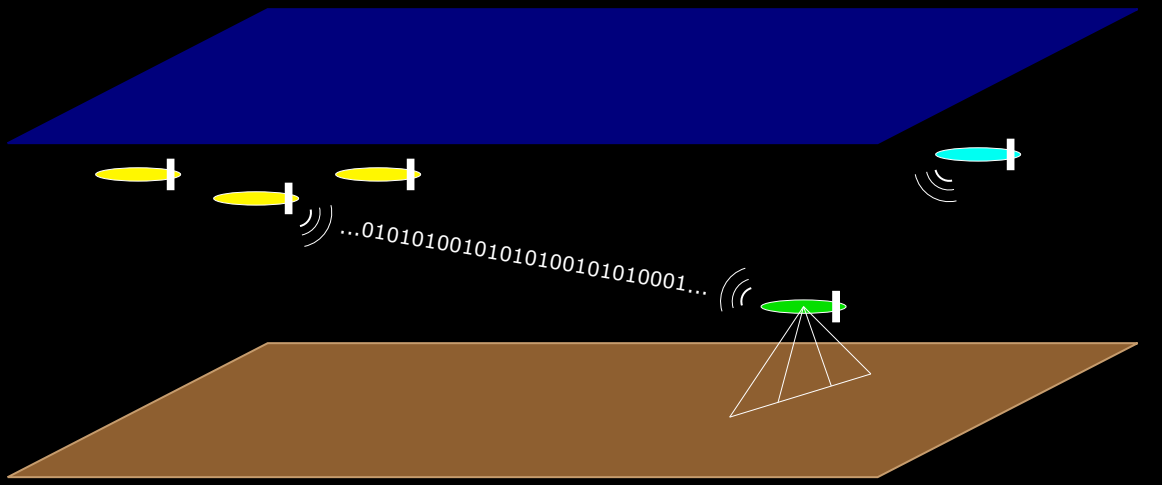
Goby3 Course

Day 1: Overview



Course Sponsored by:

Mission Systems

BlueOcean SEISMIC SERVICES

Raytheon Technologies

Toby Schneider

GobySoft, LLC

Mashpee, MA, USA

gobysoft.org
aquatic software

What is Goby?

- A C++ library with a collection of marine robotics related code?
- Drivers for acoustic modems and related "slow links" (e.g. satellites)?
- A publish/subscribe middleware (framework)?
- An open source project that is freely available under the terms of the LGPL?
- Any of more than 2,200 species of small, carnivorous fishes?

Goby is all of these things.
The goal is that you can use what you need, and no more.

What is Goby?

- A C++ library with modular components for:
  - acoustic communications
  - utilities for marine software (AIS, seawater calculations, NMEA-0183, ...)
  - time functions, supporting faster-than-realtime sims
- A "nested comms" publish/subscribe middleware:
  - a common transport interface for thread-to-thread, process-to-process, and vehicle-to-vehicle comms
  - application base classes for quickly writing processes
  - extensible marshalling schemes, supporting Protocol Buffers, MAVLink, DCCL, and easily many more.
  - a growing list of useful applications (GUIs, GPSD, logger, ...) and threads (I/O: serial, UDP, TCP, CAN, ...)

Why create Goby?

Marine robotics is small field of engineering, but with some relatively unique technical problems:

- communications (low throughput / high latency)
- harsh environments (expensive deployments)
- wide array of sensors, many specific to seawater

My hope:

Goby is a beginning to some solutions.

More importantly, it is open source so that we (as a community of oceanographic engineers) can build on it, and improve our use of software best practices along the way.

History

MIT / LAMSS (2007-2012) [lamss.mit.edu]:

- pGeneralCodec MOOS Application -> DCCL v1 (XML)
- pAcommsHandler MOOS Application -> Queue / ModemDriver
- Refactor pAcommsHandler into the beginning of Goby (v1)
- DCCL rewrite (v2): XML to Google Protocol Buffers
- Goby 2 (primarily to support DCCL v2)

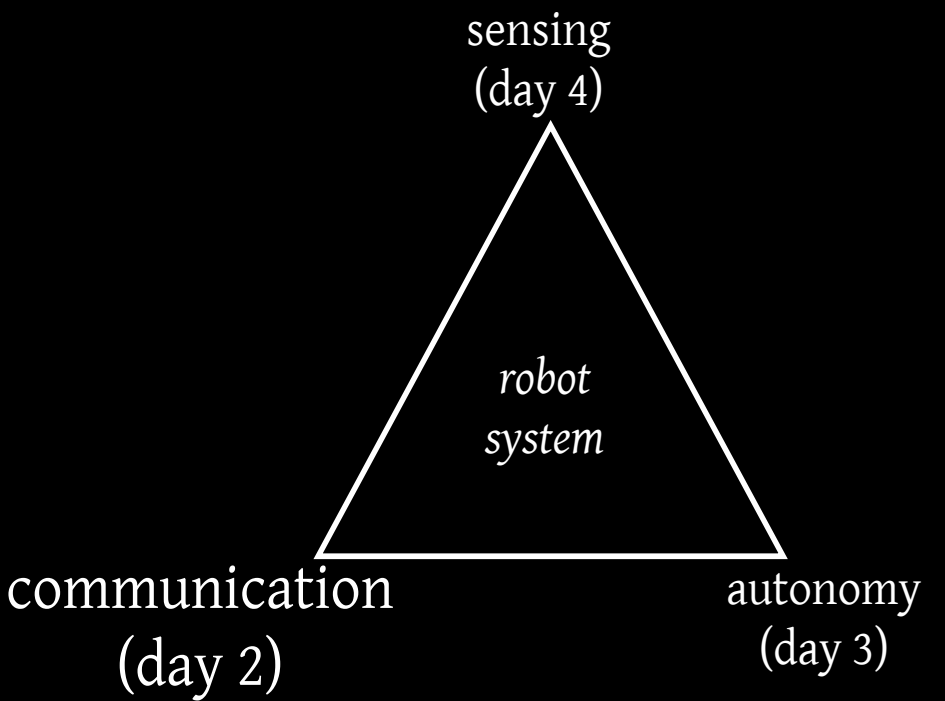
GobySoft (2013-present) [gobysoft.org]:

- DCCL standalone (v3) library, Goby 2.1
- Goby 3 (nested middleware)

Robots (and syllabus)

In many systems, this triad represents tradeoffs:

- More communications = less need for autonomy (UAVs)
- Better autonomy = better data from cheap sensors (Adaptive sampling)
- Better sensors = less need for outside data (Manned subs)

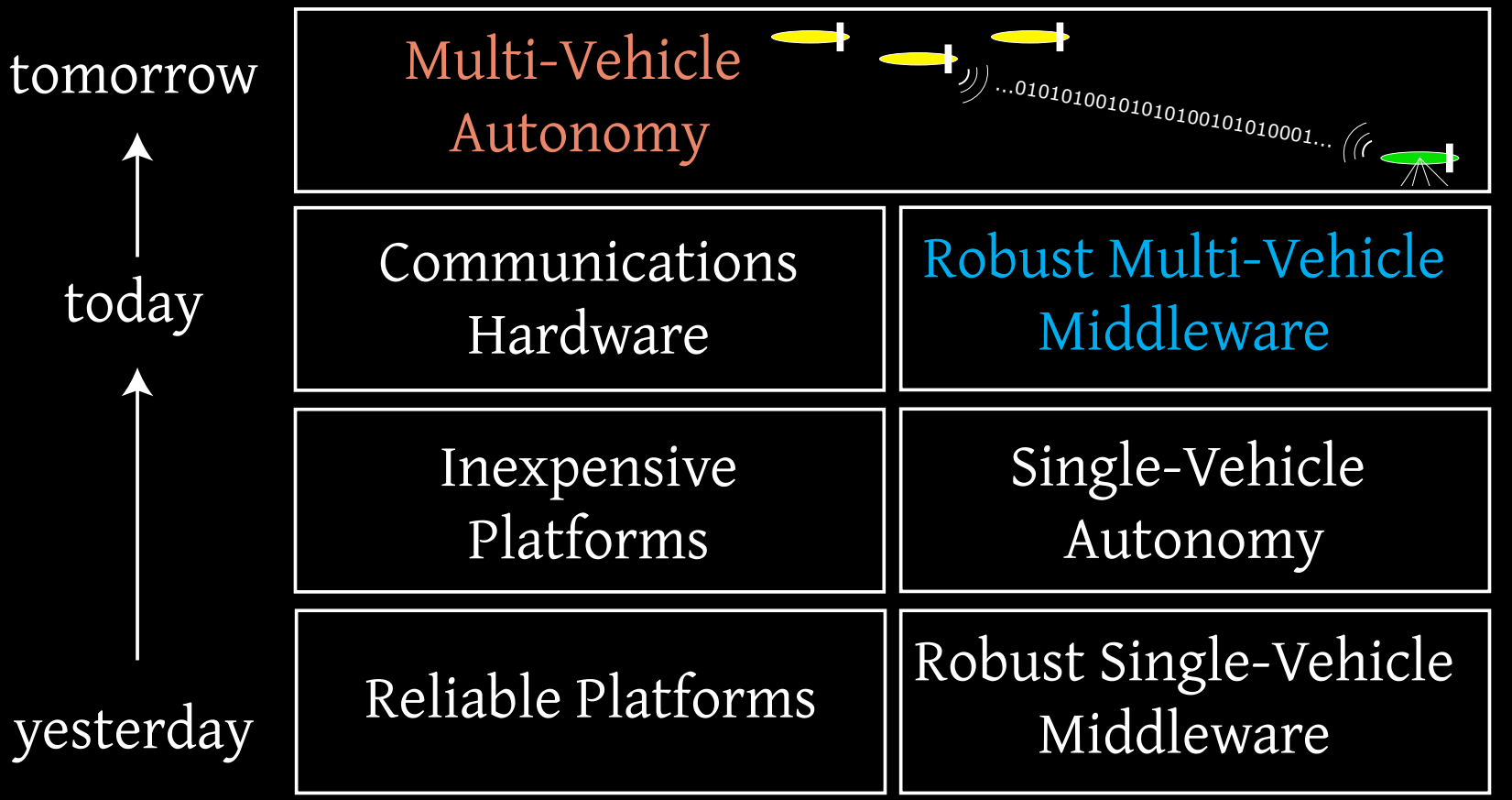


(More) Syllabus

- Day 1 (Monday, March 8): Overview
  - Lecture: 9 am-11 am EST (UTC-5).
  - Homework assignment
- Day 2 (Tuesday, March 9): Technical I: Communications
  - Lecture: 9 am-11 am EST.
  - Homework assignment.
- Day 3 (Wednesday, March 10): Technical II: Autonomy
  - Lecture: 9 am-11 am EST.
  - Homework assignment.
- Day 4 (Thursday, March 11): Technical III: Sensors
  - Lecture: 9 am-11 am EST.
  - Homework assignment.

The Road to Swarms

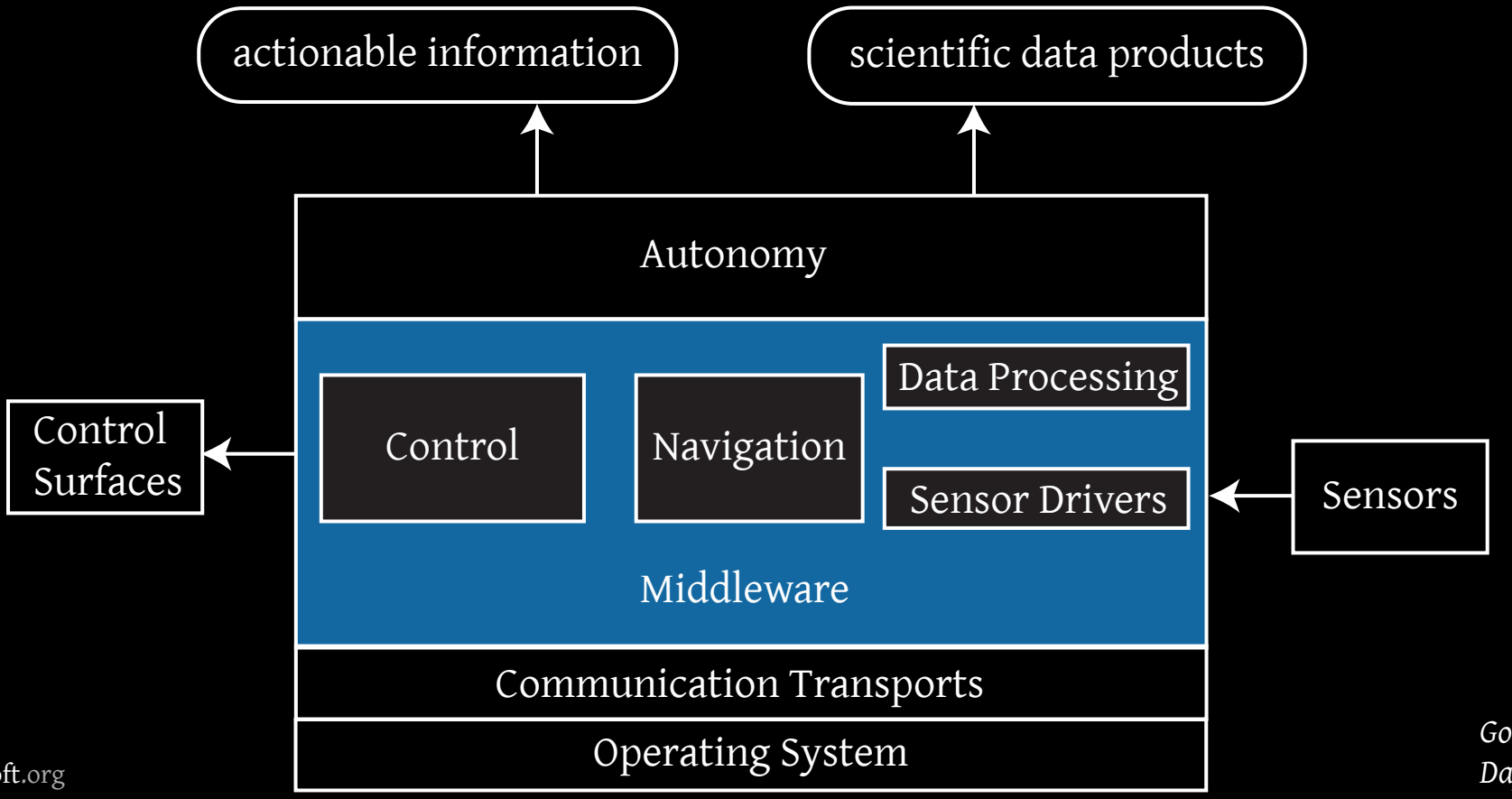
Multi-vehicle autonomy needs to be supported by multi-vehicle middleware.



What is middleware?

Primary role: asynchronous communication mechanism, typically publish/subscribe.

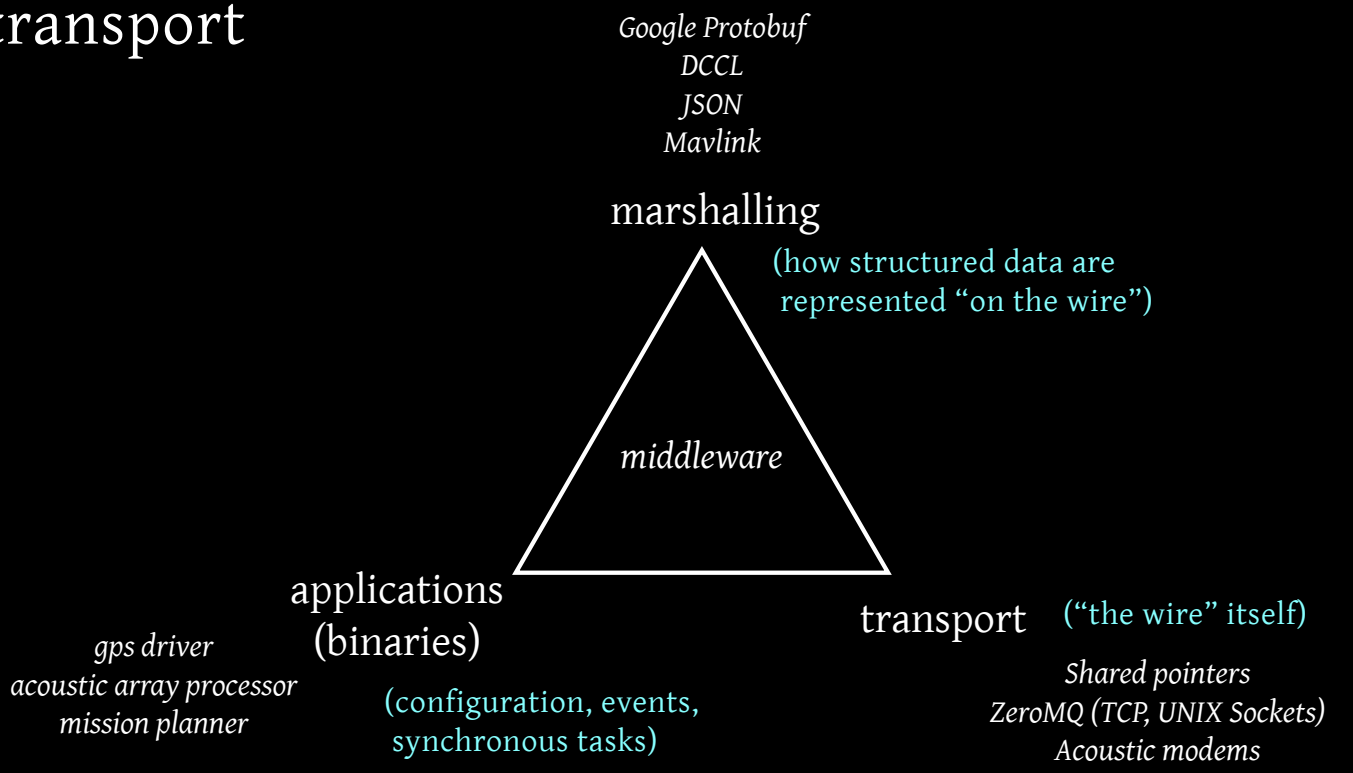
Secondary roles: tools for launching processes, logging, management, and monitoring.



Goby3 (Meta?) Middleware

This triad represents composition:

- marshalling + transport + application support = Goby3 middleware
- "meta-middleware": bring your own marshalling + transport



Existing middleware used in AUVs

MOOS - Mission Oriented Operating Suite

- *Transport:* TCP with central broker
- *Marshalling*: CMOOSMsg: string, double or binary
- *Application support*: CMOOSApp

ROS - Robot Operating System

- *Transport:* TCP with central broker;
  shared pointer interthread comms
- *Marshalling:* ROSMsg: user-defined “structs”
- *Application support*: ROS Node (loose specification)

LCM - Lightweight Communications and Marshalling

- *Transport:* UDP multicast interprocess comms,
  no central broker
- *Marshalling:* LCMType: conceptually similar to ROSMsg
- *Application support:* None

None are specifically designed for marine vehicles.
All mandate specific transport & marshalling scheme.

Goby3 Innovations

Nested communications

- Communications approach varies based on characteristic throughput and latency scale.

Neutral about choice of transport & marshalling scheme

- Allows easier inclusion of external innovations on networking and data presentation.
- New or project-specific marshalling languages can be used without middleware modification
- Interoperability with existing middleware

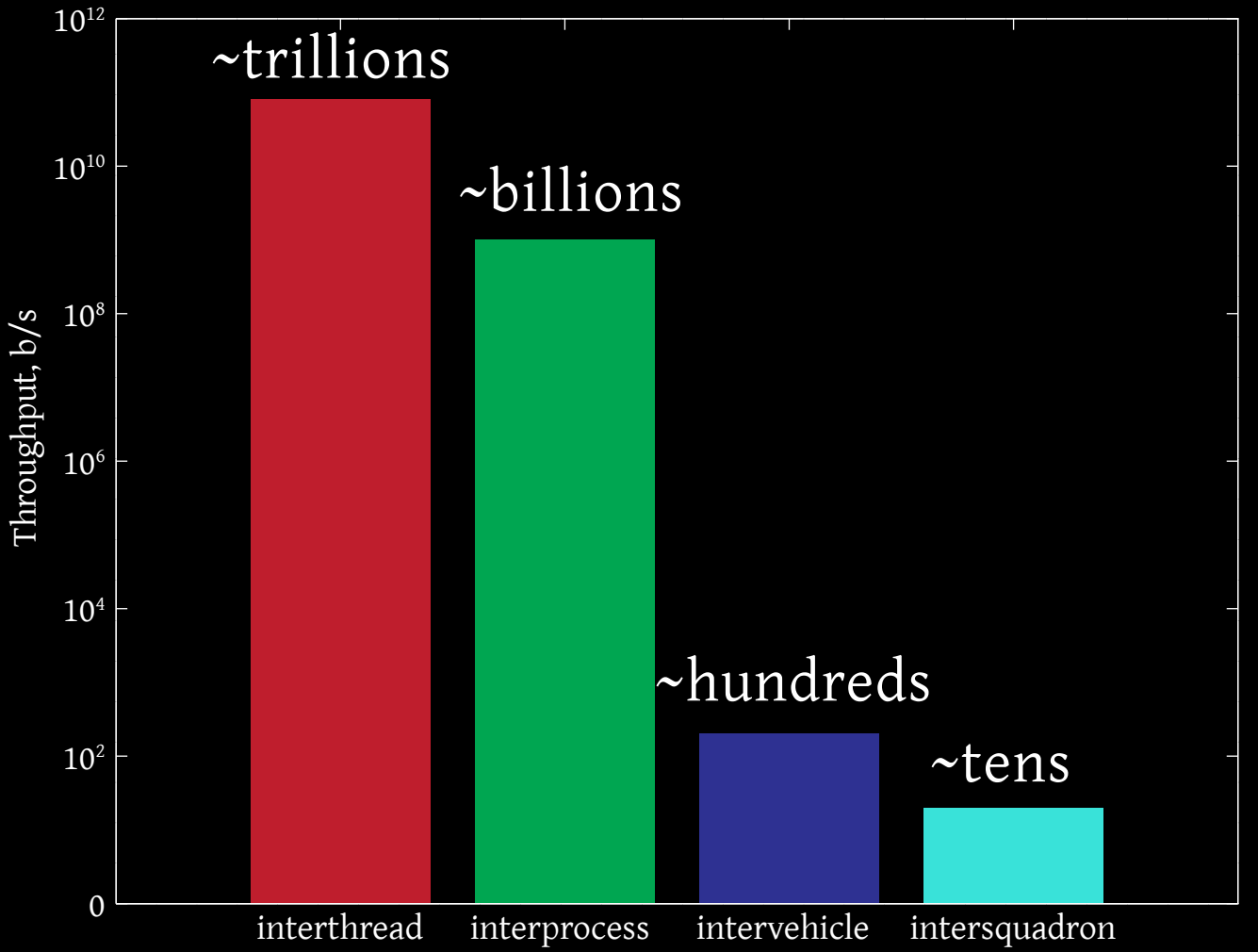
Nested Communications

Core idea: Networking approaches are fundamentally different for different characteristic latency and throughput scales.

- *Non-marine systems*: interprocess comms within and amongst vehicles are on the same scale.
- *Marine systems*: interprocess comms are an entirely different scale than intervehicle comms. Why?
  - Acoustic communications (fundamental physical limitations)
  - Sparse deployments (require satellite comms, long range radio).

Nested Communications

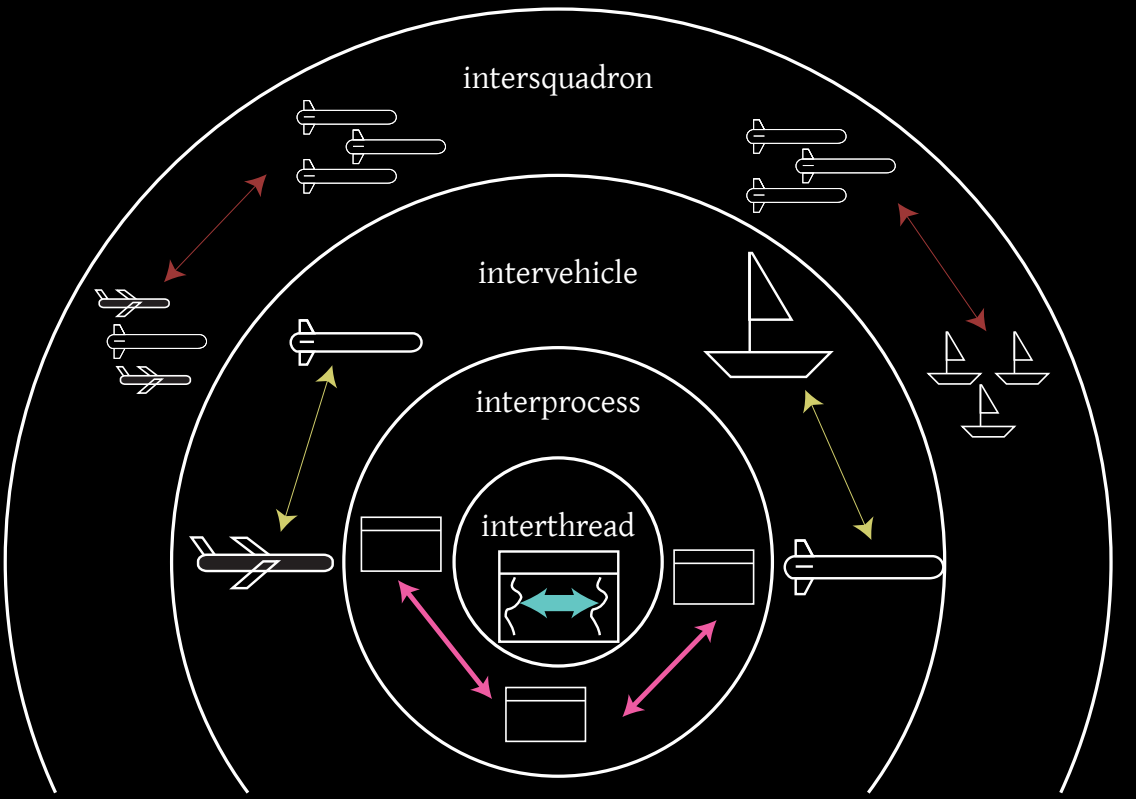
Characteristic throughput scales for AUVs:



Nested Communications

Each conceptual layer requires different transport and marshalling schemes.

Goby3 allows this and provides a common interface paradigm for publish/subscribe and cross layer forwarding.



Transport(er) Classes

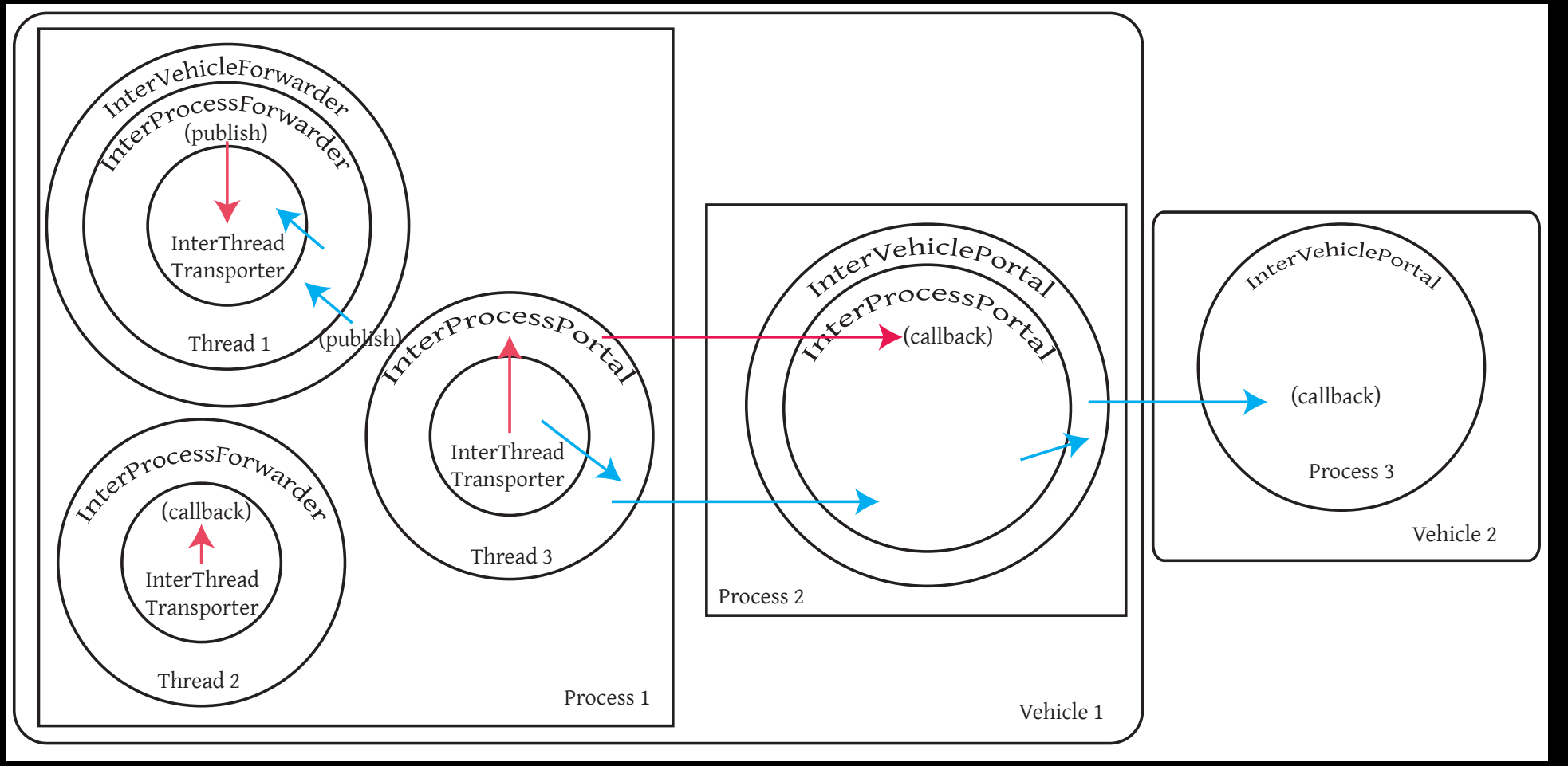
Nested comms transporter classes are in two categories (or concepts)

- Portal concept: connects one nested layer to the next. Exactly one portal per node per layer.
  - interthread: node == thread
  - interprocess: node == process
  - intervehicle: node == vehicle

  Forwarder concept: forwards data from inner layer nodes to the layer's portal. Any number per node.

  For example: InterProcessPortal - connects the threads within a process to the rest of the processes. InterProcessForwarder - forwards data from other threads to the InterProcessPortal (and thus to other processes).

Portal/Forwarder Example



- blue is published by the InterVehicleForwarder on Vehicle 1 / Process 1 / Thread 1, and subscribed by the InterVehiclePortal on Vehicle 2 / Process 3
- red is published by the InterProcessForwarder on Vehicle 1 / Process 1 / Thread 1, and is subscribed by Vehicle 1 / Process 1 / Thread 2 & Vehicle 1 / Process 2.

Reference Implementation

Goby3 provides a framework for defining nested layers, and attaching transport layers and marshalling schemes.

For immediate use, it also provides a three-level open source reference implementation in C++14.

- Interthread: C++ shared pointers: all types supported
- Interprocess: ZeroMQ (TCP/UNIX Sockets): Google Protocol Buffers and DCCL types, extensible to any serializable type
- Intervehicle: Goby-Acomms slow link transports and DCCL types

Fully event driven; based on condition variable signaling.

Marshalling Schemes

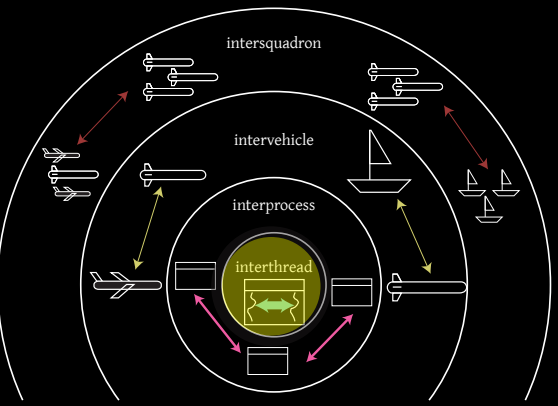
Marshalling is “the process of transforming the memory representation of an object to a data format suitable for storage or transmission” (Wikipedia)

- More concretely, in C++,
  struct/class -> array<byte> -> struct/class
- Many support multiple programming languages
- Example approaches include Google Protocol Buffers, MAVLINK, DCCL, JSON, MessagePack, ASN.1:
  - these are “marshalling schemes” in Goby3 (or just “schemes” for short)

Transport: Interthread

Zero-copy publish/subscribe implementation using std::shared_ptr. No constraints on allowable message types representable in C++.

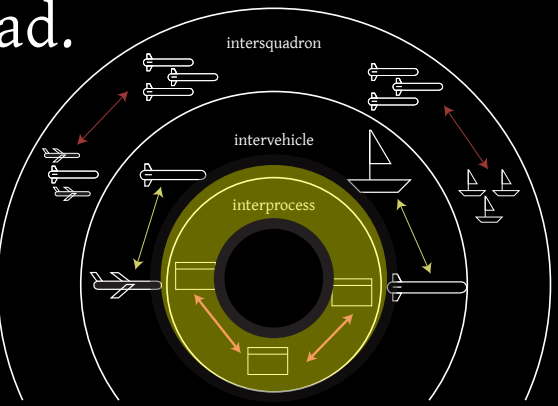
- publisher thread ---shared_ptr---> subscriber thread(s)
- Allows users unfamiliar with thread memory management to easily write multithreaded code.
- Allows multi-process code to be changed to multi-thread when needed to improve performance without changing message passing paradigm.



Transport: Interprocess

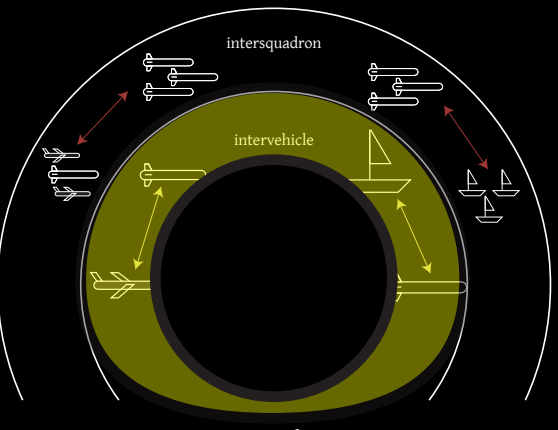
Reference implementation uses ZeroMQ. Types supported are DCCL and Google Protocol Buffers, but trivially extensible to any serializable type (by implementing functions for that marshalling scheme).

- Broker (gobyd) handles multiple publishers and subscribers over TCP or Unix Sockets.
- Subscription forwarding: publishers that have no subscribers use no bandwidth
- The inner layer (if any) is typically InterThread.
- MOOS, ROS comms is roughly analogous to this layer.



Transport: Intervehicle

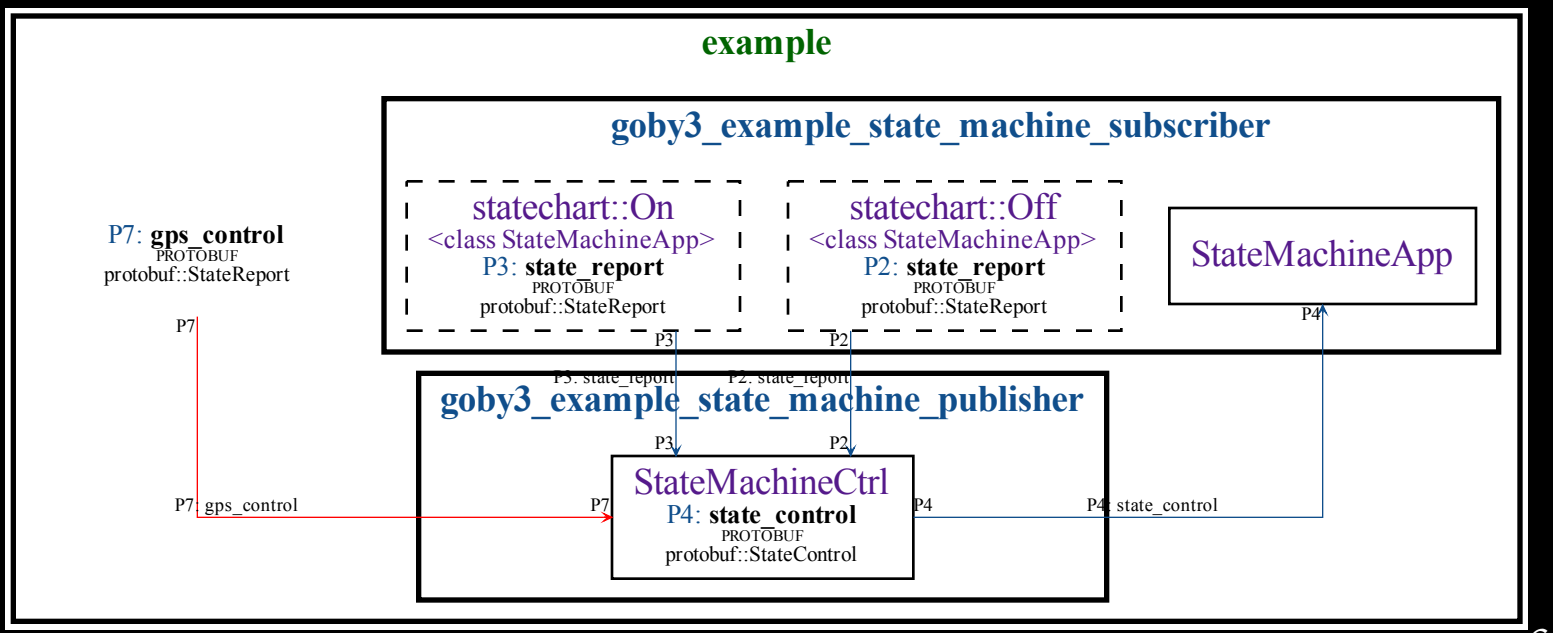
- ModemDriver: Common interface to “slow link” devices with implementations for various acoustic, satellite, etc. modems (MicroModem, Benthos, Iridium, ...).
- DCCL (libdccl.org): static unit-safe lossless marshalling that allows for physics-based bounds to create arbitrary sized fields (e.g. 6-bit int for temperature field for 0° to 40° C)
- Dynamic Buffer: deadline sensitive priority queuing
- Subscription forwarding: published data does not get sent if no subscriber exists.
- The inner layer is typically InterProcess.



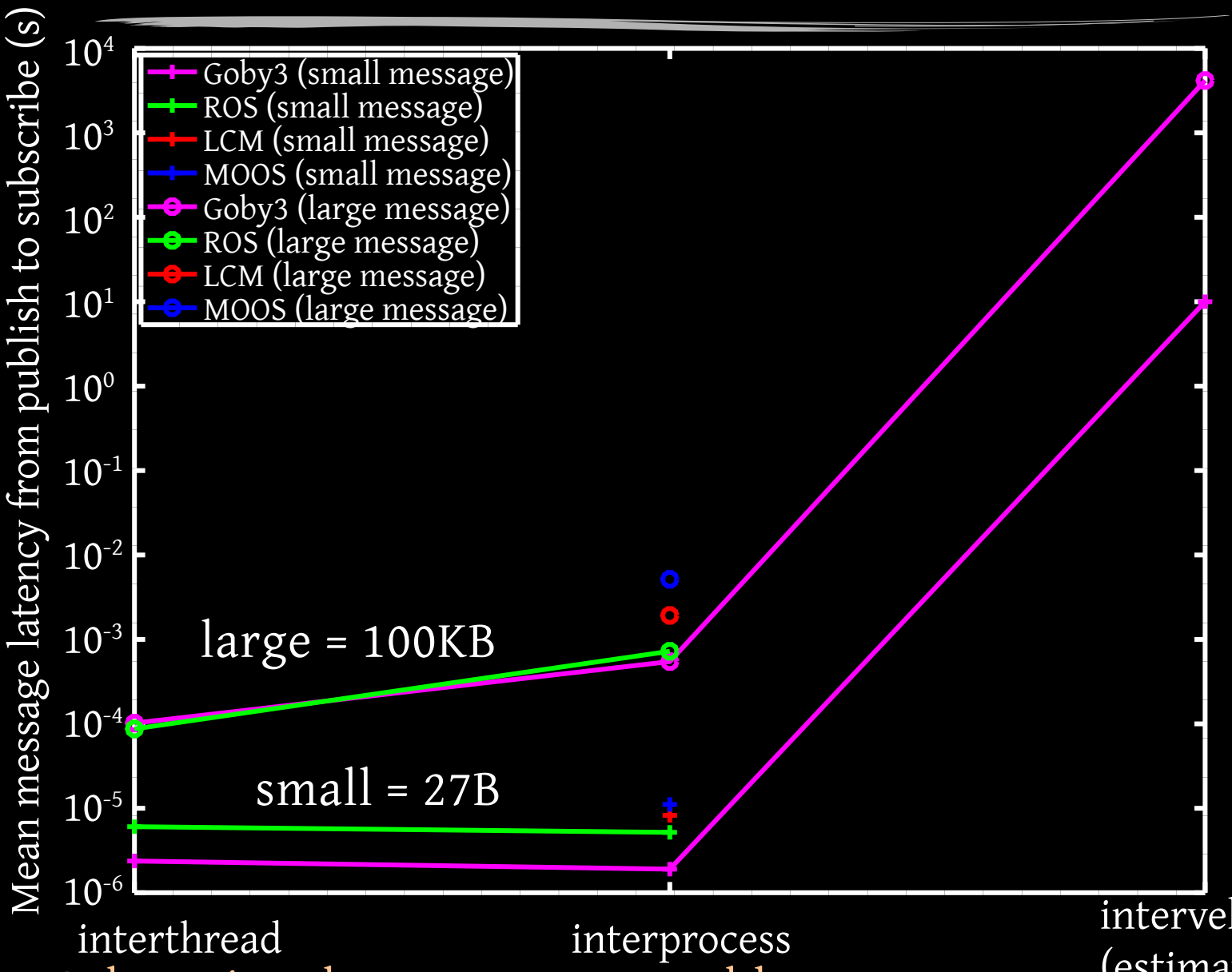
Static Analysis

Emphasis on static type safety via template "groups" (goby::middleware::Group). (Analogous to ROS topics, LCM channels, MOOS variables).

By using constexpr, we can generate static pub/sub graphs (using goby_clang_tool):



Performance Results



Goby3 gives better or comparable performance to existing middlewares

Application: Single Thread

Rapid prototyping base class: Inspired by CMOOSApp, but with significant improvements.

- Automatic configuration and command-line parsing, and syntax checking into Google Protobuf message passed as a template parameter.
- Single virtual method: loop(), analog of CMOOSApp::Iterate().
- No other virtuals (Constructor handles the equivalent of OnStartup / OnConnectToServer).
- Contains an InterProcessPortal, with no inner level.

Example (SingleThreadApplication)

publisher.cpp

```
#include "goby/middleware/single-thread-application.h"
#include "messages/nav.pb.h"
#include "messages/groups.h"
#include "config.pb.h"

class BasicPublisher :
   public goby::SingleThreadApplication<BasicPublisherConfig>
{
public:
   BasicPublisher() : Base(10 /*hertz*/)  {
        // all configuration defined in BasicPublisherConfig is in cfg();
        std::cout << "My configuration int: " << cfg().my_value() << std::endl;
     }

   void loop() override {
        protobuf::NavigationReport nav;
        nav.set_x(95 + std::rand() % 20);
        nav.set_y(195 + std::rand() % 20);
        nav.set_z(-305 + std::rand() % 10);
        transporter().publish<groups::nav>(nav);
     }
};
int main(int argc, char* argv[])
{ return goby::run<BasicPublisher>(argc, argv); }
```

groups.h

```
#include "goby/middleware/serialize_parse.h"
namespace groups {
  constexpr goby::Group nav{"navigation"};
}
```

nav.proto

```
package protobuf;

message NavigationReport {
 required double x = 1;
 required double y = 2;
 required double z = 3;
 enum VehicleClass { AUV = 1; USV = 2; SHIP = 3; }
 optional VehicleClass veh_class = 4;
 optional bool battery_ok = 5;
}
```

subscriber.cpp

```
#include "goby/middleware/single-thread-application.h"
#include "messages/nav.pb.h"
#include "messages/groups.h"
#include "config.pb.h"

class BasicSubscriber :
    public goby::SingleThreadApplication<BasicSubscriberConfig>
{
public:
   BasicSubscriber()  {
        using protobuf::NavigationReport;
        auto nav_callback = [this] (const NavigationReport& nav)
          { std::cout << "Rx: " << nav.DebugString() << std::flush; };
        transporter().subscribe<groups::nav, NavigationReport>(nav_callback);
     }
};
int main(int argc, char* argv[])
{ return goby::run<BasicSubscriber>(argc, argv); }
```

config.proto

```
import "goby/common/protobuf/app3.proto";
import "goby/middleware/protobuf/interprocess_config.proto";

message BasicPublisherConfig {
 optional goby.protobuf.App3Config app = 1;
 optional goby.protobuf.InterProcessPortalConfig interprocess = 2;
 optional int32 my_value = 3;
}
```

Application: Multi Thread

Extends the SingleThreadApplication to multiple threads.

- Each thread is a subclass of a similar interface to the SingleThreadApplication.
- This approach avoids accidental thread memory contention if all data are stored at the class level (no globals).
- Threads can be spawned and joined as necessary. Joining happens as soon as loop() returns.

Repository Structure

Core:

- libgoby.so: acomms, middleware, time, util
- middleware tools: goby_clang_tool, goby_log_tool

ZeroMQ:

- libgoby_zeromq.so
- zeromq apps: gobyd, goby_logger, etc.

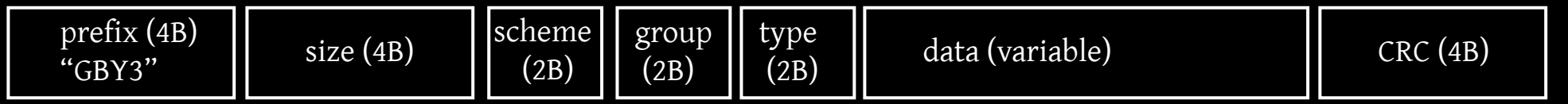
MOOS:

- libgoby_moos.so
- pAcommsHandler

(Explore goby3-repository-layout.pdf)

Binaries: Logger

goby_logger writes a flat binary log file, with each message protected by prefix word and CRC32

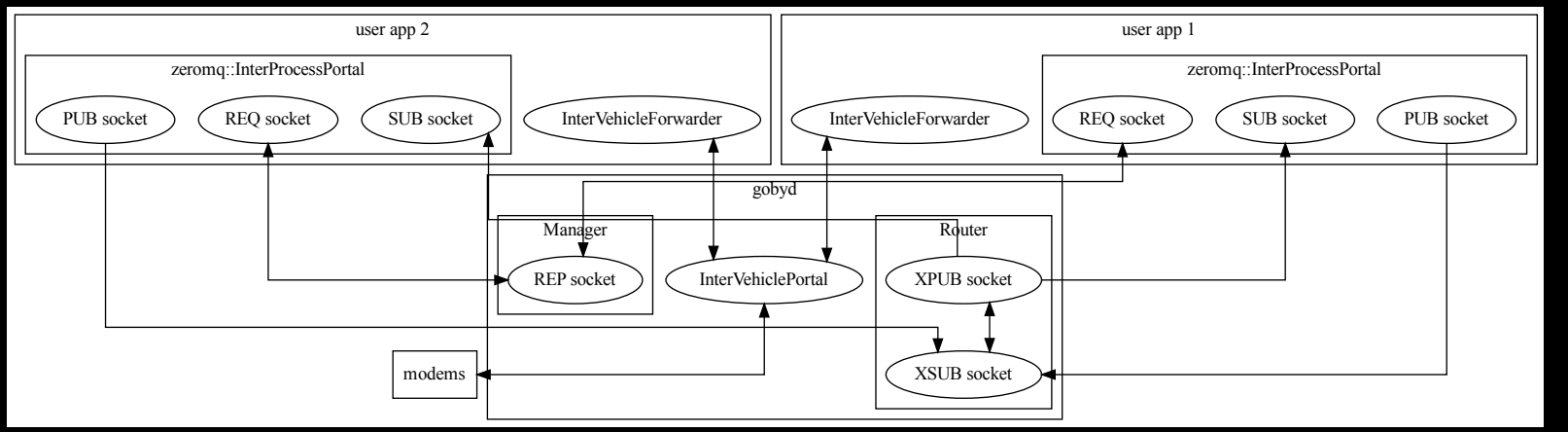


- If corruption occurs, remaining messages can be recovered
- Plugin API for additional storage of metadata for specific schemes (e.g. Protobuf descriptors)
- Post-processing can be handled by scheme-specific parsers. Includes parser in goby_log_tool for DCCL/Protobuf -> HDF5 and text.
  (HDF5 can be directly read in MATLAB/Octave, Python, C++, Julia, etc.)

Binaries: gobyd

Brokers pub/sub communications for ZeroMQ interprocess reference implementation.

- Manager:
  - ZeroMQ REP socket: Accepts client (zeromq::InterProcessPortal) connections and provides (dynamic) pub/sub ports
- Router:
  - ZeroMQ XPUB/XSUB proxy
- InterVehiclePortal
  - Manages connections to various modems and InterVehicleForwarder(s)



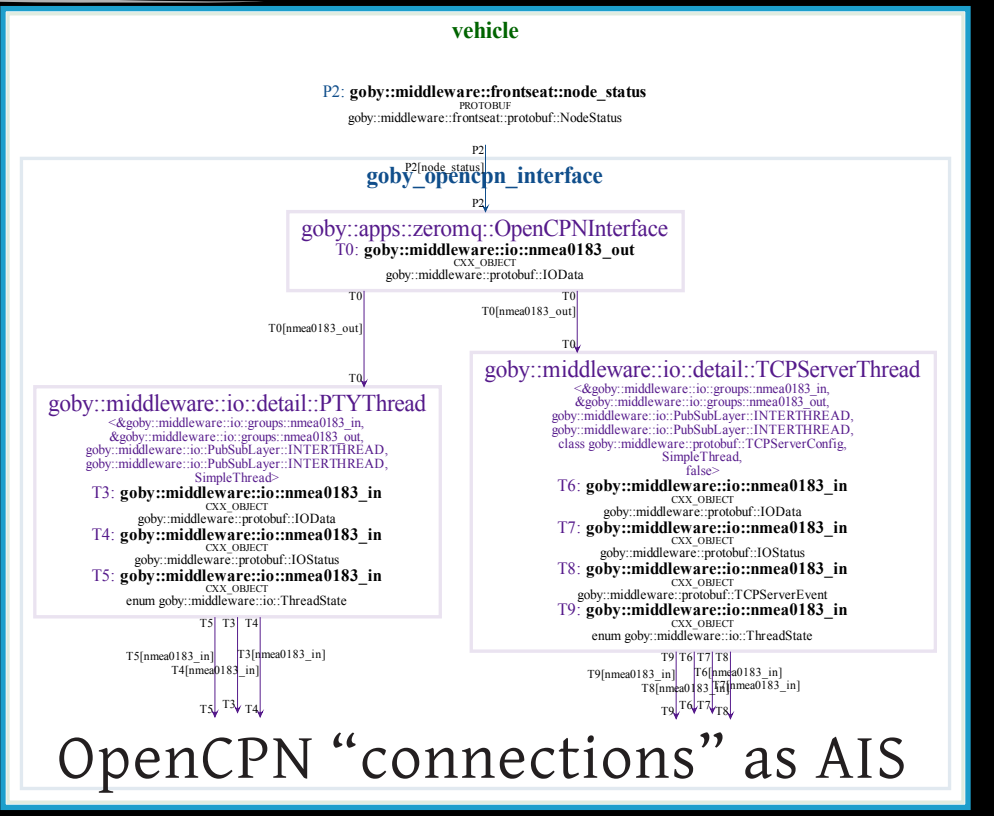
Binaries: Viewer Interfaces

goby_opencpn_interface

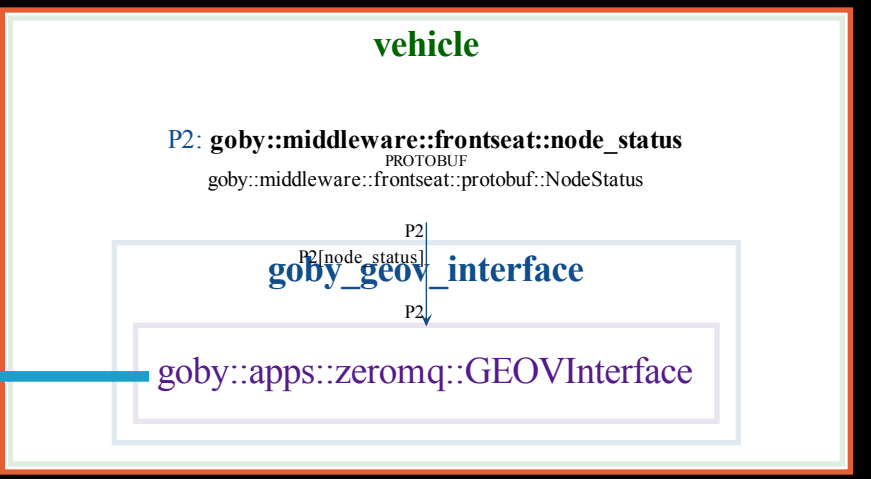
- Provides position data as a fake AIS message to OpenCPN chart plotter (TCP or (pseudo)serial)

goby_geov_interface

- Inputs data to GEOV (Google Earth interface for Ocean Vehicles): https://gobysoft.org/geov



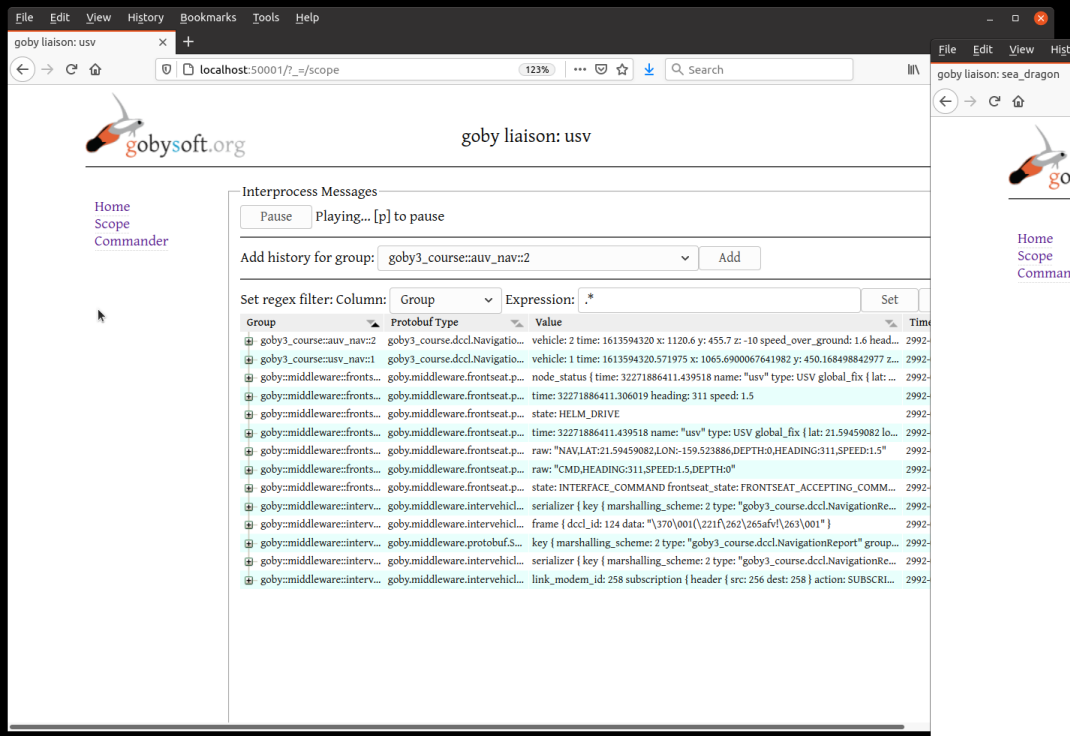
Google Earth via MySQL

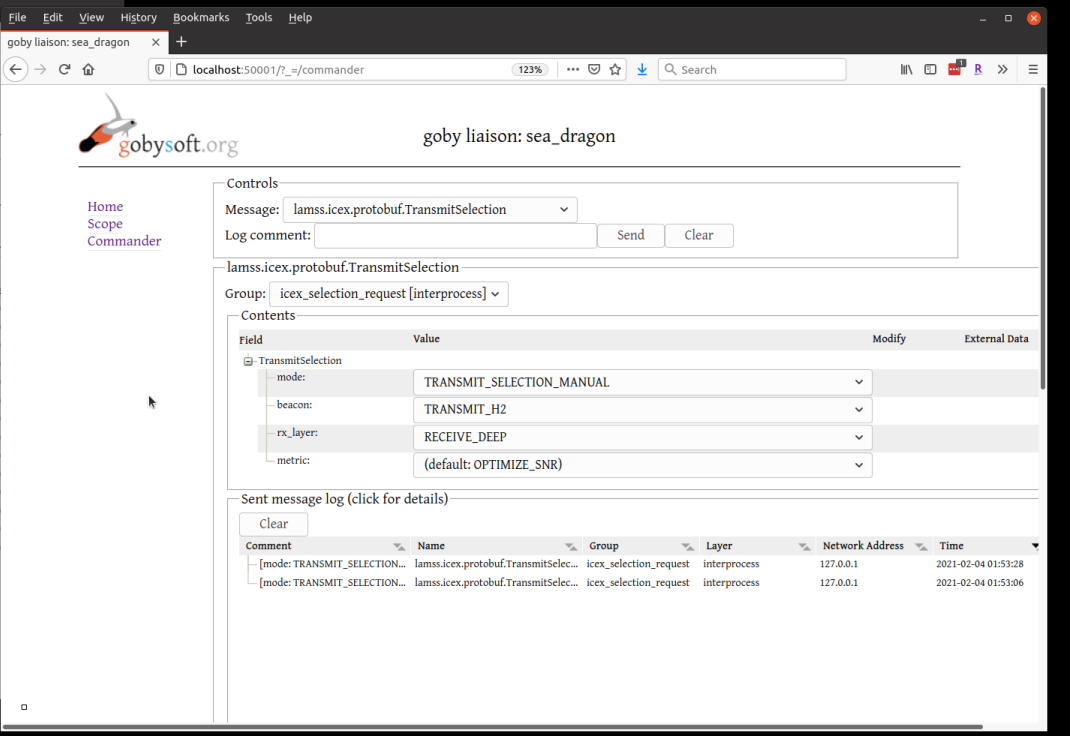


Binaries: goby_liaison

Extensible server/client UI based on Wt (C++ web toolkit).

- Two built-in tabs:
  - Scope: see interprocess data
  - Commander: send Protobuf via a form





Binaries: goby_frontseat_interface

Implements “backseat” part of “frontseat”/ “backseat” abstractions

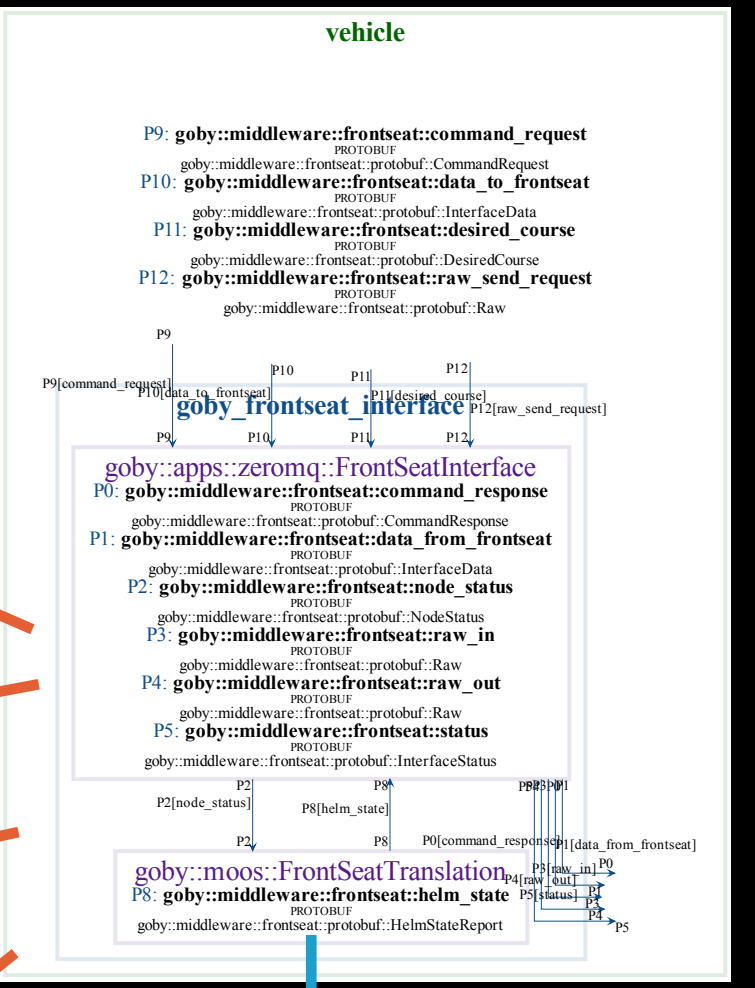
- Backseat = payload autonomy: desired set-points
- Frontseat = vehicle control computer
- New vehicles are C++ .so plugin

plugin: basic simulator

plugin: Bluefin

plugin: Waveglider (SV2)

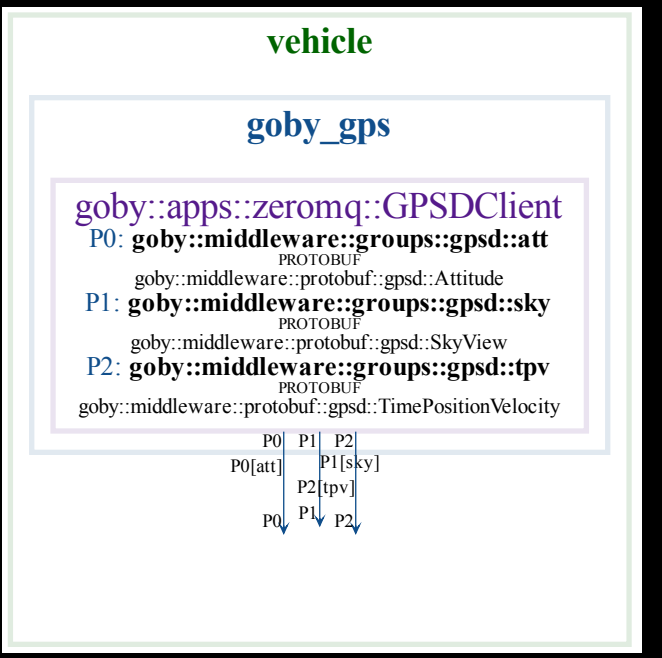
plugin: Iver3



Binaries: goby_gps (beta)

Connects to gpsd (Linux "interface daemon for GPS receivers") and publishes the data (attitude, sky view, time/position/velocity) on Goby3 interprocess

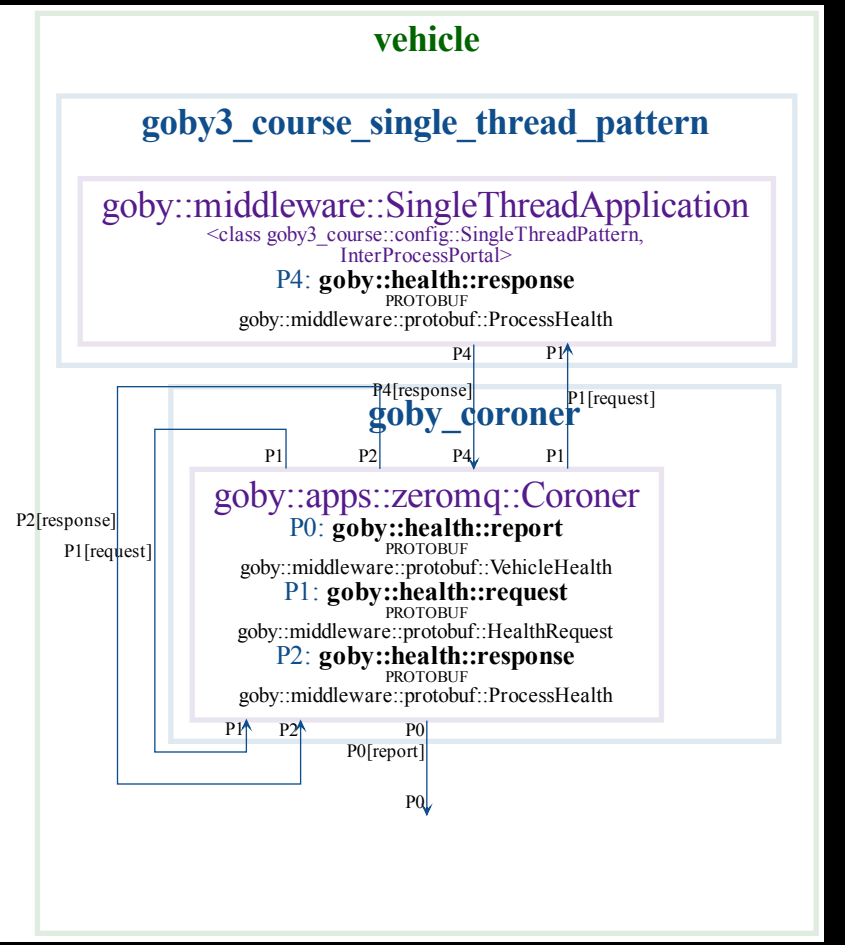
- Can handle filter publications based on device name or publish data from all devices



Binaries: goby_coroner

Keep track of health of Goby applications

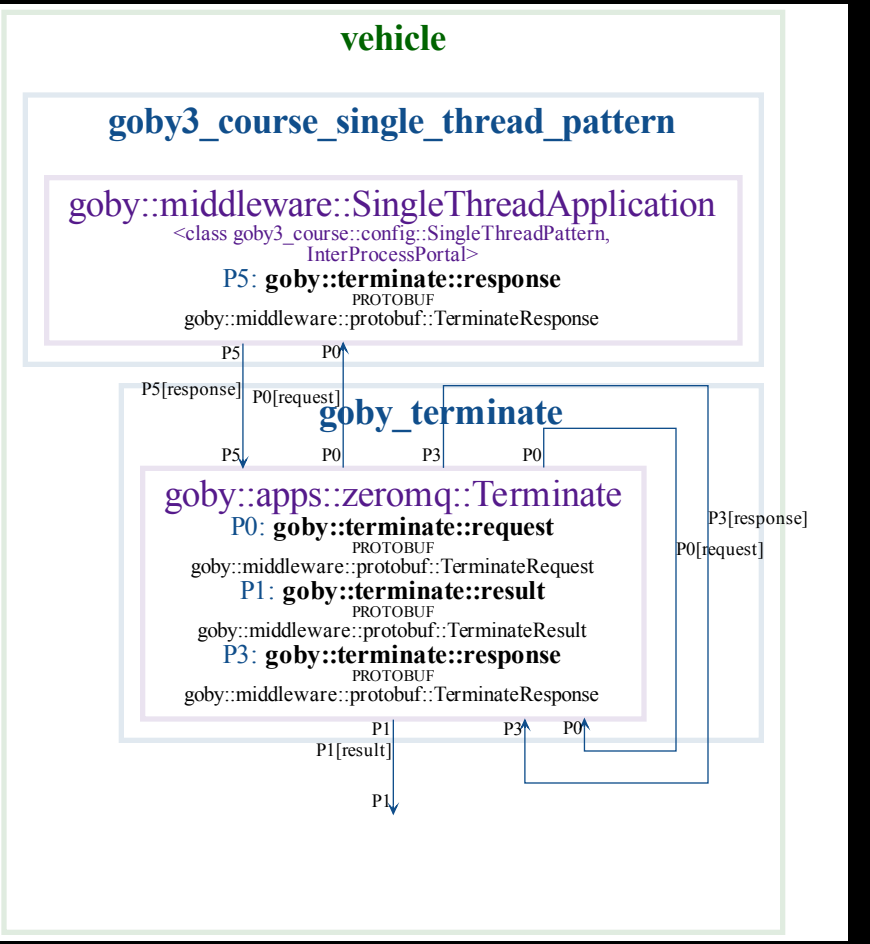
- Request for health given periodically, aggregate as goby::health::report
- Applications can override response to give more detail.



Binaries: goby_terminate

Clean shutdown tool.

- goby_terminate requests application to quit (based on PID or name)
- Application responds and quits (cleanly)
- If no response after timeout, goby_terminate exits with non-zero code.



Scripts: goby_launch

Bash script to launch and cleanup applications.

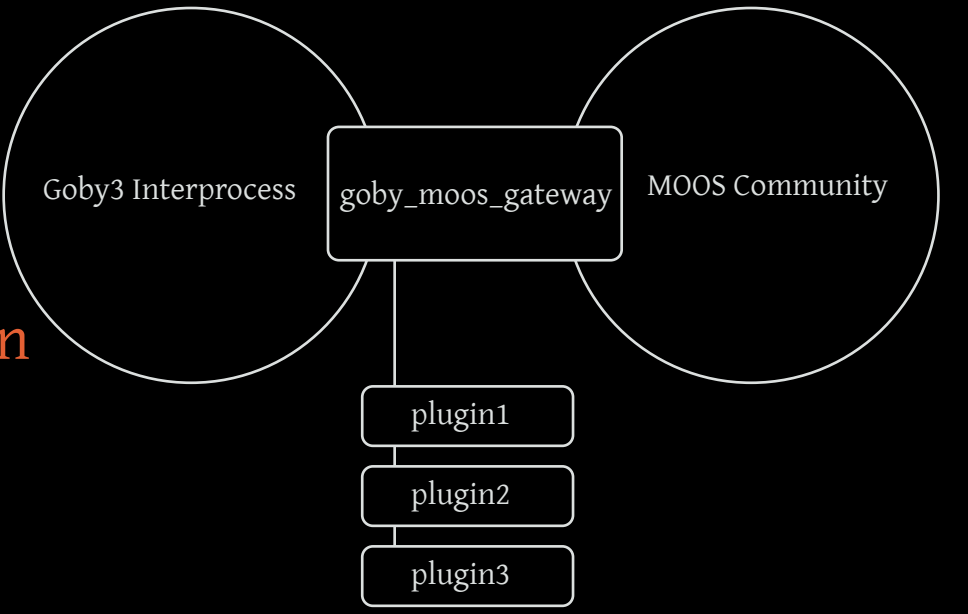
- Designed for multi-process/multi-vehicle simulations (systemd is more suited for actual deployments)
- By default, uses goby_terminate to cleanup, failing that: SIGINT, failing that: SIGKILL.
- At its simplest, launch file is just a list of applications and command line parameters:

```
#!/usr/bin/env goby_launch

gobyd <(config/topside.pb.cfg.py gobyd) -vvvv -n

goby3_course_topside_manager <(config/topside.pb.cfg.py goby3_
course_topside_manager)

goby_liaison <(config/topside.pb.cfg.py goby_liaison)

goby_opencpn_interface <(config/topside.pb.cfg.py goby_opencpn_
interface)

goby_geov_interface <(config/topside.pb.cfg.py goby_geov_inter-
face)
```

Interoperability

Plugin API for Goby3 <-> MOOS translation.
(future) Goby3 <-> ROS translation will be similar.

- Allows translations to be done in C++, with minimal code; can be as simple or complicated as necessary.
- Example: convert MOOS variables "TEST_LATITUDE" and "TEST_LONGITUDE" into Protobuf GPSPosition. Conversely, turn GPSPosition into MOOS variables "GPS_LATITUDE" and "GPS_LONGITUDE."



Interoperability

```
#include "goby/moos/middleware/moos_plugin_translator.h"
#include "messages/gps.pb.h"
#include "messages/groups.h"

using goby::moos::Translator;
class NavTranslation : public goby::moos::Translator
{
public:
   NavTranslation(const GobyMOOSGatewayConfig& cfg) : Translator(cfg)   {
         goby_comms().subscribe<groups::gps_data, GPSPosition>(
            [this](const GPSPosition& pos) {
              moos_comms().Notify("GPS_LATITUDE", pos.latitude());
              moos_comms().Notify("GPS_LONGITUDE", pos.longitude());
            });
         add_moos_trigger("TEST_LATITUDE");
         add_moos_buffer("TEST_LONGITUDE");
     }
private:
   void moos_to_goby(const CMOOSMsg& moos_msg) override {
         if(moos_msg.GetKey() == "TEST_LATITUDE" && moos_buffer().count("TEST_LONGITUDE"))   {
               protobuf::GPSPosition pos;
               pos.set_time(moos_msg.GetTime());
               pos.set_latitude(moos_msg.GetDouble());
               pos.set_longitude(moos_buffer().at("TEST_LONGITUDE").GetDouble());
               goby_comms().publish<groups::gps_data>(pos);
         }
     }
};

extern "C"
{
   void goby3_moos_gateway_load(goby::MultiThreadApplication<GobyMOOSGatewayConfig>* handler)
   { handler->launch_thread<NavTranslation>(); }
   void goby3_moos_gateway_unload(goby::MultiThreadApplication<GobyMOOSGatewayConfig>* handler)
   { handler->join_thread<NavTranslation>(); }
}
```

Goby to MOOS

MOOS to Goby

BREAK

5 minute break

Comments, questions, feedback: Please leave in Slack channel!

Preview: Trail Example

This week we will focus around a particular deployment:

- Fleet of ~10 autonomous underwater vehicles (AUVs) trailing a unmanned surface vehicle (USV)
- USV following pre-planned route.
- Topside (ship or shore station) communicating to the USV.

Communications:

- AUV <-> USV: Acoustic communications
- USV <-> topside: Satellite communications

Run trail example

Alpha Example

Let's put aside the trail example, and build back up to it.

This is the "s1_alpha" mission from MOOS-IvP but with:

- goby_frontseat_interface with basic sim plugin
  (connects to goby_basic_frontseat_simulator)
  - could swap plugins to use real vehicle or vehicle sim
- goby3_course_usv_manager
  - publishes data to topside
- gobyd with satellite link simulated via UDP multicast

Topside with gobyd, goby3_course_topside_manager, goby_opencpn_interface, goby_geov_interface.

Launching

```
cd goby3-course/launch/alpha
./usv.launch
(new terminal)
./topside.launch
(new terminal)
opencpn
(new terminal)
google-earth-pro
(click deploy from pMarineViewer)
...
to end, <CTRL>+C on usv.launch, topside.launch
```

Debug logger

All Goby applications have access to goby::glog which is much like std::cout, except glog has:

- runtime configurable verbosity settings (warn > verbose > debug1 > debug2 > debug3)
- thread safety (mutex lock from .is_*() to std::endl/ std::flush)
- ability to write to terminal and file(s) simultaneously
- support for colors and grouping of streams

```
glog.is_verbose() && glog << “This is verbose” <<
std::endl;
```

Configuration

Goby applications will automatically parse command line parameters and/or configuration files using a given "Configurator"

The default configurator is ProtobufConfigurator:

- The application writer defines a Protobuf message that forms the valid configuation for that application.
- The message is then used to automatically define command line parameters (`> app --help`) and configuration file syntax (`> app --example_config`)
- Alpha mission configs are in topside_config, usv_config directories

Configuration (app)

All applications will have an common "`app { }`" block which can be used to change:

- glog verbosity and output locations
- simulation settings (faster-than-realtime clock)
- geodesy (basic UTM projection)

```
app {
  glog_config {
    file_log {
      file_dir: "../../logs/usv" verbosity: DEBUG2
    }
  }
  simulation {
    time { use_sim_time: true  warp_factor: 10 }
  }
}
```

Configuration (interprocess)

All applications that communicate on interprocess will have an common "`interprocess {}`" block:

- platform name (used to form socket path with using the default transport, `transport: IPC`)
- transport type (IPC or TCP), address, port for TCP
- ZeroMQ queue size and worker thread count

```
interprocess {
    platform: "usv"
} // or

interprocess {
    platform: "usv"
    transport: TCP
    ipv4_address: "192.168.1.1"
    tcp_port: "11144"
}
```

Debugging

goby_launch by default sends each application's output to GNU screen.

- See all screens: `screen -ls <filter>`
- Attach a screen: `screen -r usv.gobyd`
- Detach a screen: `<CTRL>+A, D`

goby applications default to QUIET (no terminal output). To increase verbosity use -v[vvv] on command line (or in .launch file) where:
-v is `glog_config {tty_verbosity: VERBOSE}`
-vv is `glog_config {tty_verbosity: DEBUG1}`
-vvv is `glog_config {tty_verbosity: DEBUG2}`
-vvvv is `glog_config {tty_verbosity: DEBUG3}`

and/or use NCurses GUI (-n)