Evolving Messages Over Time - REP-2011

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Overview

- Conceptual Overview of REP-2011
- New Features Needed in ROS 2
- Dive into Run-Time Interface Reflection
- Future Work and Known Issues

REP-2011

Motivation for REP-2011

Reasons for this REP:

- It is natural for types to evolve over time
  - In your projects
  - And in ROS 2 itself
- We need tools to detect when this happens
- We need tools to help transition between versions

The Problem

In ROS 2 today:

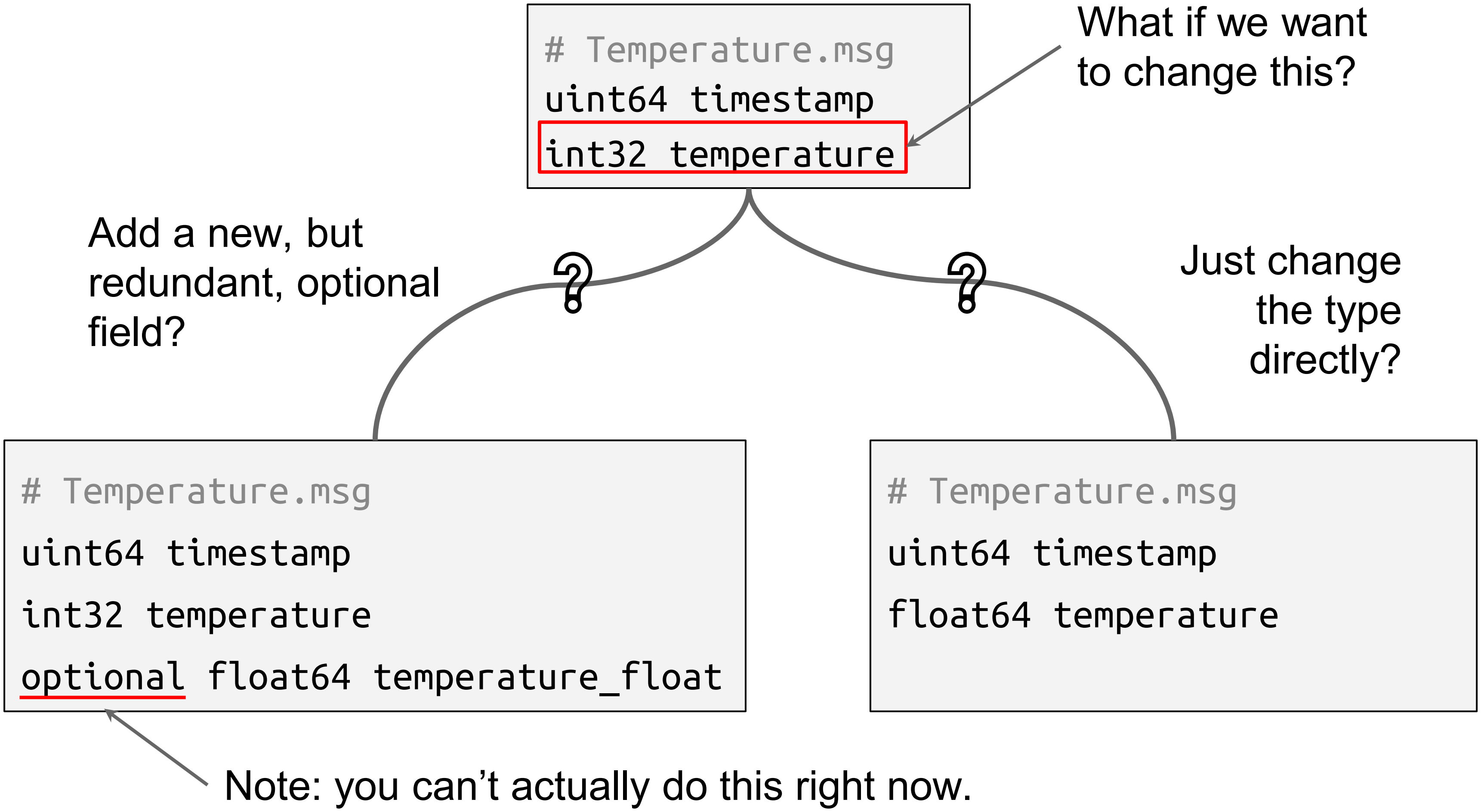
- If you try to change a type unevenly across your system:
  - Some middlewares may allow communication, depending on the change
  - Warnings/errors when types are incompatible vary
  - Limited features exposed in ROS 2 to help you evolve types in a backward/forward way

The Problem - Example

```
# Temperature.msg
uint64 timestamp
int32 temperature
```

What if we want to change this?

The Problem - Example



```
# Temperature.msg
uint64 timestamp
int32 temperature
```

What if we want to change this?

Add a new, but redundant, optional field?

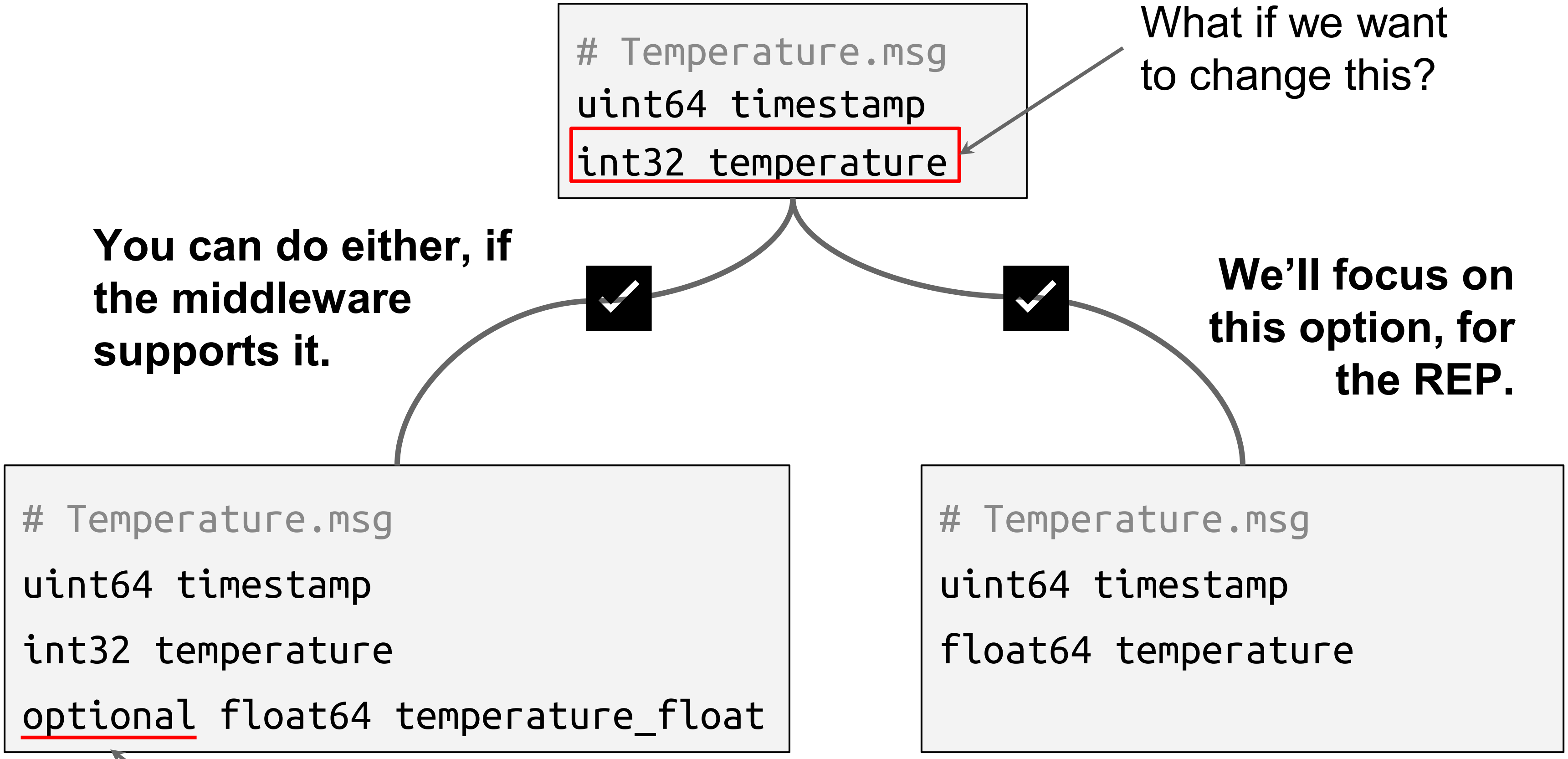
Just change the type directly?

```
# Temperature.msg
uint64 timestamp
int32 temperature
optional float64 temperature_float
```

```
# Temperature.msg
uint64 timestamp
float64 temperature
```

Note: you can’t actually do this right now.

The Problem - Example



```
# Temperature.msg
uint64 timestamp
int32 temperature
```

What if we want to change this?

You can do either, if the middleware supports it.

We'll focus on this option, for the REP.

```
# Temperature.msg
uint64 timestamp
int32 temperature
optional float64 temperature_float
```

```
# Temperature.msg
uint64 timestamp
float64 temperature
```

Note: you can't actually do this right now.

The Proposed Solution

- REP-2011:
  - https://github.com/ros -infrastructure/rep/pull/358
- REP-2011 aims to help users:
  - Know when messages have changed
  - Convert between versions on demand
  - Write code to convert between versions
- It will do so by depending on the ability to:
  - Interact with types using only their description
- This REP does not try to:
  - Expose “advanced” serialization features like optional fields, extensible types, or inheritance
  - Prevent these “advanced” features from working

What will this look like in practice?

```
% ros2 topic echo /scan sensor_msgs/msg/LaserScan
[WARN] [1666081526.522630000] [ros2_bag]: Publisher '[gid...]' on topic '/scan' is
using a version of 'sensor_msgs/msg/LaserScan' ('abc123') that does not match the
version used locally ('def456').
```

```
% ros2 interface transfer_functions info sensor_msgs/msg/LaserScan abc123 def456
Conversion available with transfer functions:
  - [abc123 -> cba321]:
    - pkg: sensor_msgs_migration
    - description: new field added to describe ...
  - [cba321 -> def456]:
    - pkg: sensor_msgs_migration
    - description: changed the type of field ...
```

Subject to change

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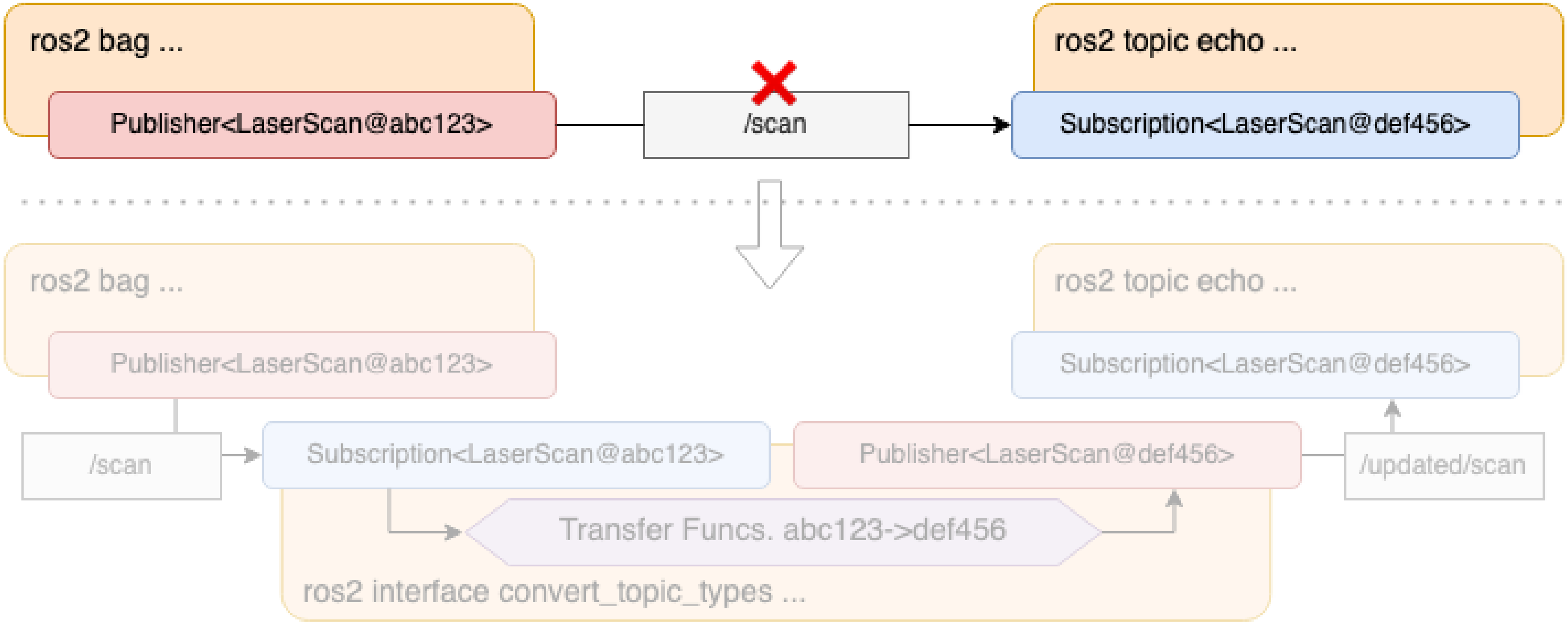
What will this look like in practice?


ros2 bag ...
Publisher<LaserScan@abc123>
/scan
ros2 topic echo ...
Subscription<LaserScan@def456>
ros2 bag ...
Publisher<LaserScan@abc123>
ros2 topic echo ...
Subscription<LaserScan@def456>
/scan
Subscription<LaserScan@abc123>
Publisher<LaserScan@def456>
/updated/scan
Transfer Funcs. abc123->def456
ros2 interface convert_topic_types ...

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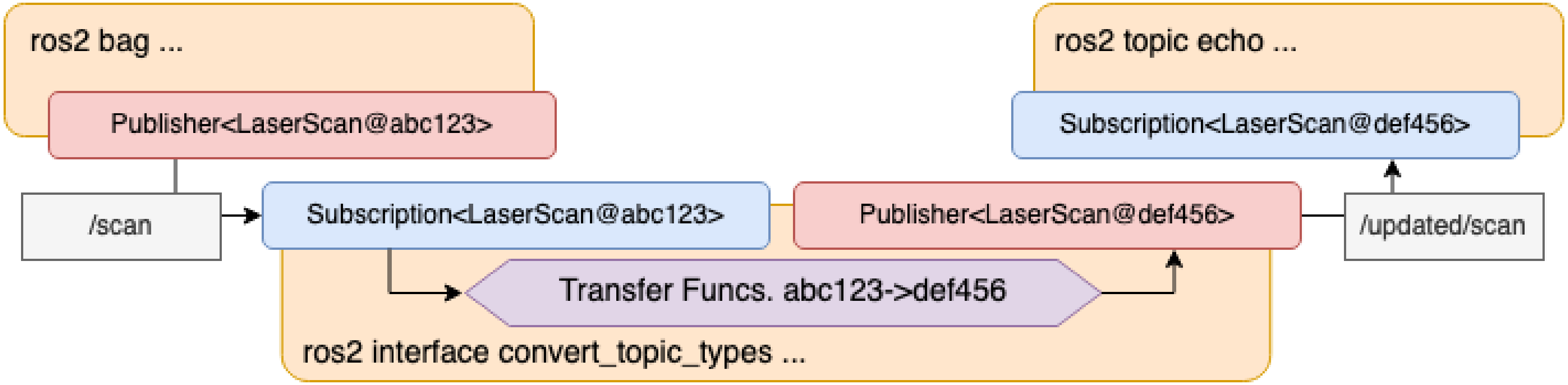
What will this look like in practice?

```
% ros2 interface convert_topic_types \
    --from /scan \
    --to /updated/scan \
    # --component-container <container name>
```


ros2 bag ...
Publisher<LaserScan@abc123>
/scan
Subscription<LaserScan@abc123>
Publisher<LaserScan@def456>
Transfer Funcs. abc123->def456
ros2 interface convert_topic_types ...
ros2 topic echo ...
Subscription<LaserScan@def456>
/updated/scan

```
% ros2 topic echo /updated/scan sensor_msgs/msg/LaserScan
...
```

What will this look like in practice?

- Ways to set up conversions:
    - as a stand-alone node
    - as a node component
    - syntactic sugar in a launch file
- Benefits of this approach:
    - keeps QoS and queuing in middleware
    - easy to observe from tools (e.g. `rqt_graph`)
- Downsides of this approach:
    - requires extra topics and hops through pub/sub
    - requires transfer functions to exist

Needed Underlying Technical Changes

- TypeDescription.msg
  - Description of Other Message/Service/etc.
- Type Version Hashing and Enforcement
  - Generation and Access via ROS Graph APIs
- Type Description Distribution
  - Accessing definition of types remotely
- Run-Time Interface Reflection
  - Interacting with types using only the TypeDescription, i.e. reading, writing, sending, and receiving

Run-Time Interface Reflection

The Context

Normally for ROS:

Message files → Compile-time Generated Code and Headers

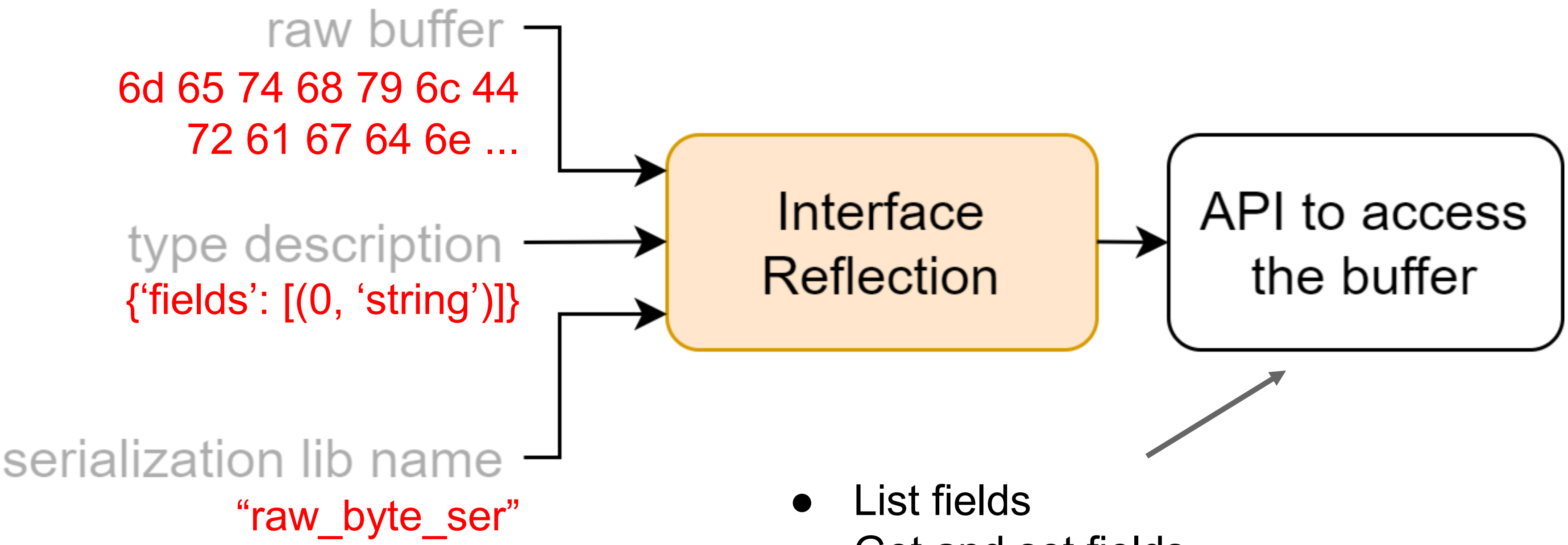
- E.g. String.msg → std_msgs::msg::String (std_msgs/msg/string.hpp)

But what if…

- You don’t have the message headers
- But you obtain the message description at runtime
  - E.g. From a bagfile, published over a topic, etc.

Run-time Interface Reflection

“At run -time, given a byte buffer and its description…
Can we access its members?”



raw buffer

6d 65 74 68 79 6c 44
72 61 67 64 6e ...

type description

{‘fields’: [(0, ‘string’)]}

serialization lib name

“raw_byte_ser”

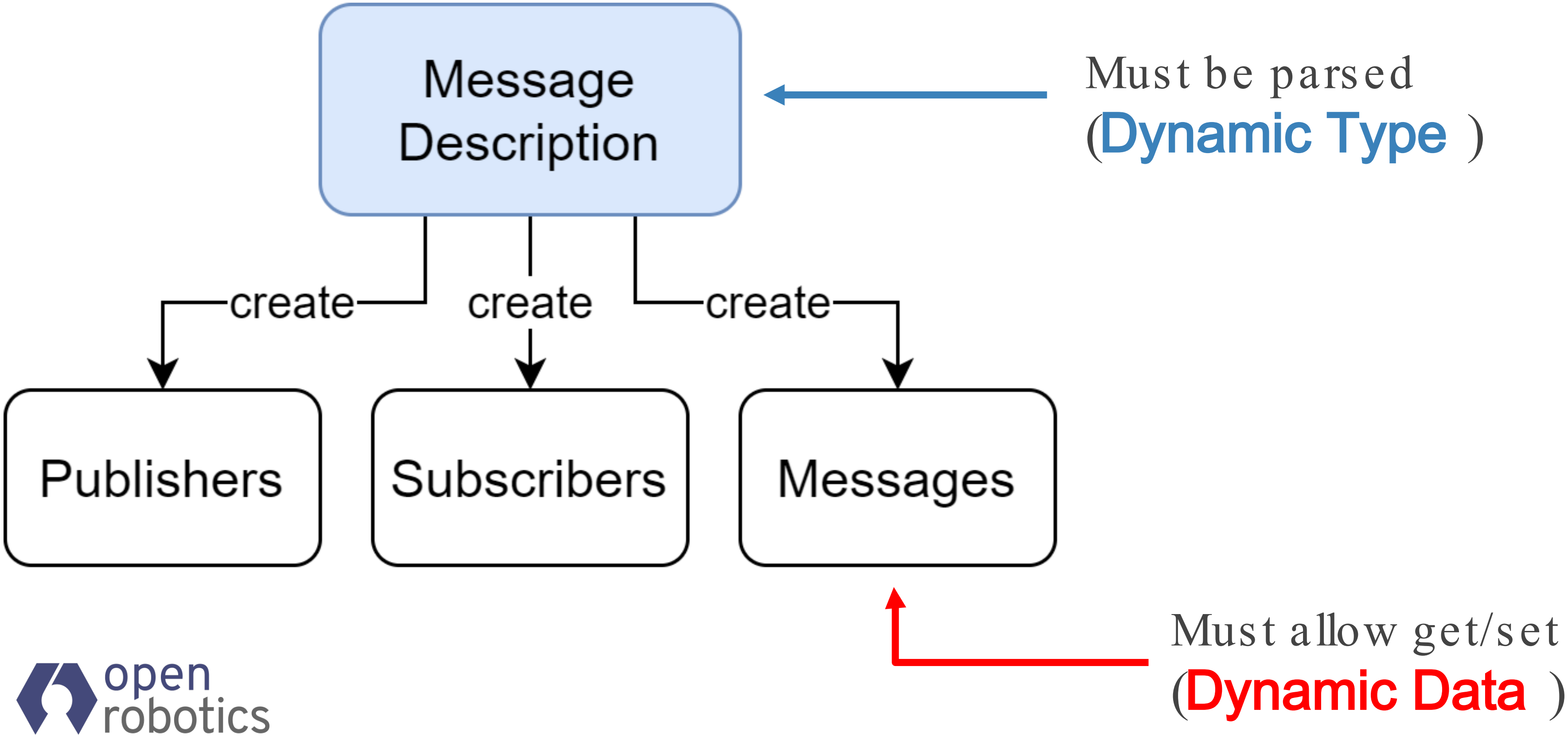
Interface Reflection

API to access the buffer

- List fields
- Get and set fields
- Construct new message instances
- …

Pub-Sub (At run-time)

Using **interface reflection** , and a **message description** , dynamically create at run-time…



Message Description

create

create

create

Publishers

Subscribers

Messages

Must be parsed (Dynamic Type)

Must allow get/set (Dynamic Data)

Pub-Sub (At run-time)

Pub

1. Parse **description** to create a **dynamic type**
2. Use **dynamic type** to create **dynamic data**
3. Publish **dynamic data**

Sub

1. Receive **dynamic data**
2. Parse **description** to create a **dynamic type**
3. Use **dynamic type** to access **dynamic data**

How will run-time interface reflection be implemented?

Reflection for Different Technologies

For most technologies, we can just create a wrapper

Technology	Dynamic Type	Dynamic Data
FastRTPS (C++)	DynamicType	DynamicData
RTI Connext (C)	DDS_TypeCode	DDS_DynamicData
Protobuf (C++)	FileDescriptorProto	DynamicMessage
…	…	…

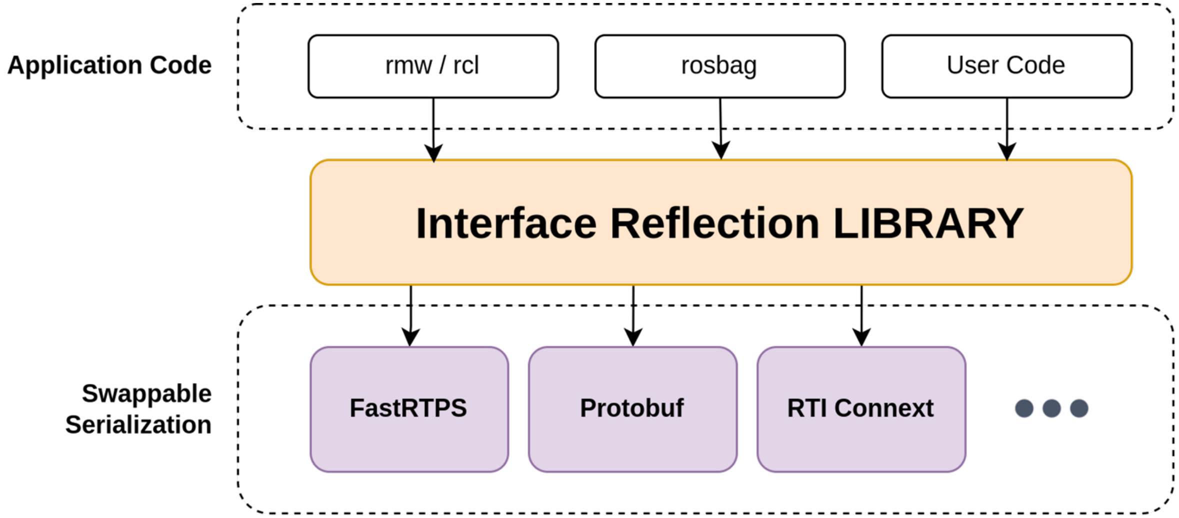
For middlewares that don't have structured messages,
we can just piggyback off any serialization library (e.g. FastCDR)

The type description helps retain type information!

Run-time Interface Reflection Library

This functionality **should be a standalone C library** that can be used separately from RMW.

The **run-time interface reflection library should abstract away serialization!** (By piggybacking off a middleware or wrapping a serialization lib!)



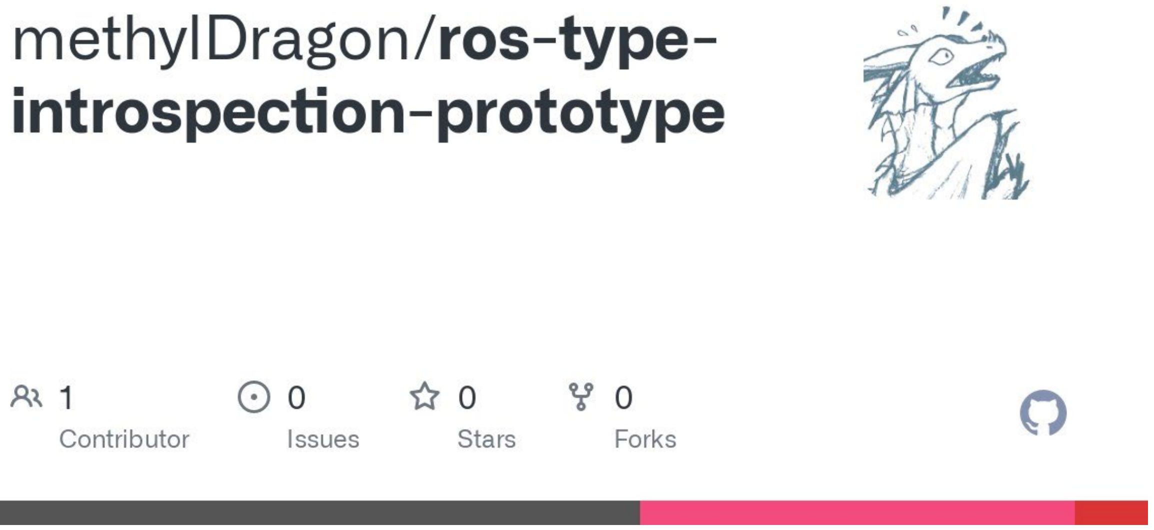
This library should be able to support non-DDS, non-XTypes libs! (e.g. Protobuf/Zenoh)

Demo

We made a prototype to check for feasibility and refine the interfaces

✨ It WORKS with FastDDS pub-sub!! ✨

(And there's a protobuf dynamic example too!!)



methylDragon/**ros-type-introspection-prototype**

1 Contributor

0 Issues

0 Stars

0 Forks

Future Work

Future Work

- More prototypes (e.g. Connext)
- Create the interfaces to abstract away getters and setters

- Type description distribution
- Plug it all into rcl/rmw!

Known Issues

- Some bugs need to be fixed in middlewares related to run-time interface reflection
- Some middlewares lack the necessary interfaces right now
- Some conceptual discrepancies in the type description message, e.g. bounded sequences of bounded strings

Questions

This presentation: https://bit.ly/3dFitlq

The REP PR: https://tinyurl.com/rep-2011-pr

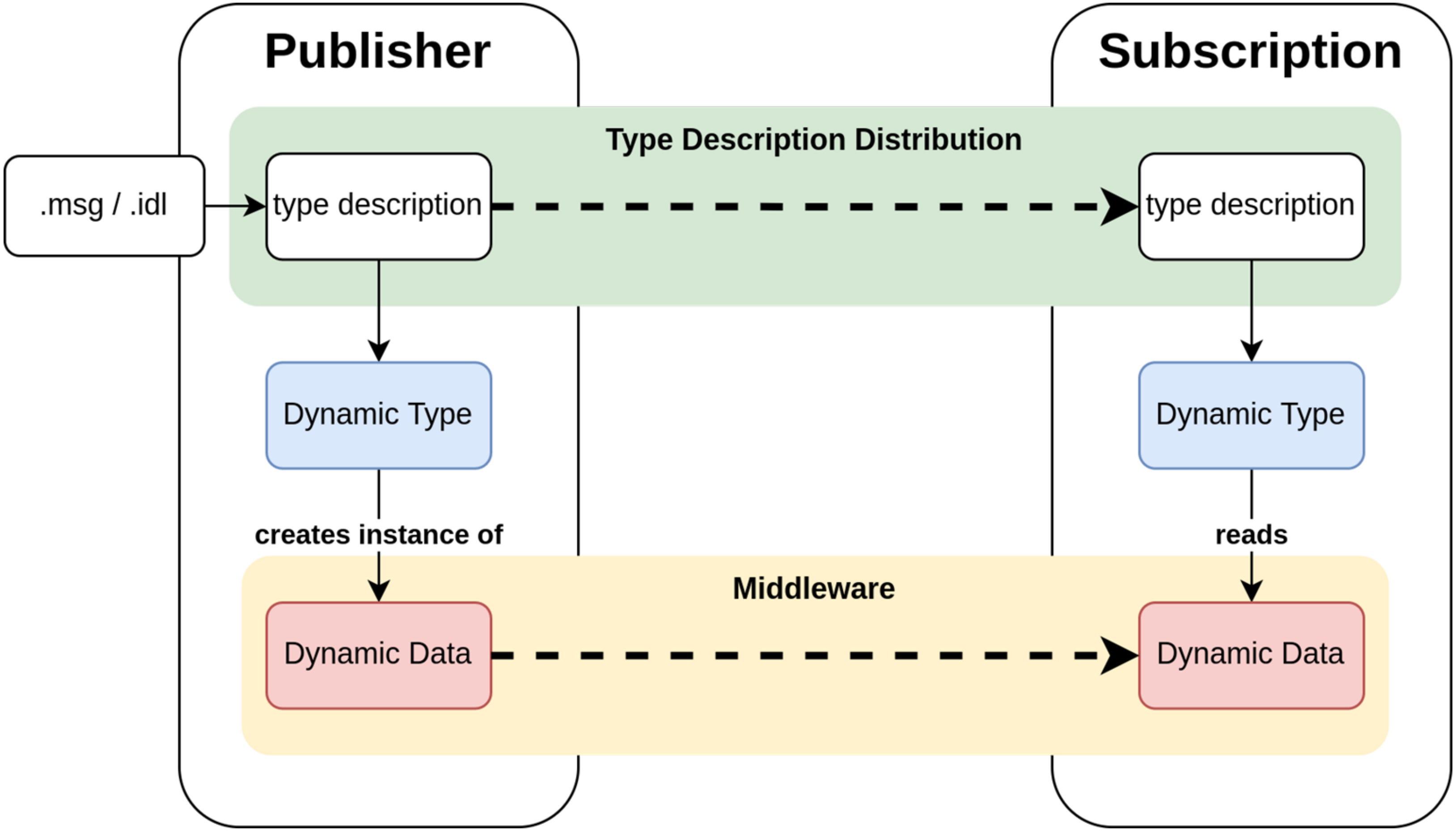
Presentation Slides

[redacted]

[redacted]

Appendix

Pub-Sub



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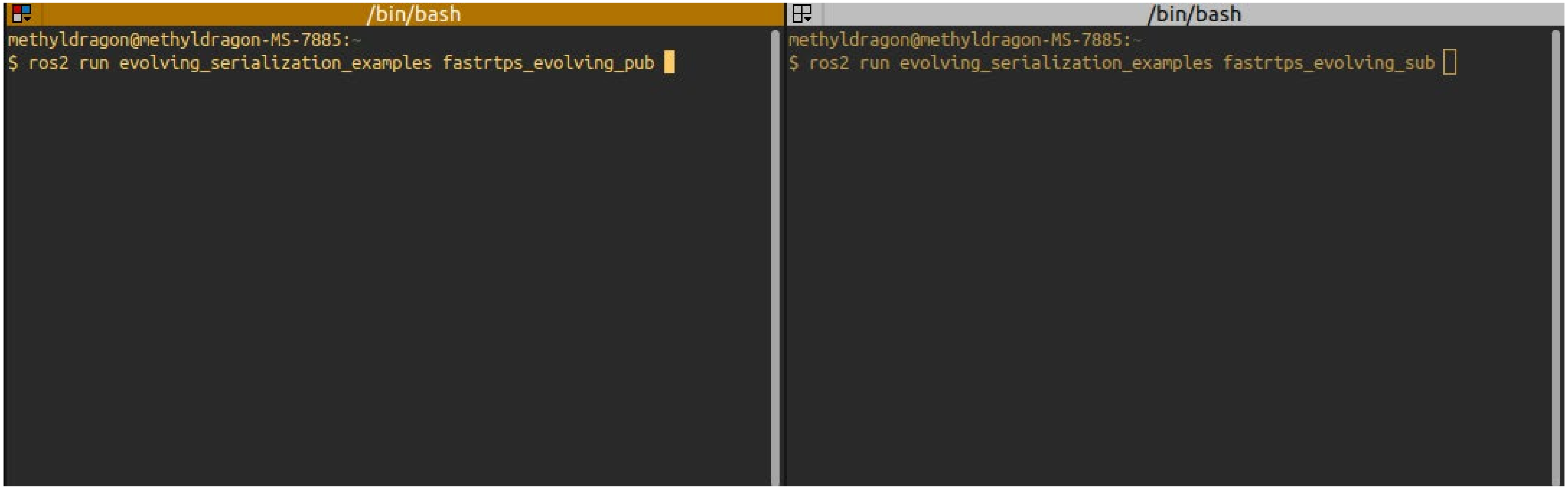
Demo: It works! (FastDDS Pub-Sub)



```
methyldragon@methyldragon-MS-7885:~
$ ros2 run evolving_serialization_examples fastrtps_evolving_pub
```

```
methyldragon@methyldragon-MS-7885:~
$ ros2 run evolving_serialization_examples fastrtps_evolving_sub
```

Pub-sub Demo Code

tinyurl.com/fastdds-ets-pubsub

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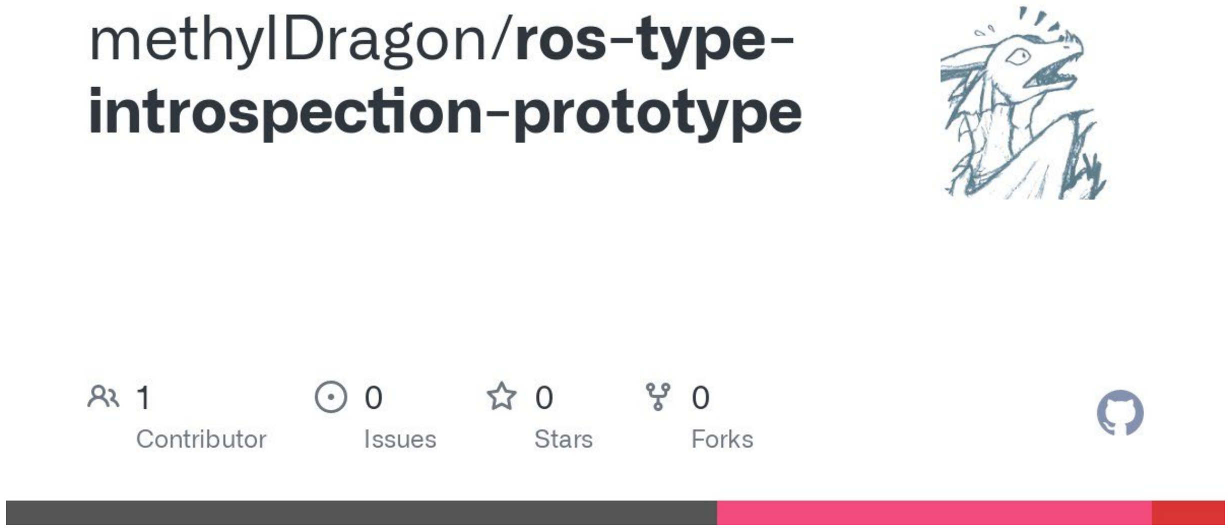
Demo

We made a prototype to check for feasibility and refine the interfaces

✨ It **WORKS** with FastDDS pub-sub!! ✨

(And there's a protobuf dynamic example too!!)



methylDragon/**ros-type-introspection-prototype**

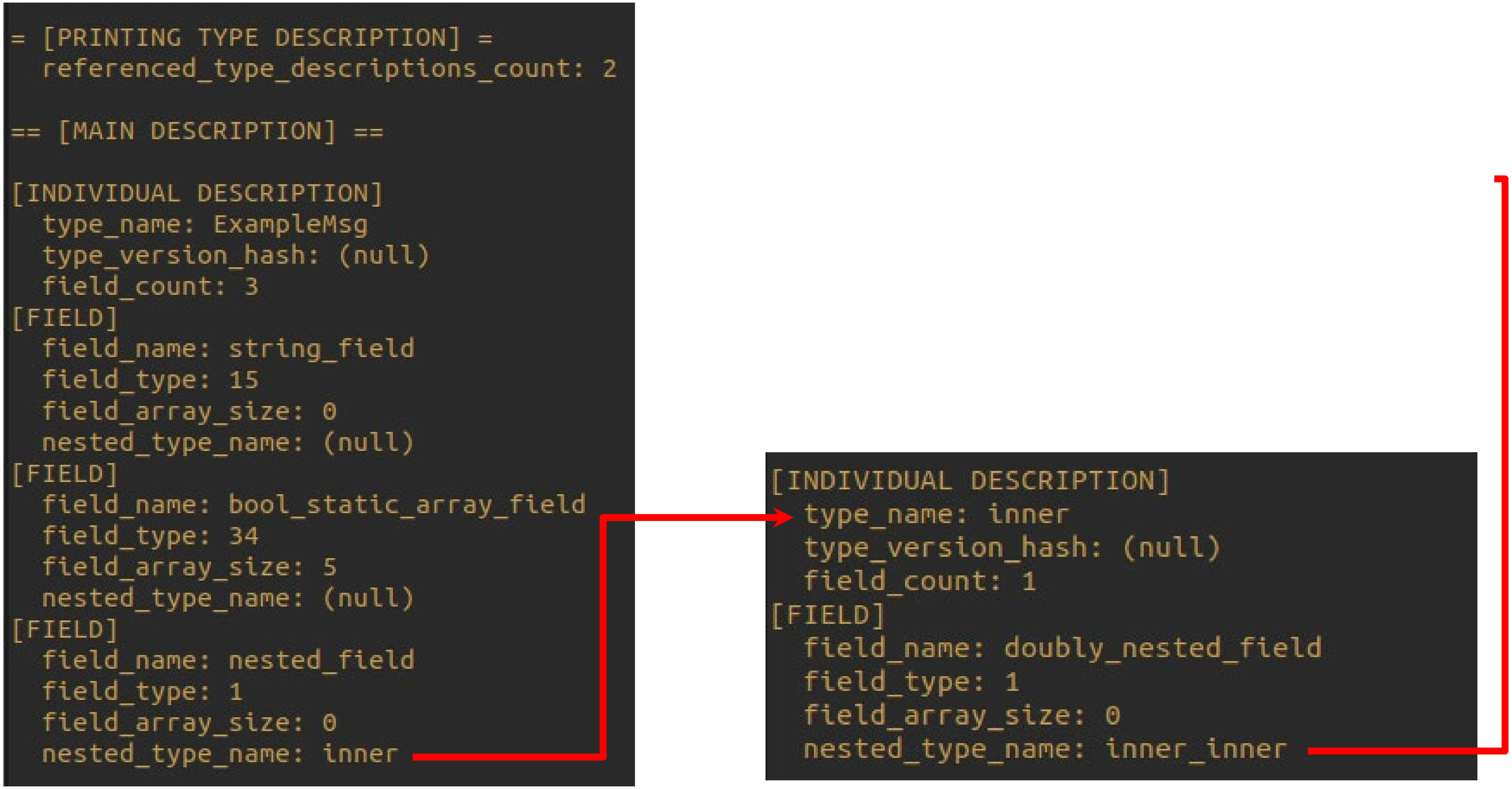
1 Contributor

0 Issues

0 Stars

0 Forks

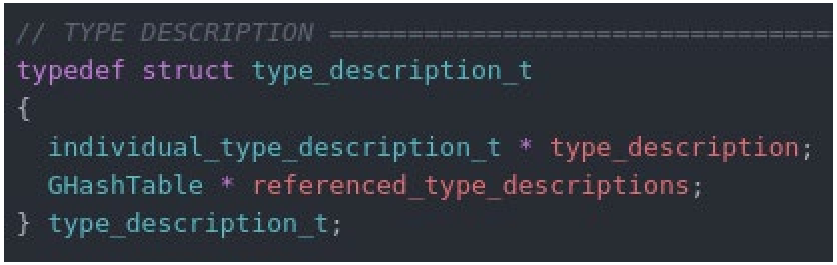
Demo: Type Description



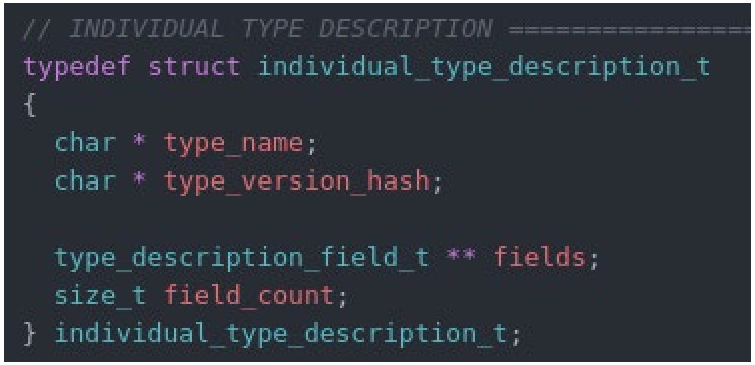
```
= [PRINTING TYPE DESCRIPTION] =
  referenced_type_descriptions_count: 2

== [MAIN DESCRIPTION] ==

[INDIVIDUAL DESCRIPTION]
  type_name: ExampleMsg
  type_version_hash: (null)
  field_count: 3
[FIELD]
  field_name: string_field
  field_type: 15
  field_array_size: 0
  nested_type_name: (null)
[FIELD]
  field_name: bool_static_array_field
  field_type: 34
  field_array_size: 5
  nested_type_name: (null)
[FIELD]
  field_name: nested_field
  field_type: 1
  field_array_size: 0
  nested_type_name: inner
```

```
[INDIVIDUAL DESCRIPTION]
  type_name: inner
  type_version_hash: (null)
  field_count: 1
[FIELD]
  field_name: doubly_nested_field
  field_type: 1
  field_array_size: 0
  nested_type_name: inner_inner
```

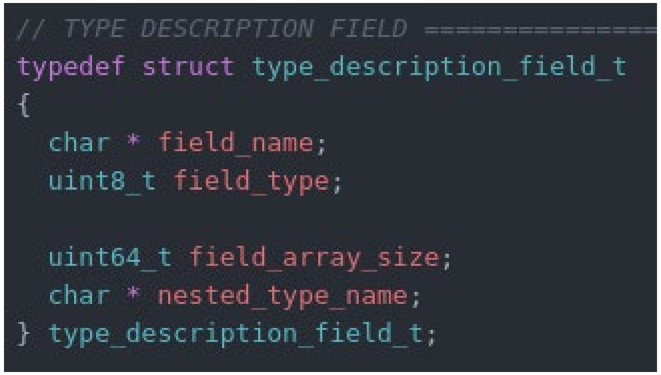
FastDDS Prototype: Type Description



```
// TYPE DESCRIPTION ================================
typedef struct type_description_t
{
  individual_type_description_t * type_description;
  GHashTable * referenced_type_descriptions;
} type_description_t;
```



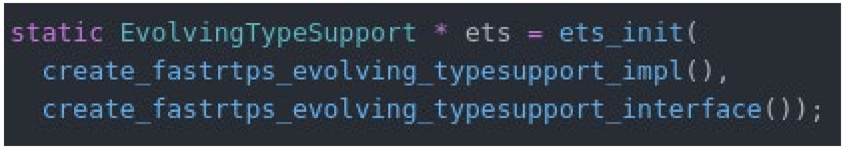
```
// INDIVIDUAL TYPE DESCRIPTION ===============
typedef struct individual_type_description_t
{
  char * type_name;
  char * type_version_hash;

  type_description_field_t ** fields;
  size_t field_count;
} individual_type_description_t;
```



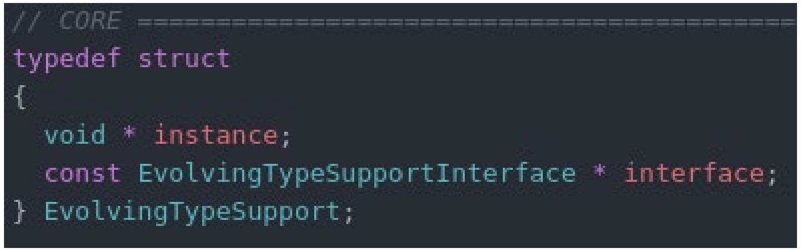
```
// TYPE DESCRIPTION FIELD ==============
typedef struct type_description_field_t
{
  char * field_name;
  uint8_t field_type;

  uint64_t field_array_size;
  char * nested_type_name;
} type_description_field_t;
```

The type_description_t struct allows us to iterate through the fields and obtain necessary information to construct the type.

FastDDS Prototype: ETS

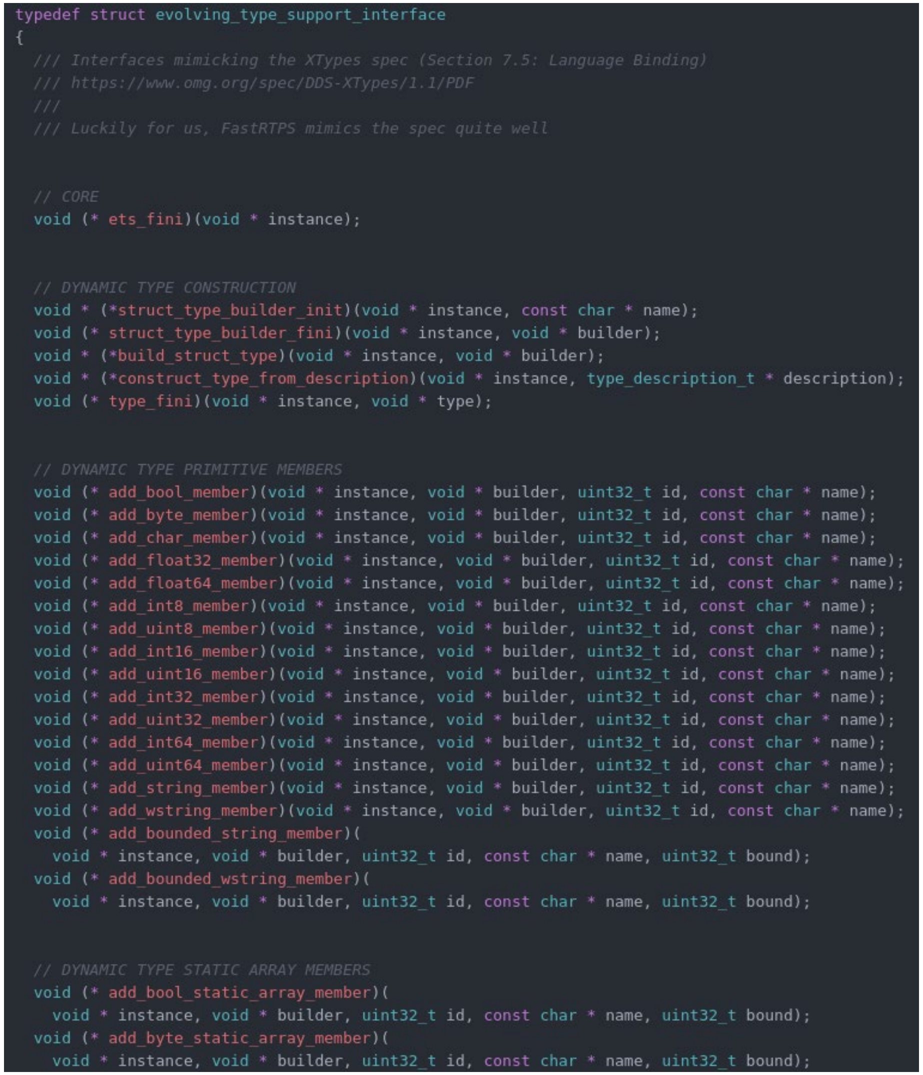


```c
static EvolvingTypeSupport * ets = ets_init(
  create_fastrtps_evolving_typesupport_impl(),
  create_fastrtps_evolving_typesupport_interface());
```



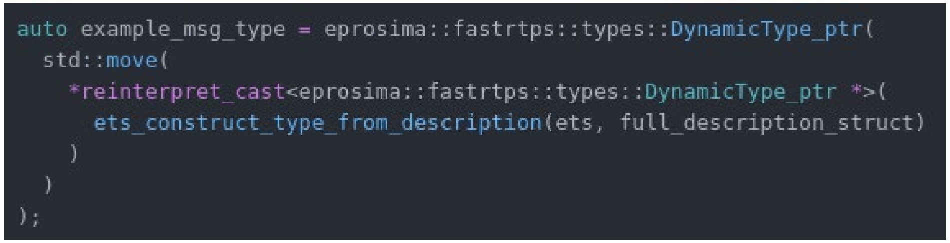
```c
// CORE ==========================================
typedef struct
{
  void * instance;
  const EvolvingTypeSupportInterface * interface;
} EvolvingTypeSupport;
```

The EvolvingTypeSupport (ETS) is a C interface to be filled by any downstream implementations!



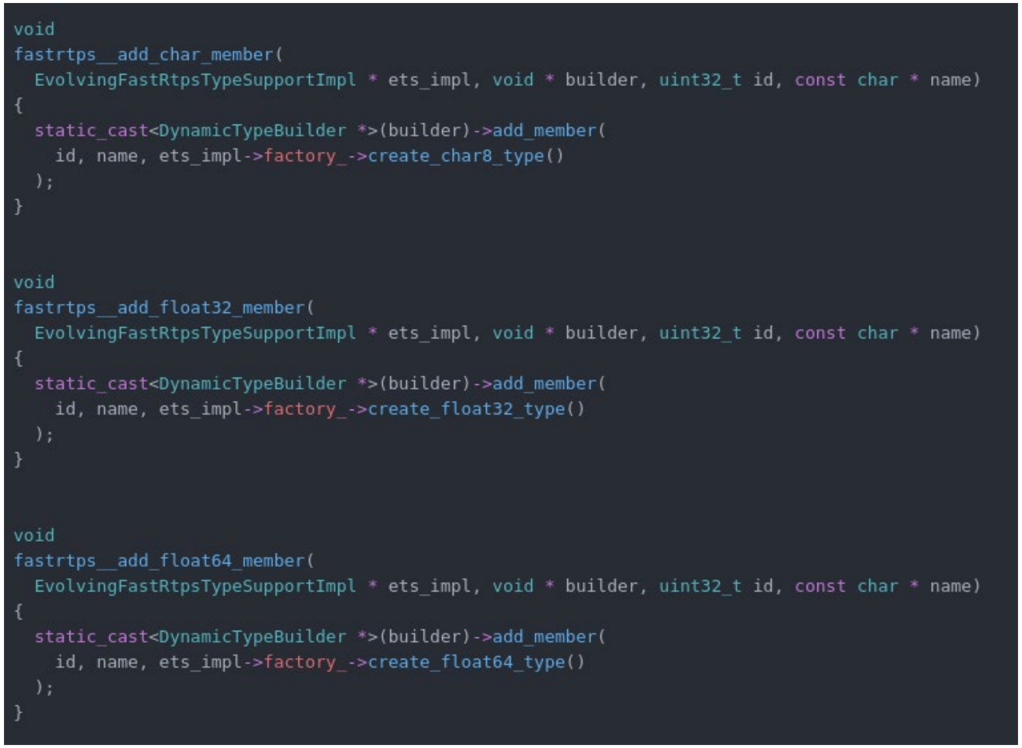
```c
typedef struct evolving_type_support_interface
{
  /// Interfaces mimicking the XTypes spec (Section 7.5: Language Binding)
  /// https://www.omg.org/spec/DDS-XTypes/1.1/PDF
  ///
  /// Luckily for us, FastRTPS mimics the spec quite well


  // CORE
  void (* ets_fini)(void * instance);


  // DYNAMIC TYPE CONSTRUCTION
  void * (*struct_type_builder_init)(void * instance, const char * name);
  void (* struct_type_builder_fini)(void * instance, void * builder);
  void * (*build_struct_type)(void * instance, void * builder);
  void * (*construct_type_from_description)(void * instance, type_description_t * description);
  void (* type_fini)(void * instance, void * type);


  // DYNAMIC TYPE PRIMITIVE MEMBERS
  void (* add_bool_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_byte_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_char_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_float32_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_float64_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_int8_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_uint8_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_int16_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_uint16_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_int32_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_uint32_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_int64_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_uint64_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_string_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_wstring_member)(void * instance, void * builder, uint32_t id, const char * name);
  void (* add_bounded_string_member)(
    void * instance, void * builder, uint32_t id, const char * name, uint32_t bound);
  void (* add_bounded_wstring_member)(
    void * instance, void * builder, uint32_t id, const char * name, uint32_t bound);


  // DYNAMIC TYPE STATIC ARRAY MEMBERS
  void (* add_bool_static_array_member)(
    void * instance, void * builder, uint32_t id, const char * name, uint32_t bound);
  void (* add_byte_static_array_member)(
    void * instance, void * builder, uint32_t id, const char * name, uint32_t bound);
```

FastDDS Prototype: ETS



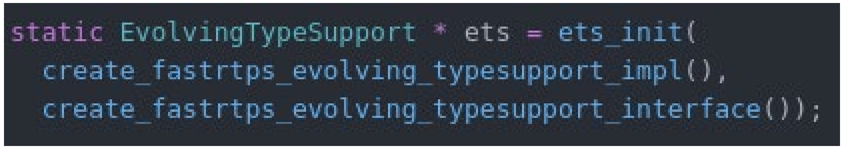
```
auto example_msg_type = eprosima::fastrtps::types::DynamicType_ptr(
  std::move(
    *reinterpret_cast<eprosima::fastrtps::types::DynamicType_ptr *>(
      ets_construct_type_from_description(ets, full_description_struct)
    )
  )
);
```

With the type_description_t struct, we can iterate through the fields and call the necessary methods to create the type!



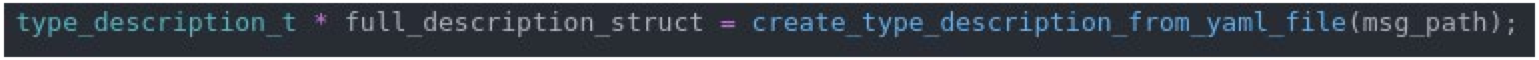
```
void
fastrtps__add_char_member(
  EvolvingFastRtpsTypeSupportImpl * ets_impl, void * builder, uint32_t id, const char * name)
{
  static_cast<DynamicTypeBuilder *>(builder)->add_member(
    id, name, ets_impl->factory_->create_char8_type()
  );
}


void
fastrtps__add_float32_member(
  EvolvingFastRtpsTypeSupportImpl * ets_impl, void * builder, uint32_t id, const char * name)
{
  static_cast<DynamicTypeBuilder *>(builder)->add_member(
    id, name, ets_impl->factory_->create_float32_type()
  );
}


void
fastrtps__add_float64_member(
  EvolvingFastRtpsTypeSupportImpl * ets_impl, void * builder, uint32_t id, const char * name)
{
  static_cast<DynamicTypeBuilder *>(builder)->add_member(
    id, name, ets_impl->factory_->create_float64_type()
  );
}
```

Demo: It works! (FastDDS Pub)

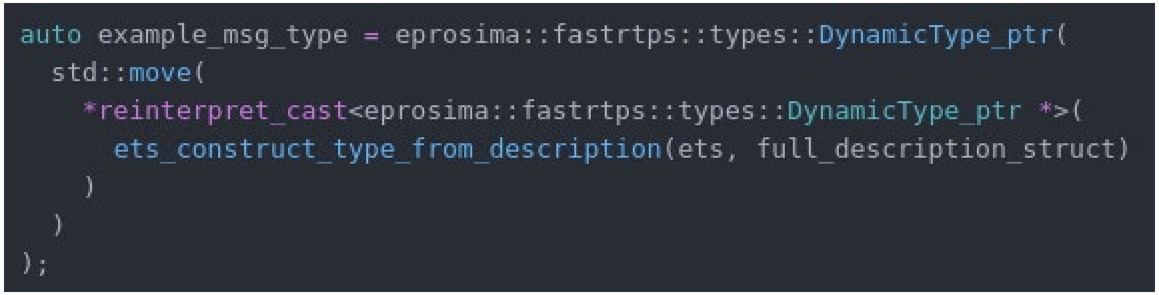


```
static EvolvingTypeSupport * ets = ets_init(
  create_fastrtps_evolving_typesupport_impl(),
  create_fastrtps_evolving_typesupport_interface());
```

You can use the same interface on the subscription side!

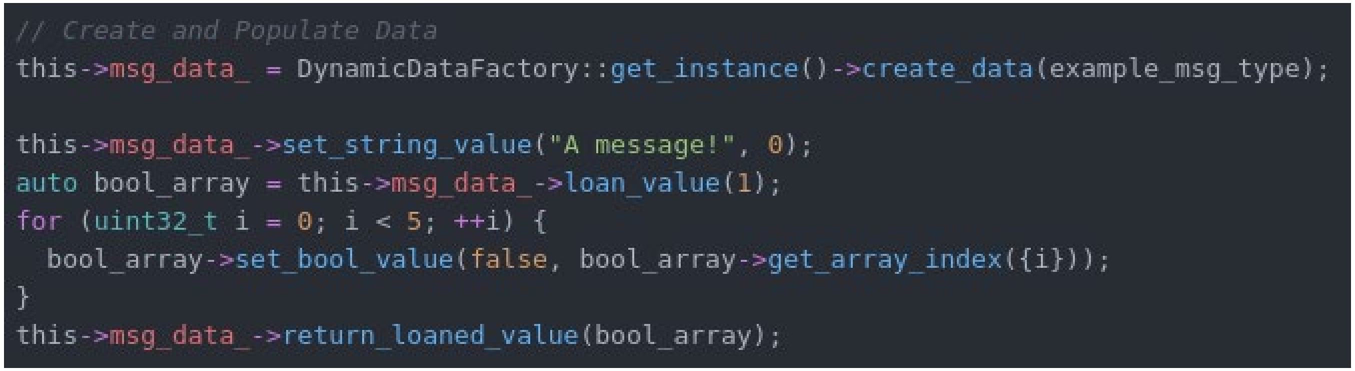


```
type_description_t * full_description_struct = create_type_description_from_yaml_file(msg_path);
```



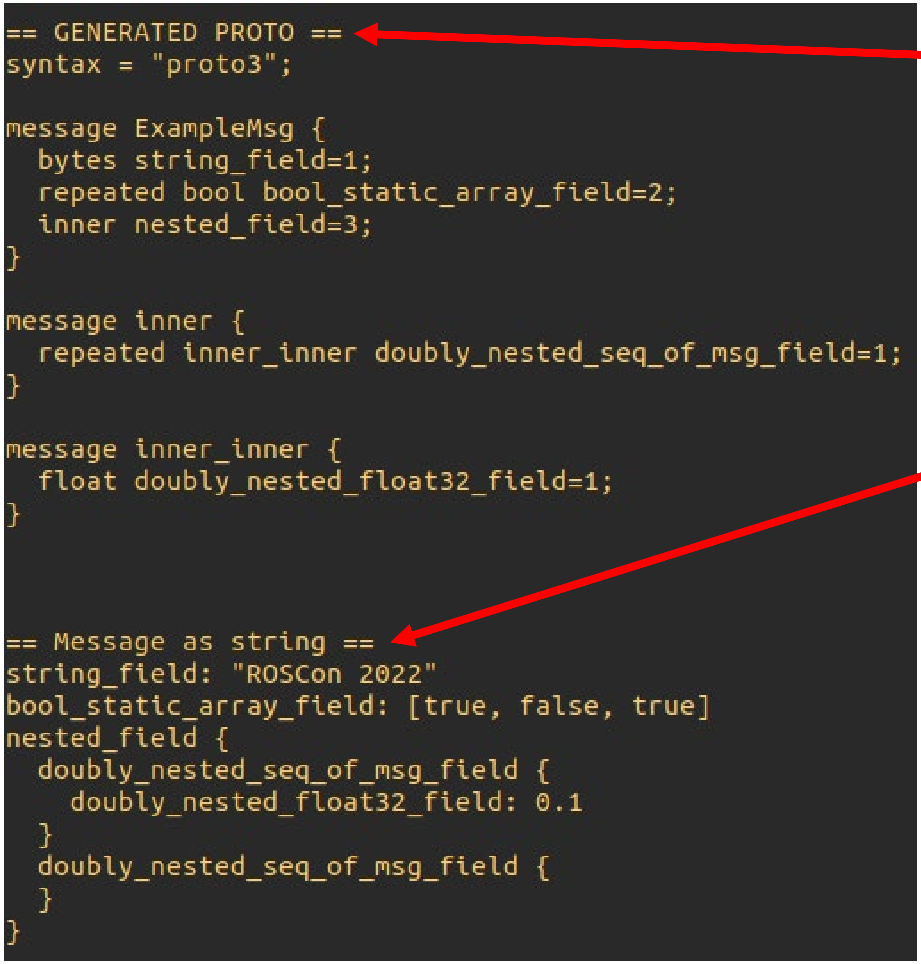
```
auto example_msg_type = eprosima::fastrtps::types::DynamicType_ptr(
  std::move(
    *reinterpret_cast<eprosima::fastrtps::types::DynamicType_ptr *>(
      ets_construct_type_from_description(ets, full_description_struct)
    )
  )
);
```

This is grabbed at runtime!



```
// Create and Populate Data
this->msg_data_ = DynamicDataFactory::get_instance()->create_data(example_msg_type);

this->msg_data_->set_string_value("A message!", 0);
auto bool_array = this->msg_data_->loan_value(1);
for (uint32_t i = 0; i < 5; ++i) {
  bool_array->set_bool_value(false, bool_array->get_array_index({i}));
}
this->msg_data_->return_loaned_value(bool_array);
```

Demo: It also works for protobuf (no protoc)!



```
== GENERATED PROTO ==
syntax = "proto3";

message ExampleMsg {
  bytes string_field=1;
  repeated bool bool_static_array_field=2;
  inner nested_field=3;
}

message inner {
  repeated inner_inner doubly_nested_seq_of_msg_field=1;
}

message inner_inner {
  float doubly_nested_float32_field=1;
}



== Message as string ==
string_field: "ROSCon 2022"
bool_static_array_field: [true, false, true]
nested_field {
  doubly_nested_seq_of_msg_field {
    doubly_nested_float32_field: 0.1
  }
  doubly_nested_seq_of_msg_field {
  }
}
```

In this case the **DynamicType** comes from a runtime-generated .proto file!

We use the **`DynamicMessage`** interfaces from protobuf to construct the message from the generated .proto file contents

The demo repo includes the proto file generator library! (***`protogen`***)

tinyurl.com/protobuf-dyn-ser

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