Multi-Vehicle Map Fusion using GNU Radio

Optimization and Acceleration Opportunities

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Acknowledgment

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- Special thanks to **Dr. Thomas Rondeau**, Program Manager of the DARPA MTO DSSoC Program

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Outline

- **Part 1: DARPA-funded EPOCHS project**
  - Domain-specific (heterogeneous) SoC development

- **Part 2: EPOCHS Reference Application (“ERA”)**
  - Application domain: *multi-vehicle cooperative perception*

- **Part 3: 802.11p Transceiver**
  - Optimization and acceleration opportunities

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DARPA's Domain-Specific System on Chip (DSSoC) Program

Program Manager: Dr. Tom Rondeau

- **Goal:** to develop a heterogeneous system-on-chip (SoC) comprised of many cores that mix general purpose processors, special purpose processors, hardware accelerators, memory, and input/output (I/O) devices to significantly improve performance of applications within a **domain** *

- **A domain is larger than any one application**
  - We target the "super" domain of embedded processors for autonomous/connected cars

"cooperative perception"

computer vision

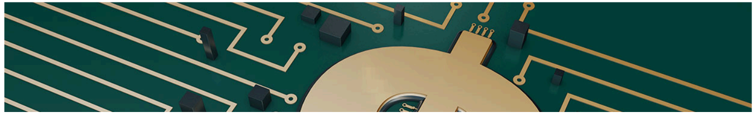
software radio

24 Jul 2018 | 17:00 GMT

DARPA Picks Its First Set of Winners in Electronics Resurgence Initiative

Teams announced in design, architecture, and materials and integration programs under the $1.5 billion effort to remake U.S. electronics

By **Samuel K. Moore**



Source: IEEE Spectrum (July 2018)

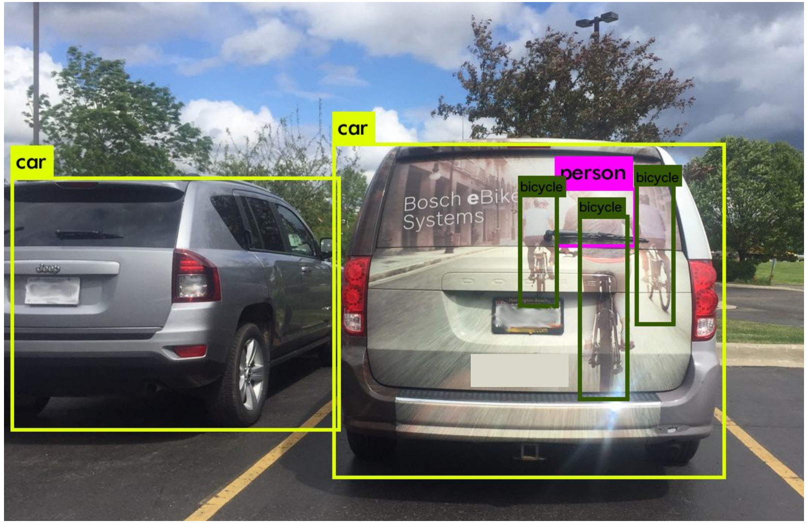
* *Source: https://www.darpa.mil/program/domain-specific-system-on-chip*

Application Domain: Cooperative Perception

- Automakers use arrays of sensors to build redundancy into their systems

This Image is Why Self-Driving Cars Come Loaded with Many Types of Sensors

When's a pedestrian not a pedestrian? When it's a decal.

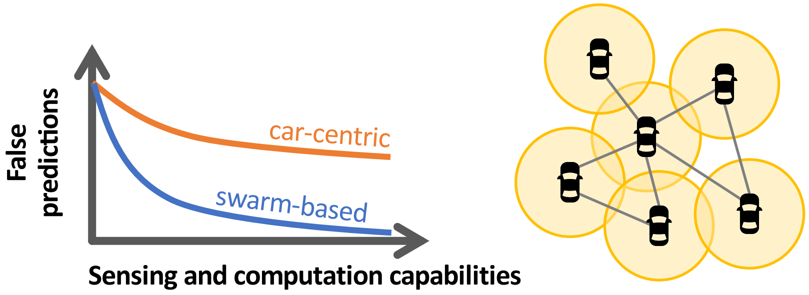


Source: MIT Technology Review

Application Domain: Cooperative Perception

- Automakers use arrays of sensors to build redundancy into their systems

- We propose a complementary approach: **multi-vehicle (cooperative) perception**
  - Cars exchange locally-generated maps
  - Each vehicle merges its local map and the received ones in real time



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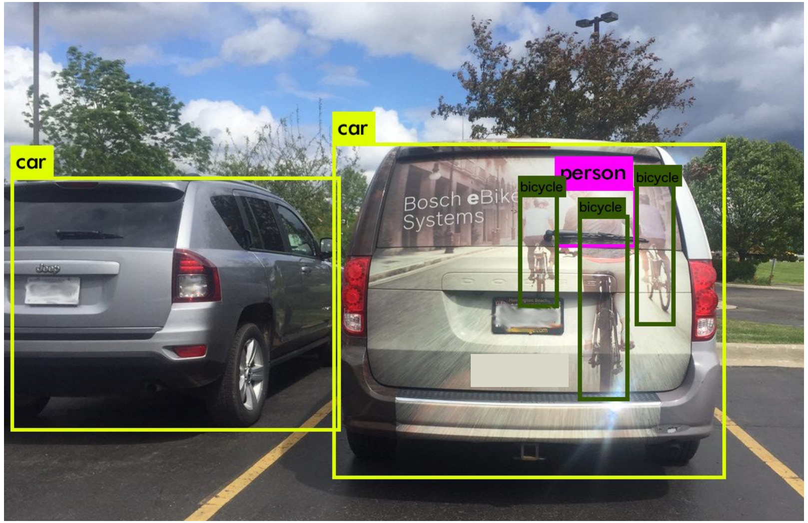

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Efficient Programmability Of Cognitive Heterogeneous Systems

"EPOCHS" → our proposed solution for the design challenge presented by the DSSoC program

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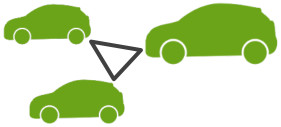
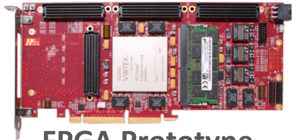
EPOCHS Reference Application



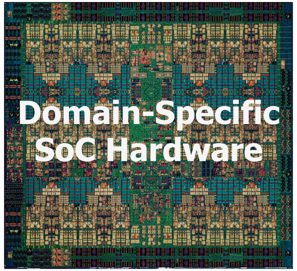
Compiler + Scheduler

Ontology & Design Space Exploration



FPGA Prototype

Agile Flow



Implementation

Accelerators + NoC + Memory Architecture

10X – 100X reduction in person-years

FPGA prototype, emulation, optimization, software bring-up

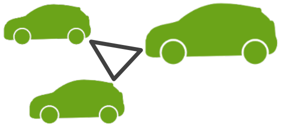
Agile methodology to quickly design and implement an easily programmed domain-specific SoC for real-time cognitive decision engines in connected vehicles

"Super"-Domain: Software-Defined Radio + Computer Vision

Efficient Programmability Of Cognitive Heterogeneous Systems

"EPOCHS" → our proposed solution for the design challenge presented by the DSSoC program

EPOCHS Reference Application



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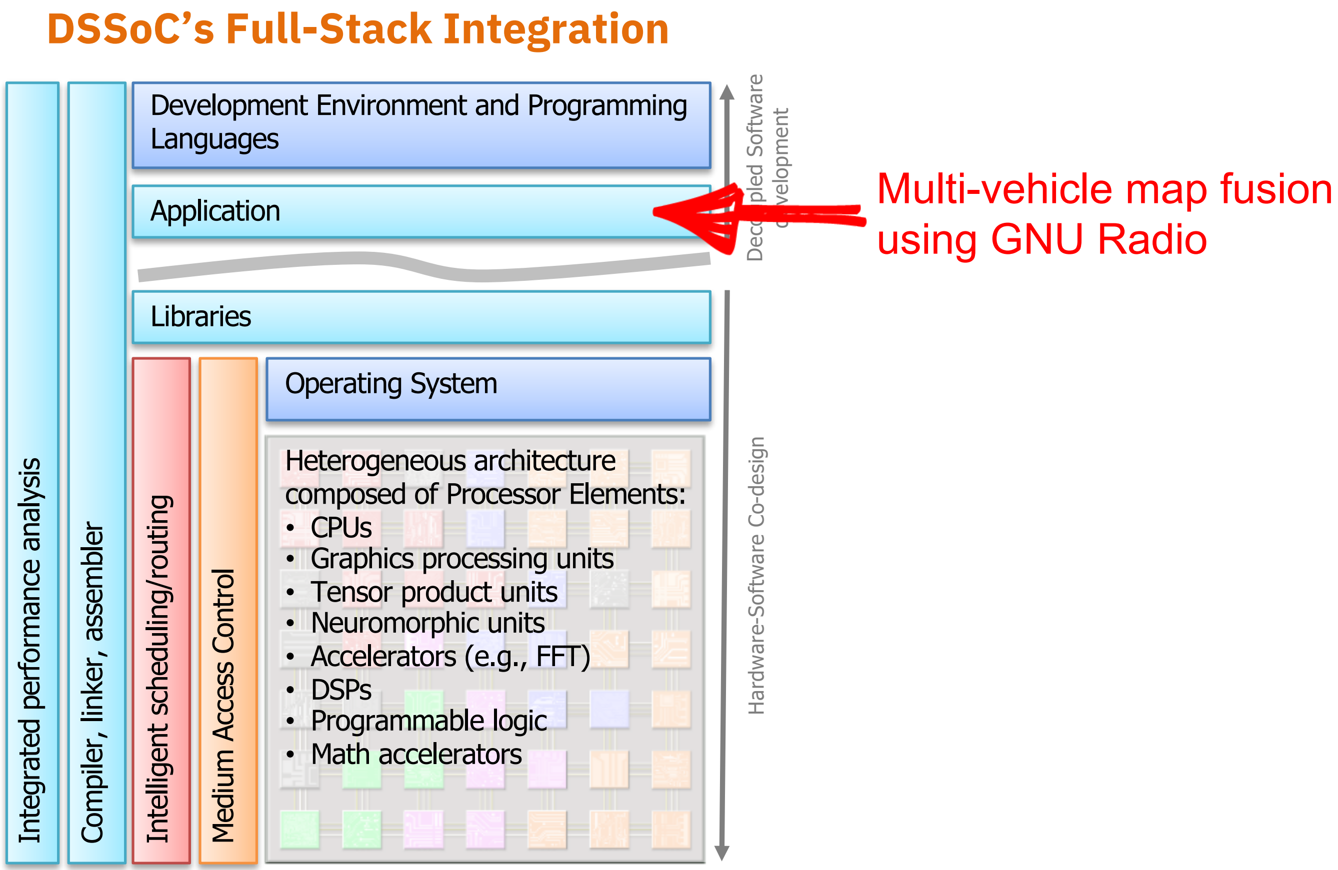
The Big Picture (Where Does This Talk Fit In?)



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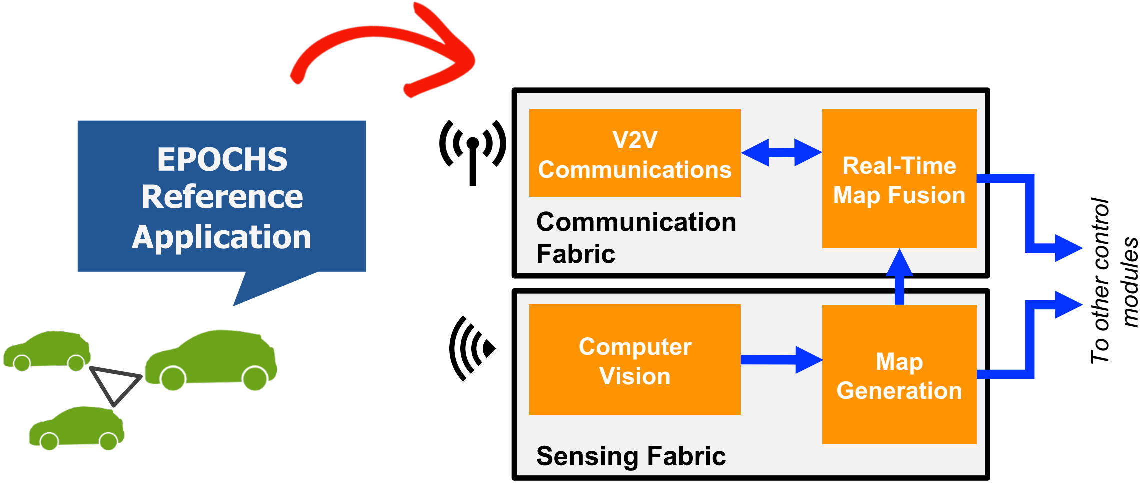
ERA: EPOCHS Reference Application

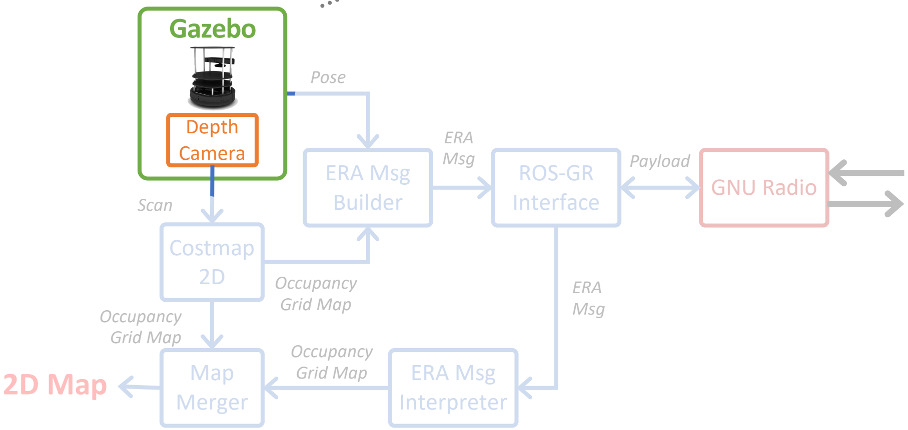


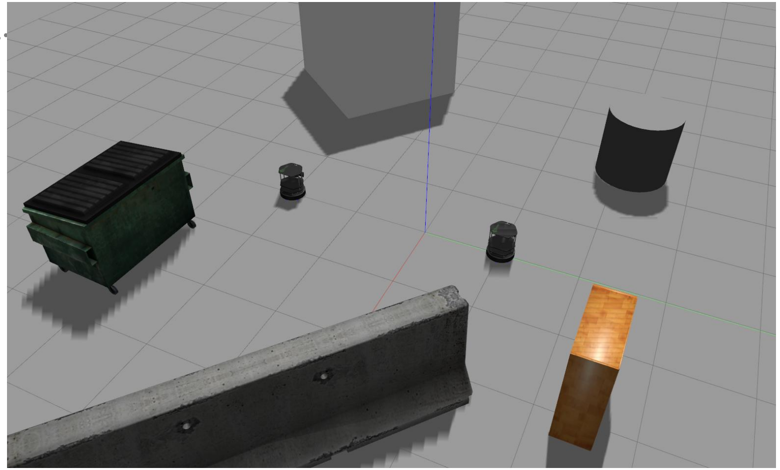
- **"Cooperative Perception" for connected/autonomous vehicles**
  - Multimodal sensing
  - Local occupancy map generation
  - DSRC-based V2V communication
  - Real-time map fusion

Contribute!
https://github.com/IBM/era

ERA Main Components (Single Robot's Viewpoint)

- Raw sensor data generated (simulated) using Gazebo in ERA v2
  – ERA v3 will replace Gazebo with an automotive simulation platform

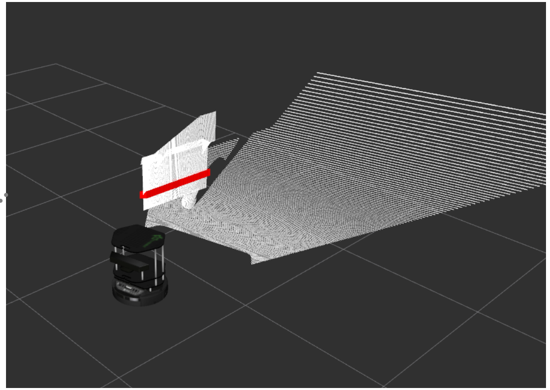




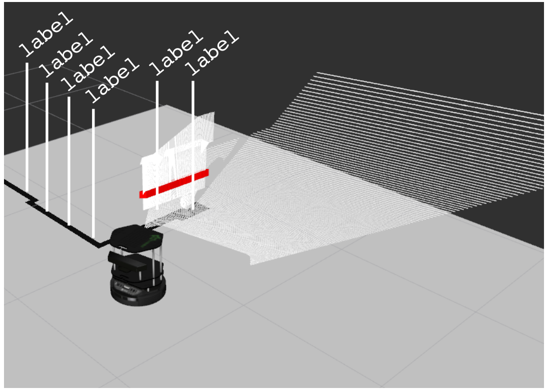
ERA Main Components (Single Robot's Viewpoint)

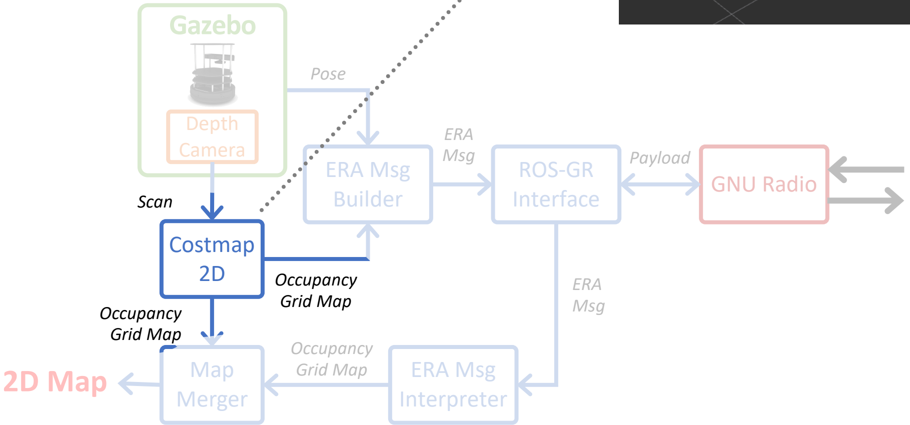
- Raw sensor data is first converted into laser scans which are used to generate a 2D occupancy grid map

Depth image → laser scans



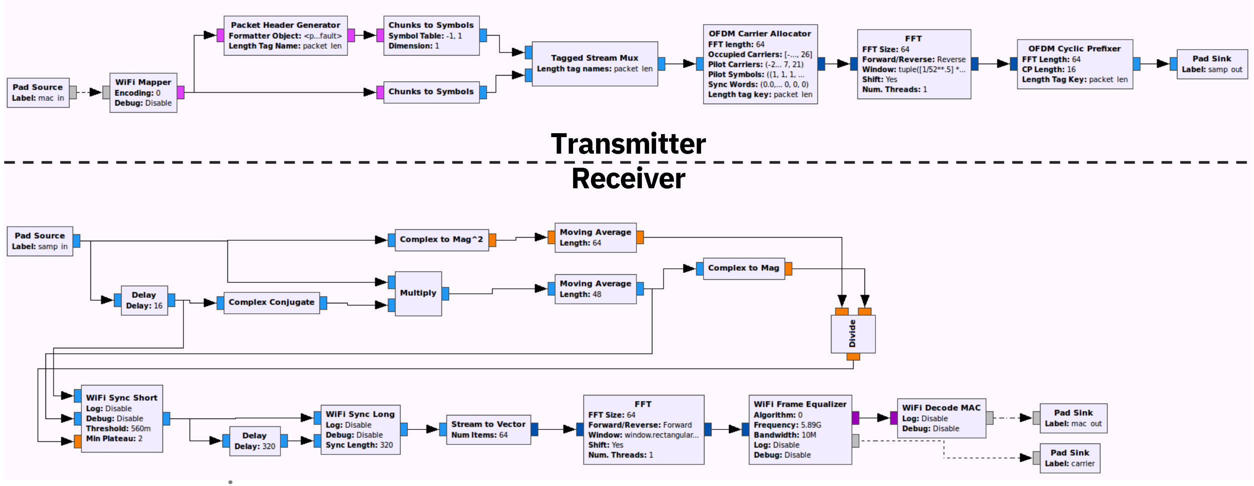
2D occupancy map generation

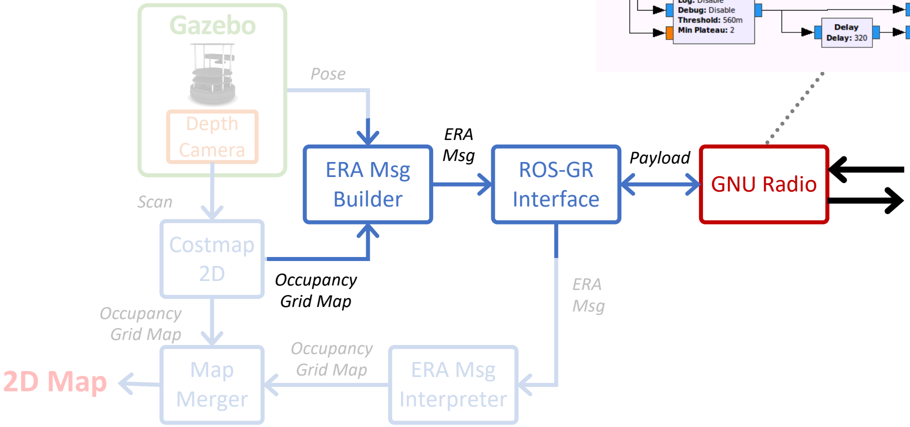




ERA Main Components (Single Robot's Viewpoint)

- Occupancy grid maps are serialized, compressed and put into a GNU Radio PDU
- Outbound PDUs are injected into the 802.11p transceiver

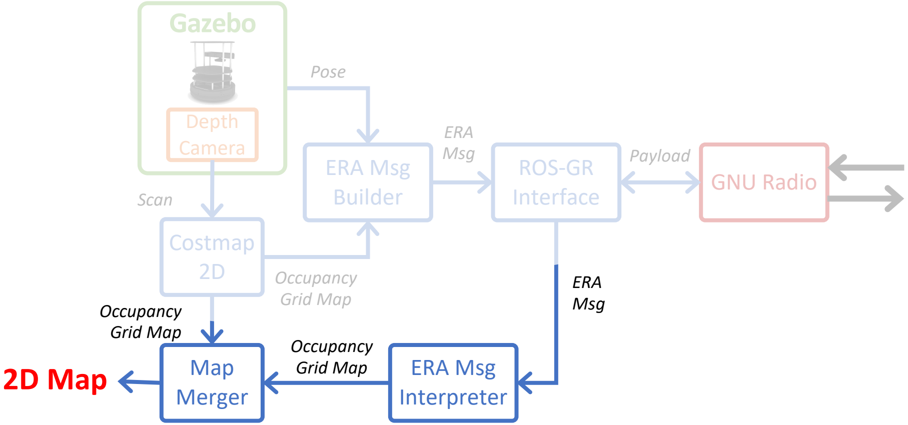




Open-source implementation by Bastian Bloessl
https://github.com/bastibl/gr-ieee802-11

ERA Main Components (Single Robot's Viewpoint)

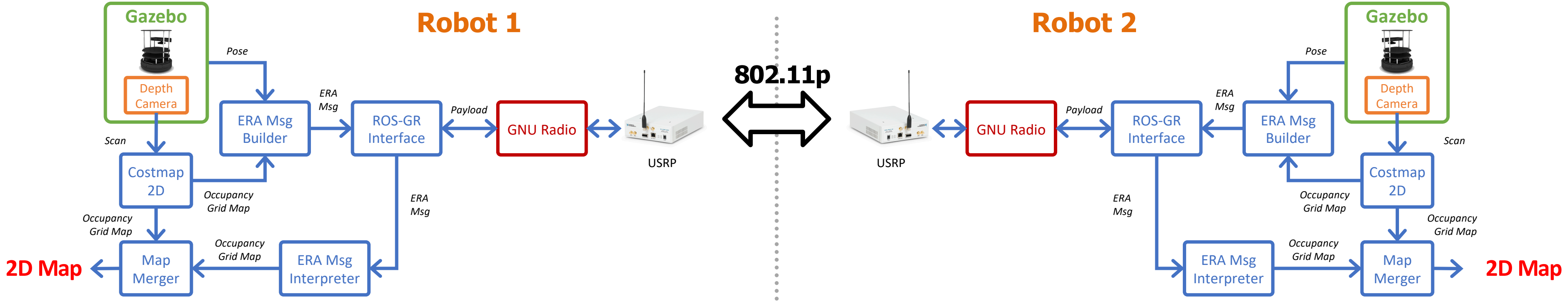
- Locally- and remotely-generated occupancy maps are merged in real time to improve the accuracy of the surroundings' view
- In ERAv2, *merging* is merely adding maps
  - Executed several times per second (!)

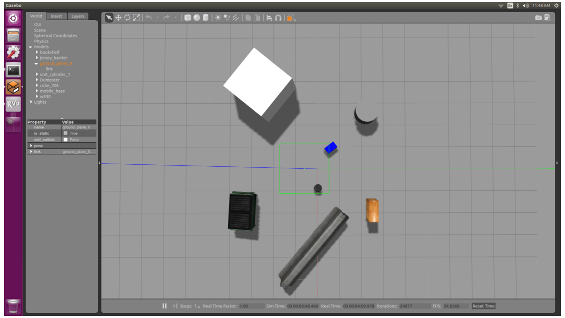


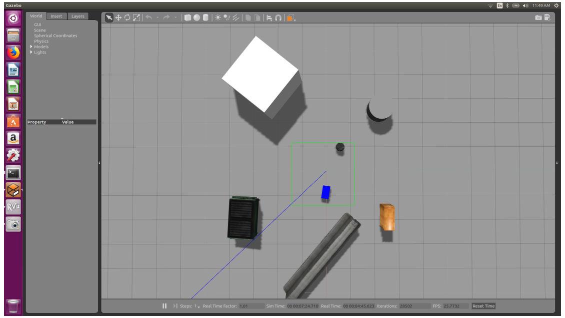

```
GridPtr combineGrids (const vector<nm::OccupancyGrid>& grids, const double resolution)
{
  GridPtr combined_grid(new nm::OccupancyGrid());
  combined_grid->info = getCombinedGridInfo(grids, resolution);
  combined_grid->data.resize(combined_grid->info.width*combined_grid->info.height);
  fill(combined_grid->data.begin(), combined_grid->data.end(), -1);
  ROS_DEBUG_NAMED ("combine_grids", "Combining %zu grids", grids.size());

  BOOST_FOREACH (const nm::OccupancyGrid& grid, grids) {
    for (coord_t x=0; x<(int)grid.info.width; x++) {
      for (coord_t y=0; y<(int)grid.info.height; y++) {
        const Cell cell(x, y);
        const signed char value=grid.data[cellIndex(grid.info, cell)];

        // Only proceed if the value is not unknown
        if ((value>=0) && (value<=100)) {
          BOOST_FOREACH (const Cell& intersecting_cell,
                         intersectingCells(combined_grid->info, grid.info, cell)) {
            const index_t ind = cellIndex(combined_grid->info, intersecting_cell);
            combined_grid->data[ind] = max(combined_grid->data[ind], value);
          }
        }
      }
    }
  }

  ROS_DEBUG_NAMED ("combine_grids", "Done combining grids");
  return combined_grid;
}
```

Option 1: Two-Computer Setup

- One Gazebo instance simulating one single robot/vehicle in each computer
- Over-the-air 802.11p communication (10-MHz OFDM with up to 64-QAM modulation)
- More info: https://github.com/IBM/era/wiki/ERA-in-two-computers

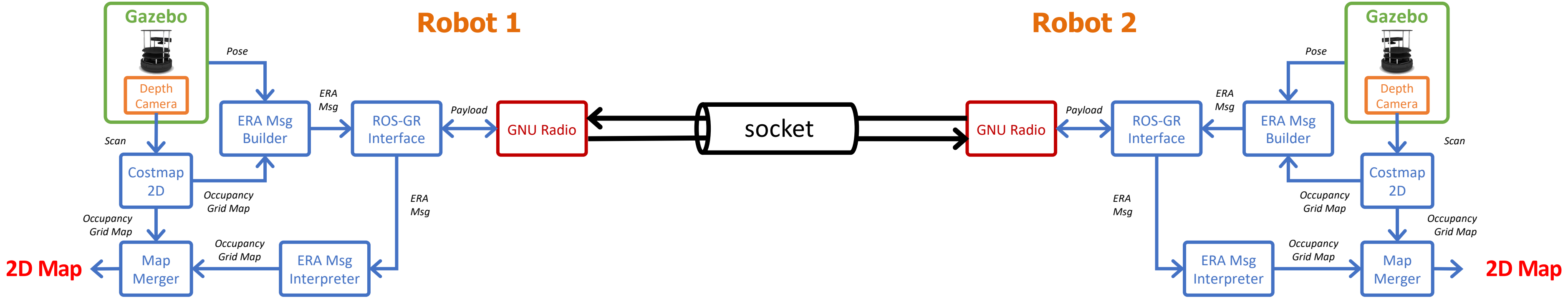


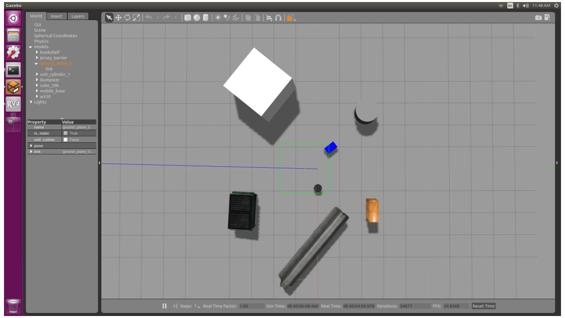


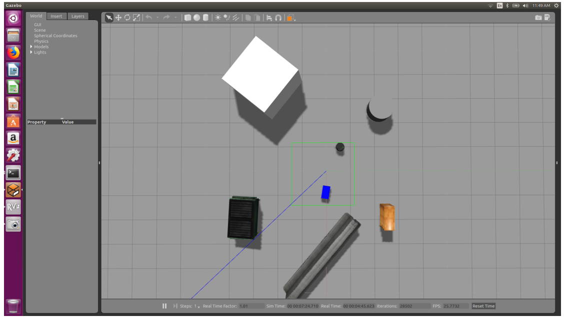


Option 2: Standalone Setup

- Runs on a single computer, replacing over-the-air communication with network sockets
- **Easiest setup to start with ✓**







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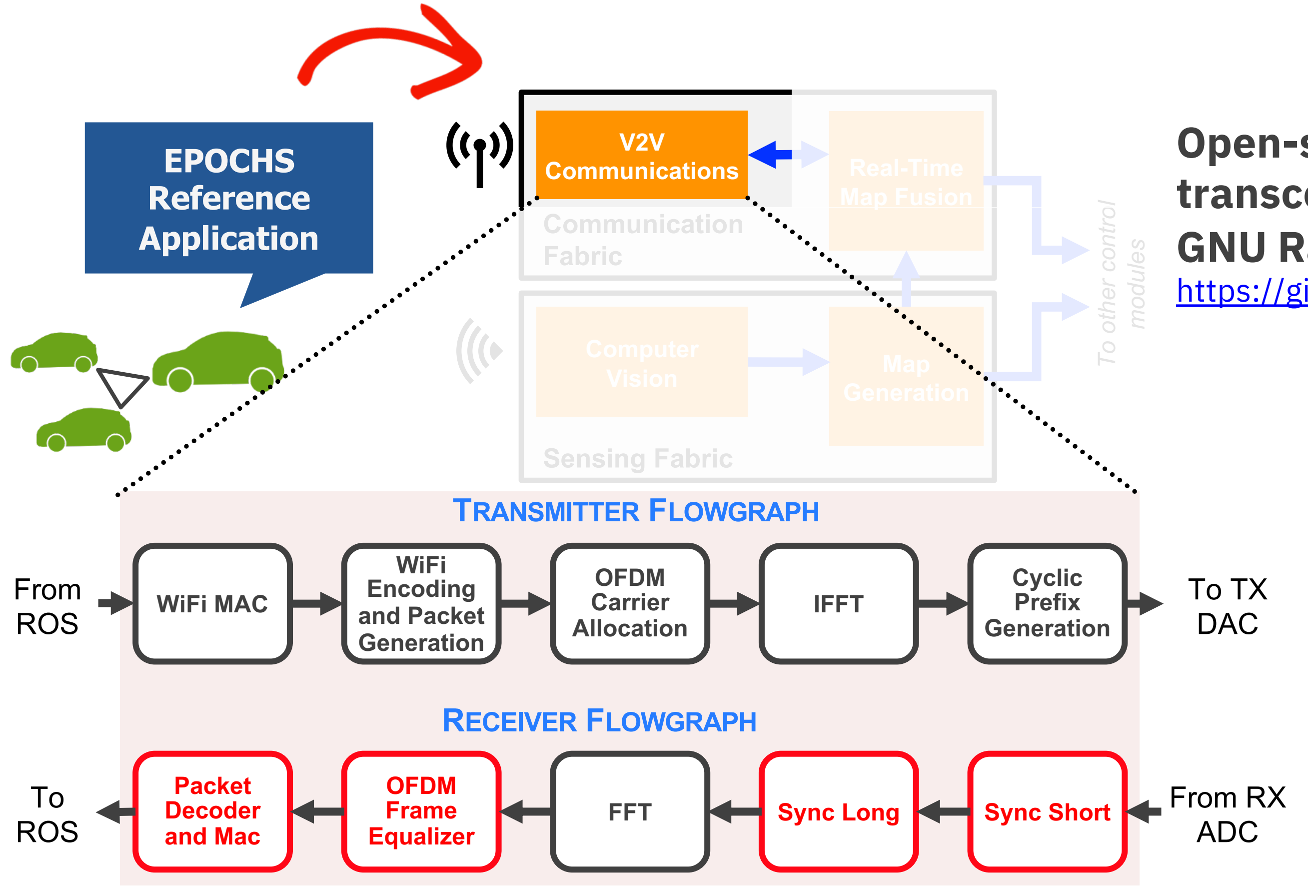
802.11p Transceiver within ERA



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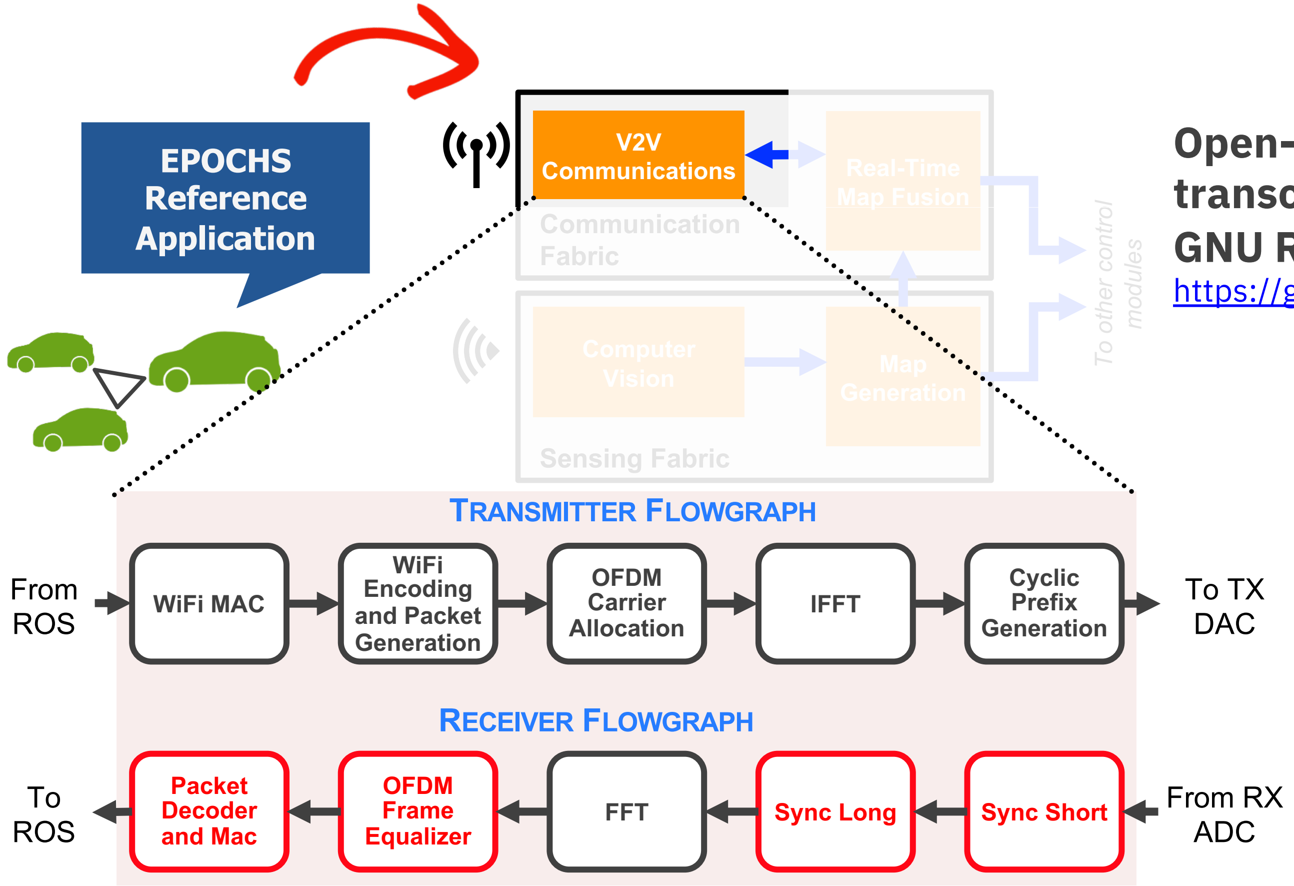

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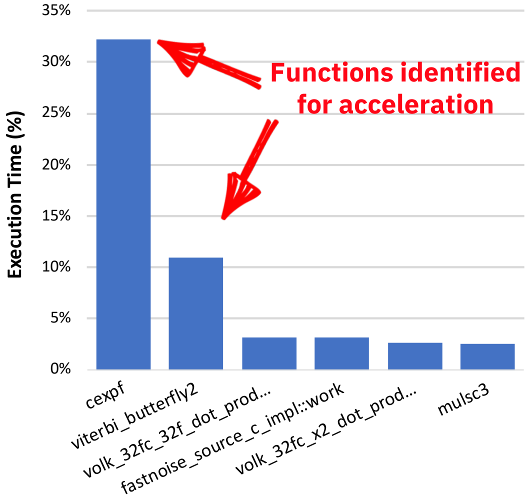
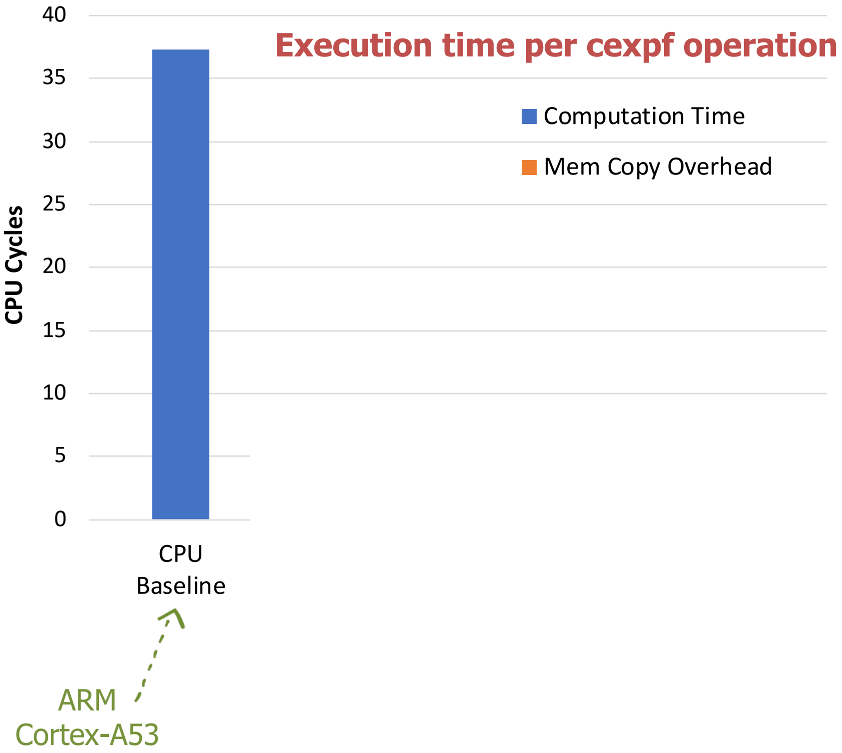


Acceleration Options (for *cexpf*): Preliminary Results



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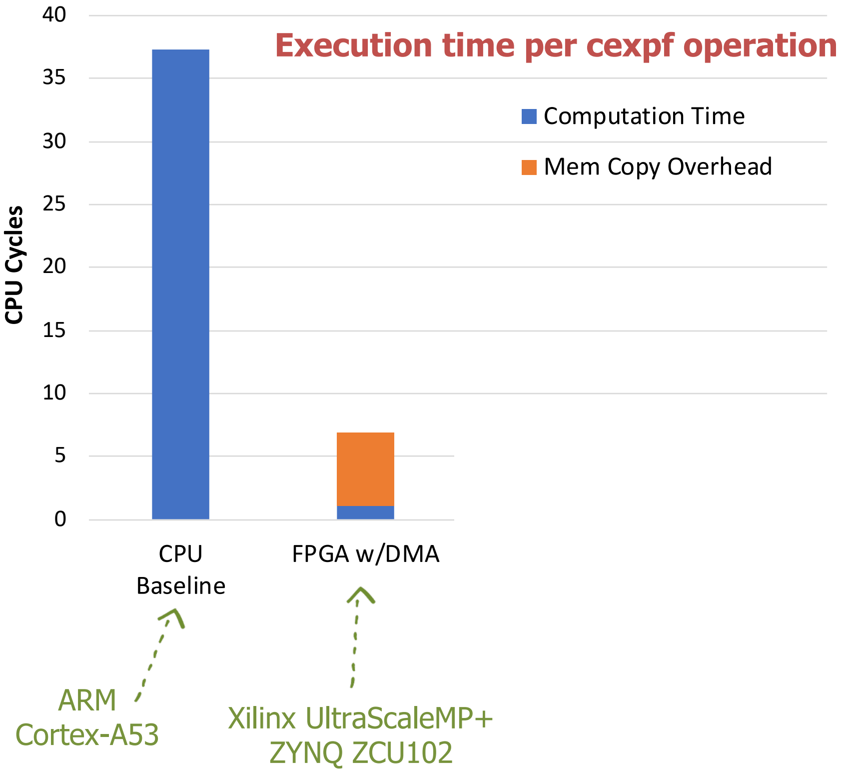
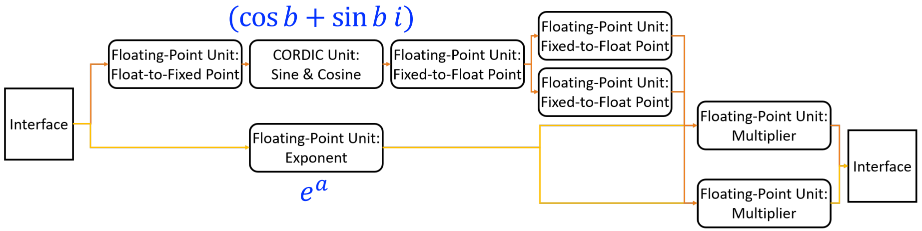


FPGA Implementation
(dual data-path pipeline)



$$e^{a+bi} = e^{a} * (\cos b + \sin b\ i)$$

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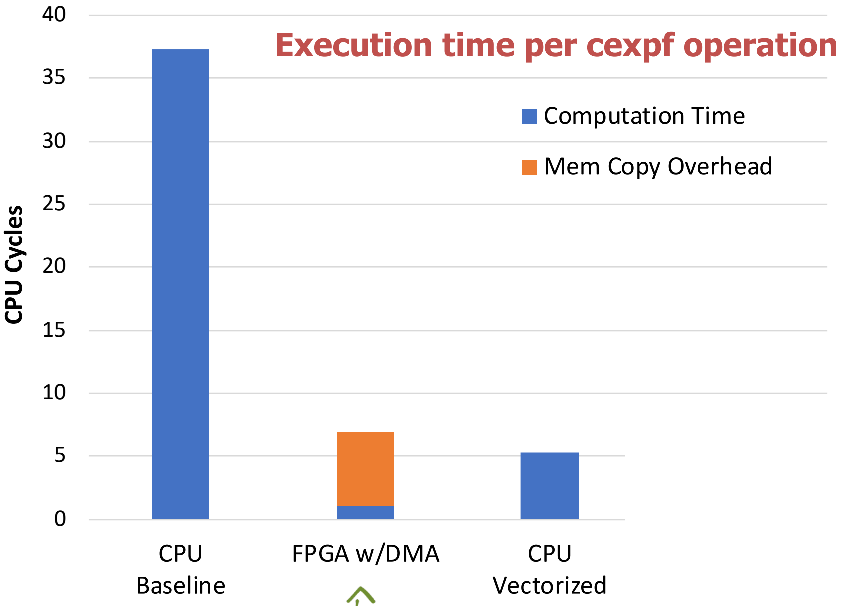

ARM Cortex-A53

Xilinx UltraScaleMP+ ZYNQ ZCU102

ARM's SIMD extension (NEON)

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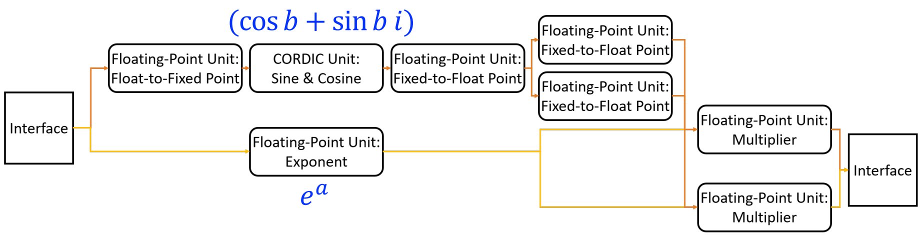

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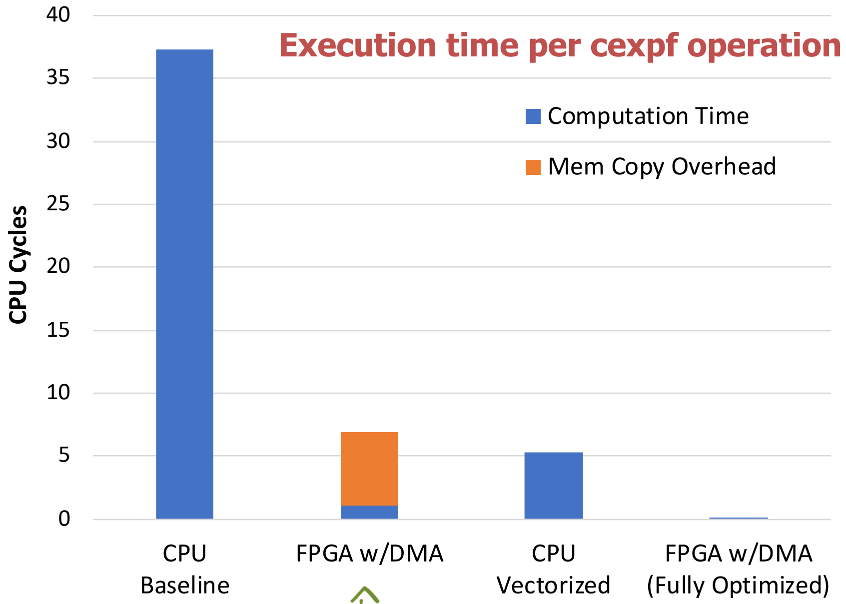

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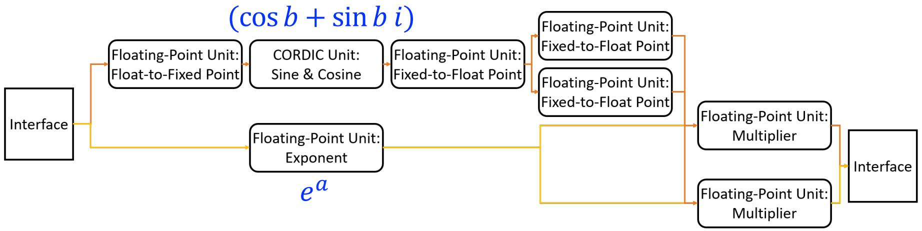
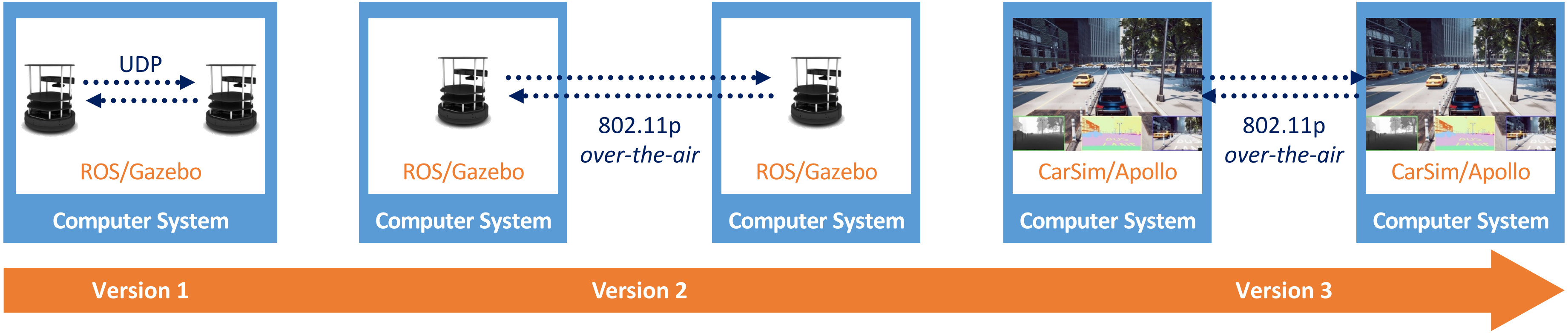


$$e^{a+bi} = e^a * (\cos b + \sin b\ i)$$

Fully-optimized implementation (idealized bound)

- 300 MHz (instead of 100 MHz)
- Four parallel computation engines
- Memory-copy elimination

ERA Roadmap


UDP
ROS/Gazebo
Computer System
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Computer System
802.11p
over-the-air
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Version 1
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Version 3

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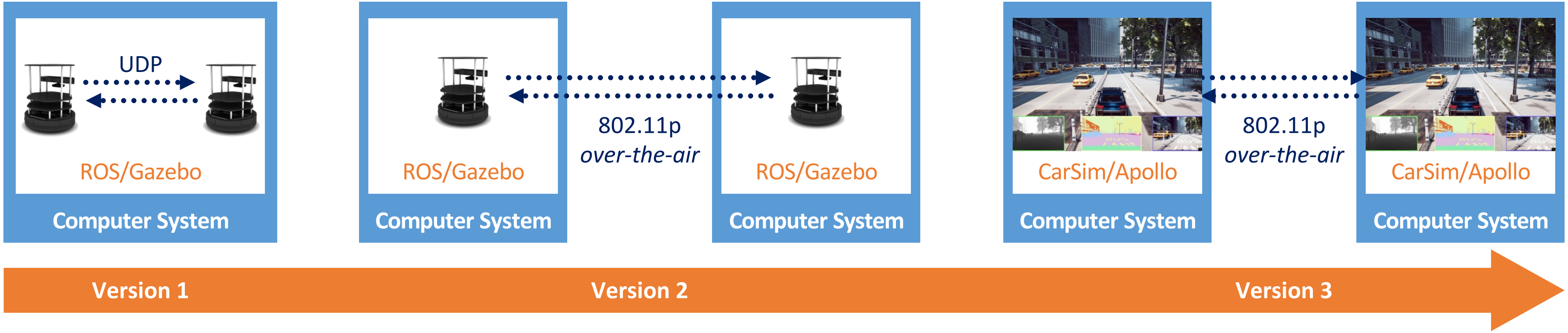

ERA is only intended to enable **cooperative automotive**, with support for DSRC, and 5G (future)

This makes ERA unique

LAYER 1
World Simulators
(sensor data source)

- CarSim
- Gazebo
- CARLA
- LGSV

LAYER 2
Automotive Platforms
(perception, plan and control)

- Apollo
- Autoware

LAYER 3
Cooperative Vehicles Platform
(swarming and V2X support)

ERA: Apollo API | Autoware API | Multi-Vehicle Cooperation Logic | 802.11p | 5G

ROS | GNU Radio

some raw sensor data is directly fed to ERA

Summary

performance

power efficiency

- The **domain-specific (heterogeneous) SoCs** *era* is here!

- DARPA's Domain-Specific System on Chip (DSSoC) Program
  - Our proposed application domain: **multi-vehicle cooperative perception**
  - Local sensing + V2V communications
  - The **DSRC transceiver plays a critical role** for real-time V2V communications

ROS and GNU Radio "worlds" coexisting

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ROS and GNU Radio "worlds" coexisting

Turn ERA into a benchmark for cooperative mobility that can be easily "plugged" into existing platforms

Do you want to collaborate?

- Contact: ajvega@us.ibm.com
- GitHub: https://github.com/IBM/era

Thank You!

Photo by Balthazar Korab
Source: http://www.shorpy.com/node/15488

ajvega@us.ibm.com

https://github.com/augustojv