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#### Edge Autonomy at a Global Scale, 24/7

October 19th-20<sup>th</sup> October 26th-27th





Enable Autonomous Systems for the benefit of the Planet

Provide the RTI Connext software framework to allow development of Real-World applications, at Global Scale, with Safety, Security, and 24/7 Availability

Deliver outstanding support and services to ensure customer success



## Technical Trends: Connectivity and Al

- Systems Becoming More Complex, Global & Integrated
- Information flows between RT/embedded components and (edge & cloud) AI





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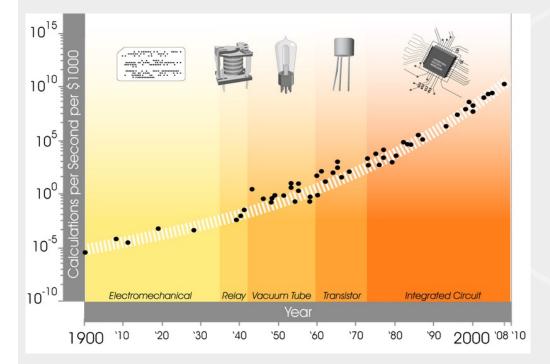
## Value creation moving towards Data and Software

#### Forces

- Edge Compute Power
- Anywhere Connectivity

#### Changing focus

- Value in the Software
- Value in the Data



Hardware	Software	Data
APPL, TSLA, NVDA, INTC, CSCO	AAPL, MSFT, AMZN, GOOG, TSLA, ADBE, CRM, ORCL	AMZN GOOG, FB, NFLX,
\$ 2.2 B	\$ 3.9 B	\$ <b>2.8</b> B

S&P 500 top 30 companies by market cap

#### Dramatic drop in cost and accessibility of Edge compute power



= 40000

~ 16 ARM cores

~ 11 Tera FLOPS

~ 70 cm^3

~ 5 Watt

~ US \$1K



Iphone 12 – Standard 2020 phone

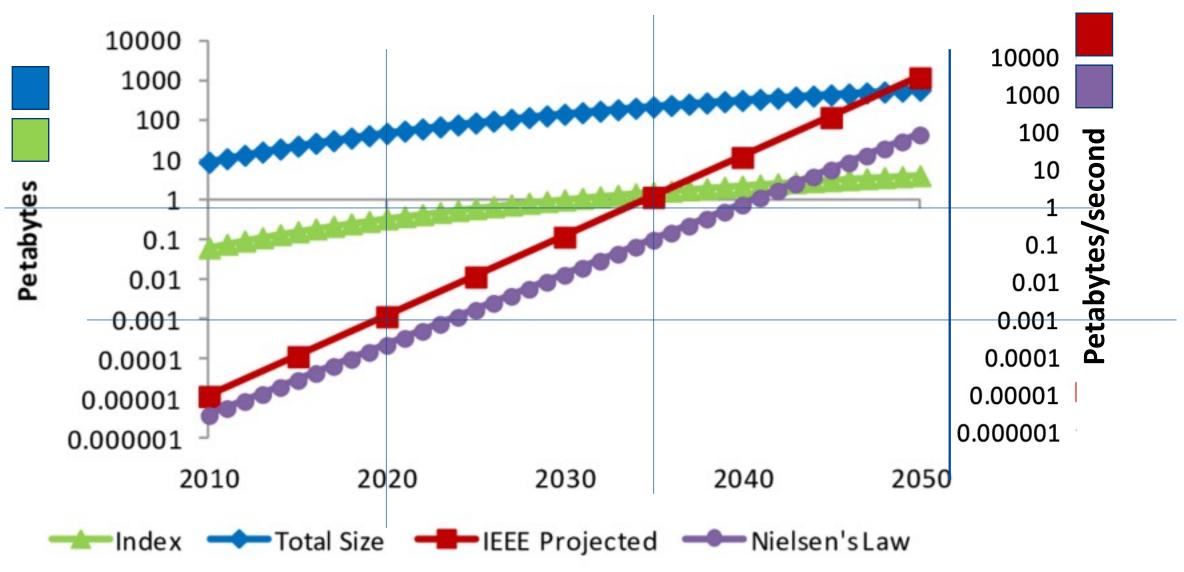
Fugaku – Worlds Fastest computer (6/2020)

- ~ 160000 ARM A64FX processors, each 48 cores
- ~ 450,000 Tera FLOPS
- ~ 430 racks (550 m^3)
- ~ 30000 kW
- ~ US \$1.3B

#### 1,300,000 x cost, 6,000,000 x power, 7,500,000 size

rt

## Web Size & Network Bandwidth



<u>Ref: Trotman & Zhang - "Future Web Growth and its Consequences"</u>

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## Edge Autonomy

Data is not only collected but also processed at the edge; decisions made and actions taken also at the edge.

Achieves Availability, Safety and Real-Time response.

Better at handling global scalability, security, and privacy requirements.



# **Technical Challenges**

And how RTI can help



This is the greatest factor — the way in which the expedition is equipped — the way in which every difficulty is foreseen, and precautions taken for meeting or avoiding it.

— Roald Amundsen

Success awaits him who has everything in order luck, people call it. Failure is certain for him who has neglected to take the necessary precautions in time; this is called bad luck. — Roald Amundsen

## **Technical Challenges**

#### Complexity

 Teams of people, integrating many components, heterogeneous systems, continually evolving, expanding applications

#### • Real-World

 Operate in "real-time" as well as mix highly-reliable and durable flows

#### Global Connectivity & Scalability

- Expand geographies and networks (LAN, WAN, 5G;
   Embedded to Datacenter to Cloud; Low-Power to Server)
- Availability with safety and security
  - Operate 24/7 "as best as possible" despite partial system failures, (accidental or attempted) disruptions





# Complexity



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## Managing Complexity

- Complex systems are developed by teams and evolve over time
  - Integrating many components
  - Combining heterogeneous parts
  - Managing continuous evolution, new requirements
  - Reusing components from previous generations
- Key: Modularity & Data-Centric Architecture
  - Modularity -> MOSA principles
  - Loose coupling -> Data-Centricity, read/write "shared" state
  - Features: E.g. Automatic Discovery, Qos
  - Comprehensive Services



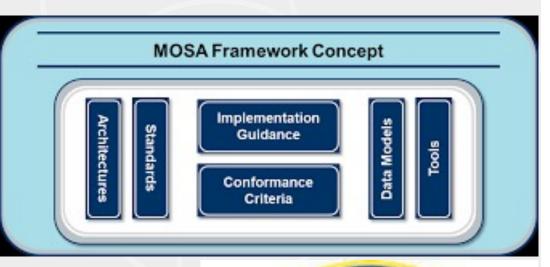


## **MOSA** Principles

Modular Open Systems Approach (MOSA)

- Employs Modular Design
- Has well defined Interfaces
- Designed for Change & Evolution
- Uses widely supported Industry Standards

Required by United States law. Title 10 U.S.C. 2446a.(b), Sec 805 for all major defense acquisition programs...





#### Industry standards using DDS/RTPS, Connext Databus



### Data-Centricity provides Modularity, Interfaces and **Evolvability**

Shared Global Datasnace (Domain)

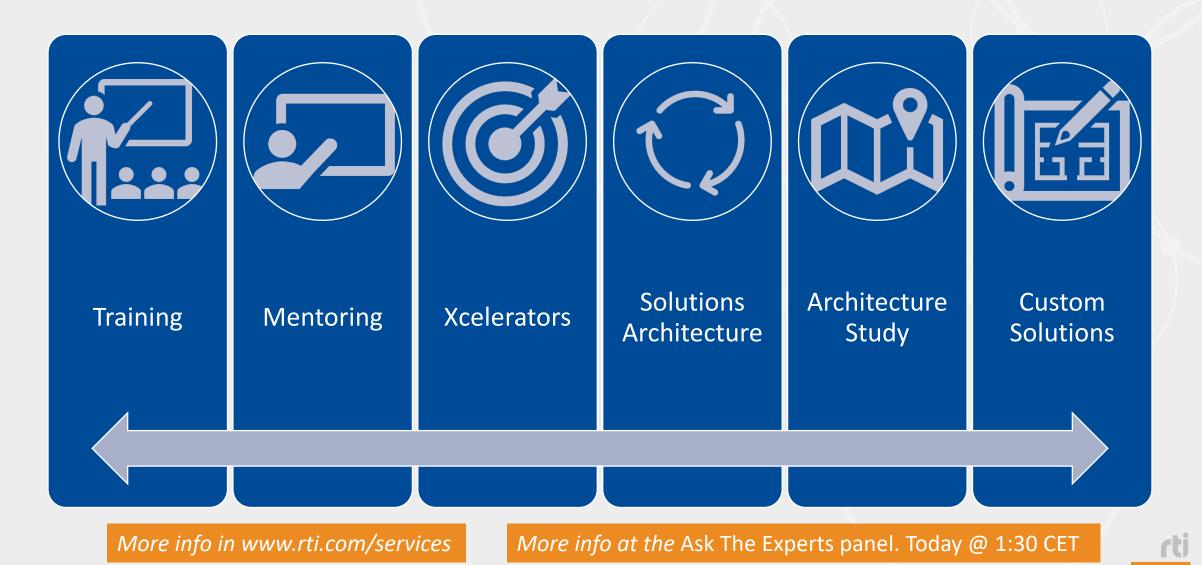
	Shared Glob	ai Dataspace	(Domain)		
	Source (Key)	Speed	Power	Position	
	CAR1	37.4	122.0	(37.41, -122.01)	
	CAR2	10.7	74.0	(36.95, -122.05)	
	CAR3	50.2	150.07	(37.42, -122.17)	
	QoS		QoS	Qc	s
	Topic A	Topic B	Req	/Reply Svc C	
		CONNE	XT DATABUS		

Not just message-passing => Observe and Update shared state Manage Application and Object Lifecycle



DDS

#### **Comprehensive Services to Accelerate Success**



#### Reducing complexity

#### Available with 6.0 - 6.1

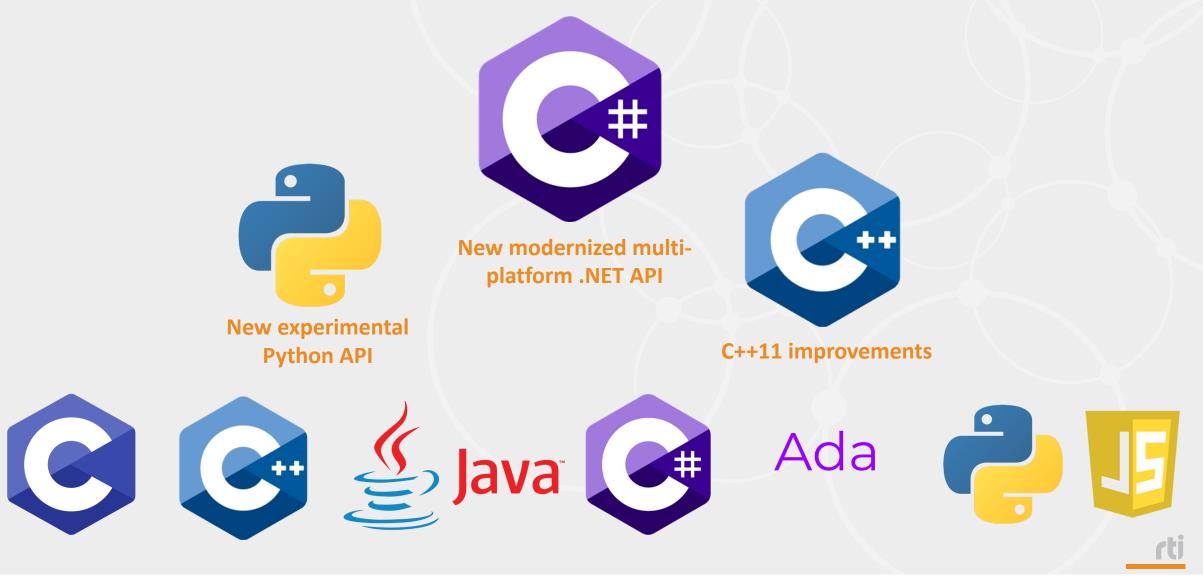
- New C# and Python APIs
- RPC (modern C++) [\*]
- ROS support (rmw\_connext)
- Connector API (Python, JavaScript)
- Web Socket API
- 60+ Platforms, Java 11
- Gateways: OPC UA, MQTT, Modbus [\*]
- Improved UX: GSG for C++ & .NET
- System Designer
- Builtin Network Capture
- New Admin Console Views
- Simulink Integration (DDS Block sets)

#### **Upcoming and Future**

- MBSE / SysML Integration
- Gateways: Kafka
- PlotJuggler data visualization
- Improved ROS support
- Improved type evolvability



## Programming Language options with Connext 6.x



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### New C# API



**C** unity



- Multi-Platform (Windows, Linux, Macos)
- Support for .NET 5 (Microsoft's new unified platform on .NET Core)
  - Flexibility to choose the OS and IDE for developing your application
  - Fully supported on Windows, Linux and macOS
  - Seamless integration with VS Code, VS 2019 and dotnet CLI
- Modern, Idiomatic
- Standards-based: OMG IDL to C# mapping and DDS-C#[\*]

```
using IDomainParticipant participant =
```

serviceEnvironment.ParticipantFactory.CreateParticipant(54);

```
ITopic<Shape> topic = participant.CreateTopic<Shape>("Example Shape");
IPublisher publisher = participant.CreatePublisher();
IDataWriter<Shape> writer = publisher.CreateDataWriter(topic);
```

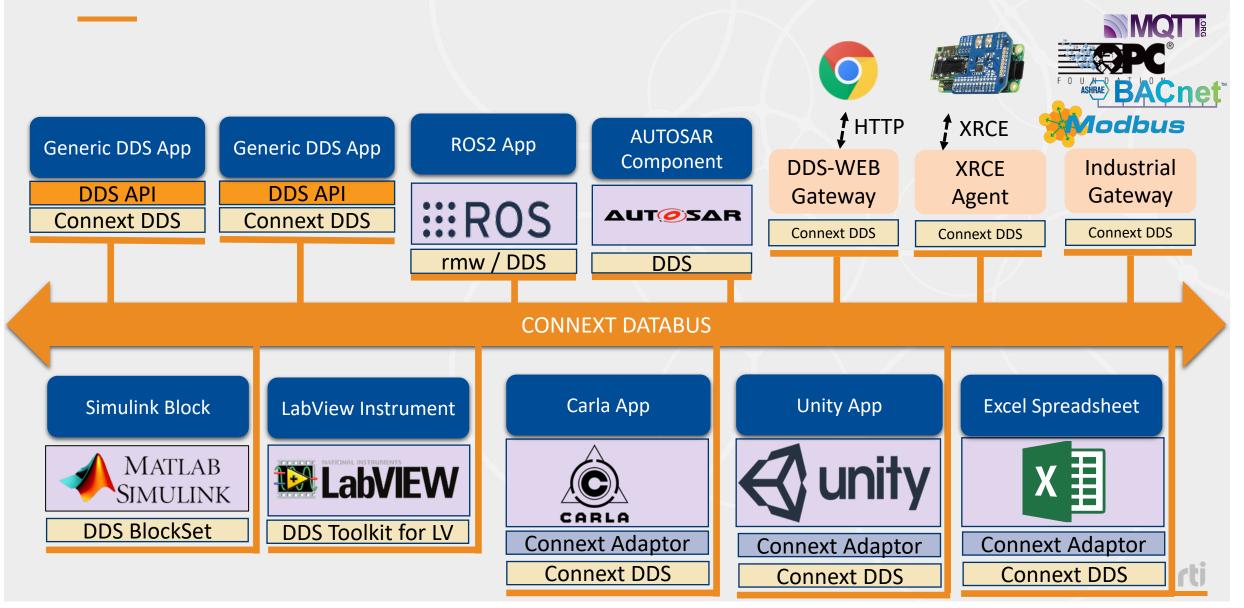
```
for (int i = 0; i < 5; i++) {
    writer.Write(new Shape());
    Thread.Sleep(1000);</pre>
```

## New (complete) Python API

- Experimental: Available on <u>RTI Community Github</u>
- Full Connext API: DynamicData, Builtin discovery types, Qos configurability, Security, ...
- Python-friendly design built on the Modern C++ API.
- Type mapping from IDL now an OMG Standard

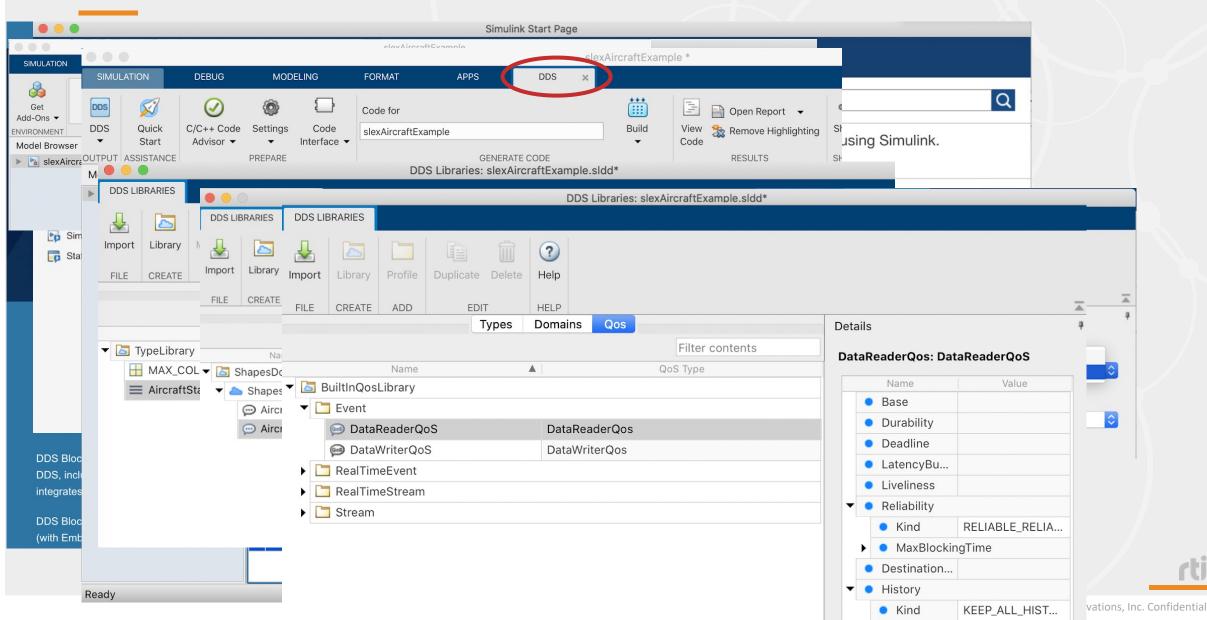
```
import rti.connextdds as dds
import time
participant = dds.DomainParticipant(0)
topic = dds.StringTopicType.Topic(participant, 'example')
writer = dds.StringTopicType.DataWriter(participant.implicit_publisher,
topic)
while True:
    writer.write("Hello World!")
    time.sleep(1)
```

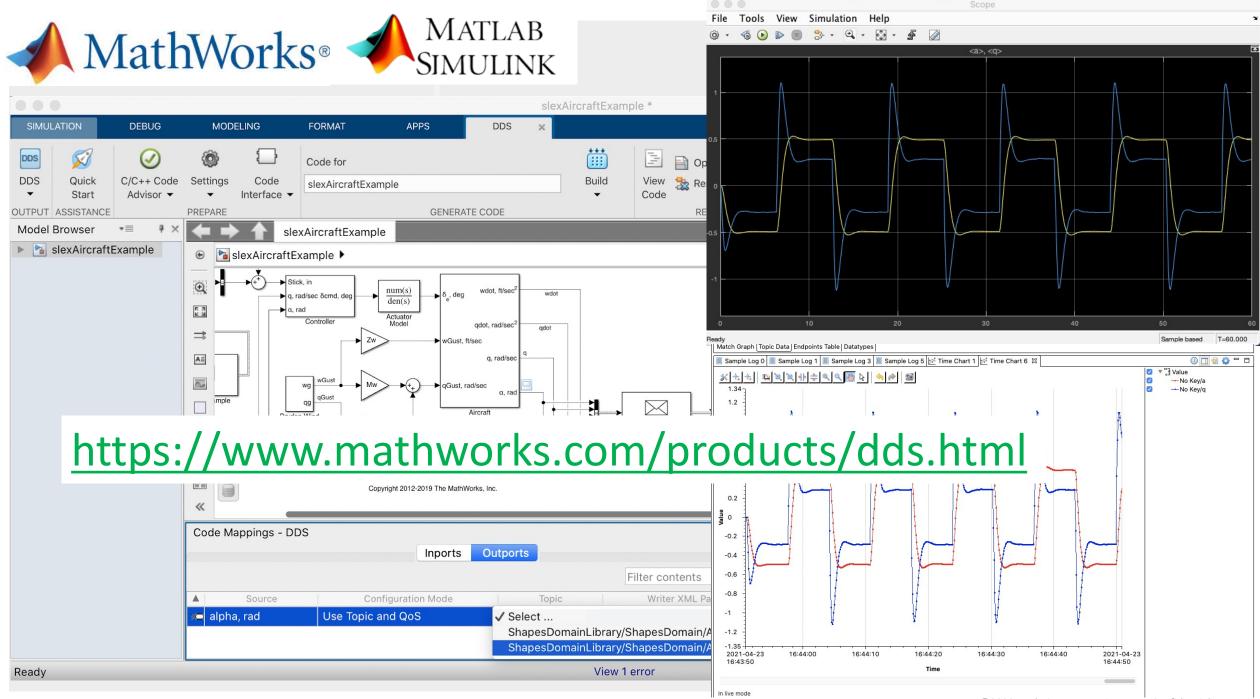
#### Control Complexity normalizing on a common DataBus



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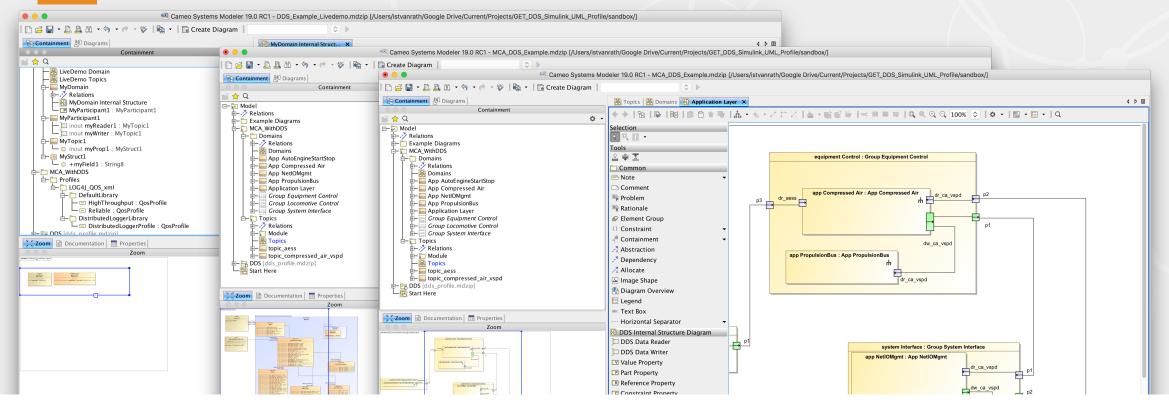
# Simulink (Connext) DDS Blocksets from A MathWorks®





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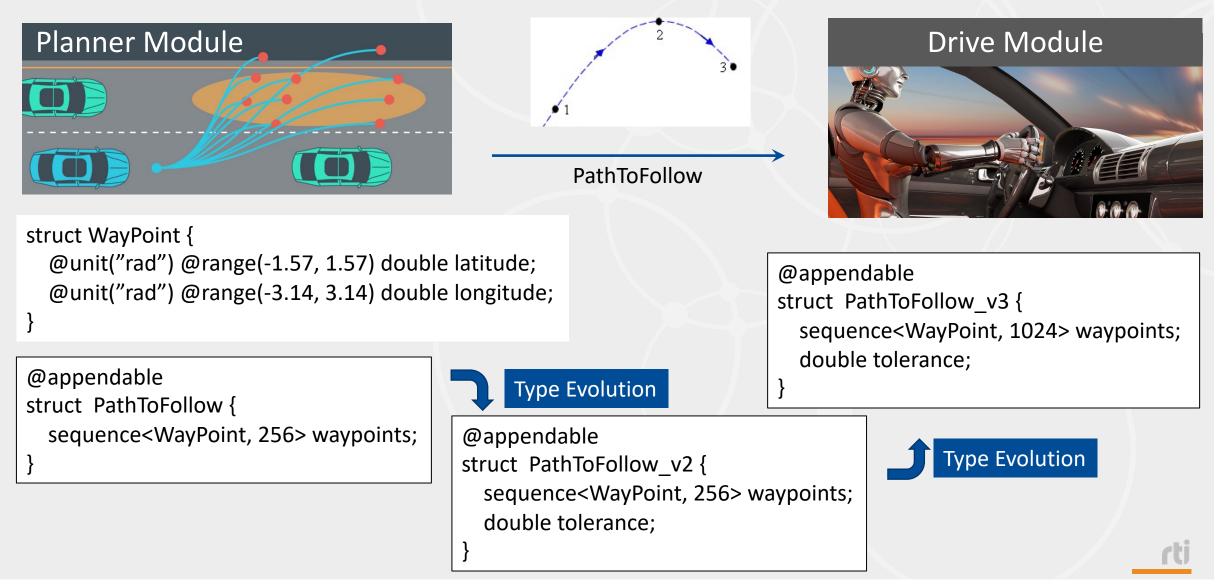
## Upcoming: MBSE/SysML from 3DS/Nomagic



#### Watch Webinar by Dassault Catia Magic and RTI -- November 4, 2021, 8:00 AM - 9:00 AM PT

Ready		Constraint Parameter  Port  Proxy Port  Full Port  Flow Port  Connector  Finding Connector  Information Flows	
No symbol at (336, 181 )		Information Flows	
	Part Property app NetlOMgmt (885, 594 )		🔺 2 W 🖏 🔅 164282

## Change & Evolution: Type system support





# Real-World



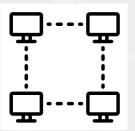
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#### **Real-World**

- Operate in "real-time" as required by the environment
  - Intelligence/Decision at the Edge
  - Fully distributed: No critical dependency on centralized servers/services
- Key Approach: Ground-up design for Real-Time:
  - Data exchanged at "wire-speed"
  - Not cloud-centric: Peer to Peer protocols and services
  - Control behavior, resources & prioritization using Quality of Service
  - Use of real-time capable APIs and protocols
    - Binary encoding (not JSON, XML, ...)
    - Non blocking, notification based, UDP vs TCP, ...







#### Improving Real-World Performance

#### Available with 6.0 - 6.1

- Zero Copy
- Decouple Durability & History
- Instance Resource Management [\*]
- Data Compression
- Security Optimizations
- Connext Nano (XRCE) [Experimental]

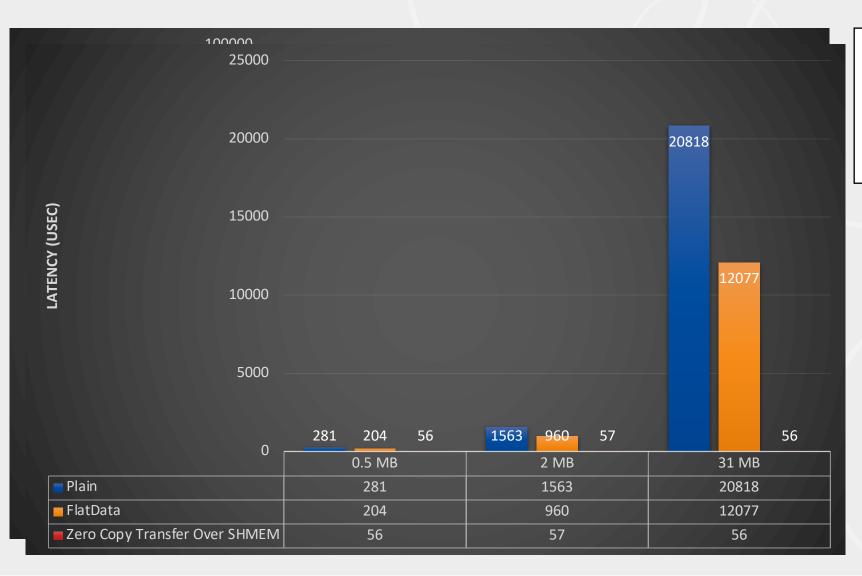
#### [\*] See technical Deep Dive at 11:00 CET

## **Upcoming and Future**

- Support of TSN
- Increased Concurrency
- Embedded crypto libraries



### Zero Copy Performance

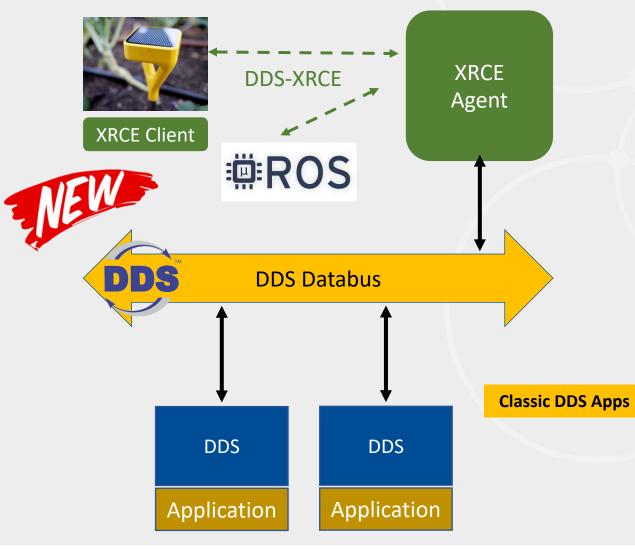


Platform Intel i7 6-core CPU 3.33GHz 12 GB RAM CentOS Linux

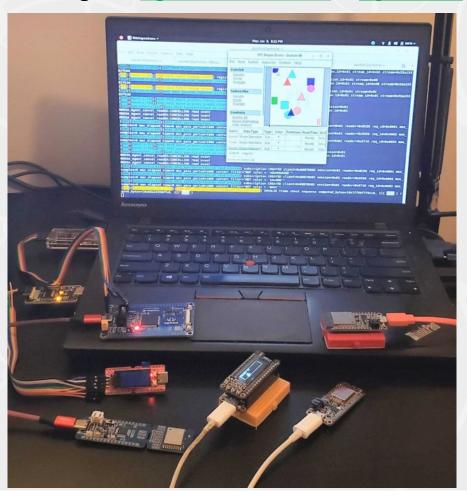
Latency is **constant** independent of the message size

## Connext Nano - µController Ready (experimental)

#### Less than 2KB RAM, 16KB FLASH!!



Download available from RTI community Github nano-client: <u>Client User Manual</u> <u>Client SDK</u> nano-agent. <u>Agent User Manual</u> <u>Agent SDK</u>

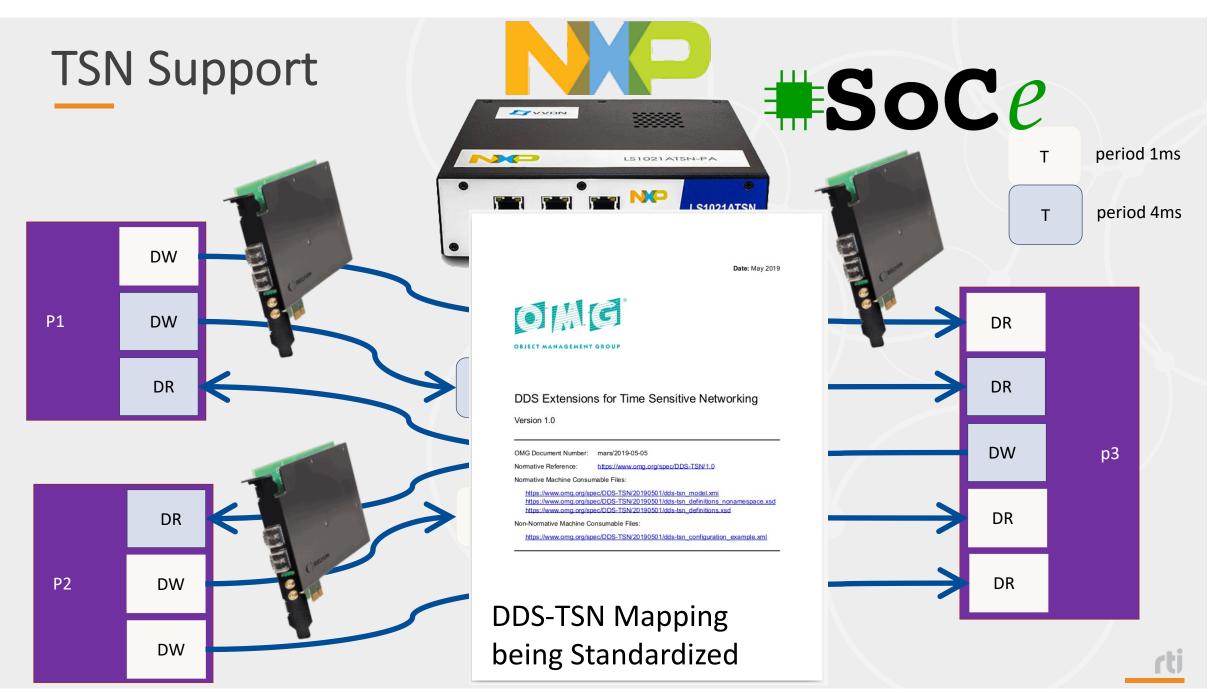


## Time-Sensitive Networking (TSN)

- TSN is a set of IEEE standards for deterministic highly reliable communication over Ethernet.
  - Data-link layer technology
  - Defined as extensions to IEEE 802.1Q Virtual LANs
- Provides aspects, such as
  - Synchronization
    - All nodes must have a common understanding of time
  - Traffic Scheduling
    - Endpoints must act according to a predefined schedule
    - Critical data cannot be dropped
  - Fault Tolerance
    - Through redundant communication streams





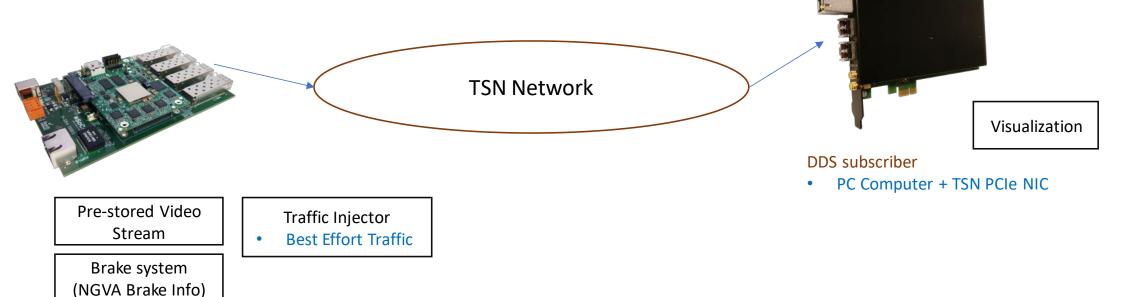


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#### NGVA & DDS & TSN Set-up: Evaluation Set-up

#### DDS publisher

- Scheduled Traffic: Emulated NGVA Brake Info (DDS Stream 1)
- Reserved Traffic: Pre-stored video Stream (DDS Stream 2)
- Best Effort Traffic: Remaining traffic (Traffic Injector)



Reference:

soce rti

Presentation: DDS over TSN to Support NATO Generic Vehicle Architecture (NGVA)

# **Global Connectivity & Scalability**





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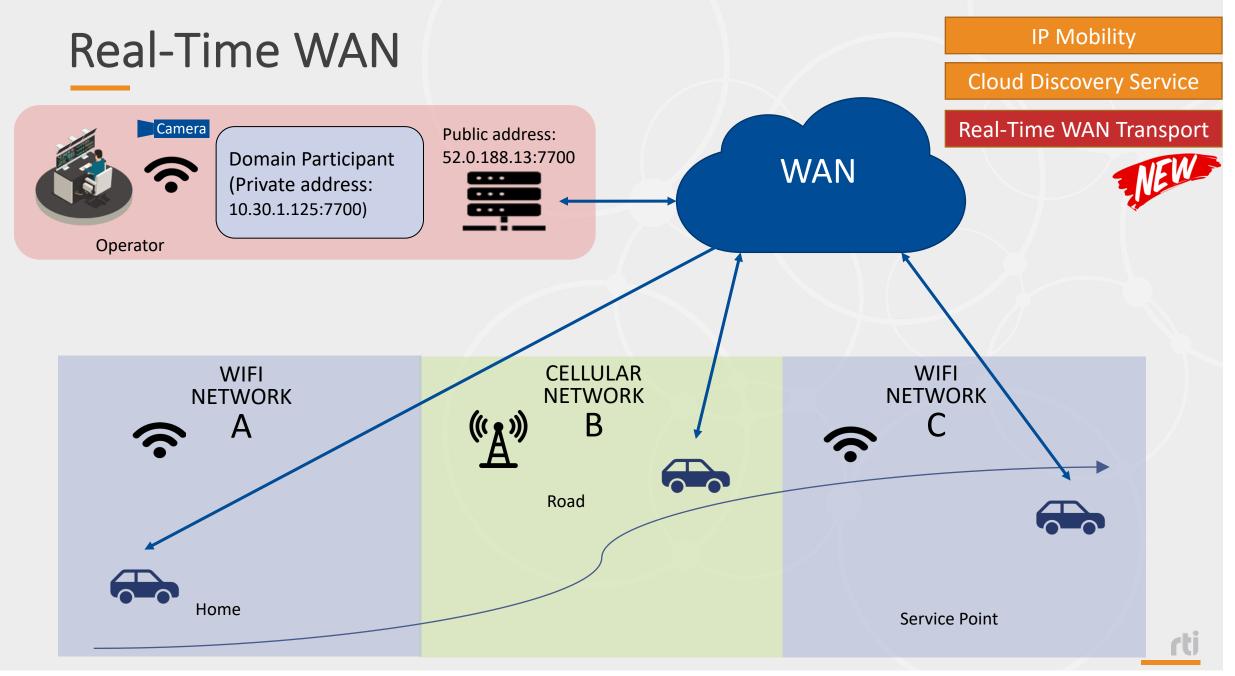
#### Improving Global Connectivity & Scalability

#### Available with 6.0 - 6.1

- Real-Time WAN Transport
- Cloud Discovery Service
- Faster (4X) Secure Discovery
- Instance Resource Management
- Type Compression
- Domain Tags

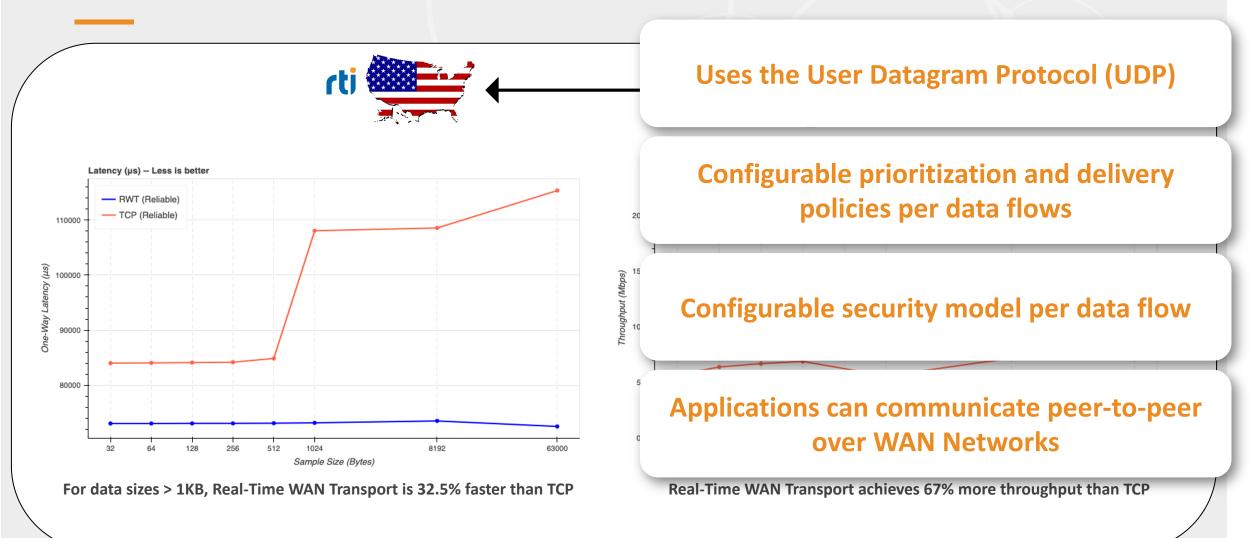
#### **Upcoming and Future**

- Optimized Discovery
- Type Service
- Bootstrapping Service
- Optimized Interface Selection
- Cloud Enablement
- Instance Lifecycle Filtering
- Instance discovery & matching



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### Performance of Connext Real-Time WAN vs TCP



## RTI Connext Anywhere WAN Connectivity Solution

Seamlessly and reliably share data across WANs, including cellular networks, without compromising security. RTI's single-vendor WAN connectivity solution is friendly to container based deployment and network load balancers.



See Technical Deep Dive today (Oct 20), 11am CET and Oct 27 11am PDT

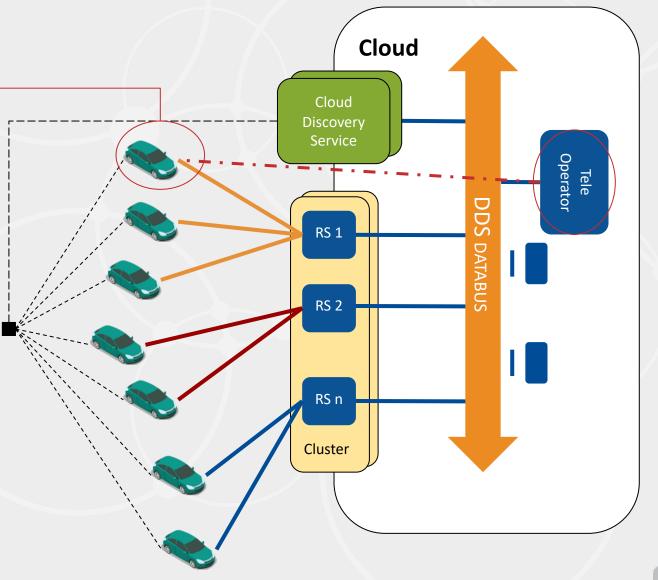
## **Cloud Enablement**

Participant Partitions enables P2P connection

Service Clusters + Load Balancing - enables 1000s of endpoint connections

#### **Participant Partitions:**

- Applied at matching time
- Can use regular expressions
- Changeable at run-time



## **Optimized Interface Selection**

Bonding

Bonding: Select which interface will send the packet

 Interface is selected based on measured link quality Destination Selection: Select which interface will receive packet

Destination Selection

 Transport priority of RTPS packet

# Availability with Safety & Security



## Availability

The bottom line, the availability and fault tolerance of the system. This system has to run 24/7. It can not fail. The system has to built that once it is turned on, and thousands of patients are connected, we never turn it off. It has to keep running, even if there are failures. It has to keep running if parts of it are disconnected.

-- Matt Grubis,

Chief Engineer, GE Health Care

References: [1] Whitepaper: DDS in Patient Monitoring [2] Webinar: Connected Healthcare



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## Low probability events?

- It only happens 1 in every 10,000,000 times....
  - Hit by lighting in 1 year odds: 1/1.2M
  - Winning PowerBall odds: 1/275M

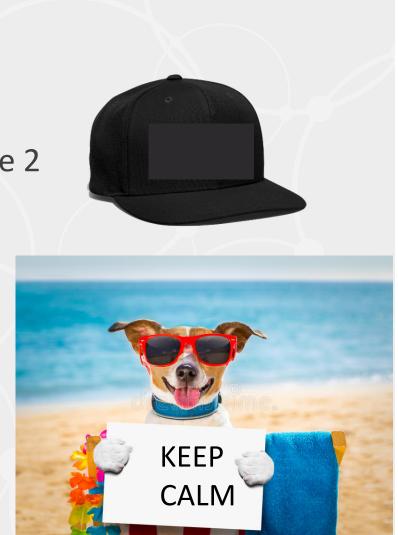


- "Small system": 100 processes sending DDS messages at 100Hz..
  - Sends 850M msgs/day.
  - Wins the powerball 3 times each day!!
- A medium size, higher performance: 1000 process, 1KHz:
  - 1KHz will win 10 PowerBalls per hour..

## Handling corner cases is critical to Availability

## Availability

- CAP Theorem:
  - Consistency, Availability, Partition Tolerance: Choose 2
  - Global scale (Partitions), Real-Word (Availability) ==> No Consistency
- CALM (Consistency as Global Monotonicity) Theorem:
  - Consistent, Coordination-free distributed implementation are possible for Monotonic problems



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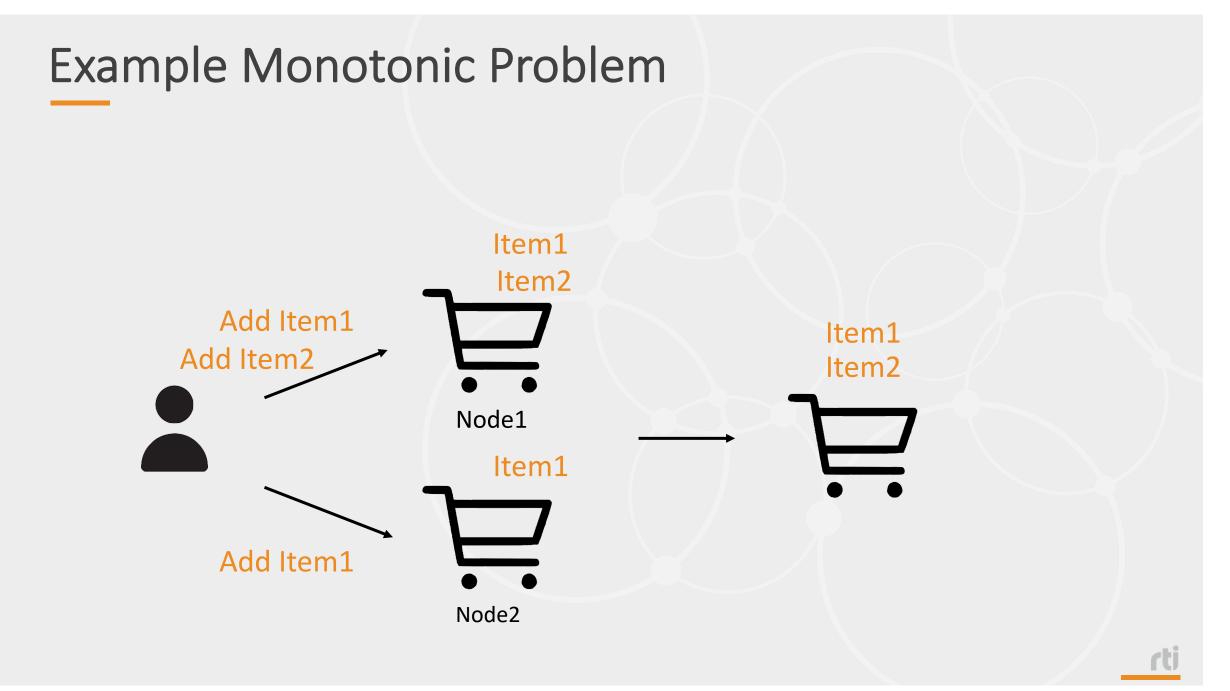
## Connext (DDS) Approach: BASE Sematics

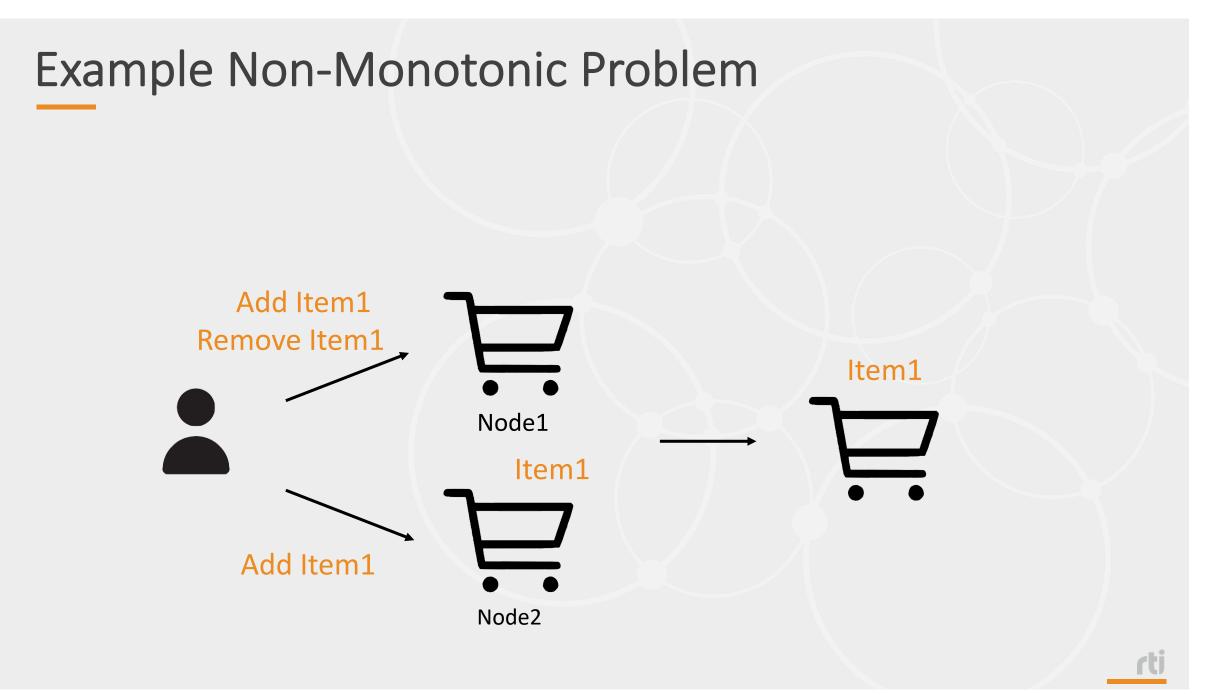
Provide Availability, Partition Tolerance and Eventual Consistency:

- Basically Available: reading and writing operations are available as much as possible (but may not be consistent across readers)
- Soft-state: readers only have a probability of knowing the "latest" state, since it may not yet have converged
- Eventually consistent: after a time period with not further writes, all readers will see the same state.

### CALM -> Eventually Consistent $\Leftrightarrow$ Monotonic

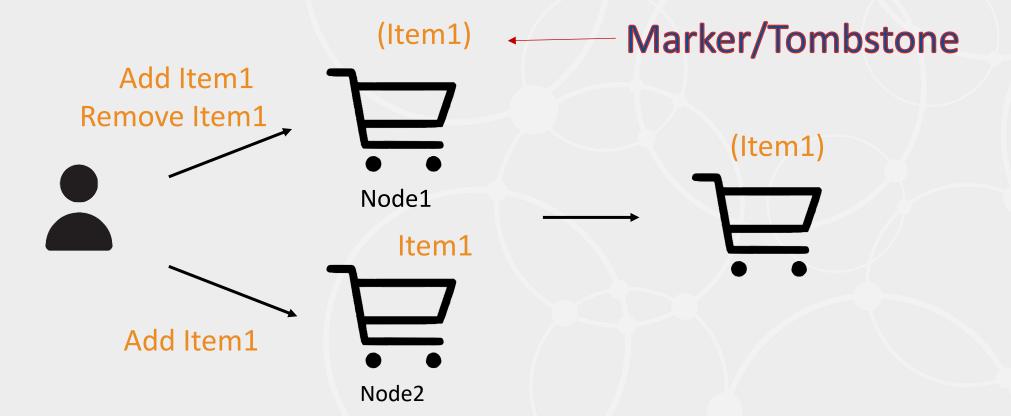
Connext DDS approximates **BASE semantics**, but there are edge cases where eventual consistency may not be achieved





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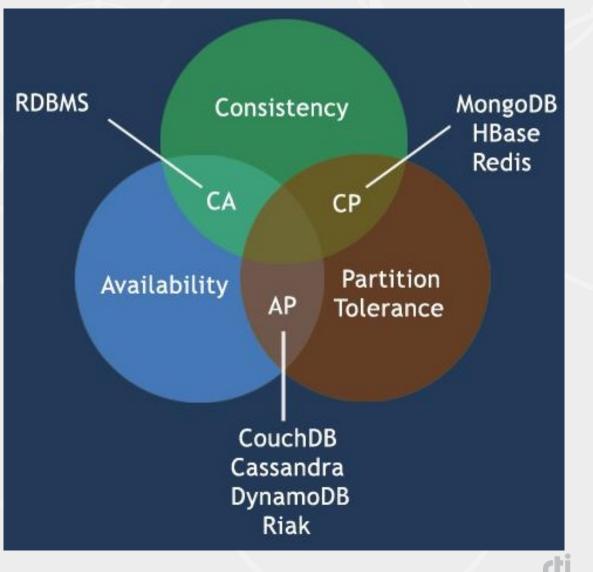
## Example Refactor as Non-Monotonic Problem



Connext DDS uses similar techniques, e.g., keeps some state on disposed instances, but that impacts resource usage... More on this on the Technical Deep Dive

## Database systems face similar tradeoffs

Modern cloud databases moving away from the relational model (CA) in order to provide Partition Tolerance.



## Improving Availability, Safety & Security

#### Available with 6.0 - 6.1

- Coherent Group Access
- Logging Context & Backtrace
- Qos Logging & New Metrics
- Static code analysis. Memory Integrity
- New Tests: RTI WAN, Endurance, Interoperability, ...
- Continuous build and test
- OpenSSL store
- PSK-based protection

### **Upcoming and Future**

- Expanded Instance Lifecycle
- Improved Partition Tolerance
- Eventual consistency of instance state
- Observability
- Certificate Renewal & Revocation
- New crypto algorithms

### Limiting temporary "inconsistencies"

Topic = "Heading" value = 'E'

Topic = "Speed" value = 0.1'

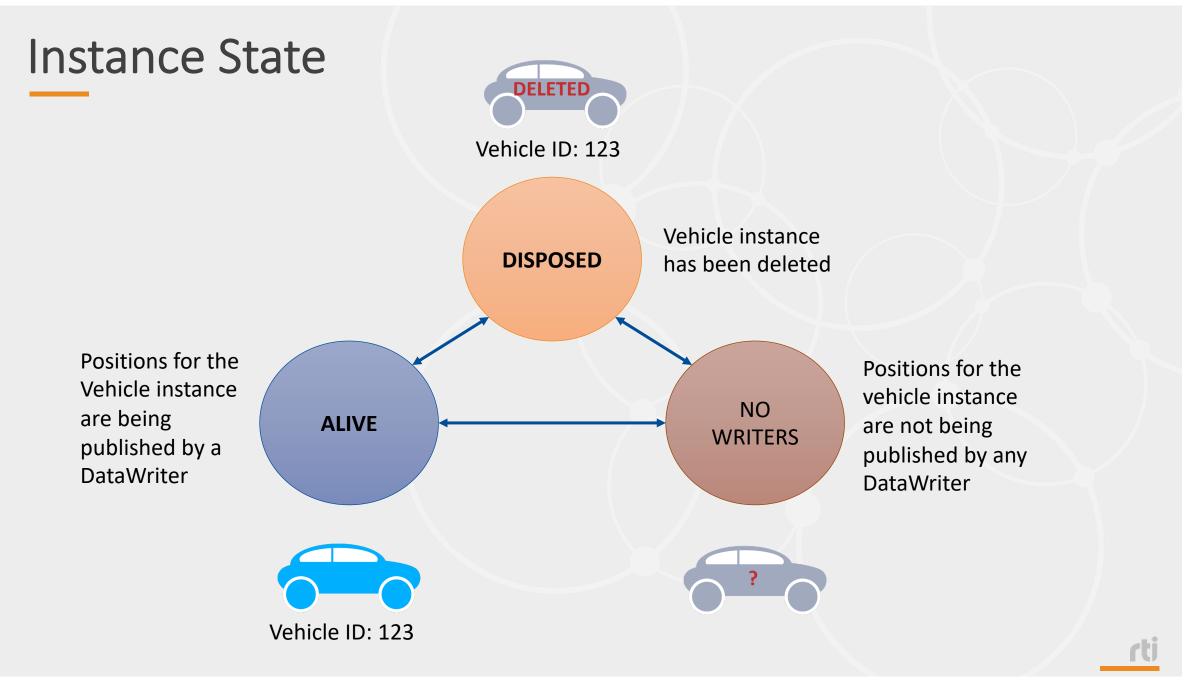




If **Heading** is received before **Speed** Controller will raise false collision Alarm! Temporary inconsistency has side-effect

Solutions (both supported now):

- Group order
- Group coherence



## Content Filter Topic (CFT) on Instances

CFT: (latitude >= x0 and latitude <= x1) and (longitude >= y0 and longitude <= y1)

Moscone Rec ය රූ Chestnut St Avila Center on )ctavia 21013 Chestnut St Lombard St Chestnut St [101] ombard S Greenwich St (101) Lombard St Moulton St Filbert St 115 11 Greenwich St Pixley St Filbert St Union St UNION STREET Green St Bonita Shopping District cott S Univo Green St **x0** X1 Vallejo St Broadway S lerce Vallejo St Broadway St 21013 Pacific Ave Jac Broadway S S

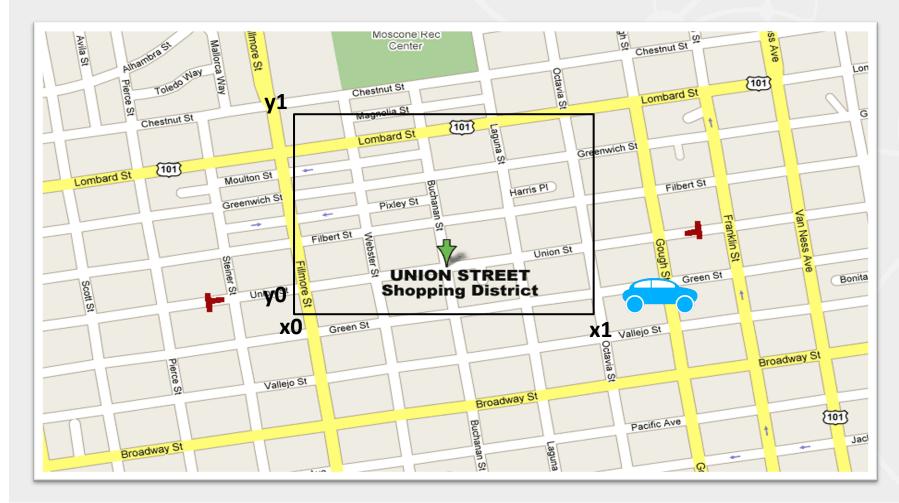
DataReader

DataReader can be created with a CFT

It only receives samples that match filter expression

## Instance Filtered Out or Not Updated?

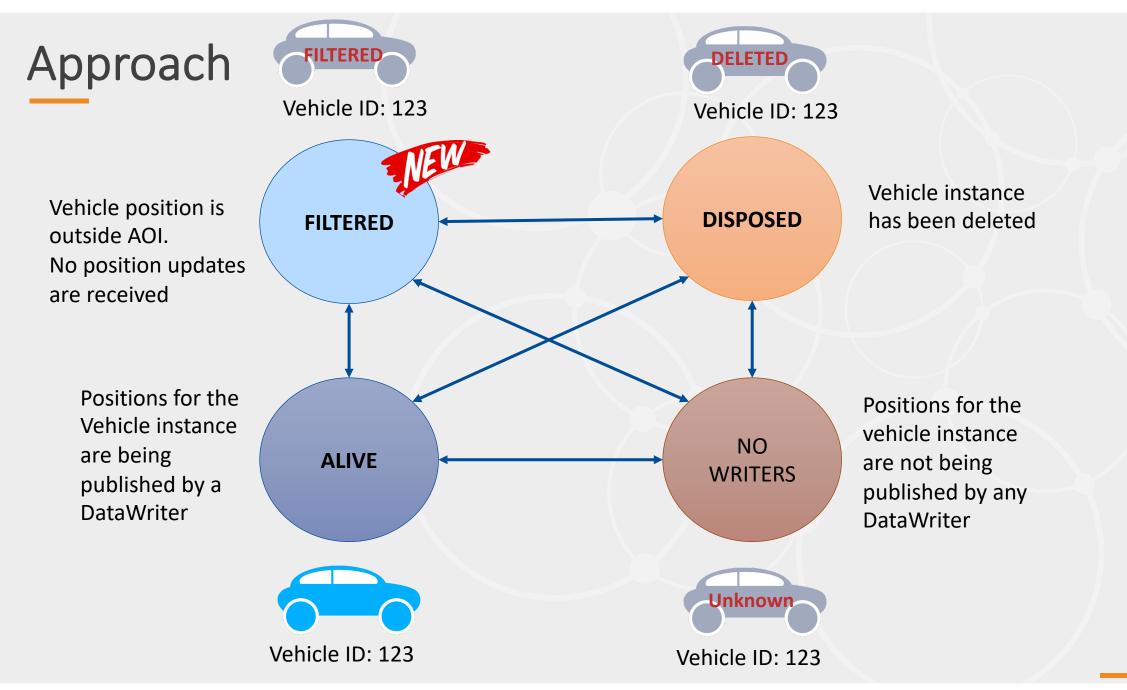
#### CFT: (latitude >= x0 and latitude <= x1) and (longitude >= y0 and longitude <= y1)



#### DataReader

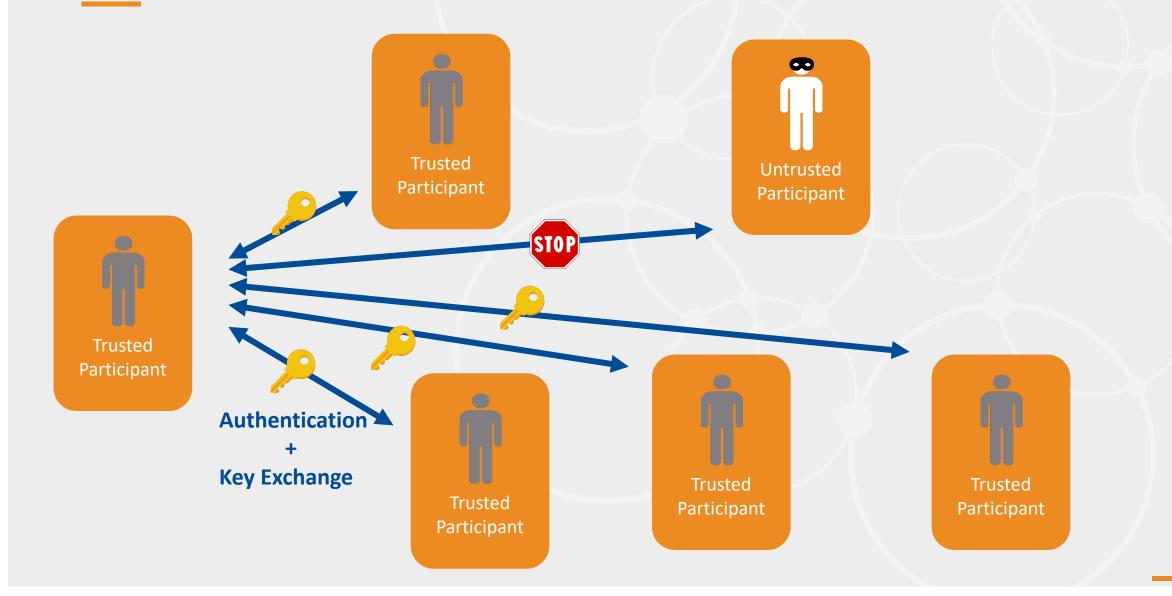
No way to distinguish between:

- A stopped car within the filtered region
- A car running outside the filtered region



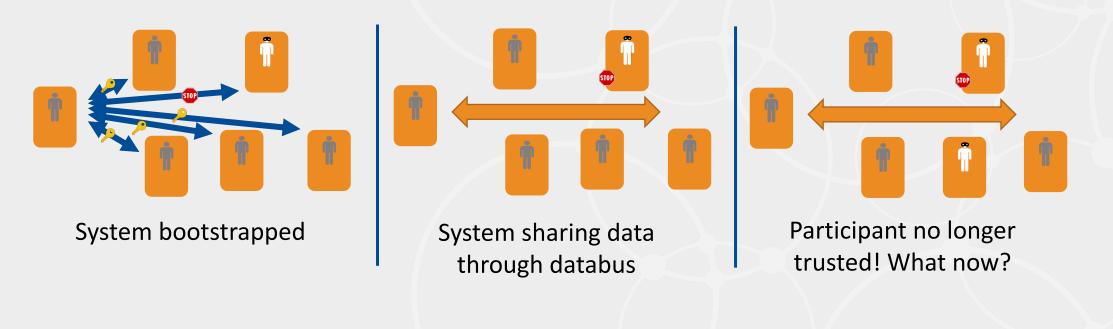
Granular Security is based on sharing the keys with trusted+allowed particicpants







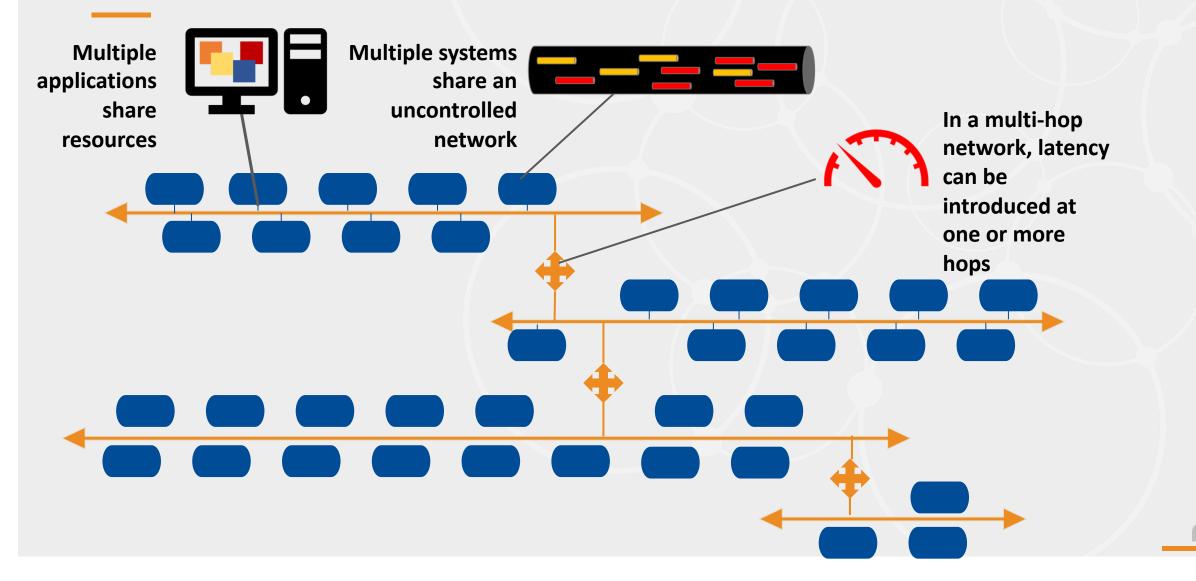
Long-running systems require a way to renew/revoke participants

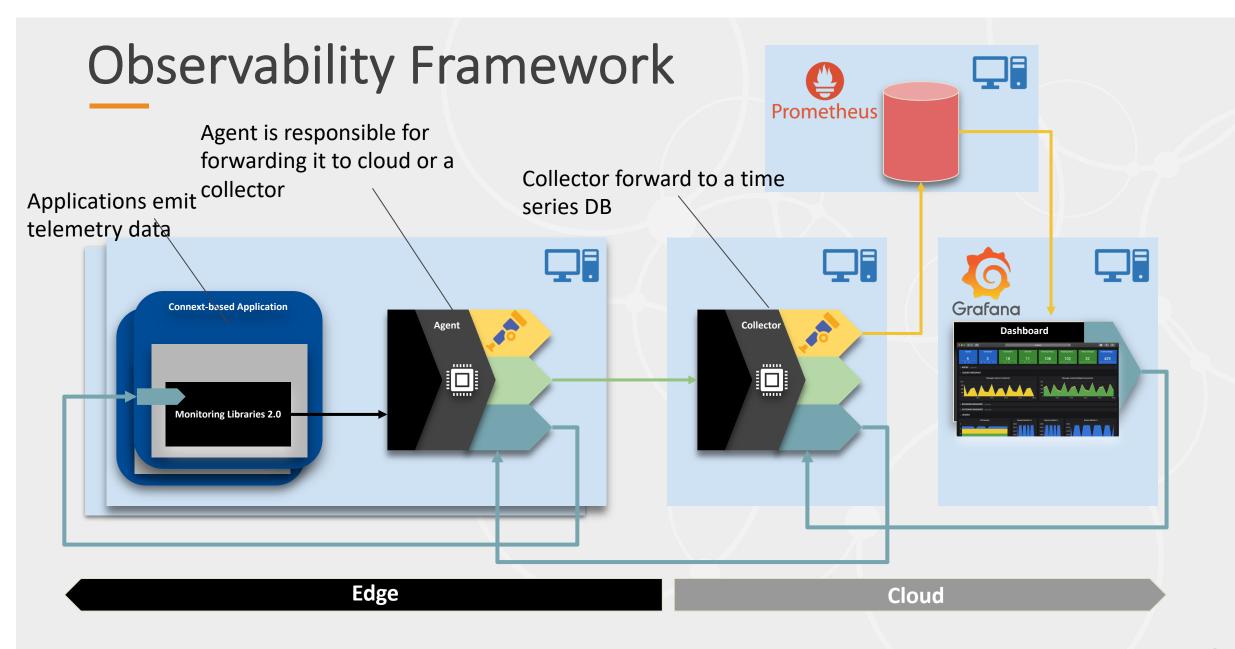


#### Time

Need to continually re-assess Participant Credentials and change/redistribute Cryptographic material as needed

### Observability: Knowing that a system is working property and *why* it is not





#### Leverage existing standards (OpenTelemetry) – Integrate popular frameworks

# Conclusion



We must always remember with gratitude and admiration the first sailors who steered **W** their vessels through storms and mists, thus increasing our knowledge of the lands of ice in the South.

— Roald Amundsen

# Thank You



# Stay Connected





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