Data Distribution Service (DDS) Tutorial

dds/2006-09-01

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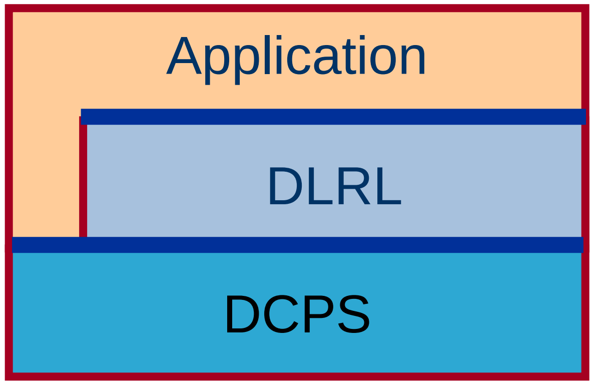
The DDS Standard

- Data Distribution Service for Real-Time Systems
  - Adopted in June 2003
  - Finalized in June 2004
  - Revised June 2005
  - Joint submission (RTI, THALES, OIS)
  - Specification of API required to facilitate the Data-Centric Publish-Subscribe communication environment for real-time distributed systems.

DDS Layers

- DDS made of two layers
  - DCPS = Data Centric Publish/Subscribe
    - Purpose: distribute the data
    - Close to Relational model
  - DLRL = Data Local Reconstruction Layer
    - Purpose: provide an object-based model to access data ‘as if’ it was local



Data Distribution Service - DCPS

Outline

- Background
  - Middleware information models
  - Publish / Subscribe
  - Topic-based Publish / Subscribe
- Focus on Topics
  - Topic definition, keys
  - ContentFilteredTopic, MultiTopic
- Publication & Subscription
  - Related DDS Entities
  - DDS Publication
  - DDS Suscription
  - Dual mechanism to access incoming information
    - Listeners
    - WaitSets and Conditions
- Quality of Service

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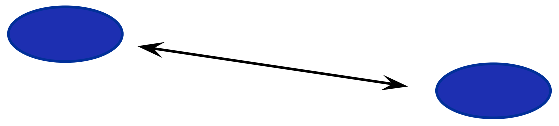
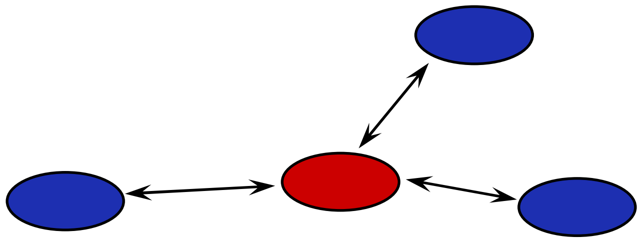
Middleware Information Models

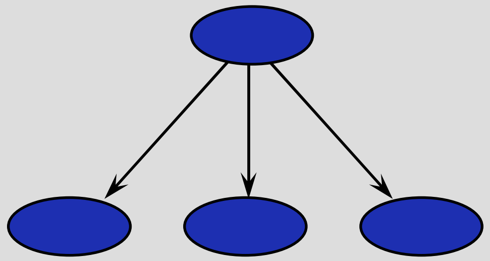


Point-to-Point
Telephone, TCP
Simple, high-bandwidth
Leads to stove-pipe systems

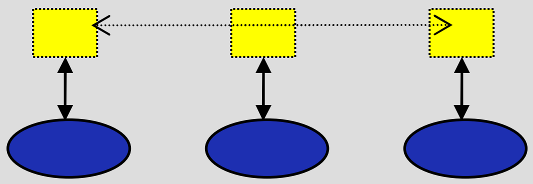


Client-Server
File systems, Database, RPC, CORBA, DCOM
Good if information is naturally centralized
Single point failure, performance bottlenecks

DDS



Publish/Subscribe Messaging
Magazines, Newspaper, TV
Excels at *many-to-many communication*
Excels at distributing *time-critical information*



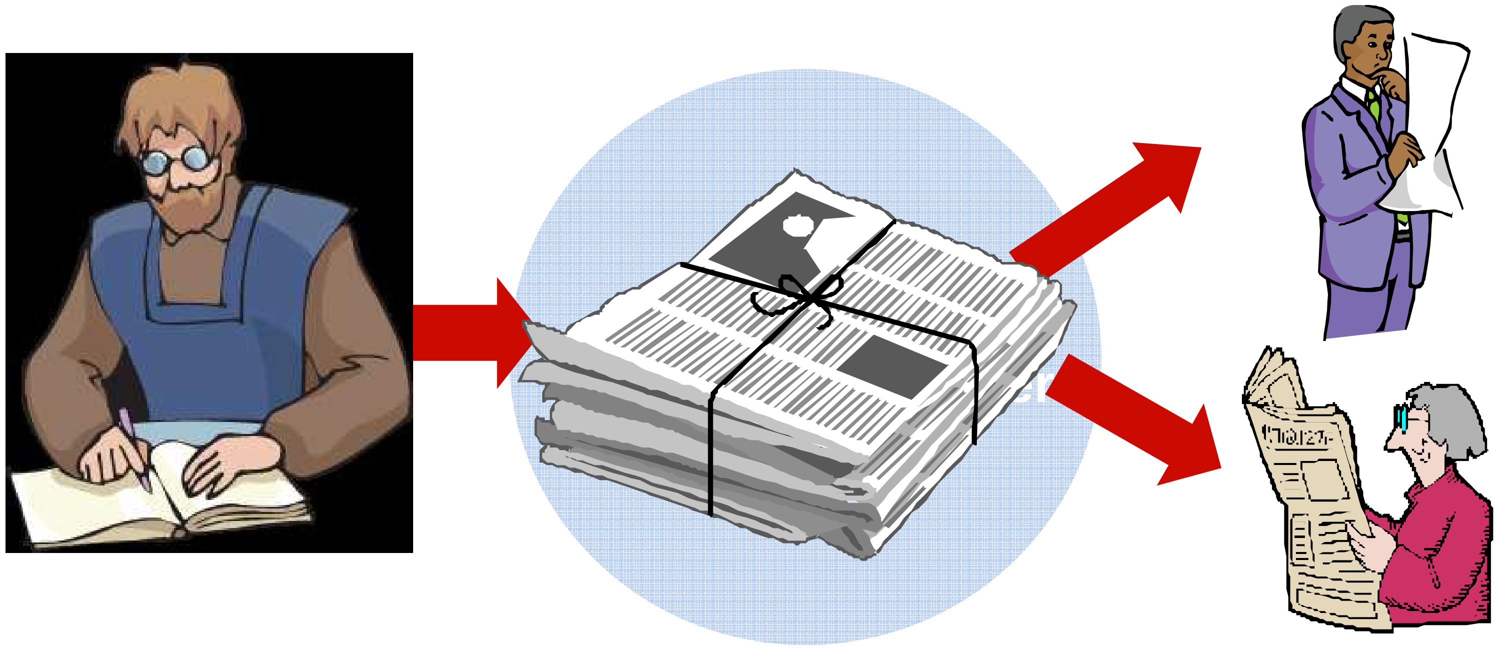
Replicated Data
Libraries, Distributed databases
Excels at data-mining and analysis

Publish Subscribe Model

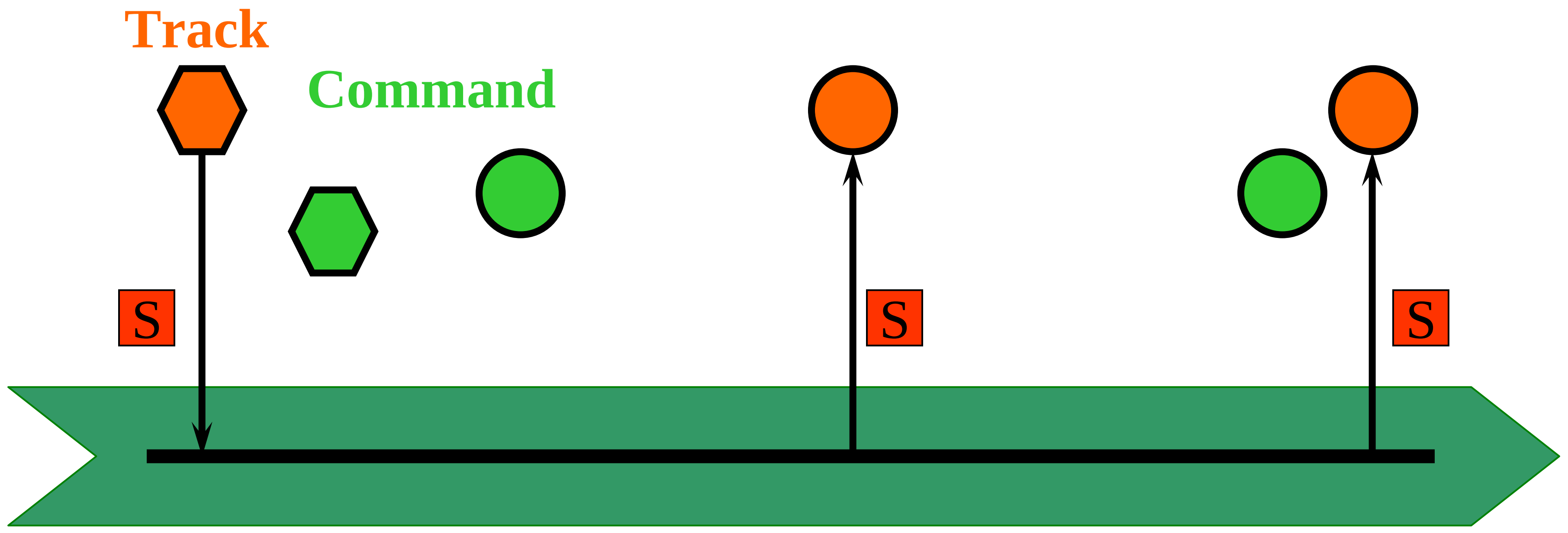
Efficient mechanism for data communications

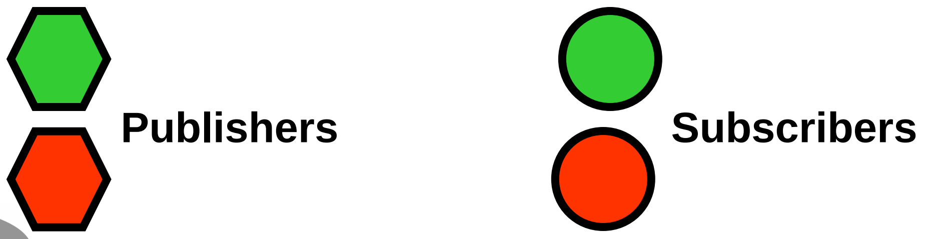
Reporter does not need to know where subscribers live.

Subscribers do not need to know where reporter lives.

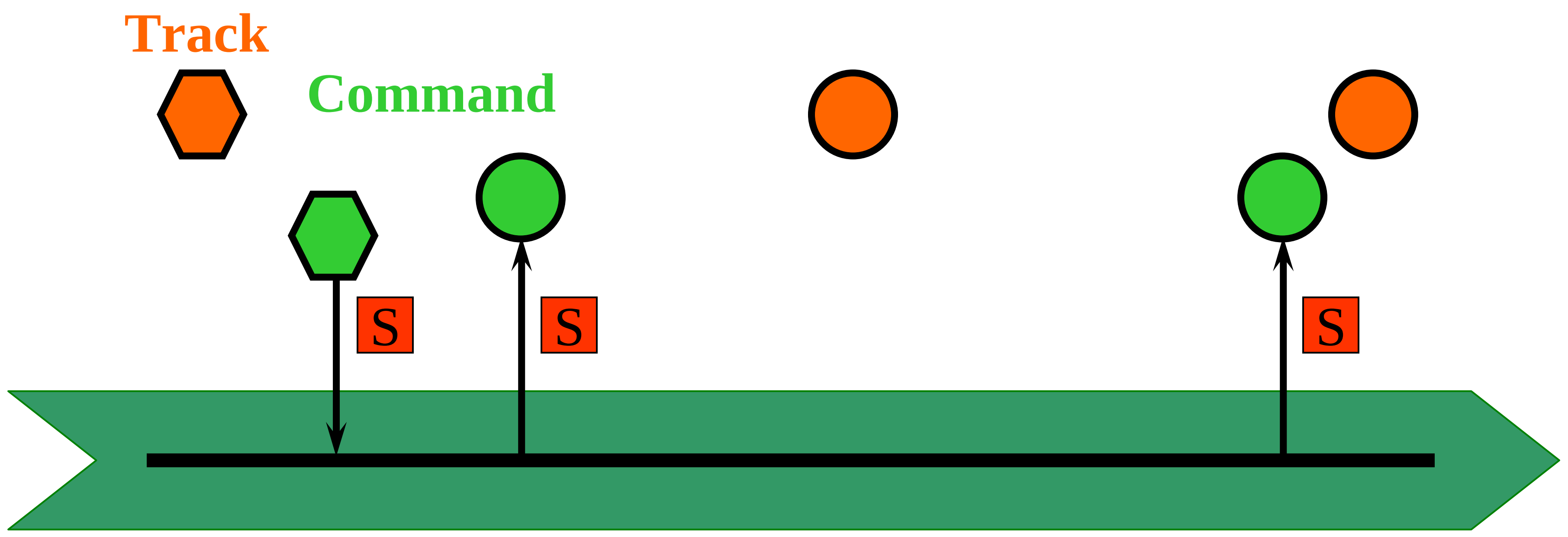


Topic-Based Publish-Subscribe





Topic-Based Publish-Subscribe

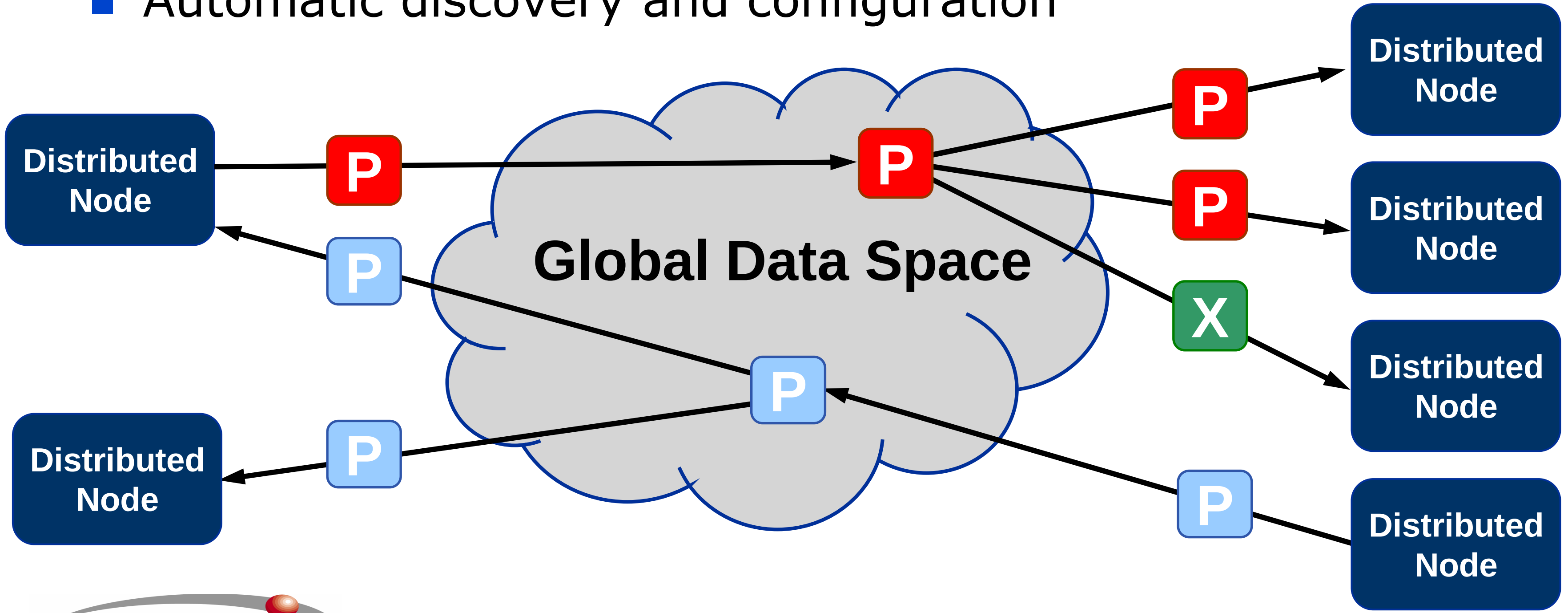


- Publish-subscribe allows infrastructure to prepare itself…
- … Such that when the data is written it is directly sent to the subscribers

DDS/DCPS

Provides a "Global Data Space" that is accessible to all interested applications.

- Data objects addressed by Topic and Key
- Subscriptions are decoupled from Publications
- Contracts established by means of QoS
- Automatic discovery and configuration



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    - Listeners
    - WaitSets and Conditions
- Quality of Service

Topics

Central DDS Entity

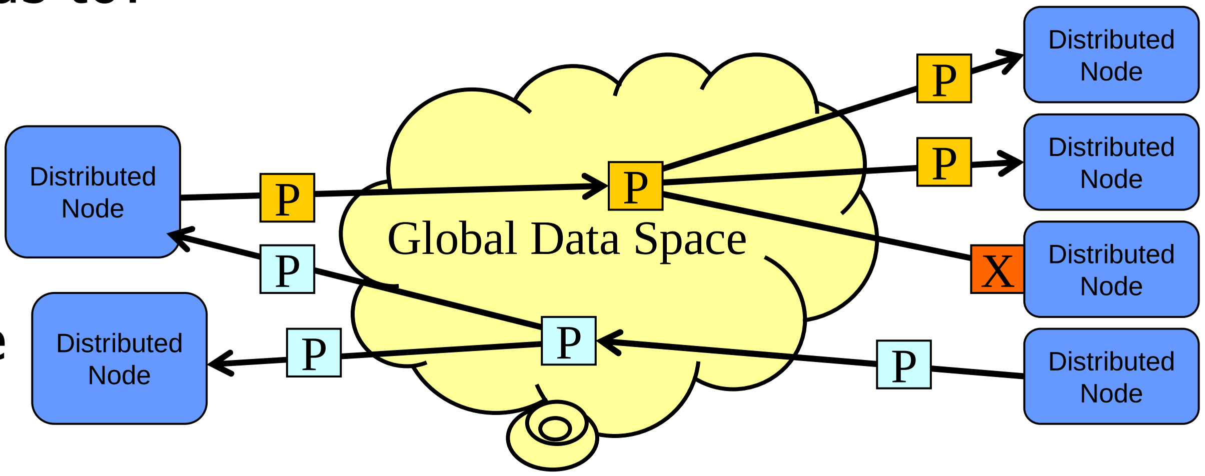
- Topics gather all 'instances' of a given data type related to a given purpose
- Topic Keys
  - Needed to model dynamic objects (e.g. tracks)
  - Can dramatically decrease system size
  - Used for reliable many-to-one (i.e. ALARM topic)
- Topic QoS
  - Convenient way to describe information model
- Data types specified in IDL and can be reused
  - eg a data structure received by DDS can be used as is in a CORBA call

ContentFilteredTopic and MultiTopic control subscription scope

Topic Definition

Good topic definition leads to:

- Better interfaces
- Easier integration
- Improved scalability
- Decreased system size
- Faster startup and discovery times



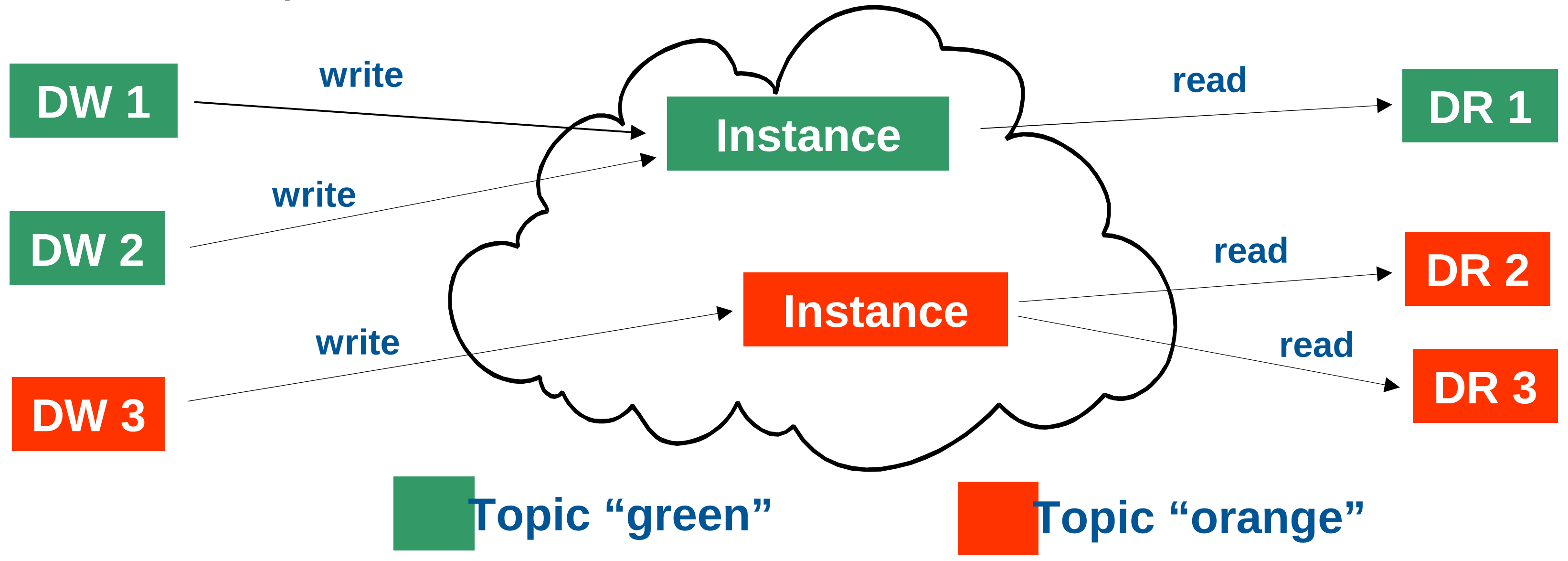
Choosing the proper Topics is the central design decision

By Sender "Role"	- MixerTank3Data
By Receiver "Role"	- AirTrackCorrelator
By Message ID	- Filter23ToGUI12
By Data "Role"	- AAWTracks
By Data Type	- CommandString

Example without Keys

When **not** using **keys**:

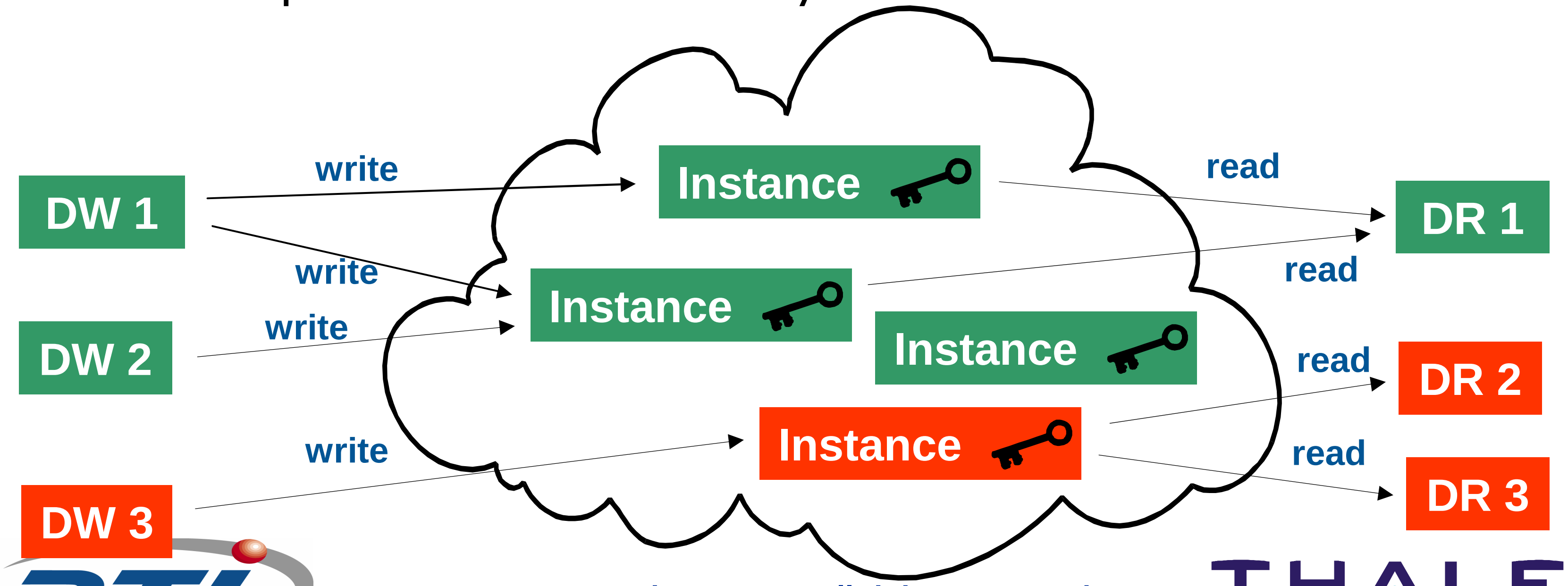
- Each Topic corresponds to a single data instance.
- A DataWriter associated with a Topic can write to the instance corresponding to That topic.
- Multiple DataWriters may write to the same instance.
- A DataReader specifies the Topic (instance) it wants to receive updates from.



Example with Keys

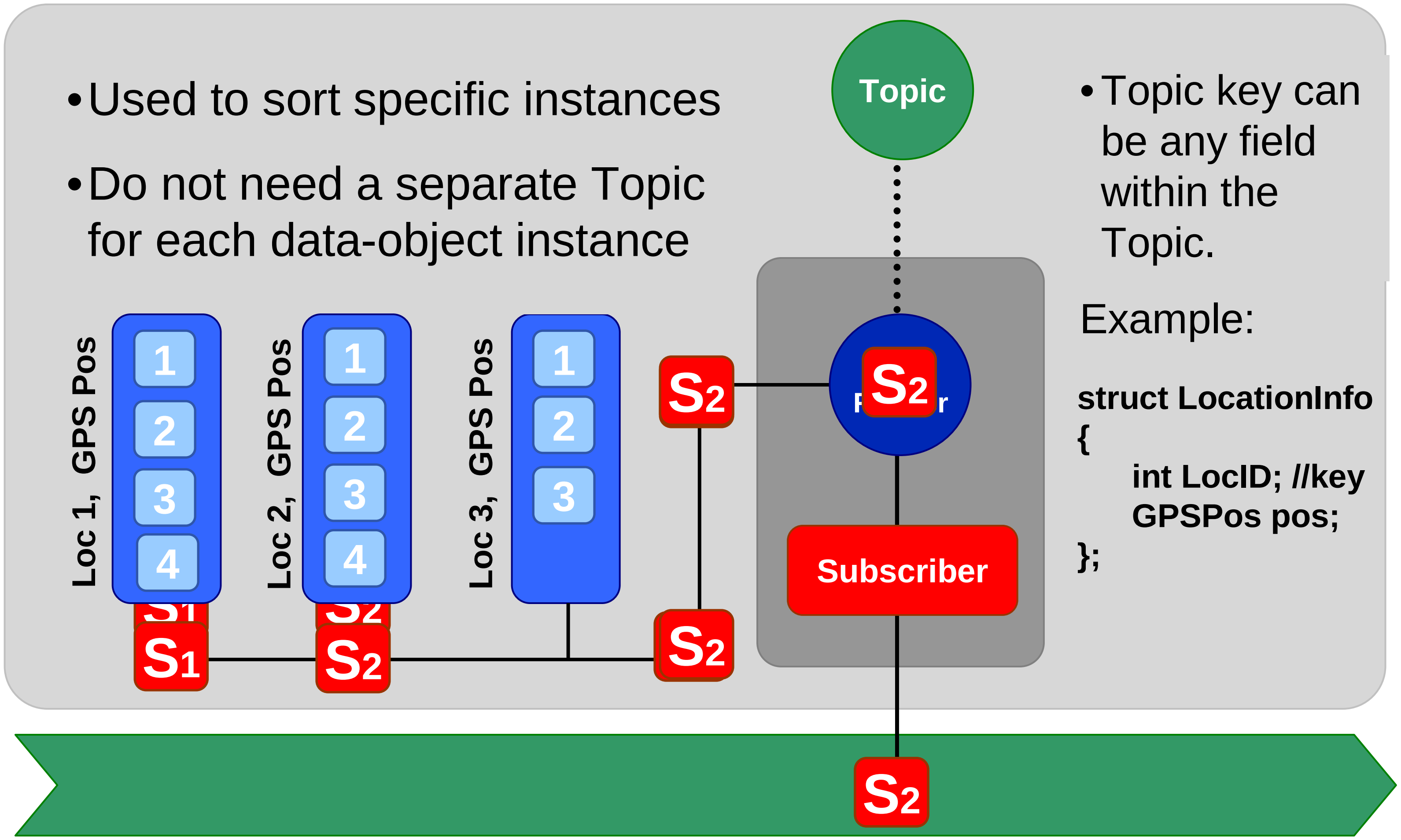
Address in Global Data Space = (Topic, Key)

- Each Topic corresponds to multiple data instances
- Each DataWriter can write to multiple instances of a single Topic
- Multiple DataWriters may write to the same instance
- Each DataReader can receive updates from multiple instances of a single Topic
- Multiple DataReaders may read from the same instances



Data Instances Addressing: Keys

- Address in Global Data Space = (Topic, Key)
  => multiple instances of the same Topic



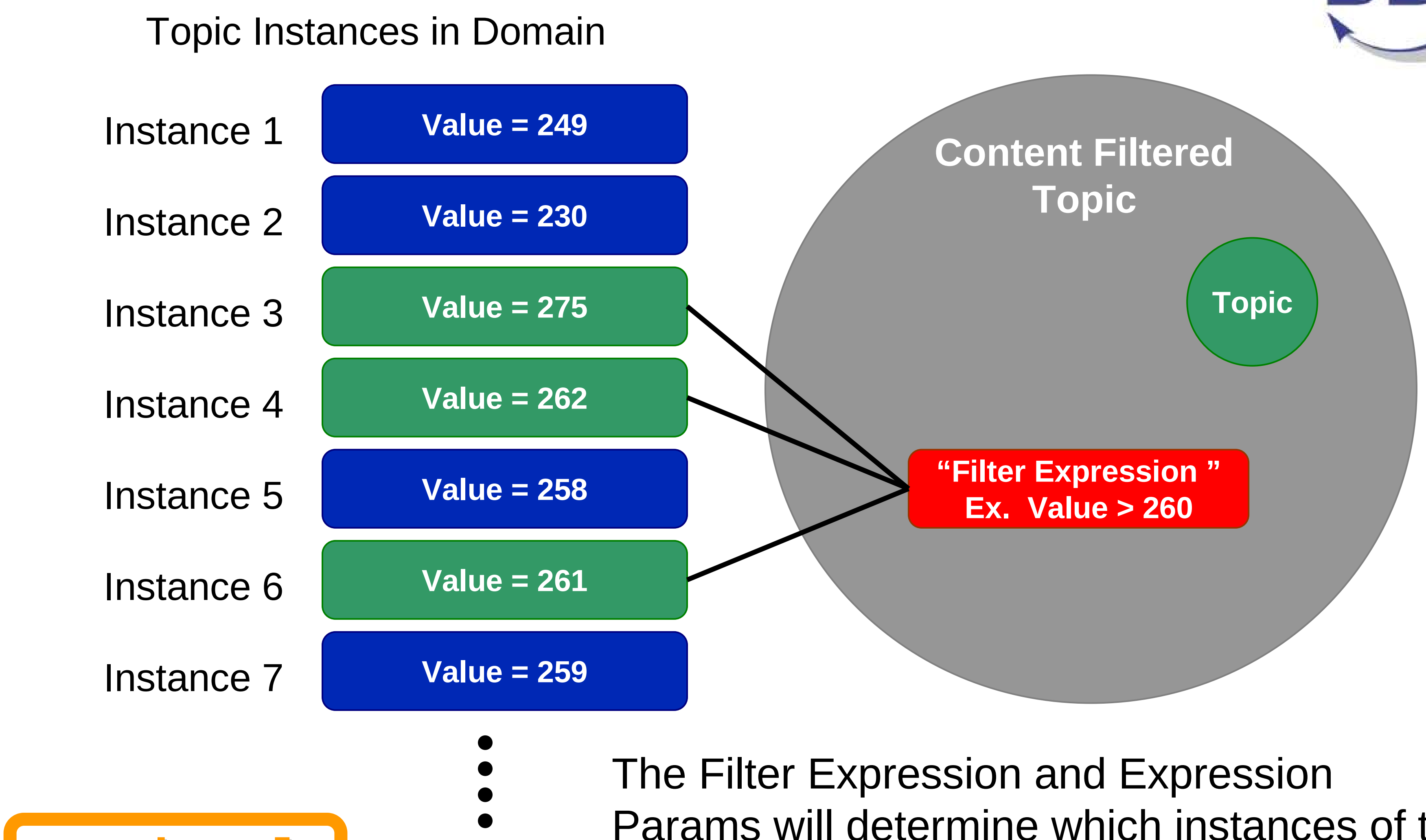
- Used to sort specific instances
- Do not need a separate Topic for each data-object instance

- Topic key can be any field within the Topic.

Example:

```
struct LocationInfo
{
        int LocID; //key
        GPSPos pos;
};
```

DDS Subscription (ContentFilteredTopic)



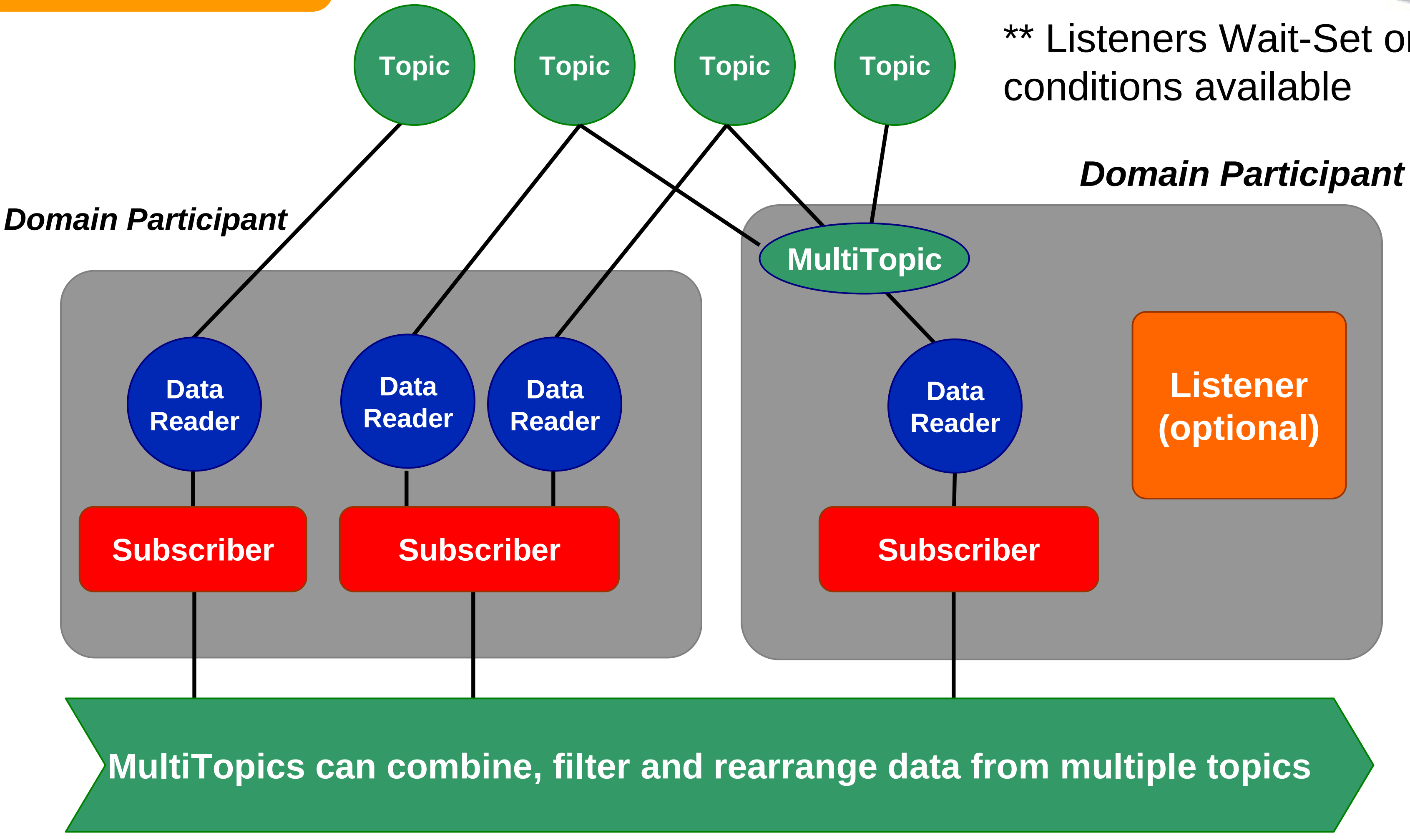
optional

The Filter Expression and Expression Params will determine which instances of the Topic will be received by the subscriber.

DDS Subscription (MultiTopic)

optional

** Listeners Wait-Set or conditions available



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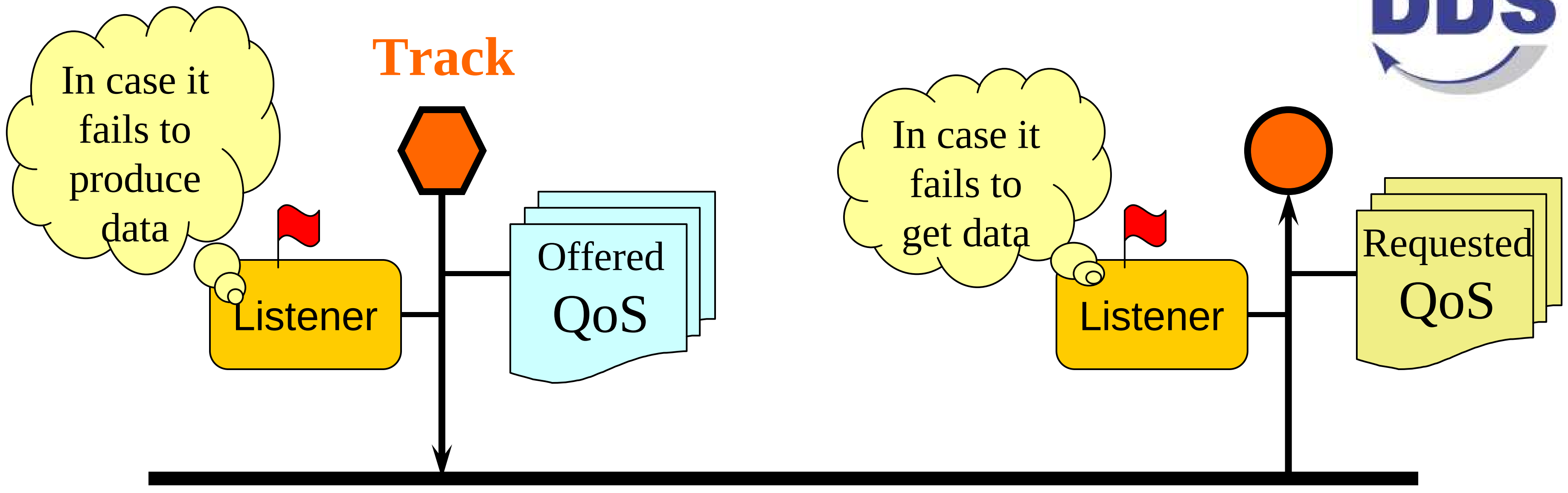
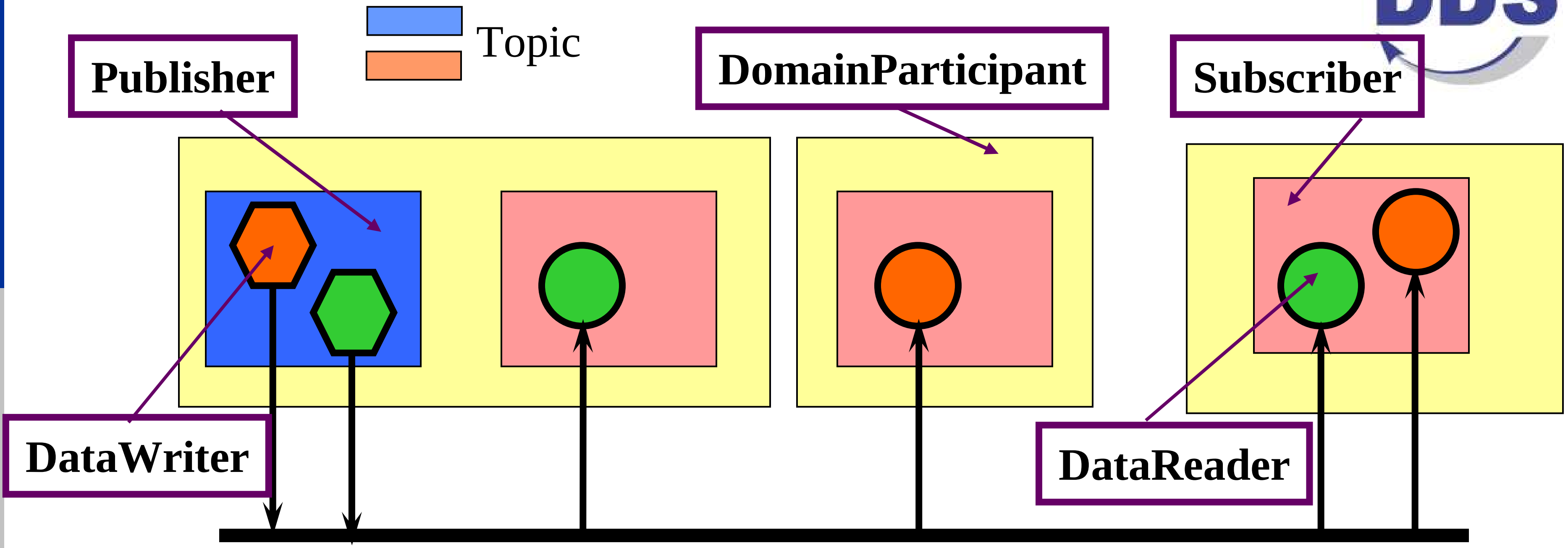
DDS Communication Model


In case it fails to produce data
Track
Listener
Offered QoS
In case it fails to get data
Listener
Requested QoS

- Publisher declares information it has by specifying the Topic…
  - …and the offered QoS contract
  - …and an associated listener to be alerted of any significant status changes
- Subscriber declares information it wants by specifying the Topic…
  - …and the requested QoS contract
  - …and an associated listener to be alerted of any significant status changes
- DDS automatically discovers publishers and subscribers
  - DDS ensures QoS matching and alerts of inconsistencies

DCPS Entities



DomainParticipant ~ Represents participation of the application in the communication collective

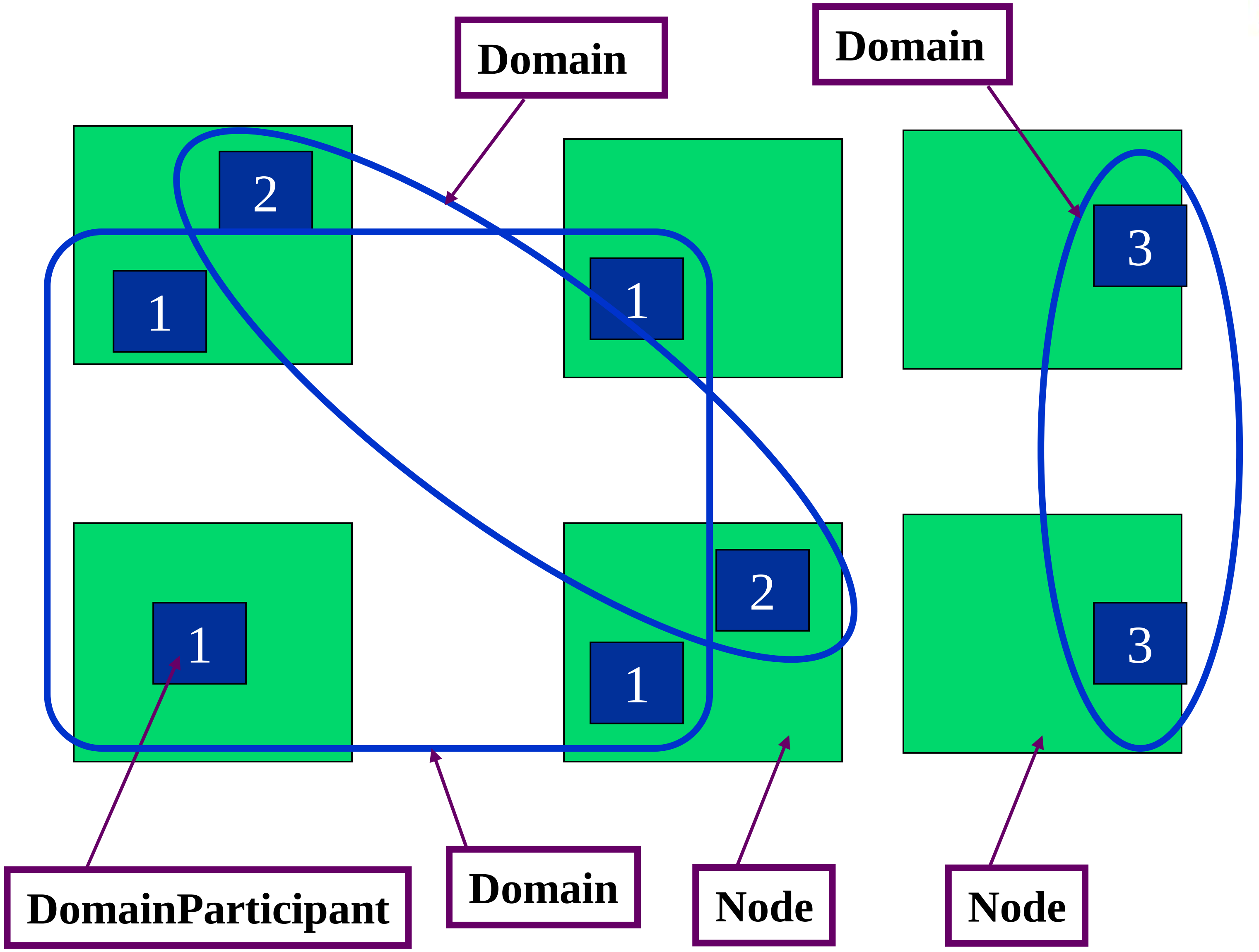
DataWriter ~ Accessor to write typed data on a particular Topic

Publisher ~ Aggregation of DataWriter objects
  Responsible for disseminating information.

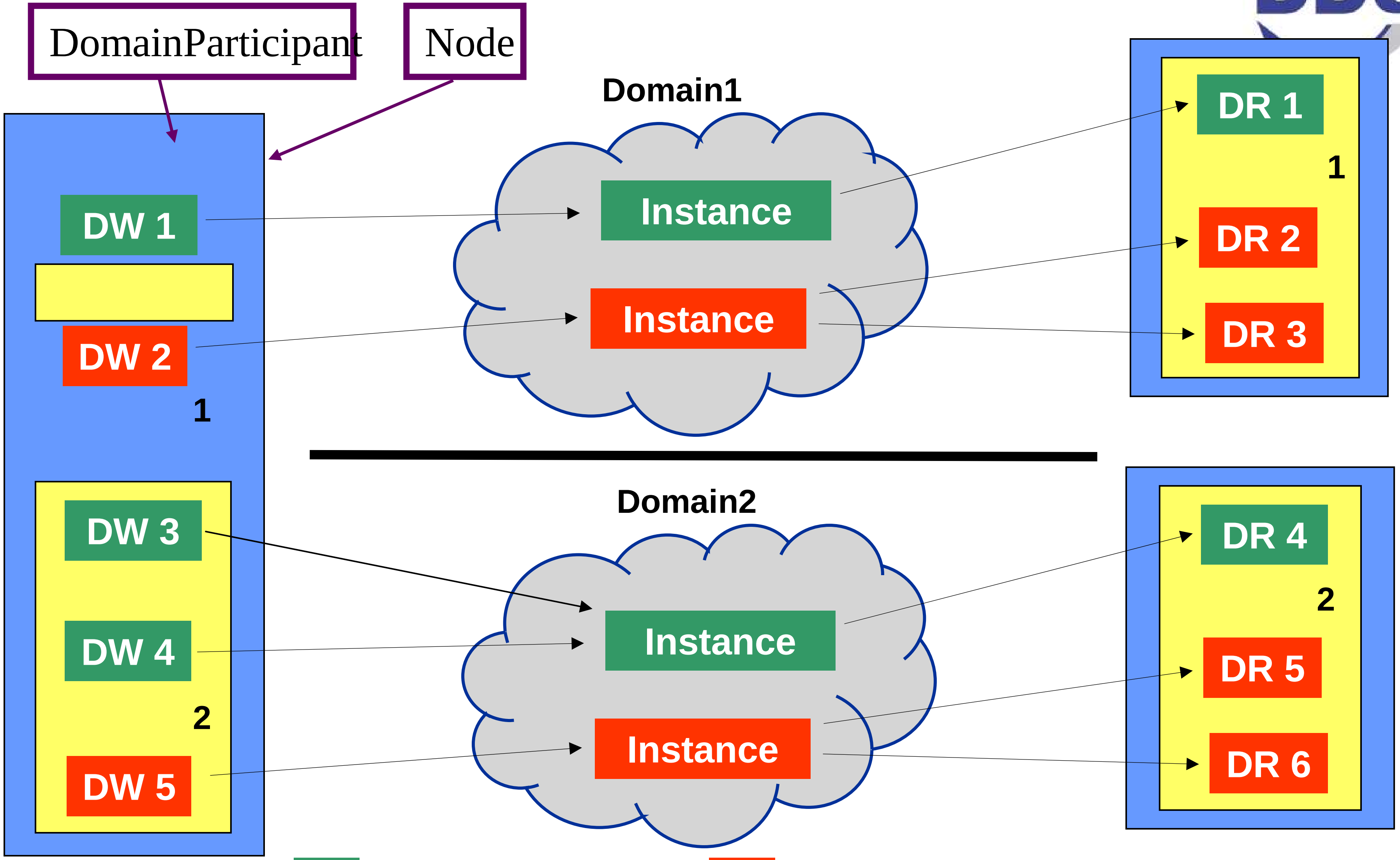
DataReader ~ Accessor to read typed data regarding a specific Topic

Subscriber ~ Aggregation of DataReader objects
  Responsible for receiving information

Domains and Participants

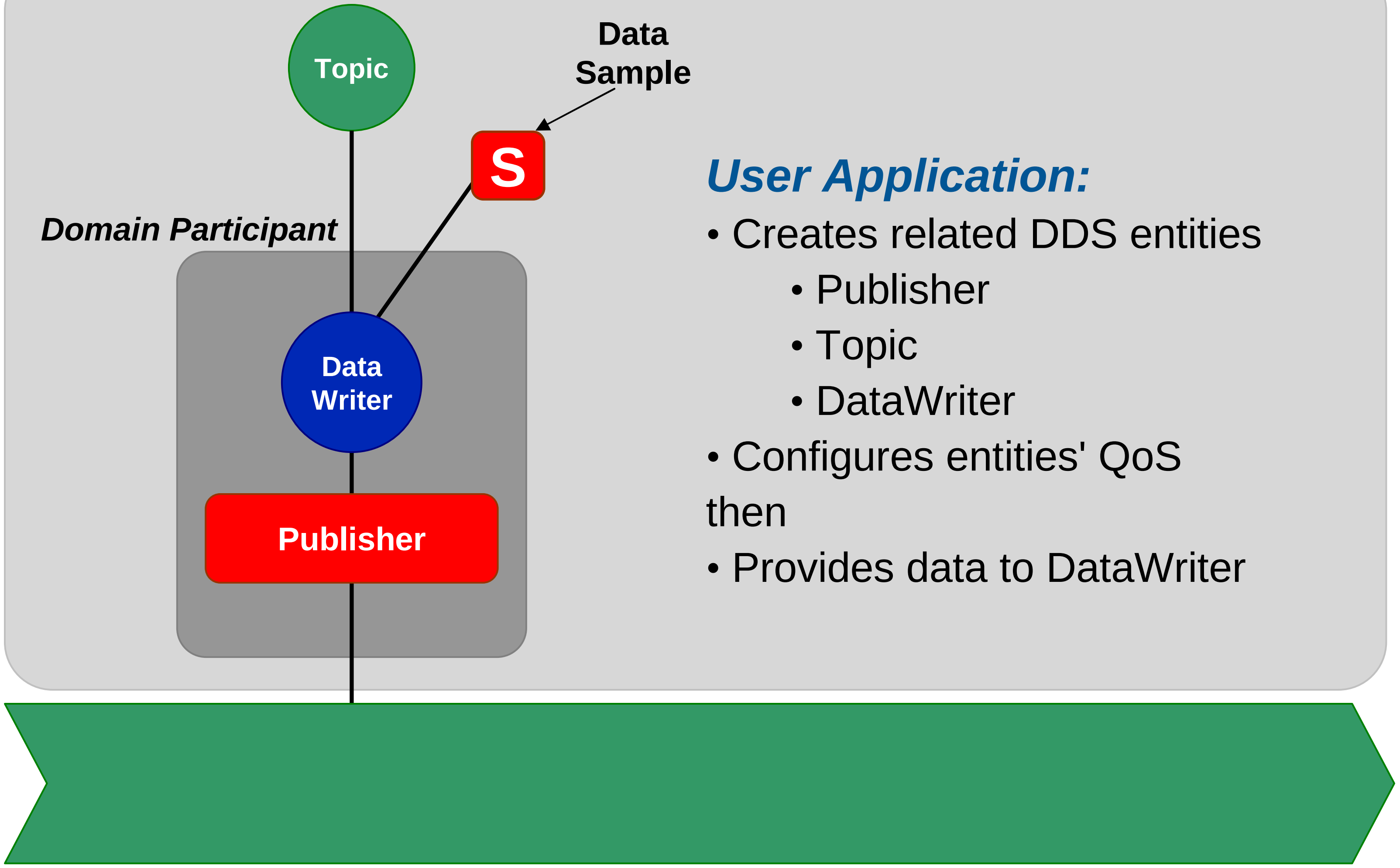


Domain Partitioning



🟩 Topic “green” 🟥 Topic “orange”

DDS Publication



User Application:
- Creates related DDS entities
  - Publisher
  - Topic
  - DataWriter
- Configures entities' QoS then
- Provides data to DataWriter

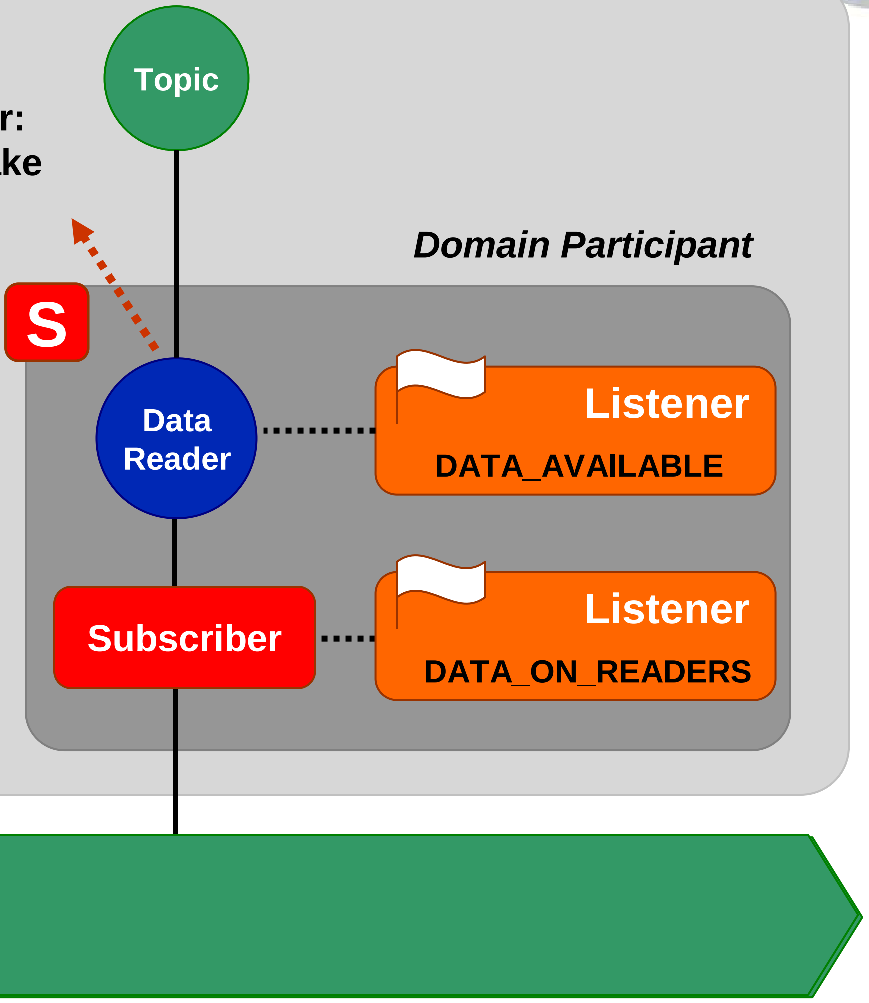
Example: Publication

```
// Entities creation
Publisher publisher = domain->create_publisher(
       publisher_qos,
       publisher_listener);

Topic topic = domain->create_topic(
       “Track”, “TrackStruct”,
       topic_qos, topic_listener);

DataWriter writer = publisher->create_datawriter(
       topic, writer_qos, writer_listener);

TrackStructDataWriter twriter =
      TrackStructDataWriter::narrow(writer);

TrackStruct my_track;
// (Repeat each time data needs to be written)
twriter->write(&my_track);
```

DDS Subscription with Listeners

User Application:

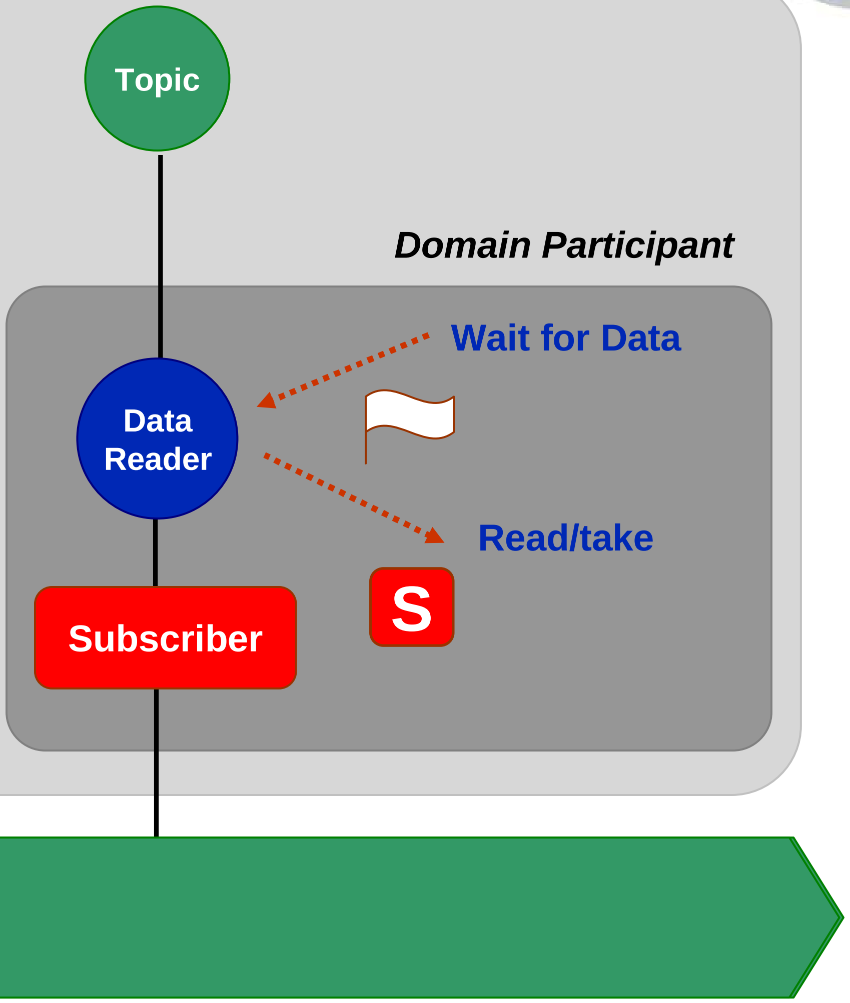
- Creates related DDS entities
  - Subscriber
  - Topic
  - DataReader
- Configures entities' QoS and attach listeners
- Receives Data from DataReader through attached listeners



DDS Subscription with Wait-Set

User Application:

- Creates related DDS entities
  - Subscriber
  - Topic
  - DataReader
- Configures entities' QoS
- Creates a Condition and attaches it to a WaitSet
- Waits on the WaitSet until data arrive, then picks it on the DataReader



Example: Subscription

```
// Entities creation
Subscriber  subscriber = domain->create_subscriber(
       subscriber_qos, subscriber_listener);

Topic topic = domain->create_topic(
       “Track”, “TrackStruct”,
       topic_qos, topic_listener);

DataReader reader = subscriber->create_datareader(
       topic, reader_qos, reader_listener);

// Use listener-based or wait-based access
```

How to Get Data? (Listener-Based)

```
// Listener creation and attachment
Listener listener = new MyListener();
reader->set_listener(listener);

// Listener code
MyListener::on_data_available( DataReader reader )
{
    TrackStructSeq received_data;
    SampleInfoSeq sample_info;
    TrackStructDataReader treader =
        TrackStructDataReader::narrow(reader);

    treader->take( &received_data,
                   &sample_info, …)
    // Use received_data
}
```

How to Get Data? (WaitSet-Based)

```
// Creation of condition and attachement
Condition  foo_condition =
   treader->create_readcondition(…);
waitset->add_condition(foo_condition);

// Wait
ConditionSeq active_conditions;
waitset->wait(&active_conditions, timeout);
// active_conditions[0] == foo_condition
// =>  data is there, ready to be picked
FooSeq received_data;
SampleInfoSeq sample_info;

treader->take_w_condition
      (&received_data,
       &sample_info,
       foo_condition);
// Use received_data
```

Listeners, Conditions & WaitSets

Middleware must notify user application of relevant events

- Arrival of data
- But also:
    - QoS violations
    - Discovery of relevant entities
- These events may be detected asynchronously by the middleware

  … Same issue arises with POSIX signals

DDS allows the application to choice:

- Either to get notified asynchronously using a **Listener**
- Or to wait synchronously using a **WaitSet**

Both approaches are unified using STATUS changes

Status Changes

DDS defines

- A set of enumerated STATUS
- The statuses relevant to each kind of DDS Entity

DDS entities maintain a value for each STATUS

STATUS	Entity
INCONSISTENT_TOPIC	Topic
DATA_ON_READERS	Subscriber
LIVELINESS_CHANGED	DataReader
REQUESTED_DEADLINE_MISSED	DataReader
RUQESTED_INCOMPATIBLE_QOS	DataReader
DATA_AVAILABLE	DataReader
SAMPLE_LOST	DataReader
SUBSCRIPTION_MATCH	DataReader
LIVELINESS_LOST	DataWriter
OFFERED_INCOMPATIBLE_QOS	DataWriter
PUBLICATION_MATCH	DataWriter

```
struct LivelinessChangedStatus
{
   long active_count;
   long inactive_count;
   long active_count_change;
   long inactive_count_change;
}
```

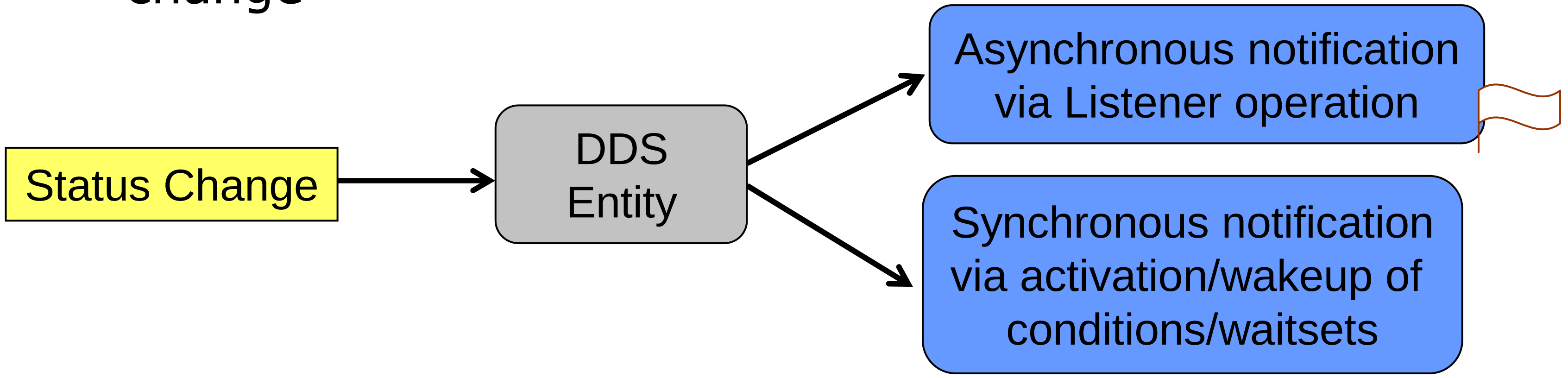
Listeners, Conditions and Statuses

- A DDS Entity is associated with:
  - A listener of the proper kind (if attached)
  - A StatusCondition (if activated)
- The Listener for an Entity has a separate operation for each of the relevant statuses

STATUS	Entity	Listener operation	
INCONSISTENT_TOPIC	Topic	on_inconsistent_topic	
DATA_ON_READERS	Subscriber	on_data_on_readers	
LIVELINESS_CHANGED	DataReader	on_liveliness_changed	
REQUESTED_DEADLINE_MISSED	DataReader	on_requested_deadline_missed	
RUQESTED_INCOMPATIBLE_QOS	DataReader	on_requested_incompatible_qos	
DATA_AVAILABLE	DataReader	on_data_available	
SAMPLE_LOST	DataReader	on_sample_lost	
SUBSCRIPTION_MATCH	DataReader	on_subscription_match	
LIVELINESS_LOST	DataWriter	on_liveliness_lost	
OFFERED_INCOMPATIBLE_QOS	DataWriter	on_offered_incompatible_qos	
PUBLICATION_MATCH	DataWriter	on_publication_match	

Listeners & Condition duality

- A StatusCondition can be selectively activated to respond to any subset of the statuses
- An application can wait changes in sets of StatusConditions using a WaitSet
- Each time the value of a STATUS changes DDS
  - Calls the corresponding Listener operation
  - Wakes up any threads waiting on a related status change


Status Change
DDS Entity
Asynchronous notification via Listener operation
Synchronous notification via activation/wakeup of conditions/waitsets

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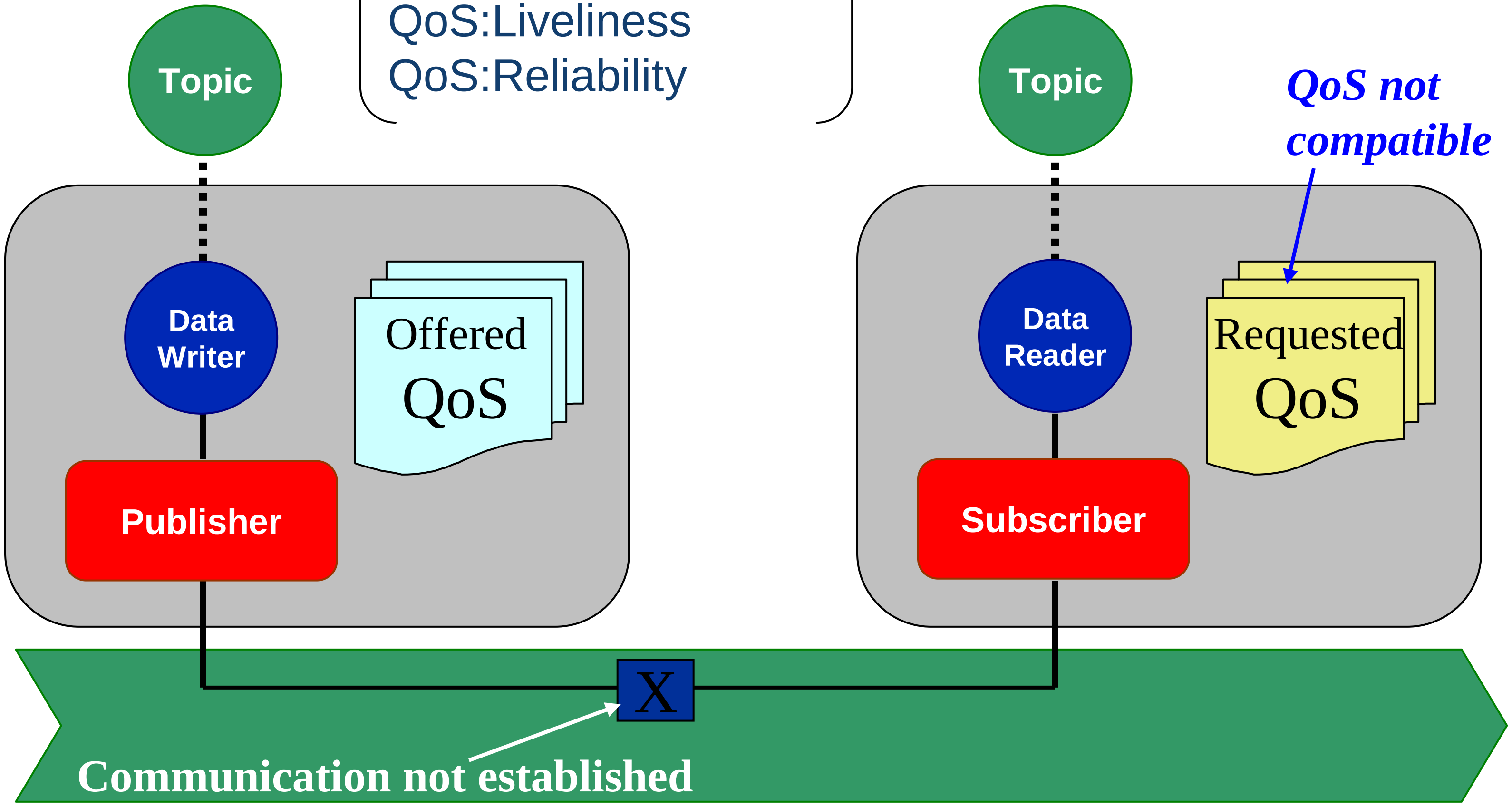
QoS Contract "Request / Offered"

QoS:Durability
QoS:Presentation
QoS:Deadline
QoS:Latency_Budget
QoS:Ownership
QoS:Liveliness
QoS:Reliability

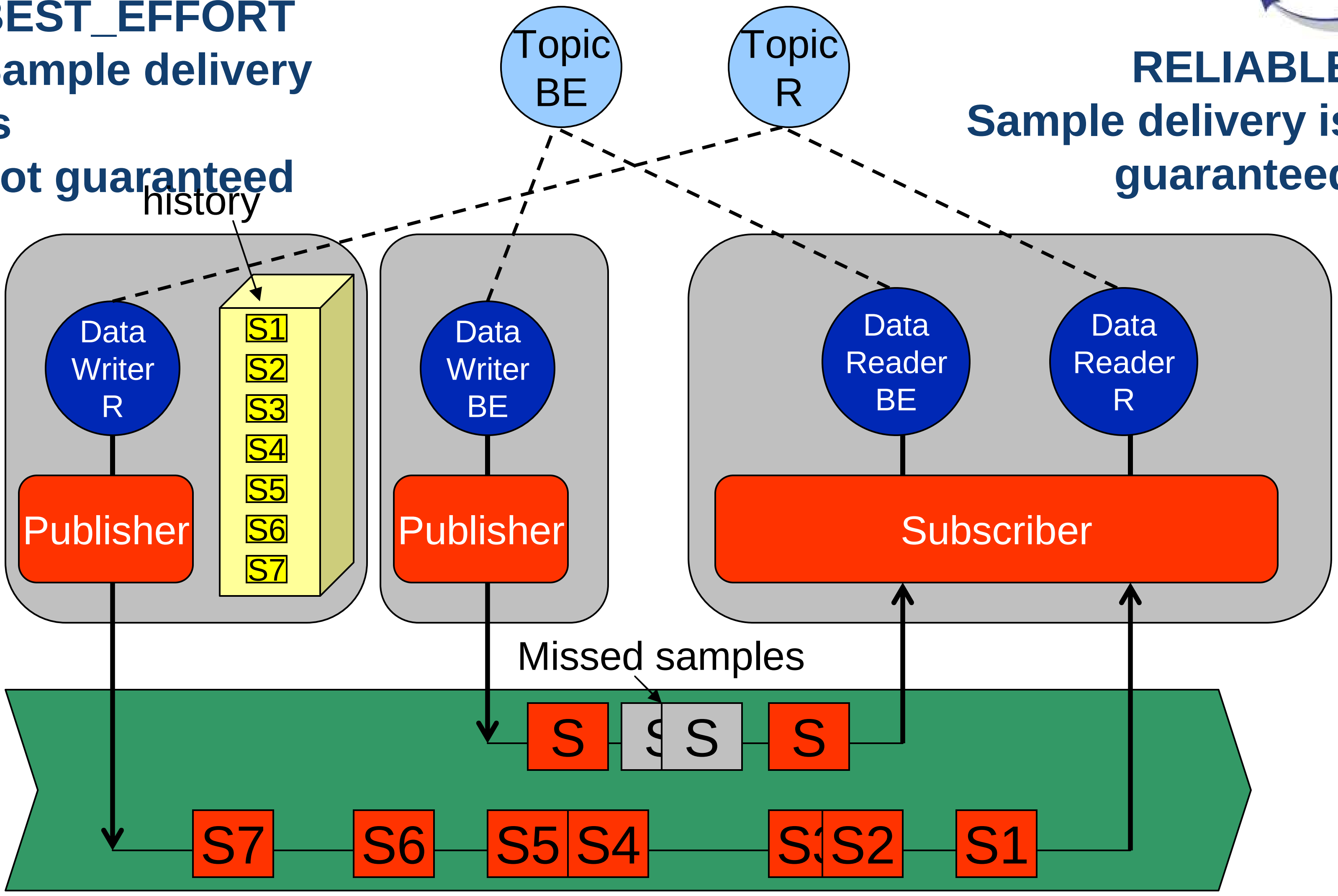
QoS Request / Offered:
Ensure that compatible QoS parameters are set.



QoS: RELIABILITY

BEST_EFFORT
Sample delivery is not guaranteed

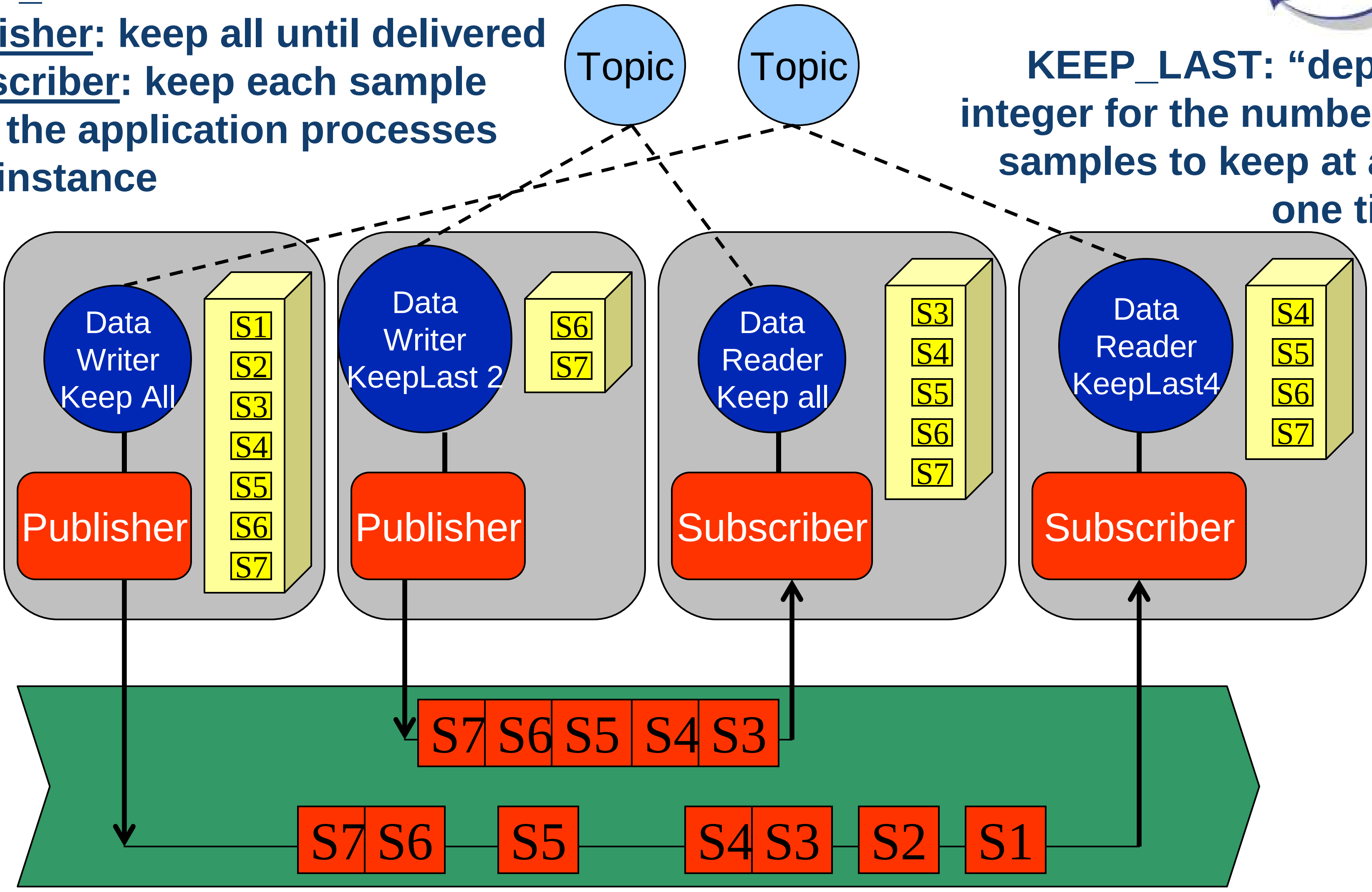
RELIABLE
Sample delivery is guaranteed



QoS: HISTORY – Last x or All

KEEP_ALL:
<u>Publisher</u>: keep all until delivered
<u>Subscriber</u>: keep each sample until the application processes that instance

KEEP_LAST: “depth” integer for the number of samples to keep at any one time



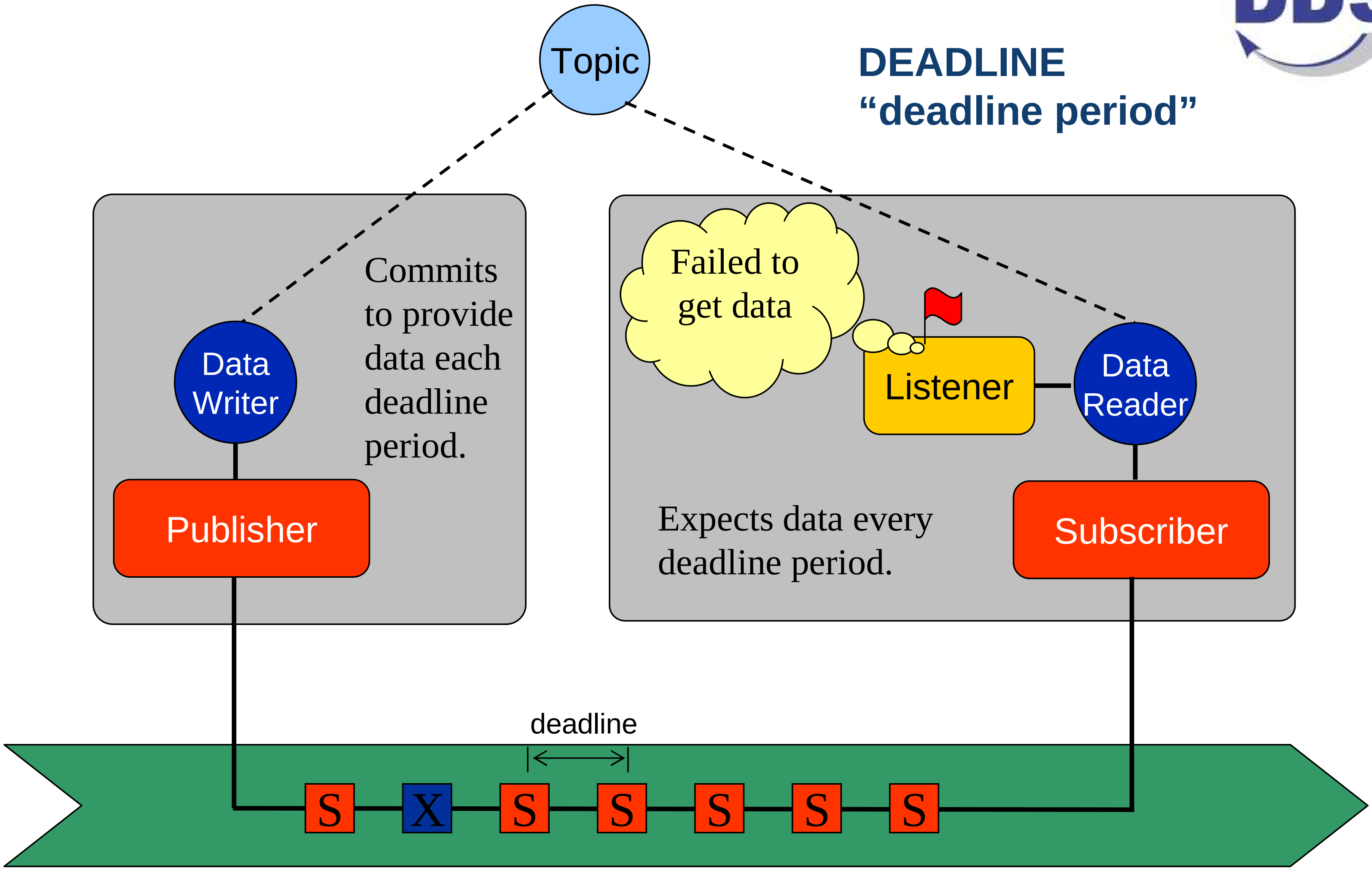
State Propagation

- System state
  - Information needed to describe future behavior of the system
    - System evolution defined by state and future inputs.
  - Minimalist representation of past inputs to the system
- State variables
  - Set of data-objects whose value codifies the state of the system
- Relationship with DDS
  - DDS well suited to propagate and replicate state
  - Topic+key can be used to represent state variables
  - KEEP_LAST history QoS exactly matches semantics of state-variable propagation

Present in many RT applications

Key ingredient for fault-tolerance

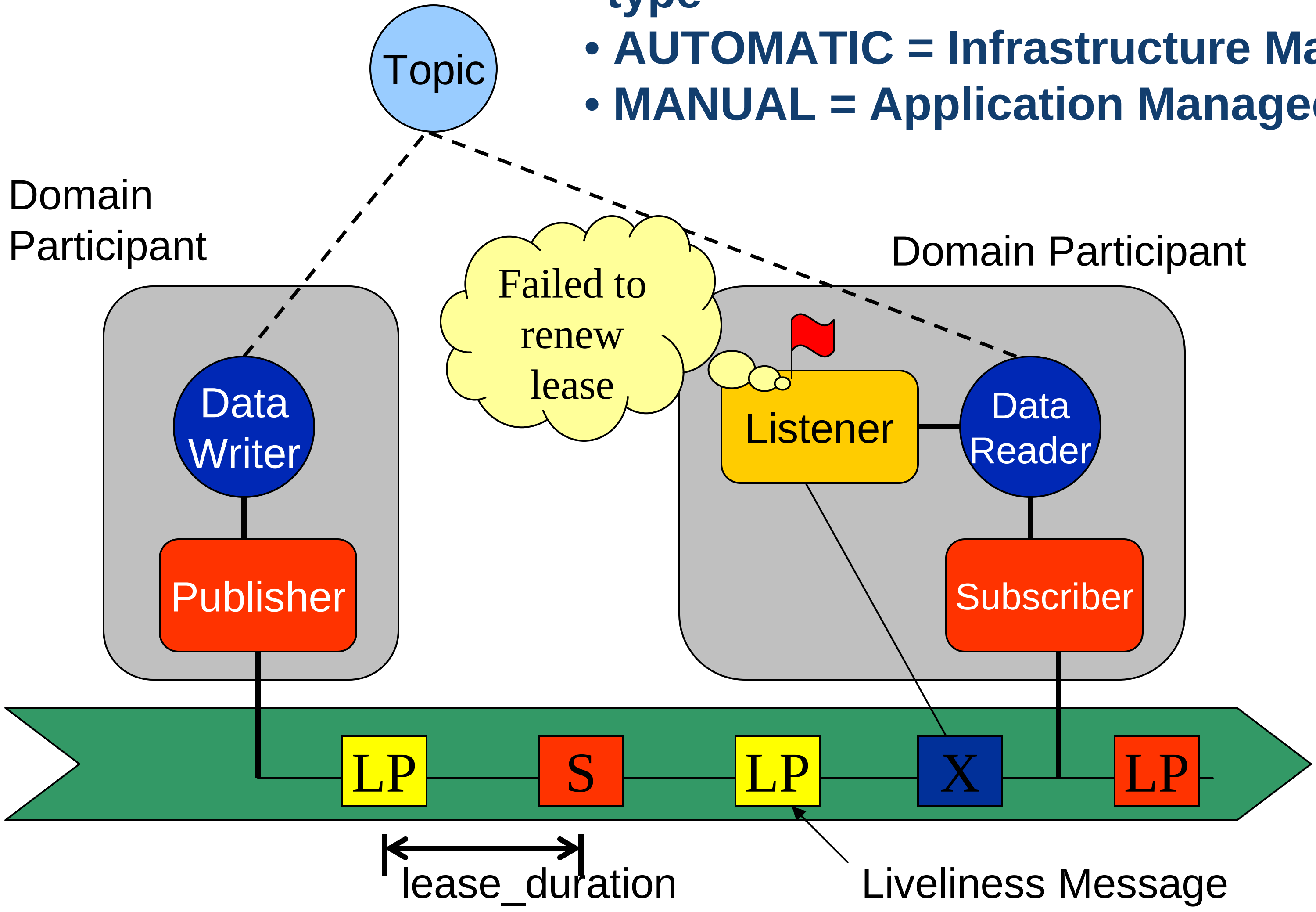
QoS: DEADLINE



QoS: LIVELINESS – Type, Duration

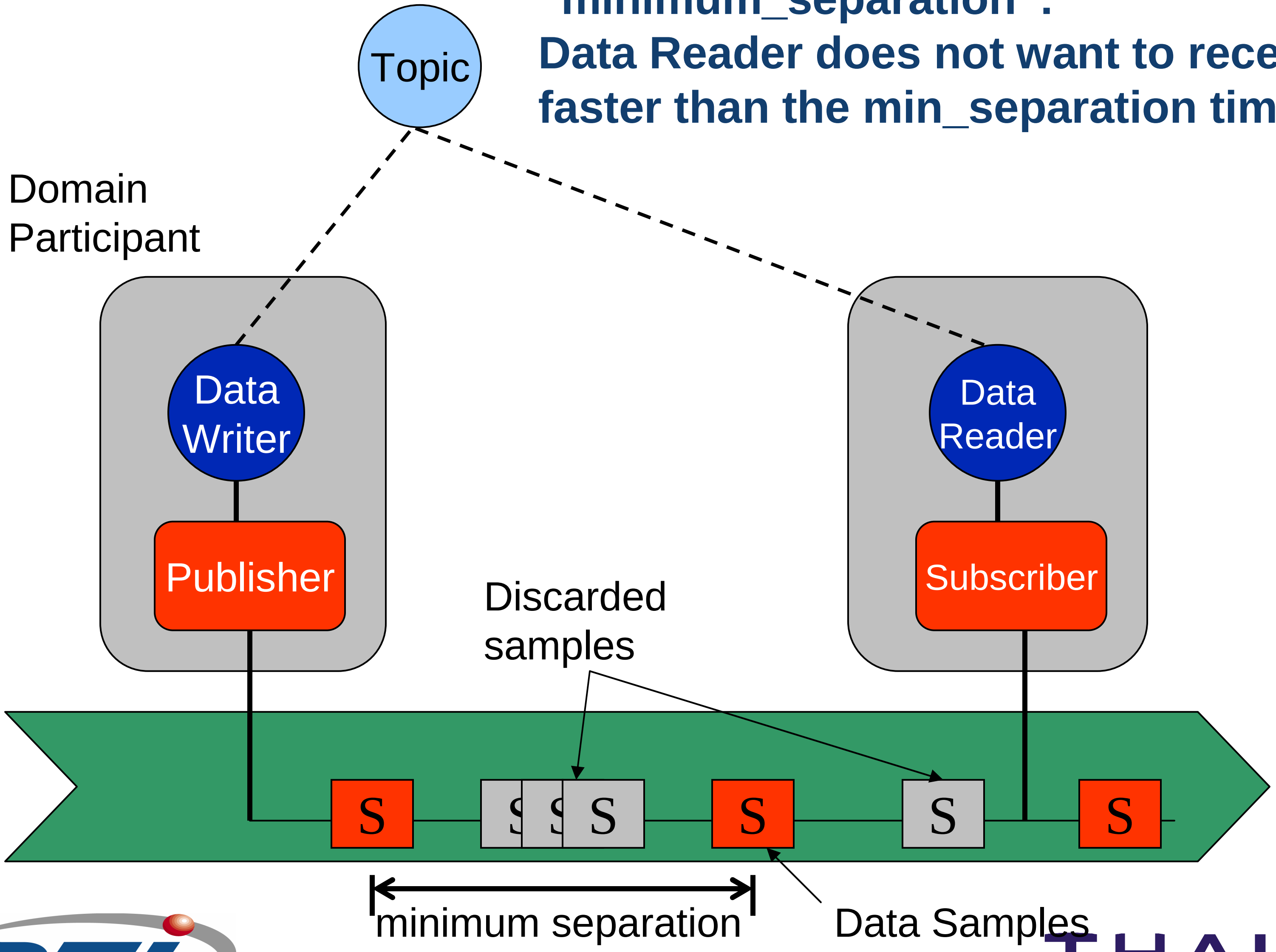
"type"

- **AUTOMATIC = Infrastructure Managed**
- **MANUAL = Application Managed**



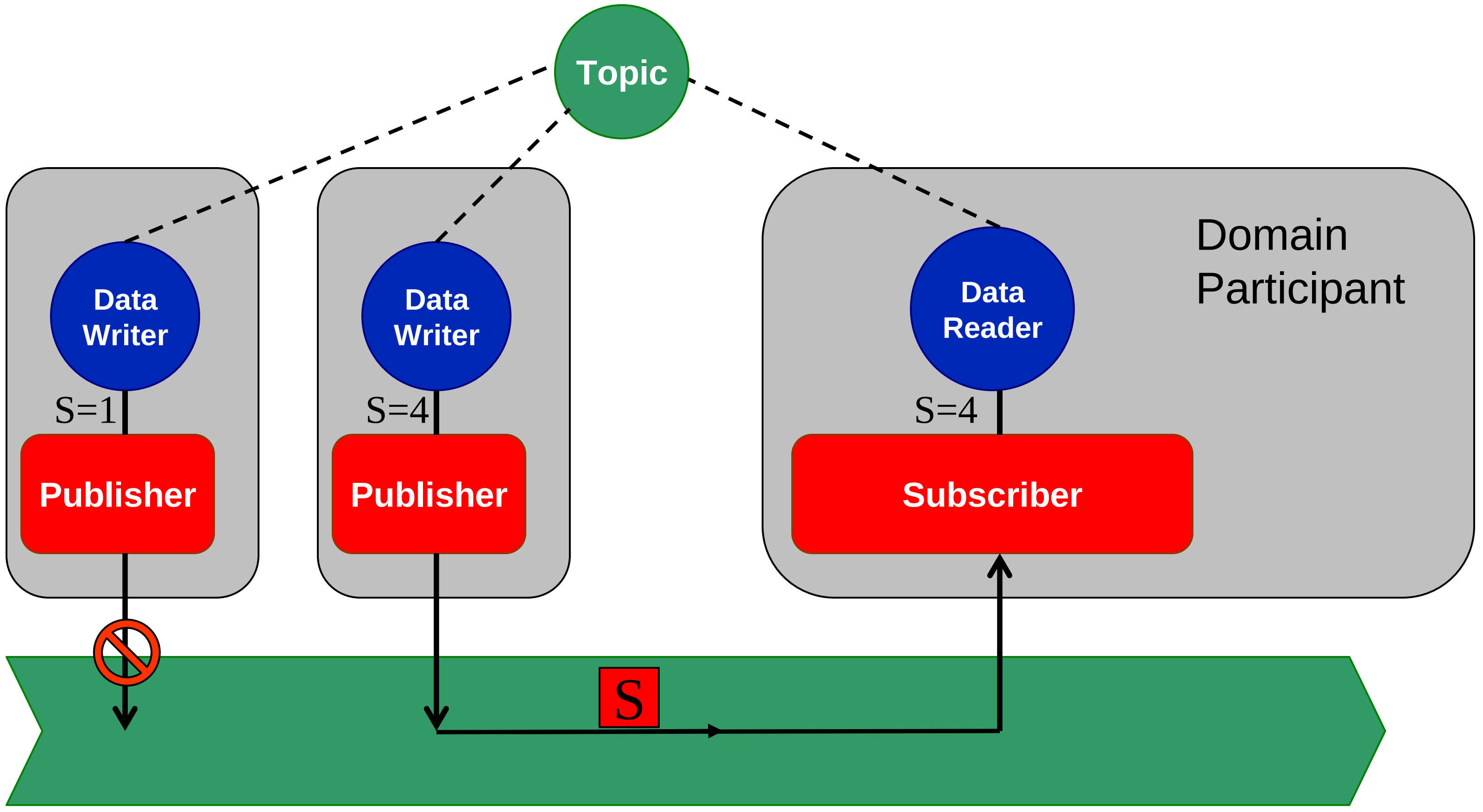
QoS: TIME_BASED_FILTER

"minimum_separation":
Data Reader does not want to receive data faster than the min_separation time



QoS: OWNERSHIP_STRENGTH

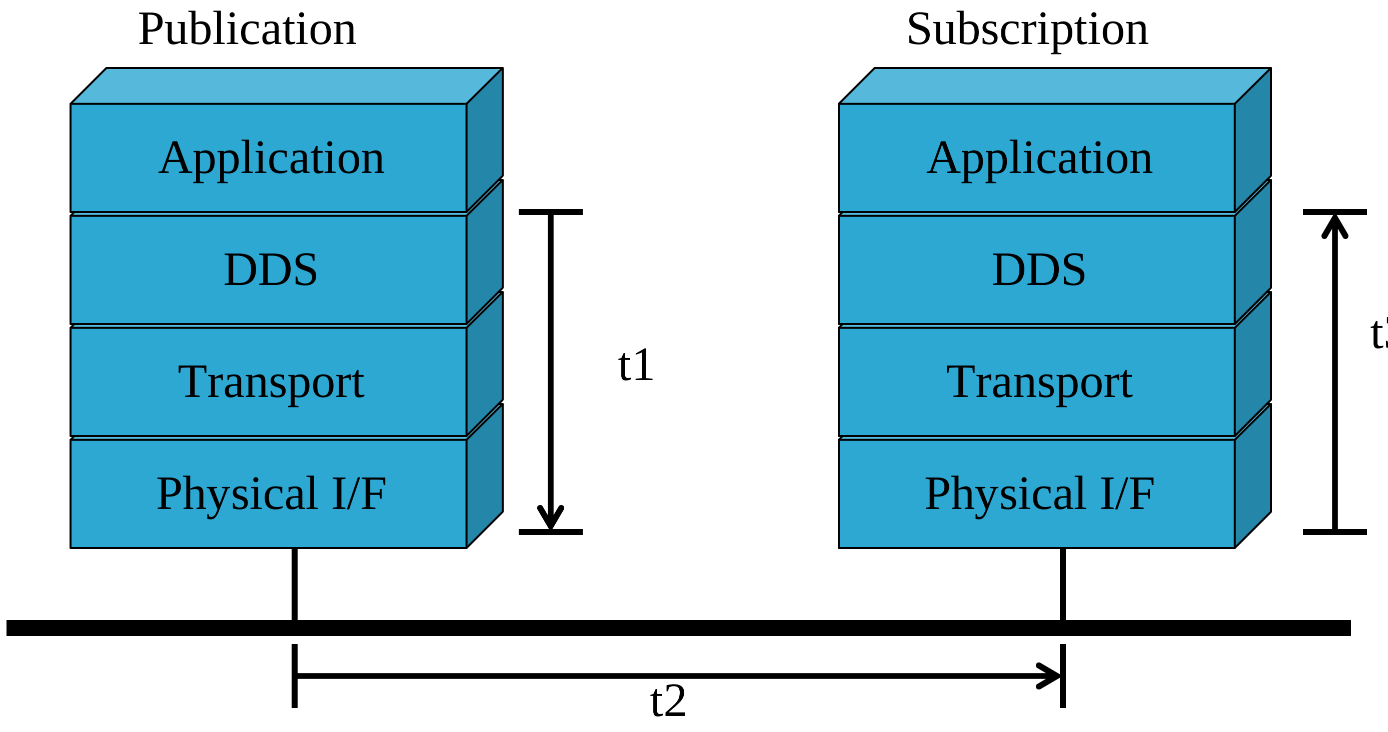
OWNERSHIP_STRENGTH:
Specifies which writer is allowed to update the values of data-objects



Note: Only applies to Topics with OWNERSHIP=Exclusive

QoS: LATENCY_BUDGET

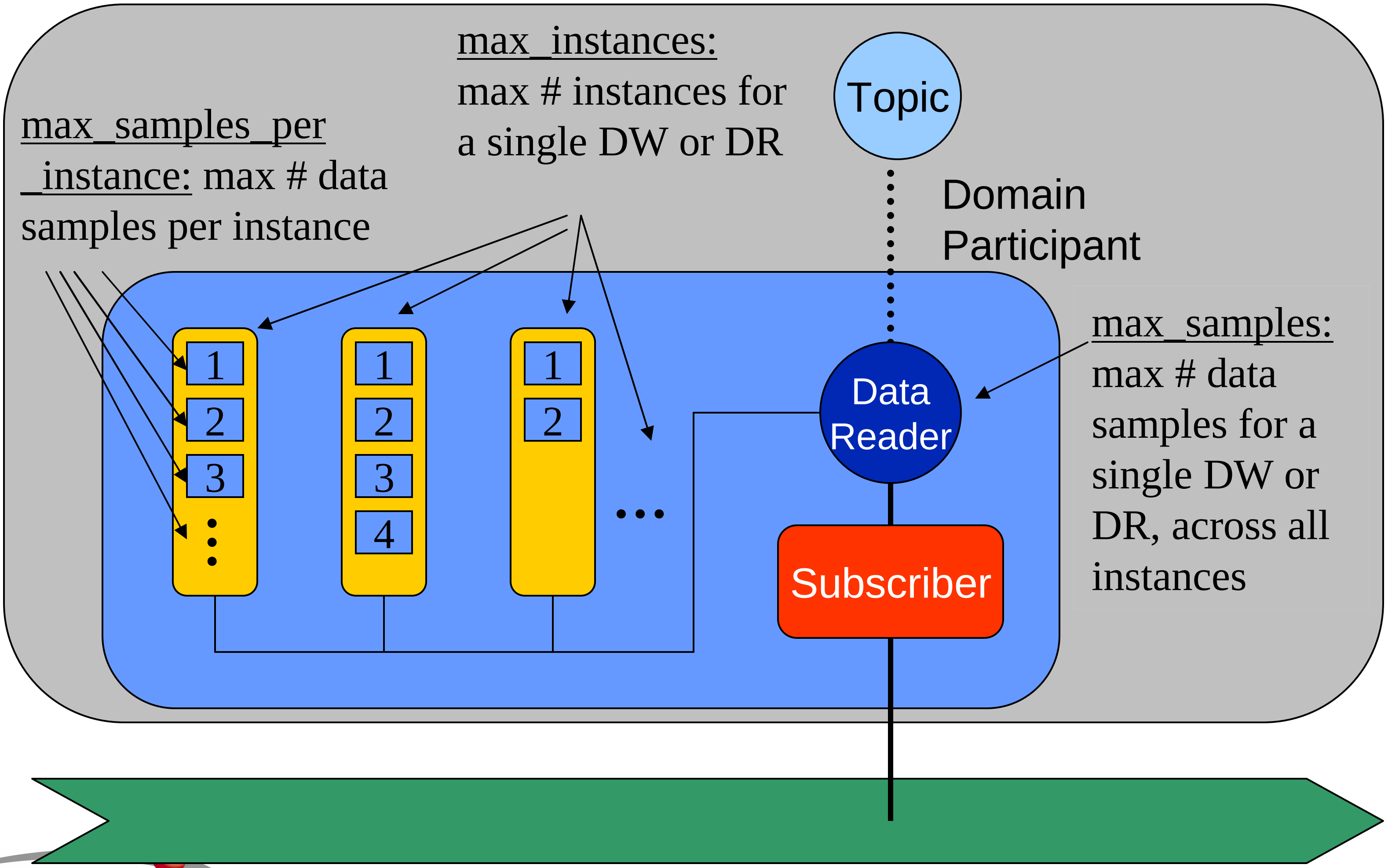
- Intended to provide time-critical information to the publisher for framework tuning where possible.
- Will not prevent data transmission and/or receipt.



Latency = t1 + t2 + t3

QoS: RESOURCE_LIMITS

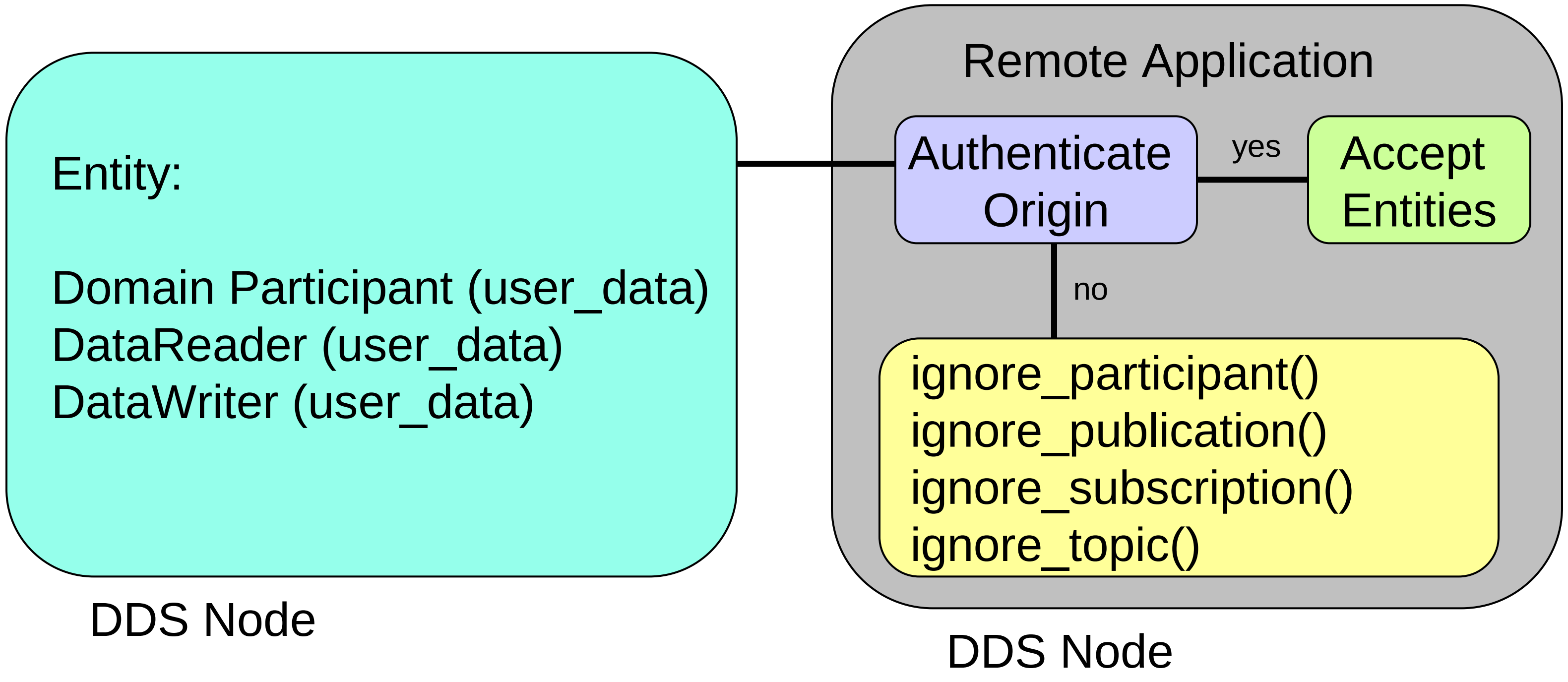
- Specifies the resources that the Service can consume to meet requested QoS



max_instances: max # instances for a single DW or DR
Topic
max_samples_per _instance: max # data samples per instance
Domain Participant
max_samples: max # data samples for a single DW or DR, across all instances
1
2
3
1
2
3
4
1
2
…
Data Reader
Subscriber

QoS: USER_DATA

- User-defined portion of Topic metadata
- Example of use: Security Authentication

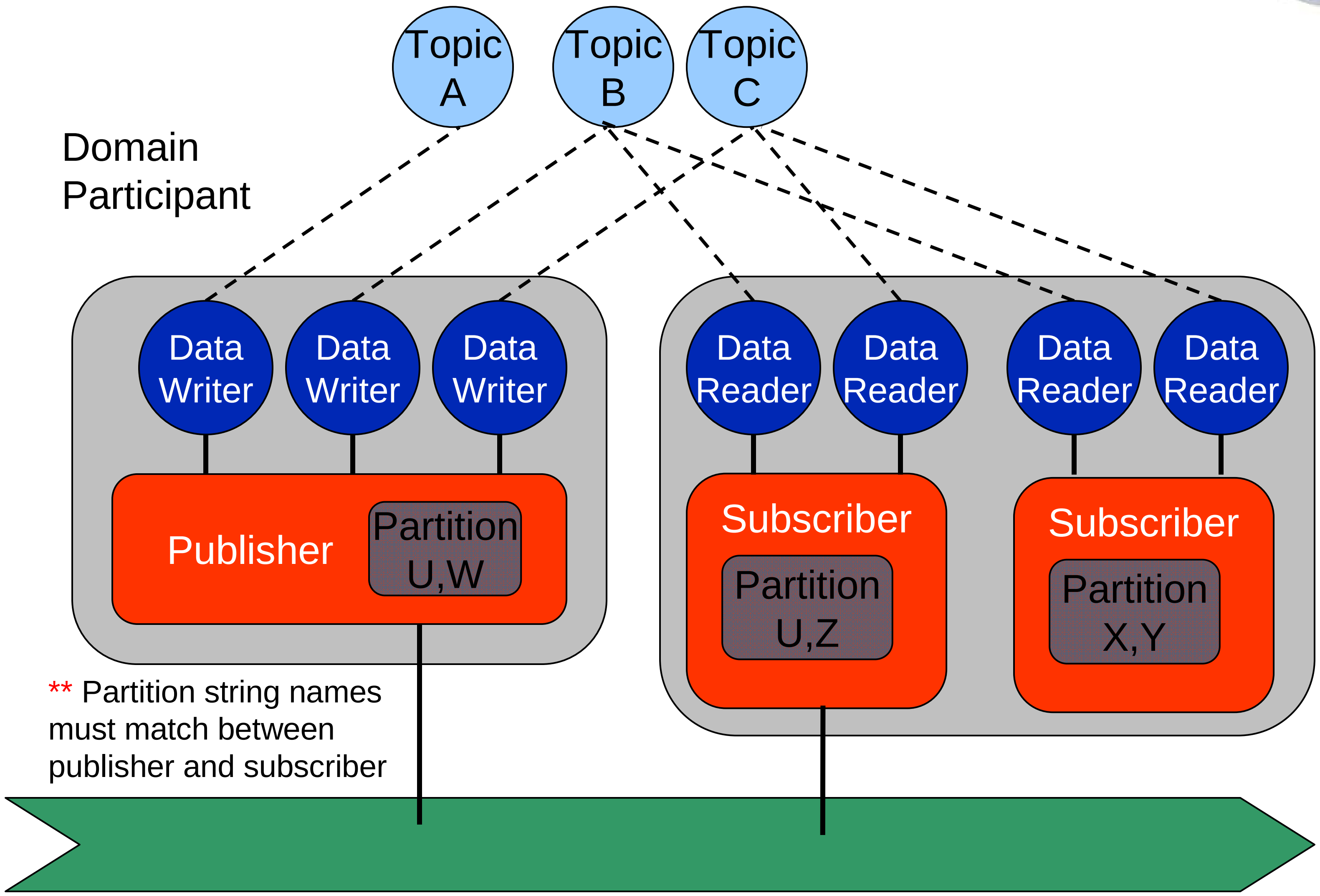


USER_DATA can be used to authenticate an origination entity.

Note: USER_DATA is contained within the DDS metadata.

QoS: PARTITION

Logical "namespace" for topics

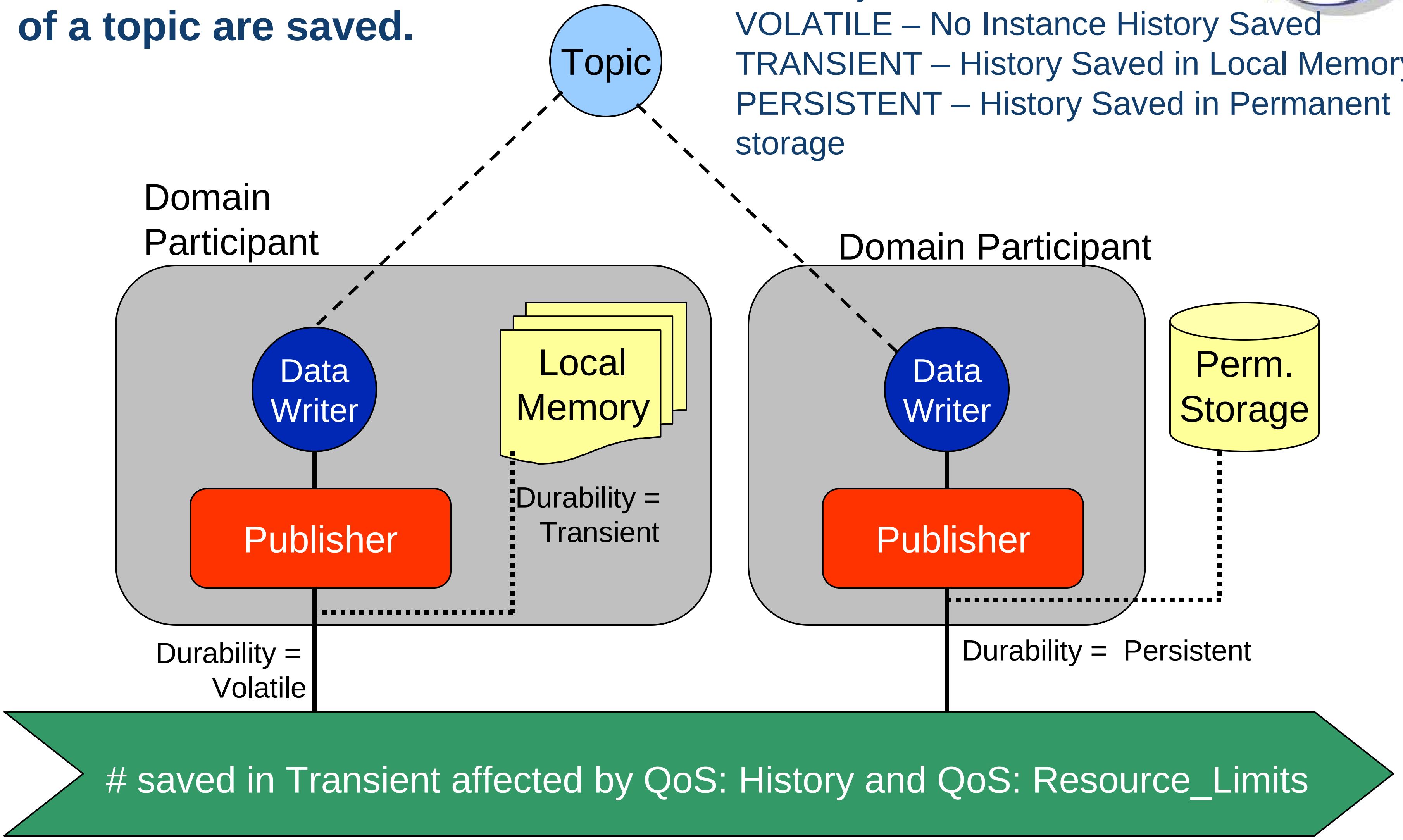


** Partition string names must match between publisher and subscriber

QoS: DURABILITY

Determines if/how instances of a topic are saved.

Durability Kind:
VOLATILE – No Instance History Saved
TRANSIENT – History Saved in Local Memory
PERSISTENT – History Saved in Permanent storage



QoS: PRESENTATION

Governs how related data-instance changes are presented to the subscribing application.

Type: Coherent Access and Ordered Access

- Coherent access: All changes (as defined by the Scope) are presented together.
- Ordered access: All changes (as defined by the Scope) are presented in the same order in which they occurred.

Scope: Instance, Topic, or Group

- Instance: The scope is a single data instance change. Changes to one instance are not affected by changes to other instances or topics.
- Topic: The scope is all instances by a single Data Writer.
- Group: The scope is all instances by Data Writers in the same Subscriber.

QoS: Quality of Service (1/2)

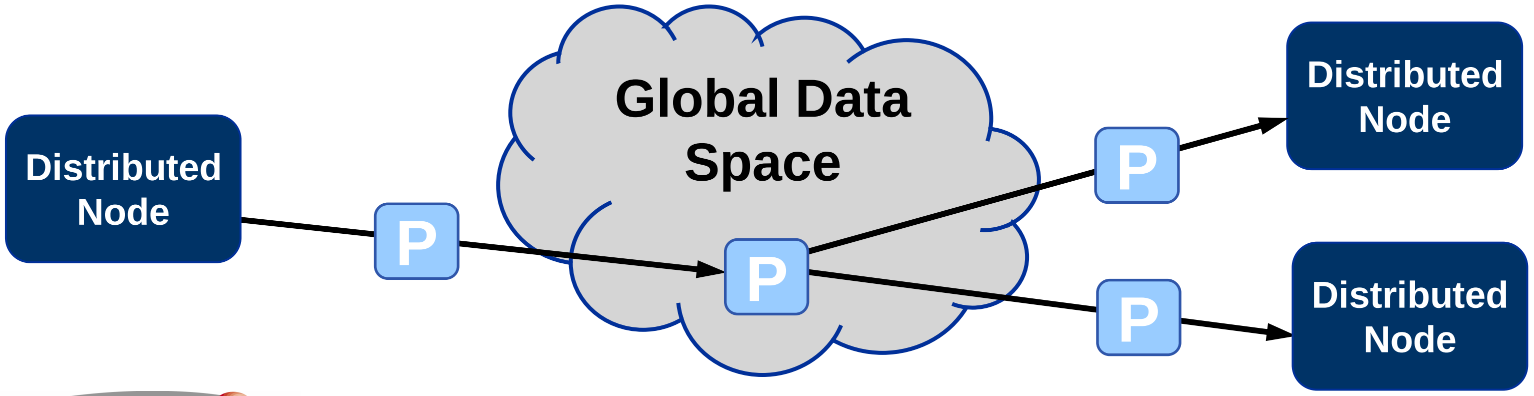
QoS Policy	Concerns	RxO	Changeable
DEADLINE	T,DR,DW	YES	YES
LATENCY BUDGET	T,DR,DW	YES	YES
READER DATA LIFECYCLE	DR	N/A	YES
WRITER DATA LIFECYCLE	DW	N/A	YES
TRANSPORT PRIORITY	T,DW	N/A	YES
LIFESPAN	T,DW	N/A	YES
LIVELINESS	T,DR,DW	YES	NO
TIME BASED FILTER	DR	N/A	YES
RELIABILITY	T,DR,DW	YES	NO
DESTINATION ORDER	T,DR	NO	NO

QoS: Quality of Service (2/2)

QoS Policy	Concerns	RxO	Changeable
USER DATA	DP,DR,DW	NO	YES
TOPIC DATA	T	NO	YES
GROUP DATA	P,S	NO	YES
ENTITY FACTORY	DP, P, S	NO	YES
PRESENTATION	P,S	YES	NO
OWNERSHIP	T	YES	NO
OWNERSHIP STRENGTH	DW	N/A	YES
PARTITION	P,S	NO	YES
DURABILITY	T,DR,DW	YES	NO
HISTORY	T,DR,DW	NO	NO
RESOURCE LIMITS	T,DR,DW	NO	NO

DDS-DCPS Summary

- DDS targets applications that need to distribute data in a real-time environment
- DDS is highly configurable by QoS settings
- DDS provides a shared “global data space”
  - **Any application can publish data it has**
  - **Any application can subscribe to data it needs**
  - **Automatic discovery**
  - **Facilities for fault tolerance**
  - **Heterogeneous systems easily accommodated**


Global Data Space
Distributed Node
P
P
P
P
Distributed Node
Distributed Node