Using Reference System to evaluate features and performance in a standardized and repeatable way

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1. Filling a tooling gap  
2. Execution management configuration  
3. Saving time in automotive development
Filling a tooling gap

A Big Bang of executor modes led to the creation of the Reference System tool.
What led to creating Reference System

1. Apex.AI developed a custom executor. ROS 2 was adding a few executor modes.

2. Needed a fair and standard way to measure the executor’s performance, both against itself and other implementations.

3. 

4. Need a standardized, repeatable test fixture that can deliver three things:

   A. **Measure performance KPIs** like latency, jitter, CPU, and memory usage
   B. **Flexibility** to allow for different executors and various executor configurations while still keeping the overall system the same
   C. And **tooling** to automate running experiments and coordinating test campaigns
Creating the Reference System

Motivation

https://ros-realtime.github.io/reference-system/main/
Extending Reference System

1. After ROS World 2021, Apex.AI took the Reference System and brought it in house
2. Integrated it into a **nightly test pipeline** running on a Linux RT Raspberry Pi 4B with fixed CPU frequencies and isolated cores
3. By having this report available nightly, our developers could immediately see key performance improvements or regressions that took place, and address them as needed
4. We also added another Reference System implementation to test new features of the Apex.Grace Executor
Execution management configuration

Knobs to turn and KPIs to track
Execution management configuration

We will isolate specific variables so that we may evaluate their effect on the system.

The KPIs are valuable for application developers, architects, and system integrators to better reason about the desired deployment architecture.

A handful of configuration knobs are turned between experiment runs:

- Message size
- Message publishing frequency
- QoS configuration
- Processing time (budget) per node
- Operating mode of the executor

These metrics are measured and used to understand the system behavior:

- CPU utilization
- Memory utilization
- Latency of message delivery
- Dropped messages
- Jitter of cyclic events
Operating modes for the executor

Overview of the ROS 2 Executor modes that exist with the Iron distro.

- Multi-threaded
- Prioritized
  - Setting the thread priority of the *hot path* (the processing pipeline we care about) processes to the highest and set the rest of the threads to lower priorities
- Single-threaded
- Static single-threaded
  - Optimizes the runtime costs by scanning the structure of a node to determine subscriptions, timers, service servers, action servers, etc that the node has
  - It performs this scan only once when the node is added, while the other two executors regularly scan for such changes
Saving time in automotive development

Using the Reference System to detect regressions and improve stability within Apex.Grace
Using Reference System at Apex.AI

We use the Reference System as part of our CI system for different types of regression testing:

- **Topology**
  - Ensure specific and complex processing chains remain within desired latency bounds
  - Generate empirical evidence that shows the benefits of one solution over another, both for internal needs as well as in discussions with customers

- **Execution management**
  - Continuous comparisons to the ROS 2 executor
    - We care about the Rolling branch
    - But any distro can be tested
  - Perfect companion to the (non-functional) Performance Testing framework
    - [gitlab.com/ApexAI/performance_test](https://gitlab.com/ApexAI/performance_test)
Let's look at the numbers

- **Latency**
- **Jitter**
- **Memory and CPU usage**

Experiments
Latency — Humble

Latency variance of the different executor modes in ROS 2 Humble to Rolling with two RMW layers.
Latency variance of the different executor modes in ROS 2 Humble to Rolling with two RMW layers
Latency — Rolling

Latency variance of the different executor modes in ROS 2 Humble to Rolling with two RMW layers.
Execution jitter of the different executor modes in ROS 2 Humble to Rolling with two RMW layers
Execution jitter of the different executor modes in ROS 2 Humble to Rolling with two RMW layers
Execution jitter of the different executor modes in ROS 2 Humble to Rolling with two RMW layers
CPU — Humble

CPU consumption of the different executor modes for ROS 2 Humble to Rolling with two RMW layers

RMW: Cyclone DDS
- Benchmark
- Multi-threaded
- Prioritized
- Single-threaded
- Static single-threaded

RMW: Fast DDS
- Benchmark
- Multi-threaded
- Prioritized
- Single-threaded
- Static single-threaded
CPU — Iron

CPU consumption of the different executor modes for ROS 2 Humble to Rolling with two RMW layers
CPU — Rolling

CPU consumption of the different executor modes for ROS 2 Humble to Rolling with two RMW layers
In closing

Prepare your questions!
Use Reference System as part of your prototyping workflow
Thank you!

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