Data Distribution Service

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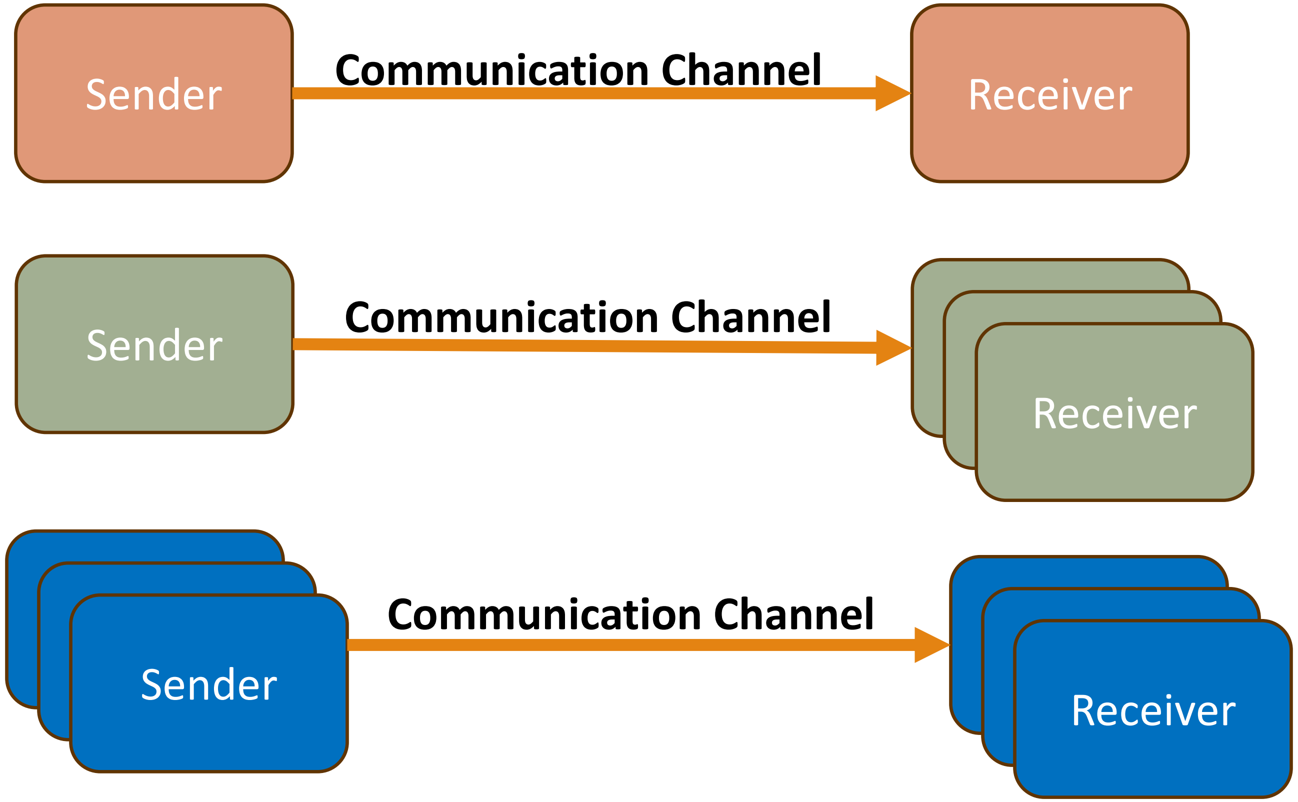
Communication Models

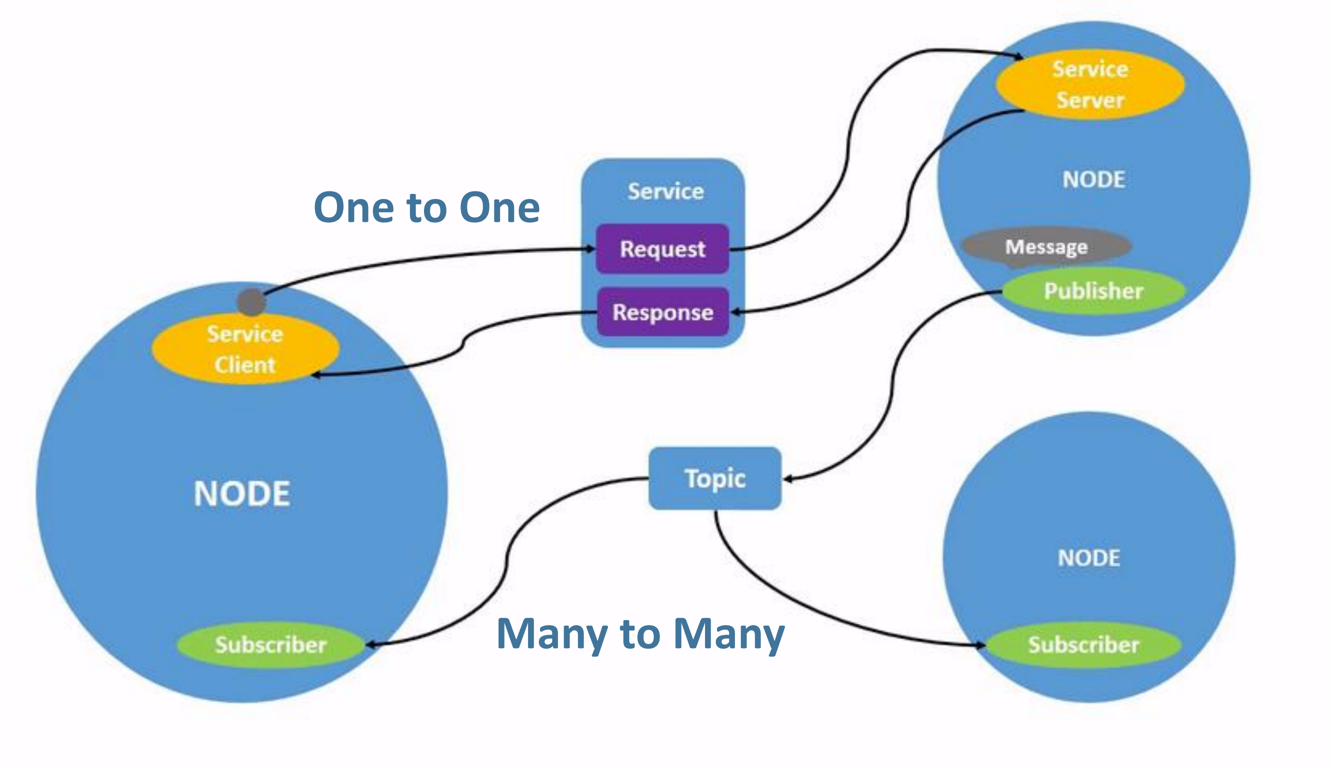
One to One — Sockets

One to Many — Server/Client

Many to Many — Pub/Sub

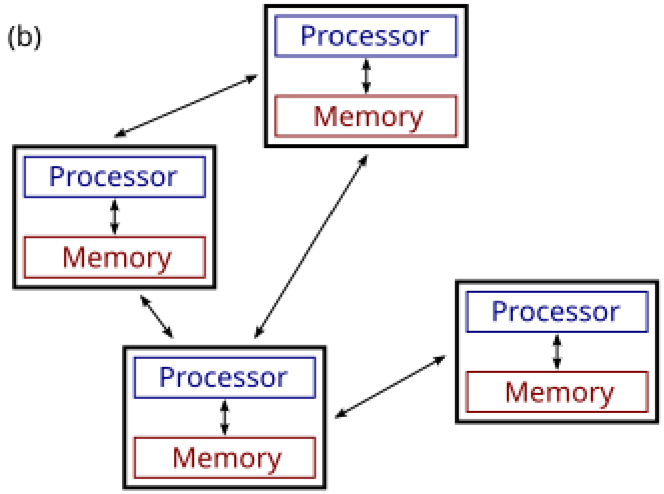


Robotics Communication Model (ROS)



What is DDS?

- A data-centric communication protocol for distributed software systems.
- Protocol is designed by **Object Management Group (OMG)**
- Based on the **Data-Centric Publish Subscribe (DCPS)** model.
  - **Publication Entities**: Define information-generating objects.
  - **Subscription Entities**: Define information-consuming objects.
  - **Configuration Entities**
- Defines **APIs** and **Communication Semantics** for data providers and consumers.



Example Project

DDS Middleware Implementations

- **Open-Source Implementations**
  - Fast DDS (eProsima)
    - High performance and low latency
    - Extensive QoS support and ROS2 compatibility
    - Apache-2.0 license
  - Cyclone DDS (Eclipse Foundation)
    - Lightweight and optimized for embedded systems.
    - Popular in ROS2 environments.
    - Eclipse-2.0

DDS Middleware Implementations

- **Commercial Implementations:**
  - RTI Connext DDS**:**
    - Industry-leading performance and reliability.
    - Comprehensive tools for monitoring and debugging.
  - OpenSplice DDS:
    - Focused on scalability and fault tolerance.
    - Offers both open-source and commercial versions.

Fast DDS

Key DCPS Elements

- **Publisher:**
  - Creates and configures **DataWriters**.
  - **DataWriter**: Handles the actual publication of data.
  - Publishes messages under assigned **Topics**.
- **Subscriber:**
  - Receives data published under subscribed **Topics**.
  - Manages **DataReaders** that notify the application of new data.

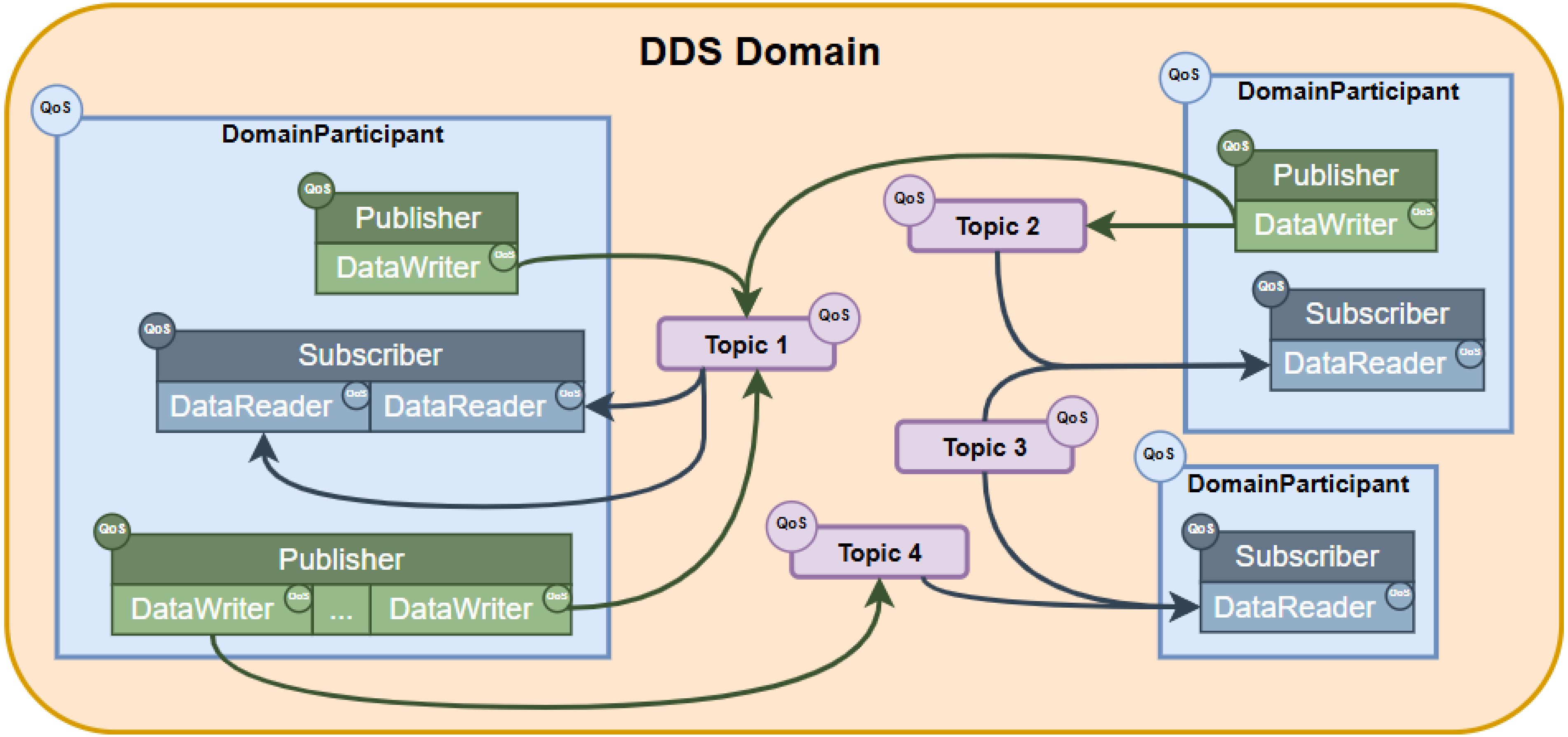
Key DCPS Elements

- **Topic:**
  - Binds publications and subscriptions.
  - Ensures uniform data types between publishers and subscribers.
  - Unique within a **DDS domain**.
- **Domain:**
  - Links all **Publishers** and **Subscribers** in a DDS domain.
  - Identified by a unique **domain ID:**
    - Different IDs create independent communication channels.
    - Prevents interference between multiple applications.

Key DCPS Elements

- **DomainParticipant:**
  - Defines the **domain ID** to specify the DDS domain it belongs to.
  - Acts as a **container** for DCPS Entities (**Publisher**, **Subscriber**, and **Topic**).
  - Serves as a **factory** for creating these entities.

DDS Model (DCPS)



Installing FastDDS (3.1.0)

- Download FastDDS Binaries

```
curl -o fastdds.tgz 'https://www.eprosima.com/component/ars/item/eProsima_Fast-DDS-v3.1.0-Linux.tgz?format=tgz&category_id=7&release_id=169&Itemid=0'
```

- Unzip fastdds.tgz

```
mkdir fastdds
tar -xvzf ./fastdds.tgz -C ./fastdds
cd fastdds
sudo ./install.sh
```

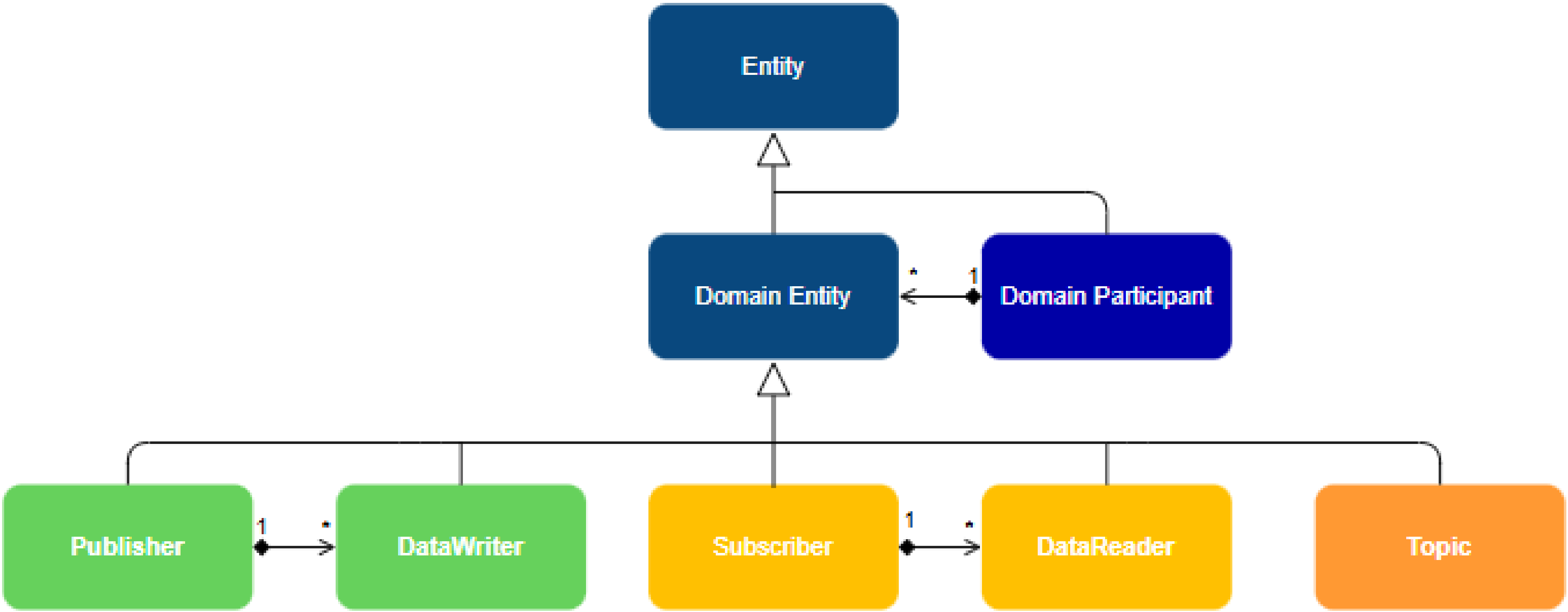
Linking DDS

Tasks.json → Adding gcc args

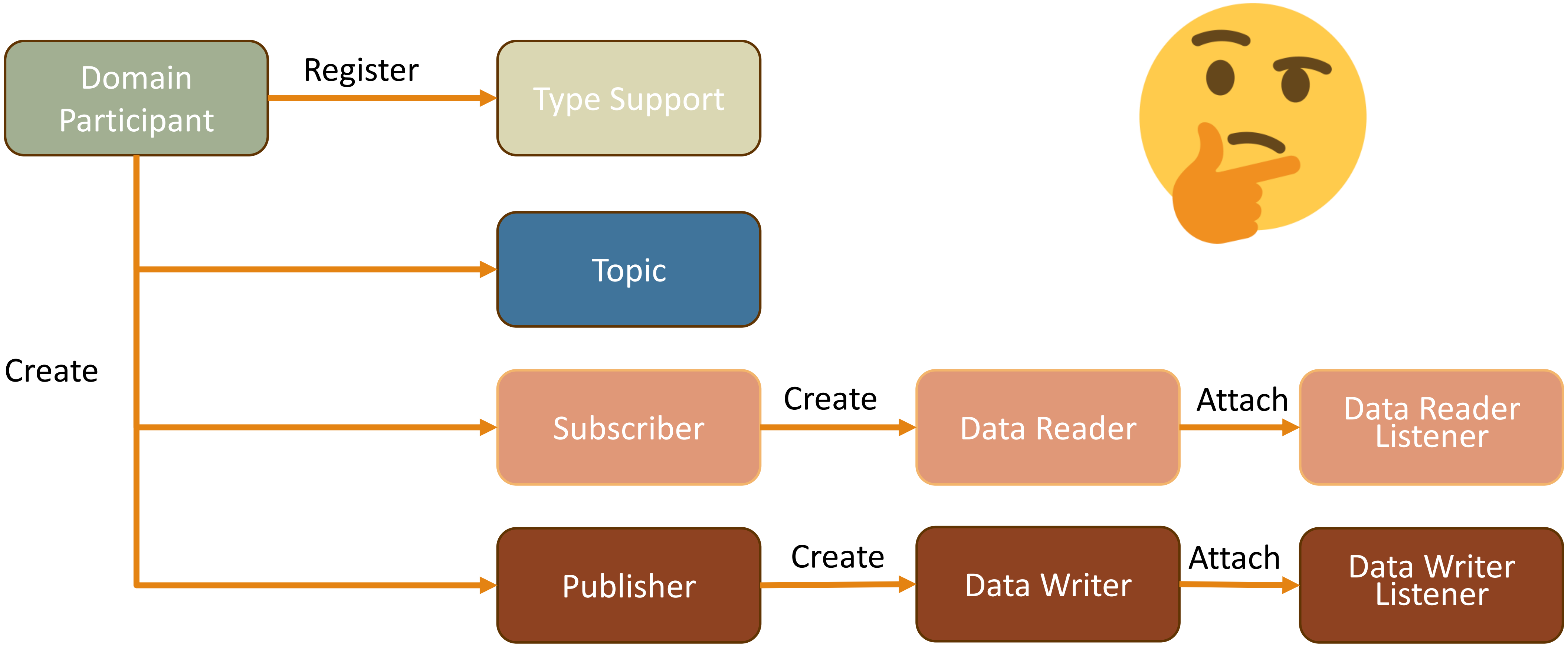
"-I/usr/include/fastdds" → FastDDS include directory
"-I/usr/include/fastcdr" → FastCDR include directory
"-std=c++11" → We want to use C++11
"-lstdc++" → link standard C++ library
"-lfastcdr" → link libfastcdr (for serialization and deserialization)
"-lfastdds" → link libfastdds

HelloWorld Example

Entities Relations



Entities Relations



Data Listeners

- **Data Reader Listener:** abstract class defining the callbacks that will be triggered in response to state changes on the **DataReader**.
  - `on_subscription_matched:` There is new data available for the application on the **DataReader**.
  - `on_data_available:` The **DataReader** has found a **DataWriter** that matches the **Topic**.

- **Data Write Listener:** abstract class defining the callbacks that will be triggered in response to state changes on the **DataWriter**.
  - `on_publication_matched:` **DataWriter** has found a **DataReader** that matches the **Topic**

Listeners Example

Type Support & IDL

- IDL: Interface Definition Language
- For Publisher and subscriber to be able to communicate they should agree on a message structure
- Message structure is defined using IDL
- To convert from IDL to Cpp we use **Fast DDS-Gen.**
- Fast DDS-Gen is not case sensitive (string message = string Message)

```
struct HelloWorld
{
    unsigned long index;
    string message;
};
```

Primitive Types

IDL	C++11
char	`char`
octet	`uint8_t`
short	`int16_t`
unsigned short	`uint16_t`
long	`int32_t`
unsigned long	`uint32_t`
long long	`int64_t`
unsigned long long	`uint64_t`
float	`float`
double	`double`
long double	`long double`
boolean	`bool`
string	`std::string`

Arrays(std::array)

IDL	C++11
char a[5]	`std::array<char,5> a`
octet a[5]	`std::array<uint8_t,5> a`
short a[5]	`std::array<int16_t,5> a`
unsigned short a[5]	`std::array<uint16_t,5> a`
long a[5]	`std::array<int32_t,5> a`
unsigned long a[5]	`std::array<uint32_t,5> a`
long long a[5]	`std::array<int64_t,5> a`
unsigned long long a[5]	`std::array<uint64_t,5> a`
float a[5]	`std::array<float,5> a`
double a[5]	`std::array<double,5> a`

Sequences (std::vector)

IDL	C++11
sequence<char>	`std::vector<char>`
sequence<octet>	`std::vector<uint8_t>`
sequence<short>	`std::vector<int16_t>`
sequence<unsigned short>	`std::vector<uint16_t>`
sequence<long>	`std::vector<int32_t>`
sequence<unsigned long>	`std::vector<uint32_t>`
sequence<long long>	`std::vector<int64_t>`
sequence<unsigned long long>	`std::vector<uint64_t>`
sequence<float>	`std::vector<float>`
sequence<double>	`std::vector<double>`

IDL to CPP Classes

```
fastddsgen ~/CustomIDL/src/MyMessage.idl -d ~/CustomIDL/src/Generated
```

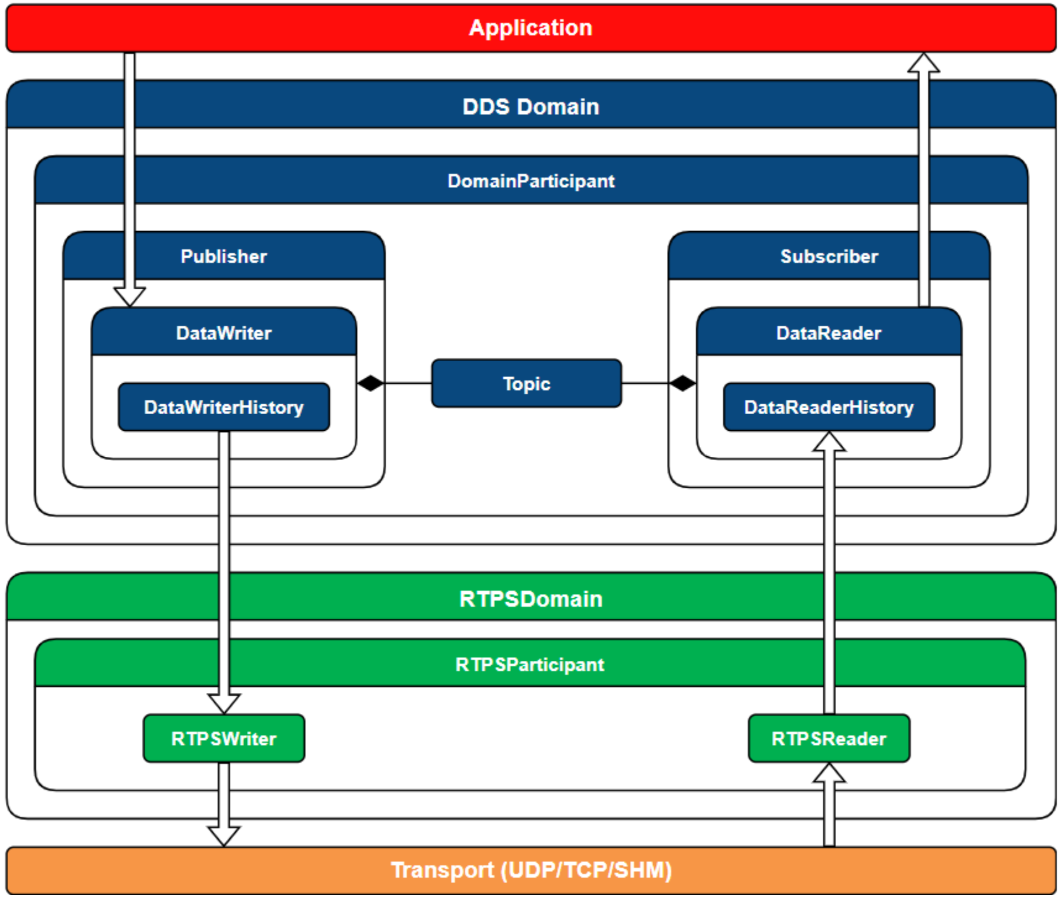
```
struct MyMessage
{
    unsigned long index;
    double first_number;
    double second_number;
};
```

Generated
- MyMessage.hpp
- MyMessageCdrAux.hpp
- MyMessageCdrAux.ipp
- MyMessagePubSubTypes.cxx
- MyMessagePubSubTypes.hpp
- MyMessageTypeObjectSupport.cxx
- MyMessageTypeObjectSupport.hpp

Header File to Include

CustomIDL Example

DDS Layer Model



This is our Application

DDS Layer that we use to build our App

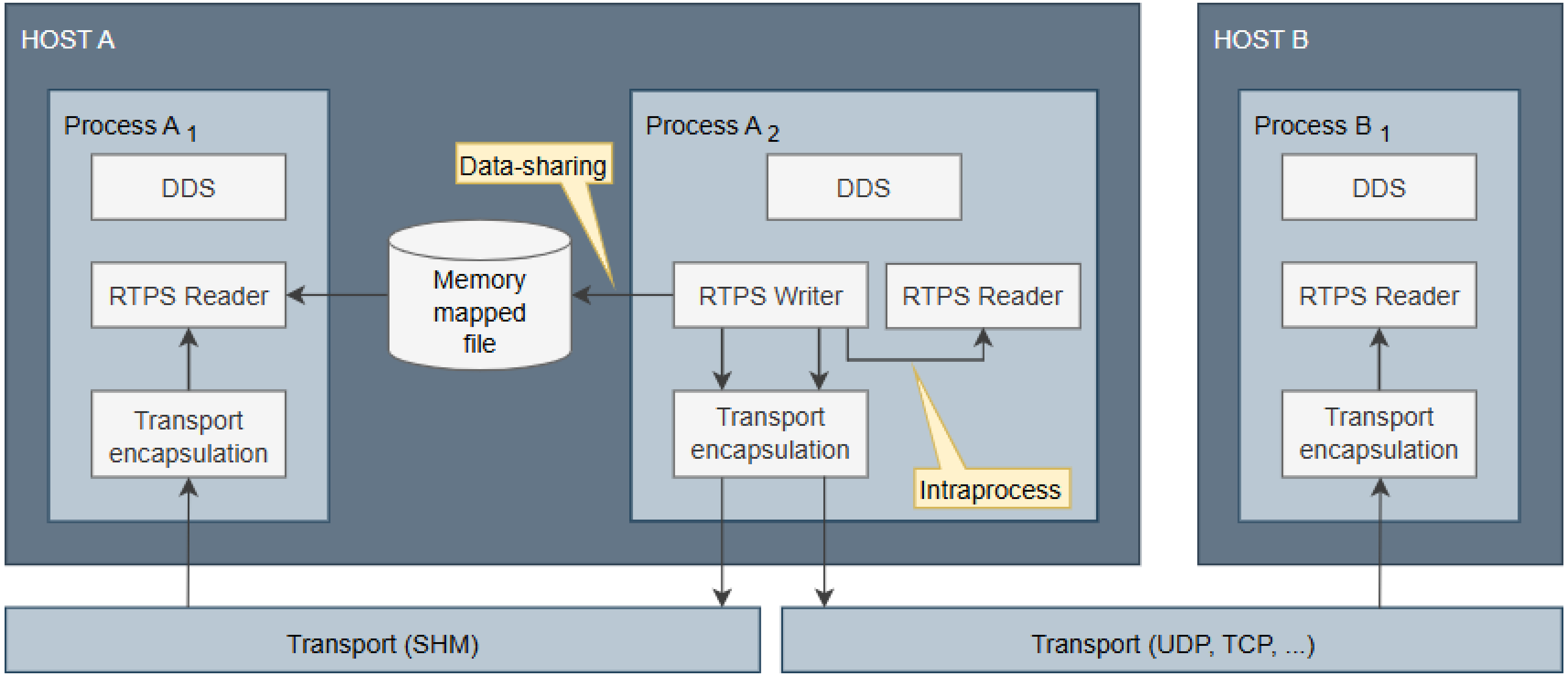
Abstraction of DDS application entities from the transport layer

Protocol that is going to be used by the App

Transport Layer

- **UDPv4**: UDP Datagram communication over IPv4. (Default Protocol)
- **UDPv6**: UDP Datagram communication over IPv6.
- **TCPv4**: TCP communication over IPv4.
- **TCPv6**: TCP communication over IPv6.
- **SHM**: Shared memory communication among entities running on the same host.

Transport Layer



Transports Example

Selecting a Transport

- By default, UDPv4 is used.

```
Starting publisher.
Publisher matched.
Using UDPv4
```

```cpp
// Explicit configuration of shm transport
participantQos.transport().use_builtin_transports = false;
auto shm_transport = std::make_shared<SharedMemTransportDescriptor>();
shm_transport->segment_size(10 * 1024 * 1024);
participantQos.transport().user_transports.push_back(shm_transport);
```

```
Starting subscriber.
Subscriber matched.
Using Shared Memory
```

Introduction to Discovery in Fast DDS

- A mechanism for **automatic identification** of participants (publishers and subscribers) in a distributed system.
- Why is Discovery Important?
  - **Dynamic Networks**: Allows participants to join and leave the system dynamically.
  - **Automatic Matching**: Identifies compatible publishers and subscribers based on Topics, Data Types, Quality of Service (QoS).

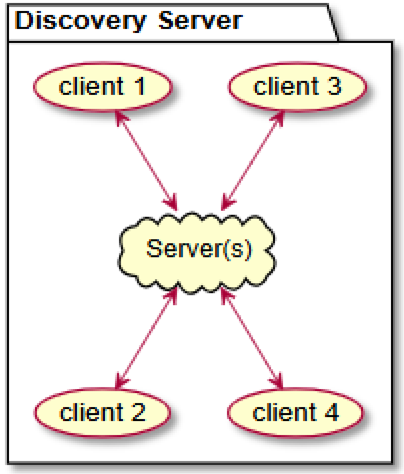
Discovery Phases in Fast DDS

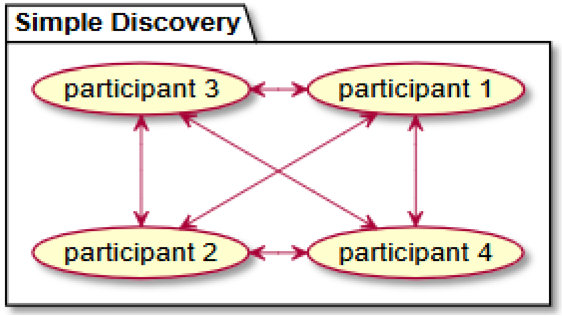
- Participant Discovery Phase (PDP):
  - DomainParticipants acknowledge each other's existence.
  - **Matching Criteria**: Must be in the same DDS Domain

- Endpoint Discovery Phase (EDP):
  - DataWriters and DataReaders acknowledge each other.
  - **Matching Criteria**: Topic and data type must match.

Discovery mechanisms

- Simple Discovery: This is the default mechanism. It uses Multicast for discovery.
- Static Discovery: Requires preconfiguring participant information (e.g., IP addresses). Use an XML configuration file to define static participants.
- Discovery Server: A **Discovery Server** acts as a central point where participants registers and participants query the server to find and match endpoints.





Static Discovery

- An xml configuration is required
- Xml contains all the participants and their respective Protocols, Ips, and Ports
- Then this xml file should be loaded at the level of DomainParticipantQos

```xml
<profiles>
    <participant profile_name="static_discovery">
        <rtps>
            <builtin>
                <initialPeersList>
                    <locator>
                        <udpv4> <!-- Participant protocol -->
                            <address>172.17.0.3</address> <!-- Participant IpV4 -->
                            <port>7412</port> <!-- Participant port -->
                        </udpv4>
                    </locator>
                </initialPeersList>
            </builtin>
        </rtps>
    </participant>
</profiles>
```

```cpp
DomainParticipantQos pqos;

pqos.wire_protocol().builtin.discovery_config.use_SIMPLE_EndpointDiscoveryProtocol = false;
pqos.wire_protocol().builtin.discovery_config.use_STATIC_EndpointDiscoveryProtocol = true;
pqos.wire_protocol().builtin.discovery_config.static_edp_xml_config("file://static_discovery.xml");
```

Discovery Server

- DomainParticipants may be *clients* or *servers*.
- A **SERVER** is a participant to which the *clients* (and maybe other *servers*) send their discovery information.
- A **CLIENT** is a participant that connects to one or more servers from which it receives only the discovery information they require to establish communication with matching endpoints.
- A **SUPER_CLIENT** is a client that receives the discovery information known by the server, in opposition to clients, which only receive the information they need.

```
DomainParticipantQos pqos;

pqos.wire_protocol().builtin.discovery_config.discoveryProtocol =  DiscoveryProtocol::CLIENT;
pqos.wire_protocol().builtin.discovery_config.discoveryProtocol =  DiscoveryProtocol::SUPER_CLIENT;
pqos.wire_protocol().builtin.discovery_config.discoveryProtocol =  DiscoveryProtocol::SERVER;
```

Discovery Server

```
DomainParticipantQos participantQos;
participantQos.wire_protocol().builtin.discovery_config.discoveryProtocol = DiscoveryProtocol::CLIENT;
Locator_t locator;
locator.port = 8888;
IPLocator::setIPv4(locator, 127,0,0,1);
participantQos.wire_protocol().builtin.discovery_config.m_DiscoveryServers.push_back(locator);
```

Client

```
DomainParticipantQos qos;
qos.builtin.discovery_config.discoveryProtocol = DiscoveryProtocol_t::SERVER;
qos.builtin.discovery_config.m_DiscoveryServers.push_back(eprosima::fastrtps::rtps::Locator_t());
DomainParticipant* participant = DomainParticipantFactory::get_instance()->create_participant(0, qos);
```

Server

Advantages of Each Approach

- **Simple Discovery Protocol**:
  - Best for small networks with dynamic participants.
  - No extra configuration needed.
- **Static Discovery**:
  - Useful for stable, preconfigured networks.
  - Reduces discovery time.
- **Client-Server Discovery**:
  - Scales well in large, distributed systems.
  - Minimizes multicast traffic for discovery.