The Usability Argument for ROS-based Robot Architectural Description Languages

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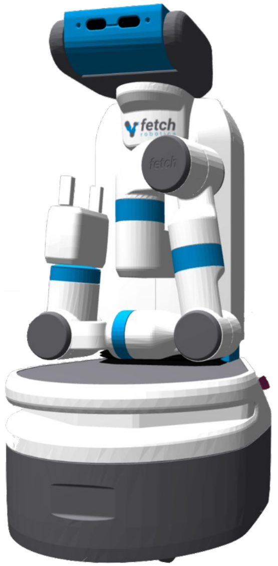
The Robot Operating System (ROS) allows developers to quickly compose and integrate components

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

Libraries and tools available for composing



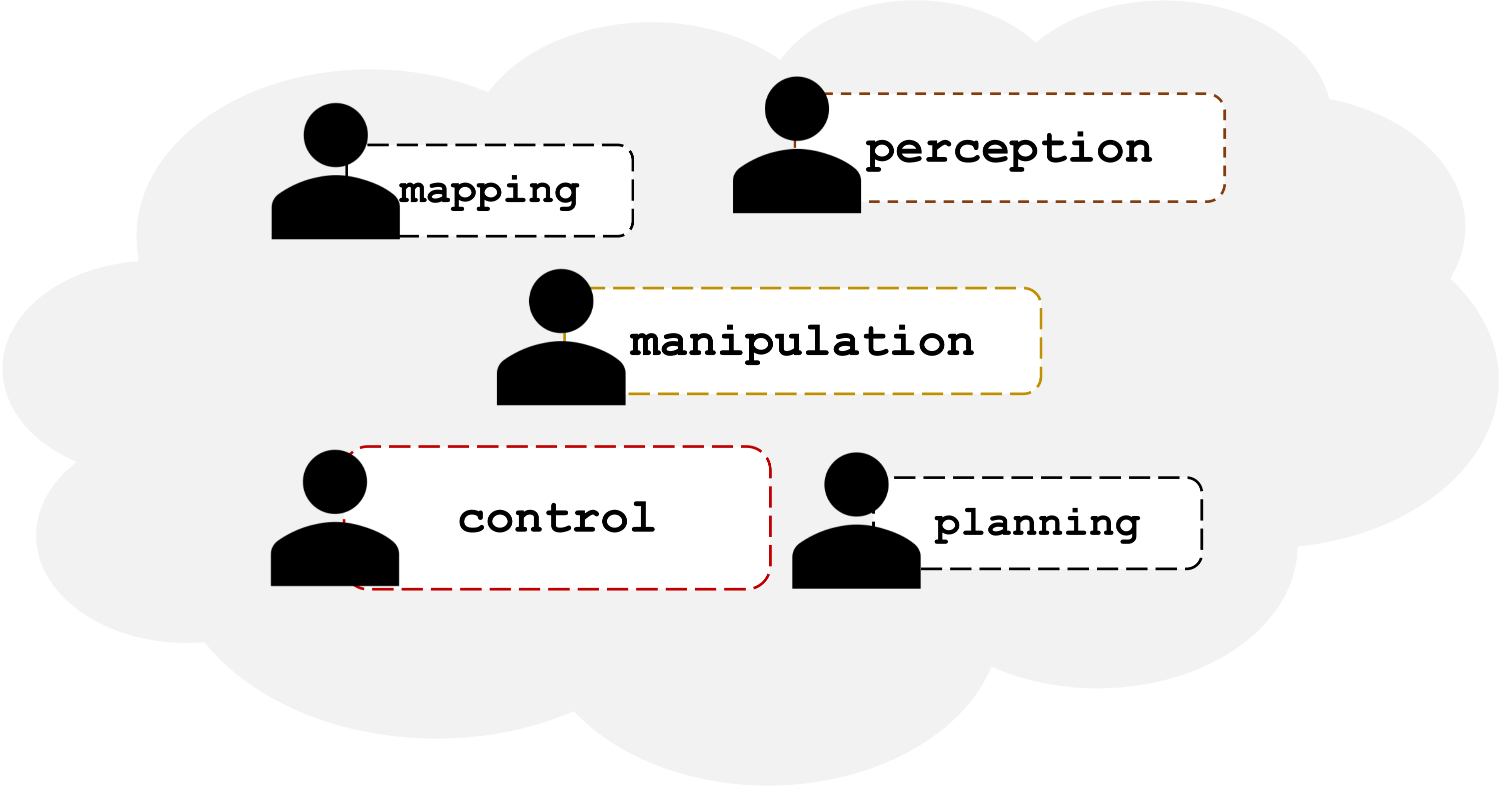
Quickly prototype the robotic system

BOSCH

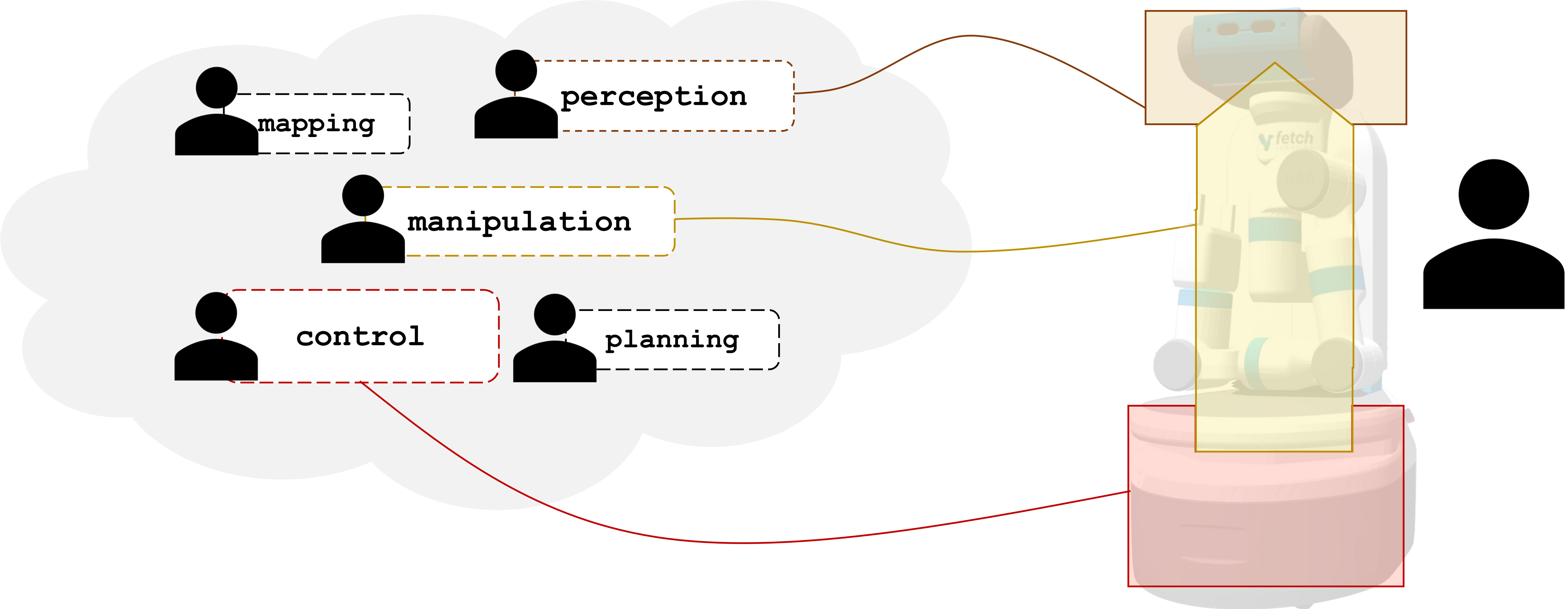
BOEING

Popular adoption in the industry

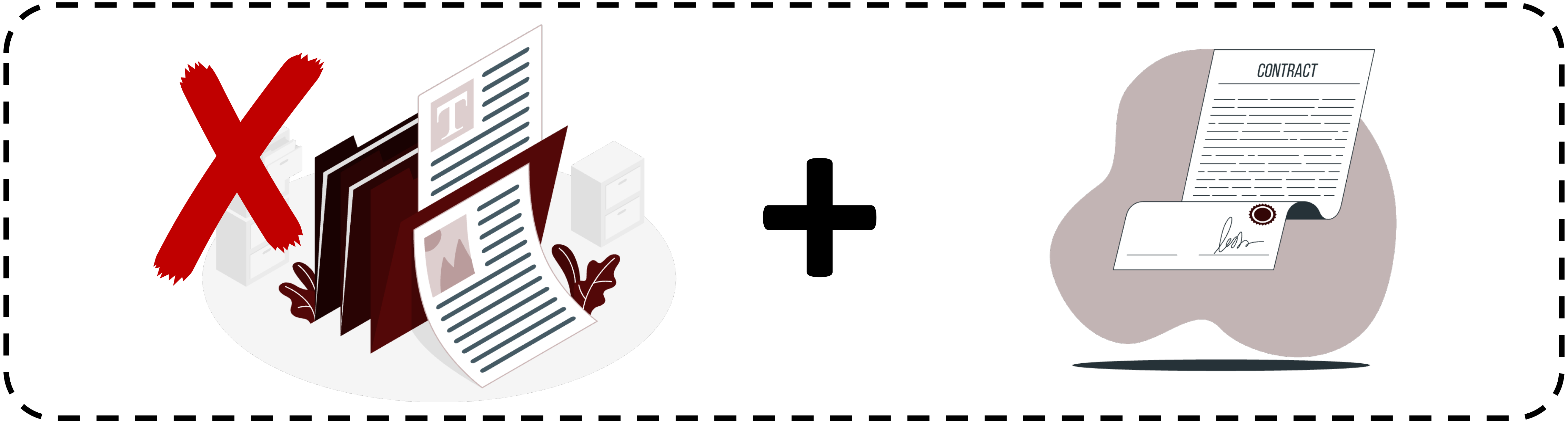
Component Writers create reusable components



Component Writers create reusable components; System Integrators compose them into a system



However, when trying to integrate components, misconfigurations arise due to lack of documentation or since it is not enforced



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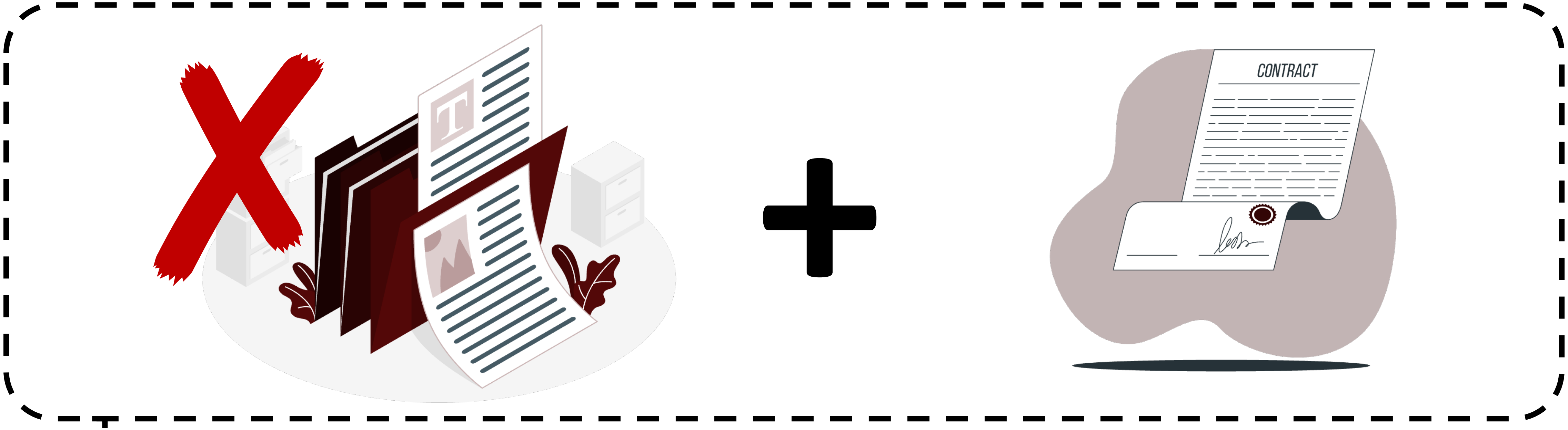
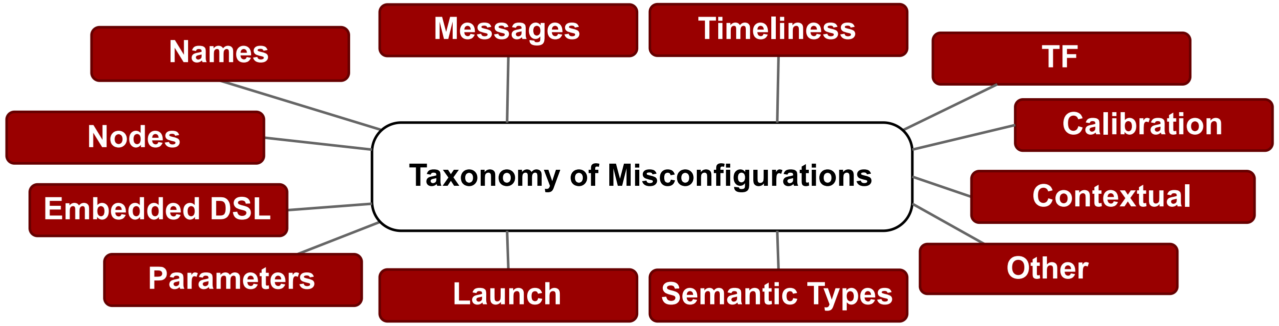


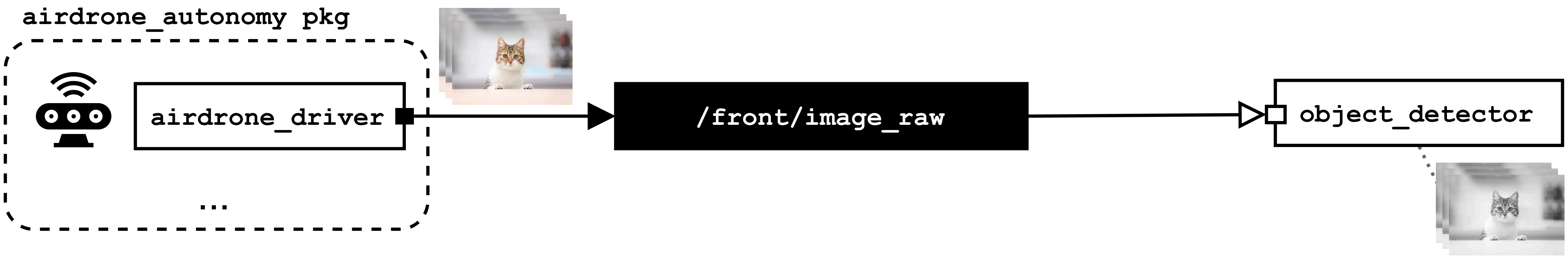


Taxonomy of Misconfigurations

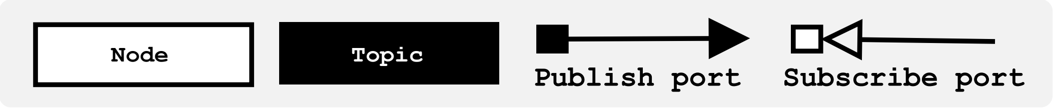
- Names
- Nodes
- Embedded DSL
- Parameters
- Messages
- Launch
- Timeliness
- Semantic Types
- TF
- Calibration
- Contextual
- Other

[Canelas et al, 2024]

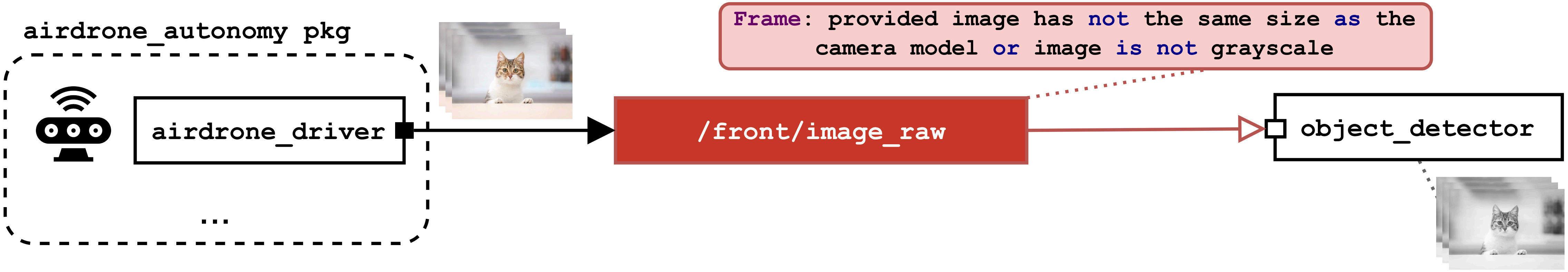
The airdrone_driver sends sensor data, while the object_detector receives and processes the information



Legend



Missing semantic information regarding image format leads to mismatches image color expectations



airdrone_autonomy pkg

airdrone_driver

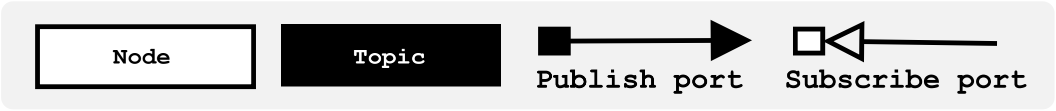
...

/front/image_raw

Frame: provided image has not the same size as the camera model or image is not grayscale

object_detector

Legend



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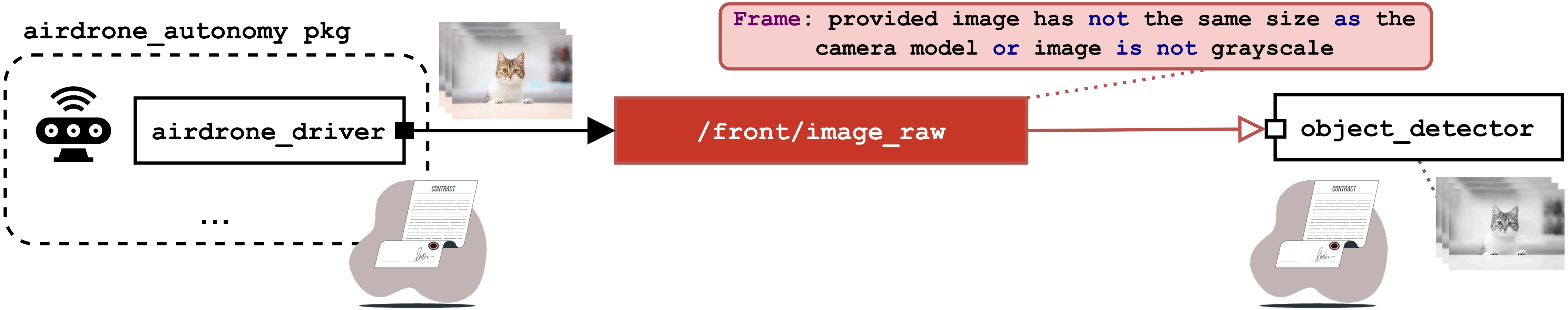

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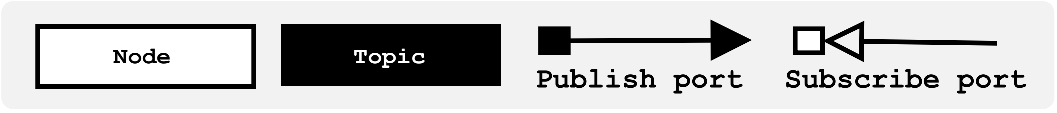
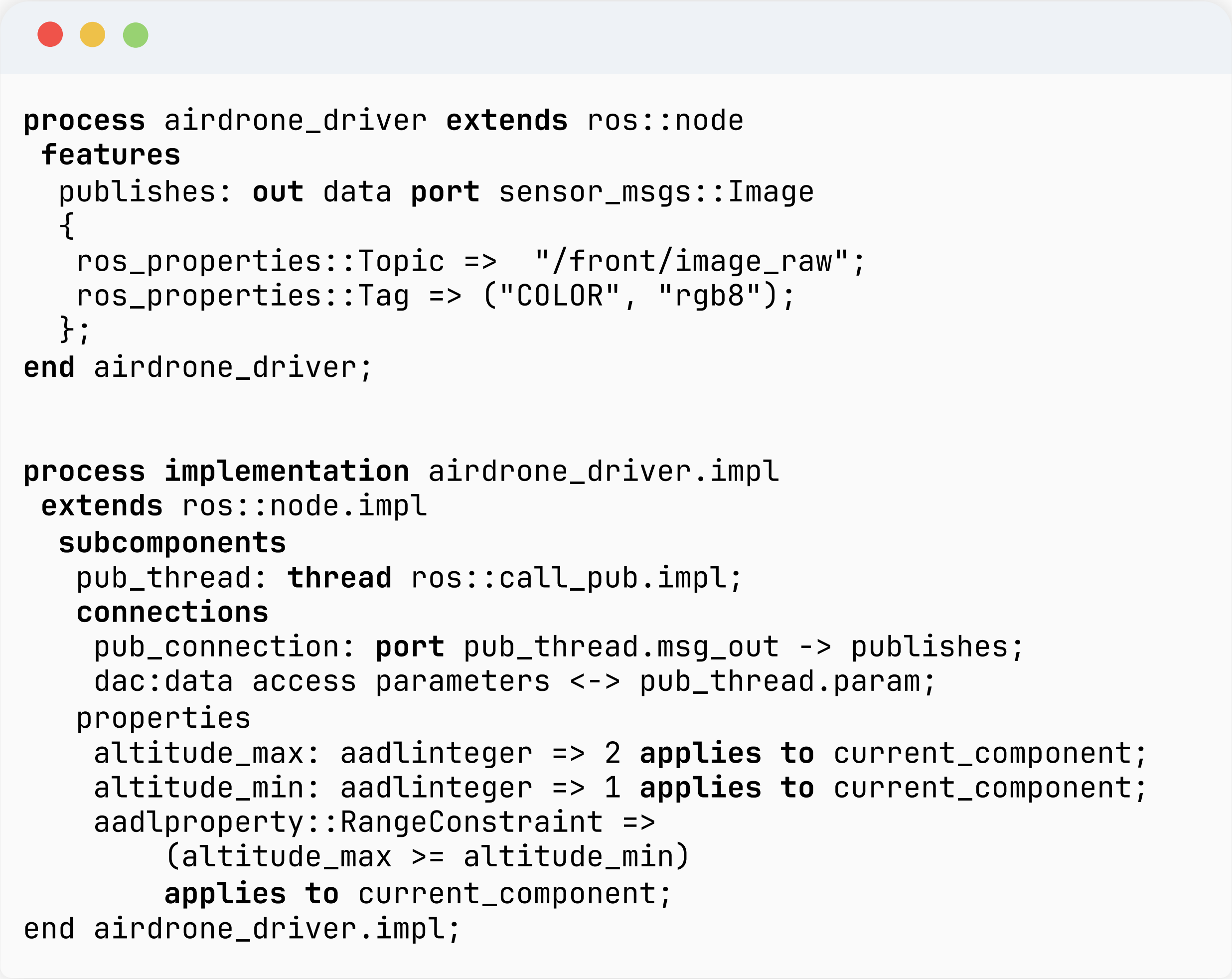


General Purpose Architectural Description Languages have been used specify components



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process airdrone_driver extends ros::node
 features
  publishes: out data port sensor_msgs::Image
  {
   ros_properties::Topic =>  "/front/image_raw";
   ros_properties::Tag => ("COLOR", "rgb8");
  };
end airdrone_driver;


process implementation airdrone_driver.impl
 extends ros::node.impl
  subcomponents
   pub_thread: thread ros::call_pub.impl;
   connections
    pub_connection: port pub_thread.msg_out -> publishes;
    dac:data access parameters <-> pub_thread.param;
   properties
    altitude_max: aadlinteger => 2 applies to current_component;
    altitude_min: aadlinteger => 1 applies to current_component;
    aadlproperty::RangeConstraint =>
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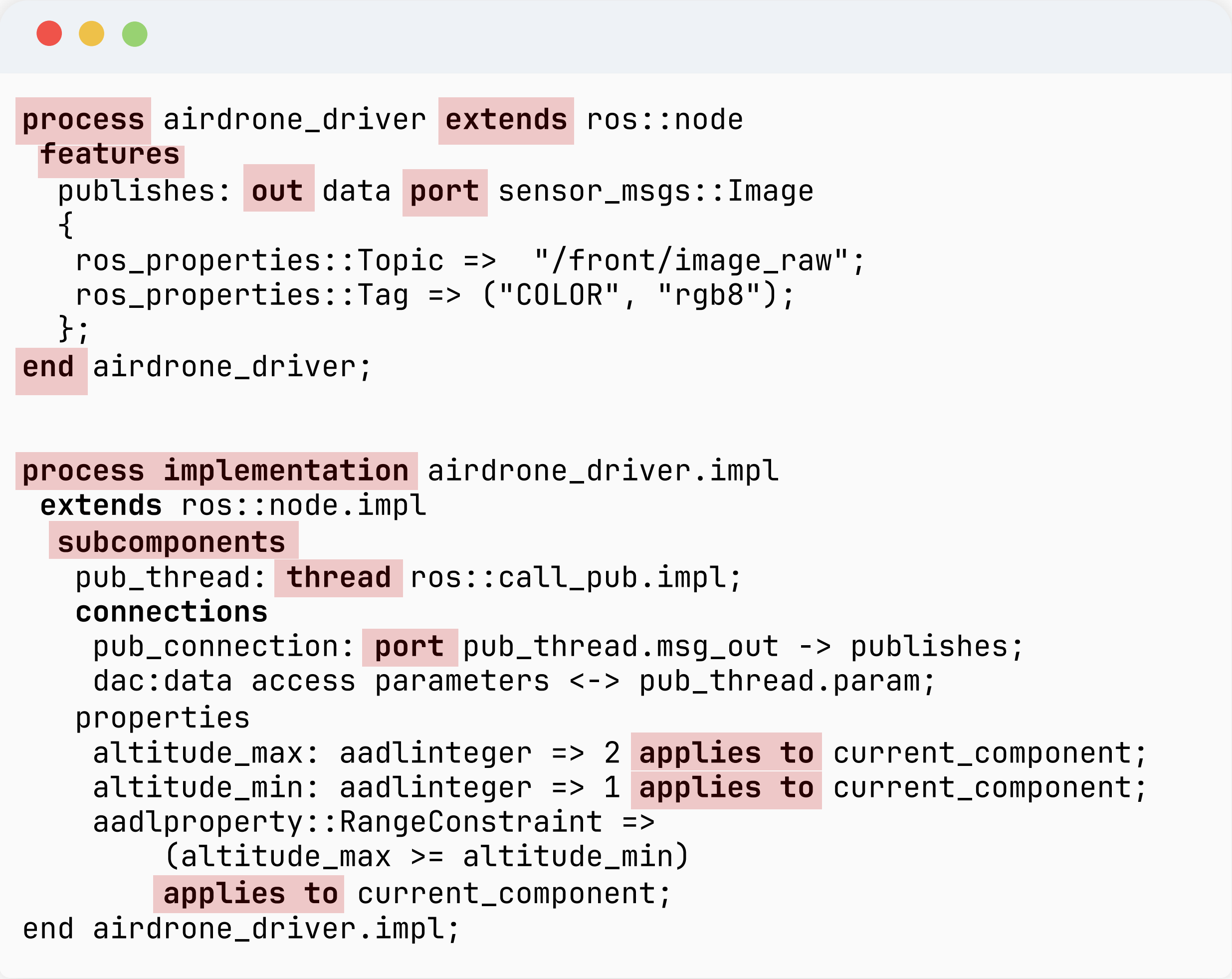
However, these require learning non-ROS concepts



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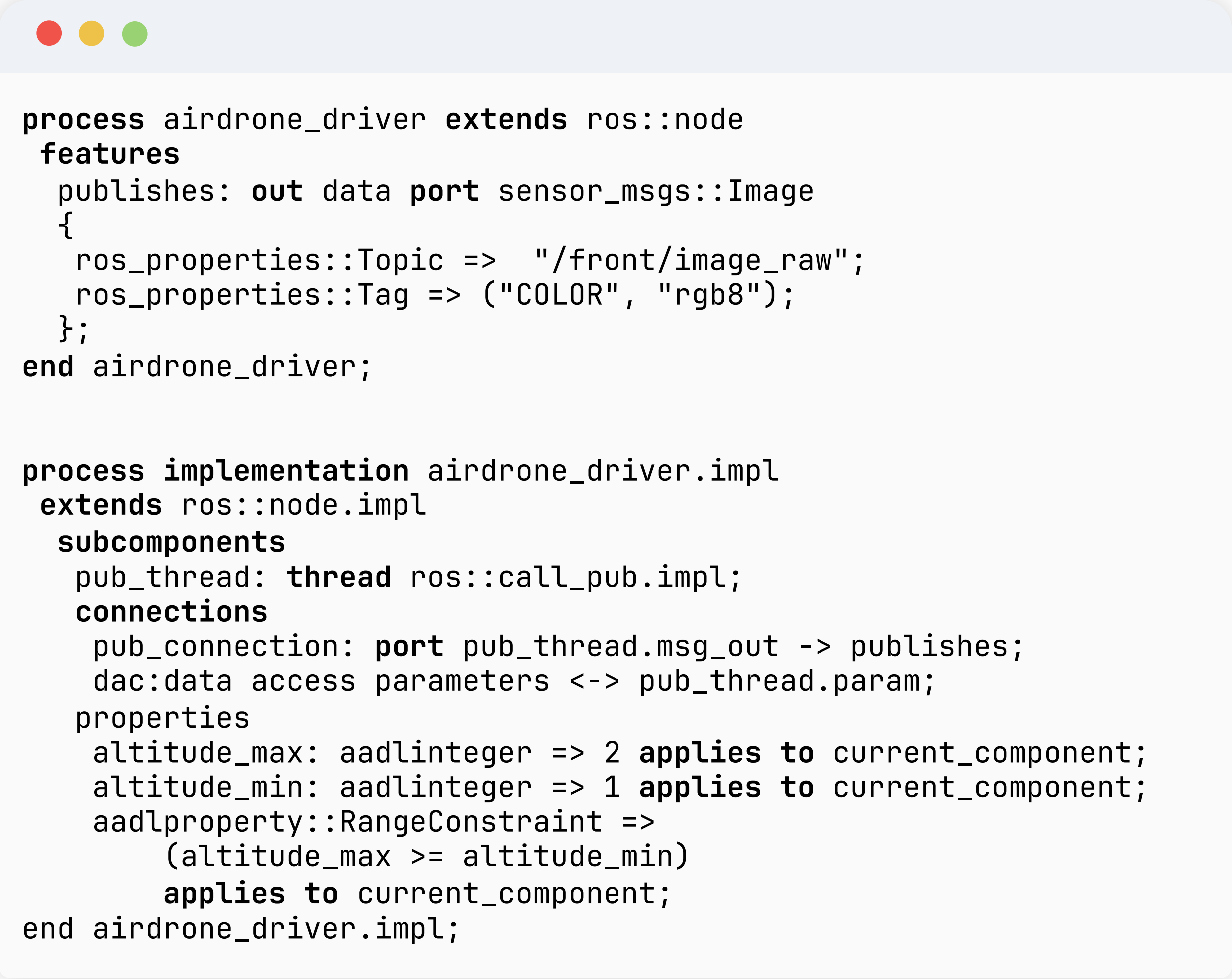
However, these require learning non-ROS concepts, do not distinguish between different stakeholders

Component writer?



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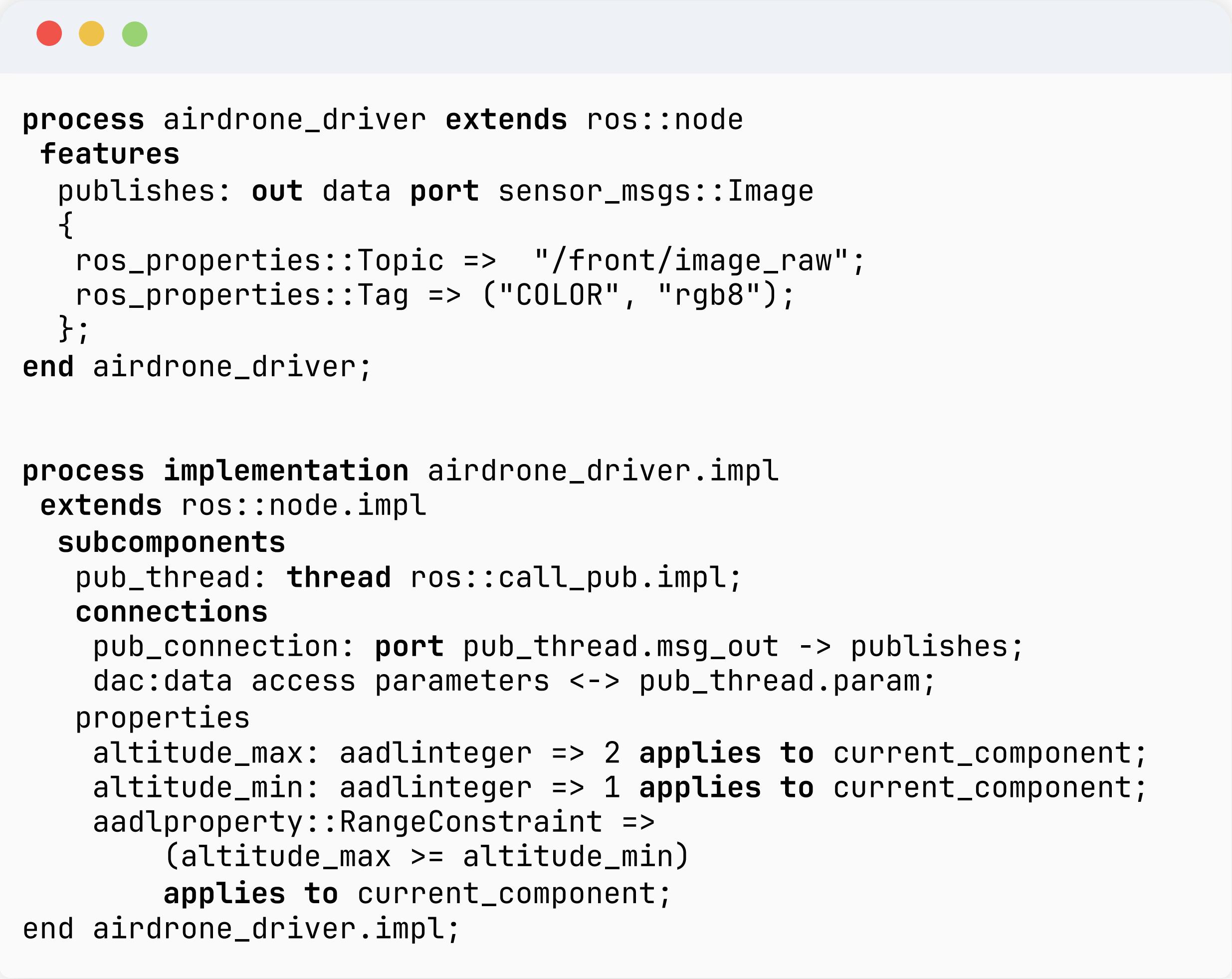
System Integrator?

However, these require learning non-ROS concepts, do not distinguish between different stakeholders, and are verbose, making it more challenging to write



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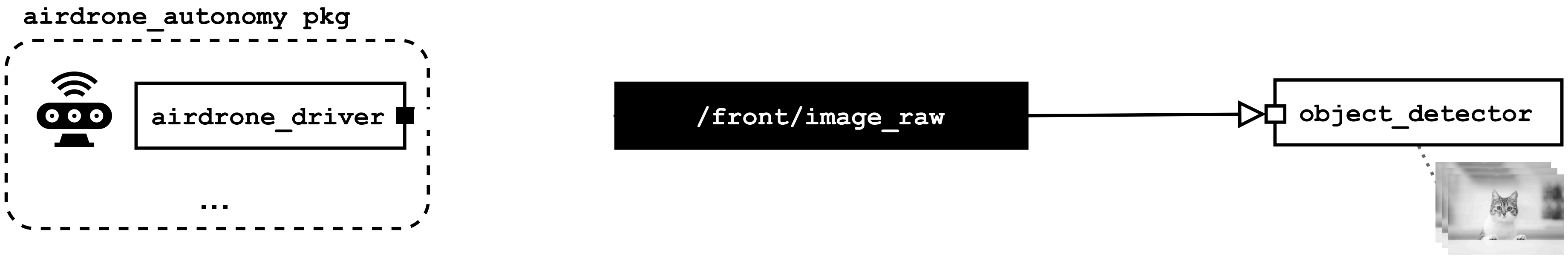
By developing ROS-tailored Architectural Description Languages (ADL), we can improve documentation and detect misconfigurations prior to execution

We introduce rospec, a architectural description language tailored to ROS to detect misconfigurations

- Language specialization to stakeholders to provide separation of concerns and improve readability
- Embedding domain knowledge into language semantics improves its usability
- Uses prior knowledge in misconfigurations to enrich the type system and detect misconfigurations

Property: A System Integrator should be able to detect missing publishers to topics containing a subscriber relationship



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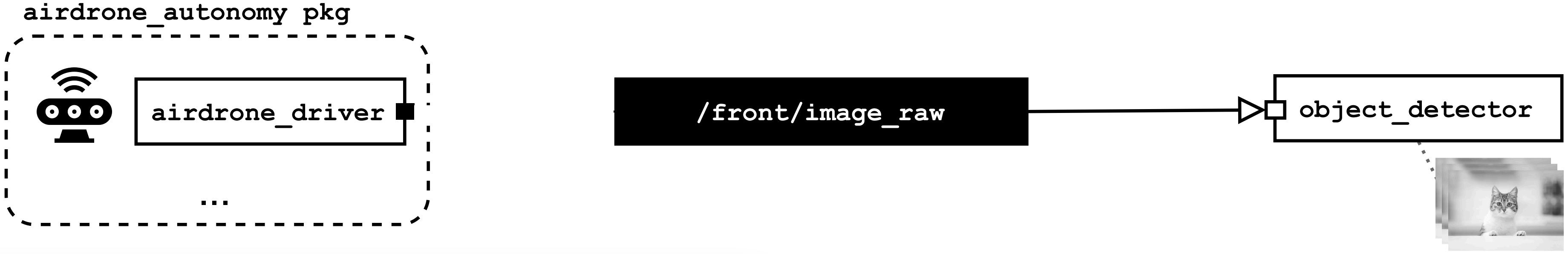

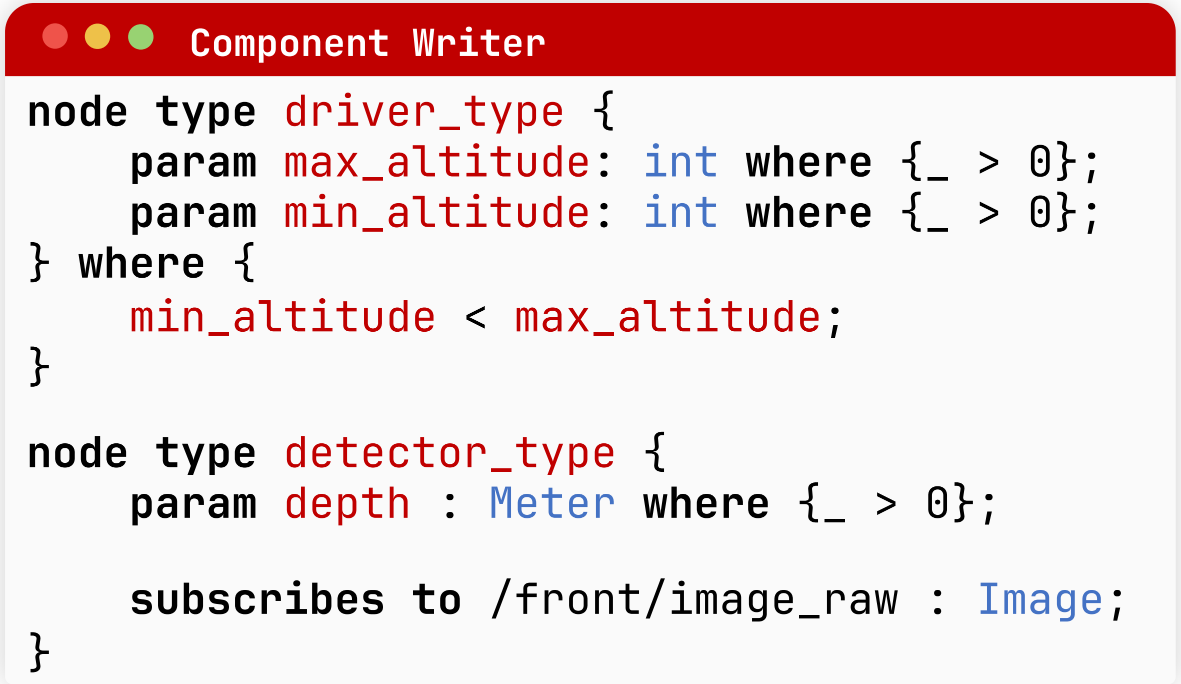

```
node type driver_type {
    param max_altitude: int where {_ > 0};
    param min_altitude: int where {_ > 0};
} where {
    min_altitude < max_altitude;
}

node type detector_type {
    param depth : Meter where {_ > 0};

    subscribes to /front/image_raw : Image;
}
```

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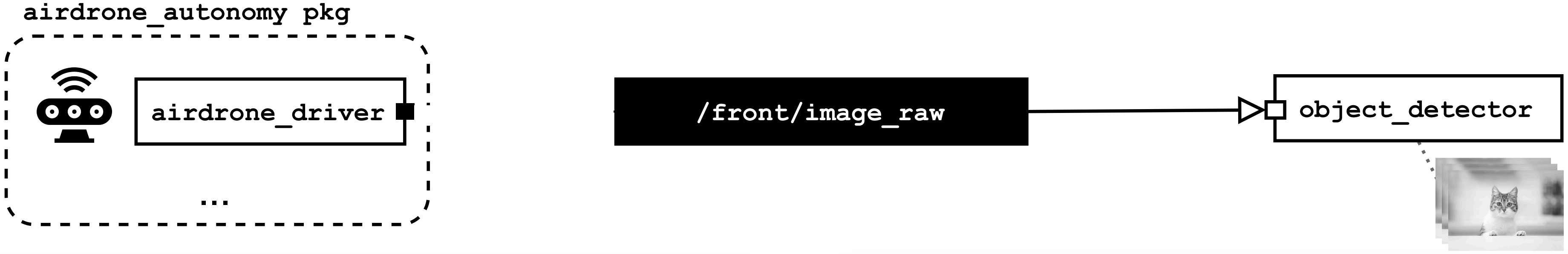

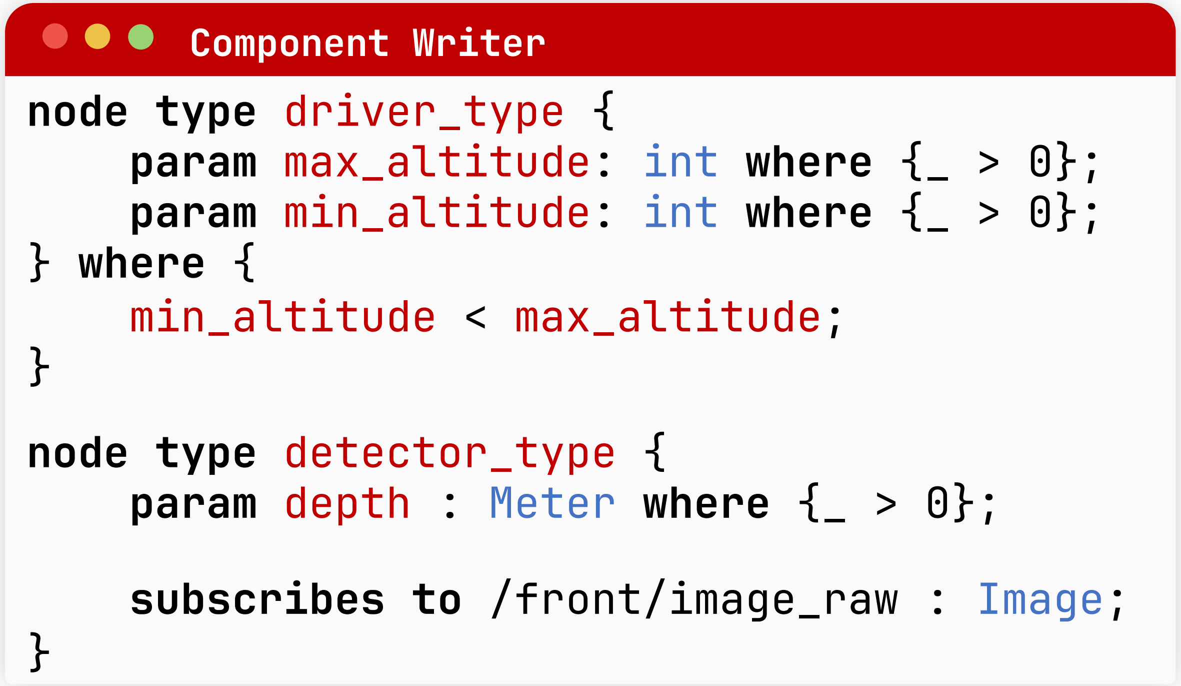

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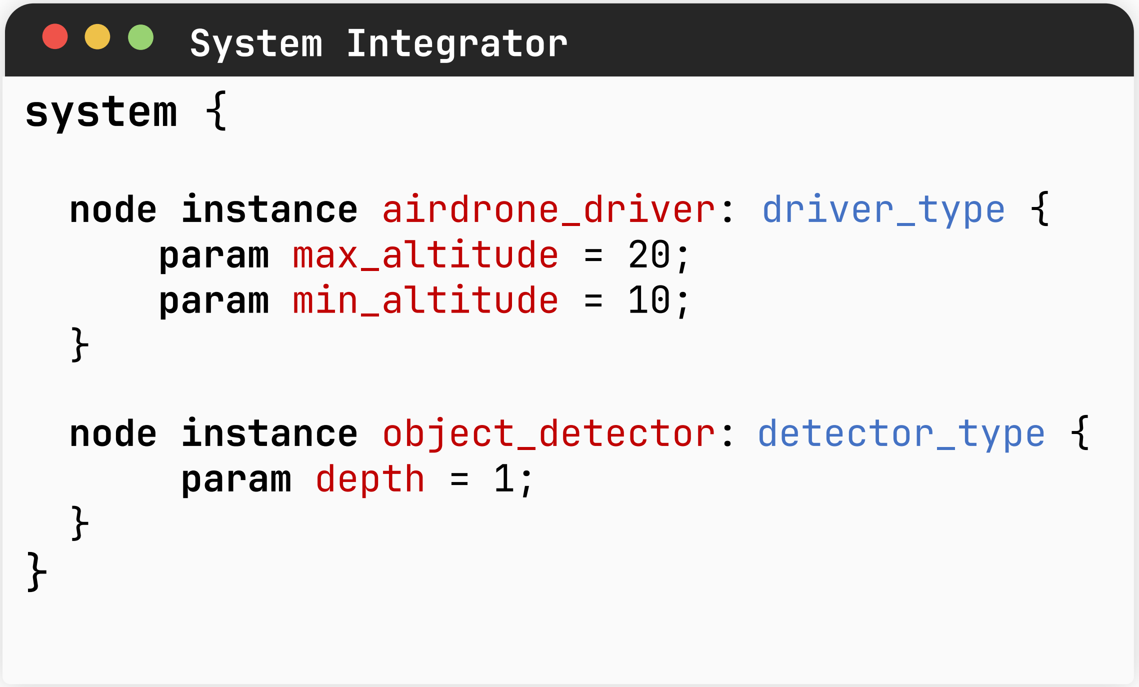

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  }
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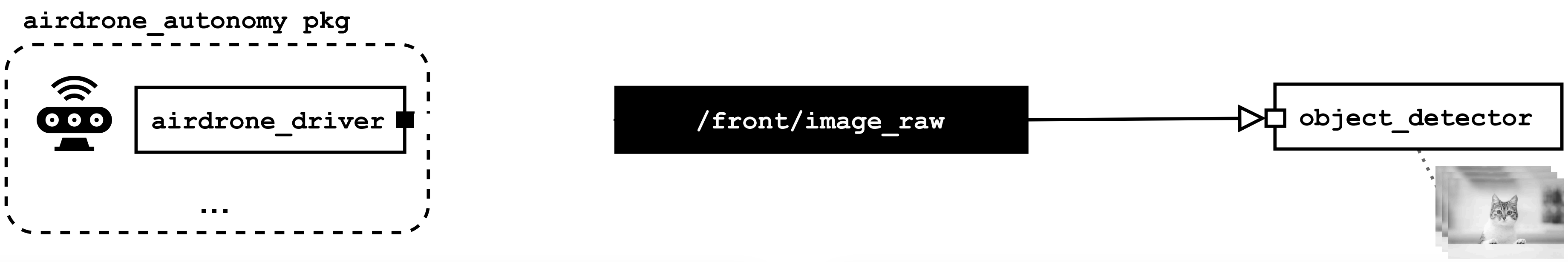

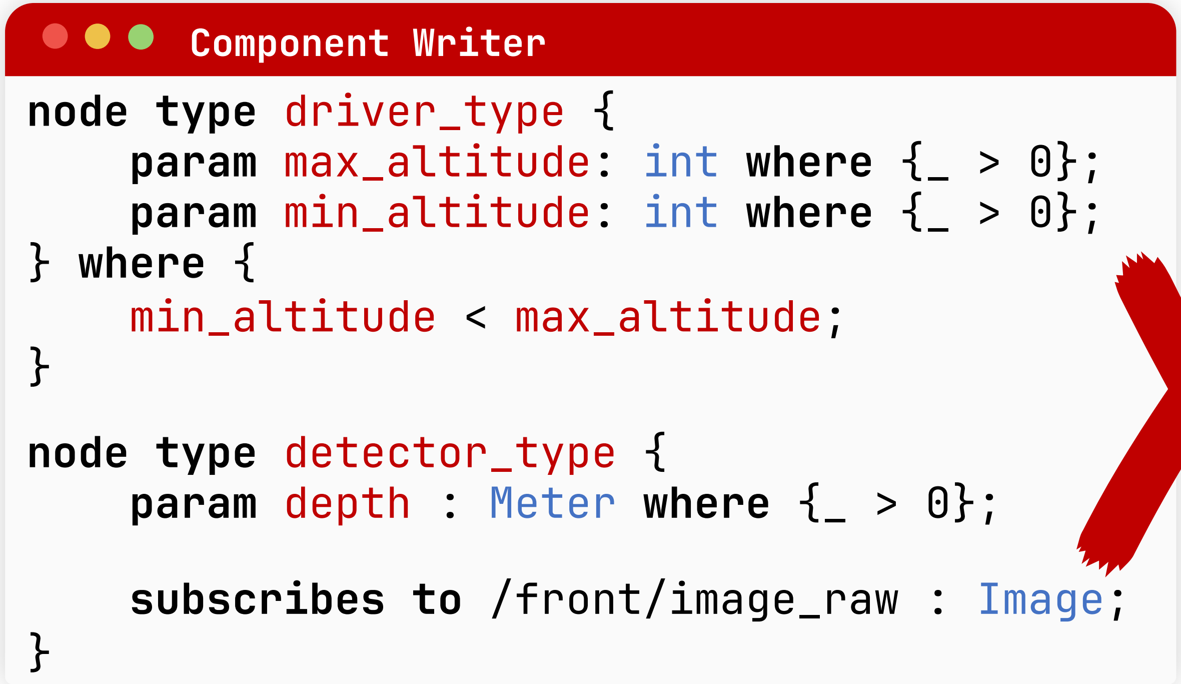

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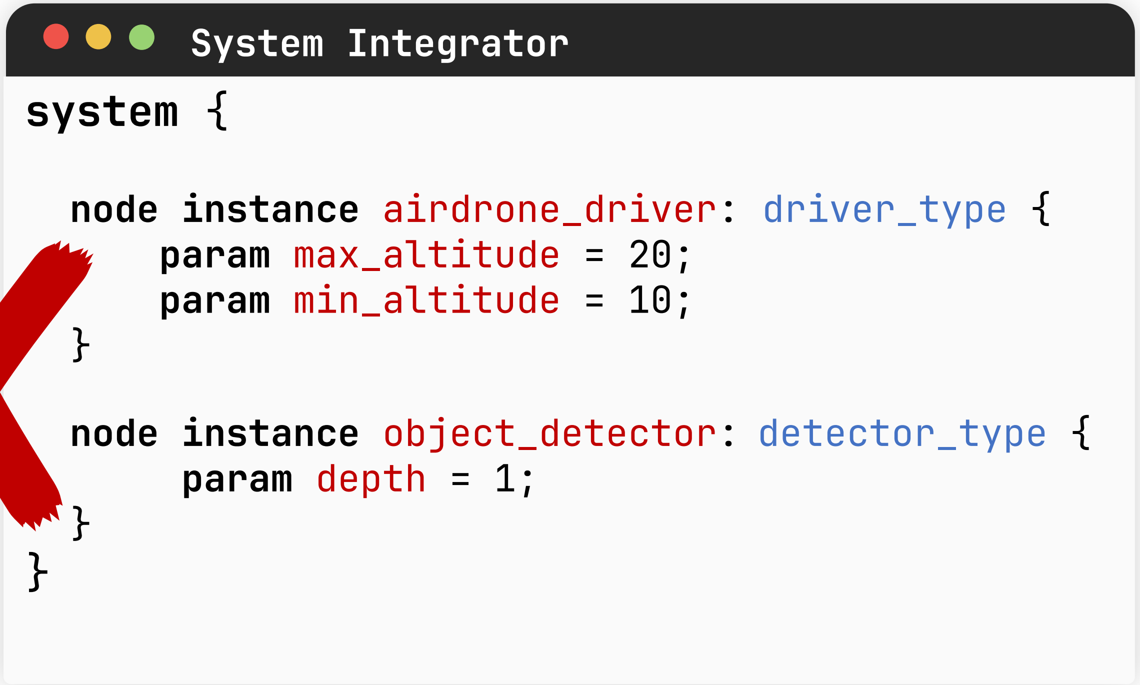

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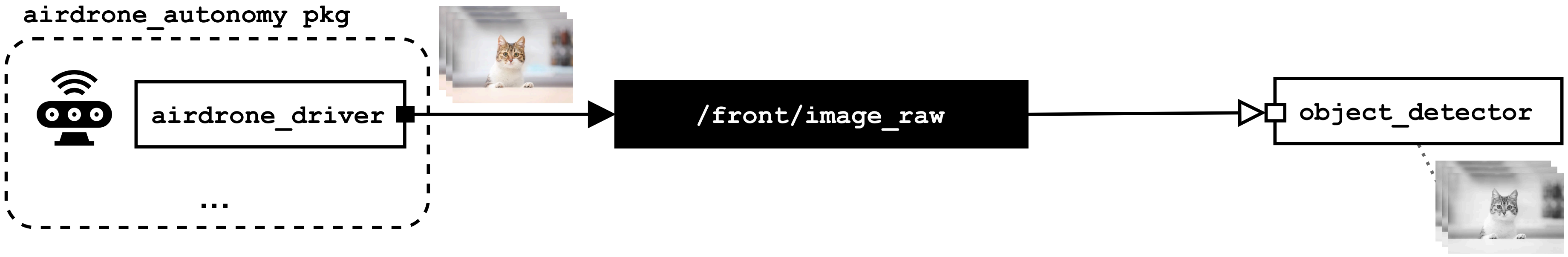

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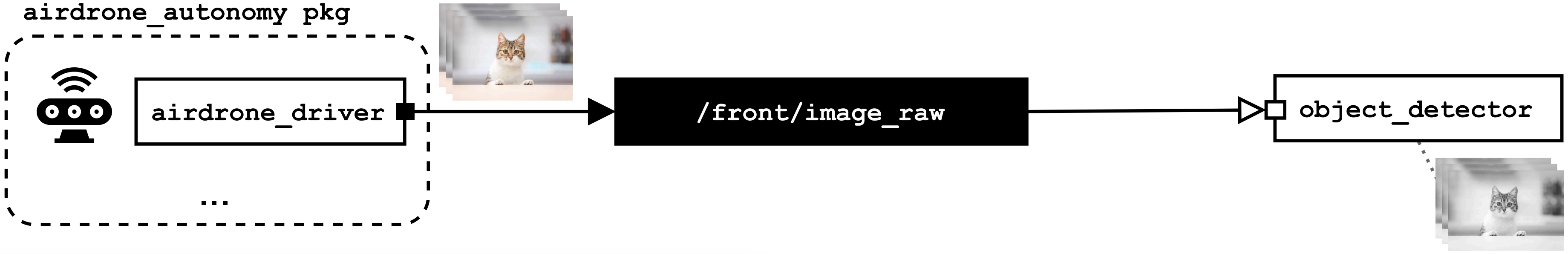

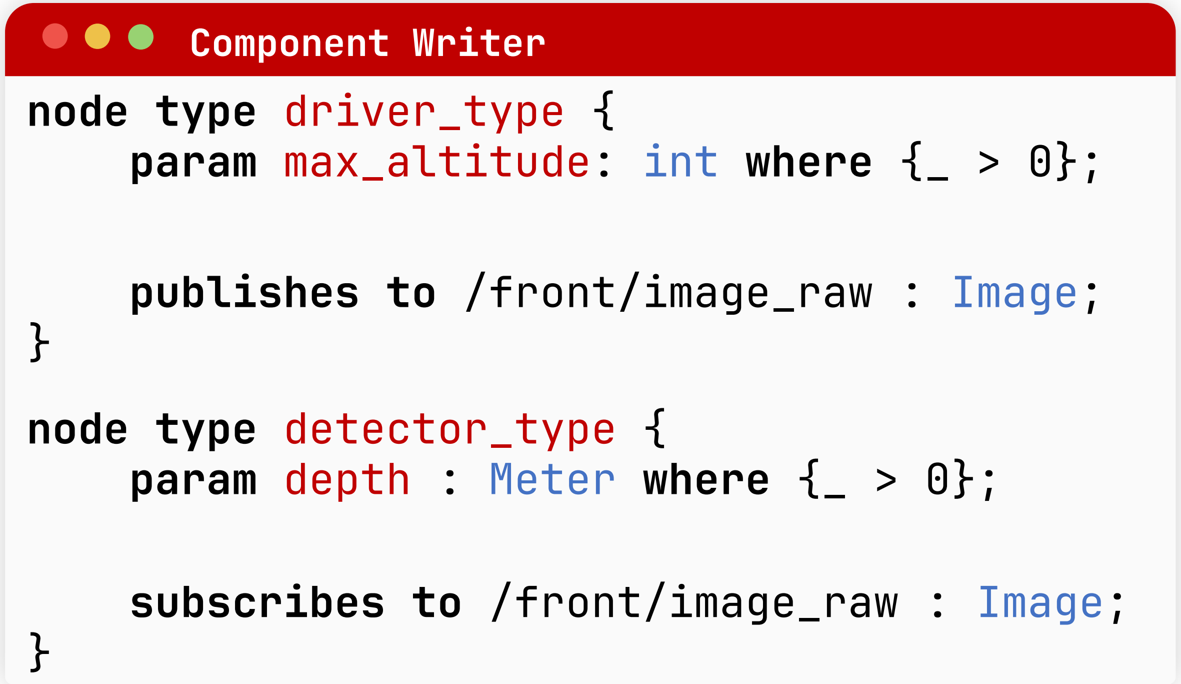

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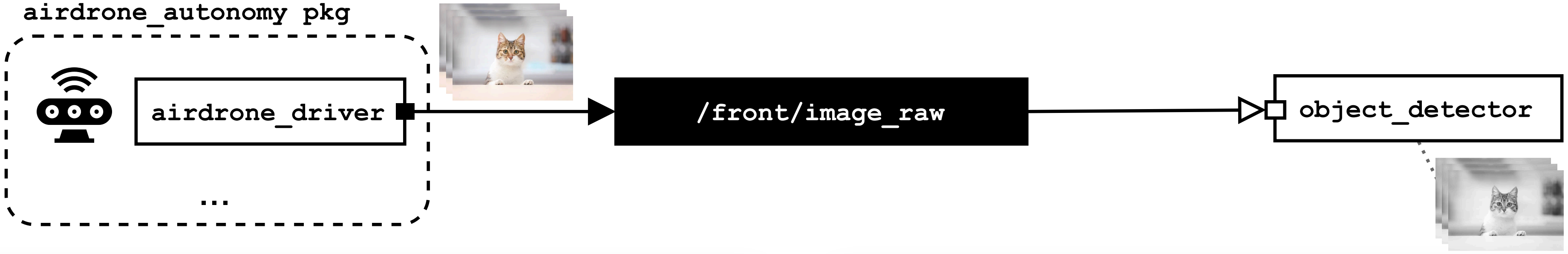

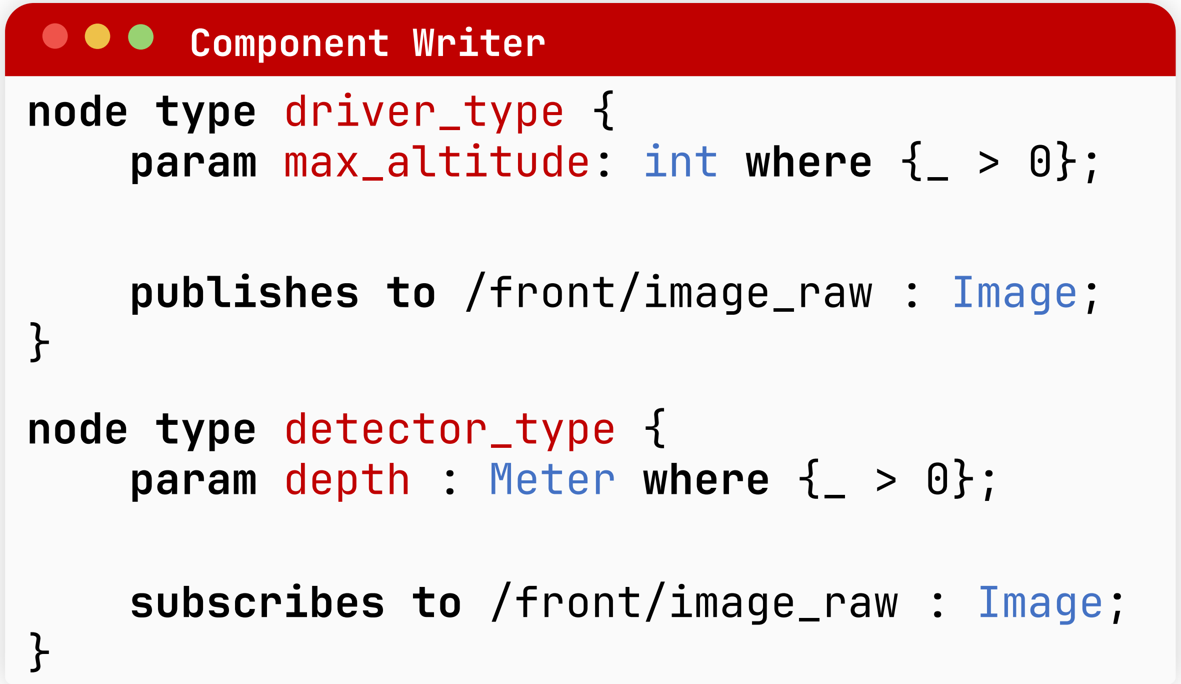

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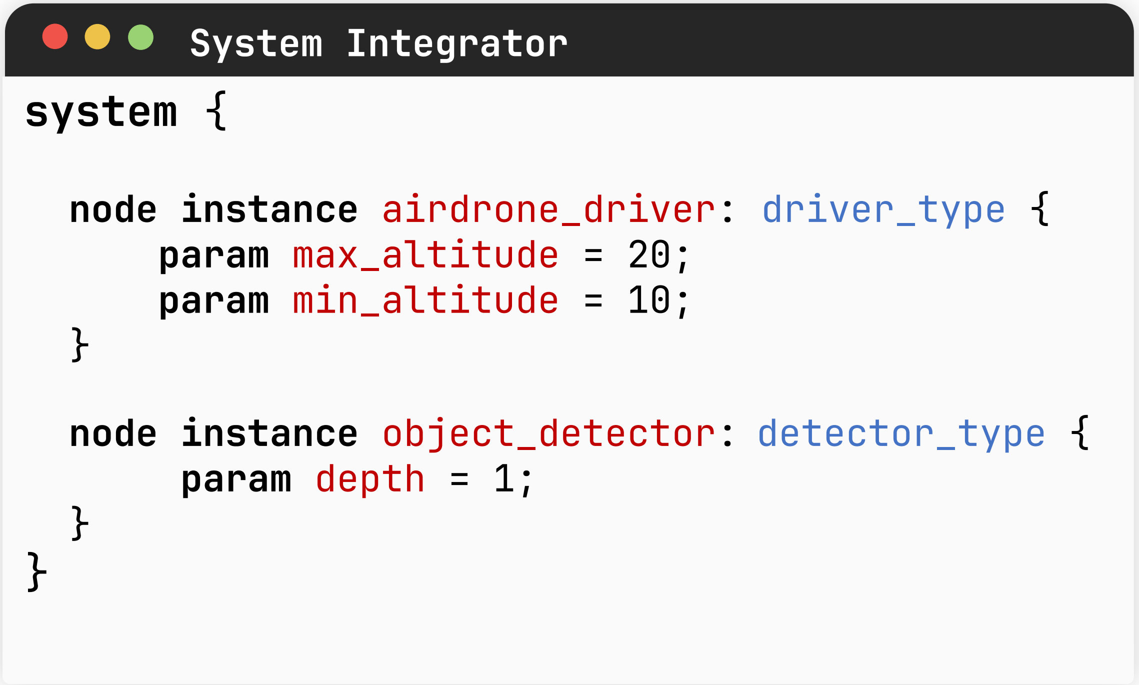

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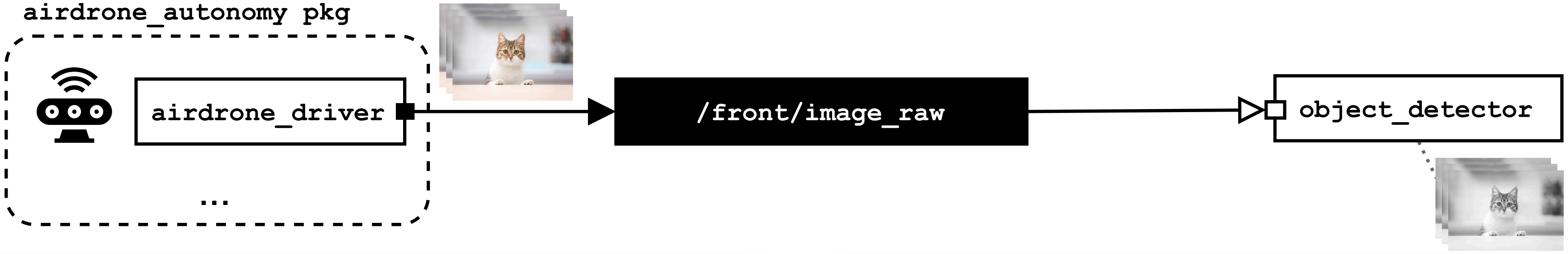

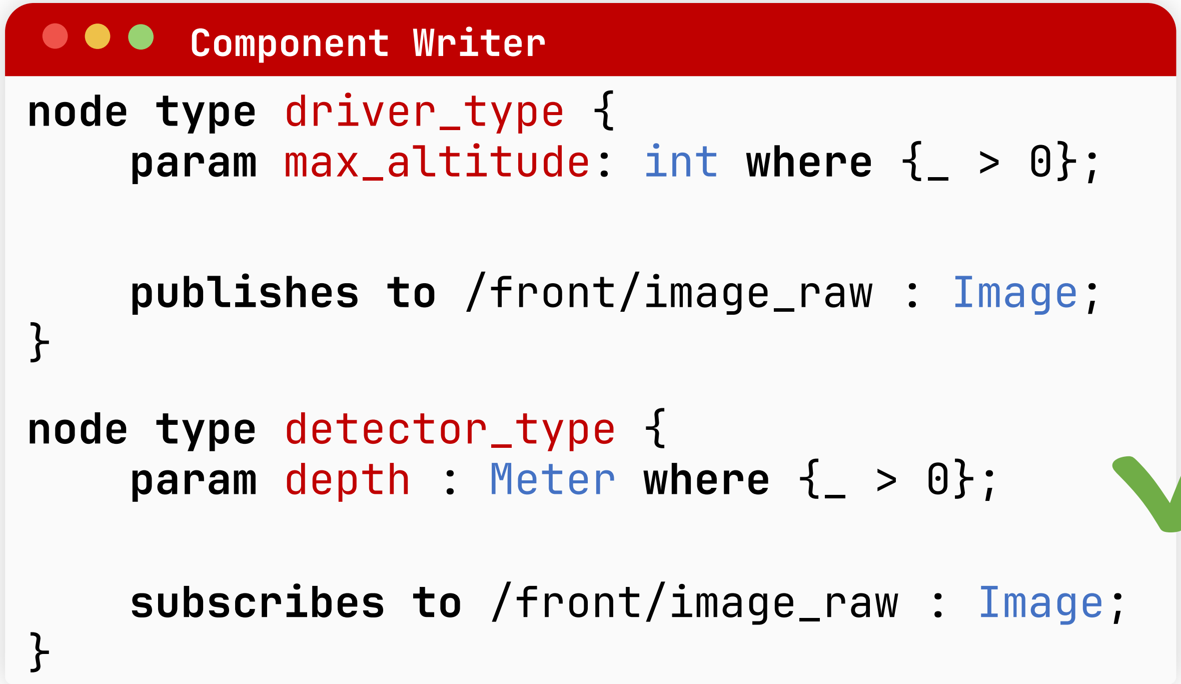

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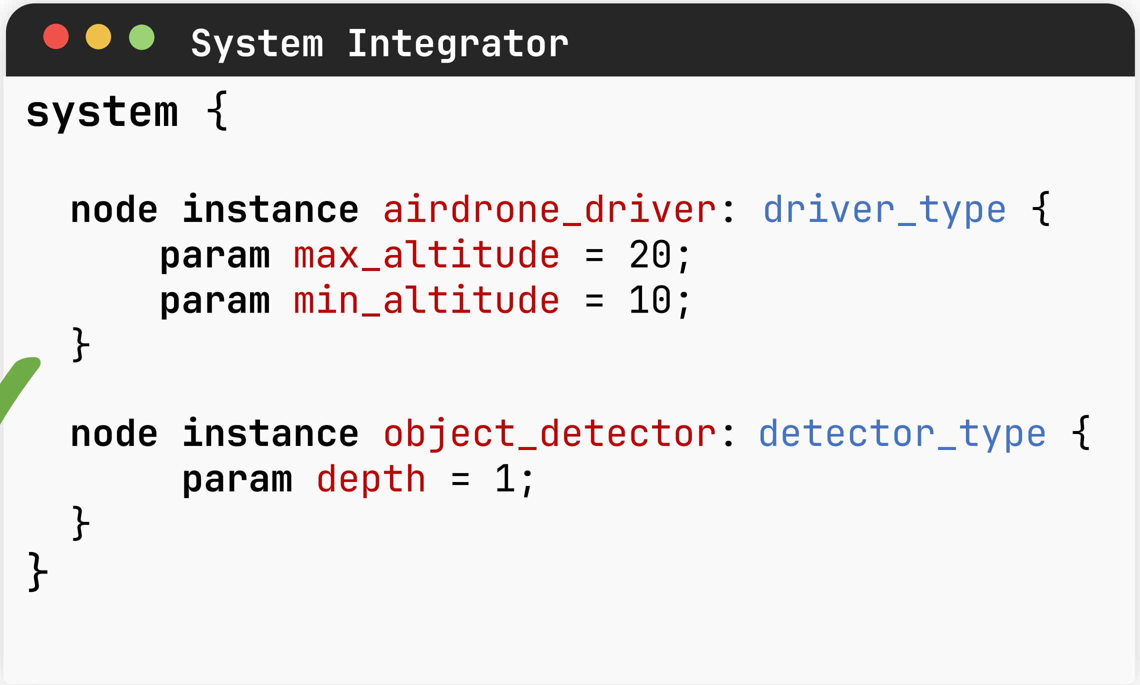

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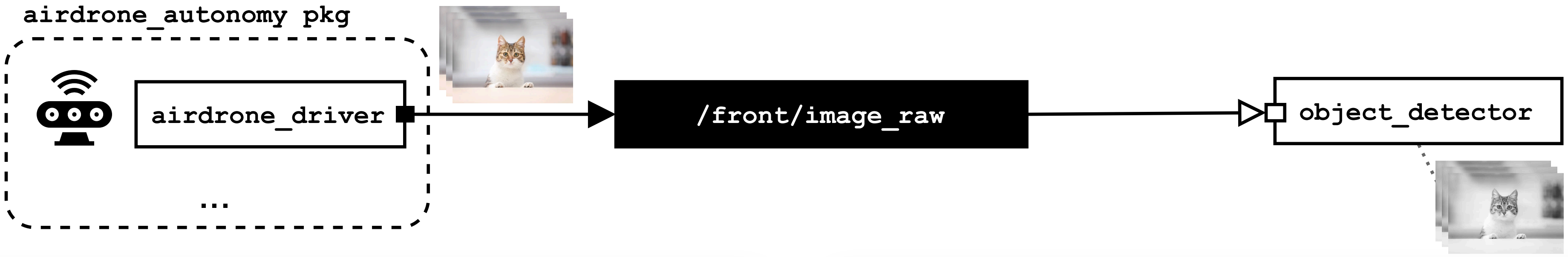

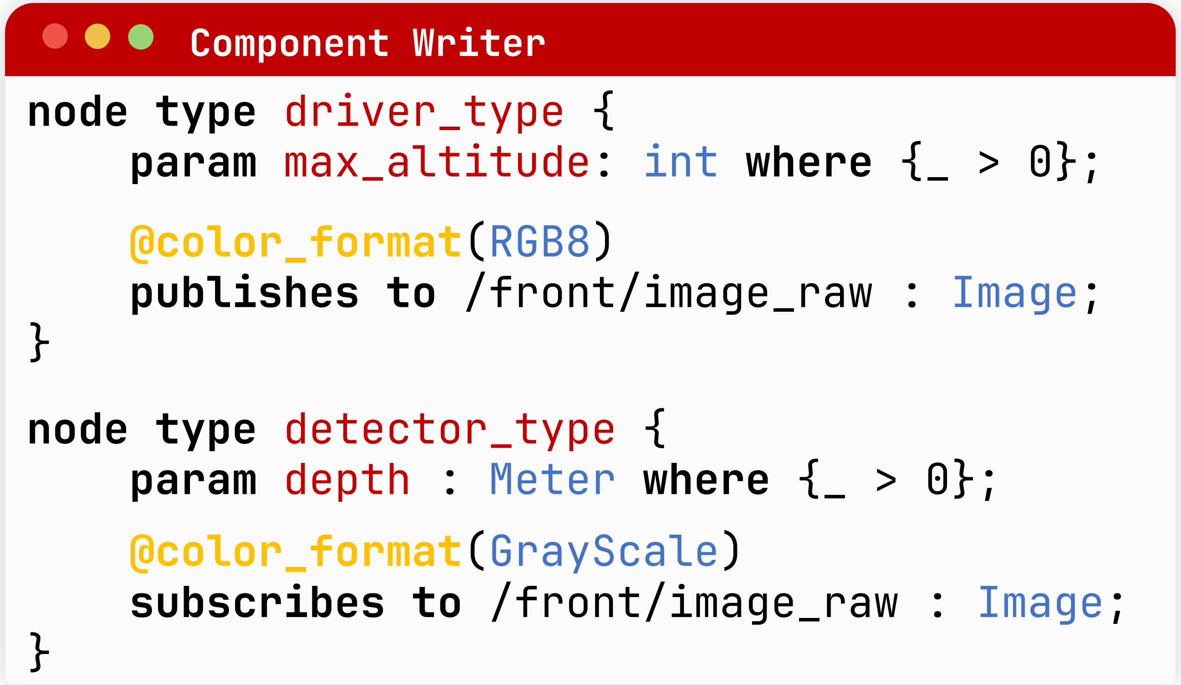

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    @color_format(RGB8)
    publishes to /front/image_raw : Image;
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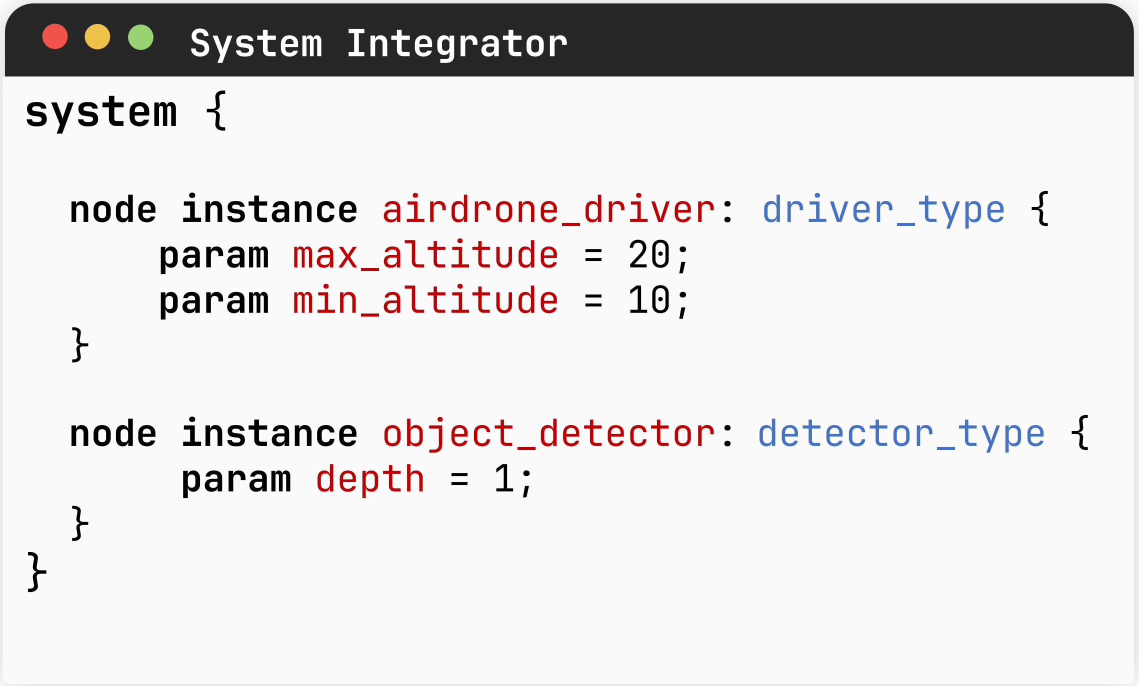

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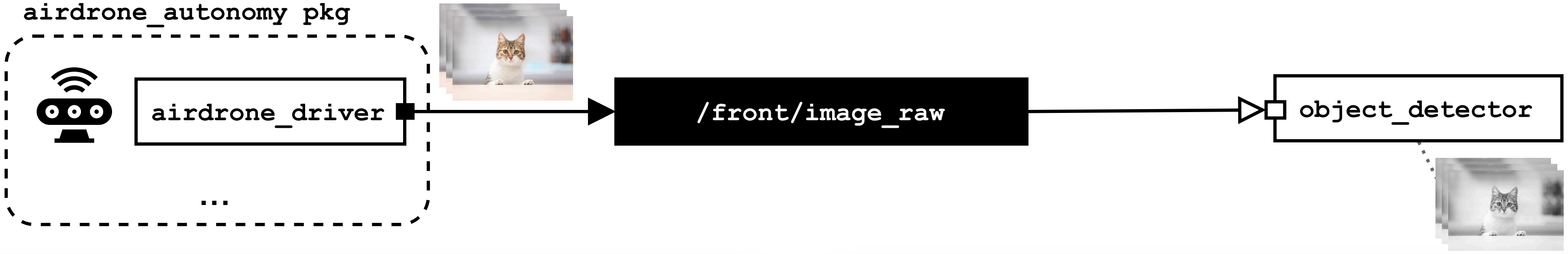

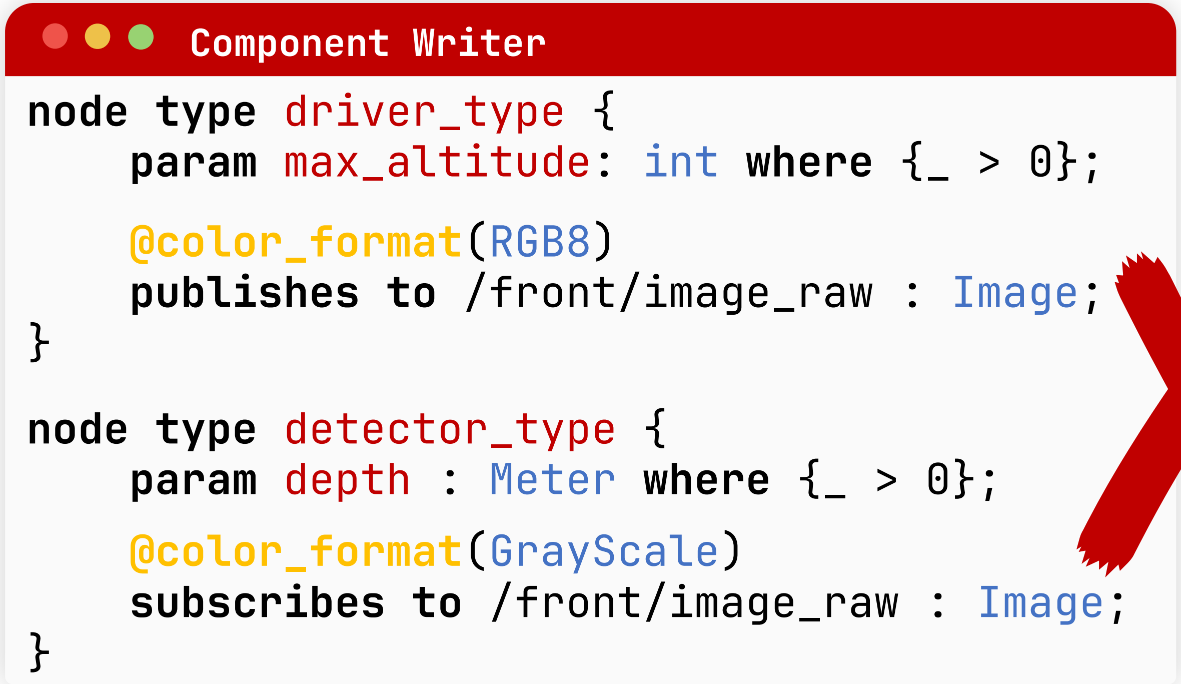

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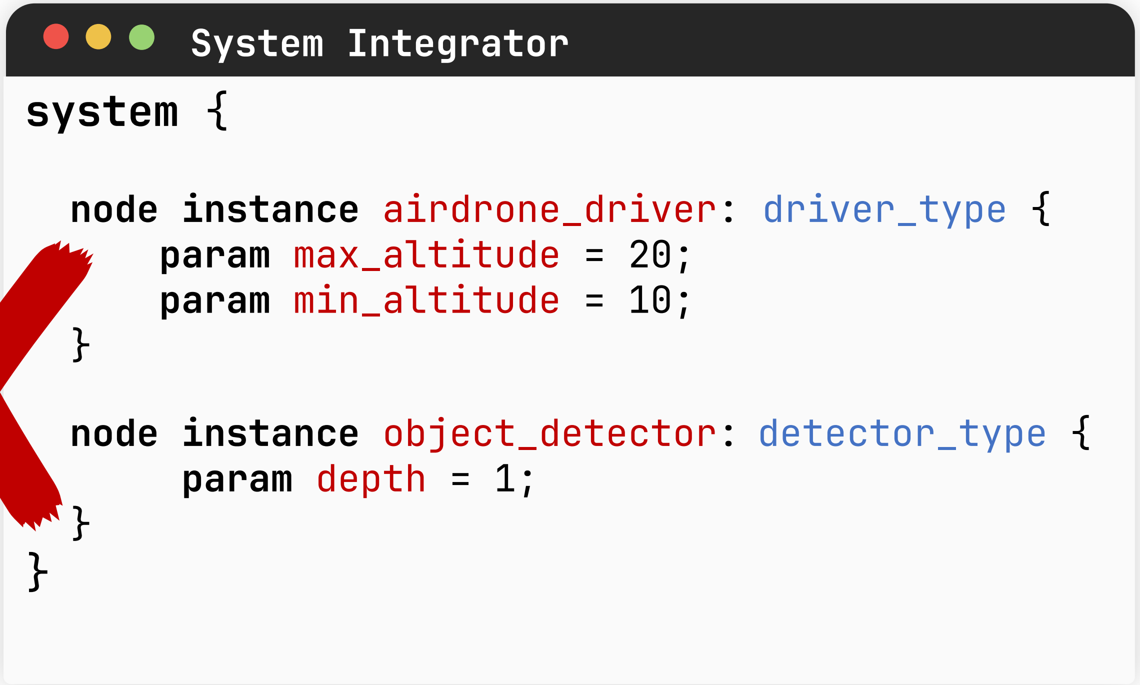

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On-going Work & Following Steps

D-NodeType

$$\frac{\begin{array}{c}\Gamma \vdash S_{p_1},\ \dots,\ S_{p_m} \dashv y_1 : T_1,\ \dots,\ y_m : T_m \quad \Gamma \vdash S_{c_1},\ \dots,\ S_{c_n} \dashv S'_{c_1},\ \dots,\ S'_{c_n} \\ \vdash U = \textbf{struct}\{\ y_1 : T_1,\ \dots,\ y_m : T_m\ \} : \text{NodeType}\end{array}}{\Gamma \vdash \textbf{node type}\ \ x\ \{\ \overline{S_p};\ \overline{S_c}\ \} \dashv \Gamma,\ x\ :\ U,\ x\ \mapsto [S'_{c_1},\ \dots,\ S'_{c_n}]}$$

D-NodeTypeWhere

$$\frac{\Gamma \vdash e : \texttt{bool} \qquad \Gamma \vdash \textbf{node type}\ \ x\ \{\ \overline{S_p};\ \overline{S_c}\ \} \qquad \Gamma \vdash x : T \quad \Gamma \vdash x \mapsto \overline{S'_c}}{\Gamma \vdash \textbf{node type}\ \ x\ \{\ \overline{S_p};\ \overline{S_c}\ \}\ \textbf{where}\ \{\ e\ \} \dashv \Gamma, x : T\ \textbf{where}\ \{\ e\ \},\ x\ \mapsto \overline{S'_c}}$$

D-NodeInstance

$$\frac{\begin{array}{c}\Gamma \vdash x_2 : T \quad \Gamma \vdash x_2 \mapsto \overline{S_{c_2}} \\ \Gamma \vdash \overline{S_p} \dashv \overline{y_p : T_p} \\ \text{We need to verify that T (which may contain dependent types) holds} \\ \Gamma \vdash \textbf{struct}\{\ \overline{y_p : T_p}\ \} <: T\end{array}}{\Gamma \vdash \textbf{node instance}\ \ x_1 : x_2\ \{\ \overline{S_p}\ \} \dashv \Gamma, x_2 : \textbf{struct}\{\ \overline{y_p : T_p}\ \},\ x_2 \mapsto \overline{S_{c_2}}}$$

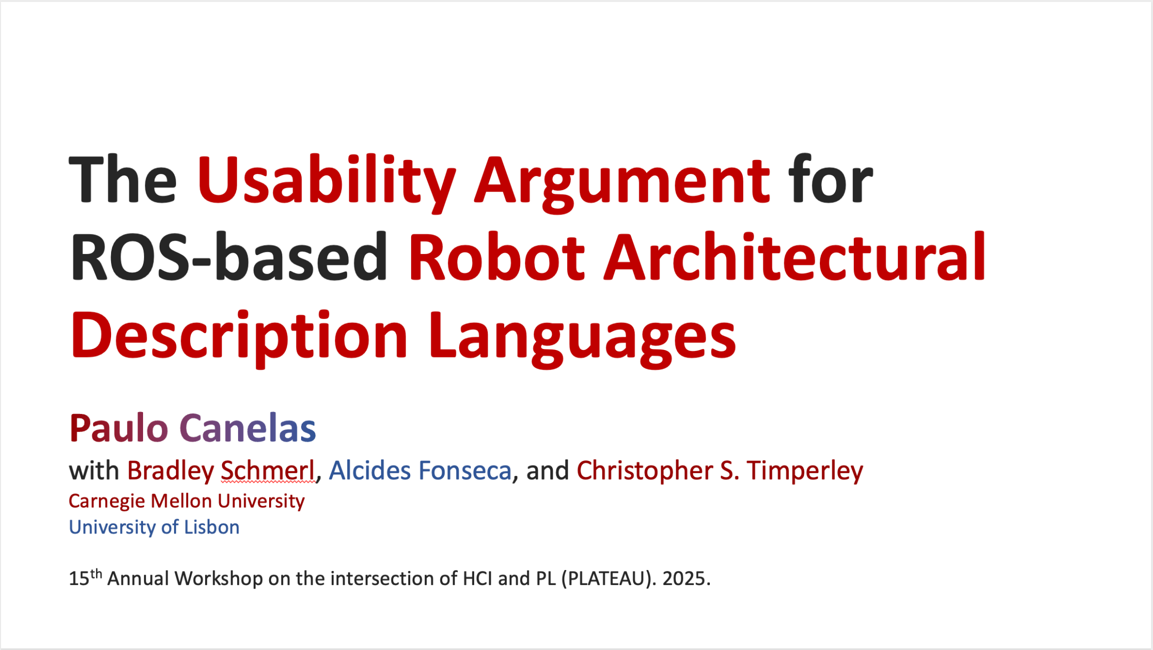
D-System

$$\frac{\Gamma \vdash \overline{D} \dashv \Gamma_2 \quad \text{Check the pub/subs}}{\Gamma \vdash \textbf{system}\ \{\ \overline{D}\ \}}$$

Formalization of the language

Case Study of a warehouse robotic system

Study the usability of ROS-based ADL



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Carnegie Mellon University
University of Lisbon

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*By **understanding misconfigurations** in Component-based Robot Software we can develop **usable domain-specific languages** to **specify components** and **detect misconfigurations** prior to the systems execution*