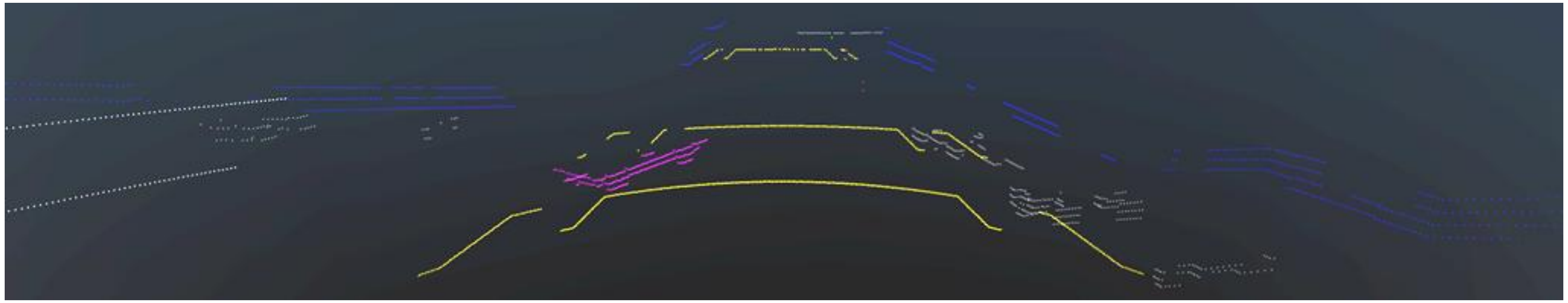
- Velodyne LiDAR Ultra Puck ~600,000 points per second
- Velodyne HDL-64E 2.2 million points per second

⇨ Number of points to be processed will increase

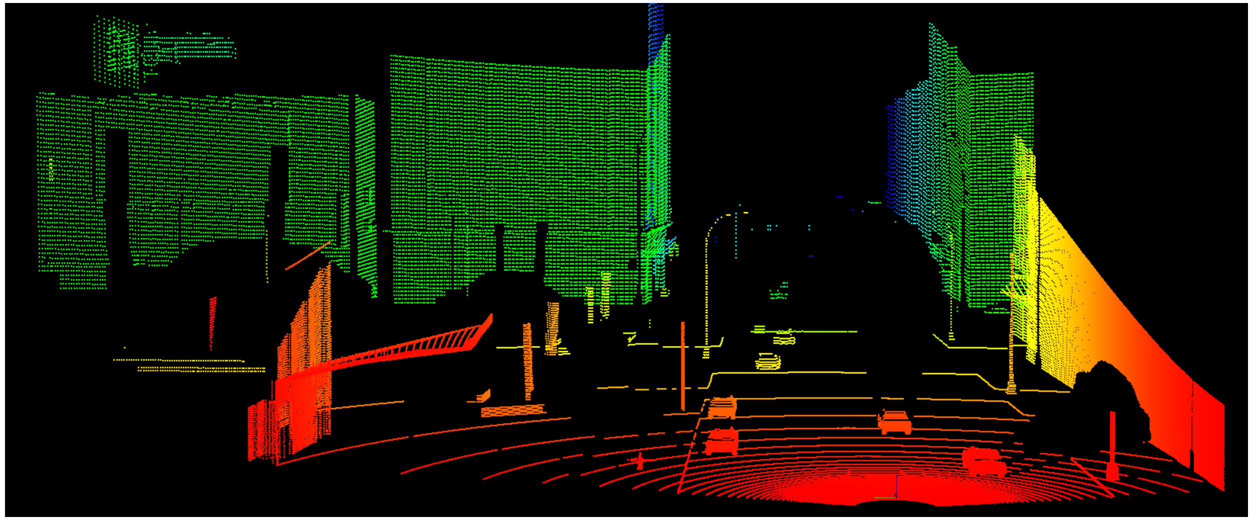
⇨ Possibility of getting more information out of the data

LIDAR SENSORS IN AUTOMOTIVE

State of the art



Possible future resolution

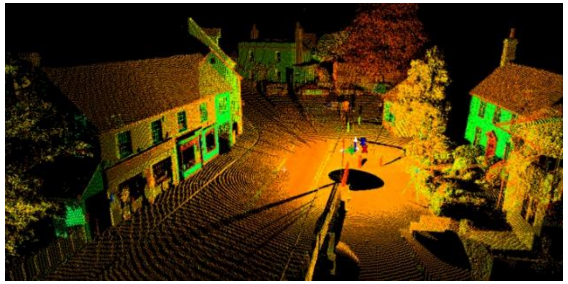


Valeo

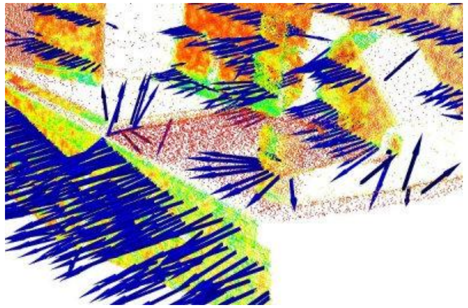
WHAT IS A POINT CLOUD

A point cloud is a set of discrete points in 3D space. Each point is represented by its cartesian coordiantes and may hold additional information

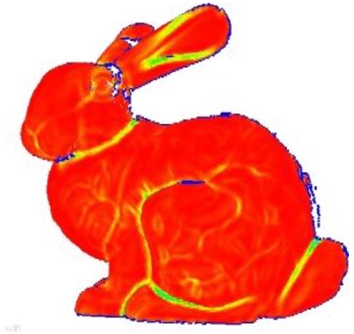
- XYZ coordinates
- RGB (Texture)
- Intensity
- Normals
- Curvature
- …



360° view

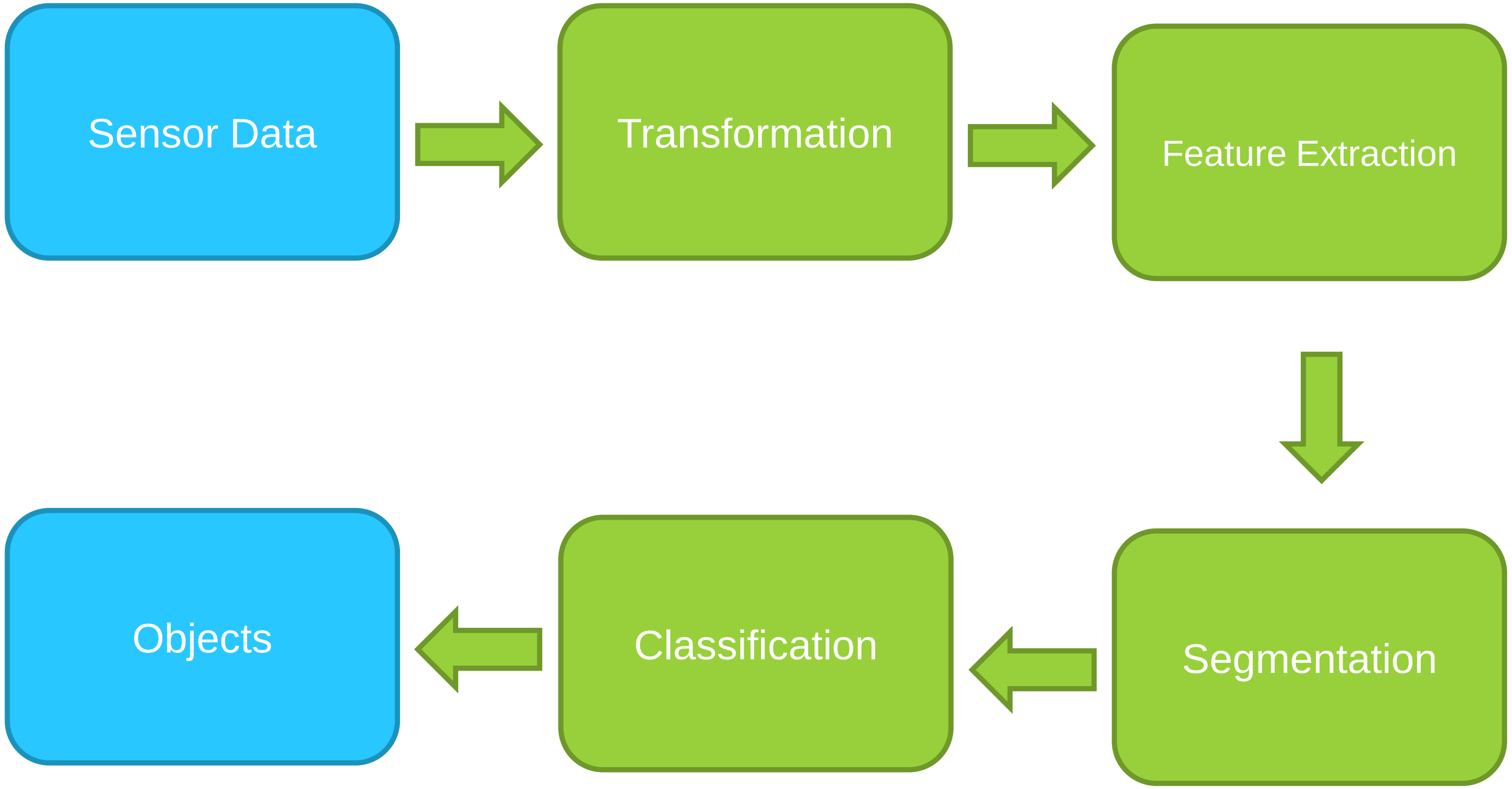


surface Normals



curvature

POINT CLOUD PROCESSING PIPELINE



POINT CLOUD - TRANSFORMATION

Transfor-
mation

- Sensor Data distance measurement
- Known column and row index (n,m)

$$d(n,m), \quad \text{with} \quad n \in [0,1,...,\#rows]\,, m \in [0,1,...,\#columns]$$

- Transformation to cartesian coordinates necessary

$$\begin{pmatrix} x(n,m) \\ y(n,m) \\ z(n,m) \end{pmatrix} = f(n,m) \cdot d(n,m) = \begin{pmatrix} \cos(pitch(n))\cos(yaw(m)) \\ \cos(pitch(n))\sin(yaw(m)) \\ \sin(pitch(n)) \end{pmatrix} \cdot d(n,m)$$

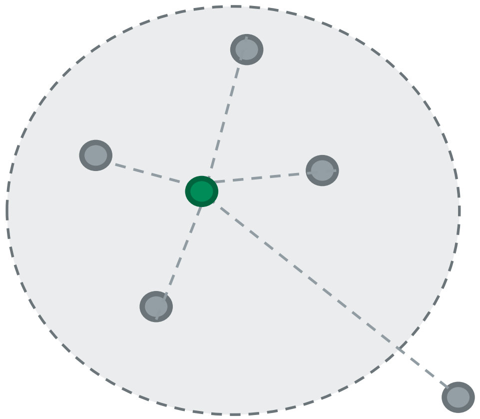
- pitch and yaw depend on resolution, mounting position

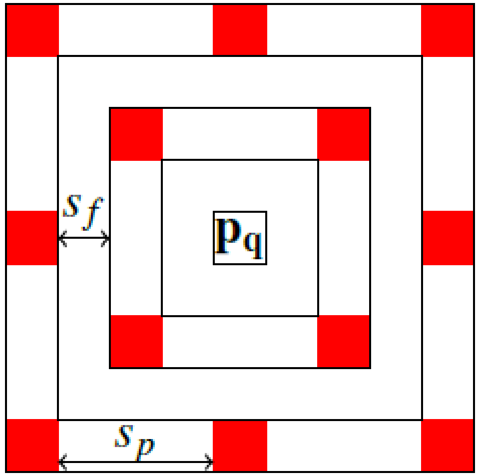
POINT CLOUD – FEATURE EXTRACTION

Feature Extraction

Normal estimation

- Nearest Neighbours for unorganized point cloud
  - Brute force
  - Kd-tree
  - Approximate nearest neighbours
- Nearest Neighbours for organized point cloud
  - Pixel like structure
  - Define a search mask
- Normal estimation using PCA
  - Surface normal corresponds to eigenvector of smallest eigenvalue





Curvature

- Estimated from Eigenvalues

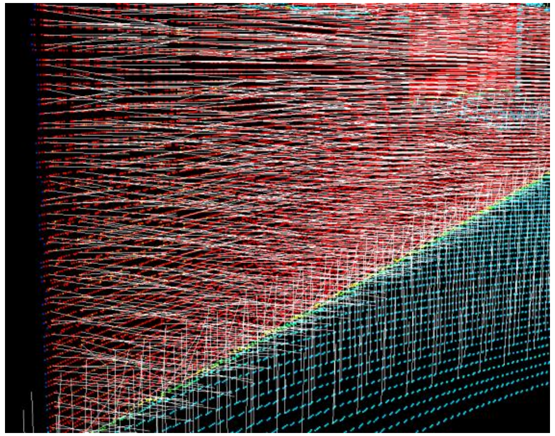
$$\frac{\lambda_0}{\lambda_0 + \lambda_1 + \lambda_2} \quad \text{with} \quad \lambda_0 \leq \lambda_1 \leq \lambda_2$$

POINT CLOUD – SEGMENTATION

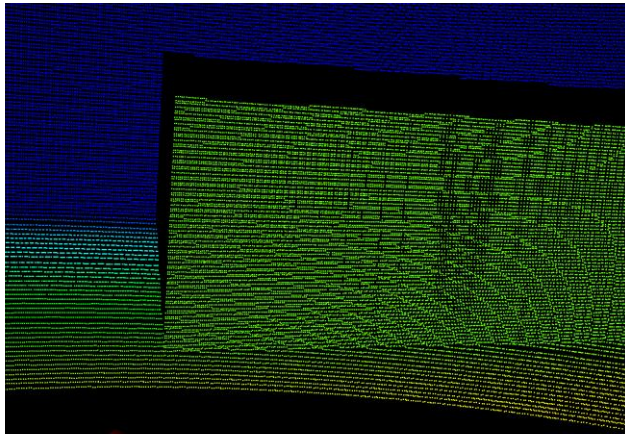
Segmen-
tation

- Evaluate features to detect
  - Depth changes

  - Edges



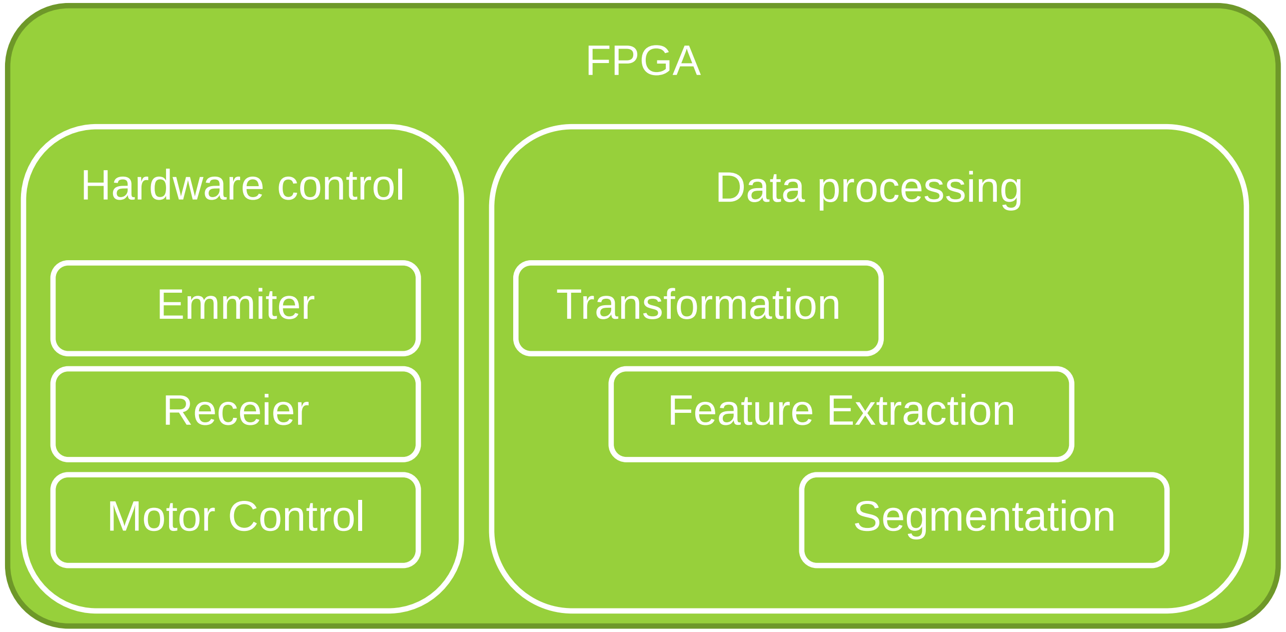
- Cluster connected points
  - Region growing algorithm



WHAT IS AN FPGA AND WHY DO WE USE IT?

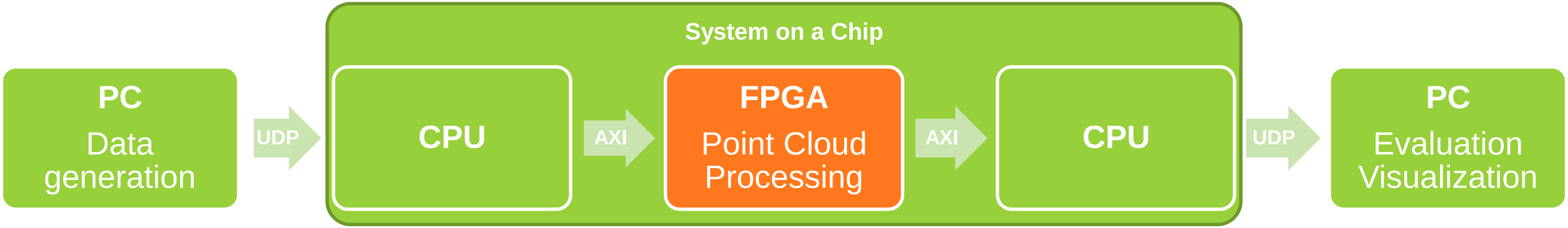
Field Progammable Gate Array

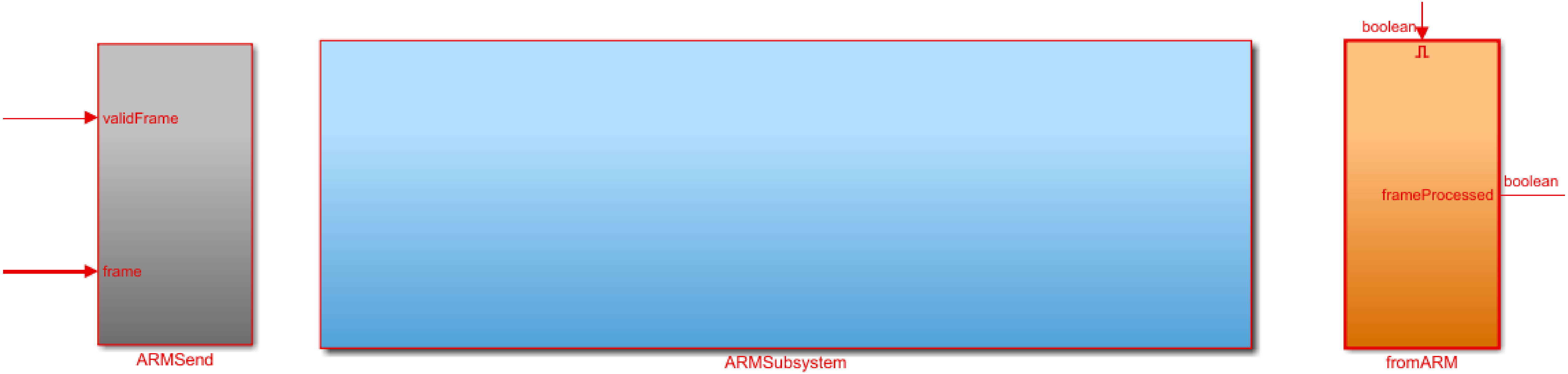
- Reconfigurable Integrated Circuit
  - Suitable for new projects
  - Implementation of bug fixes
- Parallel processing of
  - Algorithms for Hardware control
  - Each step in the data processing pipeline



POINT CLOUD PROCESSING ON FPGA

Possible data flow using Embedded-Coder and HDL-Coder





POINT CLOUD PROCESSING ON FPGA

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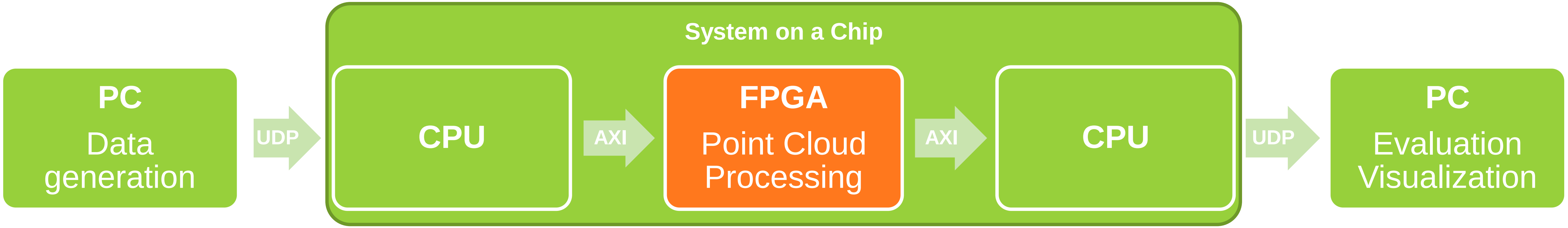
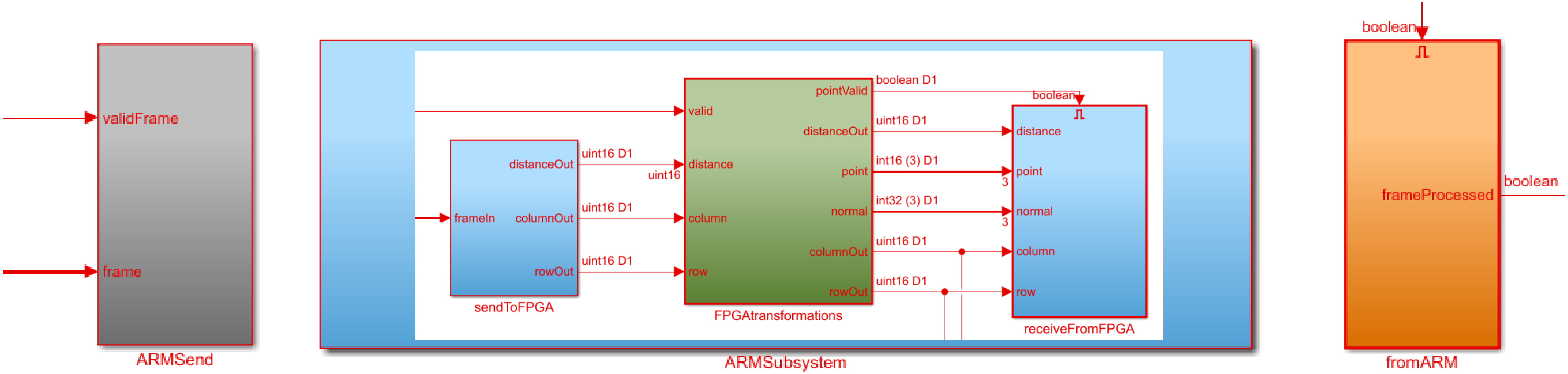
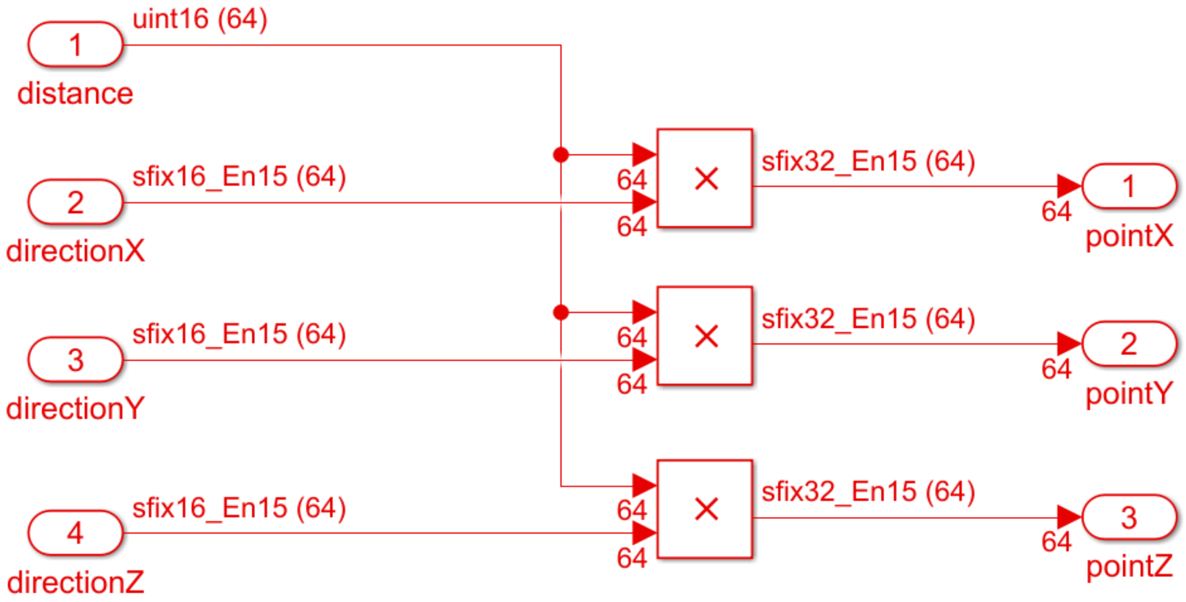




POINT TRANSFORMATION

Example:

- Column Wise data received from Sensor (64 scan points)
- Transformation multipliers from lookup table available



Summary

Multipliers	192
Adders/Subtractors	0
Registers	2
Total 1-Bit Registers	2
RAMs	0
Multiplexers	0
I/O Bits	7174
Static Shift operators	0
Dynamic Shift operators	0

Critical Path Details

Id	Propagation (ns)	Delay (ns)	Block Path
1	3.9260	3.9260	Product2

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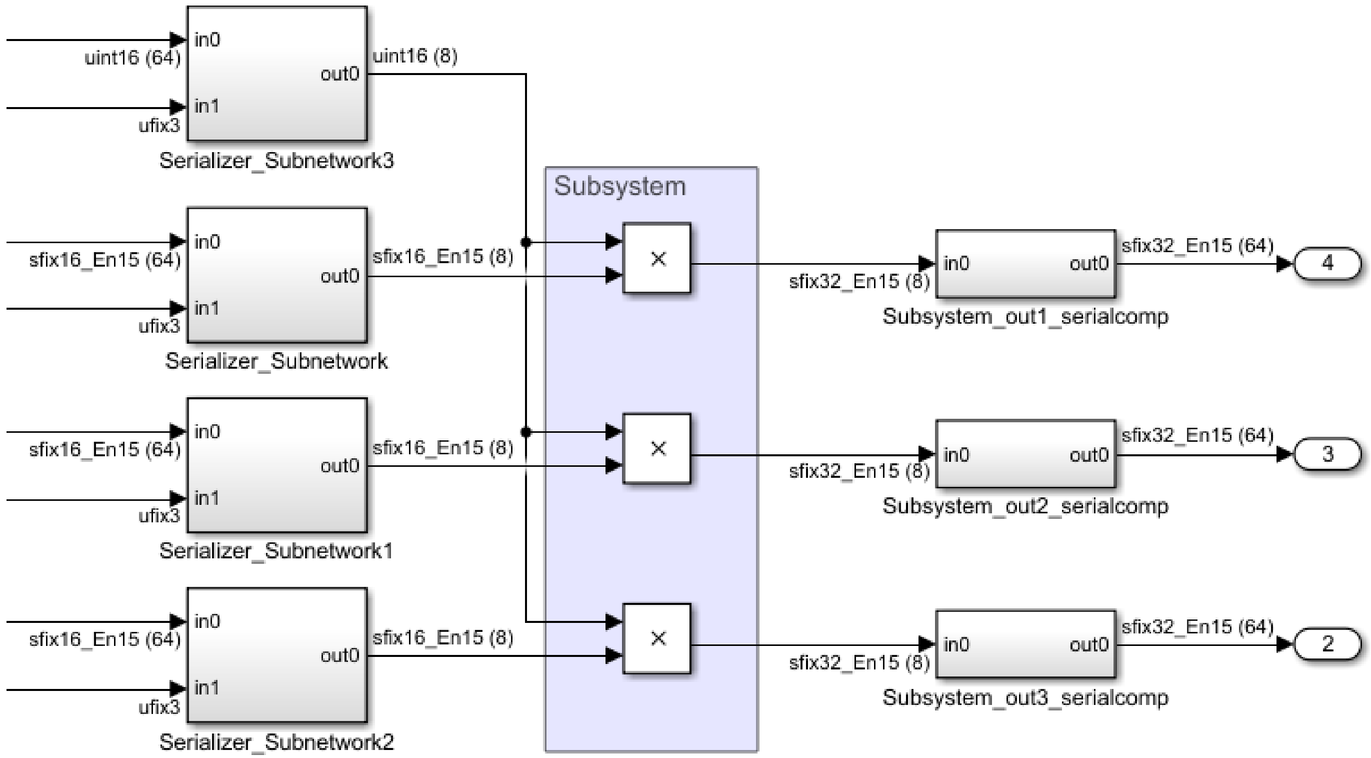
POINT TRANSFORMATION

Streaming inserted

SharingFactor	0
StreamingFactor	8



Summary

Multipliers	24
Adders/Subtractors	4
Registers	385
Total 1-Bit Registers	11565
RAMs	0
Multiplexers	44
I/O Bits	7174
Static Shift operators	0
Dynamic Shift operators	0

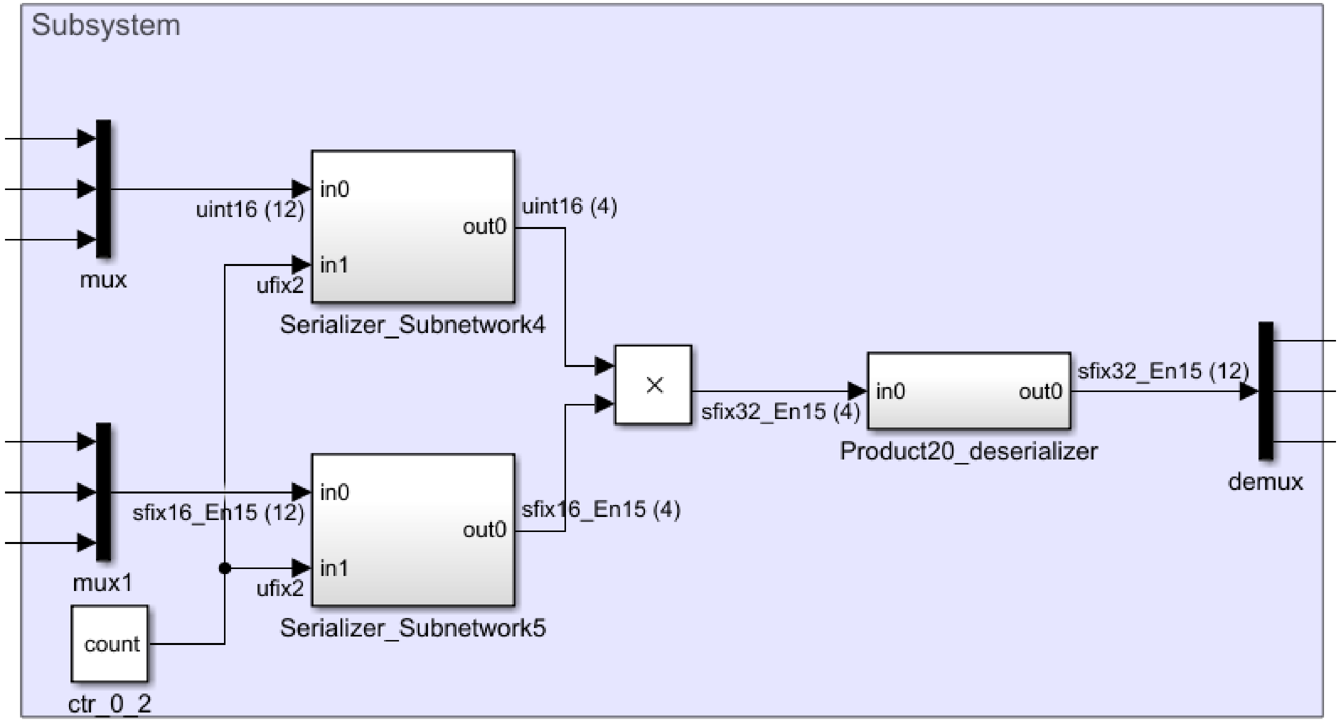
Critical Path Details

Id	Propagation (ns)	Delay (ns)	Block Path
1	0.4740	0.4740	*ctr_0_7*
2	1.3365	0.8625	*splitcomp_multiport*
3	5.2625	3.9260	*Product_out1_serialcomp_in_buff*
4	5.4320	0.1695	*Product_out1_serialcomp*

POINT TRANSFORMATION

Streaming and Sharing inserted

SharingFactor	3
StreamingFactor	16



Summary

Multipliers	4
Adders/Subtractors	6
Registers	618
Total 1-Bit Registers	18381
RAMs	0
Multiplexers	41
I/O Bits	7174
Static Shift operators	0
Dynamic Shift operators	0

Critical Path Details

Id	Propagation (ns)	Delay (ns)	Block Path
1	0.4740	0.4740	*ctr_0_15*
2	1.1465	0.6725	*splitcomp_multiport*
3	1.1465	0.0000	*mux*
4	1.1465	0.0000	*ratechange_splitcomp*
5	1.8245	0.6780	*splitcomp_multiport*
6	5.7505	3.9260	*Product20_deserializer_in_buff*
7	5.9200	0.1695	*Product20_deserializer*

NORMAL ESTIMATION

Example: Simple normal estimation

- Assumptions
  - Organized Point Cloud
  - Data processed point wise in increasing manner (column and row wise)

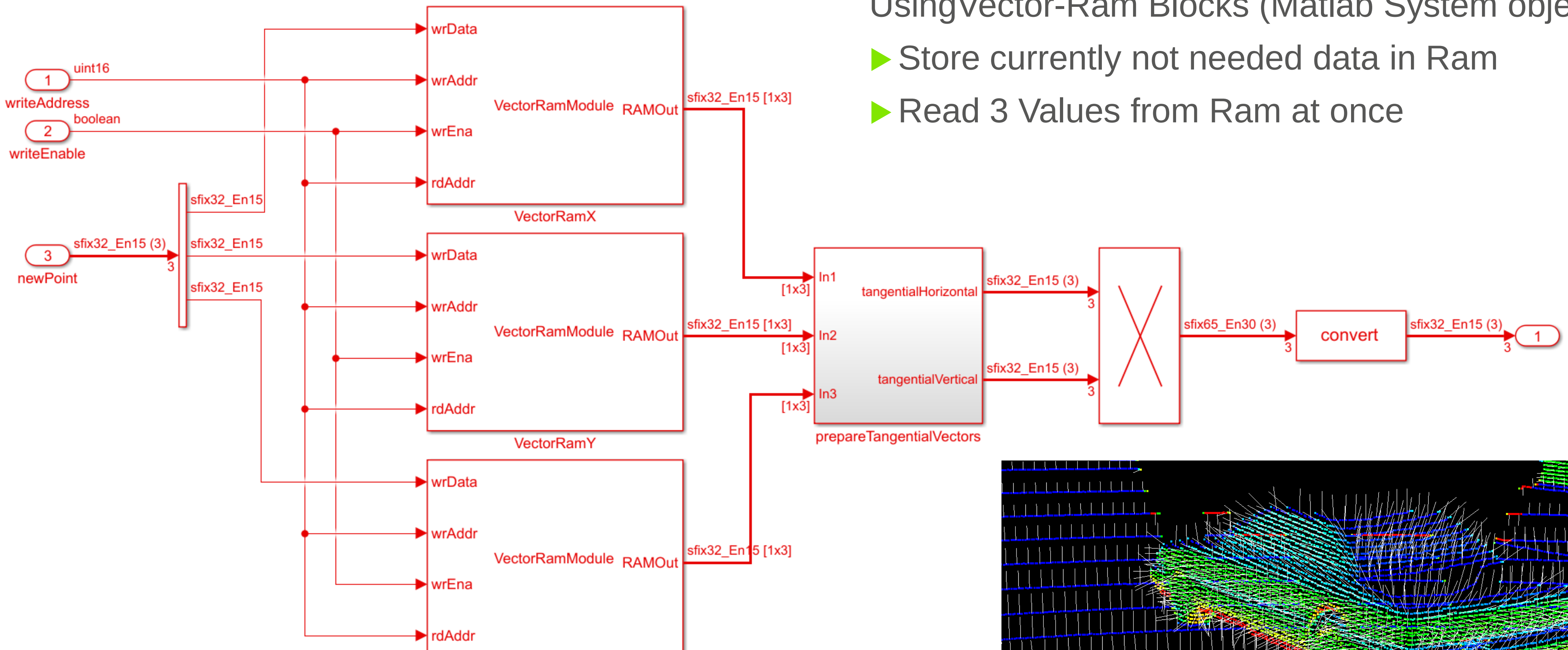
P(n-2, m-2)	P(n-2, m-1)	P(n-2,m)
P(n-1, m-2)	P(n-1, m-1)	P(n-1, m)
P(n, m-2)	P(n, m-1)	P(n, m)
P(n+1, m-2)	P(n+1, m-1)	

Point to calculate surface normal

New point

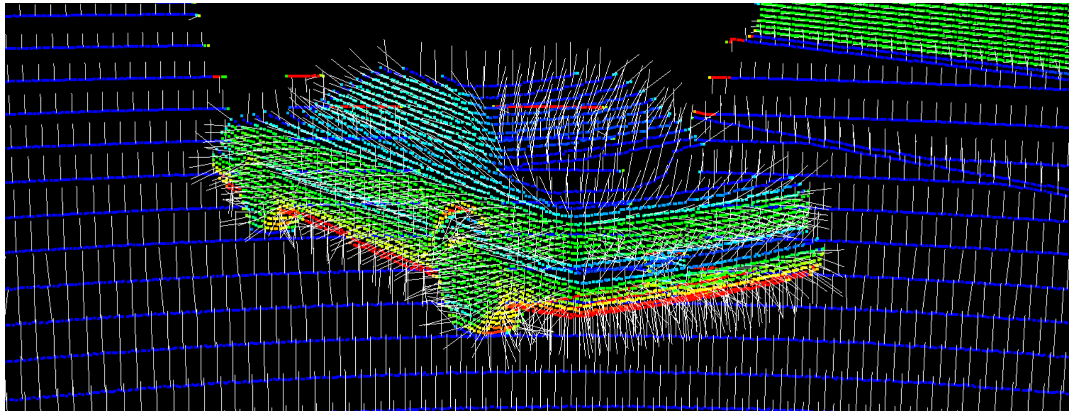
$$N(n, m-1) = \underbrace{[P(n,m) - P(n,m-2)]}_{\text{horizontal tangent}} \times \underbrace{[P(n+1,m-1) - P(n-1,m-1)]}_{\text{vertical tangent}}$$

NORMAL ESTIMATION



UsingVector-Ram Blocks (Matlab System object)

- Store currently not needed data in Ram
- Read 3 Values from Ram at once



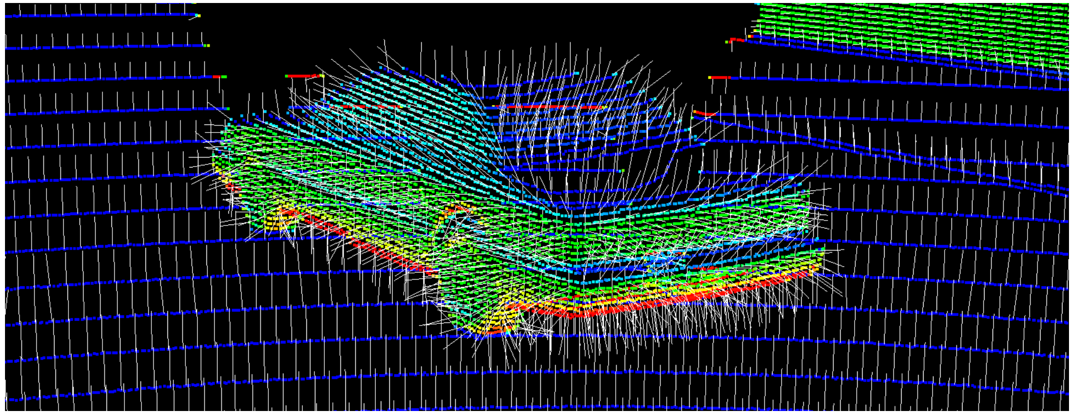
SUMMARY

HDL Coder

- Algorithm development for FPGA without VHDL coding
- Run as HiL-Setup directly
- Comparable to Simulink implementation

Challenges

- Algorithm selection
  - What can be implemented?
  - How to adopt algorithms?



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