RCLAda, or bringing Ada to the Robotic Operating System

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Centro Universitario de la Defensa Zaragoza

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  - About us
  - What is ROS2
  - Why Ada
  - ROS2 example
- RCLAda Architecture
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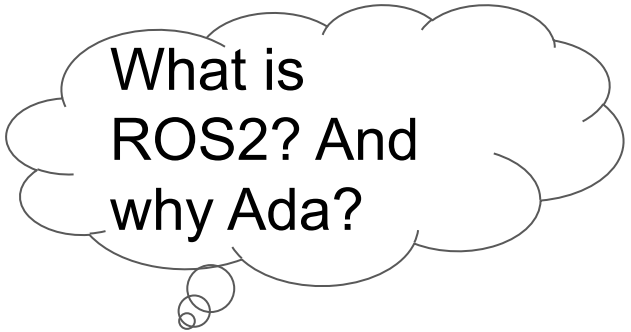


Robotics, Perception and Real-Time group - RoPeRT

University of Zaragoza

Engineering Research Institute of Aragon

Research group

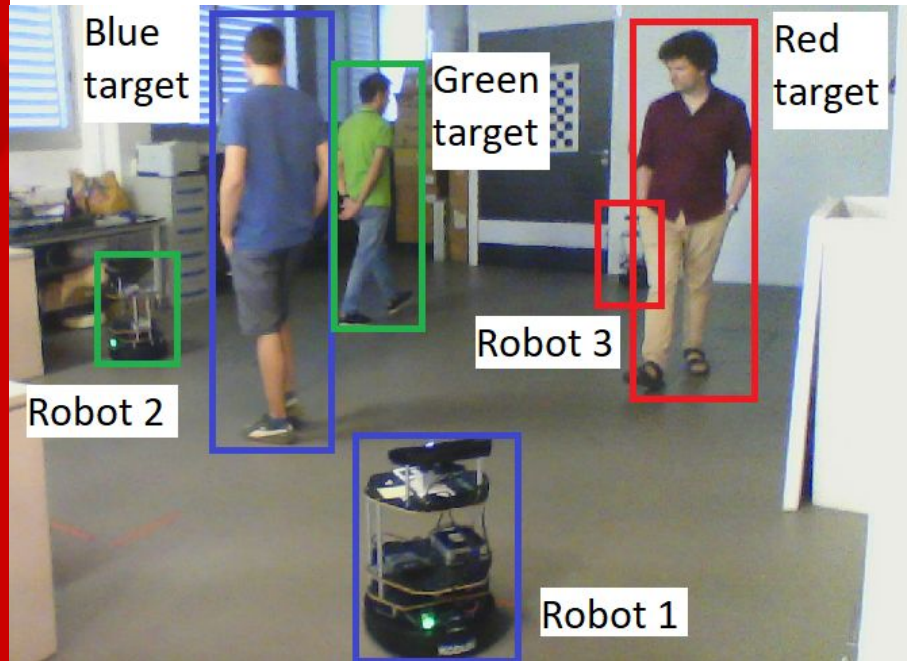
Optimal distributed coordination

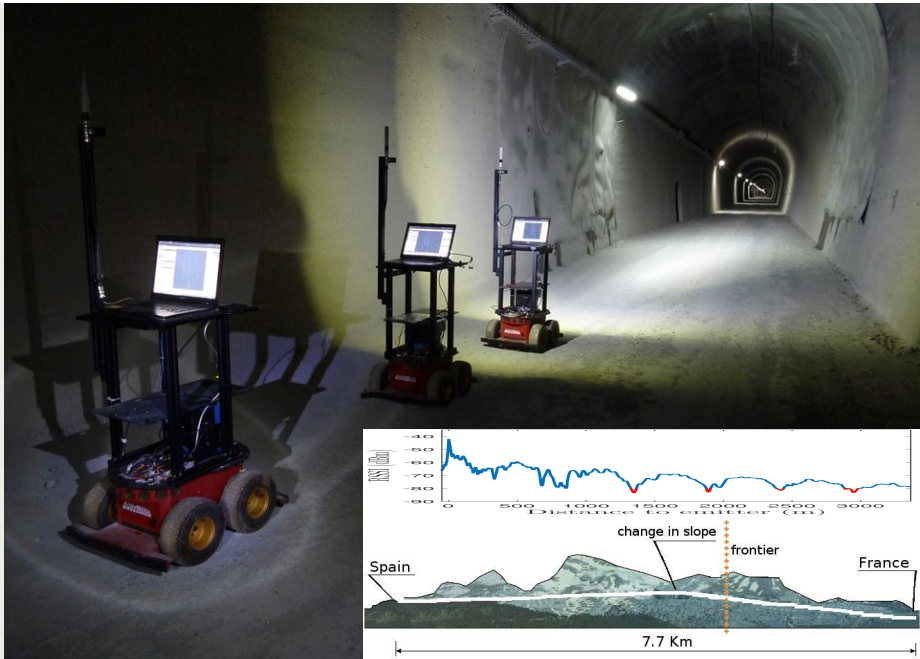
Real-time multi-hop communication

Underground drone reconnaissance

ROBOTICS
UNIVERSIDAD DE ZARAGOZA

http://robots.unizar.es/





RoPeRT

It is now possible to write ROS2 nodes in Ada 2012

(with minimal CMake knowledge)

Ada coin author: Steven Craeynest

About ROS

• Robot Operating System

– But not really

ROS

Open Source Robotics Foundation

*"The Robot Operating System (ROS) is a set of **software libraries** and **tools** that help you build robot applications. From **drivers** to state-of-the-art **algorithms**, and with powerful developer tools, ROS has what you need for your next robotics project. And it's all **open source**."*

Main OSRF project (10 years now)

ROS2 Main Parts

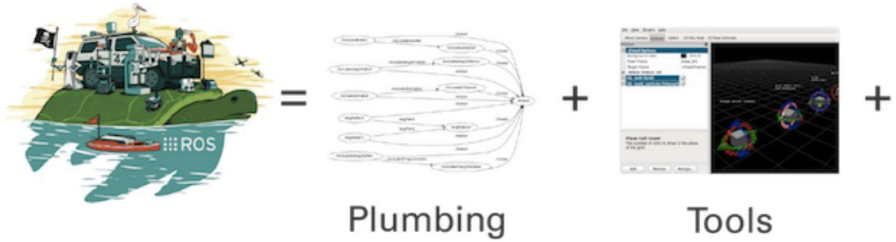
ROS

- Collection of Debian/Ubuntu packages ready to use
  - Sensor/platform/actuator drivers
  - High-level algorithms
- Build system (∈ “tools”)
  - Heterogeneous language environment
  - Nodes isolated as processes/threads
- Intercommunication facilities (“plumbing”)
  - Message publishing
  - Remote Procedure Calls
  - Actions

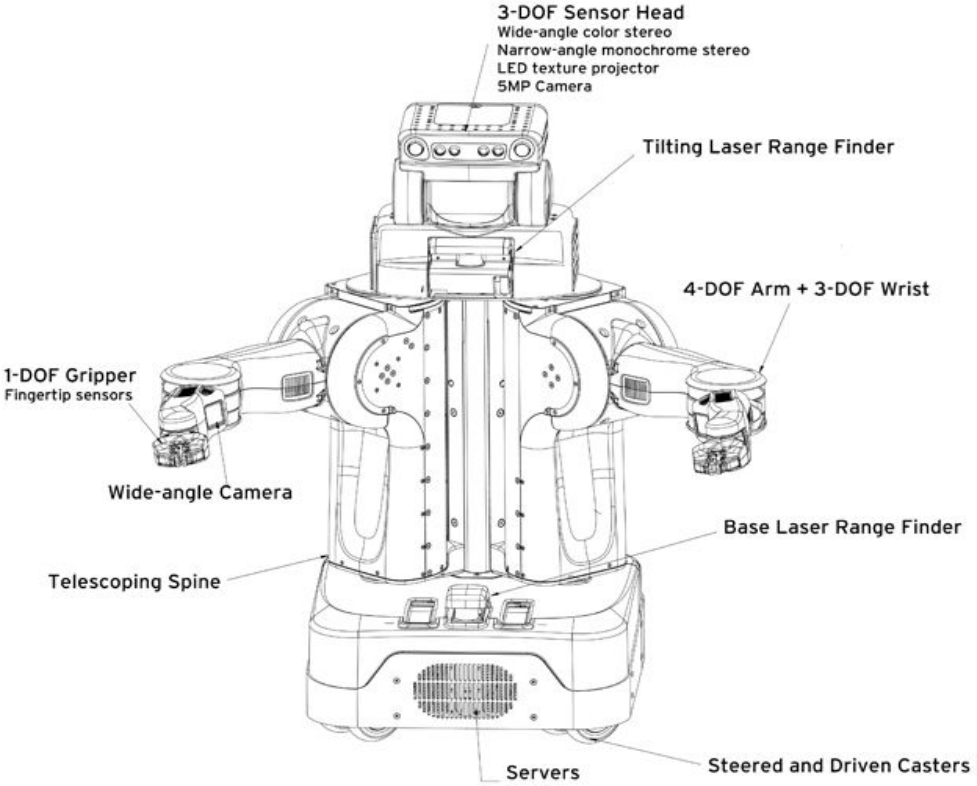
Colcon

CMake
Cross-platform Make

python



PR2: the kick-off robot



https://www.youtube.com/watch?v=c3Cq0sy4TBs

Academia & Research

- ROS support widespread
  - Expected in research/academia contexts
  - Either by 1st or 3rd parties

Summit XL 4WD Autonomous Robot
Product Code : RB-Rtk-04
1 Review(s)
USD $15,000.00

Svenzva Robotics Revel 6 DoF Robotic Arm
Product Code : RB-Svz-01
USD $6,495.00

ROSbot 2.0 w/ LIDAR & RGBD Robotic Platform
Product Code : RB-Rco-07
USD $1,899.00

TeraRanger Duo ToF Rangerfinder with Sonar Sensor
Product Code : RB-Ter-07
Excl. Tax: €185.00
Incl. Tax: €223.85

2.3 3D Sensors (range finders & RGB-D cameras)

- Argos3D P100 ToF camera
- Basler ToF ES camera
- DUO3D™ stereo camera
- Ensenso stereo cameras
- Forecast 3D Laser with SICK LIDAR
- SceneScan and SP1 by Nerian Vision Technologies
- OpenNI driver for Kinect and PrimeSense 3D sensors
- Trifo Ironsides
- PMD Camcube 3.0
- IFM O3M250 ToF camera
- Intel® RealSense™ F200/VF0800
- Intel® RealSense™
- Roboception rc_visard stereo camera
- Terabee 3D ToF camera
- Orbbec Astra
- SICK MRS1xxx lasers
- SICK MRS6xxx lasers
- SICK LD-MRS laser (identical to IBEO LUX) or csiro-asl/sick_ldmrs
- Sentis ToF M100 camera
- Mesa Imaging SwissRanger devices (3000/4000/4500)
- Velodyne HDL-64E 3D LIDAR
- Livox 3D LiDAR

2.2 2D range finders

- NaviRadar
- HLS-LFCD LDS
- Hokuyo Scanning range finder
- PepperI+Fuchs R2000 laser
- Leuze rotoScan laser rangefinder driver (ROD-4, RS4)
- RPLIDAR 360 laser scanner Driver(python)
- RPLIDAR A1/2 laser(c++)
- SICK LMS1xx lasers or LMS1xx
- SICK LMS2xx lasers or sicktoolbox_wrapper
- SICK S3000 laser
- SICK S300 Professional
- SICK TiMxxx lasers or sick_tim
- SICK Safety Scanners (microScan3)
- TeraRanger Multiflex
- TeraRanger Hub & Tower
- TeraRanger Hub Evo & Tower Evo
- TeraRanger Evo 64px ToF range finder
- Neato XV-11 Laser Driver


GAZEBO


pointcloudlibrary


ROS


ROS
industrial

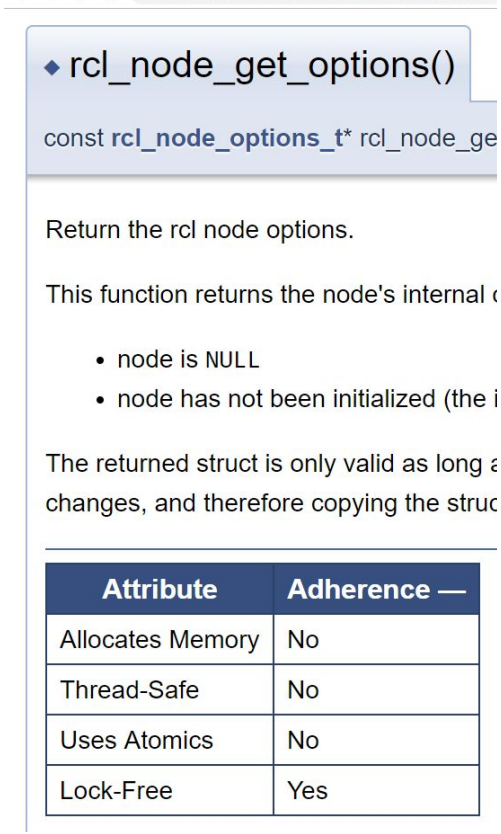

MoveIt!


OpenCV


ROSin

ROS2 vs ROS

- More emphasis on
  - Embedded (microcontrollers)
    - ROS has been mostly a linux affair
  - Real-time
    - Coming from firm/soft real-time
  - Actual readiness for industrial settings
    - Long lived processes vs short experiments
    - Standard DDS for data transport
      - Swappable implementation
- Traditional strongholds of Ada



◆ rcl_node_get_options()

const **rcl_node_options_t*** rcl_node_ge

Return the rcl node options.

This function returns the node's internal

- node is `NULL`
- node has not been initialized (the i

The returned struct is only valid as long a changes, and therefore copying the struc

Attribute	Adherence —
Allocates Memory	No
Thread-Safe	No
Uses Atomics	No
Lock-Free	Yes

At the time of this writing (may'19)

- Working Groups on
  - Real-time
  - Safety-critical
    - Already seen interest in SPARK

ROS 2 and Real-time

Next Generation ROS

Dejan_Pangercic 9d

In one of the previous ROS 2 TSC meeting it was suggested that we form a Working Group in which we will try to analyse the current state of ROS 2 and make it real-time.

To this date we have the following articles about real-time in ROS 2:

1. Original article by Jackie: https://design.ros2.org/articles/realtime_background.html 11
2. ROS 2 ported on some RTOS (https://www.esol.com/embedded/ros.html 9, http://blackberry.qnx.com/en/articles/what-adas-market-needs-now 2)
3. Apex.AI article about porting ROS 1 applications to ROS 2 applications: https://www.apex.ai/blog/porting-algorithms-from-ros-1-to-ros-2 12
4. Bosch proposing how to make Callback-group-level Executor real-time https://vimeo.com/292707644 7

Since real-time is not something that can start and stop within the ROS 2 "borders", we would like to propose to analyse an entire stack, from the hardware platform to the applications written with ROS 2.

Safety-critical WG

Next Generation ROS

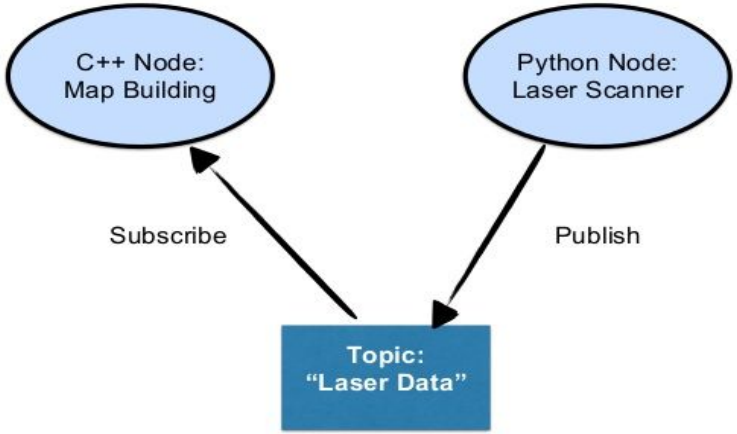
gbiggs 4d

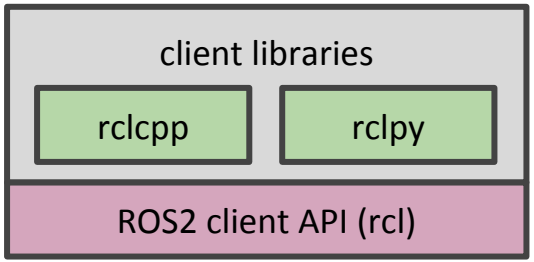
Some time ago I was asked to lead a working group looking at the use of ROS 2 in safety-critical systems. These are systems that may potentially cause harm to people or the environment, and I think that most of us agree that a large number of robot applications fall into this category.

The working group will look at topics including:

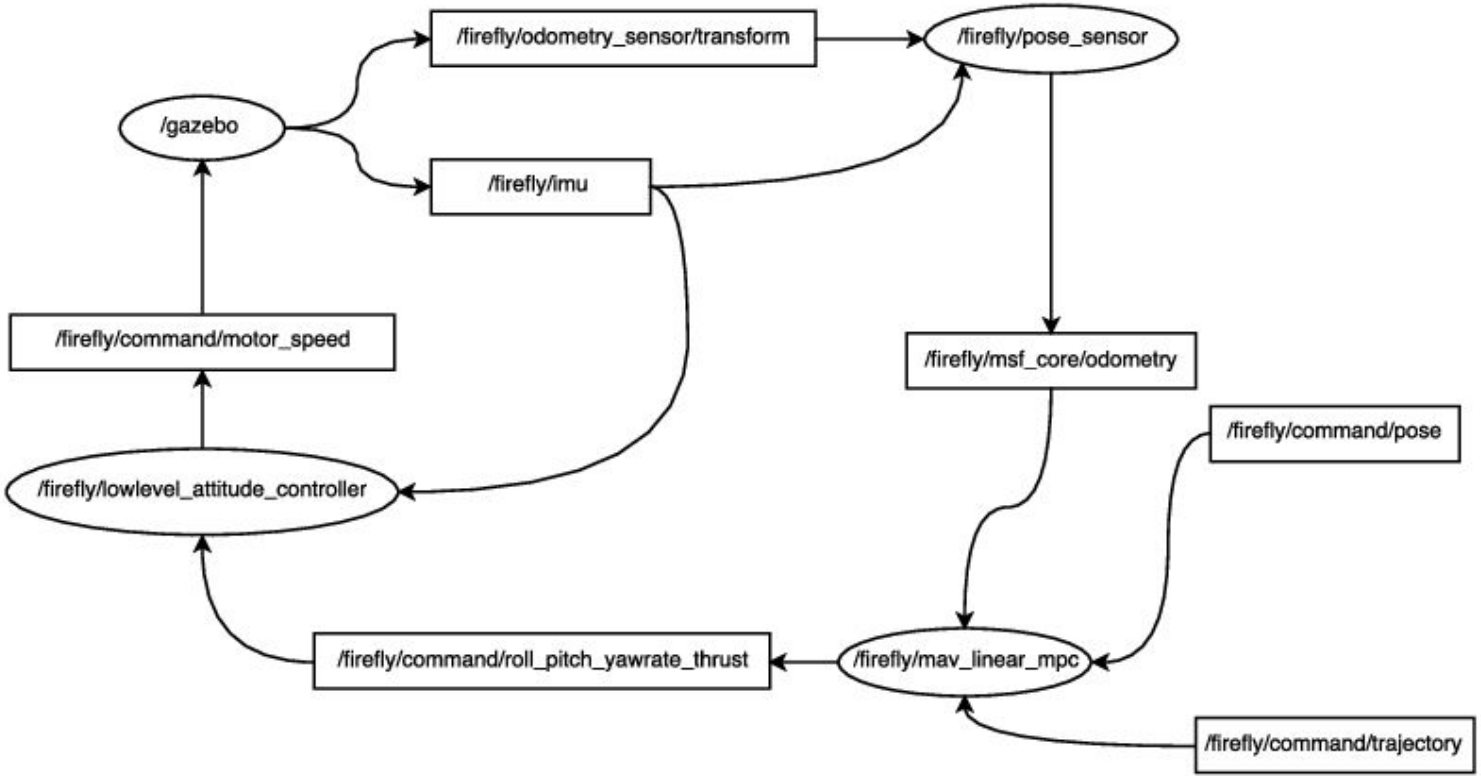
- Documenting how to use ROS 2 in a safety-critical application
- Use of tools to support the above
- Additional processes, tools and methods needed for building a safety-critical robot that are not currently covered by something in ROS but could be
- How to make the client libraries usable in a safety-critical system, and work on safety-focused client libraries (for example, a SPARK client library)
- Cross-over issues with the QA and real-time working groups for infrastructure, tooling and methods
- Cross-over issues with the navigation and manipulation working groups for sample applications
- Anything else safety-related someone brings along

- ROS2 “program”
  - Set of nodes (processes)
    - Found in ROS packages
  - Interconnected (DDS) by
    - Topics
      - Publish, Subscribe
    - Services
      - Request + Response
  - Supported languages
    - C++, Python (Client APIs)
    - C (low-level API)





Nodes + Topics



Model Predictive Control for Trajectory Tracking of Unmanned Aerial Vehicles Using Robot Operating System

May 2017 · Studies in Computational Intelligence

DOI: 10.1007/978-3-319-54927-9_1

In book: Robot Operating System (ROS) The Complete Reference, Volume 2 · Publisher: Springer
Editors: Anis Koubaa

Mina Samir Kamel · Thomas Stastny · Kostas Alexis · Roland Siegwart

Workflow (developer)

1. `$ ros2 pkg create`

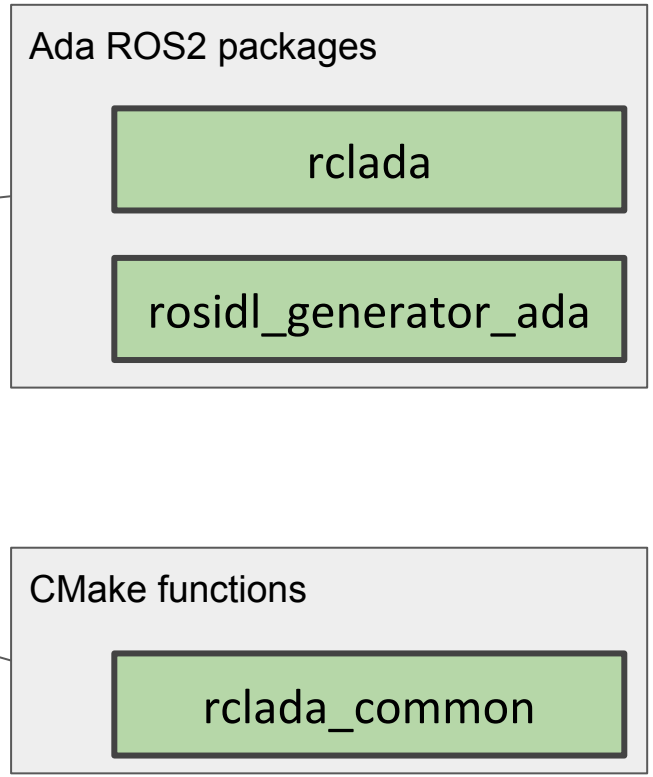
   write code

2. `$ colcon build`

   compile code

3. `$ ros2 launch`

   execute code



CMake example

```
// CMakeLists.txt
cmake_minimum_required(VERSION 3.5)

project(my_ada_ros2_project VERSION 0.1.0)

find_package(rclada_common REQUIRED)

ada_begin_package()

find_package(rclada REQUIRED)
find_package(rosidl_generator_ada REQUIRED)

ada_add_executables(
       my_ada_project         # CMake target name
       ${PROJECT_SOURCE_DIR} # Path to *.gpr
       bin                    # Path to binaries
       my_ada_main)           # Binaries (nodes)

ada_end_package()
```

Standard CMake project declaration

Import Ada-specific CMake functions

Import Ada environment

Import RCLAda GPR projects

- RCLAda: Nodes, Topics, etc
- ROSIDL_Ada: Messages

Declare our Ada GNAT project

Export our additions to downstream

Support for colcon_cmake

rclada_common

- `ada_begin_package()`
- `ada_end_package()`

  Needed to propagate Ada information through ROS2 packages

- `ada_add_executables(TARGET SRCDIR DSTDIR EXECUTABLES)`

  Declares an Ada executable to be built and exported (tab completion)
- `ada_add_library(TARGET SRCDIR GPRFILE)`

  Declares an Ada library project to be built and exported to other Ada packages

- `ada_import_msgs(PKG_NAME)`

  Generates bindings to the typesupport handle functions

  Could disappear once RCLAda is integrated in build farm

- `ada_generate_binding(TARGET SRCDIR GPRFILE INCLUDE)`

  Invokes the binding generator in the context of an Ada project

C++ vs Ada example

```cpp
class Talker : public rclcpp::Node
{
public:
 explicit Talker : Node("talker")
 {
   msg_ = std::make_shared<std_msgs::msg::String>();

   auto publish_message = [this]() -> void
     {
       msg_->data =
         "Hello World: " + std::to_string(count_++);
       pub_->publish(msg_);
     };

   pub_   = this->create_publisher
              <std_msgs::msg::String>(topic_name);
   timer_ = this->create_wall_timer(1s, publish_message);
 }
private:
  size_t count_ = 1;
  std::shared_ptr<std_msgs::msg::String> msg_;
  rclcpp::Publisher<std_msgs::msg::String>::SharedPtr pub_;
  rclcpp::TimerBase::SharedPtr timer_;
};

int main(int argc, char * argv[])
{
 auto topic = std::string("chatter");
 auto node = std::make_shared<Talker>(topic);
 rclcpp::spin(node);
}
```

```
procedure Talker is
  Support : constant ROSIDL.Typesupport.Message_Support :=
    ROSIDL.Typesupport.Get ("std_msgs", "String");

  Node : Nodes.Node             := Nodes.Init
                                     (Utils.Command_Name);
  Pub : Publishers.Publisher    := Node.Publish
                                     (Support, "/chatter");
  Msg : ROSIDL.Dynamic.Message := ROSIDL.Dynamic.Init
                                     (Support);

  Counter : Positive := 1;

  procedure Callback (Node    : in out Nodes.Node'Class;
                      Timer   : in out Timers.Timer;
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  is
     Txt : constant String := "Hello World:" & Counter'Img;
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begin
  Node.Timer_Add (1.0, Callback'Access);
  Node.Spin;
end Talker;
```

ROS2 IDL messages

```
# LaserScan.msg: Single scan from a planar laser range-finder

std_msgs/Header header  # timestamp in header is the acquisition time-axis

float32 angle_min       # start angle of the scan [rad]
float32 angle_max       # end angle of the scan [rad]
float32 angle_increment # angular distance between measurements [rad]

float32 time_increment  # time between measurements [seconds]

float32 scan_time       # time between scans [seconds]

float32 range_min       # minimum range value [m]
float32 range_max       # maximum range value [m]

float32[] ranges        # range data [m]
float32[] intensities   # intensity data [device-specific units].  If your
                        # device does not provide intensities, please leave
                        # the array empty.
```

Message fields

```
declare
   Support : ROSIDL.Typesupport.Message_Support :=
             ROSIDL.Typesupport.Get_Message_Support
               (Pkg_Name, Msg_Type);
   Msg : ROSIDL.Dynamic.Message := Init (Support);
begin
   Msg ("valid").As_Bool := True;
   Msg ("X").As_Float32  := 1.0;
   --  Individual values

   Msg ("Values").As_Array (42).As_Int8 := 0;
   --  Array indexing

   Msg ("Image").As_Matrix ((100, 50, 1)).As_Int8 := 0;
   --  Matrix indexing
end;
```

rosidl_generator_ada

Obtain message type

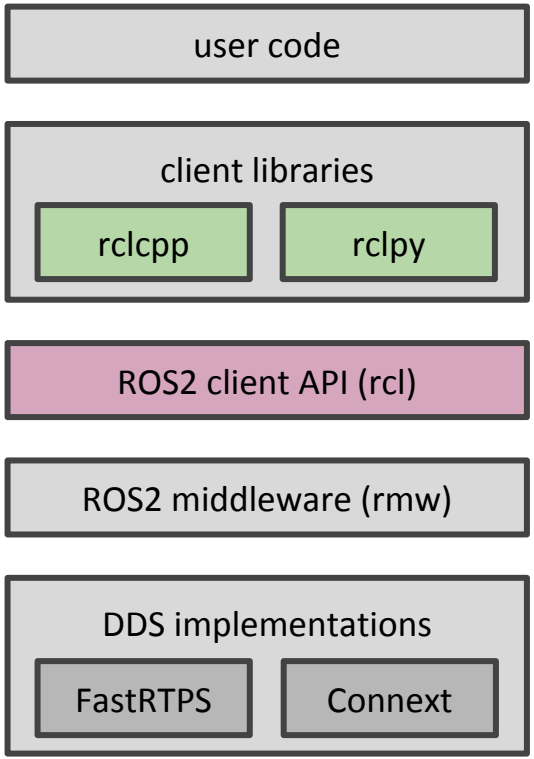
Reference to fields
- No data copy
- Type-checked

1D vector indexing
- Bounds checked

Matrix indexing
- Tuple of indices
- Dimensions checked

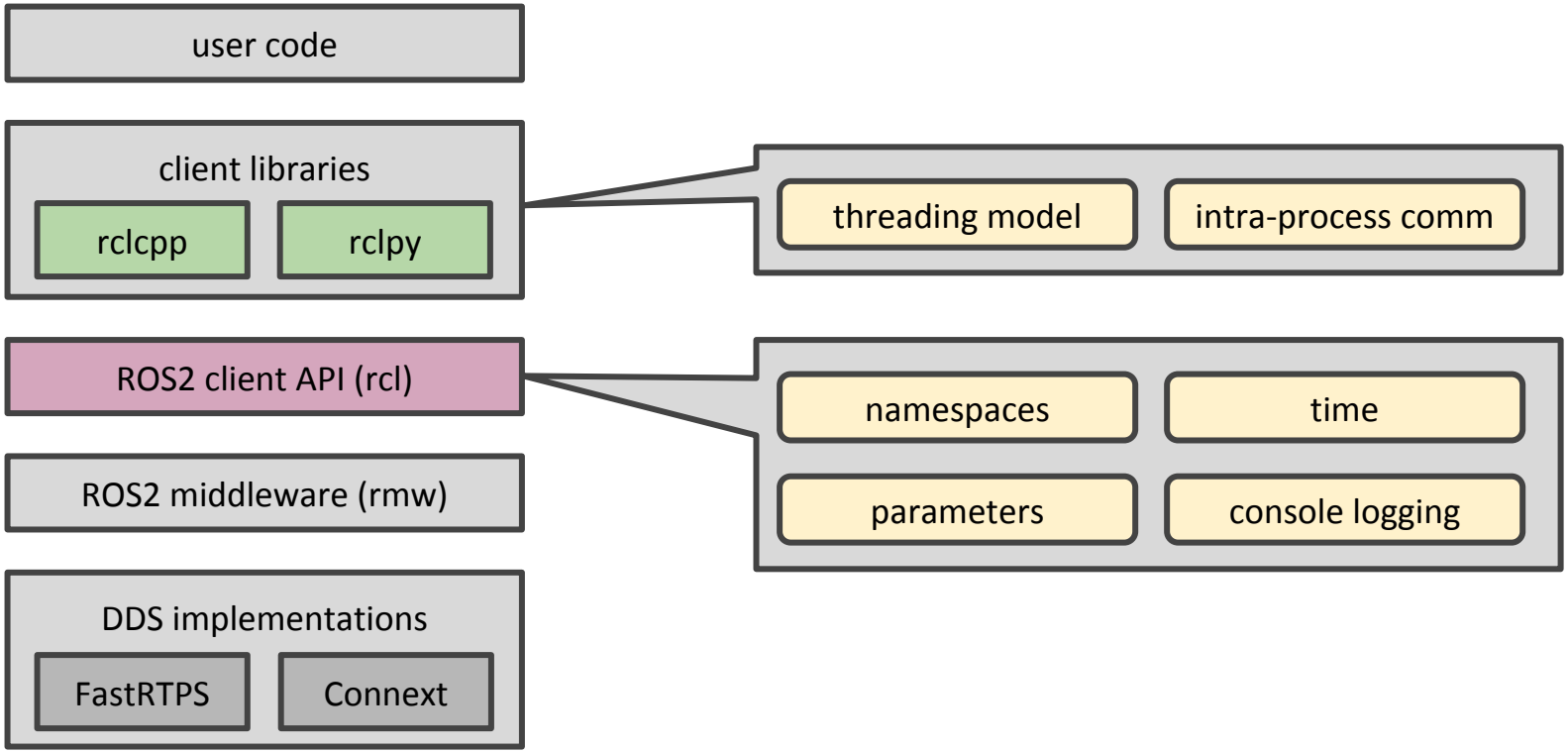
RCLAda Architecture

ROS2 client support

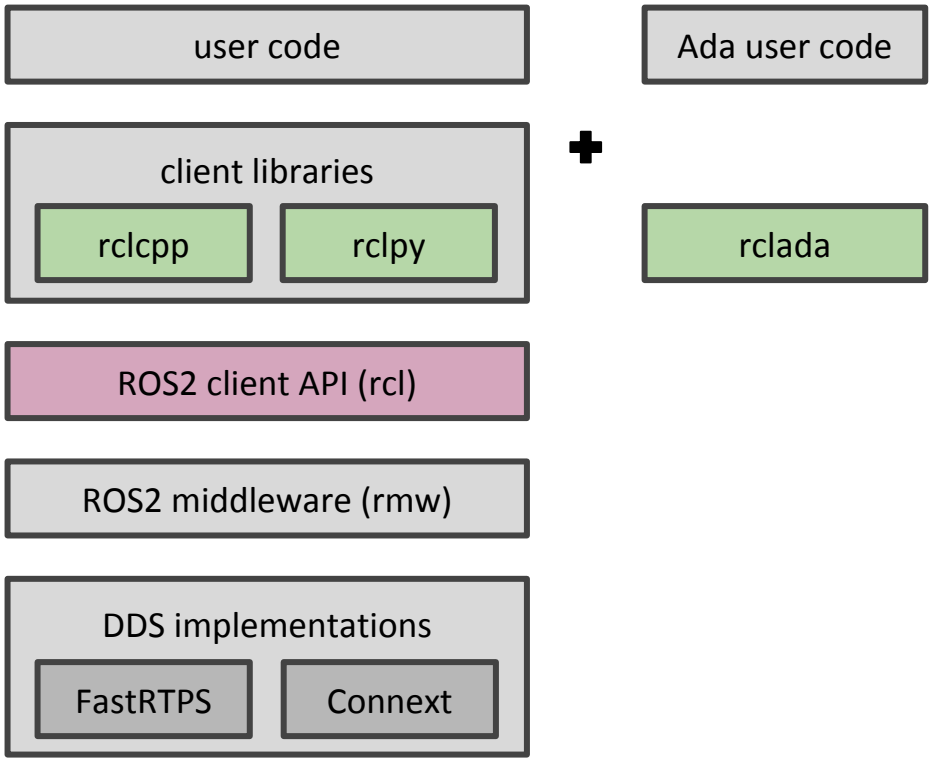


Original diagram by Deanna Hood, William Woodall: https://goo.gl/oCHR7H

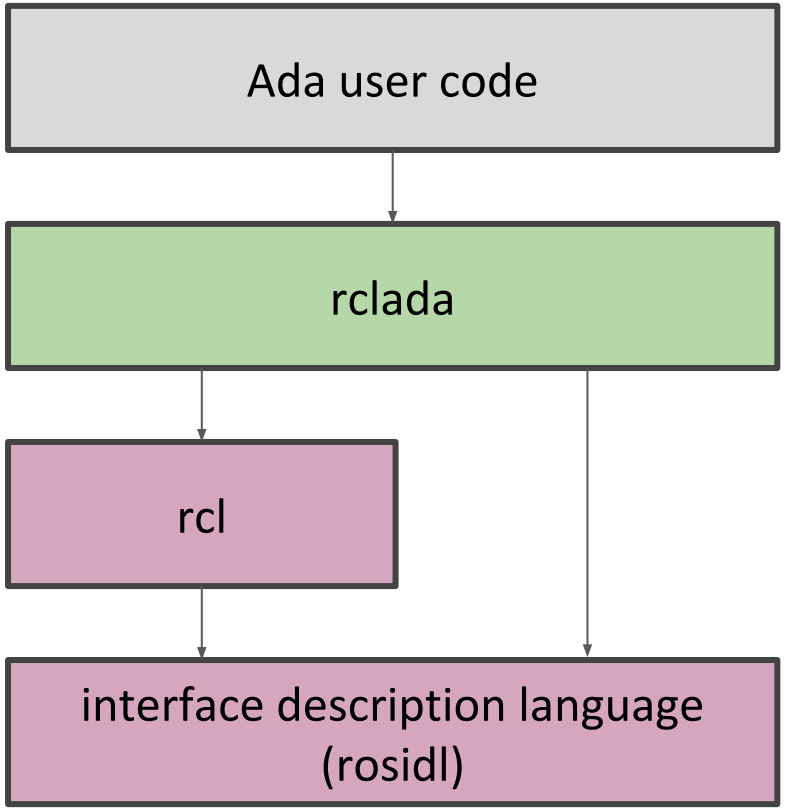
ROS2 client support



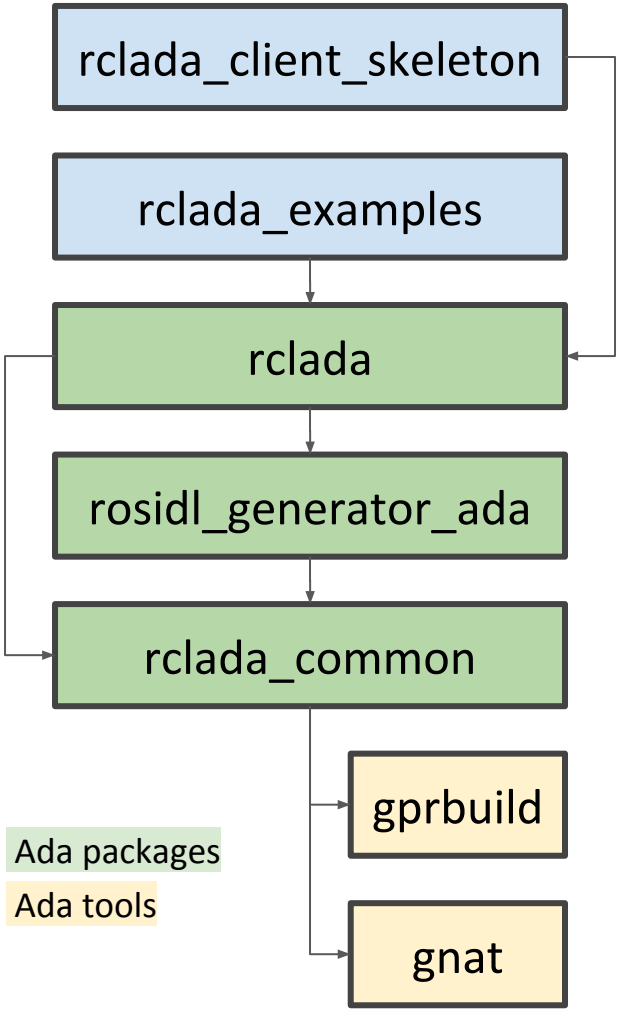
ROS2 client support



ROS2 client support + Ada



Ada ROS2 packages



Empty quickstart package

talker, listener, add_two_ints, …

Client API (nodes, topics, services, …) & self-tests

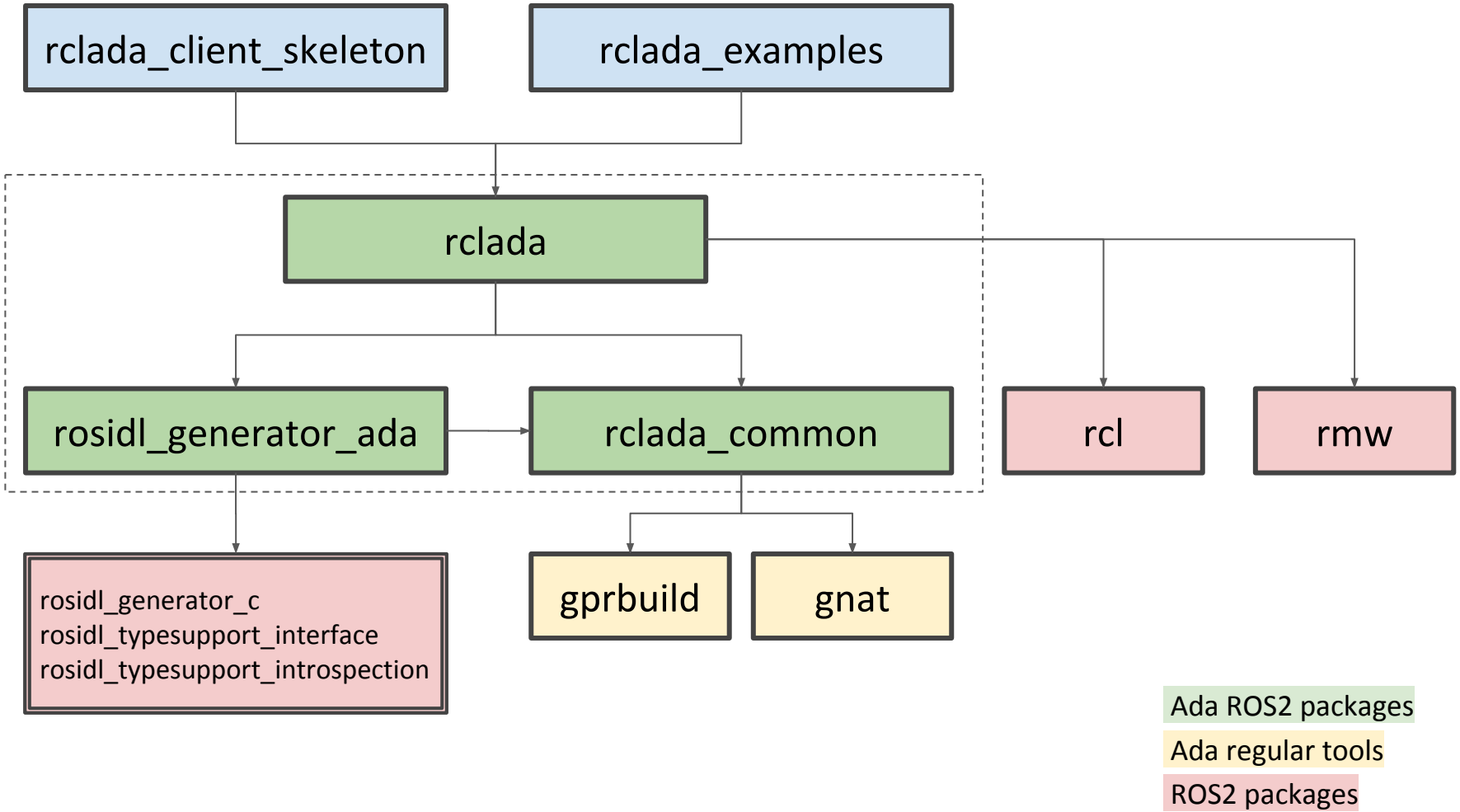
Message support

CMake functions

GNAT build system

Ada compiler (gnat-gcc) and tools

Actual packages



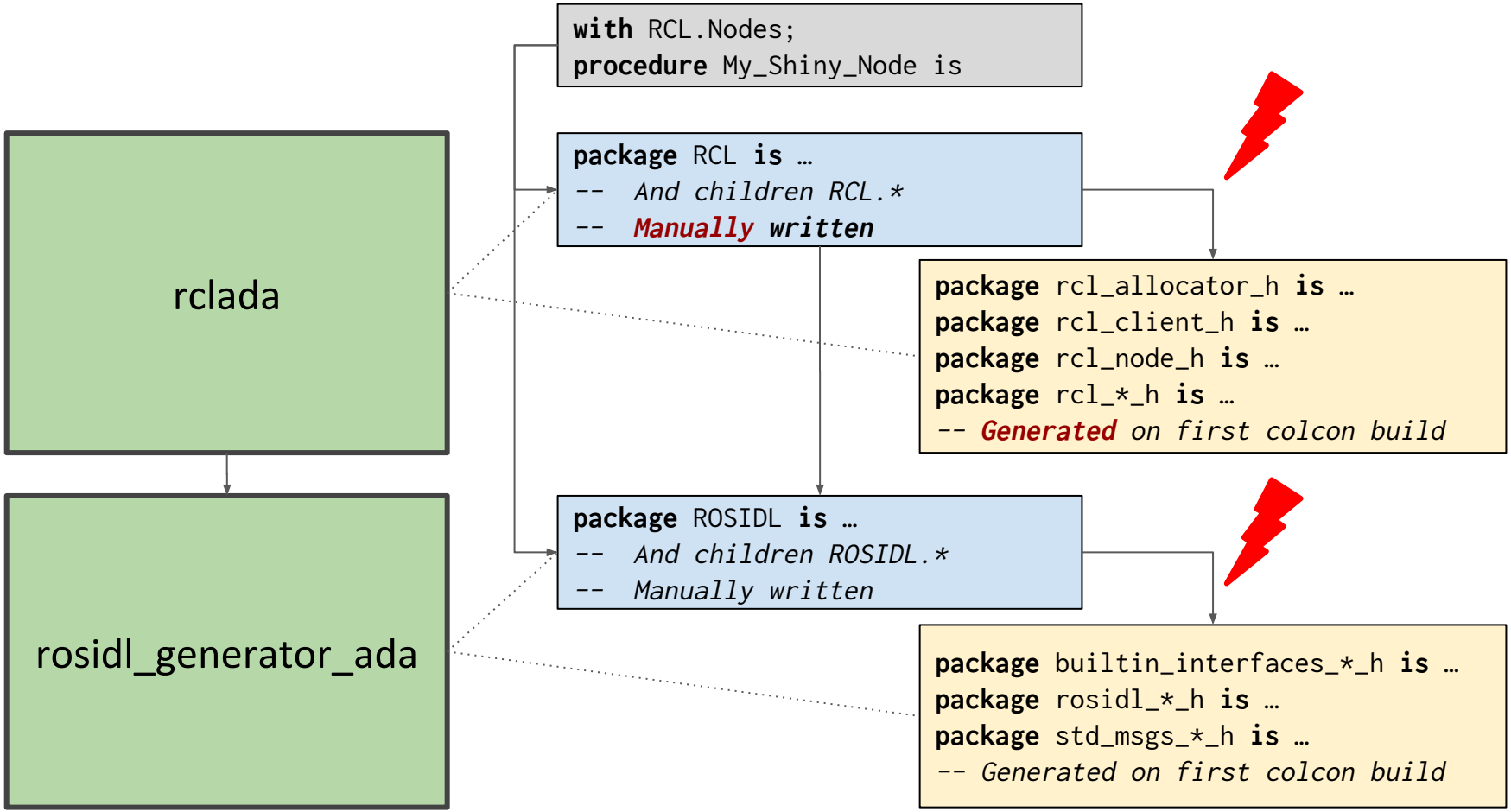
- Writing bindings:
  - Manual writing
    - 🙂 No need to be exhaustive
    - 🙂 High quality (thick binding)
    - 😕 More effort
    - 😕 May become de-sync'd
  - Automated generation
    - 🙂 "Less" work
    - 🙂 Completeness
    - 🙂 Assured consistency
    - 😕 Lower quality (thin binding)
    - 😕 Might not compile
- Ada/GNAT support:
  - Annex B: interface to other languages
    - C/C++, Fortran, Cobol
  - `gcc -fdump-ada-spec file.h`

```
/* C prototype */
int initialize(options_t *opts,
               char *argv[]);
```

```
-- Ada automatic binding
function Initialize
   (opts : access Options_T;
    argv : System.Address)
    return Interfaces.C.int
    with Import, Convention => C;
```

```
-- Ada manual binding
type Arg_Array is
  array (Natural range <>) of aliased
  Interfaces.C.Strings.Chars_Ptr
  with Convention => C;

function Initialize
   (opts : in out Options_T;
    argv :        Arg_Array)
    return Interfaces.C.int
    with Import, Convention => C;
```

RCLAda: leverage *colcon* for best of both worlds



Completion level

rclada

- Main features:
  - `RCL.Node` : Complete ■
  - `RCL.Publisher` : Complete ■
  - `RCL.Subscription` : Complete ■
  - `RCL.Client` : Complete ■
  - `RCL.Service` : Complete ■
- Support:
  - `RCL.Allocators` : Complete ■
  - `RCL.Calendar` : Complete ■
  - `RCL.Executors` : Complete ■
  - `RCL.Graph` : Complete ■
  - `RCL.Options` : Partial ■
  - `RCL.Timer` : Complete ■
  - `RCL.Wait` : Complete ■

rosidl_generator_ada

- Messages:
  - `ROSIDL.Dynamic`: Complete ■
  - `ROSIDL.Typesupport`: Complete ■
- Dynamic access (through introspection):
  - Typesupport: Complete ■
  - Simple types: Complete ■
  - Nested types: Complete ■
  - Array types: Complete ■
  - Matrix types: Complete ■
- Static access (through generated types):
  - Typesupport: Pending ■
  - Simple types: Pending ■
  - Nested types: Pending ■
  - Array types: Pending ■
  - Matrix types: Pending ■

Message fields

```
declare
   Support : ROSIDL.Typesupport.Message_Support :=
             ROSIDL.Typesupport.Get_Message_Support
               (Pkg_Name, Msg_Type);
   Msg : ROSIDL.Dynamic.Message := Init (Support);
begin
   Msg ("valid").As_Bool := True;
   Msg ("X").As_Float32  := 1.0;
   --  Individual values

   Msg ("Values").As_Array (42).As_Int8 := 0;
   --  Array indexing

   Msg ("Image").As_Matrix ((100, 50, 1)).As_Int8 := 0;
   --  Matrix indexing
end;
```

rosidl_generator_ada

Obtain message type

Reference to fields
- No data copy
- Type-checked

1D vector indexing
- Bounds checked

Matrix indexing
- Tuple of indices
- Dimensions checked

ROS2 allocators ⇔ Ada storage pools

- Ada defines Storage_Pool type for different:
  - memory areas (typical in some small boards) (associated to pointer types)
  - allocation policies (including user-defined)
- ROS2 allocators mapped into Ada storage pools
  - transparent use in Ada programs
  - immediate testing of RCLAda & ROS2 use of allocators via GNAT.Debug_Pools

```
$ rclada_test_allocators 1
Total allocated bytes:              2335
Total logically deallocated bytes:  2335
Total physically deallocated bytes: 0
Current Water Mark:                 0
High Water Mark:                    415

$ rclada_test_allocators 4
Total allocated bytes:              8095
Total logically deallocated bytes:  8095
Total physically deallocated bytes: 0
Current Water Mark:                 0
High Water Mark:                    415
```

```
type Int_Ptr is access Integer -- named pointer type
  with Storage_Pool => Debug_Pool;

type Node_Access is access all RCL.Nodes.Node'Class
  with Storage_Size => 0;      -- No heap allocations

pragma No_Allocators;
pragma No_Implicit_Heap_Allocations;
pragma No_Standard_Allocators_After_Elaboration;
pragma No_Standard_Storage_Pools;
--  See Restrictions in GNAT manual for many more
```

API & Examples

Allocator details

```
typedef struct rcutils_allocator_t
{
  void * (*allocate)(size_t size,
                     void * state);

  void (* deallocate)(void * pointer,
                      void * state);

  void * (*reallocate)(void * pointer,
                       size_t size,
                       void * state);

  void * (*zero_allocate)(size_t number_of_elements,
                          size_t size_of_element,
                          void * state);
                          void * state;
} rcutils_allocator_t;
```

```
package System.Storage_Pools is

   type Root_Storage_Pool is tagged private;

   procedure Allocate
     (Pool                     : in out Root_Storage_Pool;
      Storage_Address          :    out Address;
      Size_In_Storage_Elements : in     Storage_Count;
      Alignment                : in     Storage_Count)
   is abstract;

   procedure Deallocate
     (Pool                     : in out Root_Storage_Pool;
      Storage_Address          : in     Address;
      Size_In_Storage_Elements : in     Storage_Count;
      Alignment                : in     Storage_Count)
   is abstract;
```

```
Pool  : aliased GNAT.Debug_Pools.Debug_Pool;                    -- Ada pool, compiler provided
Alloc : aliased RCL.Allocators.Allocator (Pool'Access);         -- ROS2 allocator, wrapping Ada pool
Node  :         RCL.Node := Node.Init
                            (Options => (Allocator => Alloc'Access)); -- Set node allocator
```

Talker

```
procedure Talker is
   Support : constant ROSIDL.Typesupport.Message_Support :=
               ROSIDL.Typesupport.Get_Message_Support ("std_msgs", "String");
   Node    : Nodes.Node           := Nodes.Init   (Utils.Command_Name);
   Pub     : Publishers.Publisher := Node.Publish (Support, "/chatter");

   task Publisher;
   task body Publisher is
      Count  : Positive               := 1;
      Period : constant Duration      := 1.0;
      Next   : Calendar.Time          := Calendar.Clock;
      Msg    : ROSIDL.Dynamic.Message := ROSIDL.Dynamic.Init (Support);
   begin
      loop
         Msg ("data").Set_String ("Hello World:" & Count'Img);
         delay until Next;
         Pub.Publish (Msg);
         Counter := Count + 1;
         Next    := Next  + Period; -- Next := @ + Period; -- in Ada 202x
       end loop;
   end Publisher;

begin
   Node.Spin (Until => Forever);
end Talker;
```

Dynamic handle retrieval

Node initialization in the stack

Topic creation

An Ada task without sync entries

Duration is a built-in Ada type

Message allocation

Message fields are
- indexed by name
- type checked
- bounds checked

Delay without drift

Spin forever (named parameter)

Listener

```
procedure Listener is

   procedure Callback (Node : in out Nodes.Node'Class;
                       Msg  : in out ROSIDL.Dynamic.Message;
                       Info :        ROSIDL.Message_Info) is
   begin
      Logging.Info ("Got chatter: '" & Msg ("data").Get_String & "'");
   end Callback;

   Node : Nodes.Node := Nodes.Init ("listener");

begin
   Node.Subscribe
     (ROSIDL.Typesupport.Get_Message_Support ("std_msgs", "String"),
      "/chatter",
      Callback'Access);

   Node.Spin (Until => Forever);
end Listener;
```

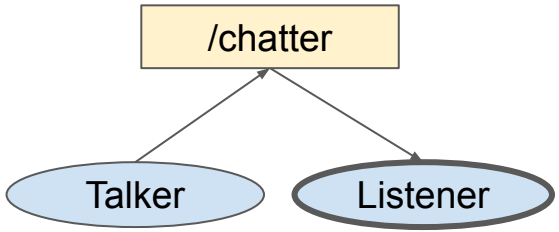
LISTENER

Callback definition

Standard ROS2 Logging

Ada String (not null-terminated)

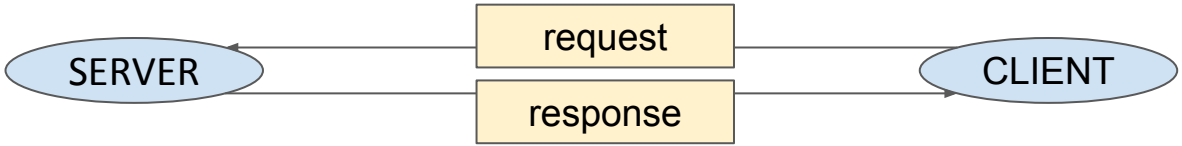
Register callback
- Using procedure pointer



```
procedure Server is
   -- Omitted declarations

   procedure Adder
     (Node : in out Nodes.Node'Class;
      Req  :        ROSIDL.Dynamic.Message;
      Resp : in out ROSIDL.Dynamic.Message)
   is
      A : constant ROSIDL.Int64 := Req ("a").As_Int64;
      B : constant ROSIDL.Int64 := Req ("b").As_Int64;
   begin
      Resp ("sum").As_Int64 := A + B;
   end Adder;

begin
   Node.Serve
     (ROSIDL.Typesupport.Get_Service_Support
        ("example_interfaces", "AddTwoInts"),
      "add_two_ints",
      Adder'Access);
end Server;
```

```
procedure Client is -- Synchronous version
   -- Omitted declarations

   Request : ROSIDL.Dynamic.Message := … ;

begin
   Request ("a").As_Int64 := 2;
   Request ("b").As_Int64 := 3;
   declare
      Response : constant ROSIDL.Dynamic.Message :=
                   Node.Client_Call (Support,
                                     "add_two_ints",
                                     Request);
   begin
       Logging.Info ("Got answer:" &
                     Response ("sum").As_Int64.Image);
   end;
end Client;
```

Blocking call (if desired)



Indefinite concurrent executor type

```
package RCL.Executors.Concurrent is

   type Runner_Pool is array (Positive range <>) of Runner;
   -- Runner task type declaration omitted

   type Executor (Max_Nodes  : Count_Type :=
                     Default_Nodes_Per_Executor;
                  Queue_Size : Count_Type :=
                     Count_Type (System.Multiprocessors.Number_Of_CPUs) * 32;
                  Threads    : Positive :=
                     Positive (System.Multiprocessors.Number_Of_CPUs);
                  Priority   : System.Priority :=
                     System.Max_Priority) is
   new Executors.Executor (Max_Nodes) with
      record
         Pool  : Runner_Pool  (1 .. Threads);
         Queue : Queues.Queue (Capacity => Queue_Size,
                               Ceiling  => Priority);
         Started : Boolean := False;
      end record;

end RCL.Executors.Concurrent;
```

Parent abstract type in RCL.Executors

Task pool type

Executor type with discriminants
- **# of nodes supported**
- **Queue size**
- **Threads in the pool**
- **Priority**

System.* defined in ARM

OO derivation syntax

Members constrained by discriminants
- Standard Ada bounded queues
- All Ada bounded containers are stack based

See `rclada_test_multicore.adb`
- One producer
- Pooled consumers

- CMake functions for build integration
  - Ada nodes have same standing as other nodes
- Ada API for pure Ada node writing
  - Ada nodes can interact with other language nodes
- RCLAda distinguishing features (vs rclcpp, rclpy, others)
  - No heap allocations
    - Guaranteed by language restrictions & libraries
  - Relies on automatic low-level binding
    - Early detection of mismatches on ROS2 API changes
  - Language ingrained in safety/HRT culture
    - All message data accesses are type and bounds checked (at runtime)
    - Static message generation is forthcoming

THANK YOU FOR YOUR ATTENTION

https://github.com/ada-ros/ada4ros2/

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?

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AdaCore

www.adacore.com

https://www.adacore.com/industries

GNU NYU Ada Translator / FSF GNAT-GCC / SPARK