genüen

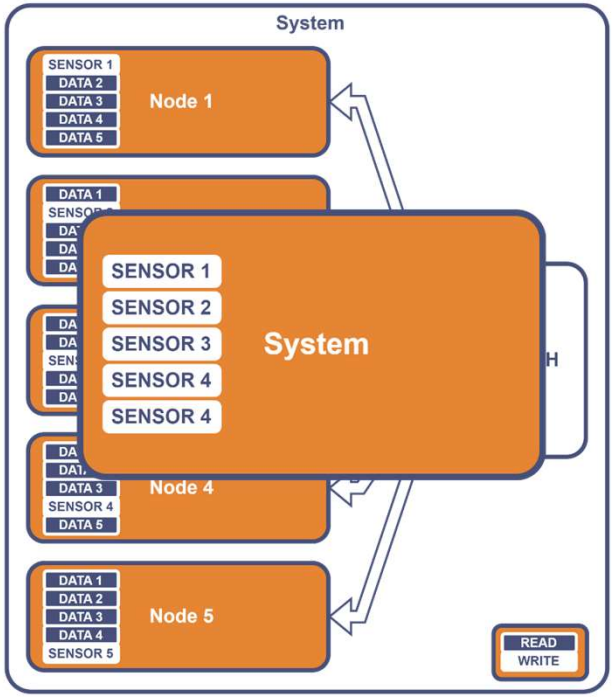
ideas taking flight

What is REPLICA?

IEEE MetroCon 2025

The Problem Space

Distributed Super Low-Latency Real-Time High-Speed – N to N communication



Distributed Low-Latency Real-Time High-Speed HIL: N to N communication

- Model Complexity is Distributed to run on Multiple HIL Nodes
- At Every RT Clock Cycle Each Node May Require Data that is Computed at Any Other Node for Its Own Computation
- This is Valid for All Nodes in the Cluster

Real-Time Networking Problem!

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“Big” Problems

CERN Uses NI LabVIEW Software and PXI Hardware to Control World’s Largest Particle Accelerator

Roberto Losito, CERN

"We selected the LabVIEW and PXI solution for the deployment platform due to the small size, ruggedness, and cost savings over the traditional VME and programmable logic controller-based model. "

- Roberto Losito, CERN

“a total of about 200 PXI systems”

“for approximately 600 stepper motors with **millisecond** synchronization over the **27 km** of the LHC”

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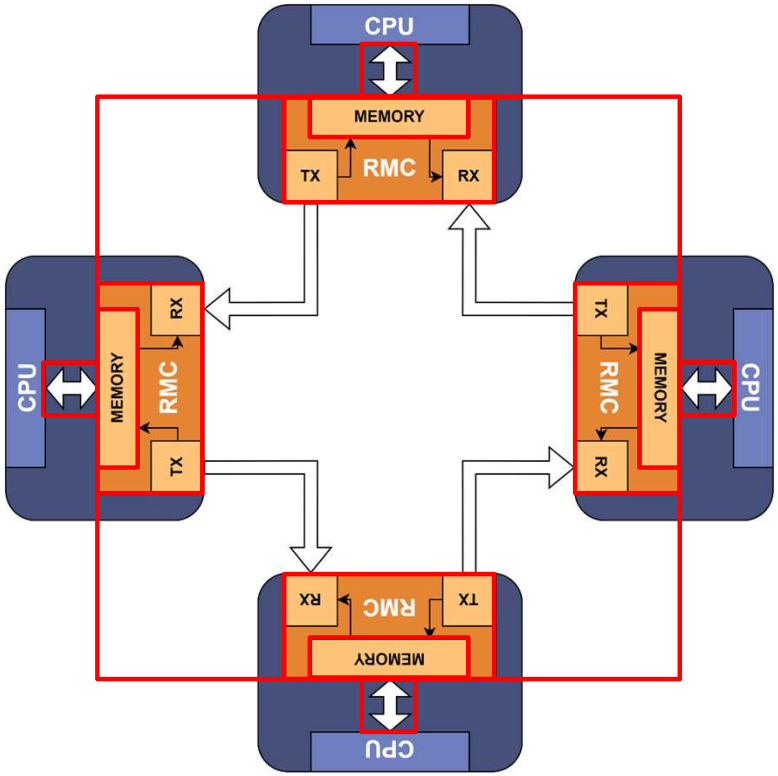
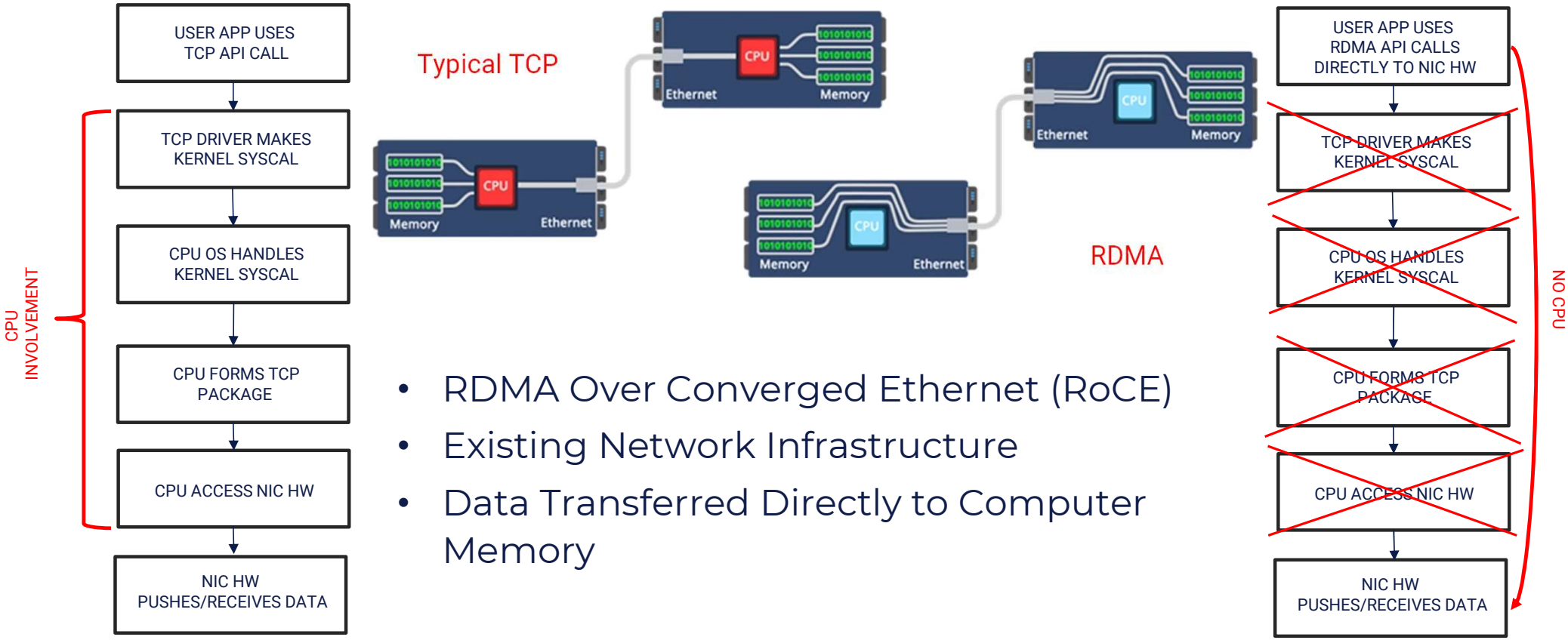
Reflective Memory Primer



- A copy of the entire memory is kept by each node
- A node modifies a local copy of the data with high writing speed
- No CPU Involvement on Traffic Control – Lower Latency

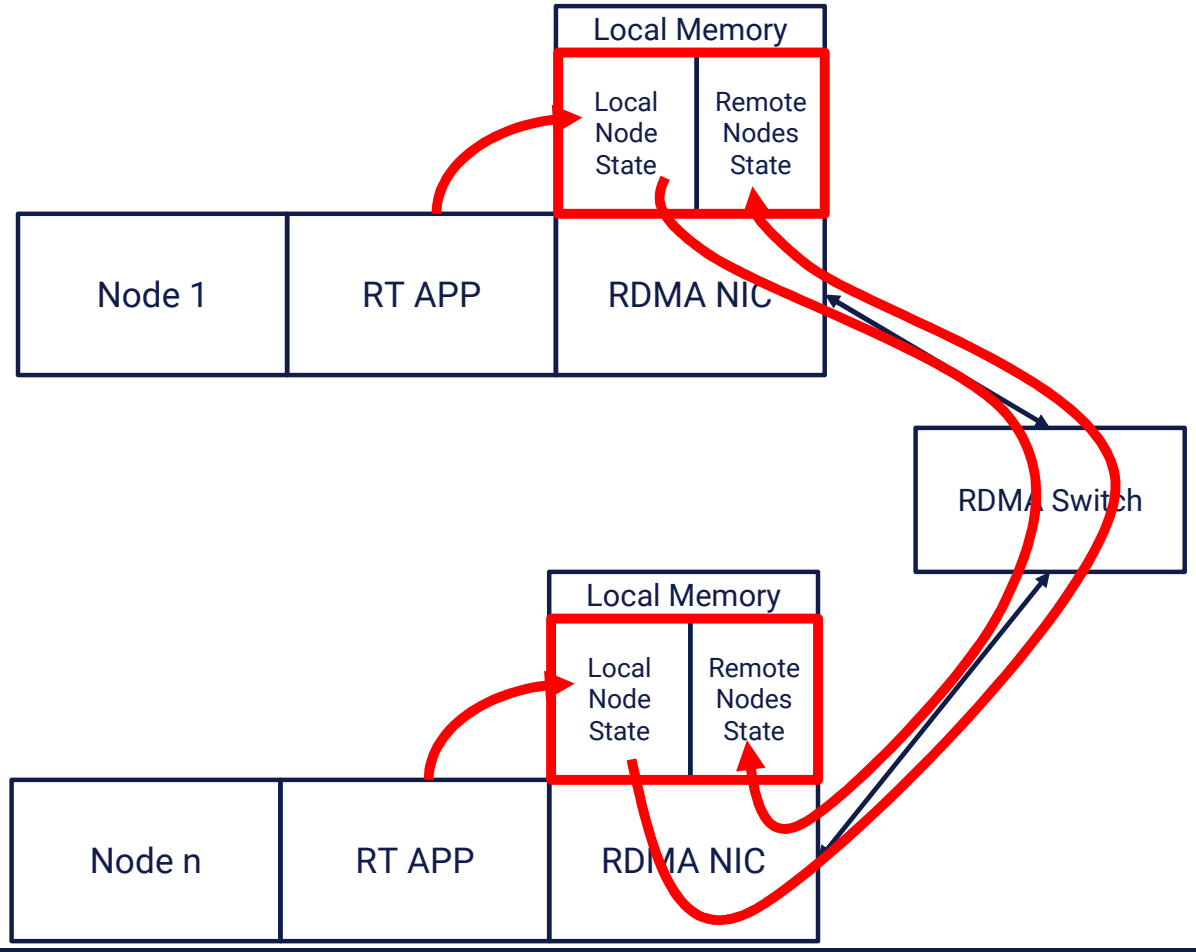
Requires on Board Memory Transfer – Can't Go Much Faster than 1-2kHz

RDMA Primer



- RDMA Over Converged Ethernet (RoCE)
- Existing Network Infrastructure
- Data Transferred Directly to Computer Memory

RDMA-Based Reflective Memory



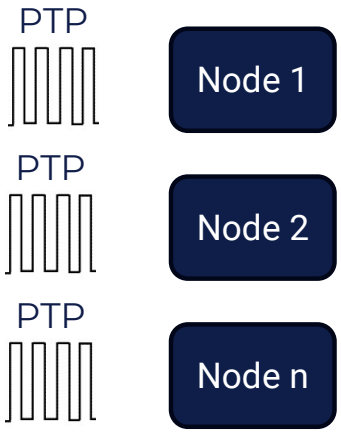
- RT Application updates Local Node State Memory Section
- Each Node updates the Remote Nodes States Memory Section
- All cluster variables available locally prior to RT scheduled tick

Much faster than RFMs!

REPLICA Use Cases

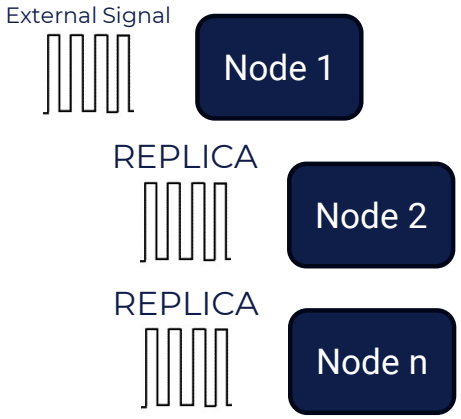
REPLICA Sync

- PTP Synchronization of All Nodes
- All Nodes Running at Same Rate
- Loop Rates: 20usec and up



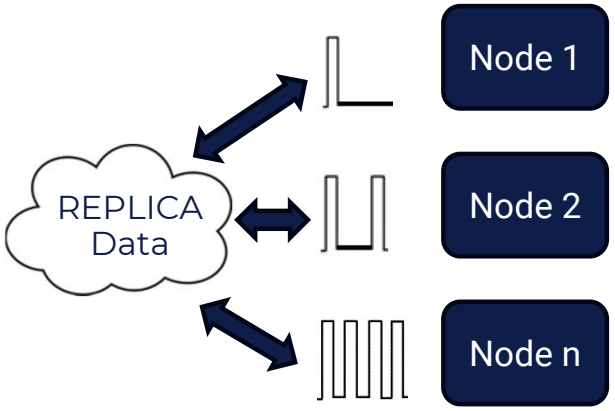
REPLICA Interrupt

- REPLICA Generates Interrupts
- All Nodes Sync to Interrupts
- Loop rates: 100usec and up



REPLICA Async

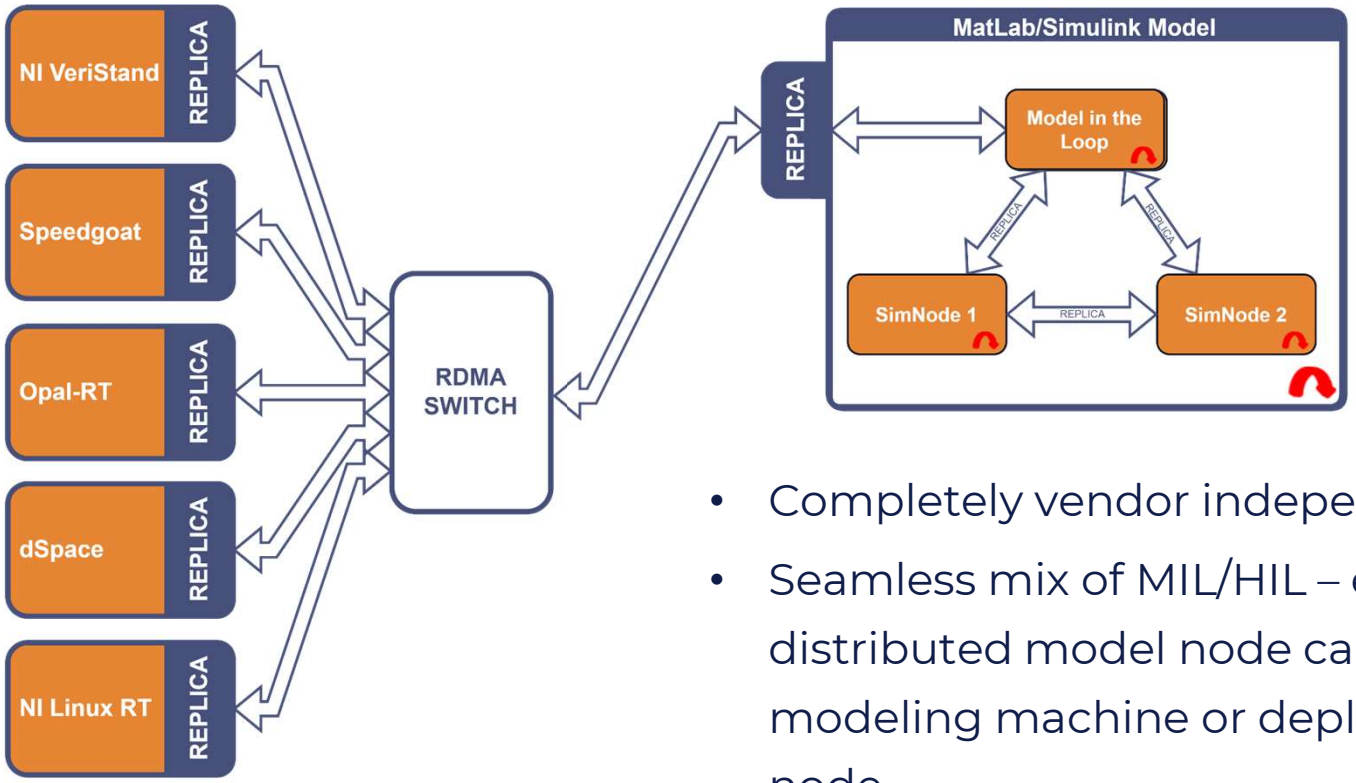
- REPLICA Runs Asynchronously
- Each Node Can Run At Any Rate
- Loop rates: 5usec and up



Ubiquitous Modeling

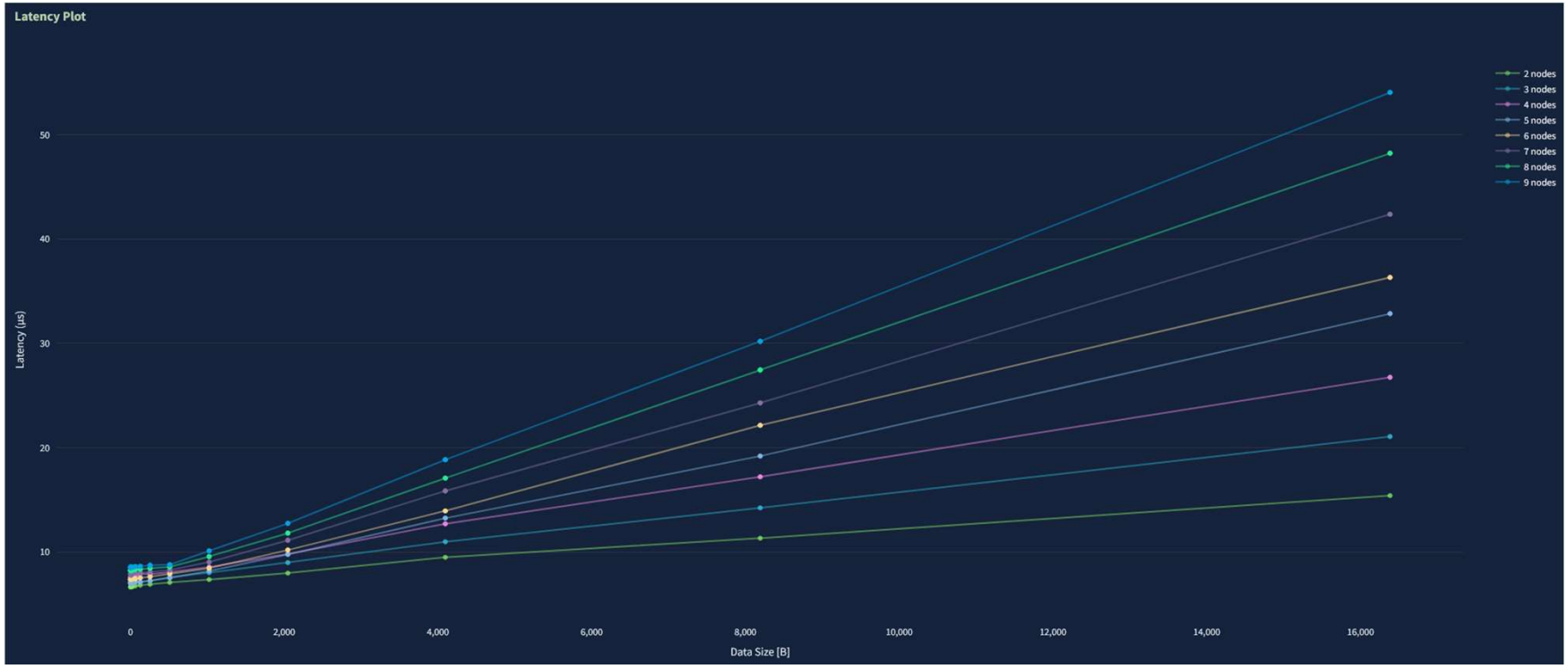
Distributed HIL System

Integrated Modeling System

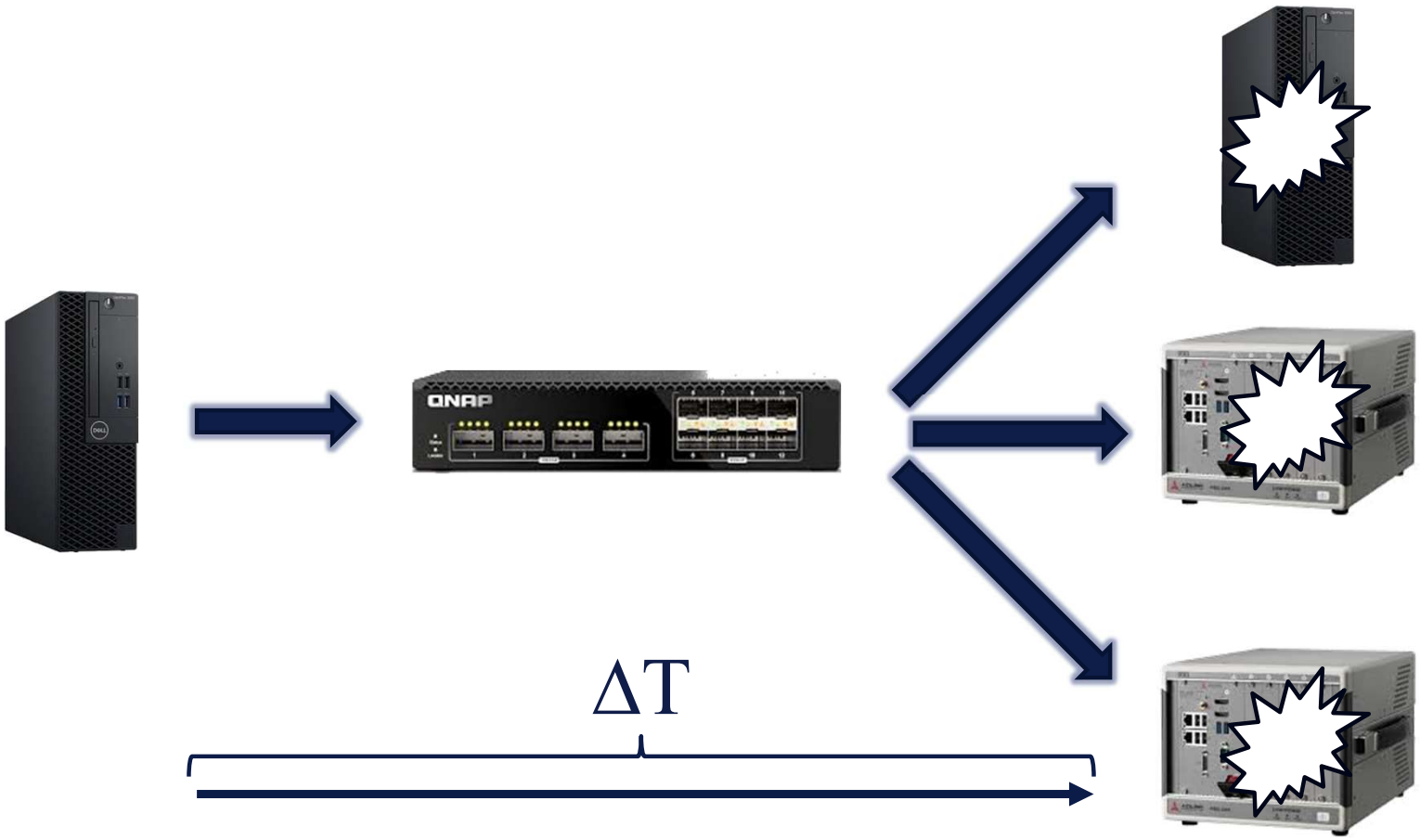


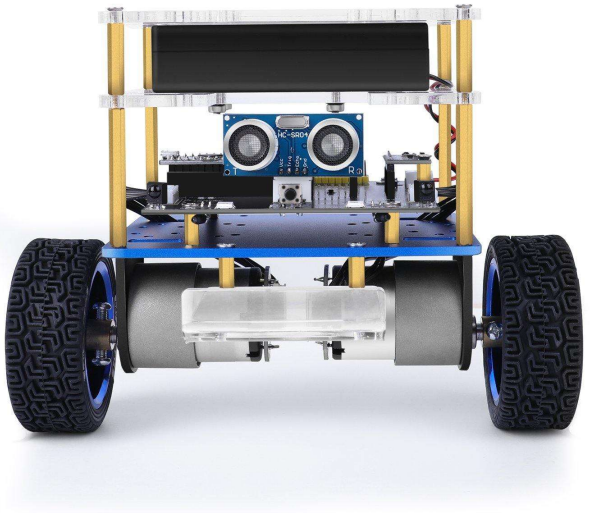
- Completely vendor independent
- Seamless mix of MIL/HIL – each distributed model node can run on modeling machine or deployed node

REPLICA Performance



Performance Testing Method

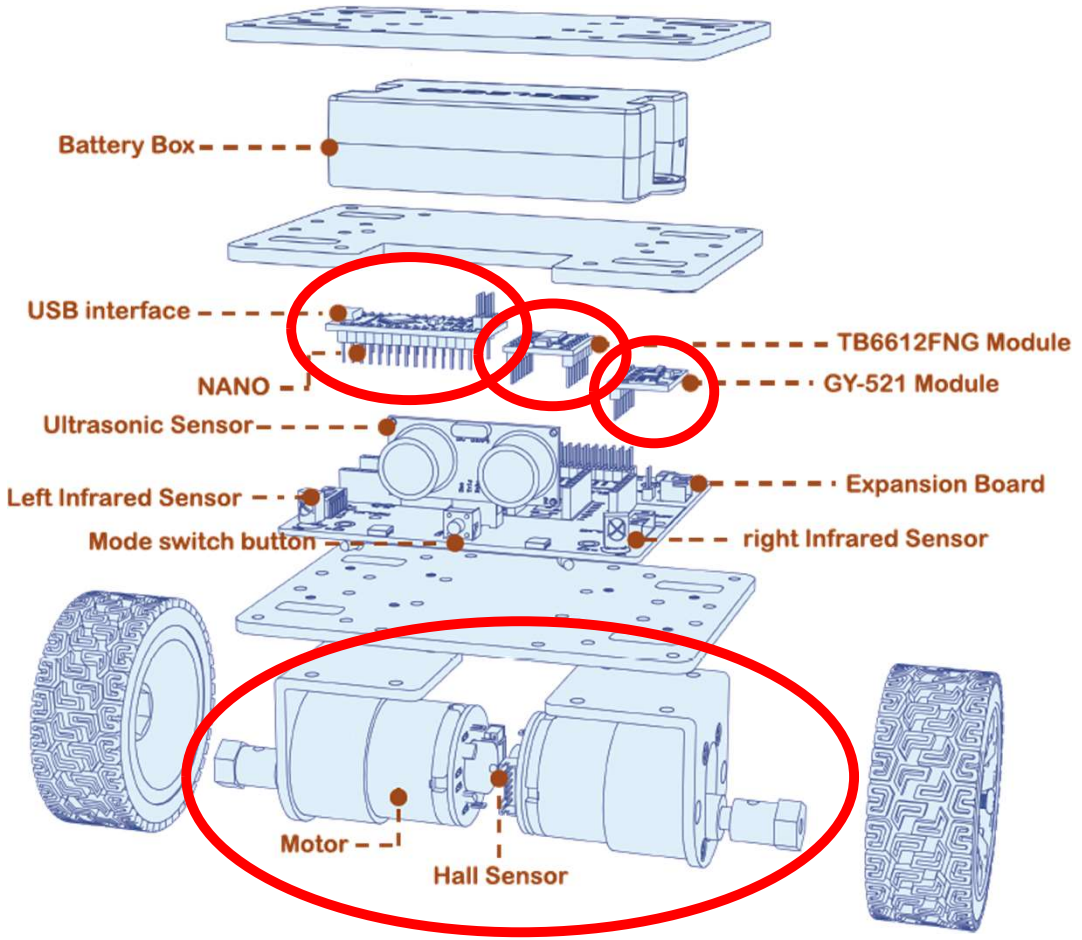




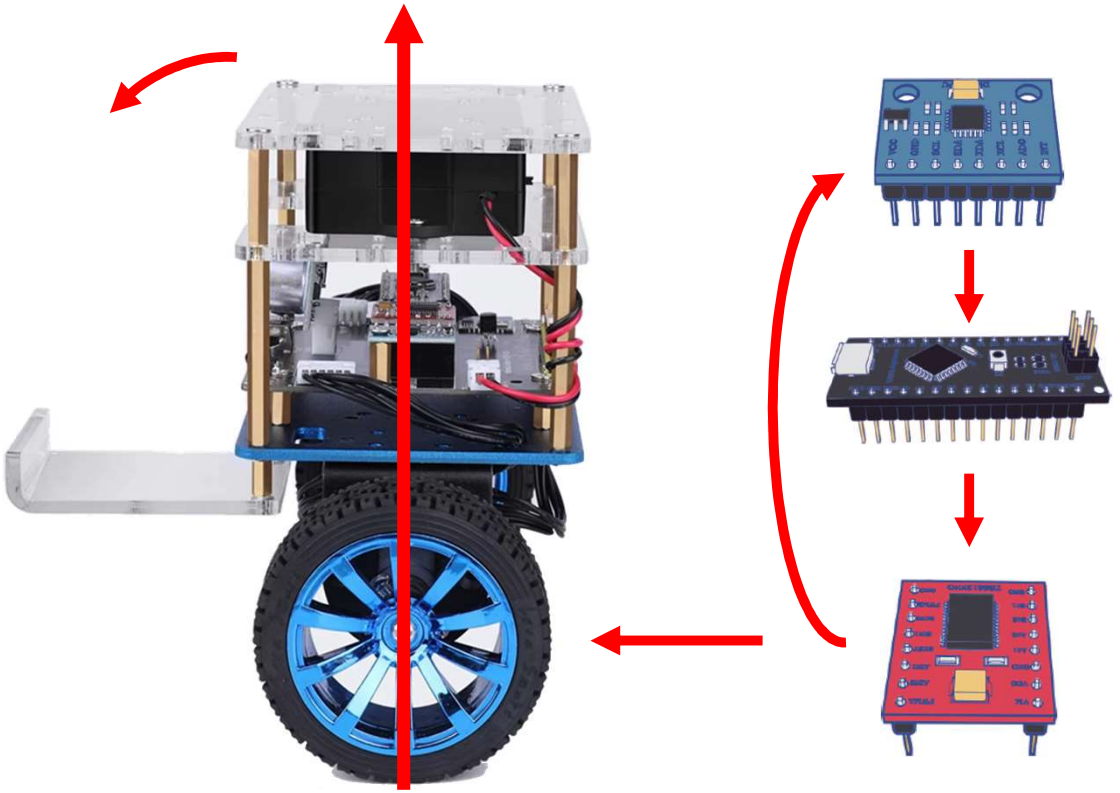
Come Say Hello to ***Gen-E***!

Anatomy of a Self-Balancing Robot

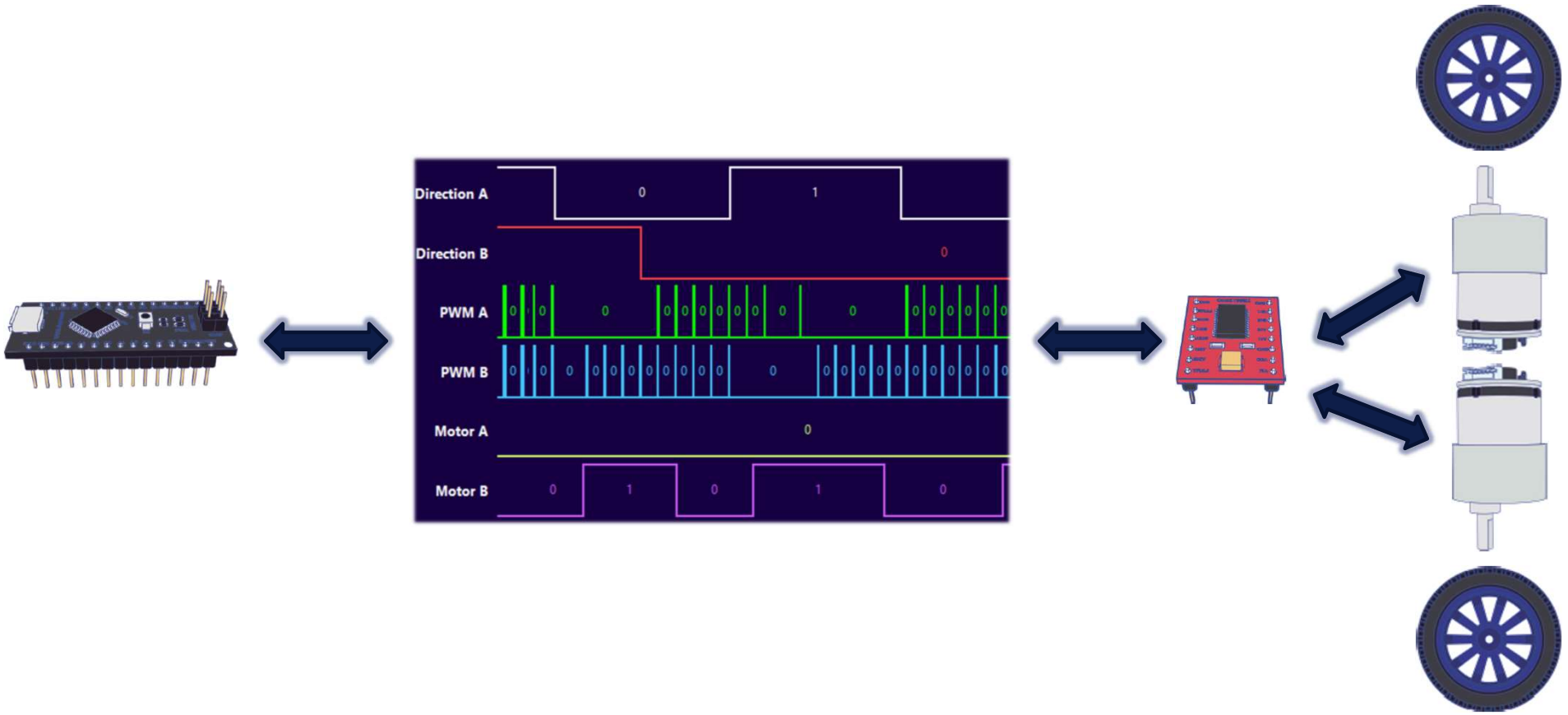
- Arduino NANO Microcontroller
- GY-521 Gyro Module
- TB6612FNG Motor Controller
- Motors w/Hall Effect Sensor



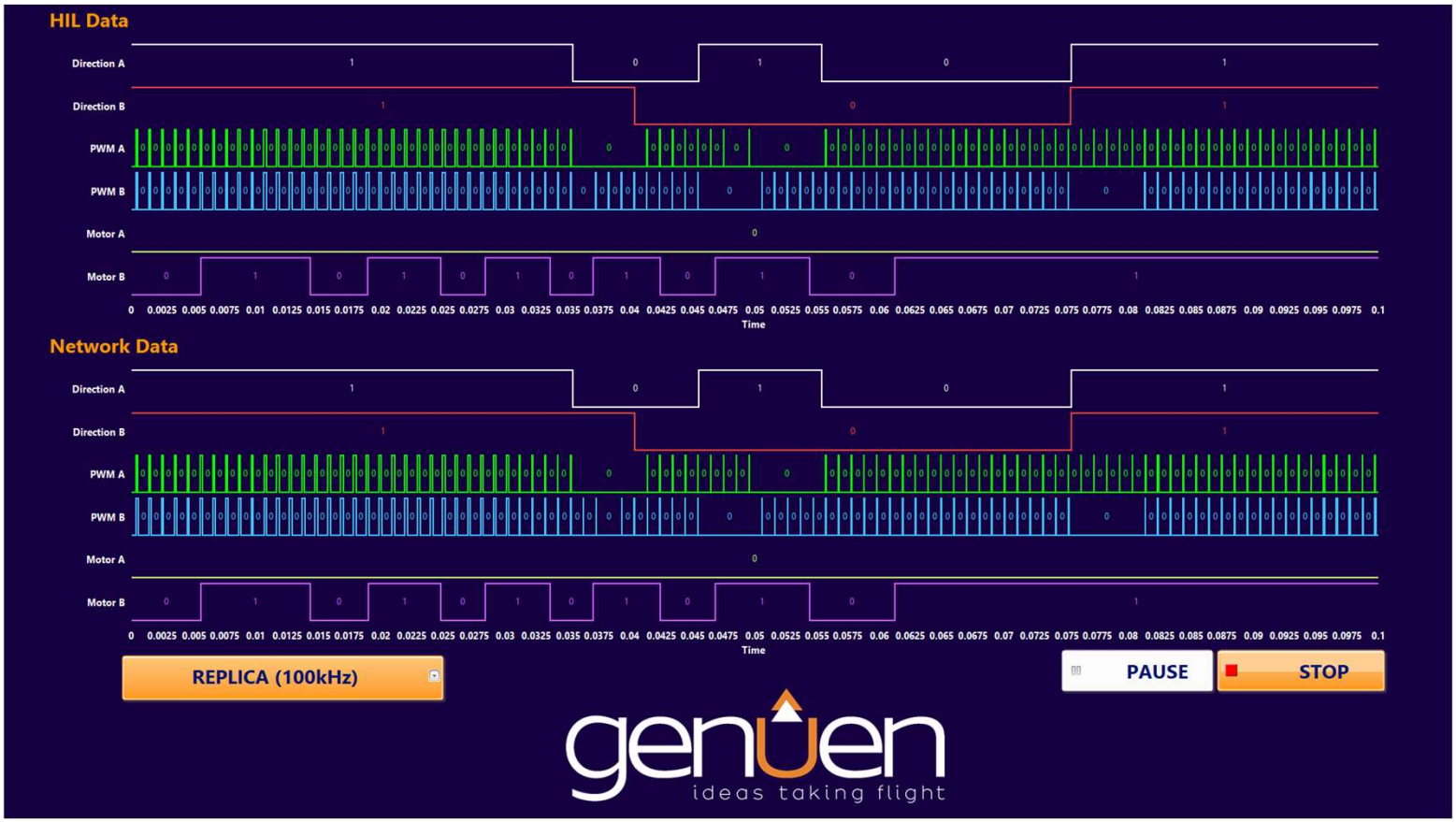
Algorithm of a Self-Balancing Robot



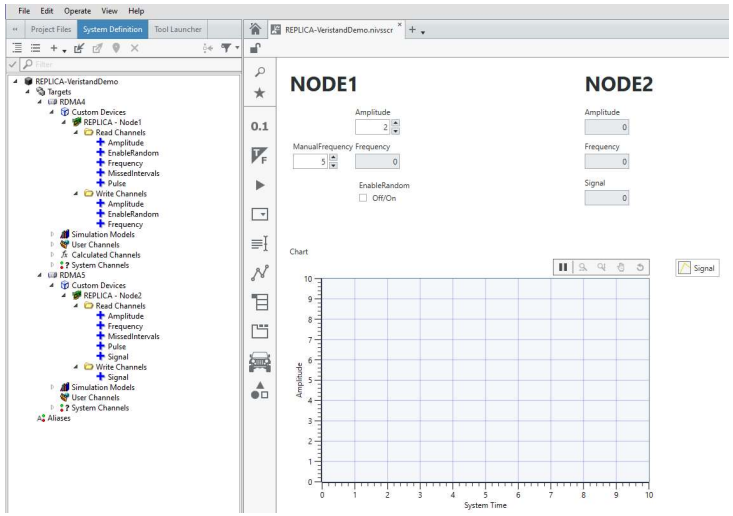
Communications View

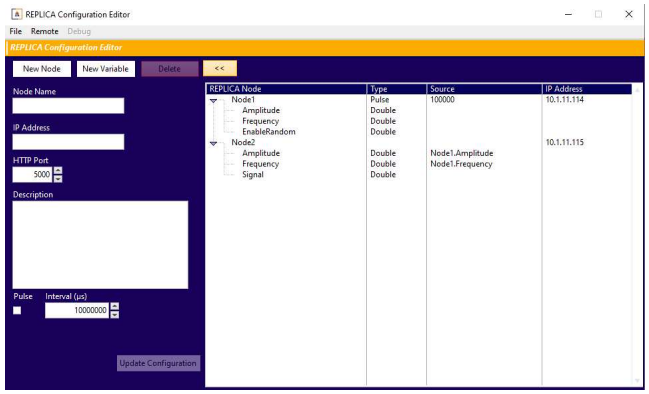


Demo Display

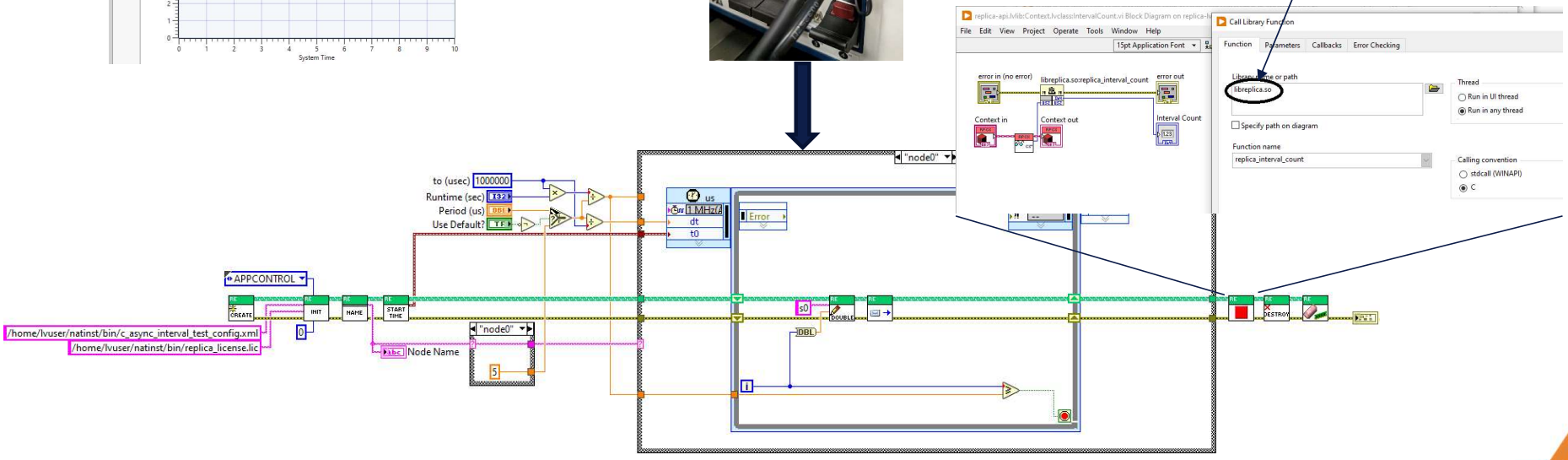


REPLICA Artifacts



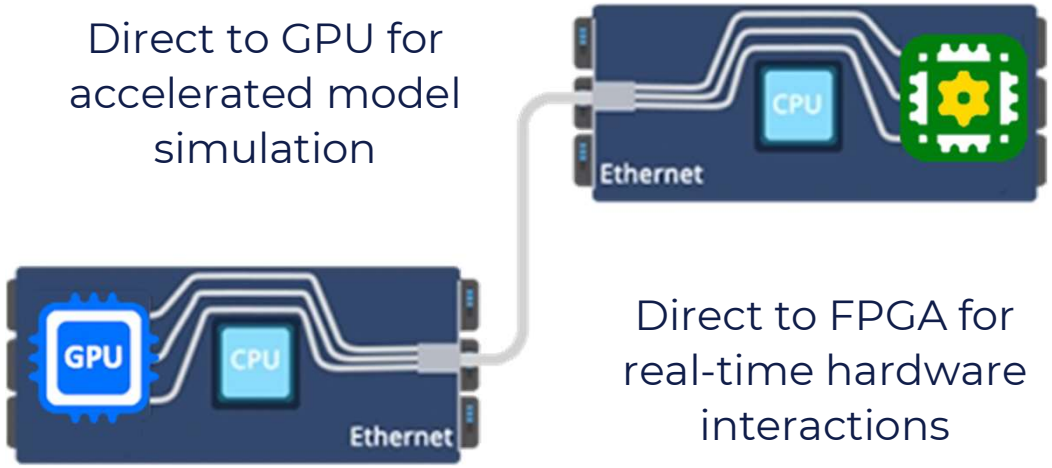


Linux RT Shared Object Library

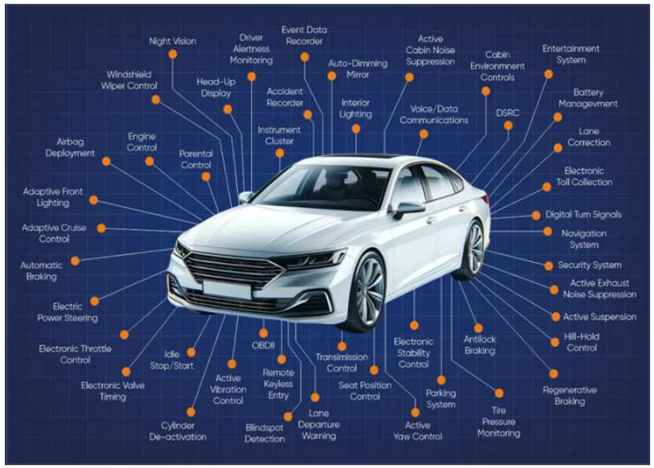


The Future of REPLICA

Direct to GPU for accelerated model simulation



Direct to FPGA for real-time hardware interactions



Embedded controllers to enable ultra-low latency communication within vehicles

Real-time Industry Open Problems

- Distributed Real-Time High-Speed Loops (>10kHz loop rates)
    - **REPLICA Async Allows 200kHz Loop Rates**
- High-speed Real-time Synchronization Requires Costly Hardware
    - **REPLICA Sync – Native PTP Synchronization**
    - **REPLICA Interrupt – Synchronization to External Clock in Single Node**
- Lack of Vendor Integration
    - **REPLICA Connects All Vendor Hardware Together**
- Lack of Integration from MIL through HIL
    - **Ubiquitous Modeling**

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