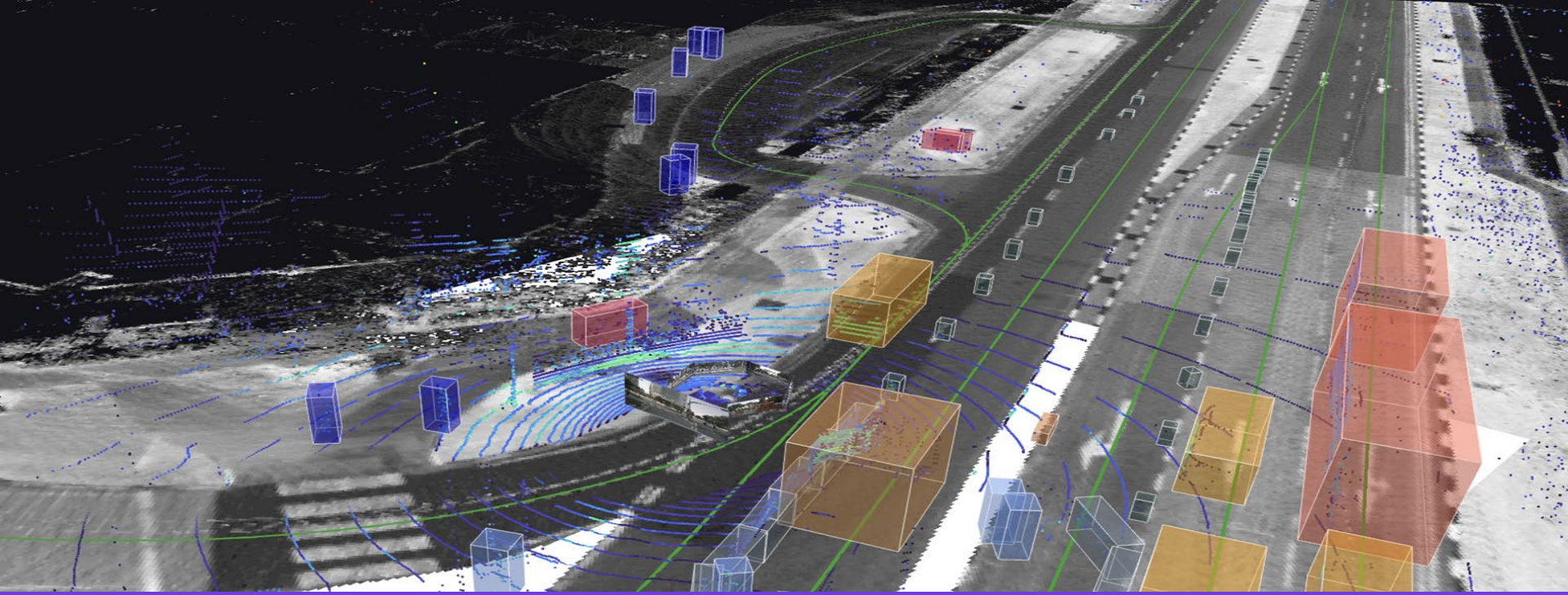

MCAP: A Next-Generation File Format for ROS Recording

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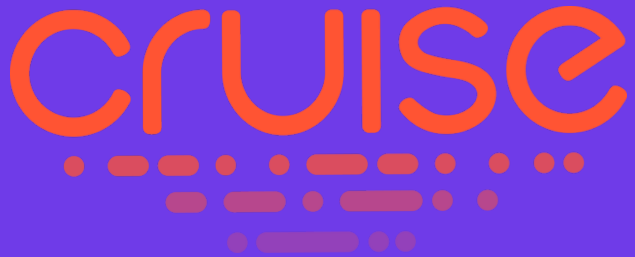
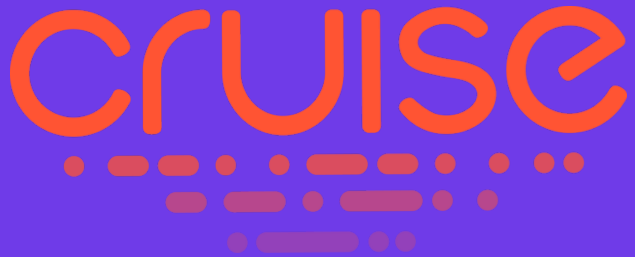
foxglove


foxglove



How can we make rosbag recordings more crash resilient and improve write throughput?



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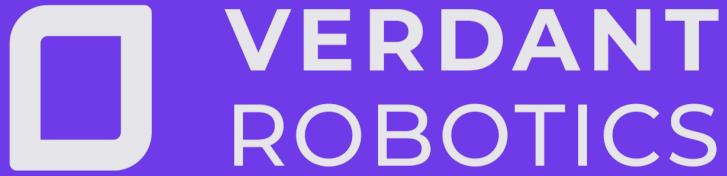

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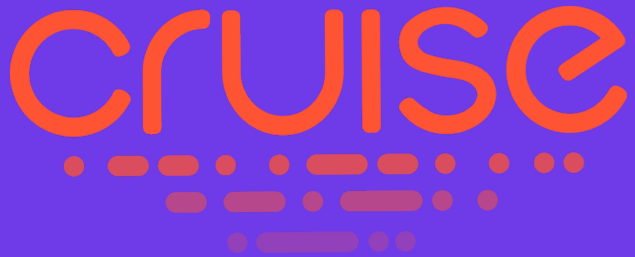

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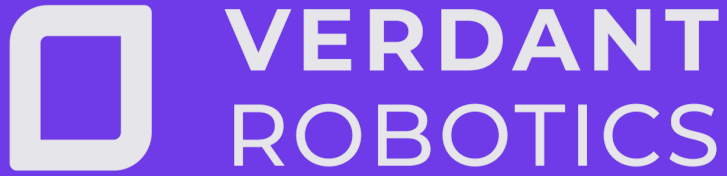

How can we leverage recording SDKs and bag tooling outside the ROS ecosystem?

How can we make recordings self-contained and remotely streamable?

Design Goals

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- Serialization Agnostic

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- Determinism

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- Corruption Resilient
- Indexing
- Standards Compatible

Why a New File Format?

- We evaluated many existing formats:
  - rosbag1
  - rosbag2 (SQLite)
  - Length-delimited Protobuf
  - Avro
  - HDF5
  - Parquet
  - EBML

mcap.dev/motivation/evaluation-of-robotics-data-recording-file-formats


Introducing: MCAP

Heterogeneous data

- Store messages encoded in multiple serialization formats in a single file
- Can store ROS 1, ROS 2 (CDR), Protobuf, Flatbuffer, JSON, etc
- Include metadata and attachments

Performant writing

- Write-optimized for fast recording on resource-constrained robots
- Append-only structure
- Recover partially-written files when recording is interrupted
- Writes can be streamed across a network
- Optional compression

Efficient seeking

- Extract data without scanning or decompressing the entire file
- Fast access to indexed summary data
- Remote reading via HTTP Range requests

Self-contained files

- Embed all message schemas in the file
- No extra dependencies needed for decoding
- CRCs ensure data integrity per chunk

Design Checklist

- [x] Serialization Agnostic
- [x] Determinism
- [x] Self-Describing
- [x] Big and Small Data
- [x] Write-Optimized
- [x] Dynamically Add New Data Streams
- [x] Corruption Resilient
- [x] Indexing
- [x] Standards Compatible

Simple Specification

Overview

MCAP is a modular container file format for recording timestamped pub/sub messages with arbitrary serialization formats.

MCAP files are designed to work well under various workloads, resource constraints, and durability requirements.

A Kaitai Struct description for the MCAP format is provided at mcap.ksy.

File Structure

A valid MCAP file is structured as follows. The Summary and Summary Offset sections are optional.

```
<Magic><Header><Data section>[<Summary section>][<Summary Offset section>]<Footer><Magic>
```

The Data, Summary, and Summary Offset sections are structured as sequences of **records**:

```
[<record type><record content length><record><record type><record content length><record>...]
```

Files not conforming to this structure are considered malformed.

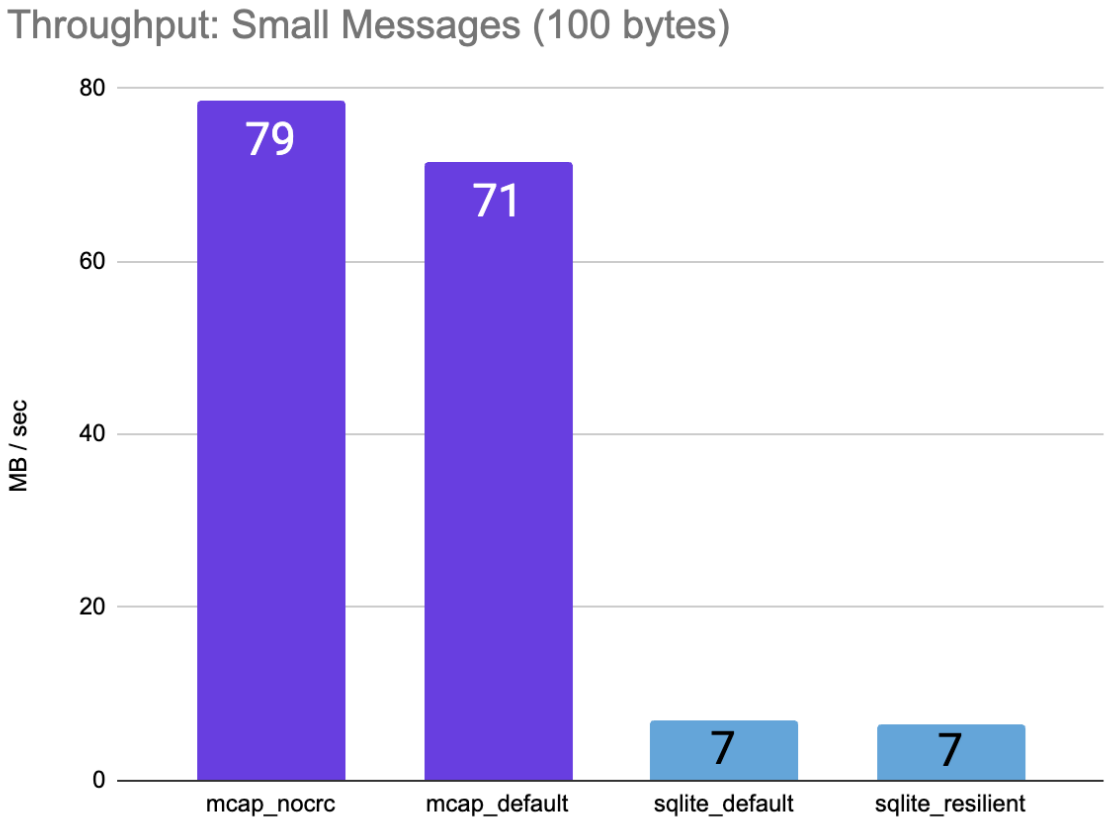
Magic

An MCAP file must begin and end with the following magic bytes:

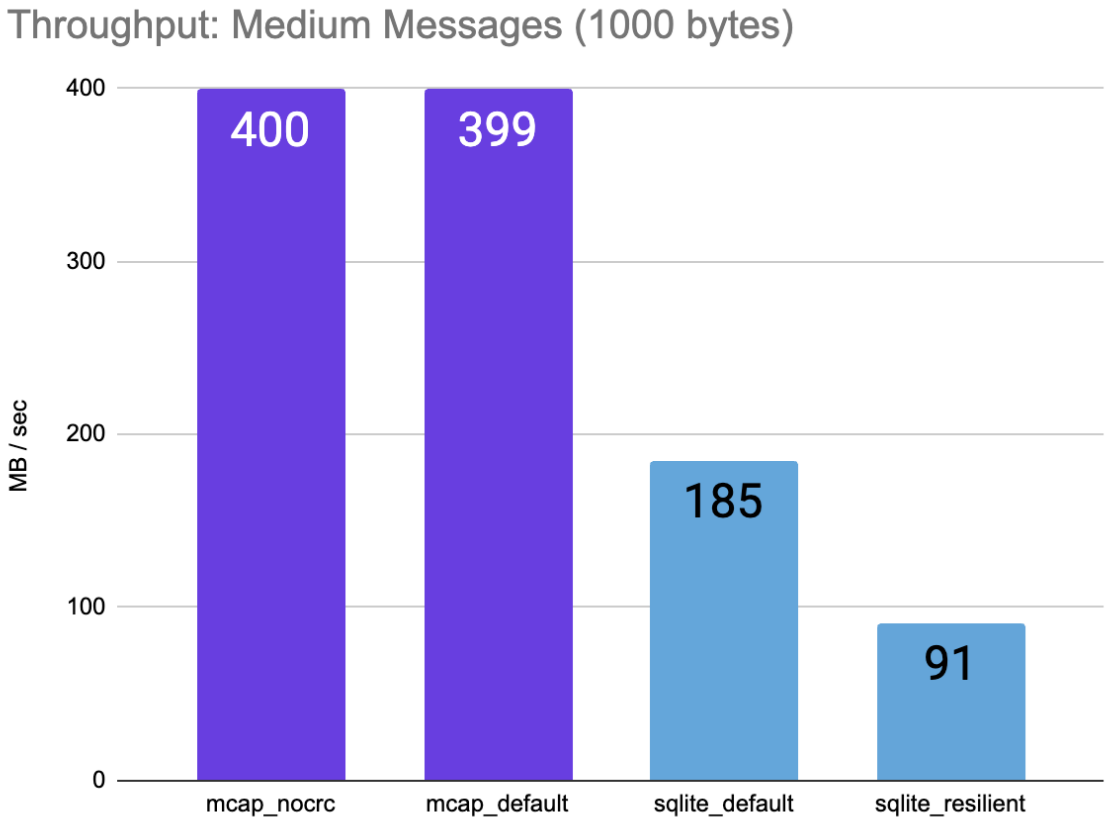
```
0x89, M, C, A, P, 0x30, \r, \n
```

```
[Header]
[Chunk A]
  [Schema A]
  [Channel 1 (A)]
  [Channel 2 (B)]
  [Message on 1]
  [Message on 1]
  [Message on 2]
[Message Index 1]
[Message Index 2]
[Attachment 1]
[Chunk B]
  [Schema B]
  [Channel 3 (B)]
  [Message on 3]
  [Message on 1]
[Message Index 3]
[Message Index 1]
[Data End]
[Schema A]
[Schema B]
[Channel 1]
[Channel 2]
[Channel 3]
[Chunk Index A]
[Chunk Index B]
[Attachment Index 1]
[Statistics]
[Summary Offset 0x01]
[Summary Offset 0x05]
[Summary Offset 0x07]
[Summary Offset 0x08]
[Footer]
```

Benchmark: Throughput



Benchmark: Throughput



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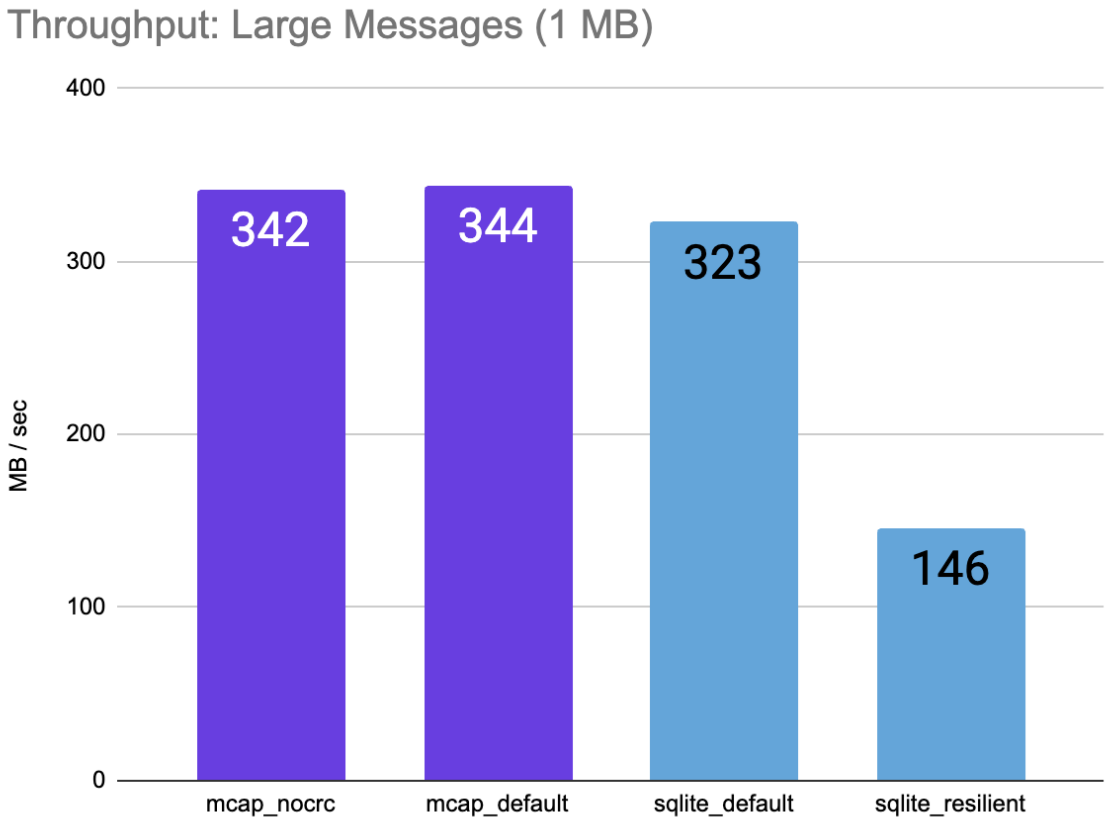
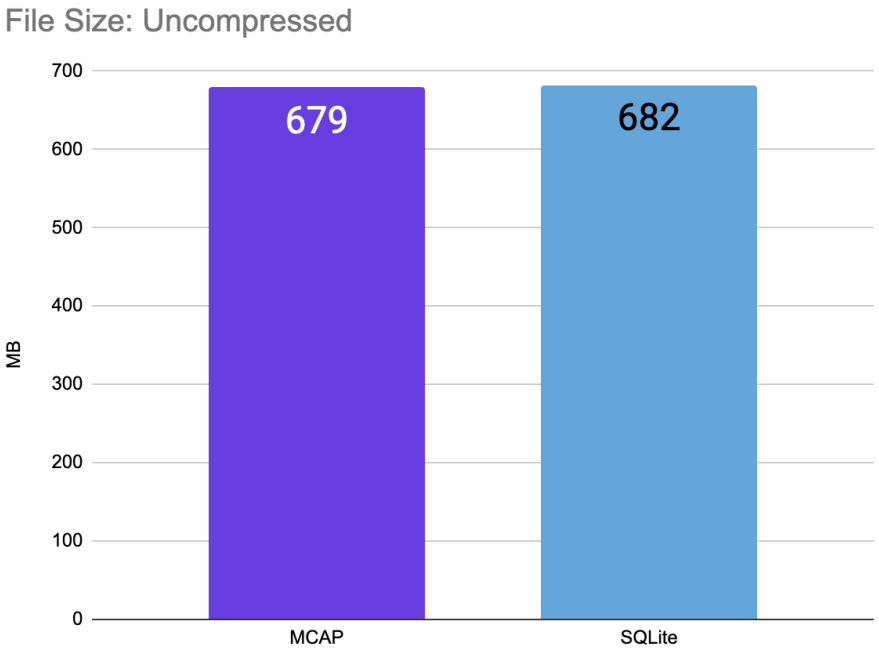
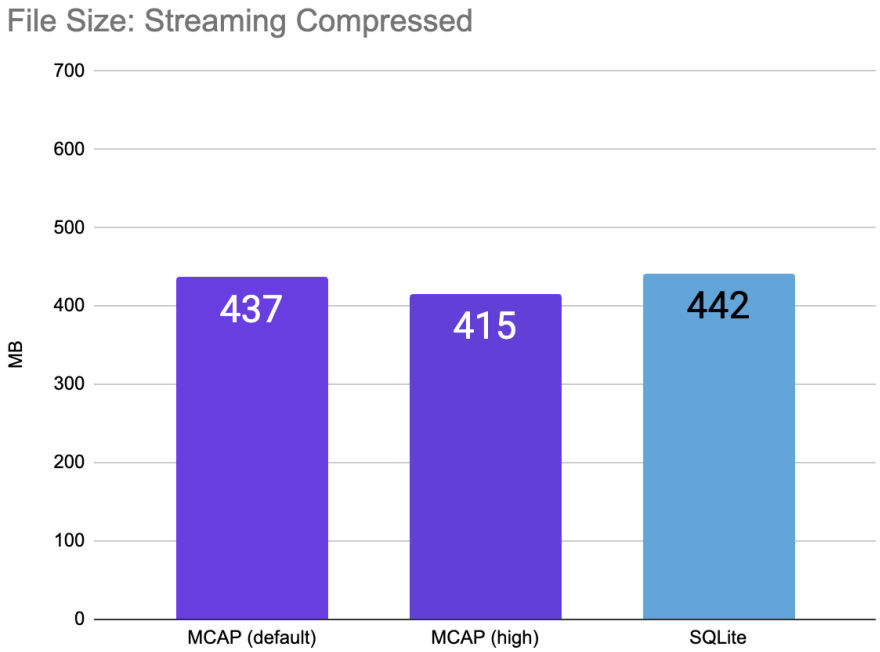


Benchmark: File Size



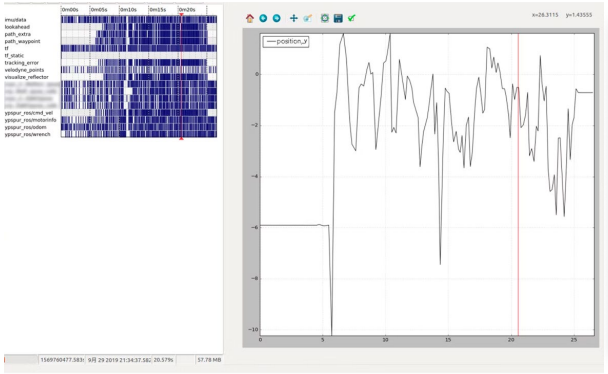


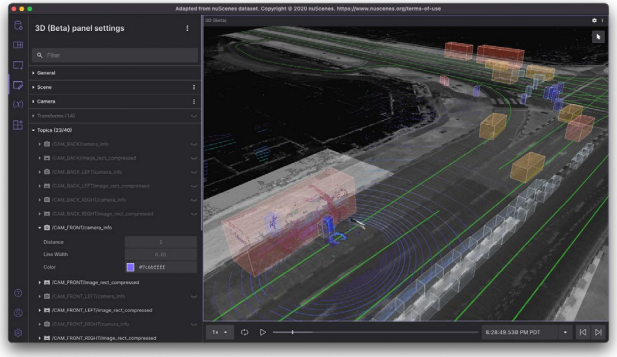
Command Line Interface

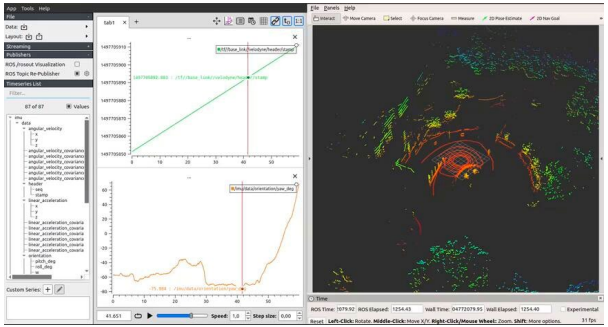
	ROS 1	ROS 2 + SQLite	ROS 2 + MCAP
	JGK:9? J=;GJ<	ros2 bag record	ros2 bag record -s mcap
	JGK:9? AF>G	ros2 bag info	mcap info
	JGK:9? HD9Q	ros2 bag play	ros2 bag play
	rosbag check		mcap doctor
	rosbag fix		mcap recover
	JGK:9? >ADL=J	ros2 bag convert	mcap filter
	JGK:9? ;GEHJ=KK	ros2 bag convert	mcap compress
	rosbag decompress	ros2 bag convert	mcap decompress
	JGK:9? J=AF<=P	ros2 bag reindex	mcap recover

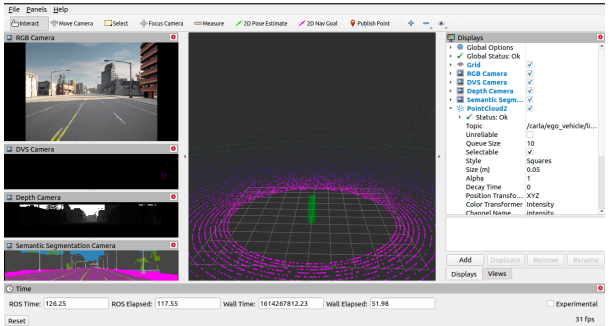
Tooling

- rosbag2
- rviz
- rqt_bag
- Foxglove Studio
- PlotJuggler







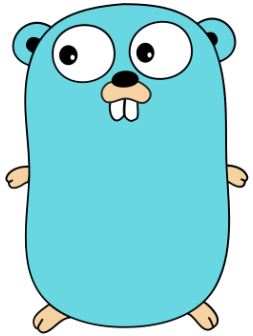


Libraries

Python

C++

TypeScript



Go

Swift

Rust

Example: Python Reader


```python
import sys
from mcap_ros1.reader import read_ros1_messages

for msg in read_ros1_messages(sys.argv[1]):
    print(f"{msg.topic} [{msg.log_time}] "\
          f"({type(msg.ros_msg).__name__}): {msg.ros_msg}")
```

Example: Python Writer

```python
import sys
from mcap_ros2.writer import Writer as McapWriter

with open(sys.argv[1], "wb") as f:
    writer = McapWriter(f)
    schema = writer.register_msgdef("std_msgs/msg/String", "string data")
    for i in range(0, 10):
        msg = {"data": f"string message {i}"}
        writer.write_message("/chatter", schema, msg)
    writer.finish()
```

Example: C++ Reader


```cpp
#define MCAP_IMPLEMENTATION
#include <mcap/reader.hpp>
#include <iostream>
#include <string>

int main(int argc, char* argv[]) {
  mcap::McapReader reader;
  reader.open(argv[1]);
  for (const auto& msgView : reader.readMessages()) {
    auto& msg = msgView.message;
    std::string str{reinterpret_cast<const char*>(msg), msg.dataSize};
    std::cout << msgView.channel->topic << " [" << msg.logTime << "] (" <<
                 msgView.schema->name << "): " << str << "\n";
  }
  reader.close();
}
```

Example: C++ Writer


```cpp
#define MCAP_IMPLEMENTATION
#include <mcap/writer.hpp>
#include <string>

int main(int argc, char** argv) {
  mcap::McapWriter writer;
  writer.open(argv[1], mcap::McapWriterOptions{""});
  mcap::Channel channel{"chatter", "text/plain", 0};
  writer.addChannel(channel);
  for (uint32_t i = 0; i < 10; i++) {
    auto str = std::string{"string message "} + std::to_string(i);
    writer.write(mcap::Message{.channelId = channel.id, .sequence = i,
      .logTime = i, .publishTime = i, .dataSize = str.size(),
      .data = reinterpret_cast<const std::byte*>(str.data())
    });
  }
  writer.close();
}
```

Use MCAP Today

ROS2

- Install: `sudo apt install ros- $ROS_DISTRO-rosbag2- storage- mcap`
- Record: `ros2 bag record -s mcap`
- Use `mcap-ros2-support` API to read and write ROS2 messages programmatically
- Convert existing .db3 files with `mcap convert` or `ros2 bag convert`

ROS1

- Use `mcap-ros1-support` API to read and write ROS1 messages programmatically
- Convert existing .bag files with `mcap convert`
- *Recording can be backported to ROS1 if there's demand*

mcap.dev

Appendix

Tuning For Different Use Cases

No CRCs, Fast Compression, Larger Blocks

```
FG! 0! ~  LJ M=
    ; @MFC1 AR=~  [ V[ [ YS[     µ  í [ +  ì
    ; GEHJ =KKAGF~  â 8 KL<â
    ; GEHJ =KKAGF*=N=D~  â $ 9 KL=KLâ
```

Minimal Overhead

```
FG! 0! ~  LJ M=
    FG! @MFCAF?~  LJ M=
    FG1 MEE9 J Q~  LJ M=
```