ROSpec: A Domain-Specific Language for ROS-based Robot Software

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Carnegie Mellon University

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This talk is about (preventing) robots crashing

The Robot Operating System (ROS) improves development by focusing on component reuse

*"We have designed ROS to support our **philosophy of modular**, tools-based software development"*
[Quigley et al, 2009]

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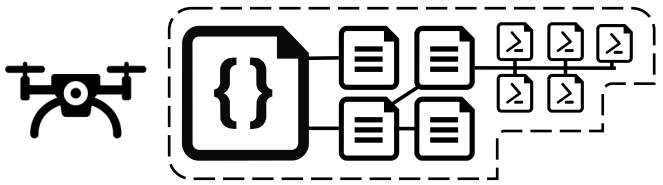

airdrone_driver

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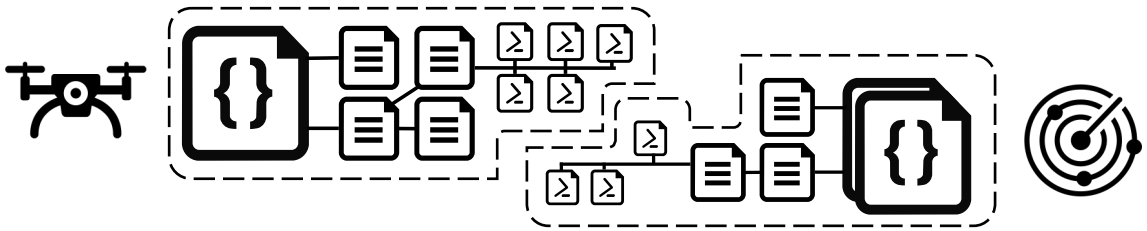

object detection

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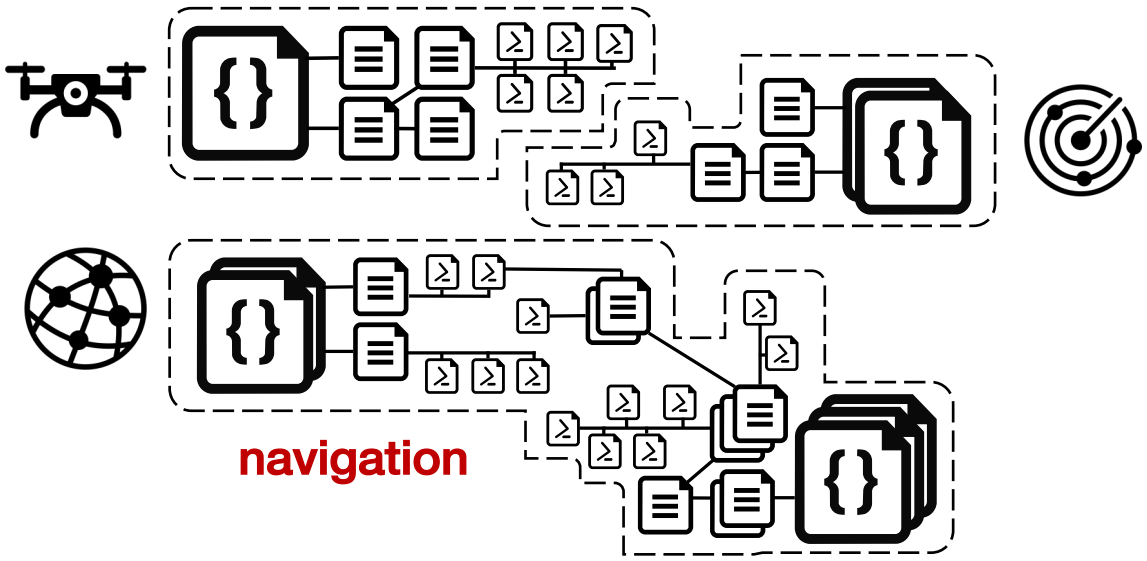

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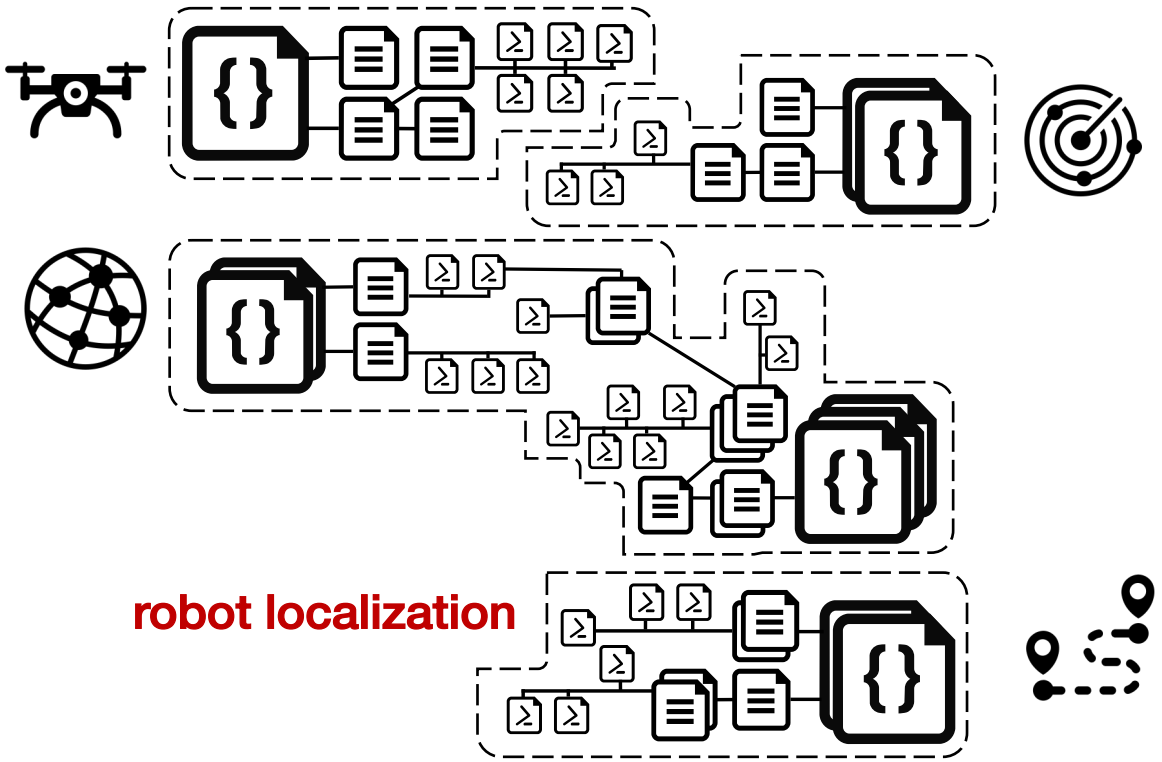

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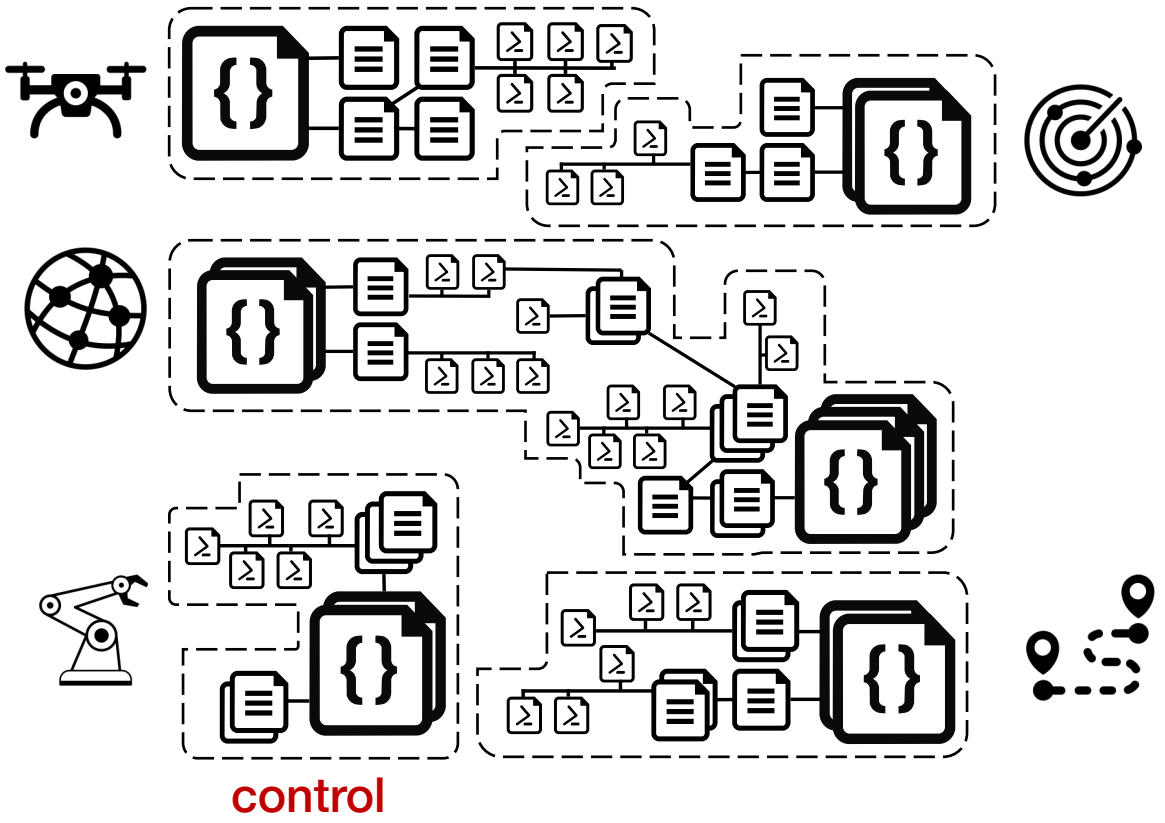

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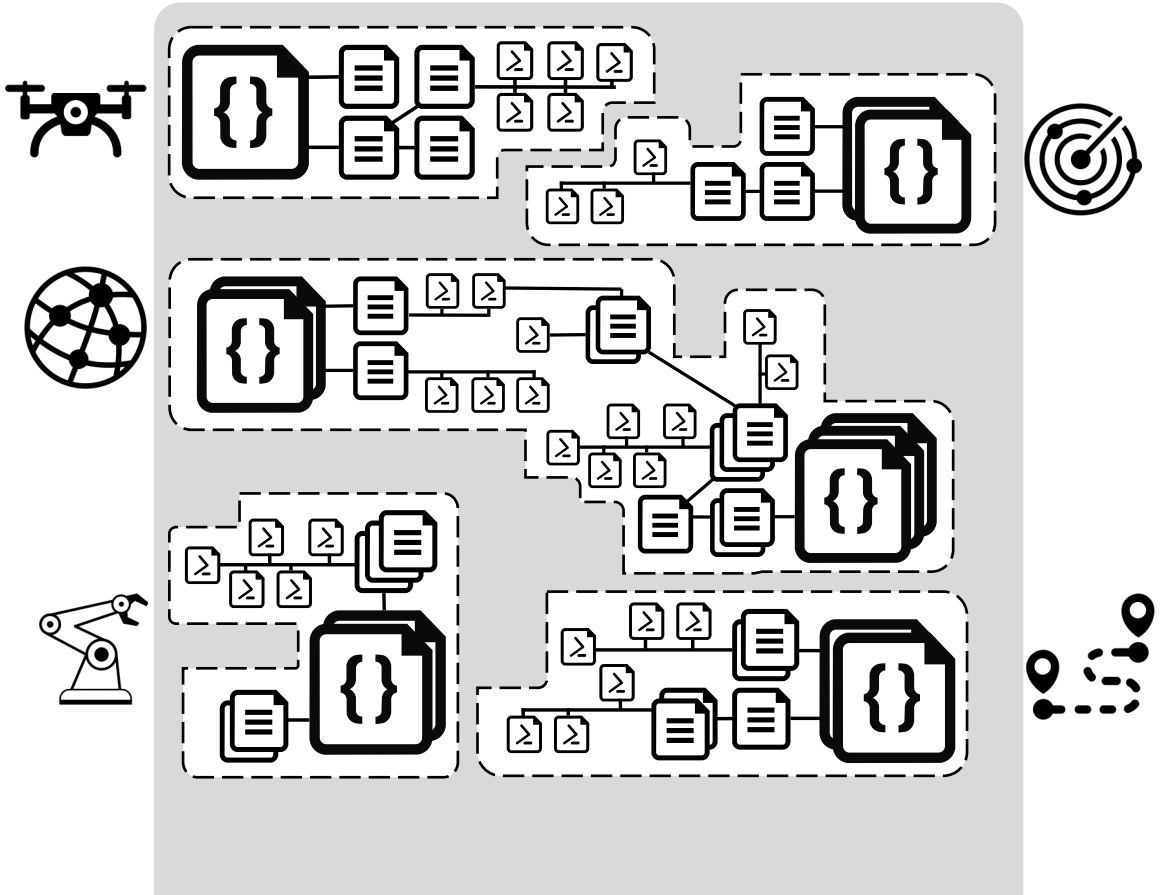

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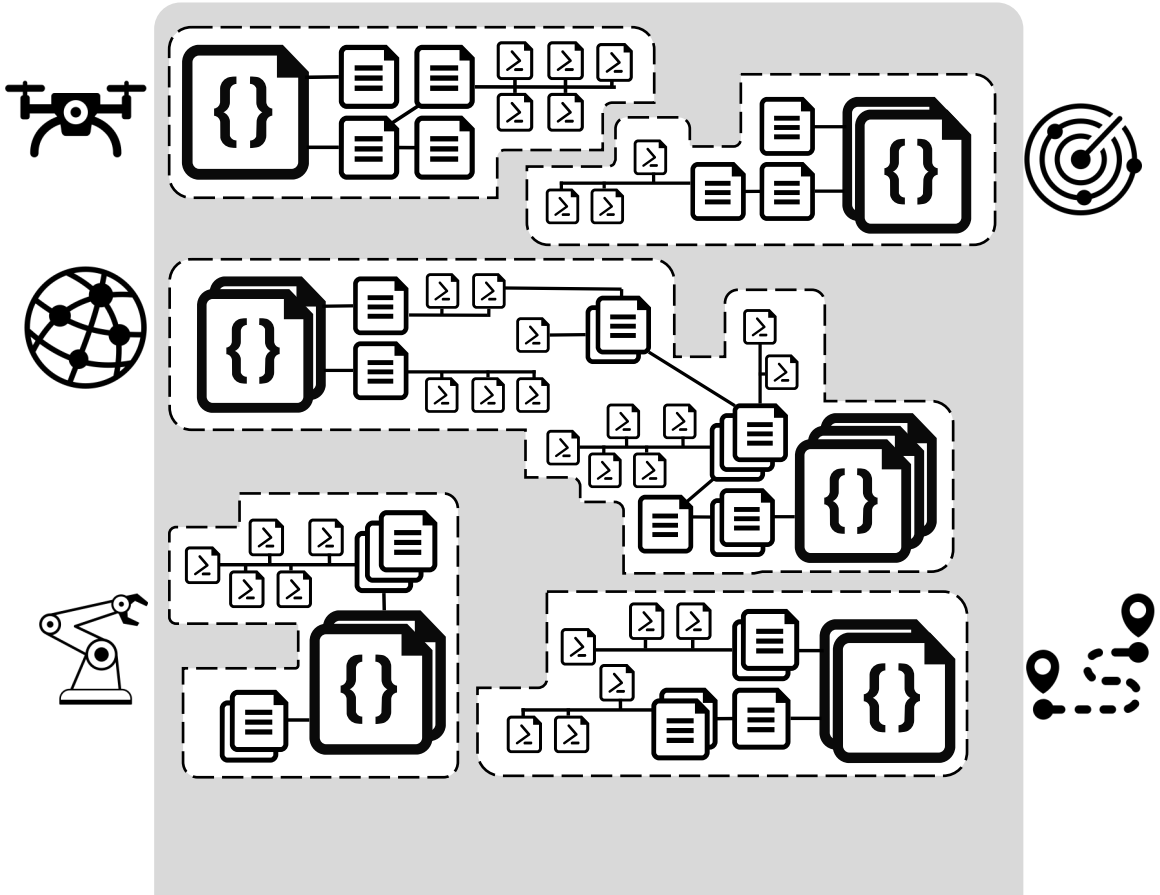
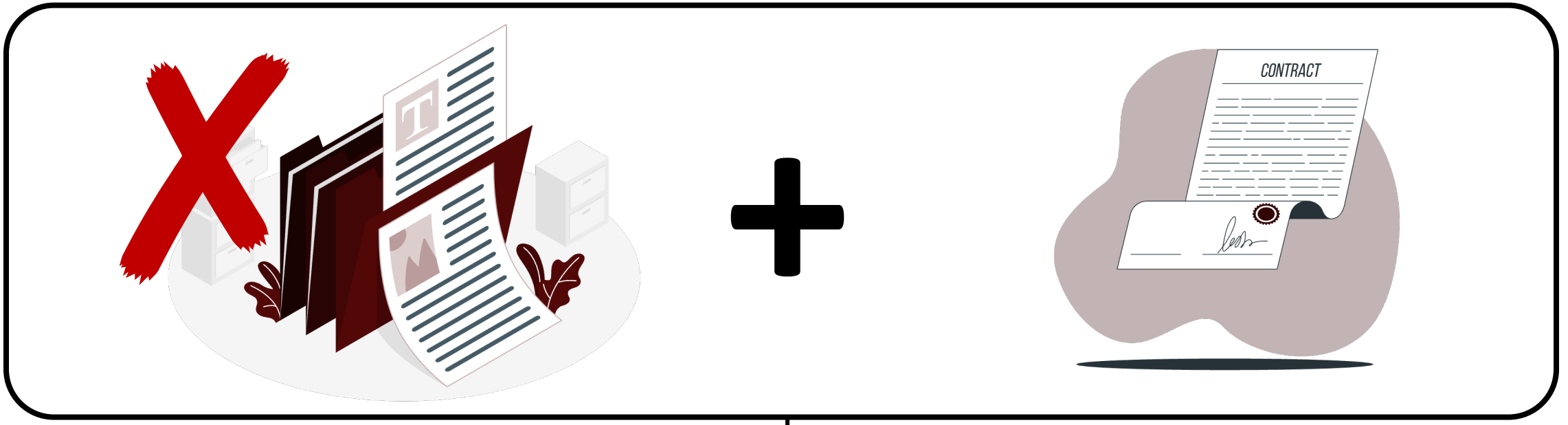


However, unchecked component assumptions and lack of documentation lead to misconfigurations

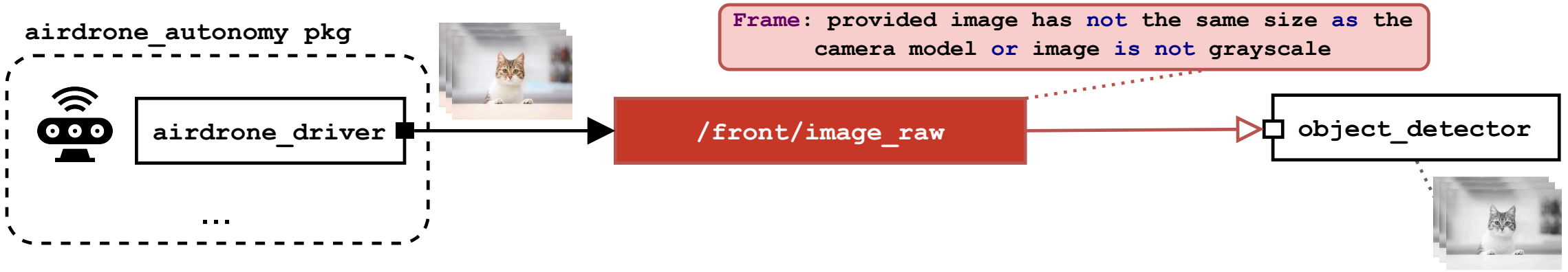


Misconfigurations arise from mismatched expectations and guarantees when configuring and integrating components

The airdrone_driver sends sensor data, while the object_detector receives and processes it

Legend

Missing semantic information regarding image format leads to image color mismatches



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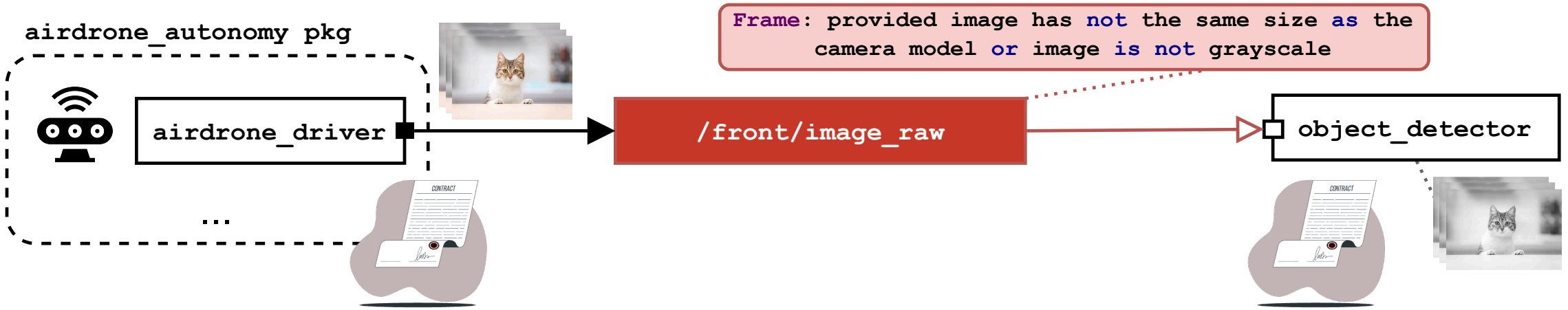
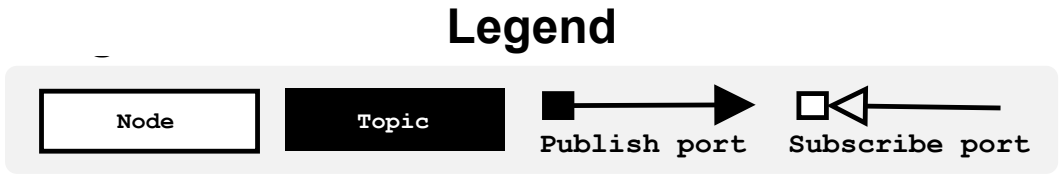
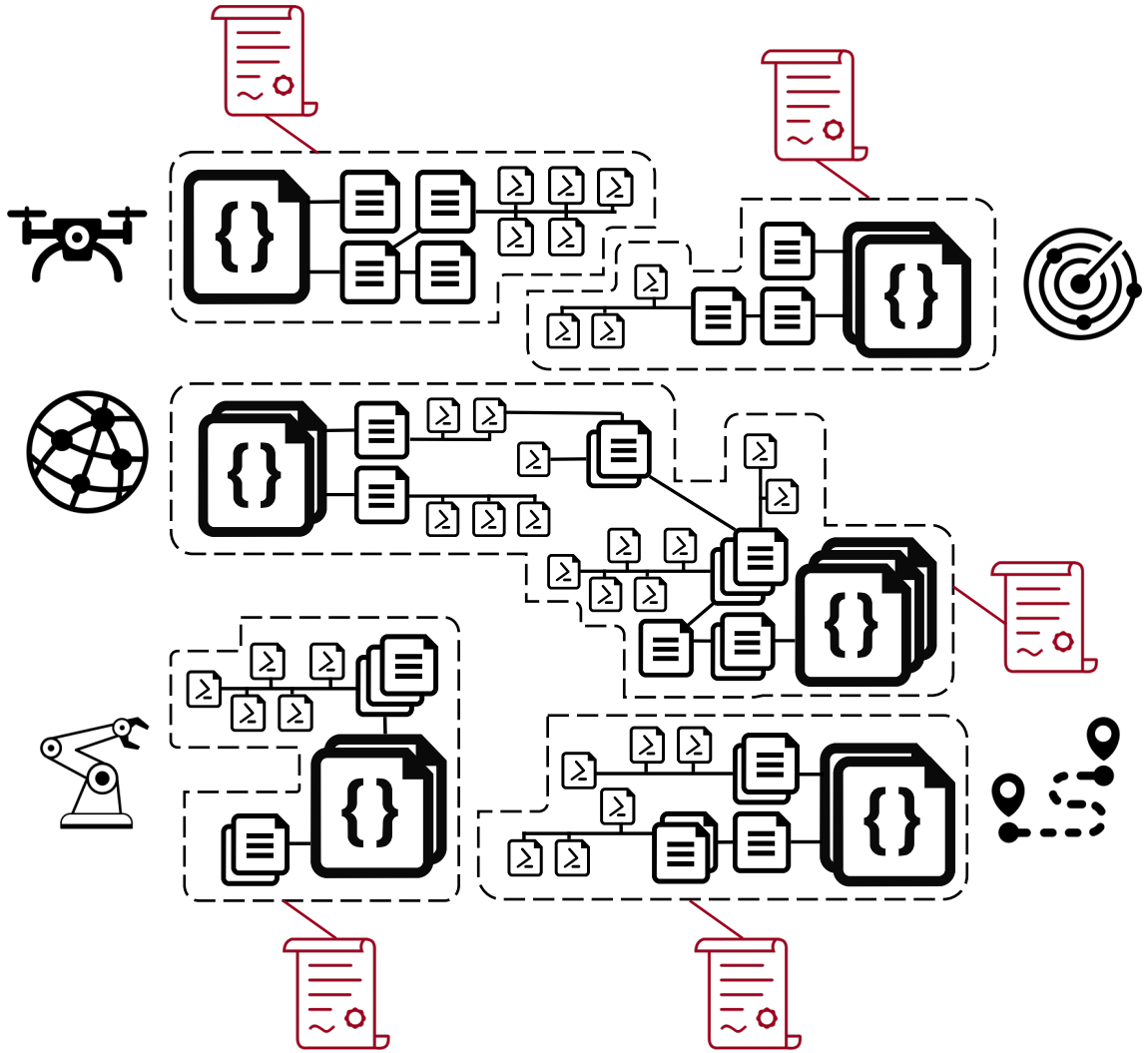




By specifying `{properties}` over **component configurations** and their **integration**, we can **detect misconfigurations** prior to deployment

ROSpec: A specification language for refining ROS components configurations and integration



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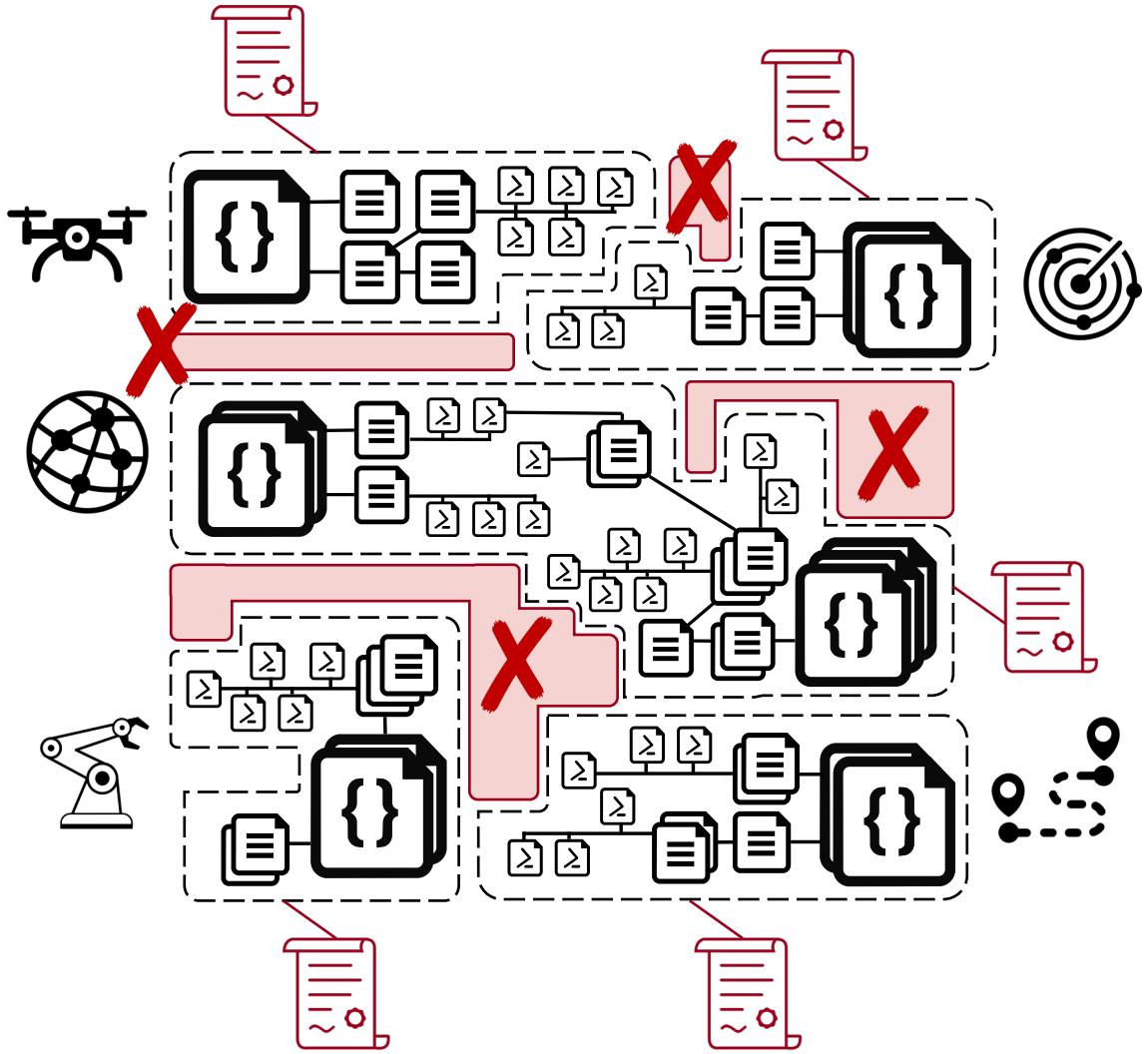
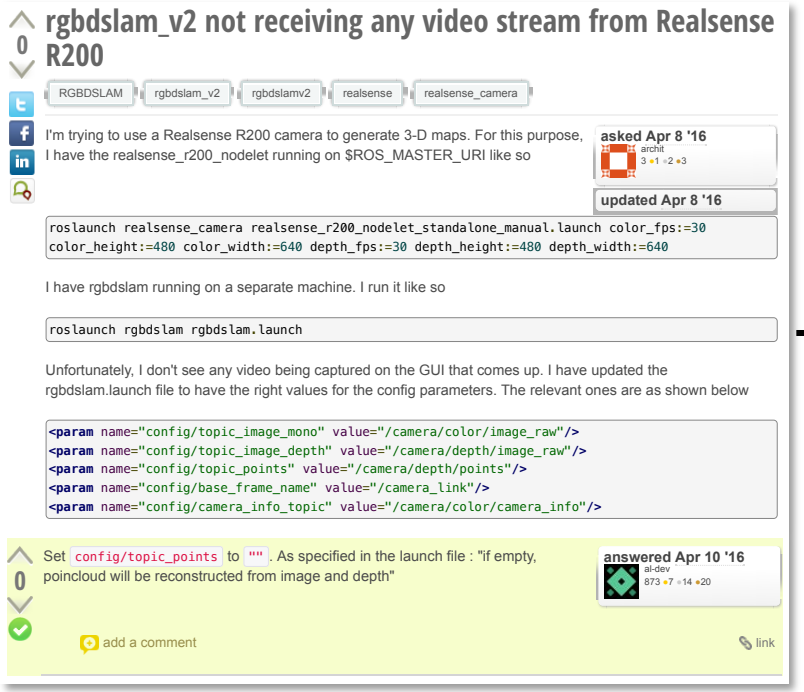


ROSpec design is based on prior work in misconfigurations [1]



rgbdslam_v2 not receiving any video stream from Realsense R200

RGBDSLAM | rgbdslam_v2 | rgbdslamv2 | realsense | realsense_camera

I'm trying to use a Realsense R200 camera to generate 3-D maps. For this purpose, I have the realsense_r200_nodelet running on $ROS_MASTER_URI like so

asked Apr 8 '16
archit
3 ●1 ●2 ●3

updated Apr 8 '16

```
roslaunch realsense_camera realsense_r200_nodelet_standalone_manual.launch color_fps:=30
color_height:=480 color_width:=640 depth_fps:=30 depth_height:=480 depth_width:=640
```

I have rgbdslam running on a separate machine. I run it like so

```
roslaunch rgbdslam rgbdslam.launch
```

Unfortunately, I don't see any video being captured on the GUI that comes up. I have updated the rgbdslam.launch file to have the right values for the config parameters. The relevant ones are as shown below

```
<param name="config/topic_image_mono" value="/camera/color/image_raw"/>
<param name="config/topic_image_depth" value="/camera/depth/image_raw"/>
<param name="config/topic_points" value="/camera/depth/points"/>
<param name="config/base_frame_name" value="/camera_link"/>
<param name="config/camera_info_topic" value="/camera/color/camera_info"/>
```

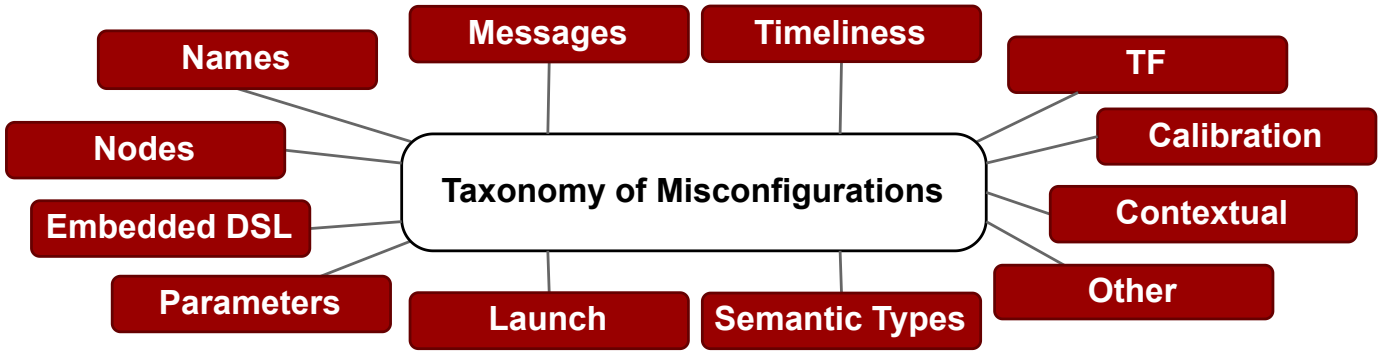
0

Set `config/topic_points` to `""`. As specified in the launch file : "if empty, poincloud will be reconstructed from image and depth"

answered Apr 10 '16
al-dev
873 ●7 ●14 ●20

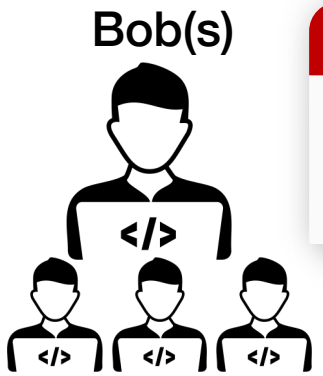
add a comment

link



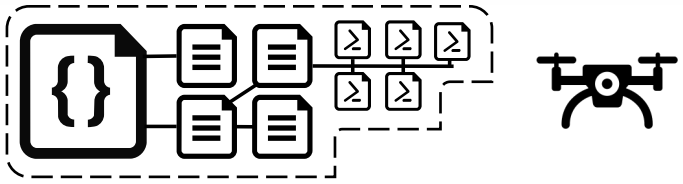
[1] Paulo Canelas, Bradley Schmerl, Alcides Fonseca, and Christopher S. Timperley. 2024. Understanding Misconfigurations in ROS: An Empirical Study and Current Approaches. In Proceedings of the International Symposium on Software Testing and Analysis.

ROSpec design is based on prior work in misconfigurations and two primary stakeholders



Component Writer

Responsible for **creating reusable packages** composed of multiple nodes that allow easy configuration.



Component Source-Code

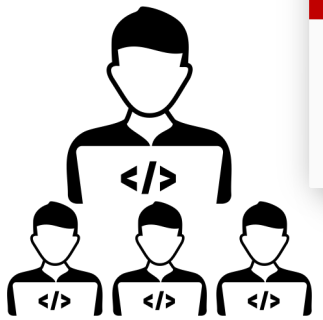
```
class VelocityPublisher:
  def __init__(self):
    rospy.init_node('velocity_publisher')

    self.min_vel_x = rospy.get_param('~min_vel_x', 0.1)
    self.max_vel_x = rospy.get_param('~max_vel_x', 0.5)

    self.pub = rospy.Publisher('/cmd_vel', Twist)
```

ROSpec design is based on prior work in misconfigurations and two primary stakeholders

Bob(s)



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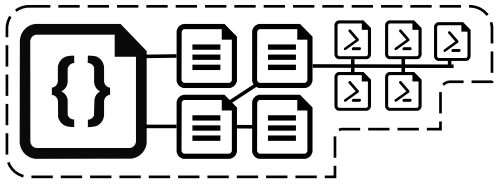

Alice

Component Integrator

Who **select and adapts components** to meet system requirements, while ensuring that configurations match the component assumptions

Component Source-Code

```
class VelocityPublisher:
  def __init__(self):
    rospy.init_node('velocity_publisher')

    self.min_vel_x = rospy.get_param('~min_vel_x', 0.1)
    self.max_vel_x = rospy.get_param('~max_vel_x', 0.5)

    self.pub = rospy.Publisher('/cmd_vel', Twist)
```

ROS Configuration File

```
max_vel_x: 0.5
min_vel_x: 0.1
global_frame: “odom”
robot_base_frame: “base_link”
update_frequency: 5.0
static_map: true
```

We enforce type restrictions and parameter dependencies using liquid and dependent types

Component Writer

```
node type move_group {

  param max_acceleration: double where {_ >= 0};

  optional param max_velocity: double = 1.2211;
  optional param has_velocity_limits: bool = false;

} where {
  exists(max_velocity) -> exists(has_velocity_limits);
}
```

Component Integrator

```
system {
  node instance mv_gp: move_group {
    param max_acceleration = 0.0;
    param max_velocity = 3.14;
  }
}
```

We enforce type restrictions and parameter dependencies using liquid and dependent types

Liquid Type: Only allow positive max accelerations

Component Writer

```
node type move_group {

  param max_acceleration: double where {_ >= 0};

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Component Integrator

```
system {
  node instance mv_gp: move_group {
    param max_acceleration = 0.0;
    param max_velocity = 3.14;
  }
}
```

In-Value Dependent Type: If max_velocity is set, then has_velocity_limits must be set

We enforce type restrictions and parameter dependencies using liquid and dependent types

Liquid Type: Only allow positive max accelerations

Component Writer

```
node type move_group {

  param max_acceleration: double where {_ >= 0};

  optional param max_velocity: double = 1.2211;
  optional param has_velocity_limits: bool = false;

} where {
  exists(max_velocity) -> exists(has_velocity_limit
}
```

Component Integrator

```
system {
  node instance mv_gp: move_group {
    param max_acceleration = 0.0;
    param max_velocity = 3.14;
  }
}
```

Dependency exists(max_acceleration) ->
exists(has_acceleration_limits) not satisfied in move_group

In-Value Dependent Type: If max_velocity is set, then has_velocity_limits must be set

Liquid types are also used to structurally refine the architecture of the system

Component Writer

```
node type openni_node {
    optional param depth_frame_id: string = "/openni_depth_optical_frame";
    optional param rgb_frame_id: string = "/openni_rgb_optical_frame";

    publishes to camera/depth/points: sensor_msgs/PointCloud2 where { count(publishers(_)) == 1 };
}
```

Liquid types are also used to structurally refine the architecture of the system

Component Writer

```
node type openni_node {
    optional param depth_frame_id: string = "/openni_depth_optical_frame";
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    publishes to camera/depth/points: sensor_msgs/PointCloud2 where { count(publishers(_)) == 1 };
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Liquid Type: There must only be one publisher to the topic

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Component Writer

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node type openni_node {
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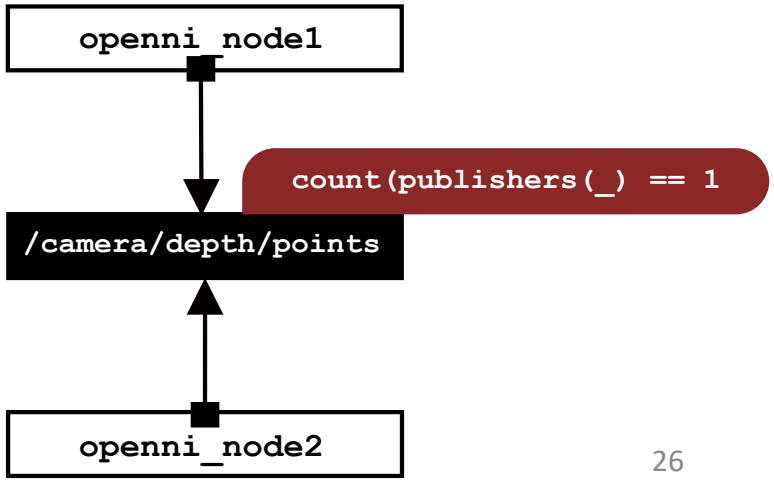
}
```

Liquid Type: There must only be one publisher to the topic

Component Integrator

```
system {
    node instance openni_node1: openni_node { … }

    node instance openni_node2: openni_node { … }
}
```



Policies refine component connections by providing semantic information

Component Writer 1

```
node type openni_camera_driver {
  @qos{effort1qos}
  publishes to /camera/rgb/image_raw: sensor_msgs/Image;
}
```

Component Writer 2

```
node type custom_node {
  @qos{reliable5qos}
  subscribes to /camera/rgb/image_raw: sensor_msgs/Image;
}
```

Policies refine component connections by providing semantic information

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Component Writer 2

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Quality of Service (QoS) policies allow you to tune communication between nodes

(history, depth, reliability, durability, deadline, …)

Policies refine component connections by providing semantic information

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Component Writer 2

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node type custom_node {
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}
```

Quality of Service (QoS) policies allow you to tune communication between nodes

(history, depth, reliability, durability, deadline, …)

Publisher	Subscription	Compatible
Best effort	Best effort	Yes
Best effort	Reliable	No
Reliable	Best effort	Yes
Reliable	Reliable	Yes

Policies refine component connections by providing semantic information

Component Writer 1

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```

Quality of Service (QoS) policies allow you to tune communication between nodes

(history, depth, reliability, durability, deadline, …)

Publisher	Subscription	Compatible
Default	Default	Yes
Default	*x*	No
x	Default	Yes
x	*x*	Yes
x	*y* (where *y* > *x*)	Yes
x	*y* (where *y* < *x*)	No

Policies refine component connections by providing semantic information

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Component Writer 2

```
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}
```

Quality of Service (QoS) policies allow you to tune communication between nodes

(history, depth, reliability, durability, deadline, …)

Publisher	Subscription	Compatible
Automatic	Automatic	Yes
Automatic	Manual by topic	No
Manual by topic	Automatic	Yes
Manual by topic	Manual by topic	Yes

Publi		
Defa		
Defa		
x		
x	*x*	Yes
x	*y* (where *y* > *x*)	Yes
x	*y* (where *y* < *x*)	No

Policies refine component connections by providing semantic information

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Component Writer 2

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Default	Default	Yes
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x	Default	Yes
		Yes
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	where *y* < *x*)	No

Publisher	Subscription	Compatible	Result
Volatile	Volatile	Yes	New messages only
Volatile	Transient local	No	No communication
Transient local	Volatile	Yes	New messages only
Transient local	Transient local	Yes	New and old messages

Policies refine component connections by providing semantic information

> *Figuring out the right QoS settings to use for nodes is also a pain, since certain combinations are not compatible with others, so for every nodes, you have to consult the compatibility matrix and make sure that all subscribers and publishers agree with each other.* [2]

[2] https://docs.google.com/forms/d/1GWb7RrSPkvdgl49LMrsTyoAy3i29LO6AuFSIUzsuwrs, from Open Robotics

Policies refine component connections by providing semantic information

Component Writer 1

```
node type openni_camera_driver {
  @qos{effort1qos}
  publishes to /camera/rgb/image_raw: sensor_msgs/Image;
}
```

```
policy instance effort1qos: qos {
    setting reliability = BestEffort;
    setting depth = 1;
}
```

Component Writer 2

```
node type custom_node {
  @qos{reliable5qos}
  subscribes to /camera/rgb/image_raw: sensor_msgs/Image;
}
```

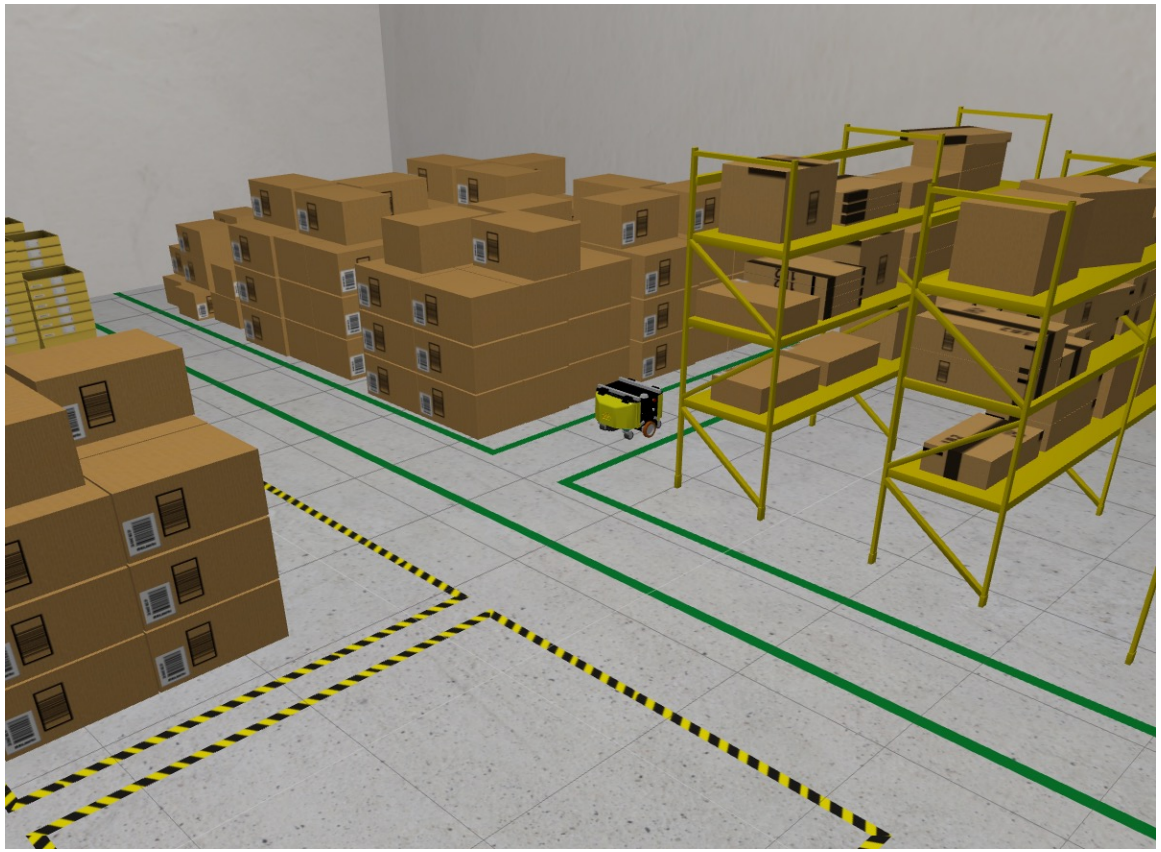
```
policy instance reliable5qos: qos {
    setting reliability = Reliable;
    setting depth = 1;
}
```

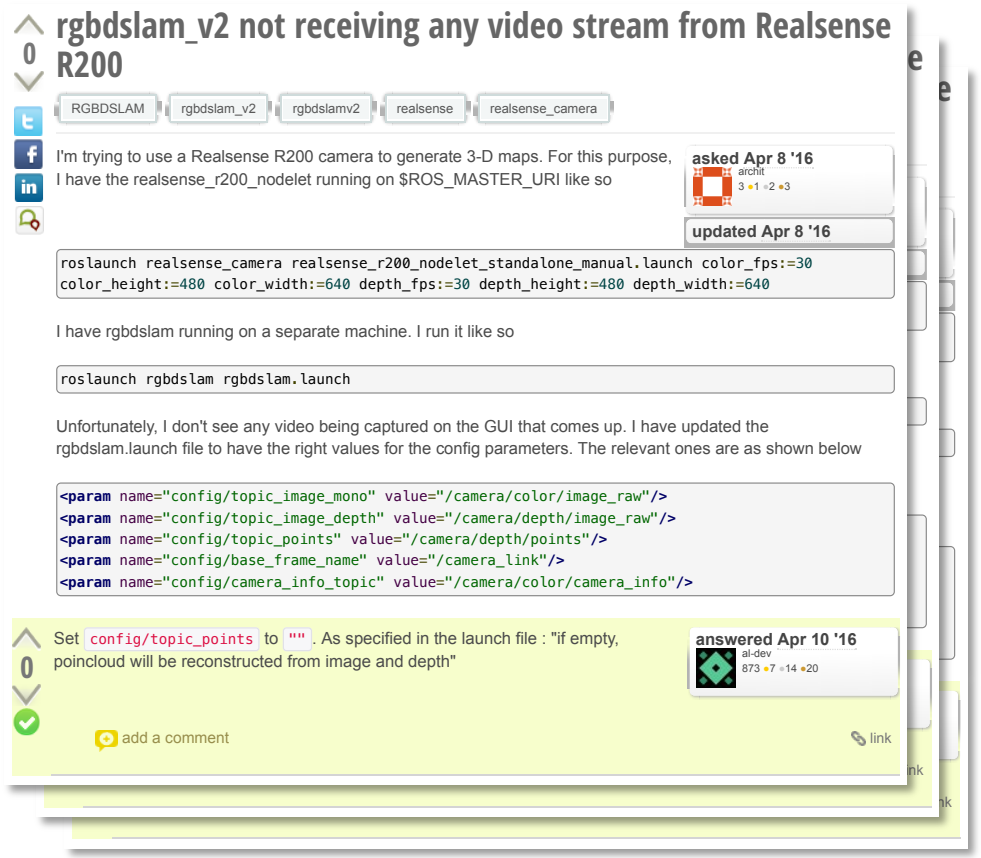
Component Integrator

```
system {
    node instance node: custom_node { }
    node instance openni_node: openni_camera_driver { }
}
```

Evaluation

We evaluate ROSpec on a medium-sized robot and a dataset of real-world misconfigurations





rgbdslam_v2 not receiving any video stream from Realsense R200

RGBDSLAM | rgbdslam_v2 | rgbdslamv2 | realsense | realsense_camera

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asked Apr 8 '16 archit 3 ●1 ●2 ●3

updated Apr 8 '16

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<param name="config/camera_info_topic" value="/camera/color/camera_info"/>
```

0

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answered Apr 10 '16 al-dev 873 ●7 ●14 ●20

add a comment

link

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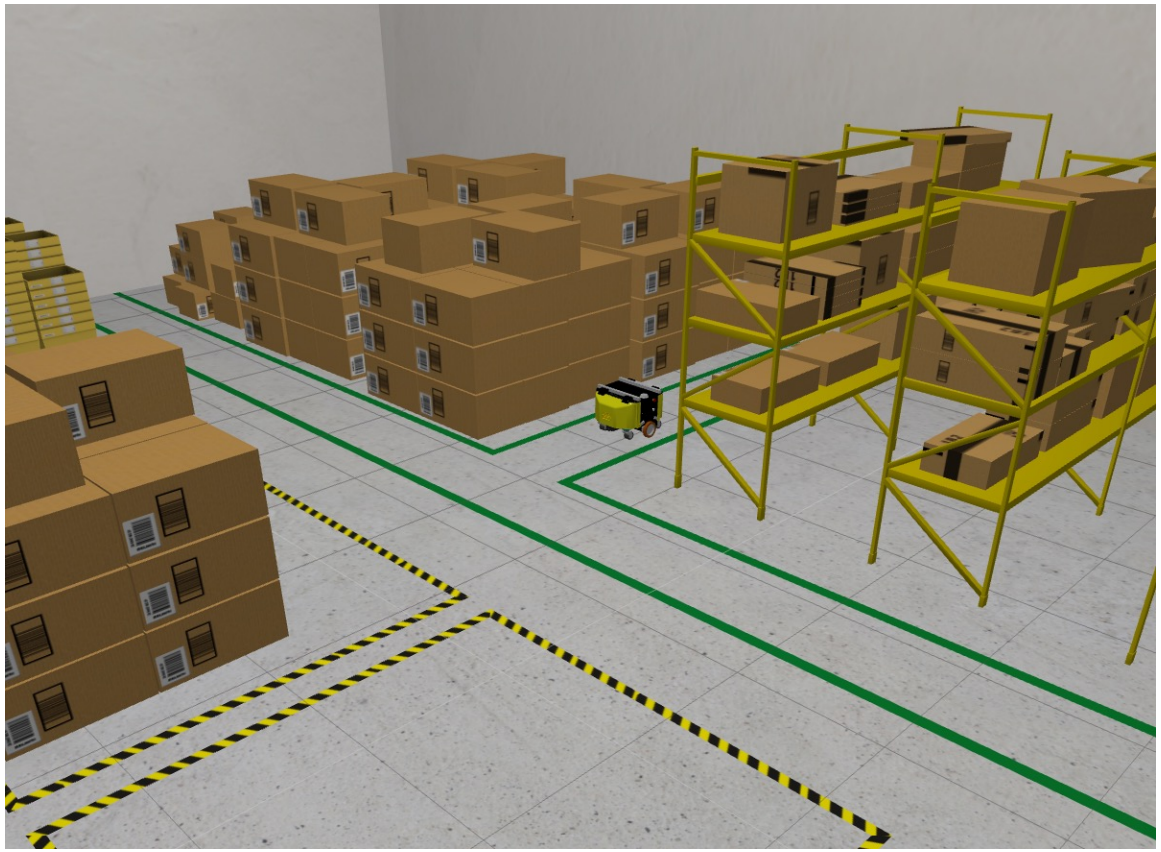
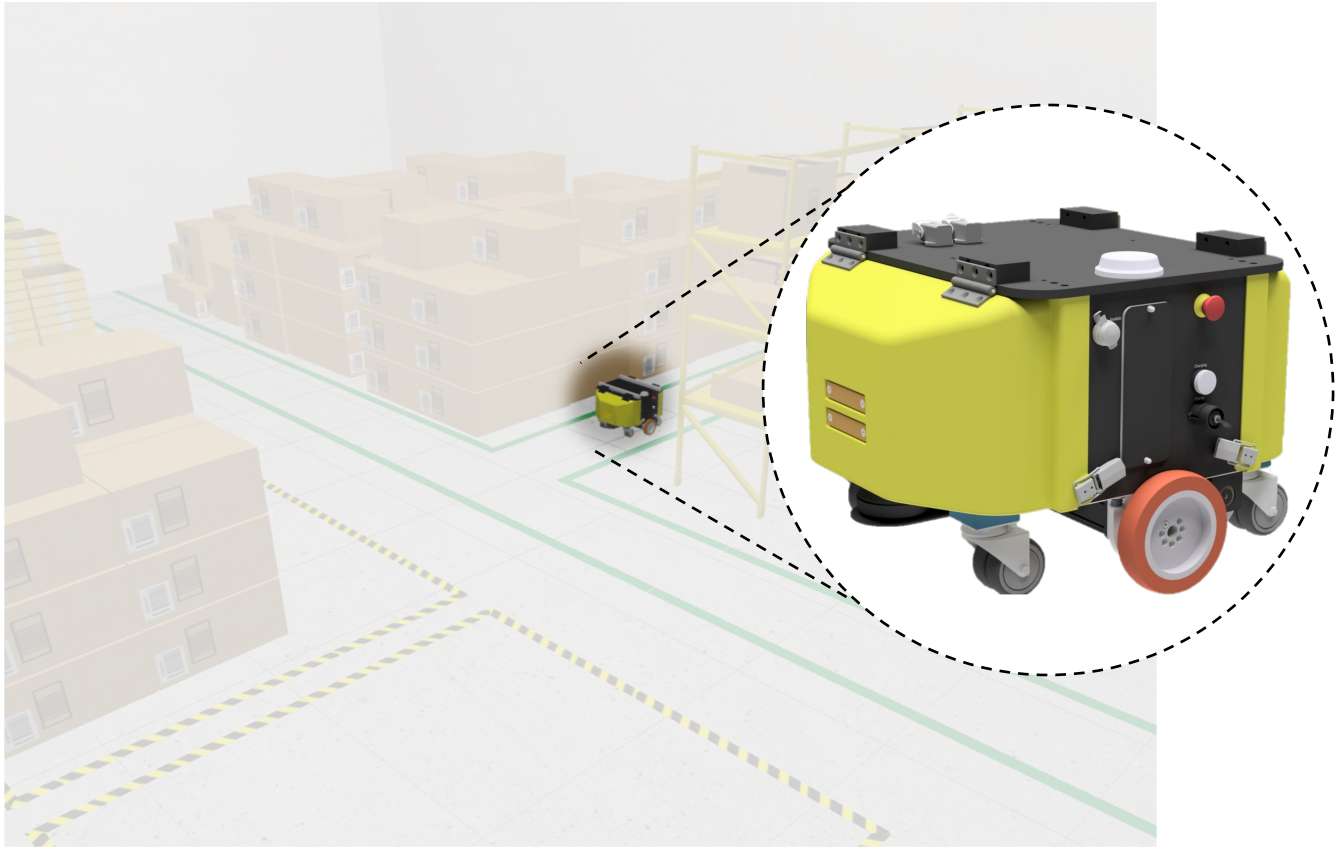


Responsible for following a path, avoiding dangerous areas, and respecting speed limits



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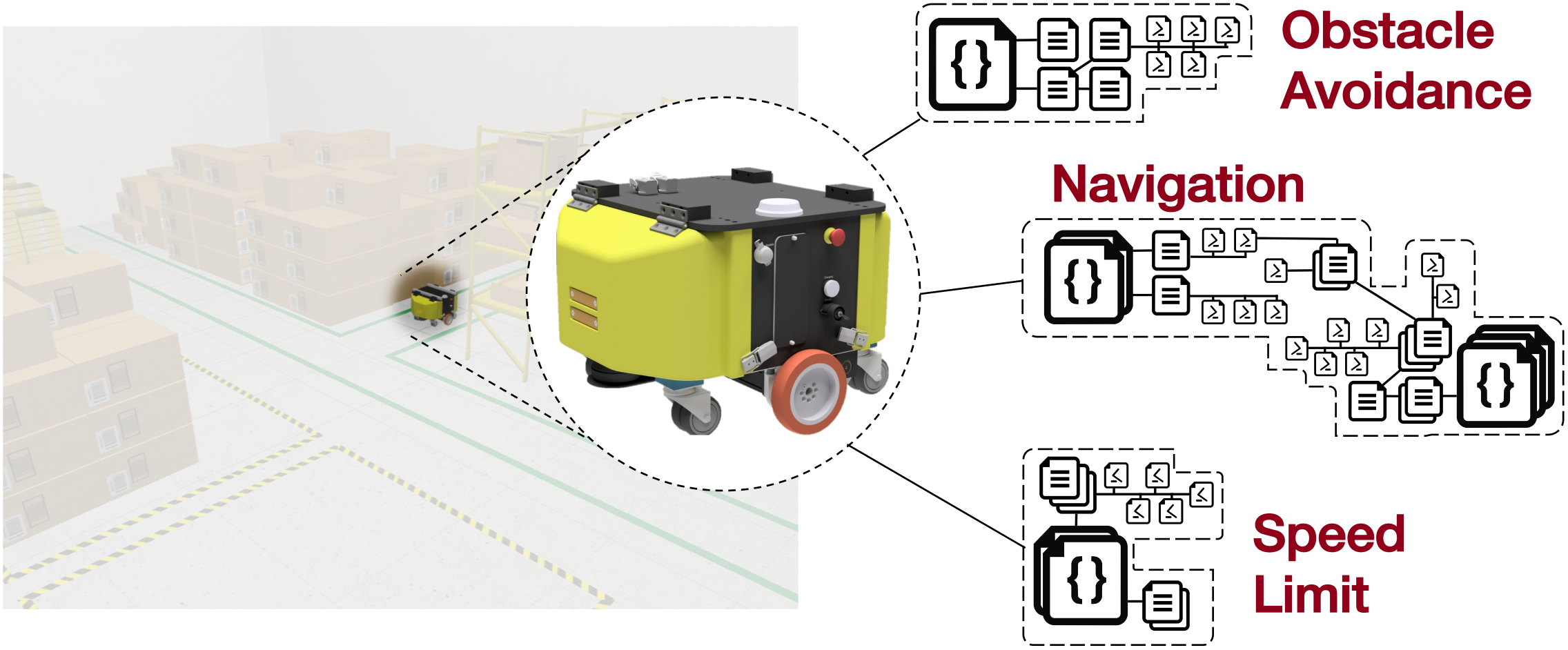

We specified 19 components, using both liquid and dependent types to refine configurations

Component: amcl

```
node type amcl {
    context distribution: AfterHumbleVersion;

    optional param max_beams: int = 60;
    optional param max_particles: int = 2000;
    optional param min_particles: int = 500;
    optional param laser_max_range: double where {_ >= 0} = 100.0;
    optional param set_initial_pose: bool = false;

    optional param initialpose: geometry_msgs/Pose2D = geometry_msgs/Pose2D {
              x = 0.0,
              y = 0.0,
              theta = 0.0,
           };

    @qos{sensor_data_profile}
    subscribes to content(scan_topic): RestrictedLaserScan;

    @qos{sensor_data_profile}
    publishes to particle_cloud: nav2_msgs/ParticleCloud;

    provides service request_nomotion_srv: std_srvs/Empty;
} where {
    min_particles < max_particles;
    set_initial_pose -> exists(initial_pose);
}
```

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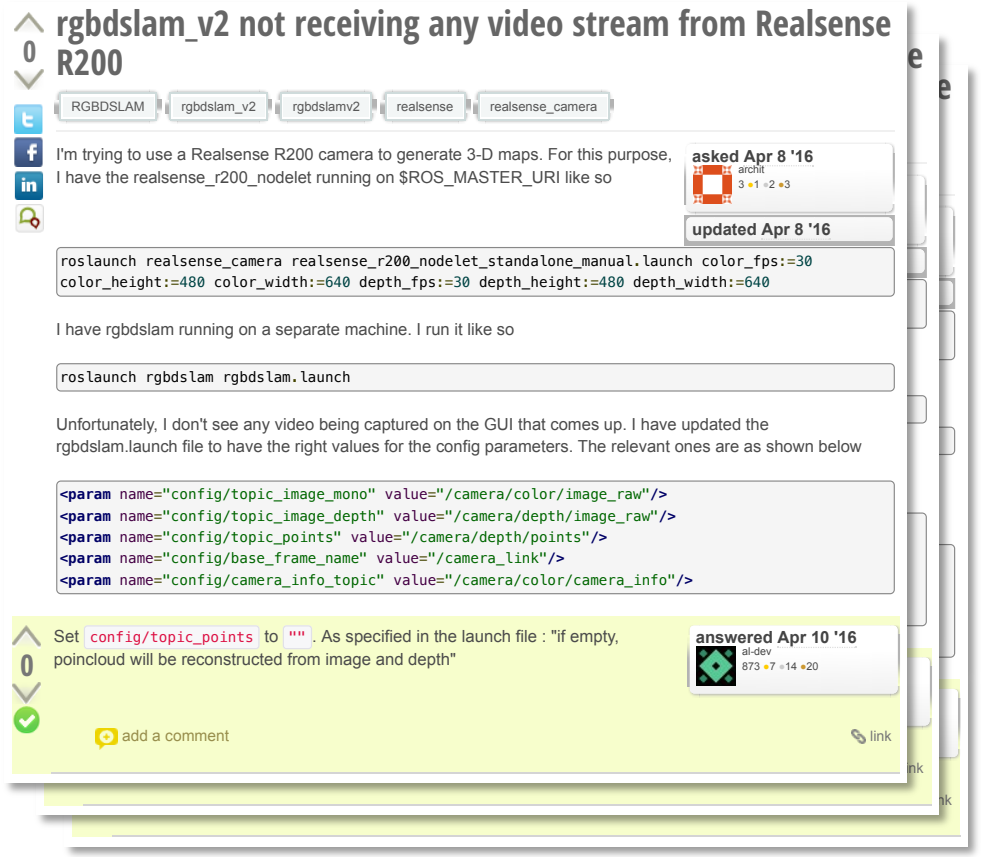
- Total: 498 lines
- ✅ Liquid types
- ✅ QoS policies
- ✅ Dependencies

We evaluate ROSpec on a medium-sized robot and a dataset of real-world misconfigurations



rgbdslam_v2 not receiving any video stream from Realsense R200

RGBDSLAM | rgbdslam_v2 | rgbdslamv2 | realsense | realsense_camera

I'm trying to use a Realsense R200 camera to generate 3-D maps. For this purpose, I have the realsense_r200_nodelet running on $ROS_MASTER_URI like so

asked Apr 8 '16
archit
3 ●1 ●2 ●3

updated Apr 8 '16

```
roslaunch realsense_camera realsense_r200_nodelet_standalone_manual.launch color_fps:=30
color_height:=480 color_width:=640 depth_fps:=30 depth_height:=480 depth_width:=640
```

I have rgbdslam running on a separate machine. I run it like so

```
roslaunch rgbdslam rgbdslam.launch
```

Unfortunately, I don't see any video being captured on the GUI that comes up. I have updated the rgbdslam.launch file to have the right values for the config parameters. The relevant ones are as shown below

```
<param name="config/topic_image_mono" value="/camera/color/image_raw"/>
<param name="config/topic_image_depth" value="/camera/depth/image_raw"/>
<param name="config/topic_points" value="/camera/depth/points"/>
<param name="config/base_frame_name" value="/camera_link"/>
<param name="config/camera_info_topic" value="/camera/color/camera_info"/>
```

0

Set `config/topic_points` to `""`. As specified in the launch file : "if empty, poincloud will be reconstructed from image and depth"

answered Apr 10 '16
al-dev
873 ●7 ●14 ●20

add a comment

link

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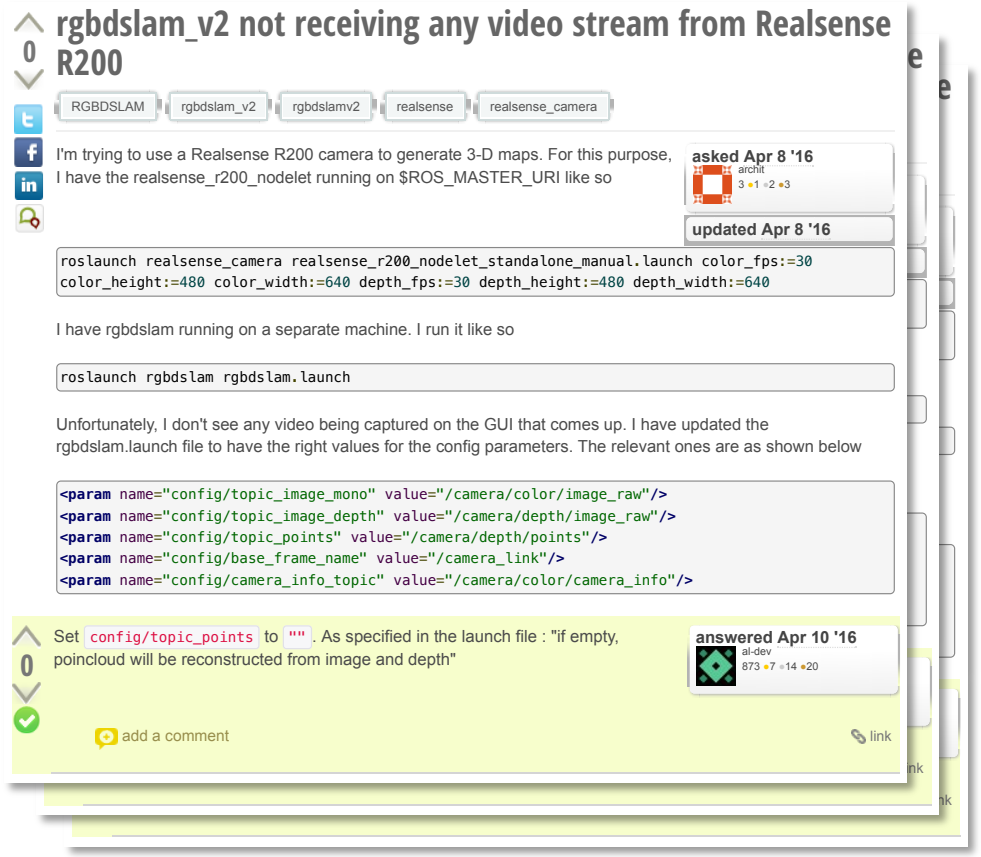

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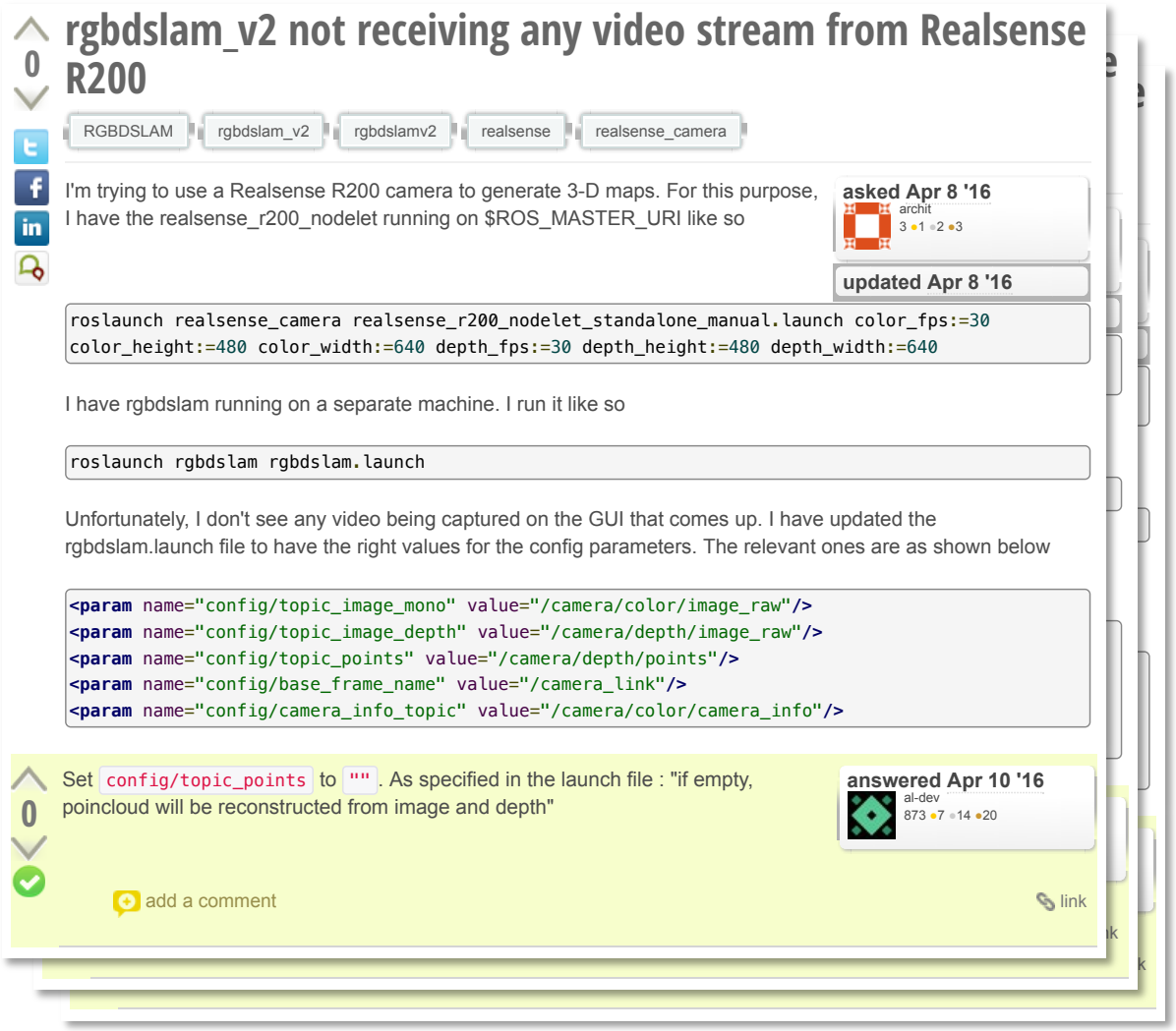
873 ●7 ●14 ●20

add a comment

link

We manually inspect 182 questions from a Q&A platform, and specify components & systems



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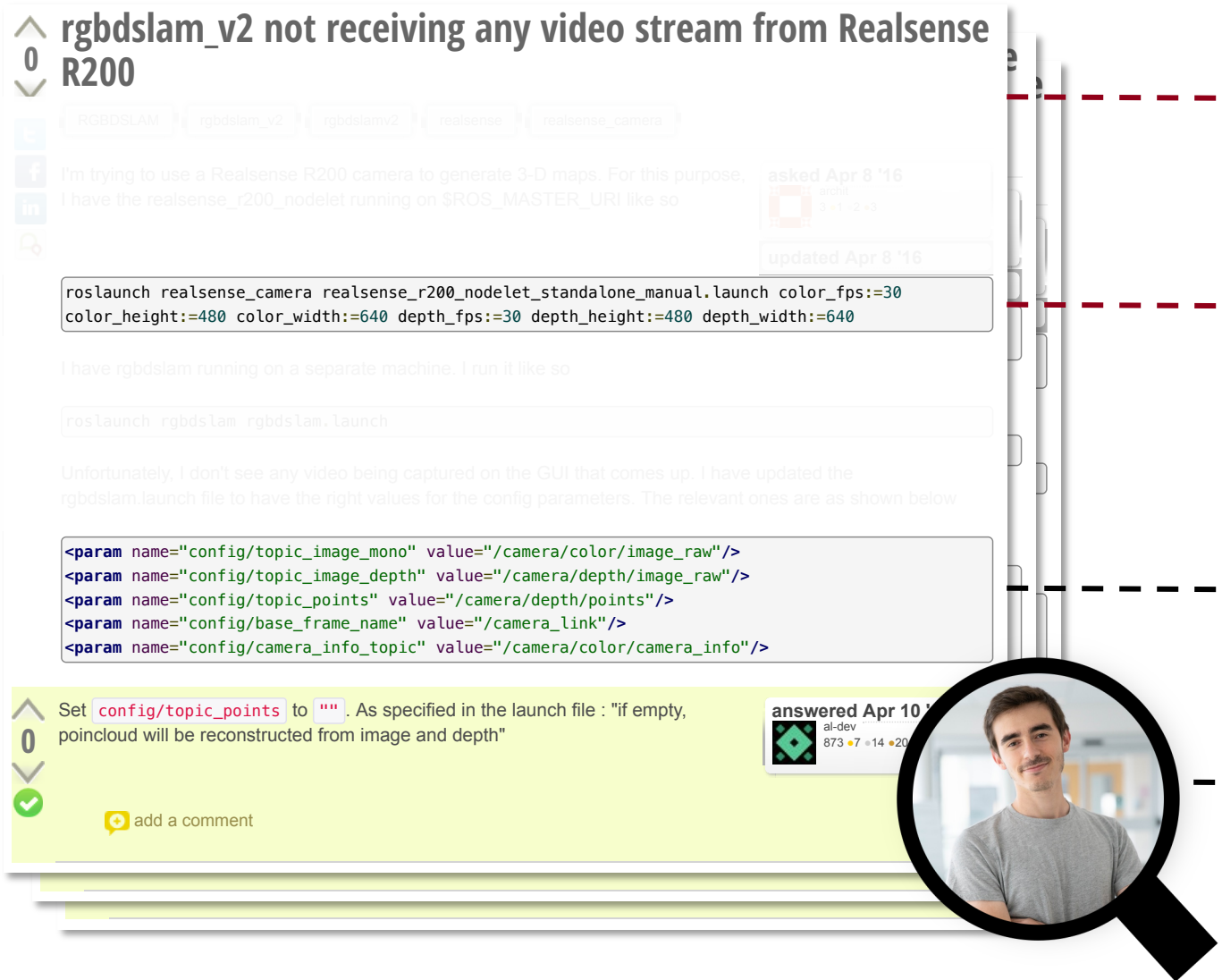


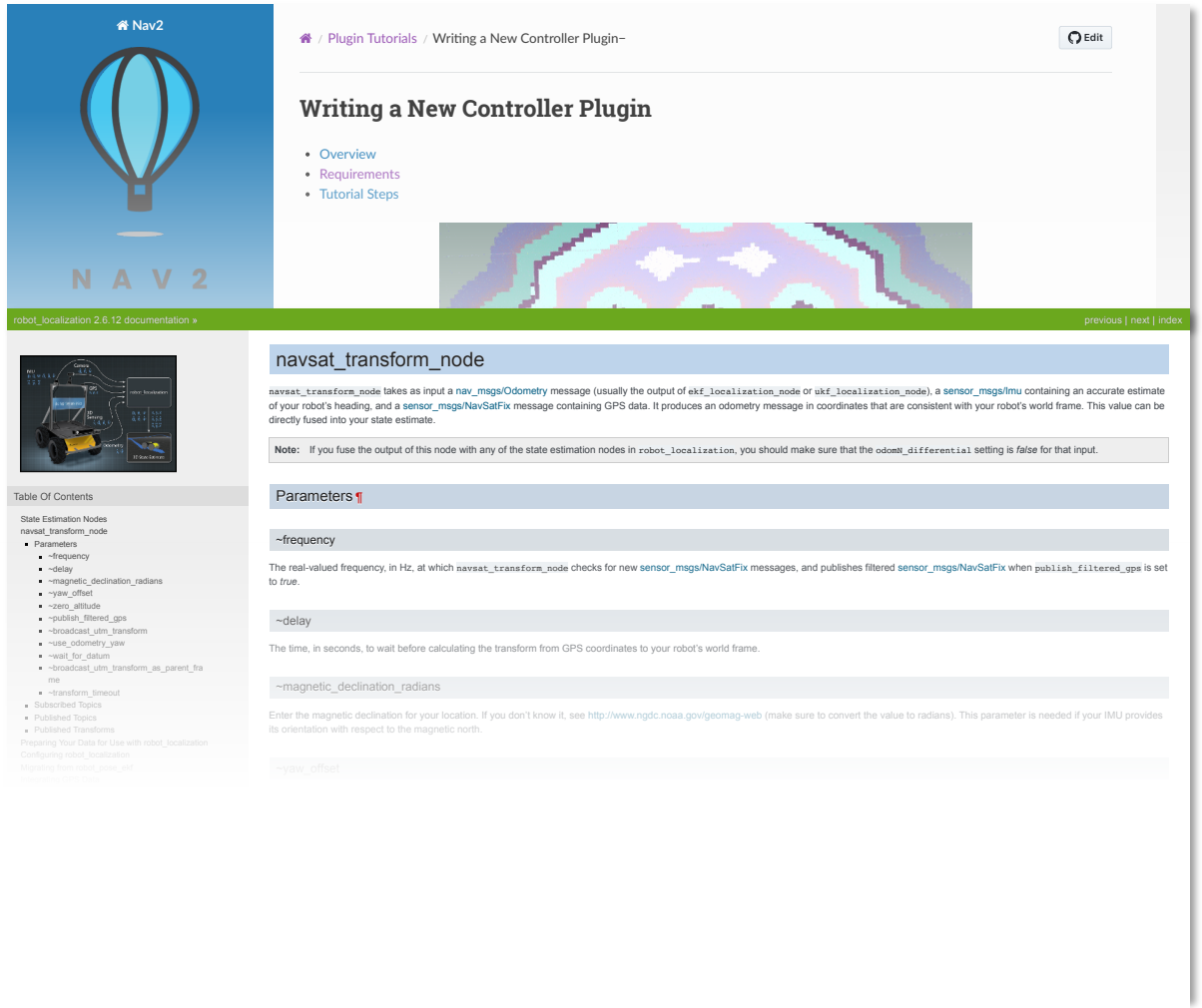
What packages are used?

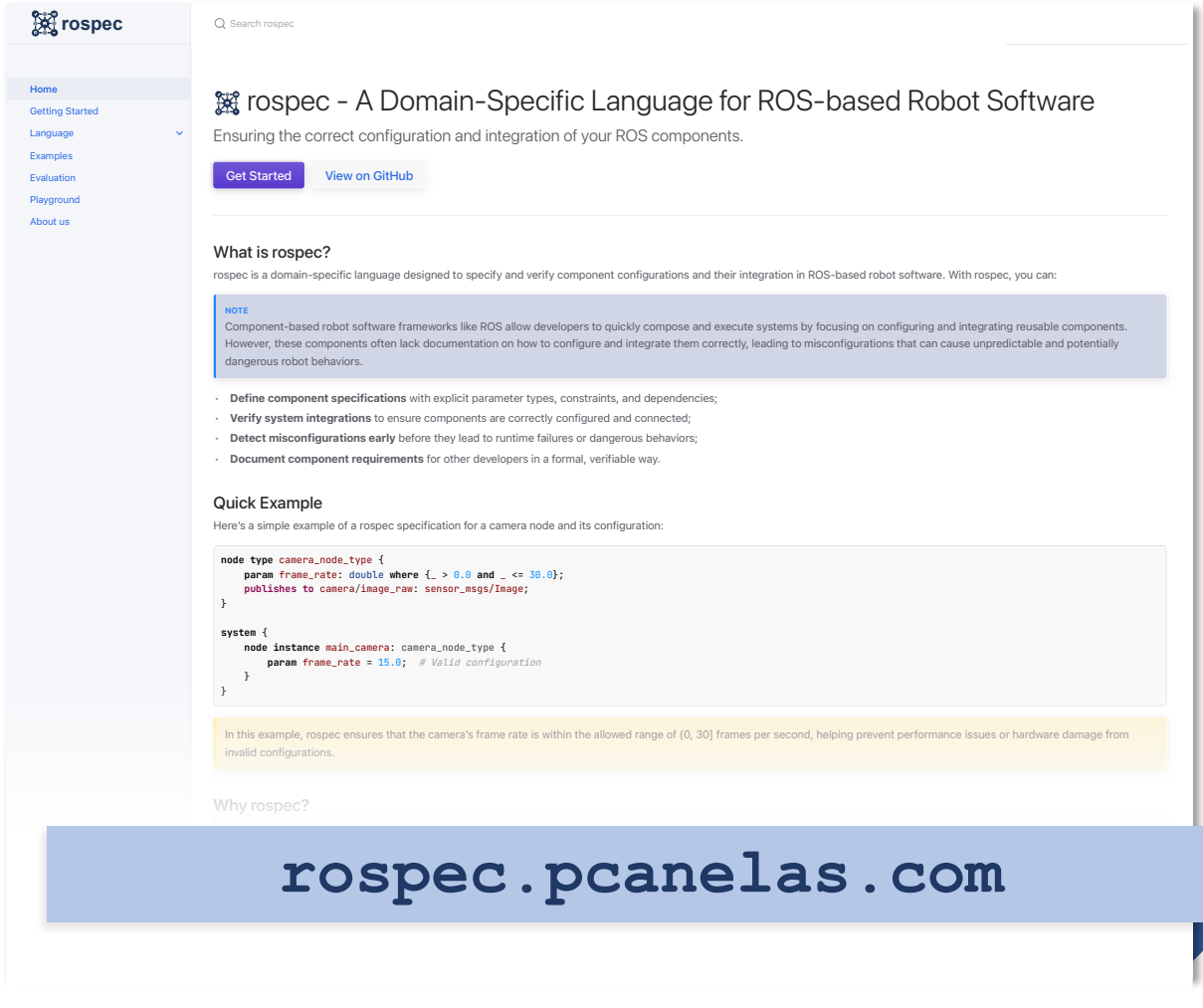
What components are used?

What configurations are used?

What is the fix?

We use components documentation, and our playground to create and refine specifications





rospec.pcanelas.com

ROSpec documents components and detects real misconfigurations made by developers

61 **Detectable**
Component specification possible

23 **Documentation**
Missing integration information

31 **Not Supported**
Cannot model the concept (e.g., URDF)

32% use of **Dependent types**

17% **explicit** use of **Liquid types**

ROSpec documents components and detects real misconfigurations made by developers

28 **Not enough context**

Missing information

Out of Scope **31**

How-to use, bug in component

61 **Detectable**

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32% use of **Dependent types**

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Cannot model the concept (e.g., URDF)

Find more on our paper, website or meet me during the coffee break! And…

ROSpec: A Domain-Specific Language for ROS-based Robot Software

Paulo Canela

Carnegie Mellon Univer

University of Lisbon

We enforce type restrictions and parameter dependencies using liquid and dependent types

Liquid Type: Only allow positive max accelerations

Component Writer

```
node type move_group {
  param max_acceleratio
  param min_velocity: d

  optional param max_ve
  optional param has_ve
  optional param has_ac
} where {
  exists(max_velocity)
}
```

Component Integrator

Depen

By specifying `{properties}` over **component configurations** and their **integration**, we can **detect misconfigurations** prior to deployment

15

ROSpec: A Domain-Specific Language for ROS-Based Robot Software

PAULO CANELAS, Carnegie Mellon University, USA and University of Lisbon, Portugal
BRADLEY SCHMERL, Carnegie Mellon University, USA
ALCIDES FONSECA, University of Lisbon, Portugal
CHRISTOPHER S. TIMPERLEY, Carnegie Mellon University, USA

Component-based robot software frameworks, such as the Robot Operating System (ROS), allow developers to quickly compose and execute systems by focusing on configuring and integrating reusable, off-the-shelf components. However, these components often lack documentation on how to configure and integrate them correctly. Even when documentation exists, its natural language specifications are not enforced, resulting in misconfigurations that lead to unpredictable and potentially dangerous robot behaviors. In this work, we introduce ROSpec, a ROS-tailored domain-specific language designed to specify and verify component configurations and their integration. ROSpec's design is grounded in ROS domain concepts and informed by a prior empirical study on misconfigurations, allowing the language to provide a usable and expressive way of specifying and detecting misconfigurations. At a high level, ROSpec verifies the correctness of argument and

We would like to thank Catarina Gamboa, Claire Le Goues, and Jonathan Aldrich for their feedback on this work.

This work was supported by Fundação para a Ciência e Tecnologia (FCT) and FEDER in the LASIGE Research Unit under the ref. (UID/00408/2025), RAP(EXPL/CCI-COM/1306/2021), RAP+ (LISBOA2030-FEDER-00663700), HPC (2025.00002.HPCVLAB.ISTUL, POR011PRE), the CMU Portugal Dual Degree PhD program (SFRH/BD/151469/2021), and a CMU Cylab seed grant.

Find more on our paper, website or meet me during the coffee break! And…

```
paulo where {paulo.job_market == True}
```

pcanelas.com

pasantos@andrew.cmu.edu

Empirical Research | **Program Analysis** | **Software Engineering** | **Programming Languages**