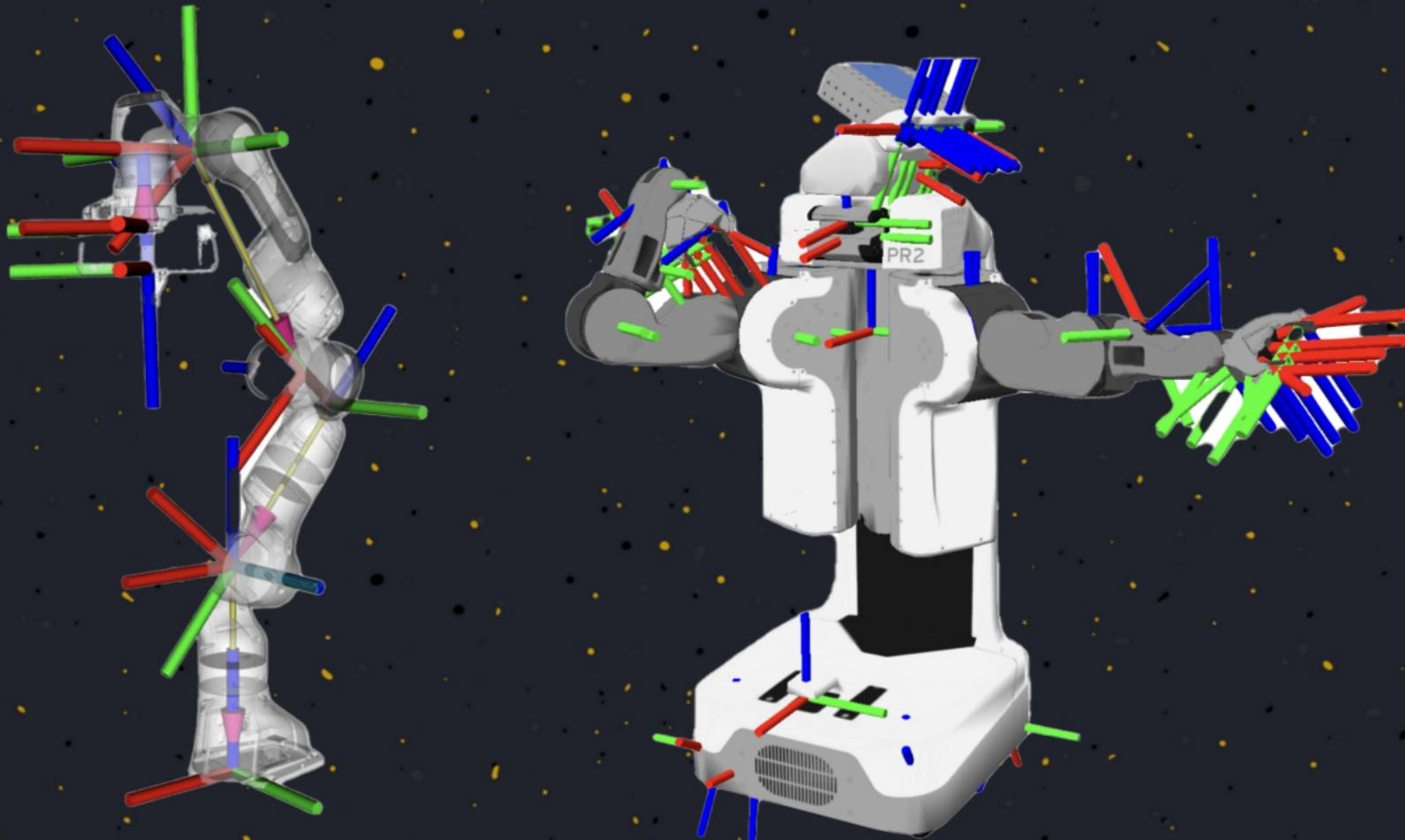
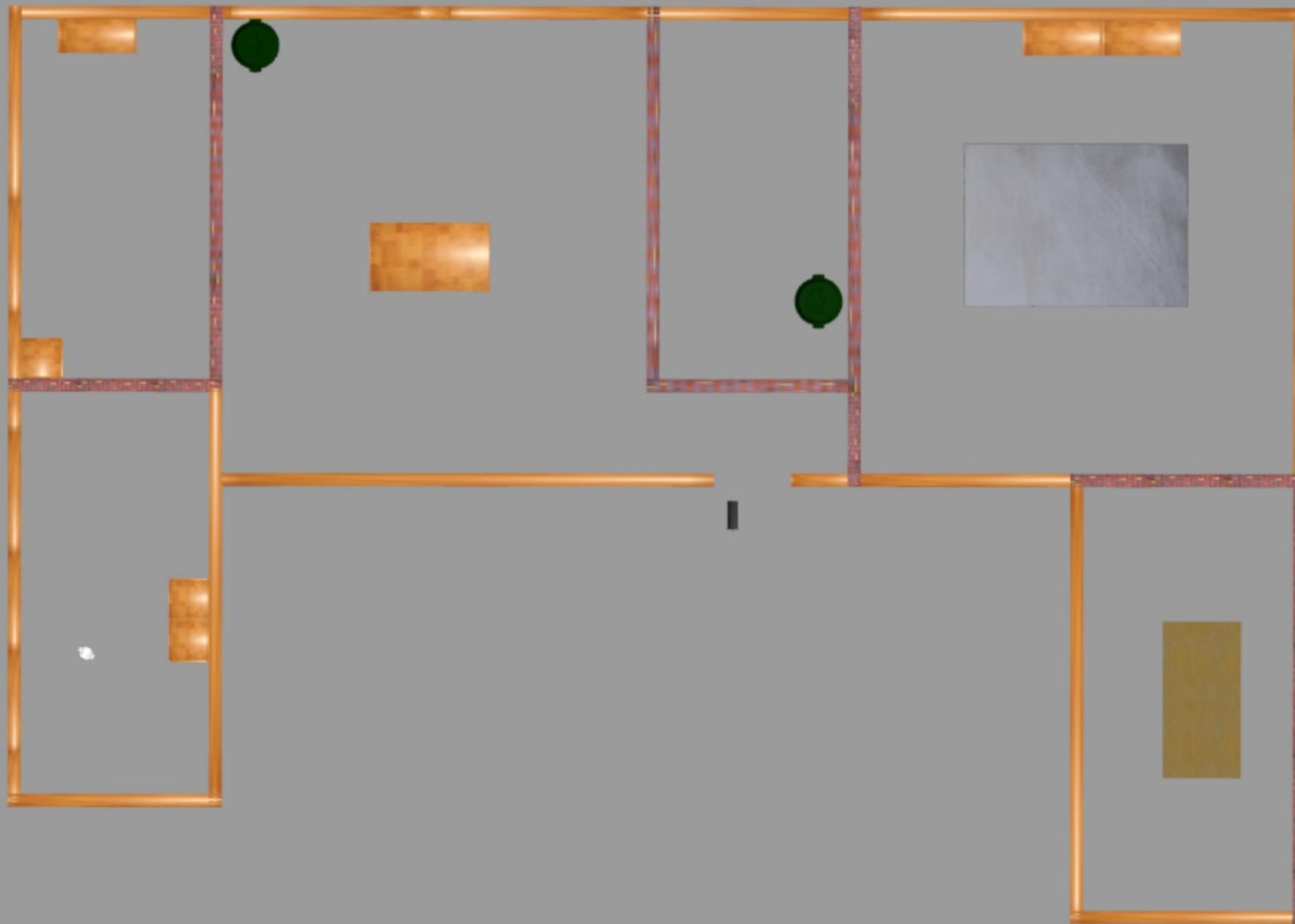
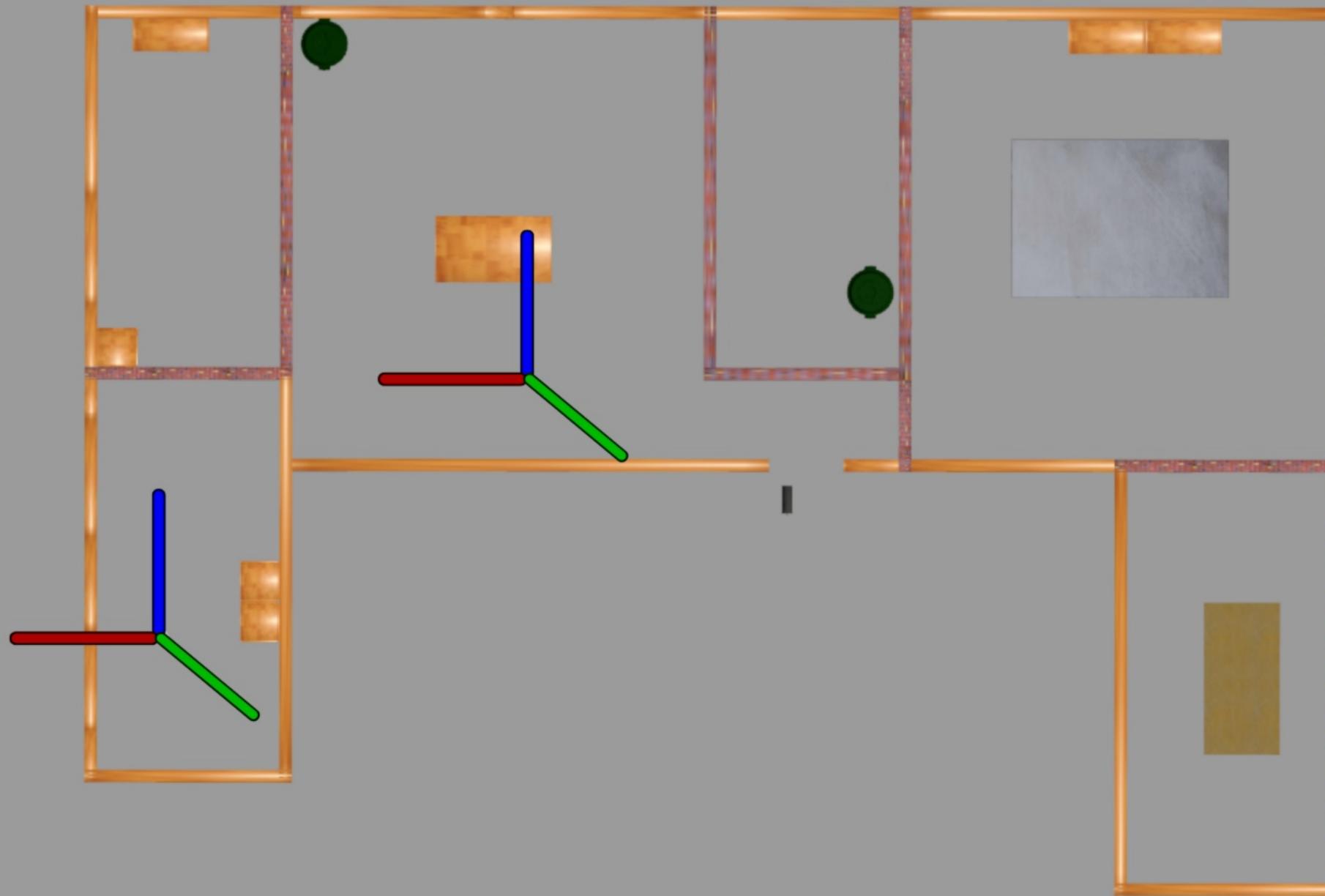
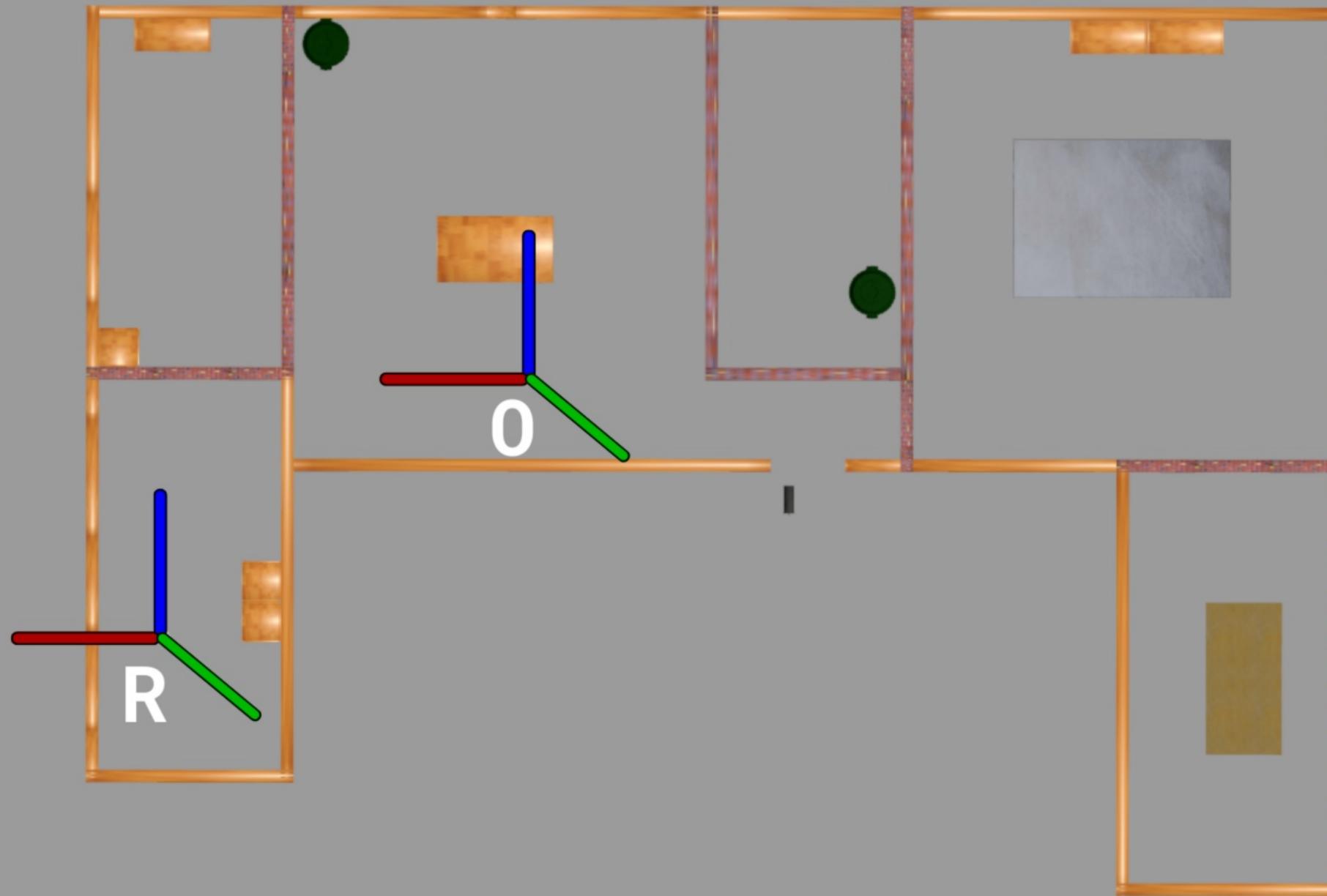


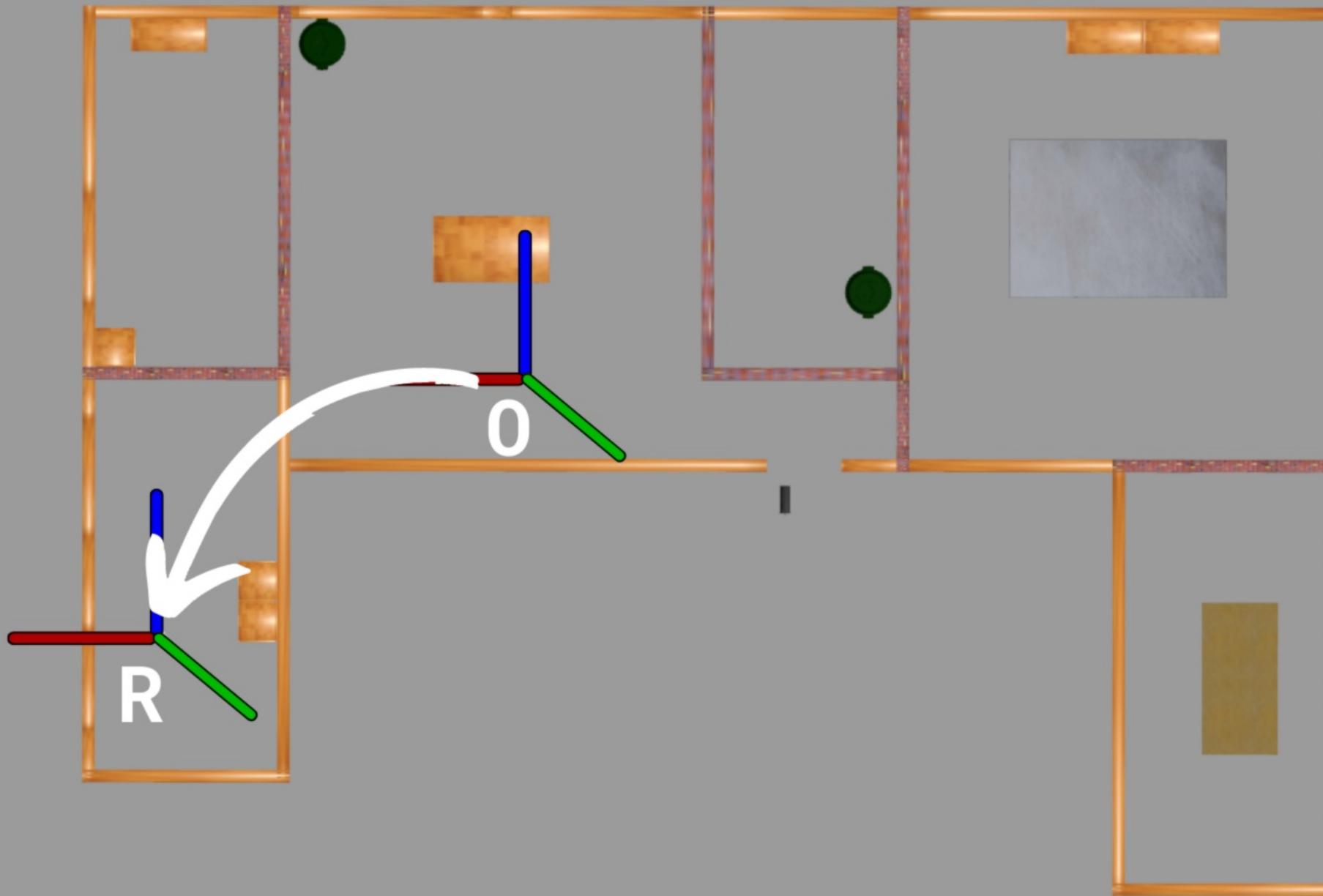
TF2 Library

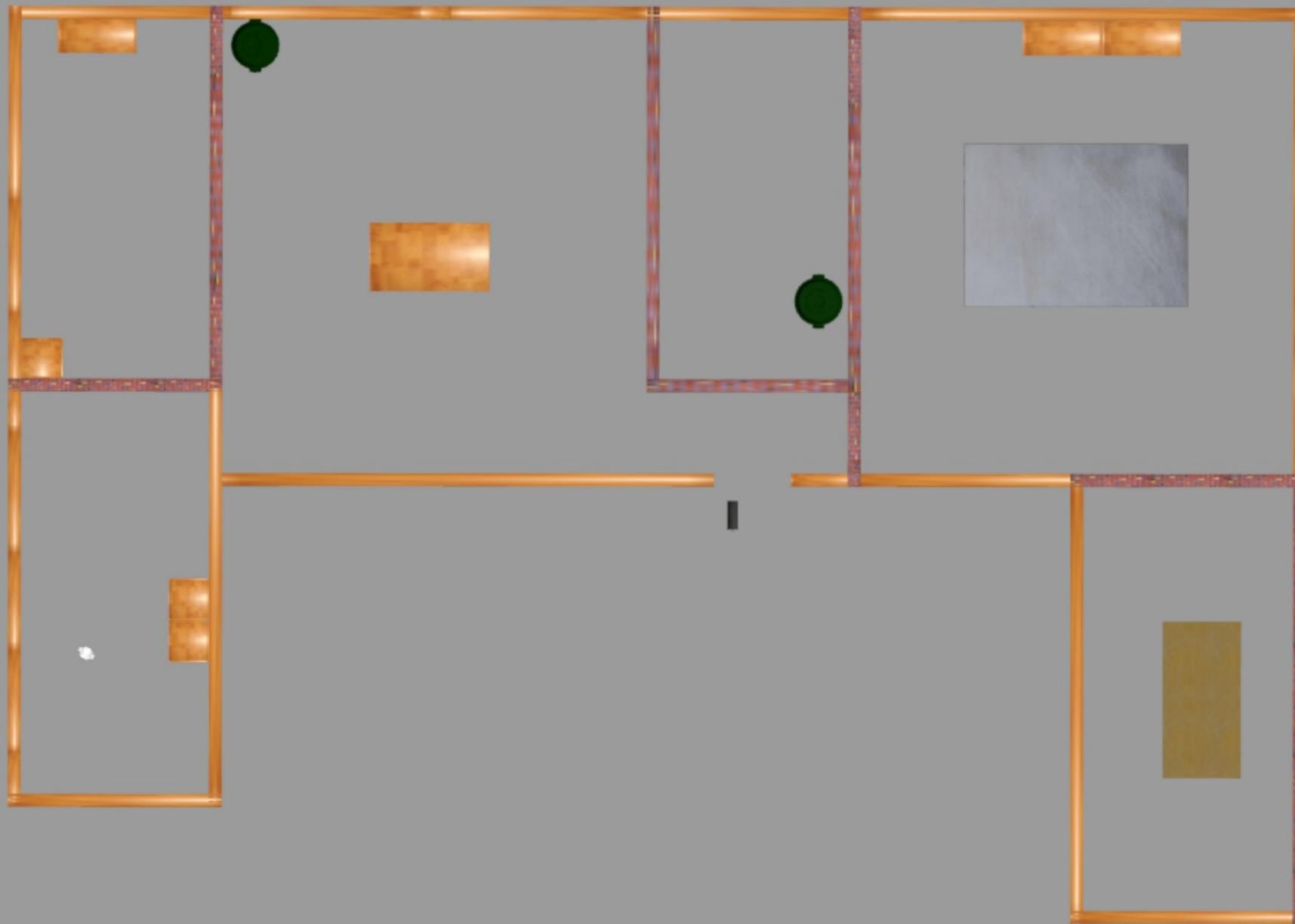


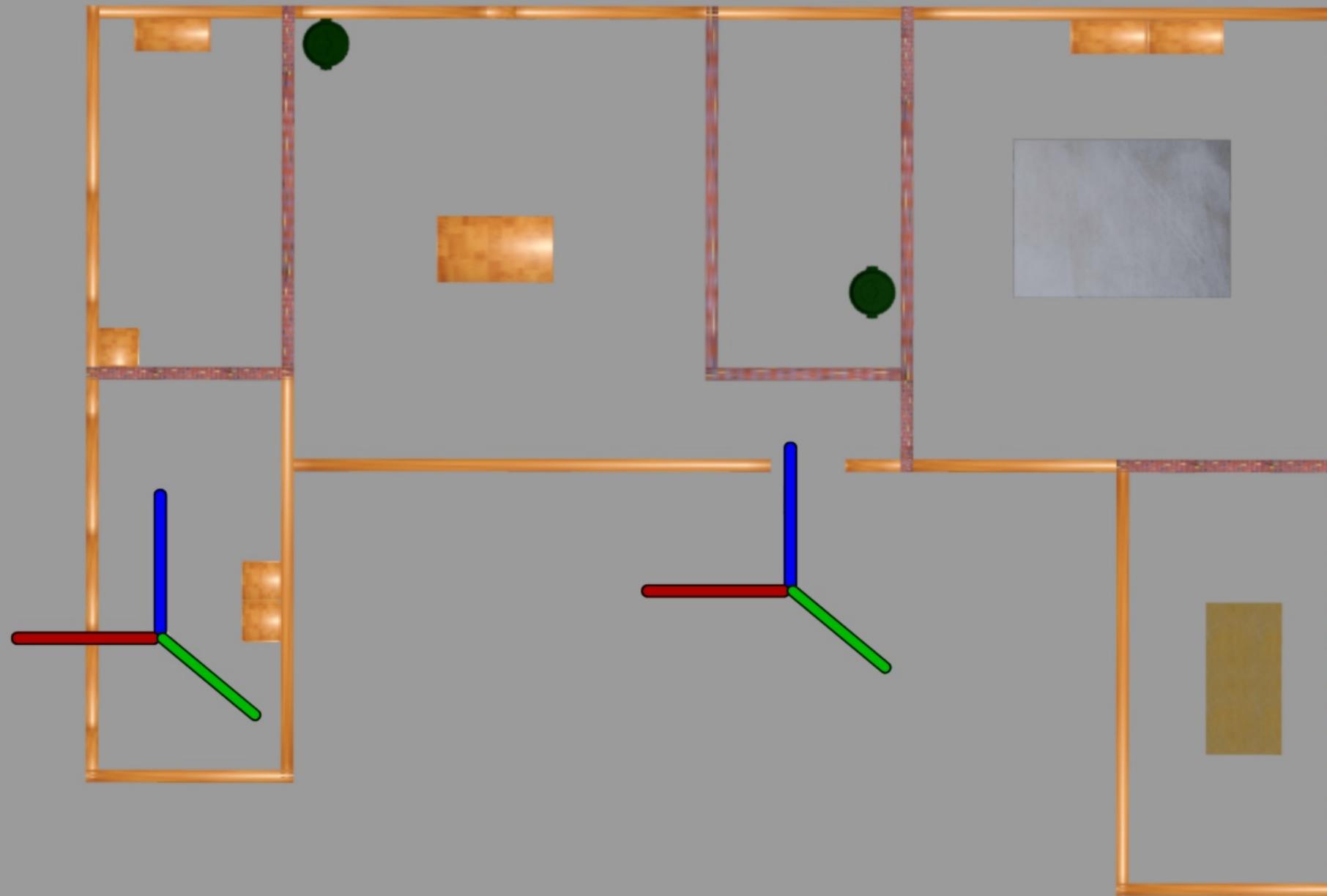


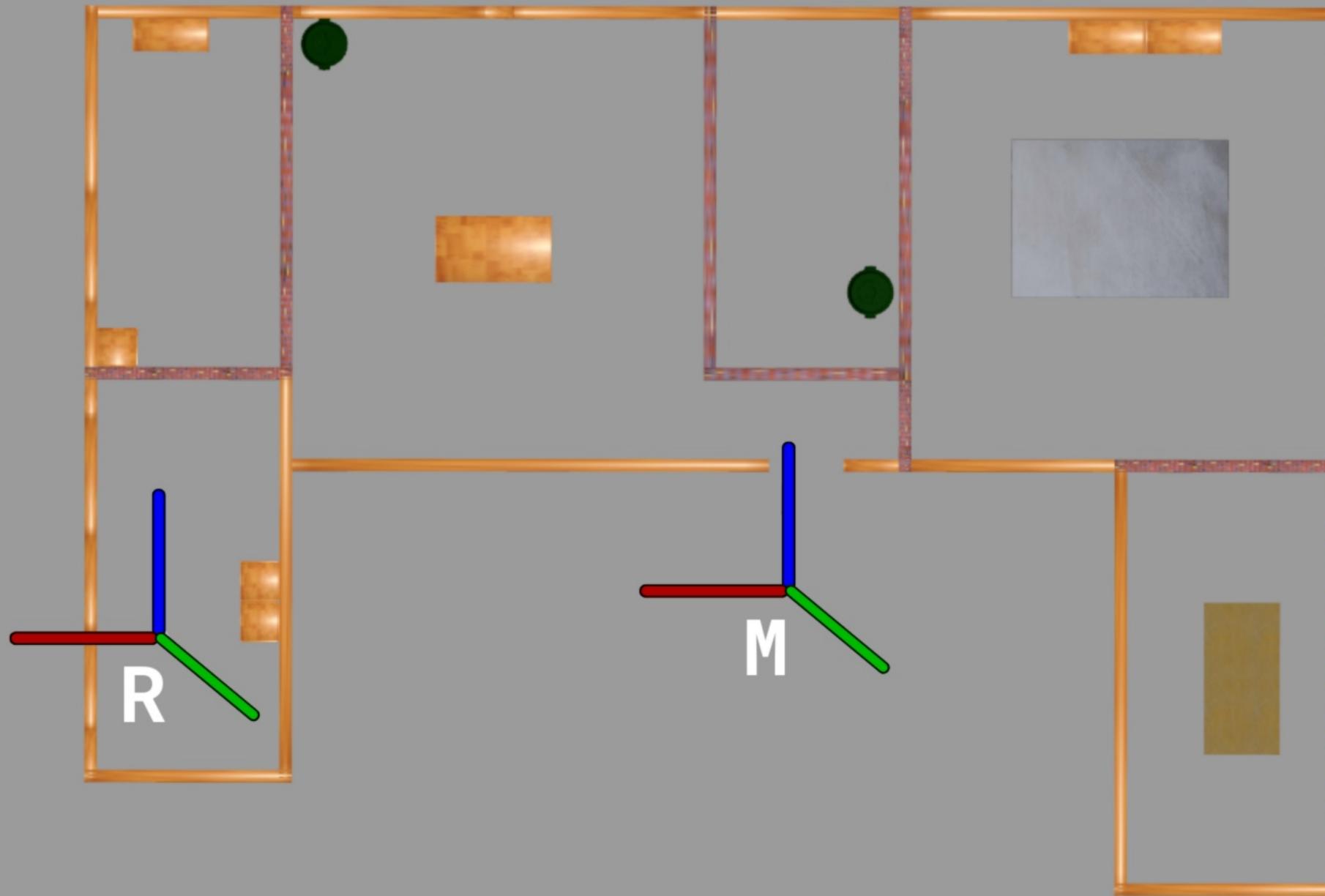


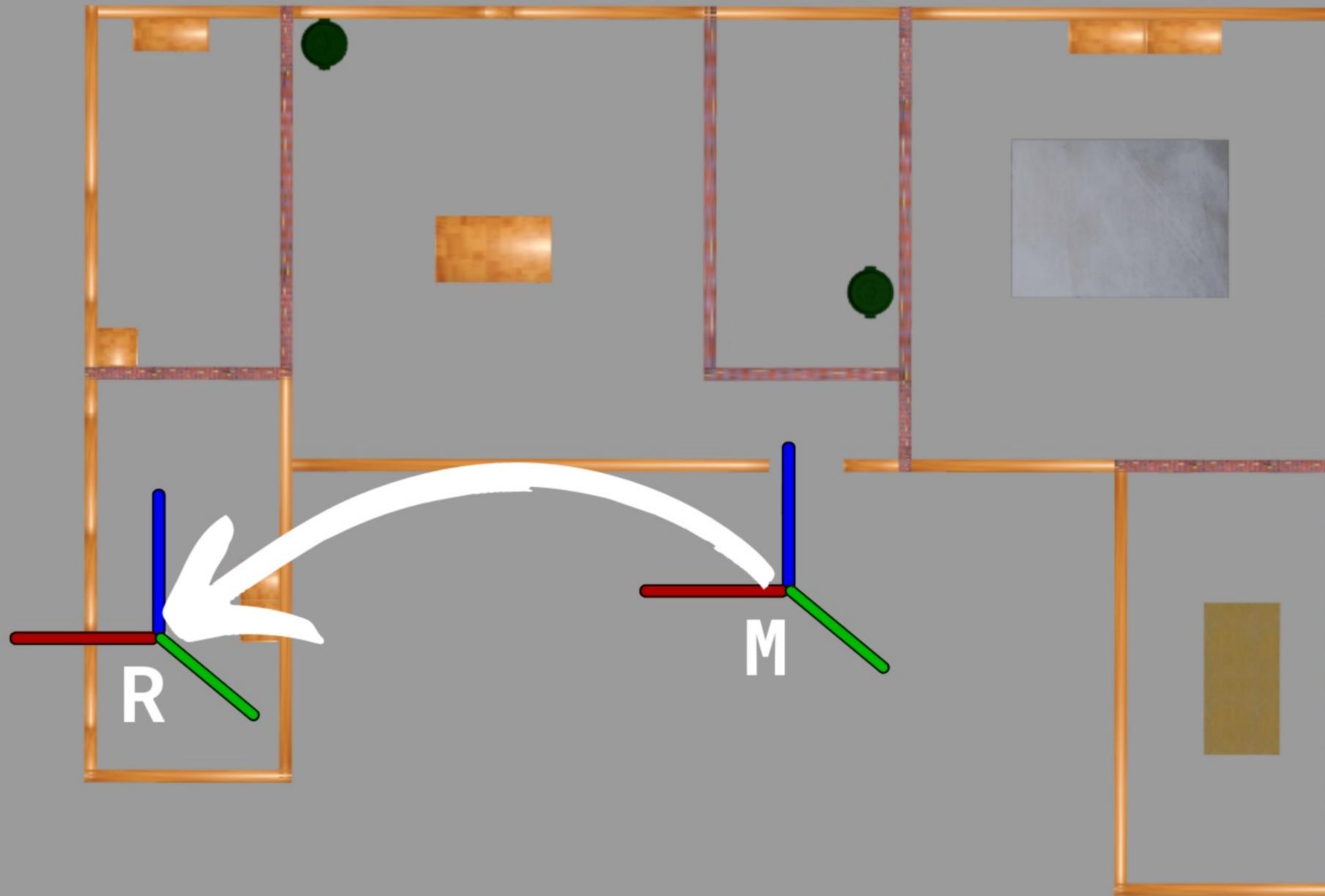


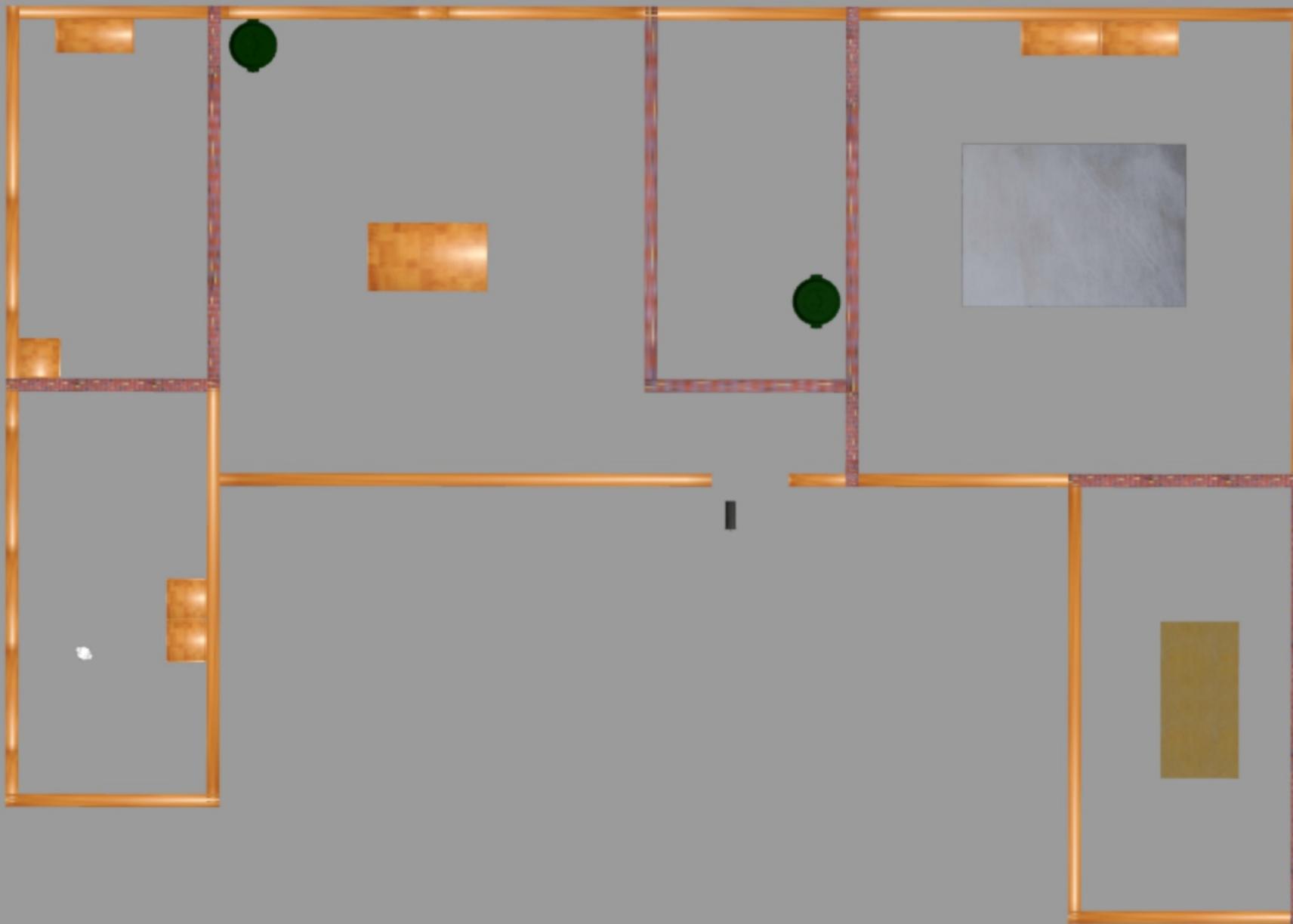


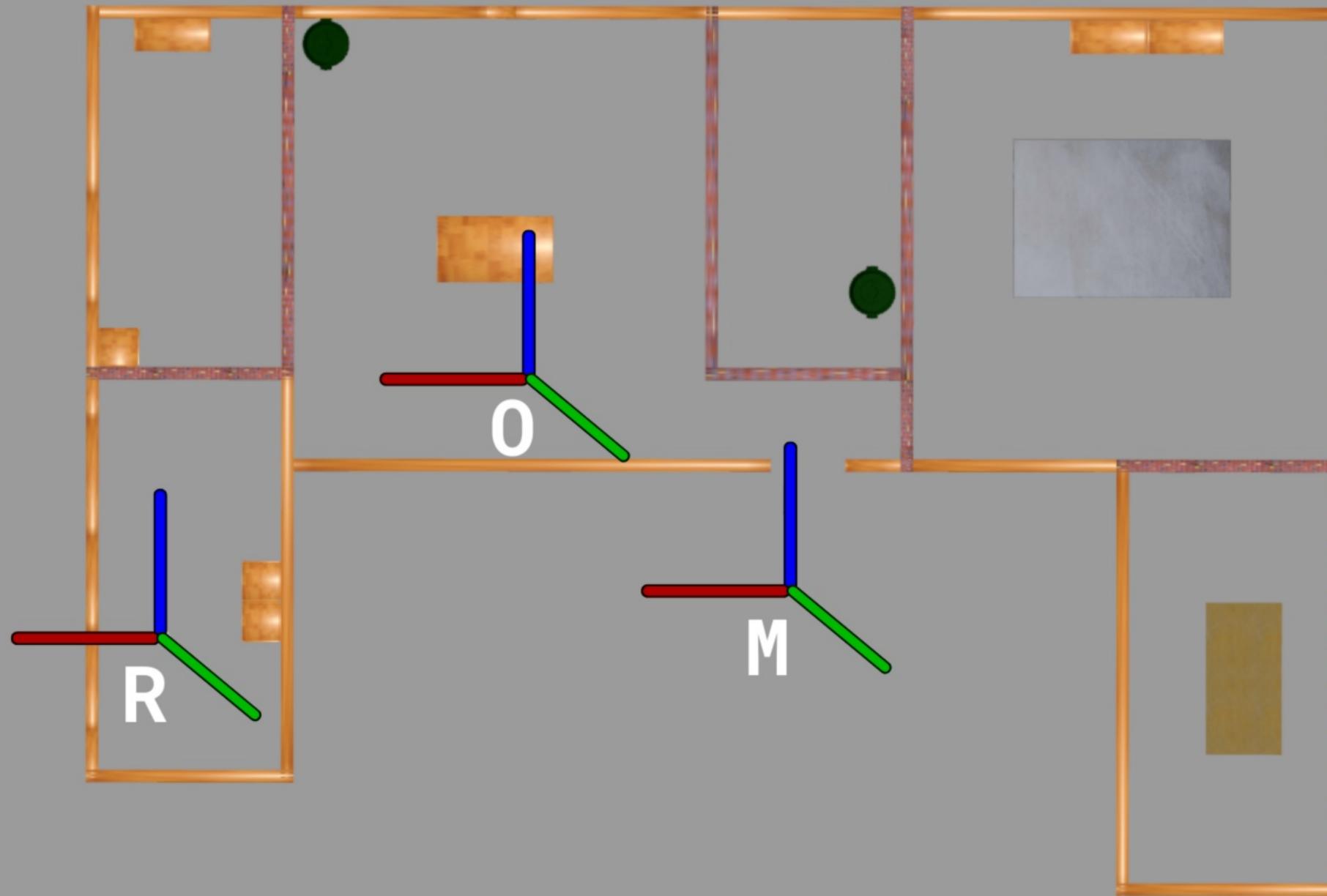


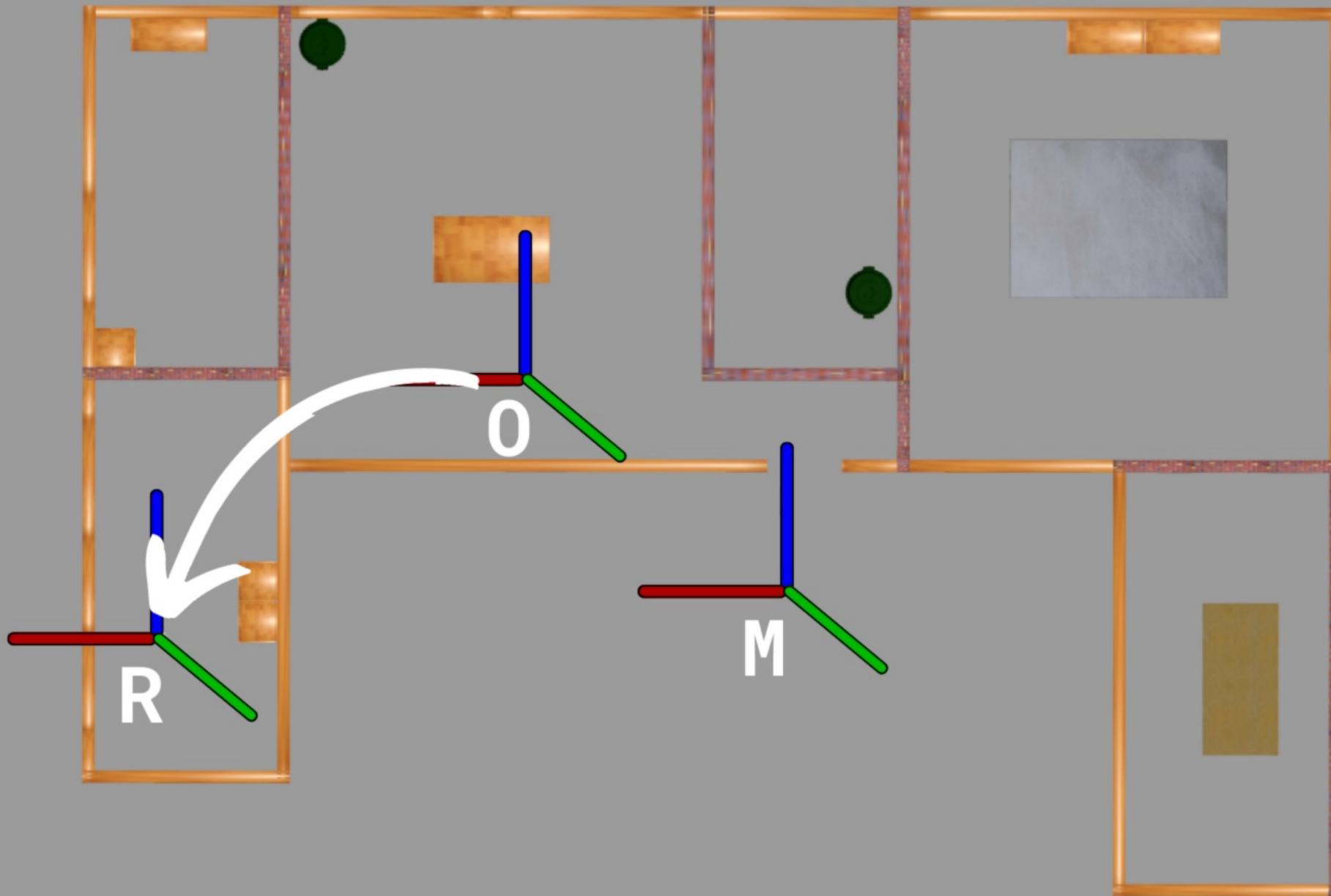


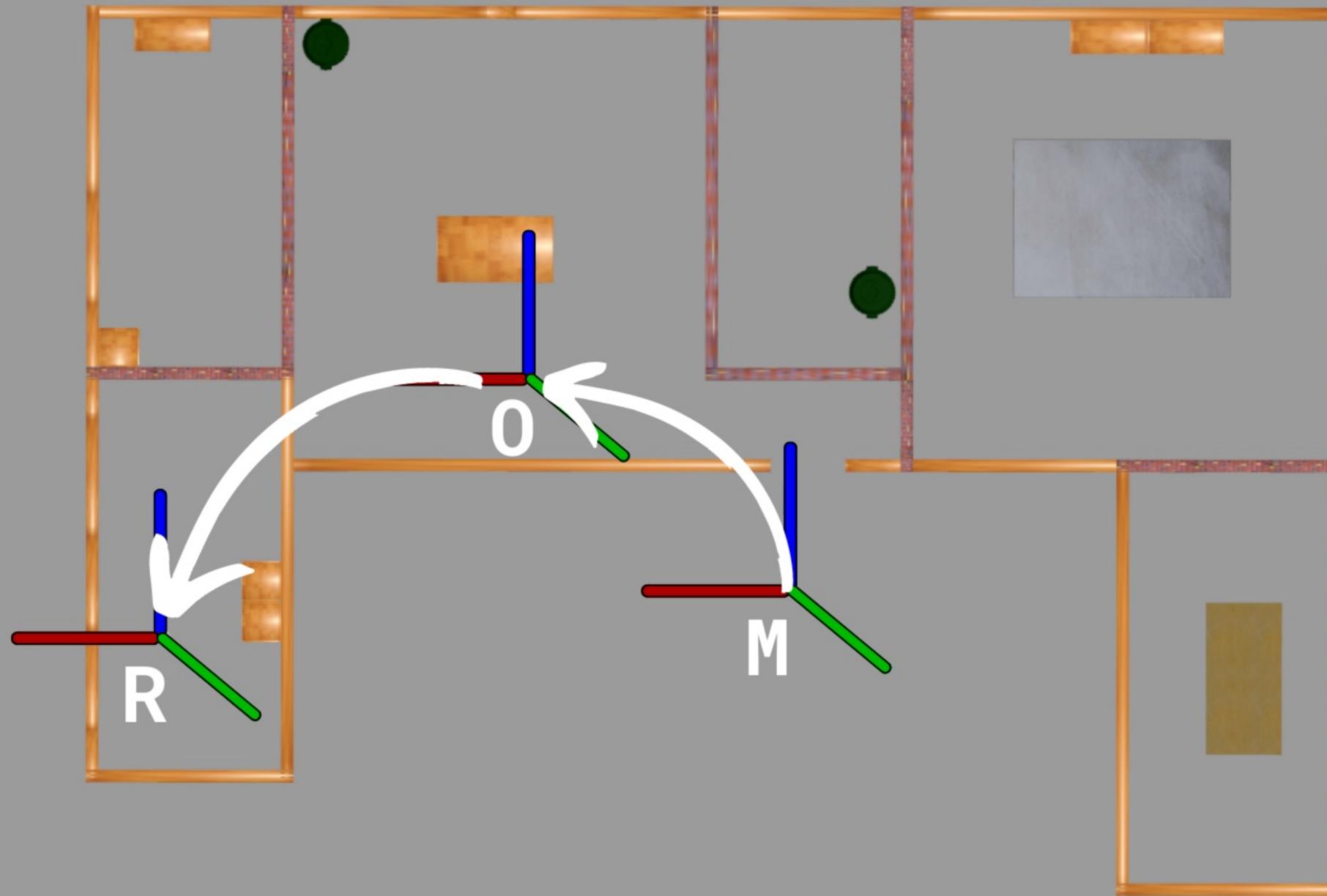




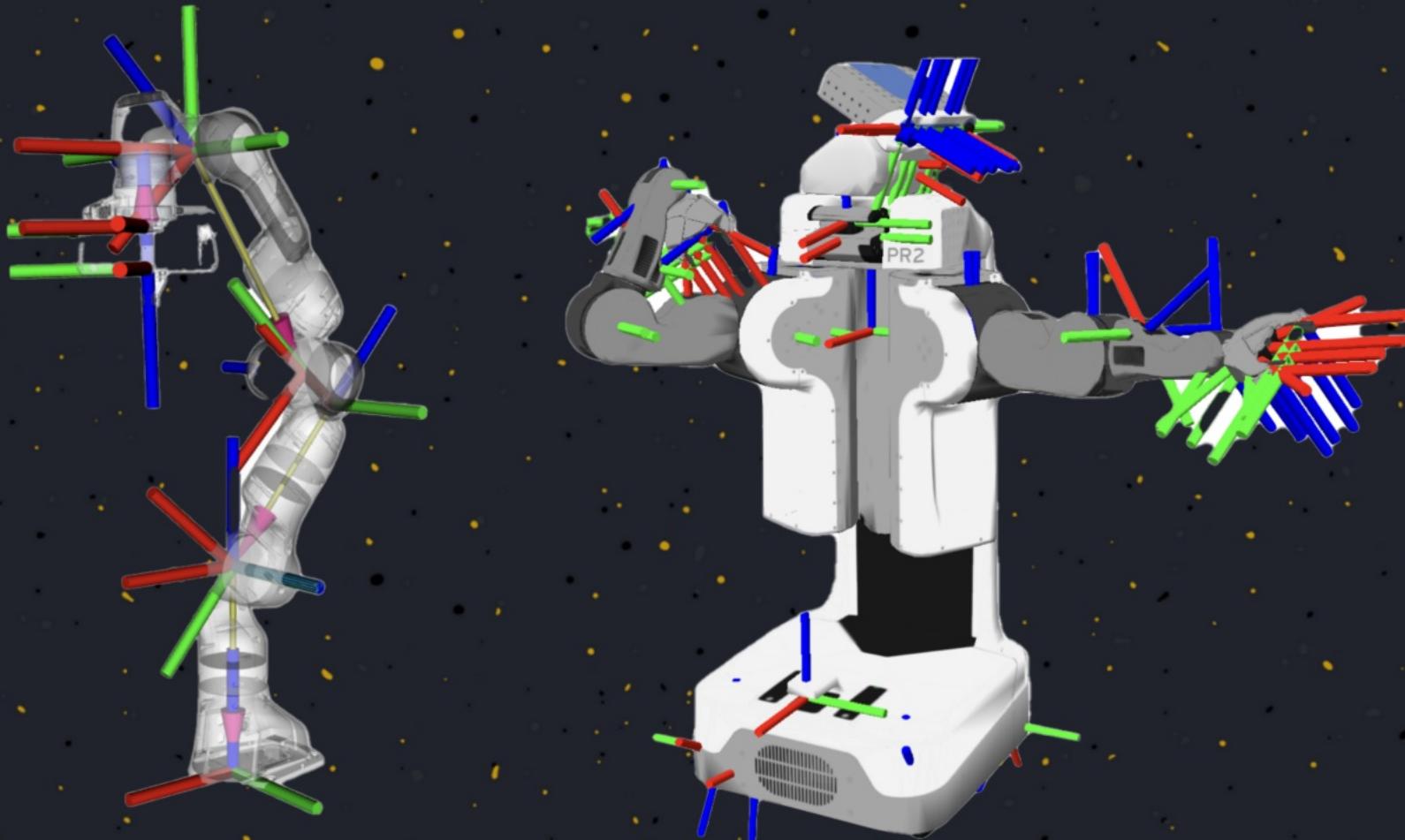






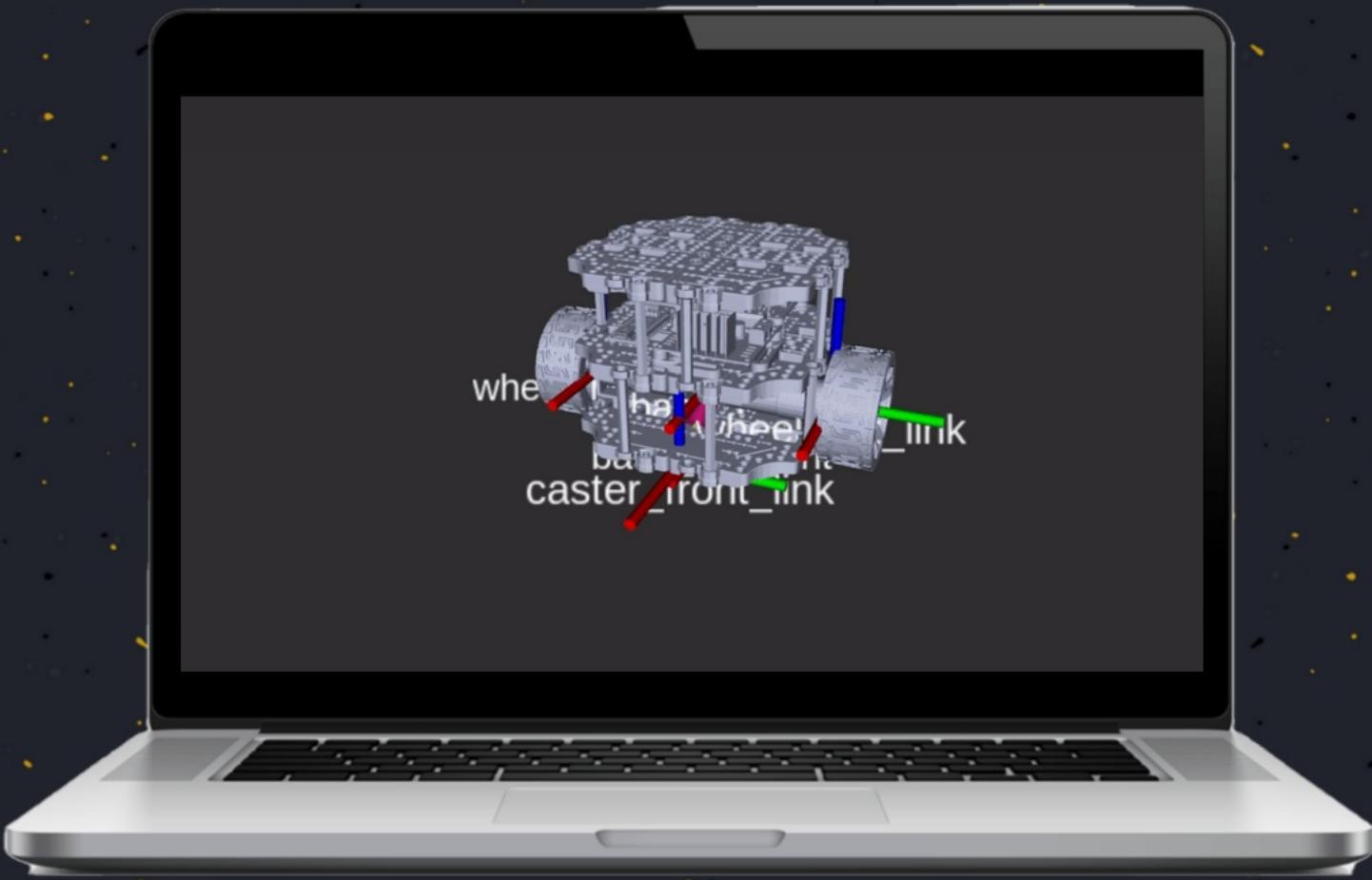


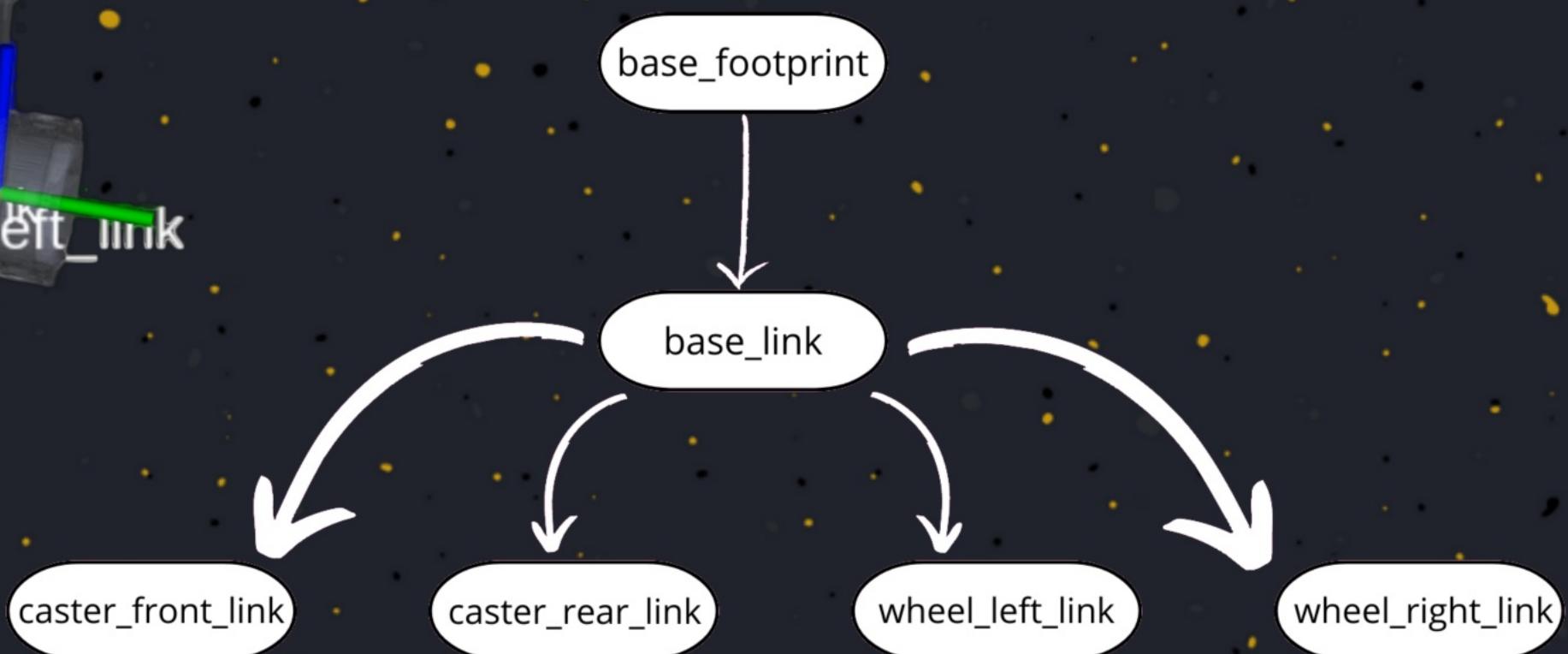
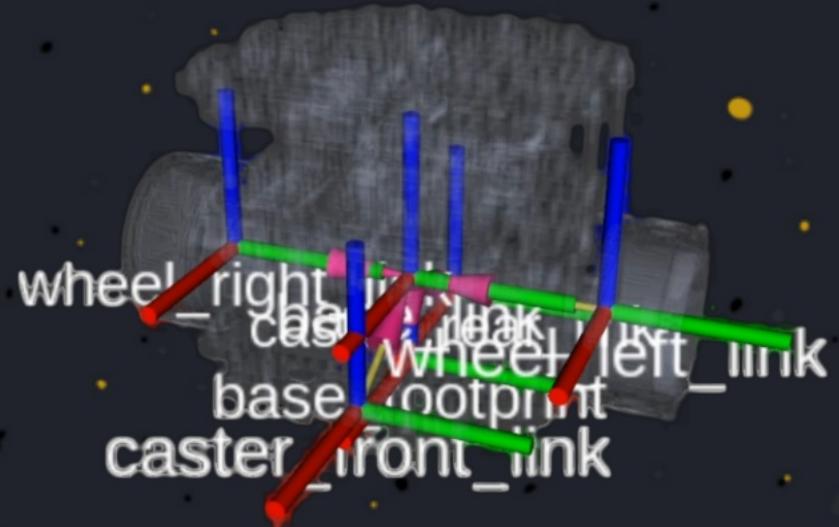
TF2 Library



TF2 Library

TF2 Library

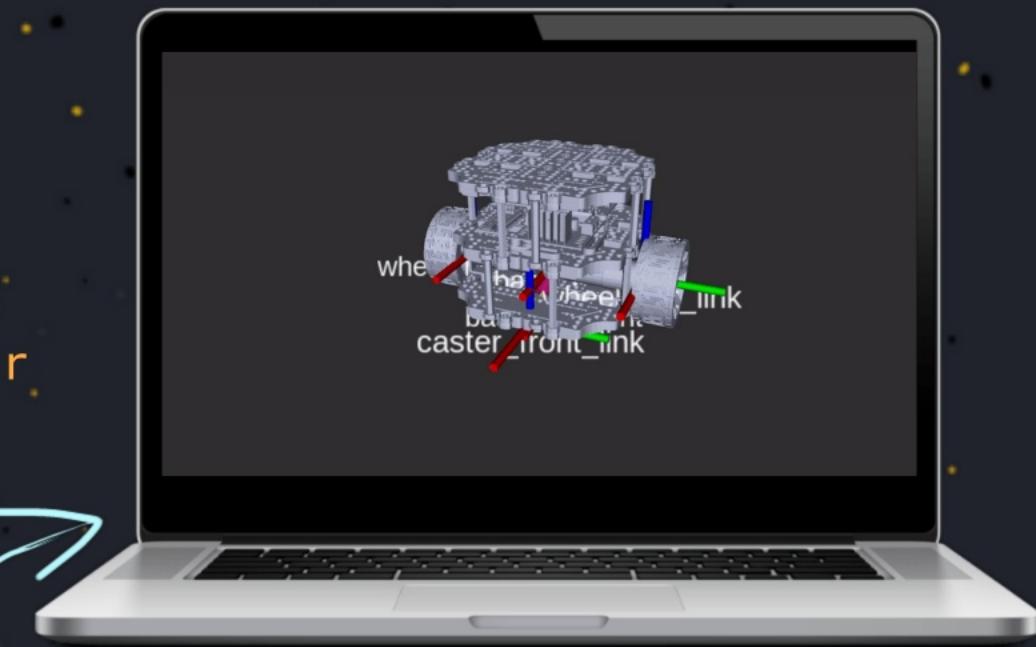


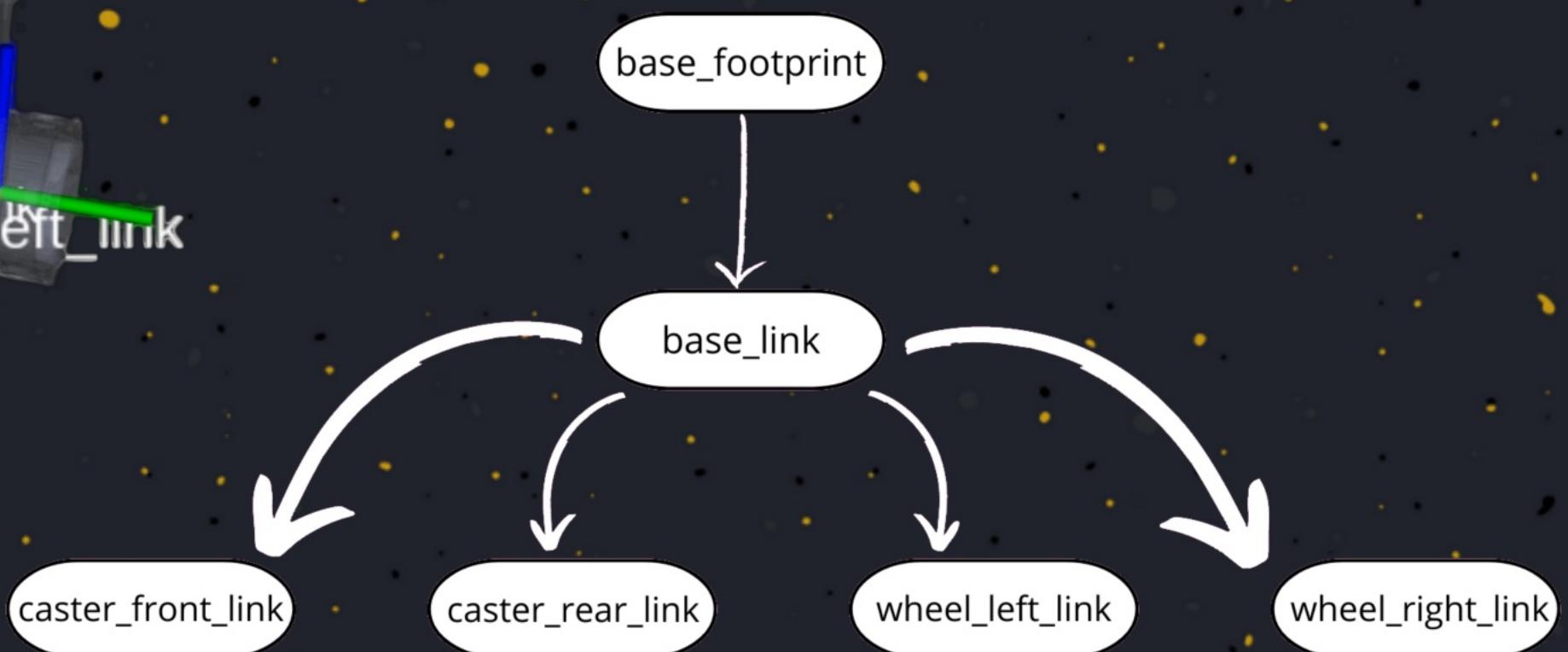
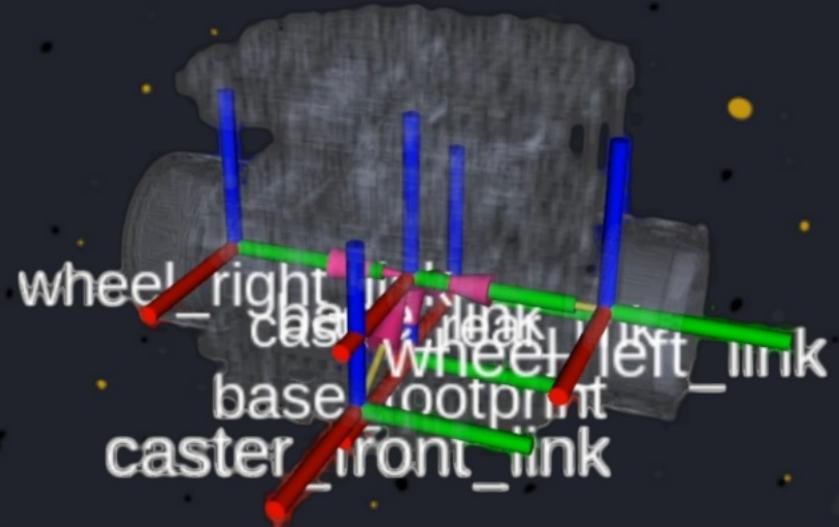


```
<robot name="bumperbot">  
  
  <link name="base_footprint"/>  
  
  <link name="base_link">  
    <visual>  
      <origin xyz="0 0 0" rpy="0 0 0" />  
      <geometry>  
        <mesh filename="base_link.STL" />  
      </geometry>  
    </visual>  
    <collision>  
      <origin xyz="0 0 0" rpy="0 0 0" />  
      <geometry>  
        <mesh filename="base_link.STL" />  
      </geometry>  
    </collision>  
  </link>  
  
  <joint name="base_joint" type="fixed">  
    <parent link="base_footprint"/>  
    <child link="base_link" />  
    <origin xyz="0 0 0.033" rpy="0 0 0"/>  
  </joint>
```

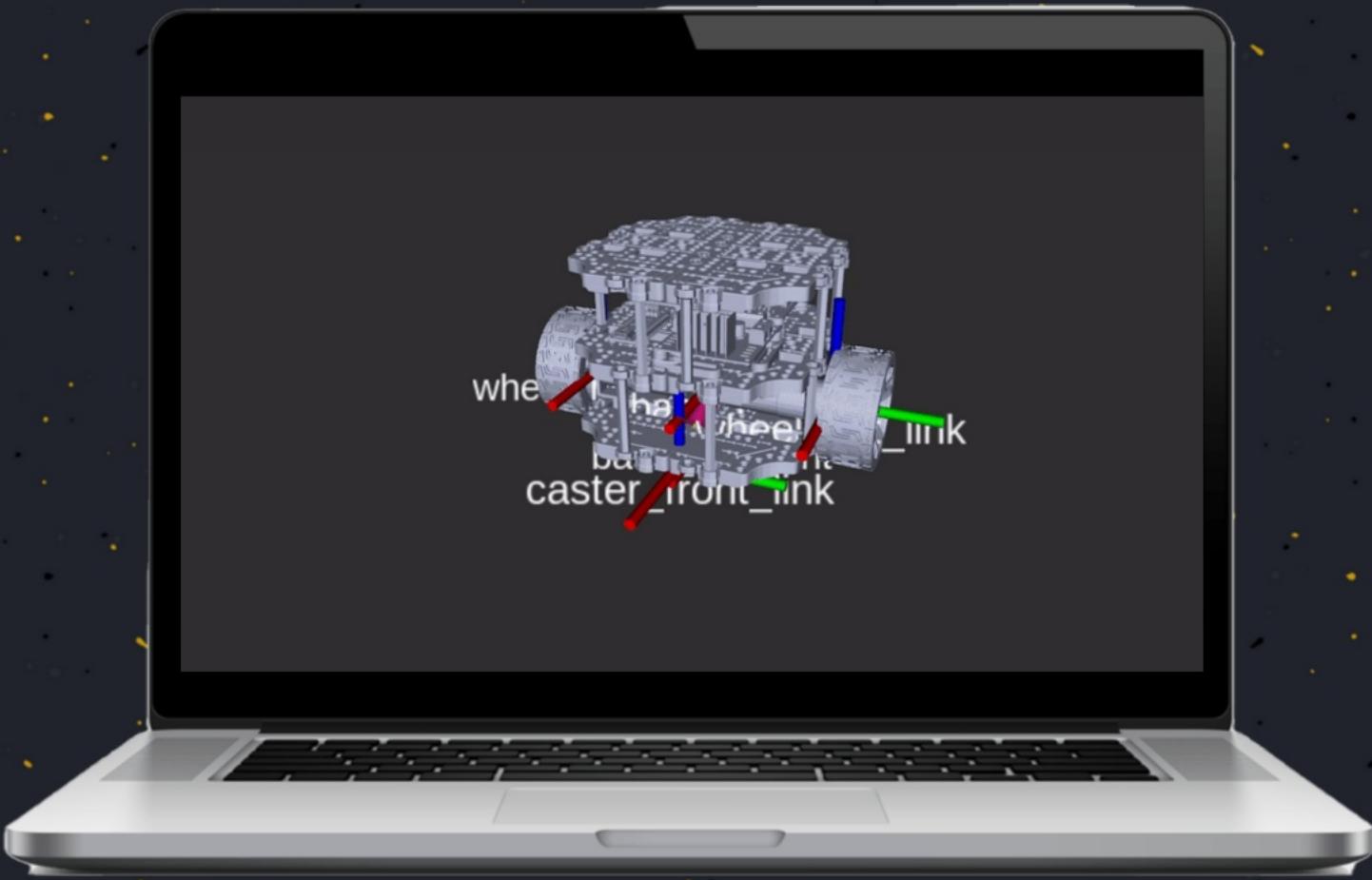
robot_state_publisher

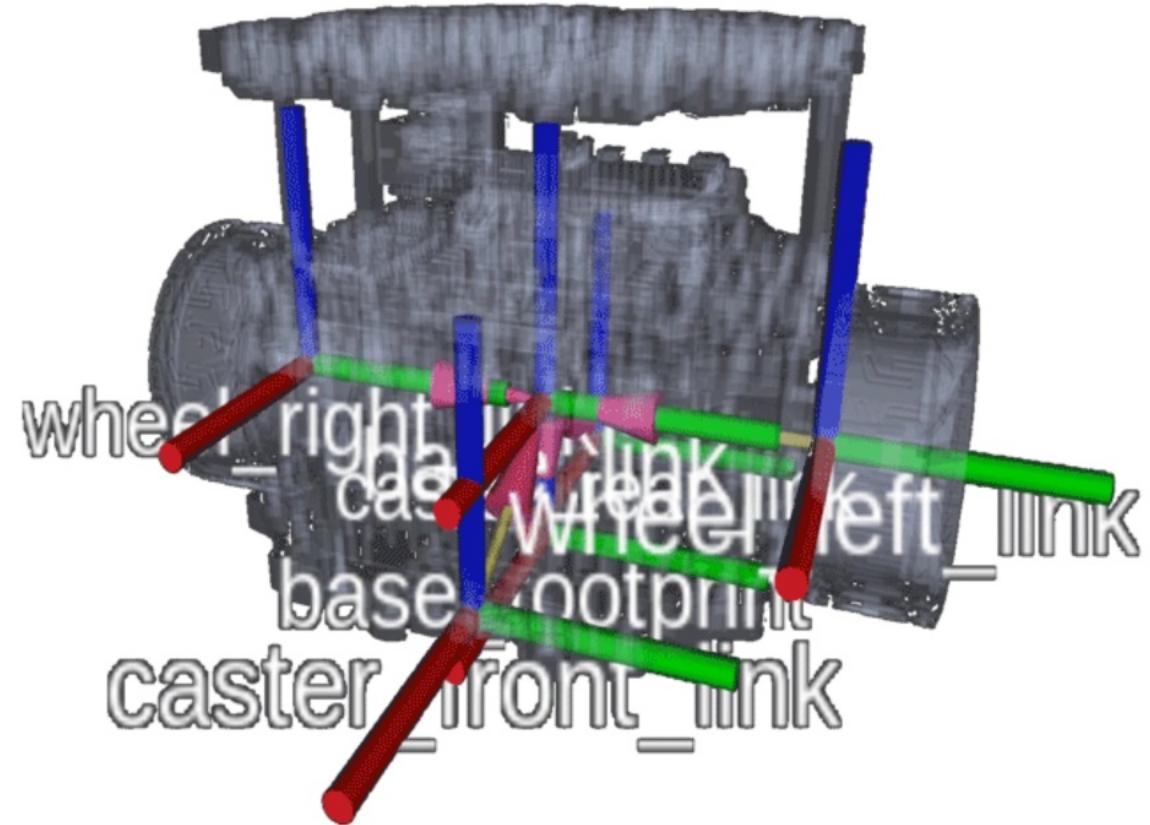
/tf



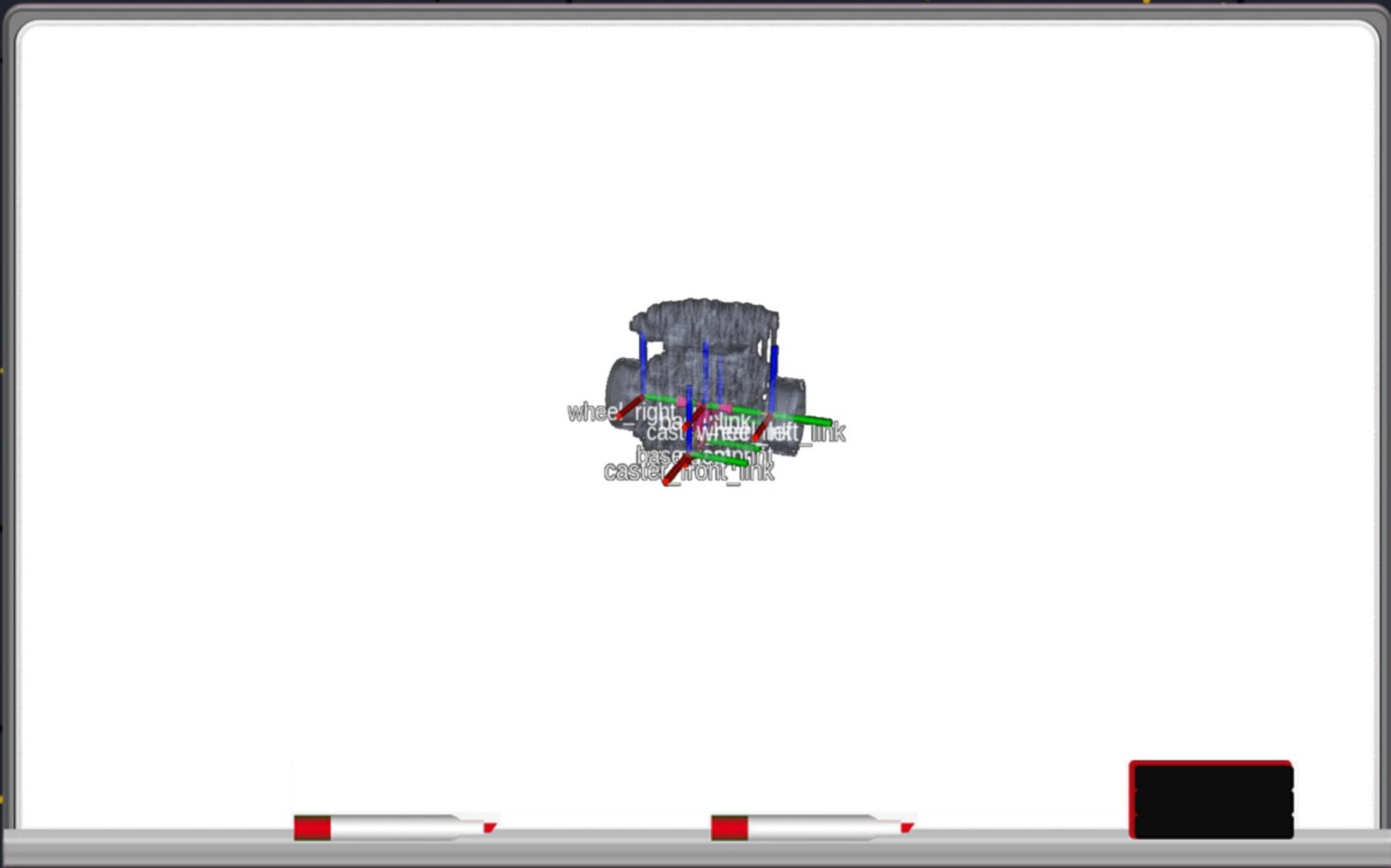


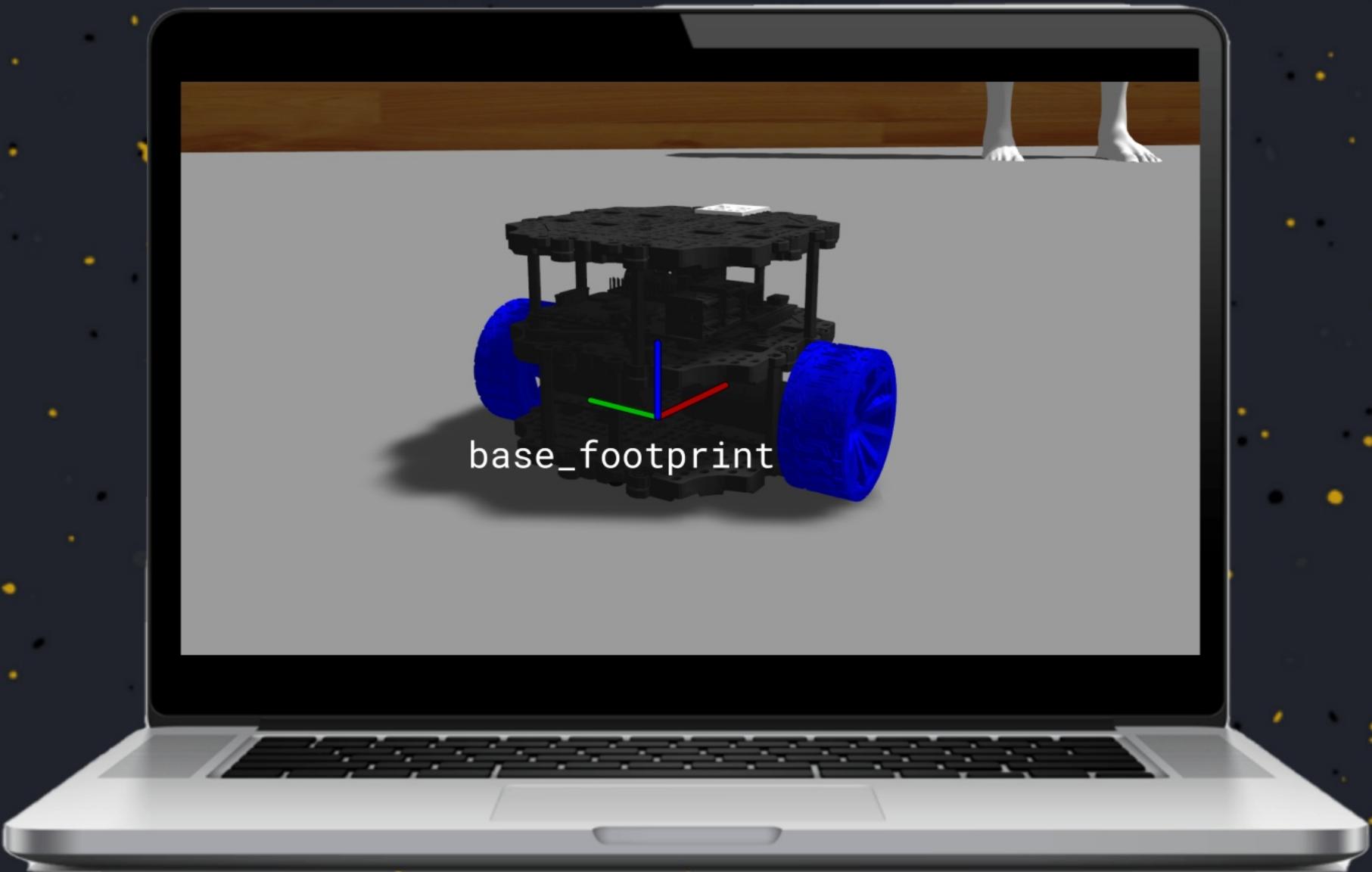
TF2 Library

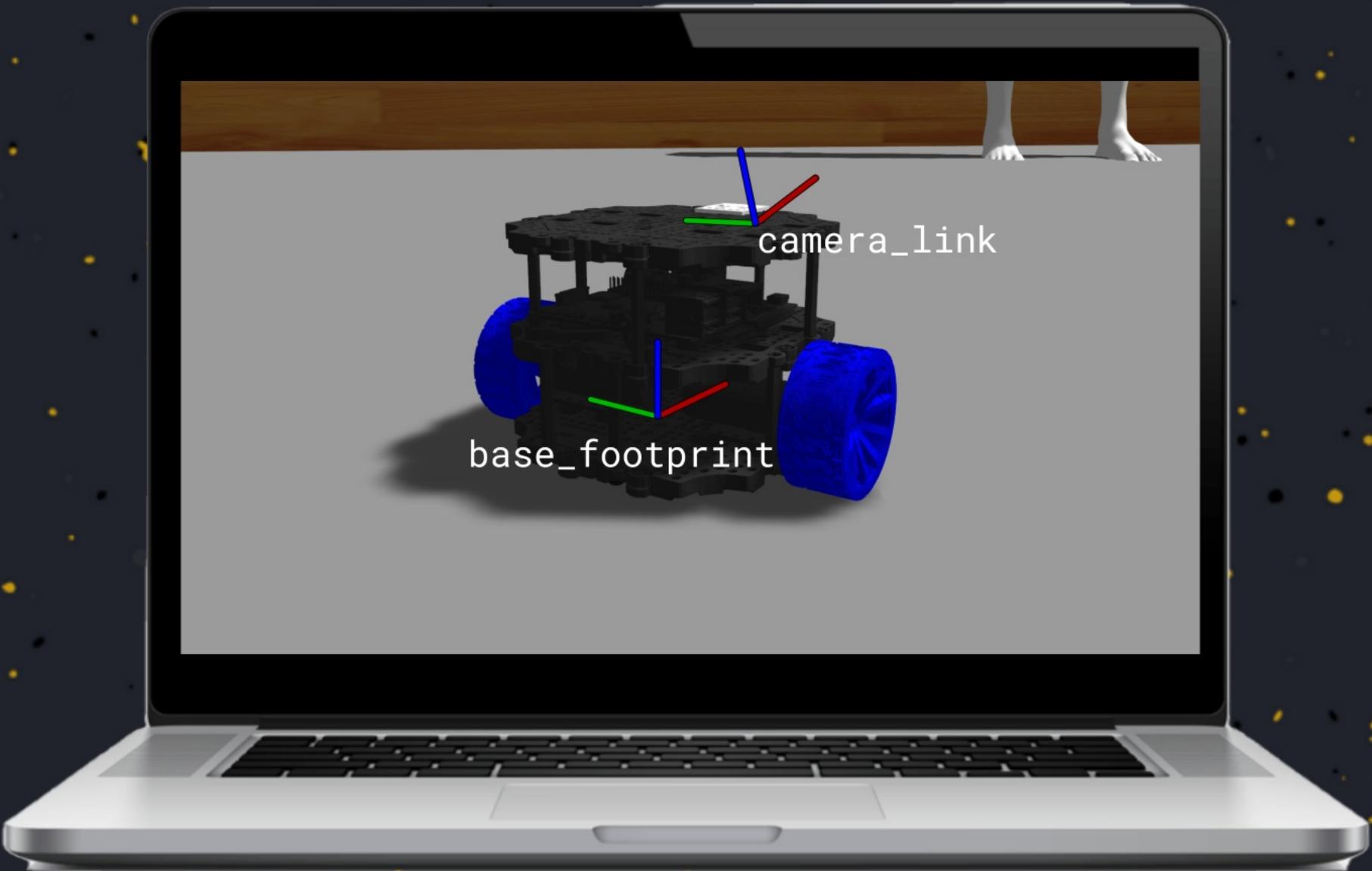




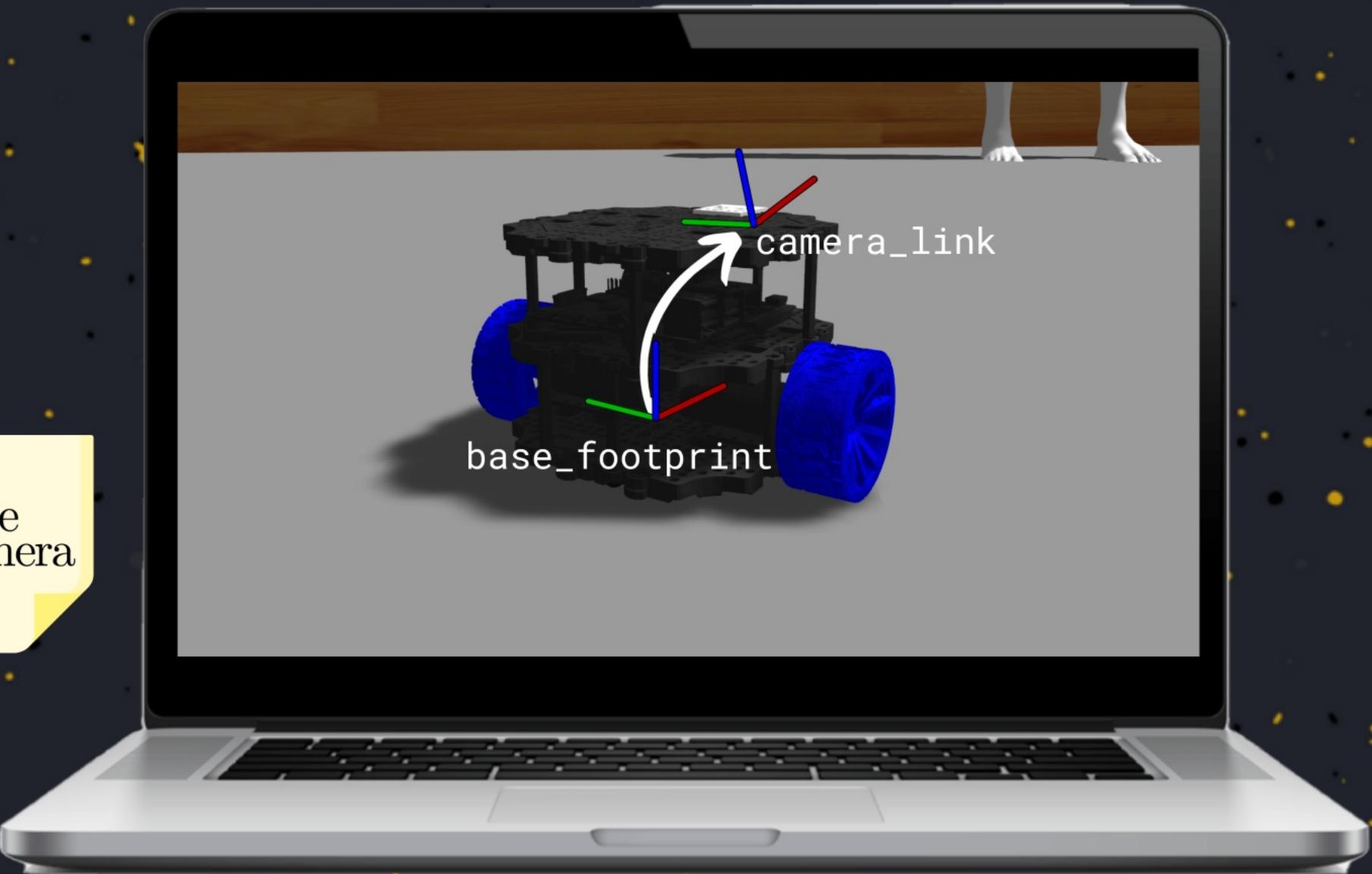




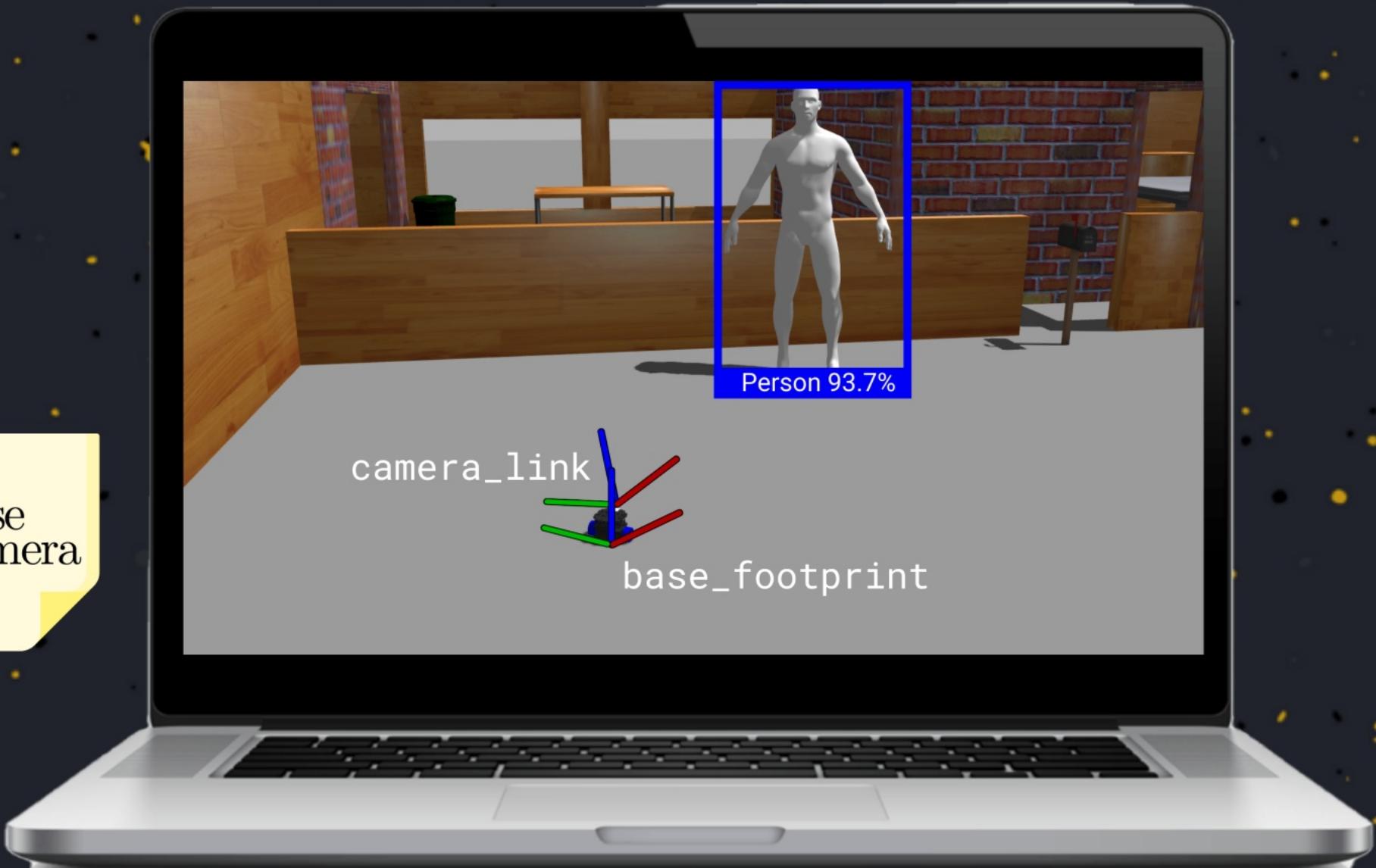




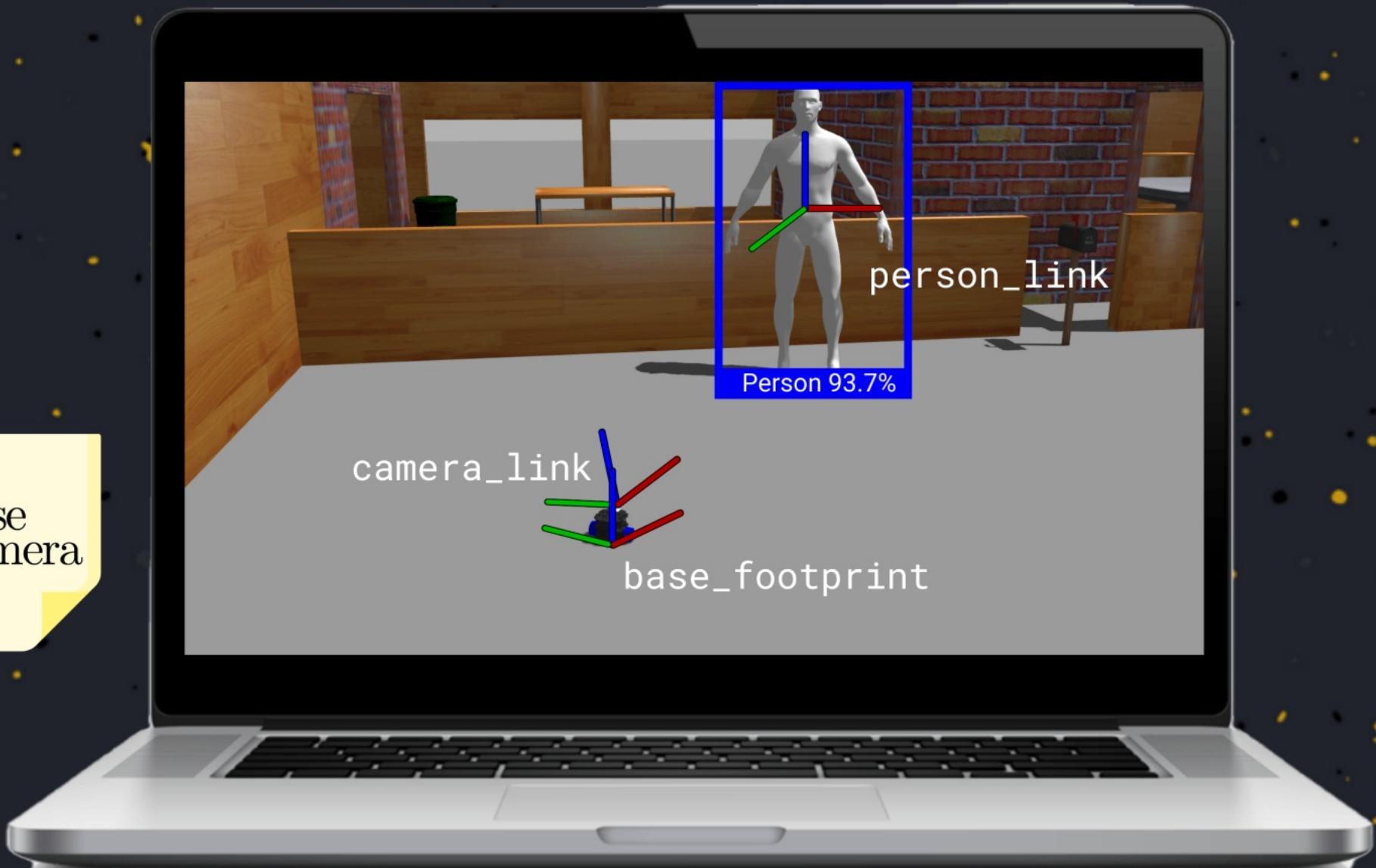
T_{base}
camera



Tbase
camera

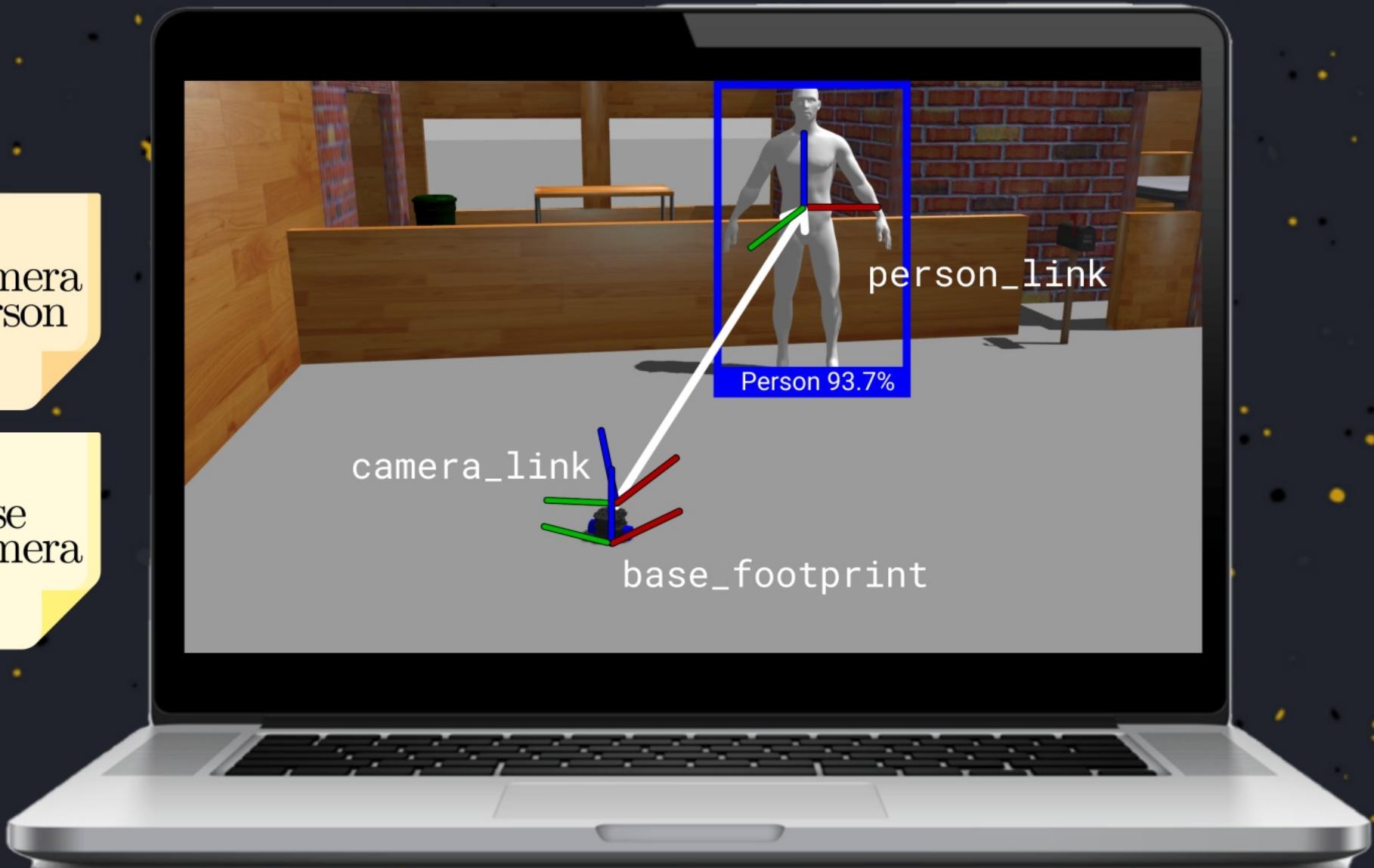


Tbase
camera



T_{camera}
 T_{person}

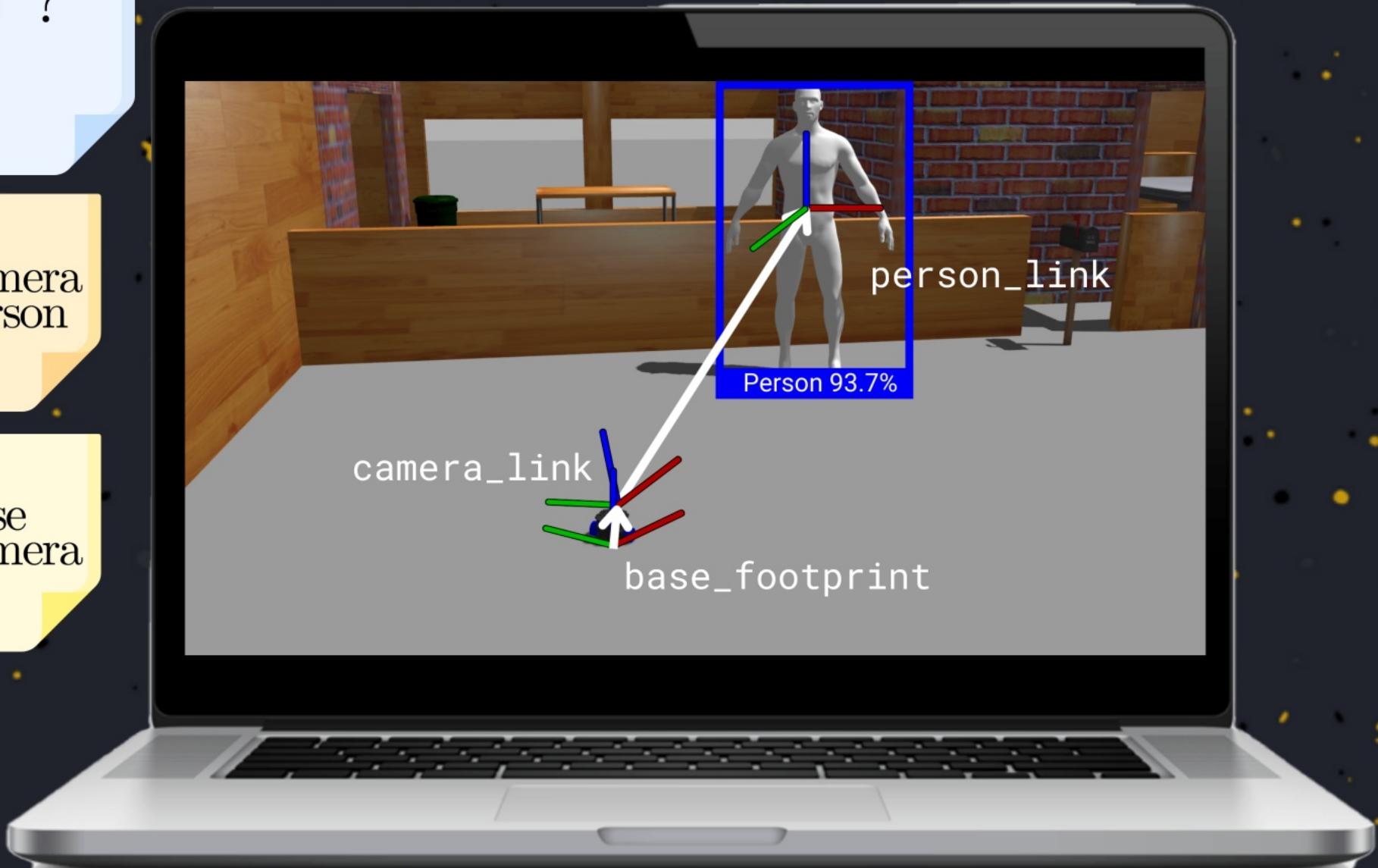
T_{base}
 T_{camera}



$T_{\text{base person}} = ?$

$T_{\text{camera person}}$

$T_{\text{base camera}}$

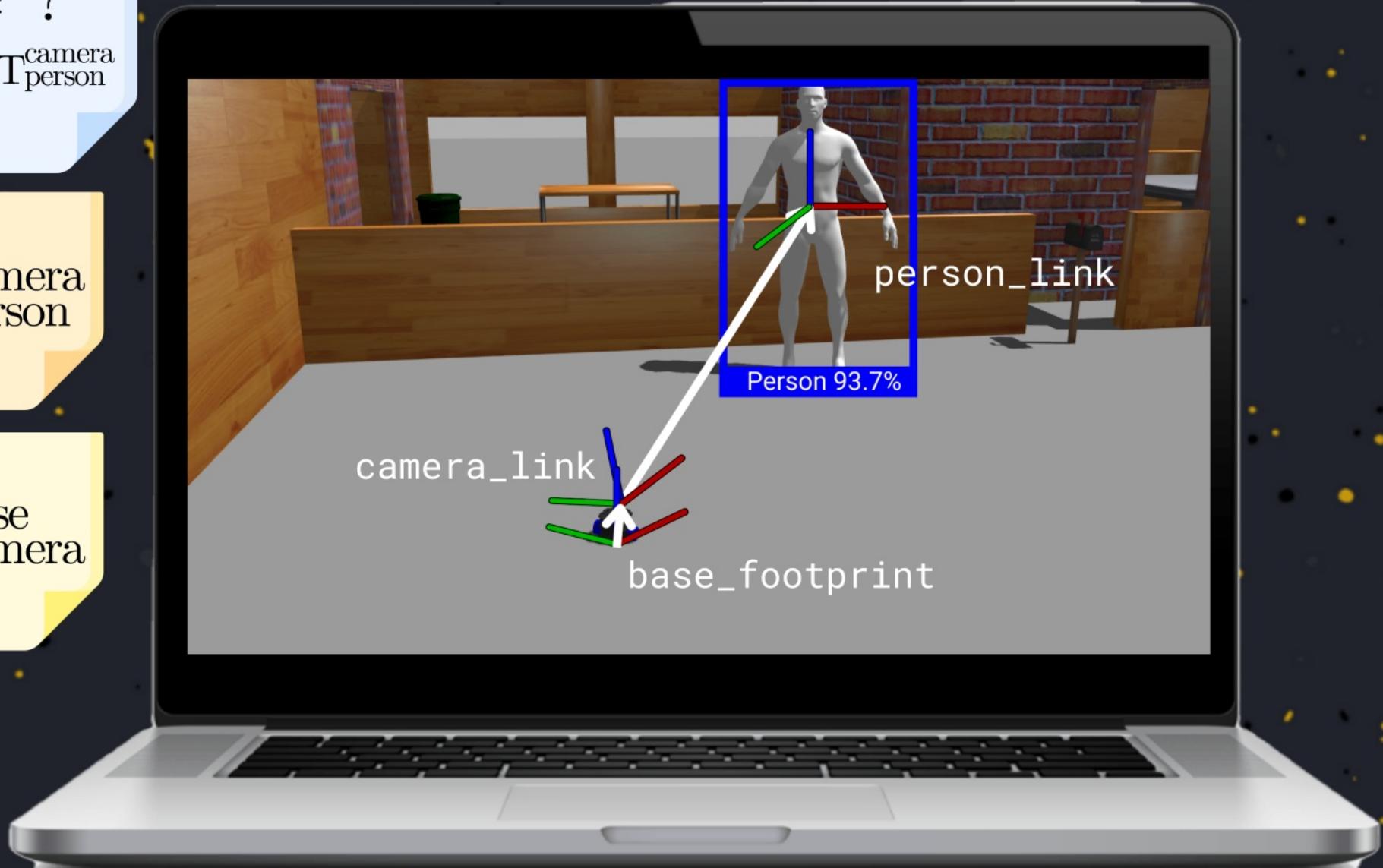


$T_{\text{person}}^{\text{base}} = ?$

$$T_{\text{person}}^{\text{base}} = T_{\text{camera}}^{\text{base}} \cdot T_{\text{person}}$$

$T_{\text{person}}^{\text{camera}}$

$T_{\text{camera}}^{\text{base}}$

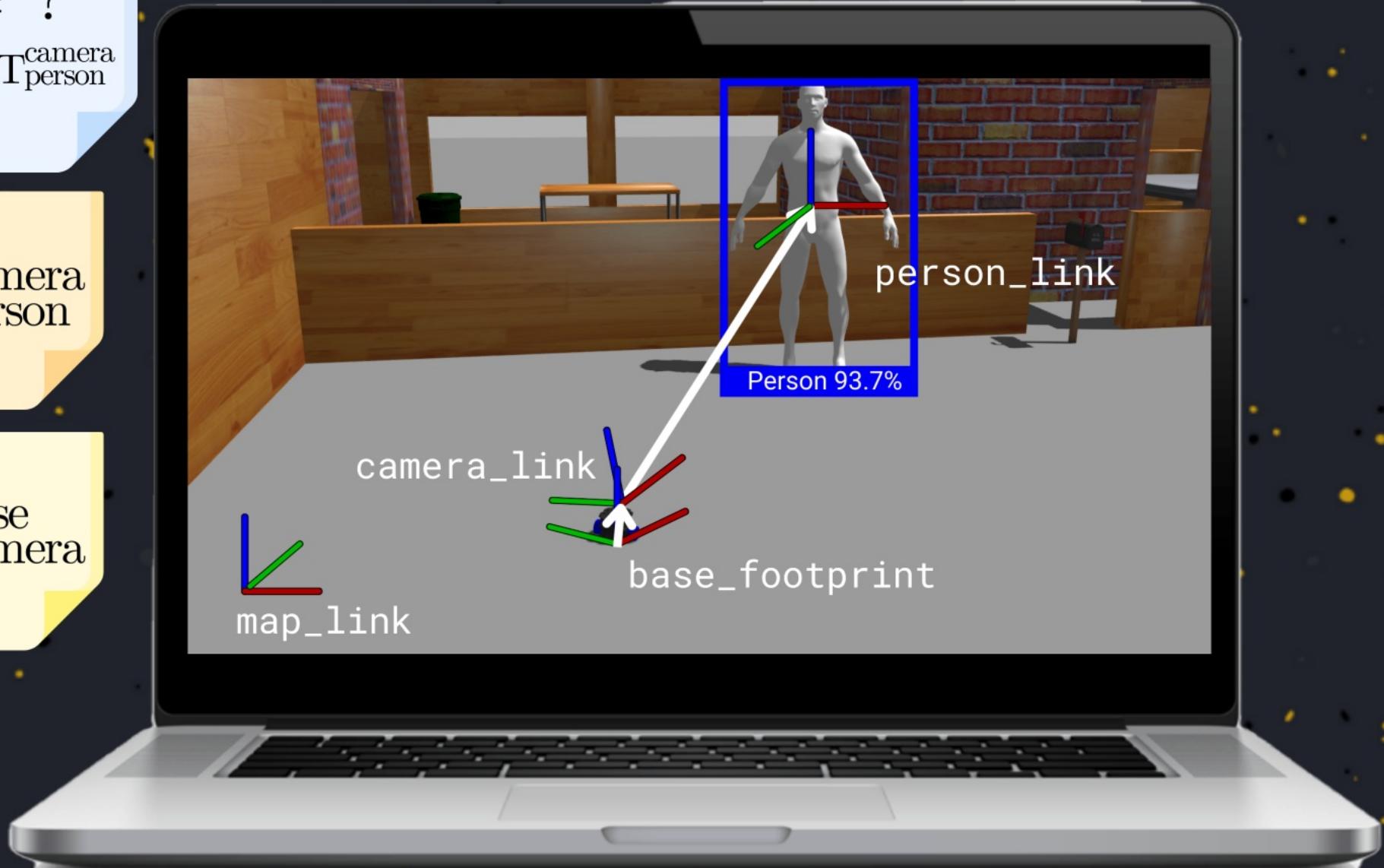


$T_{\text{person}}^{\text{base}} = ?$

$$T_{\text{person}}^{\text{base}} = T_{\text{camera}}^{\text{base}} \cdot T_{\text{person}}$$

$T_{\text{person}}^{\text{camera}}$

$T_{\text{camera}}^{\text{base}}$



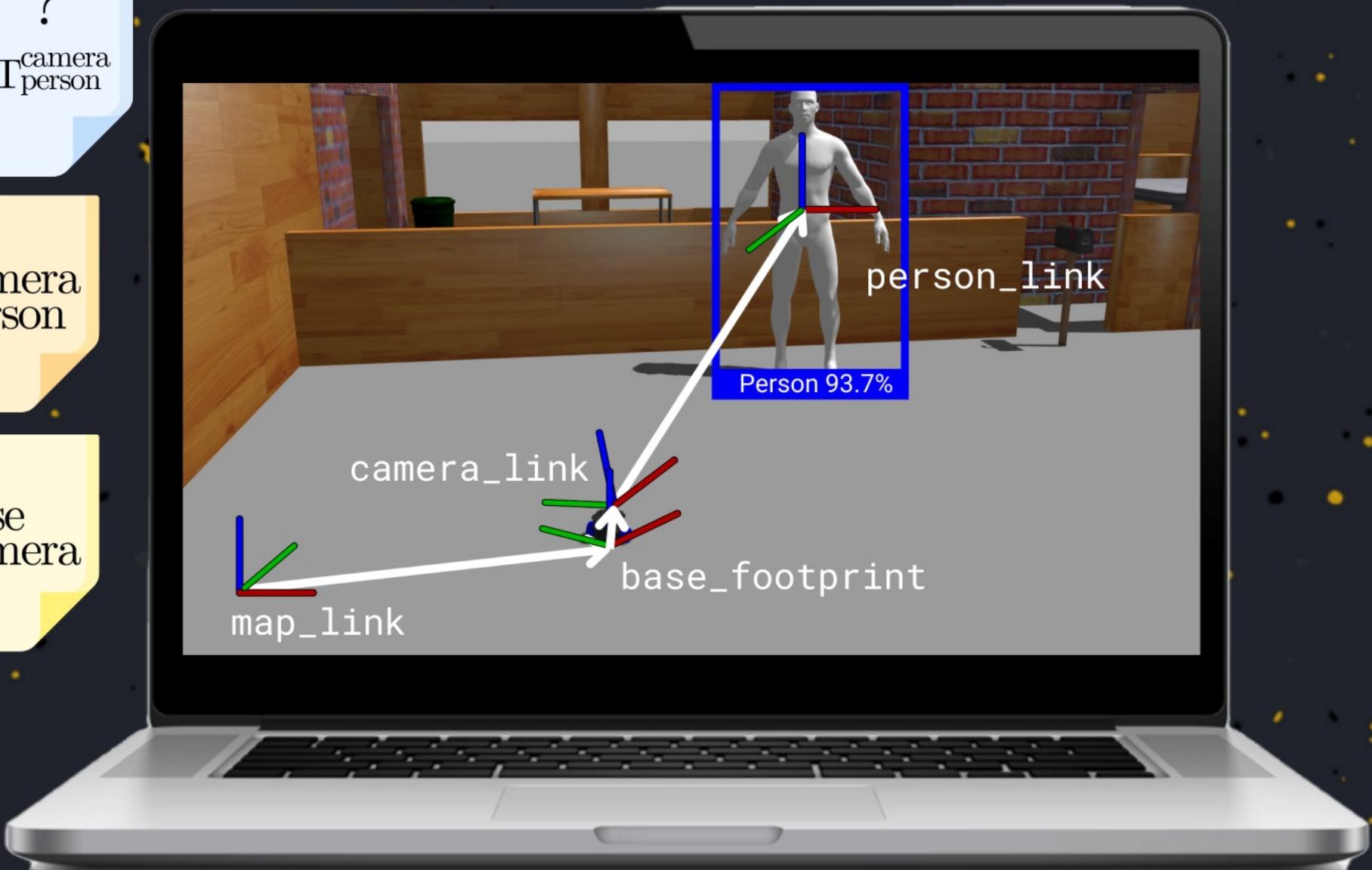
$T_{\text{person}}^{\text{base}} = ?$

$$T_{\text{person}}^{\text{base}} = T_{\text{camera}}^{\text{base}} \cdot T_{\text{person}}^{\text{camera}}$$

$T_{\text{person}}^{\text{camera}}$

$T_{\text{camera}}^{\text{base}}$

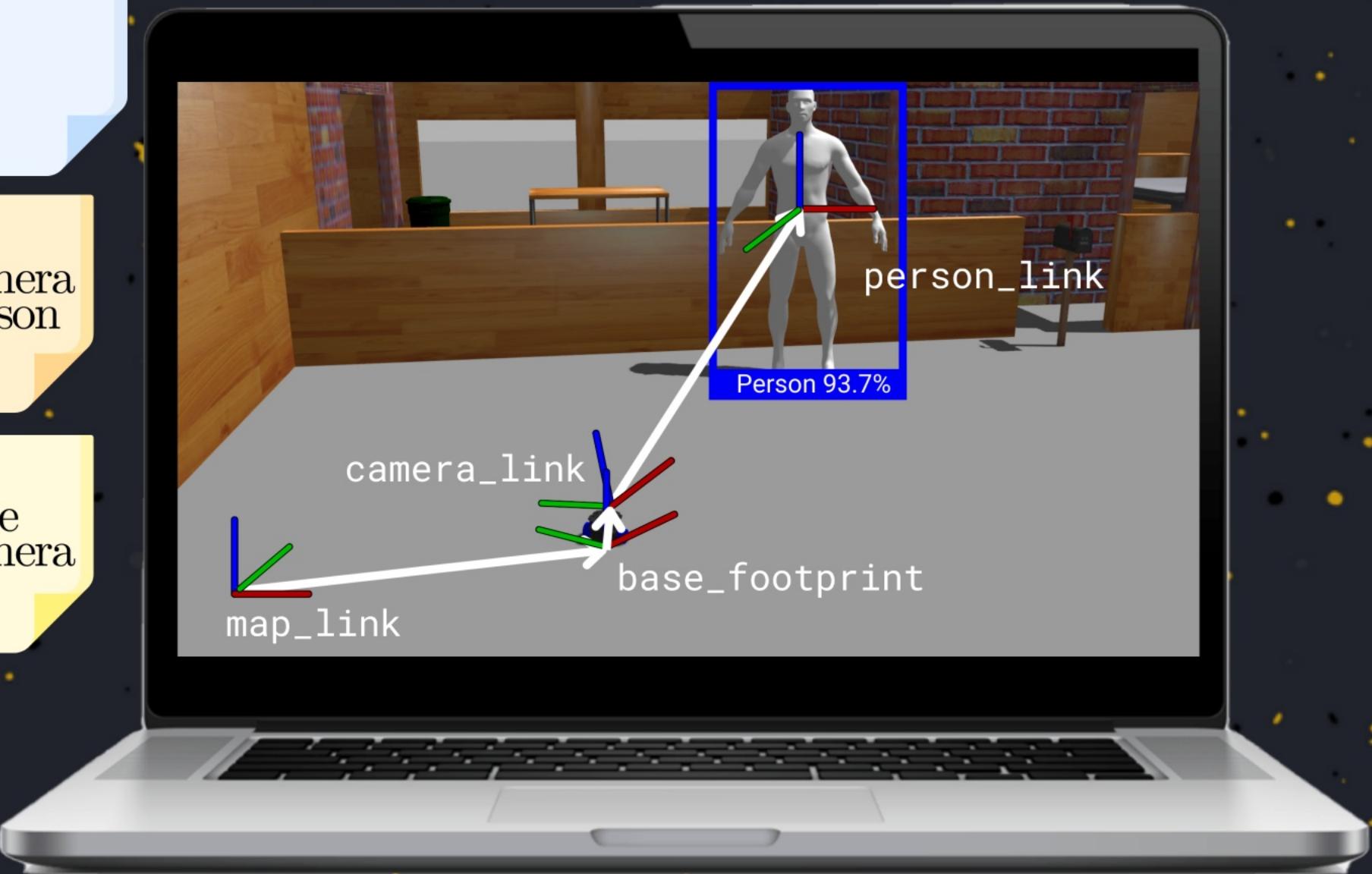
$T_{\text{base}}^{\text{map}}$



T_{camera}
 T_{person}

T_{base}
 T_{camera}

T_{map}
 T_{base}

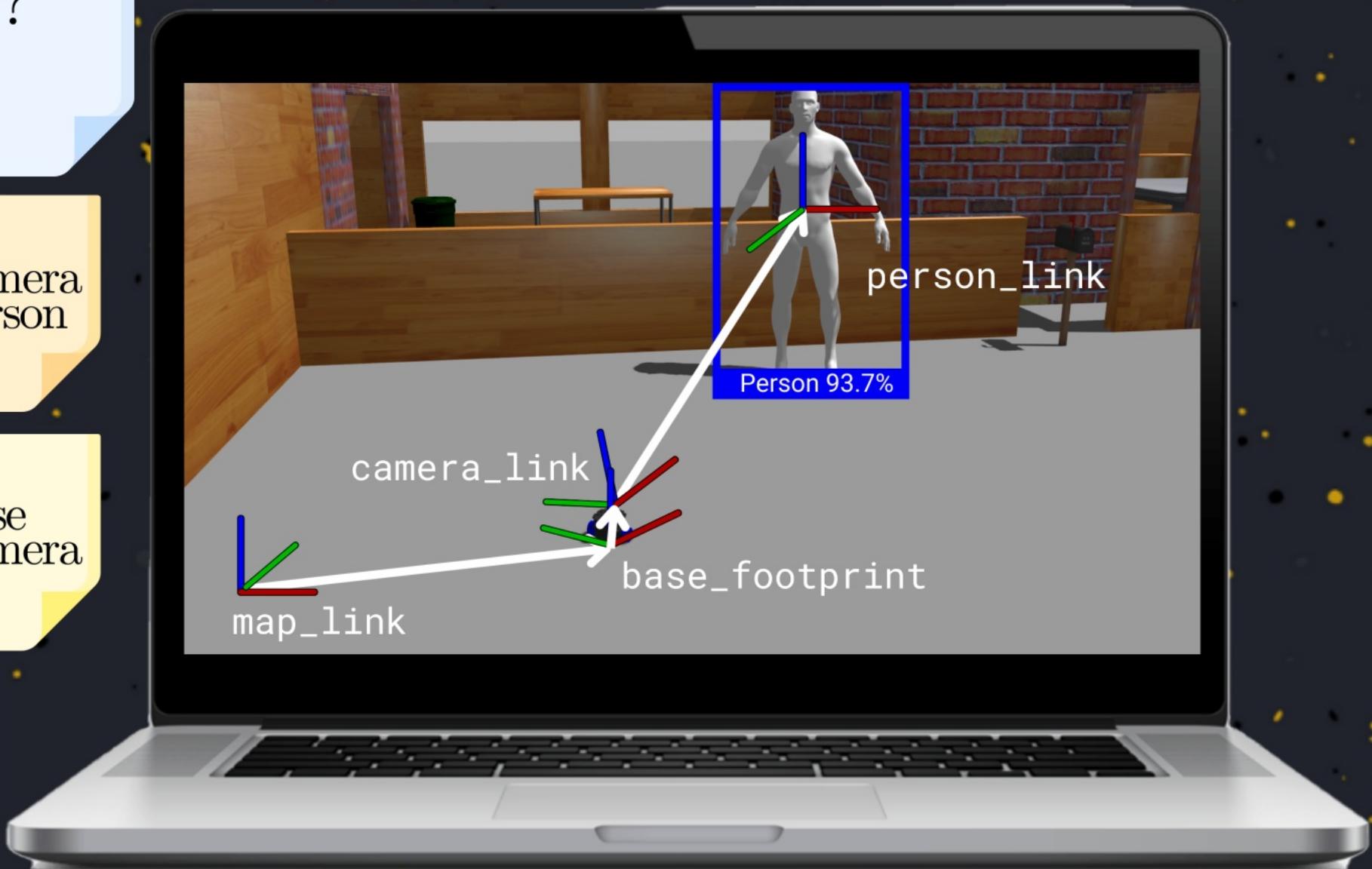


$T_{\text{person}}^{\text{map}} = ?$

$T_{\text{person}}^{\text{camera}}$

$T_{\text{camera}}^{\text{base}}$

$T_{\text{base}}^{\text{map}}$



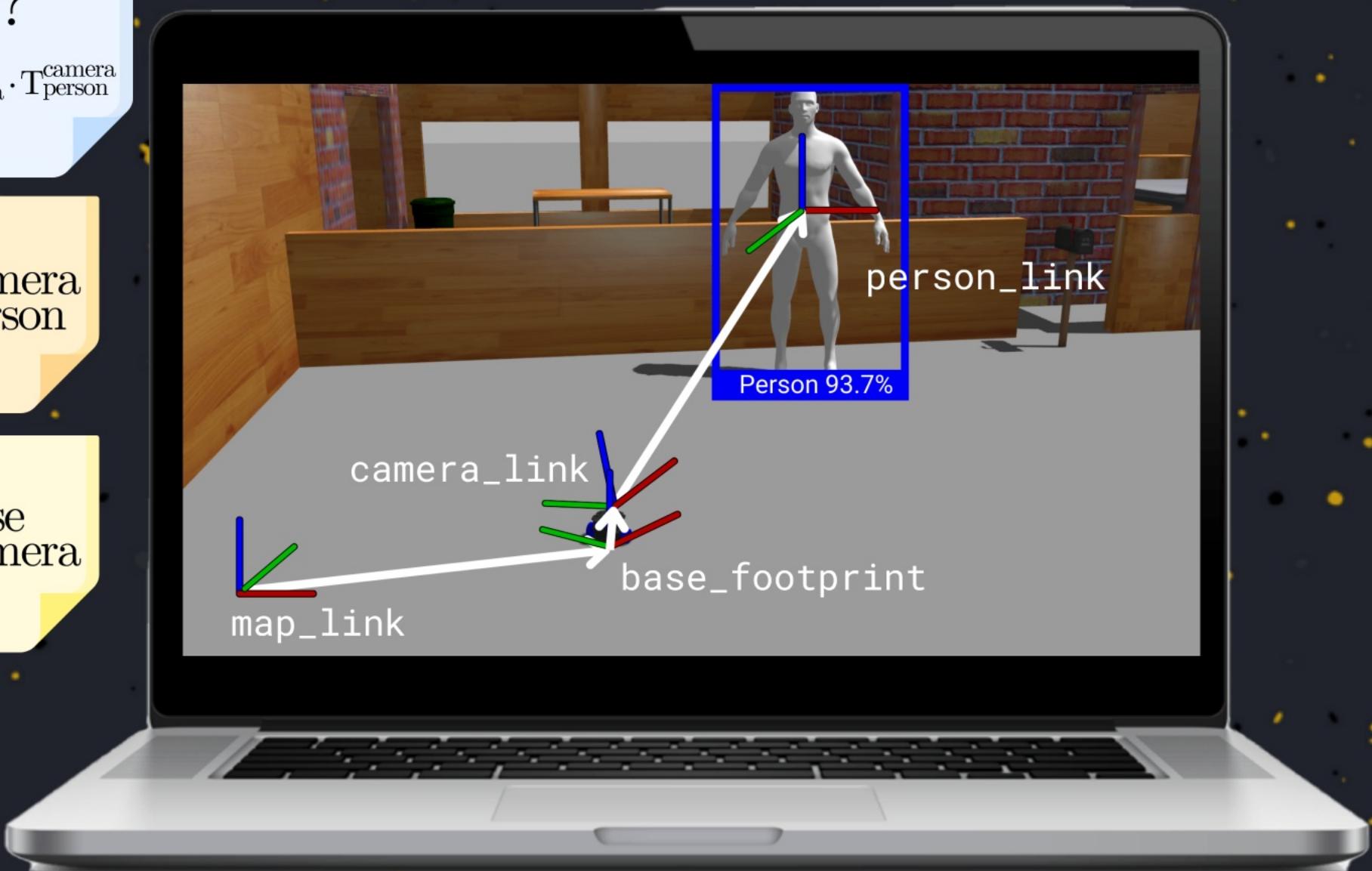
$T_{\text{person}}^{\text{map}} = ?$

$$T_{\text{person}}^{\text{map}} = T_{\text{base}}^{\text{map}} \cdot T_{\text{camera}}^{\text{map}} \cdot T_{\text{person}}$$

$T_{\text{person}}^{\text{camera}}$

$T_{\text{camera}}^{\text{base}}$

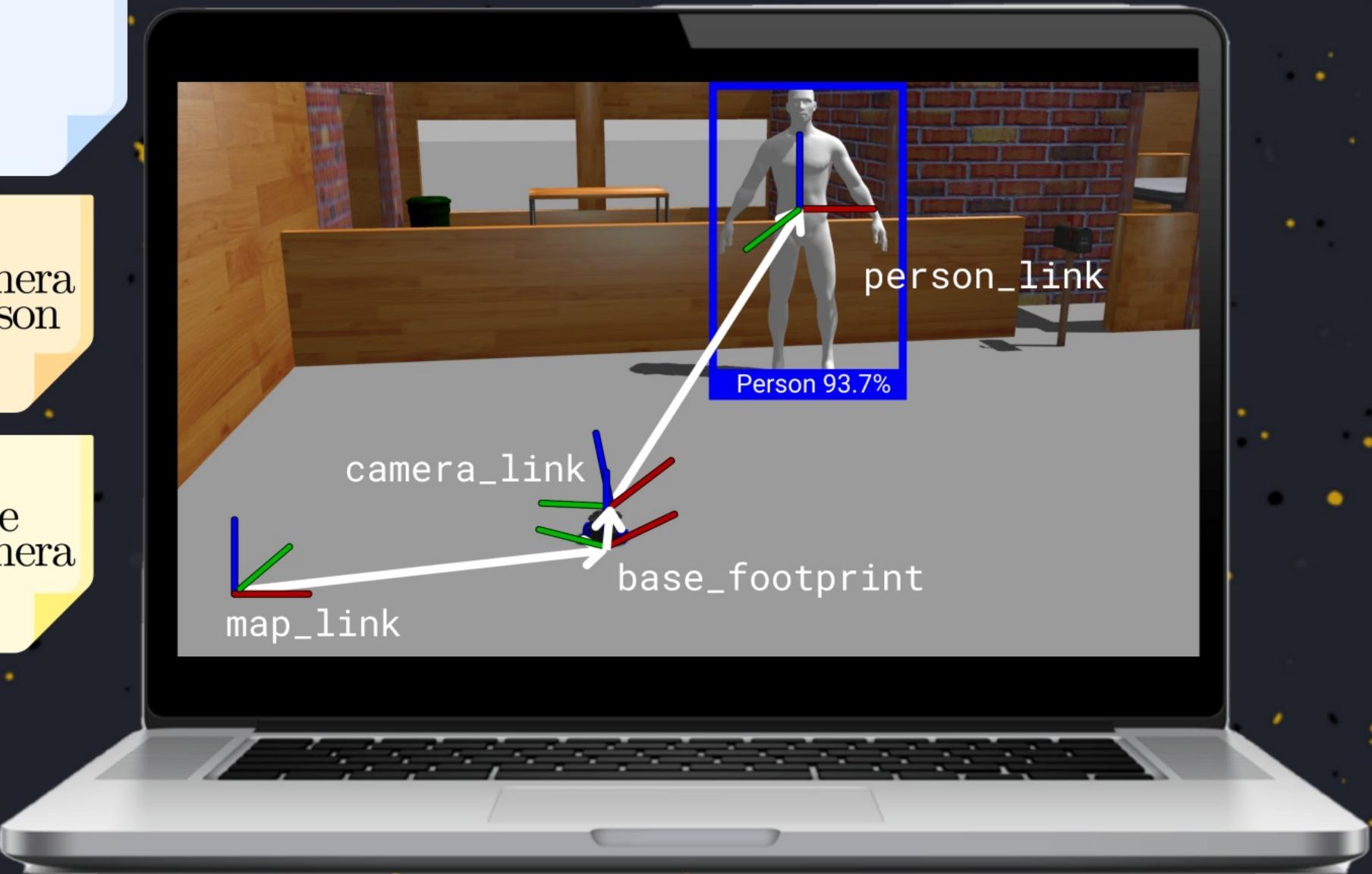
$T_{\text{base}}^{\text{map}}$



T_{camera}
 T_{person}

T_{base}
 T_{camera}

T_{map}
 T_{base}

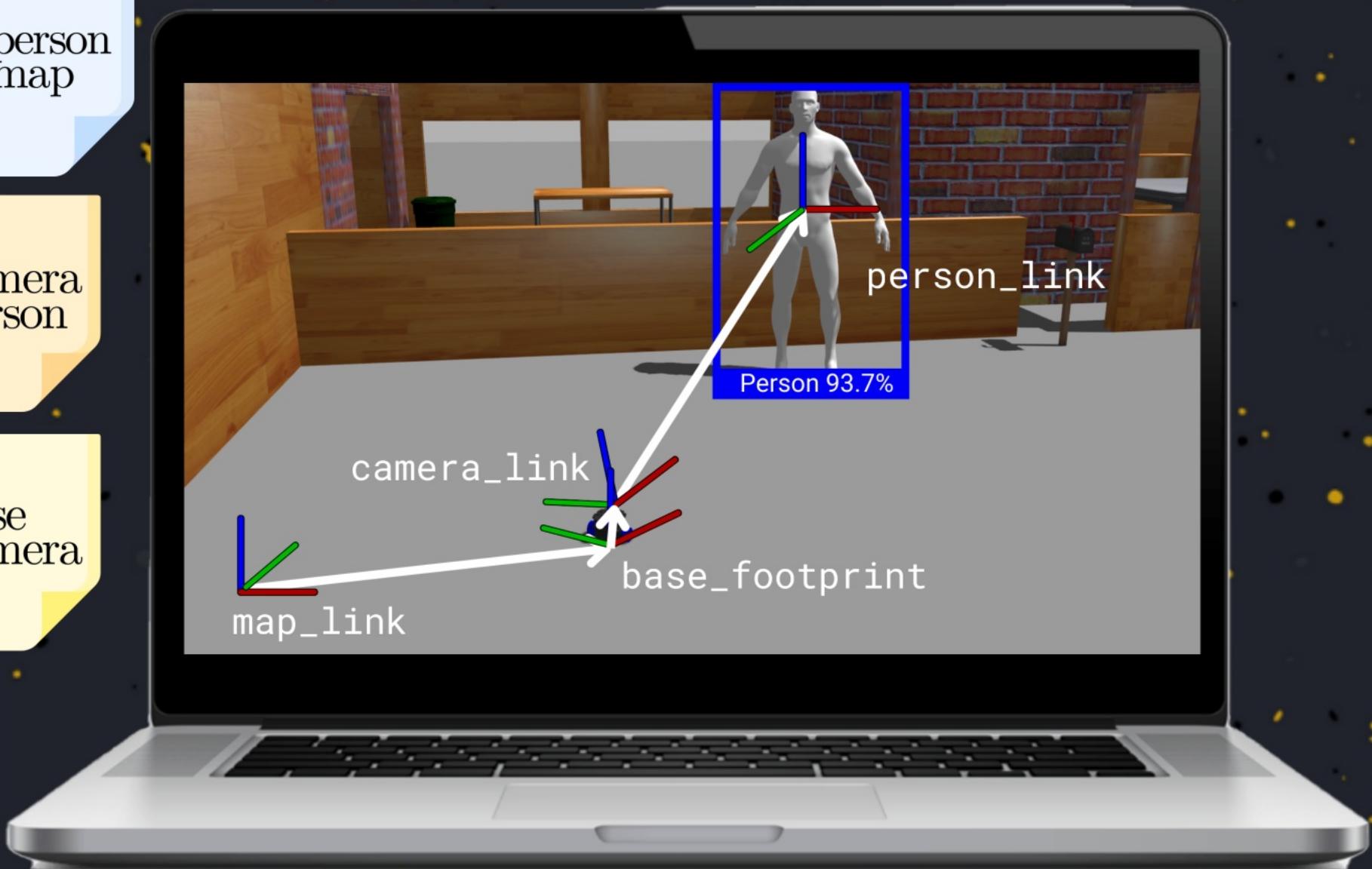


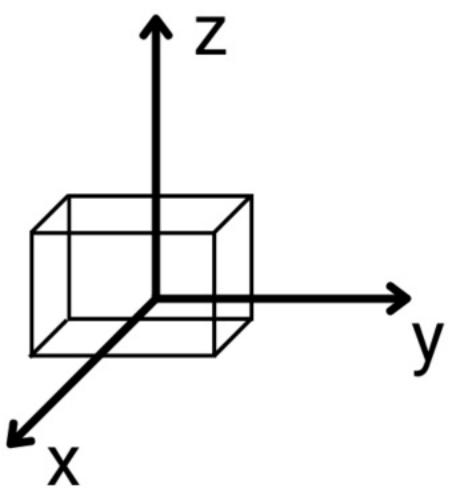
$T_{\text{person}}^{\text{map}} \neq T_{\text{map}}^{\text{person}}$

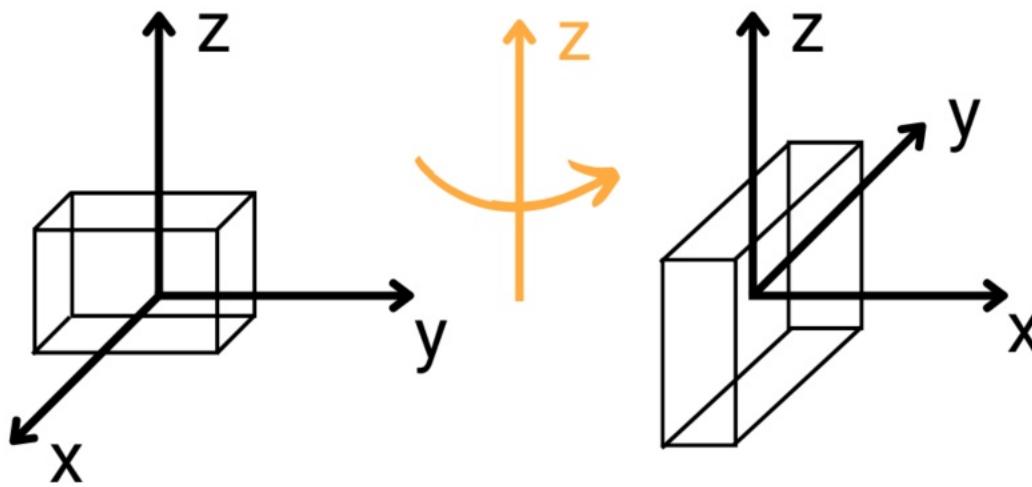
$T_{\text{person}}^{\text{camera}}$

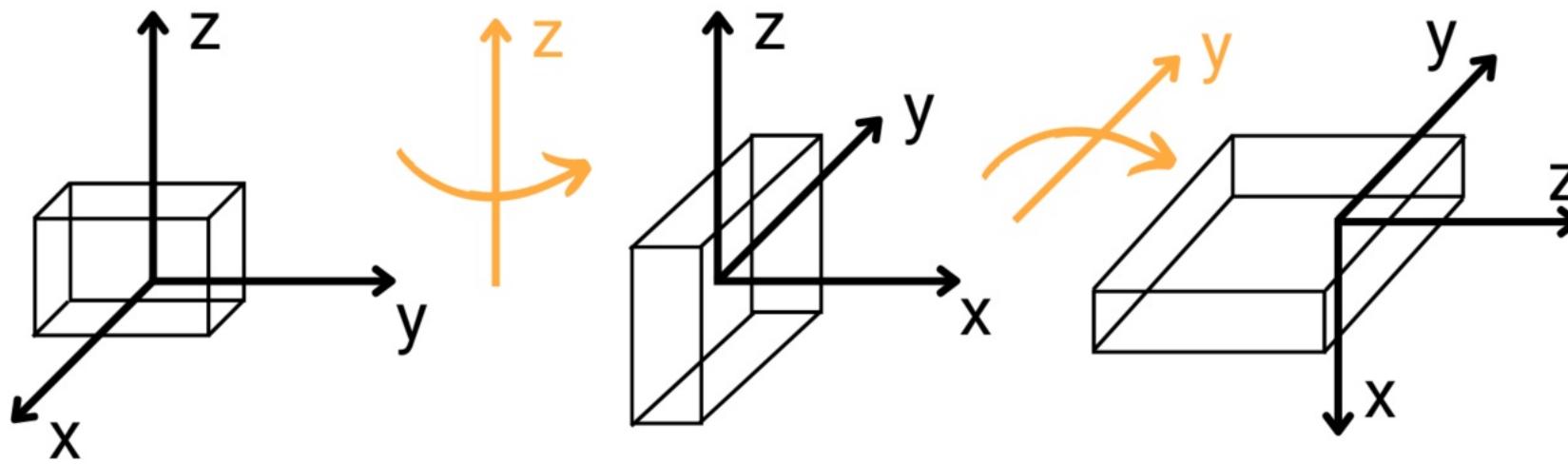
$T_{\text{camera}}^{\text{base}}$

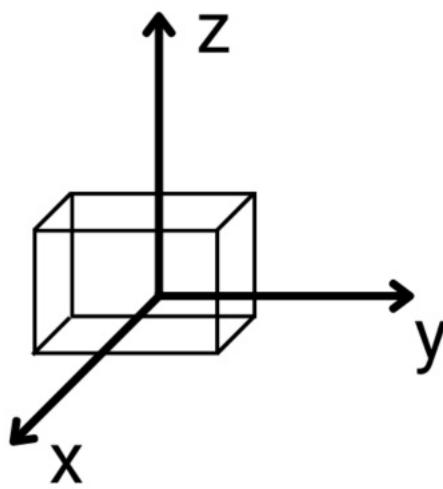
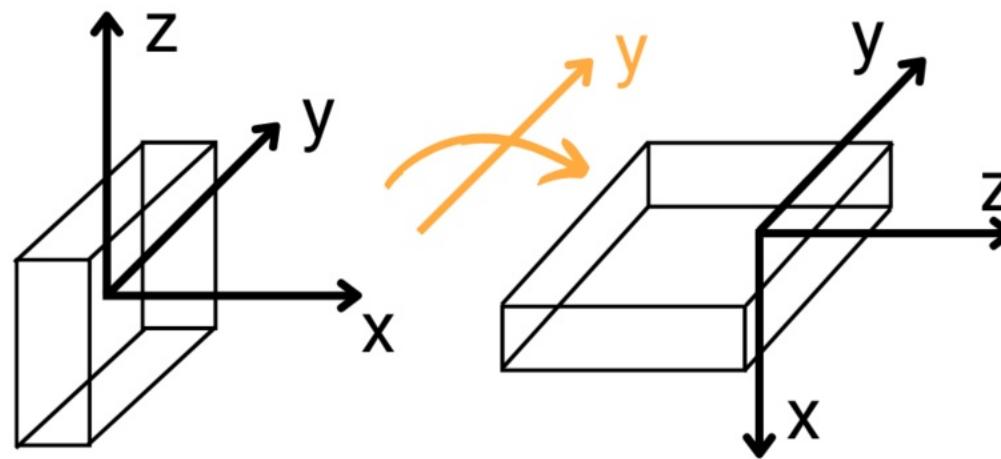
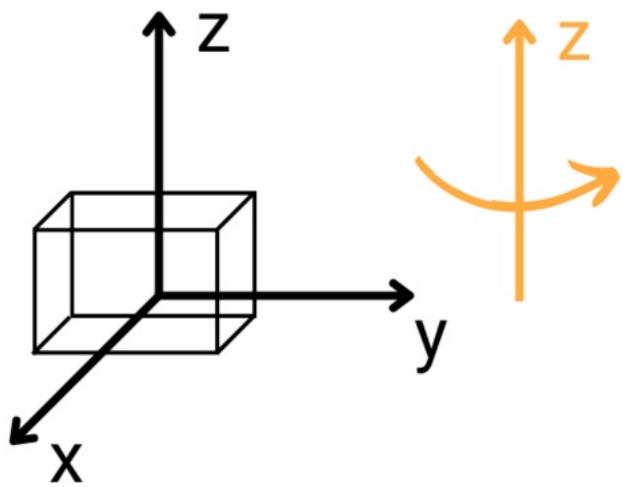
$T_{\text{base}}^{\text{map}}$

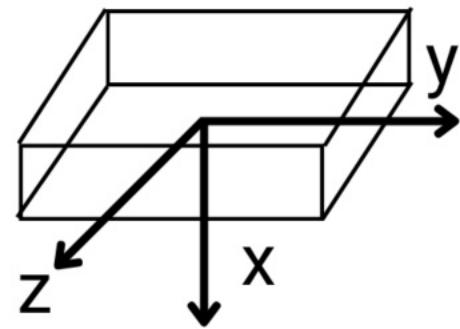
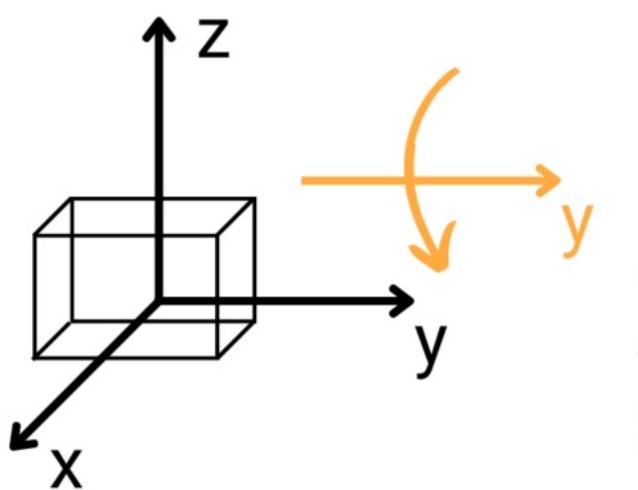
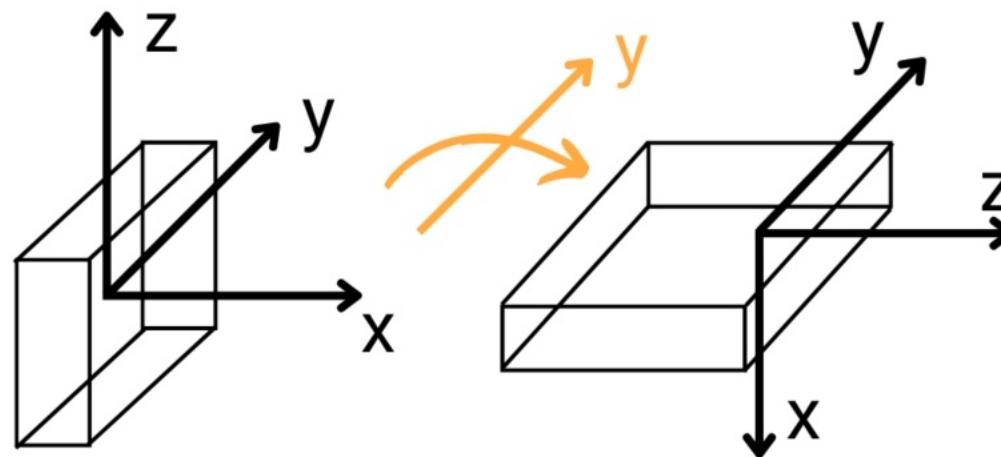
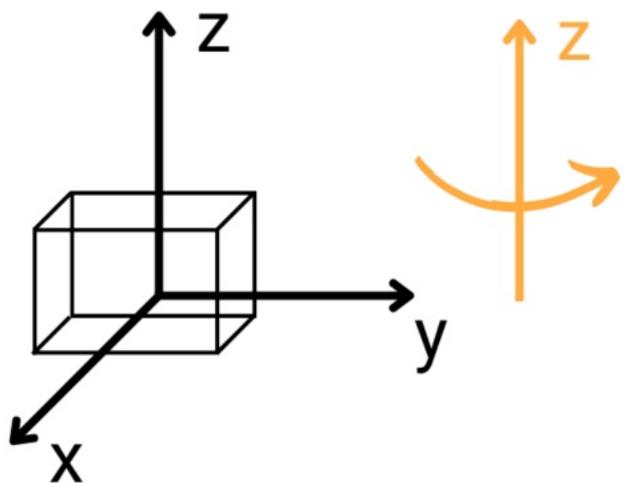


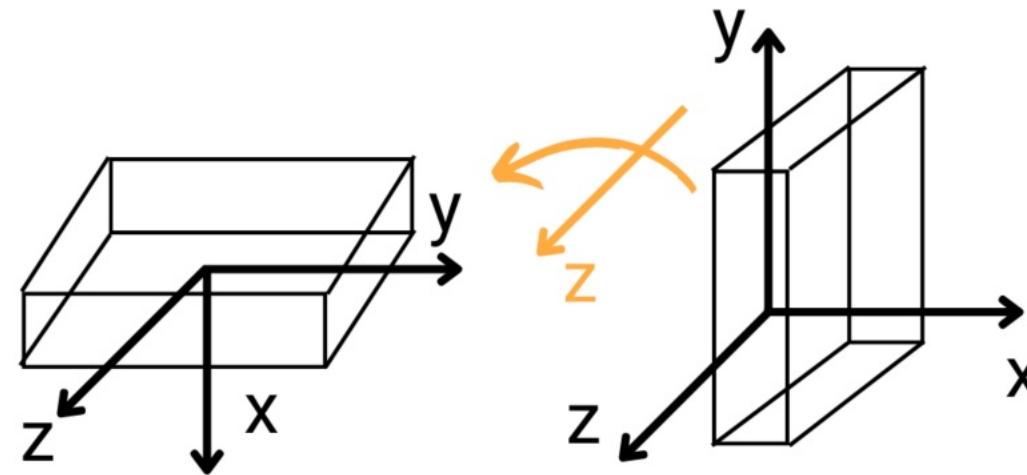
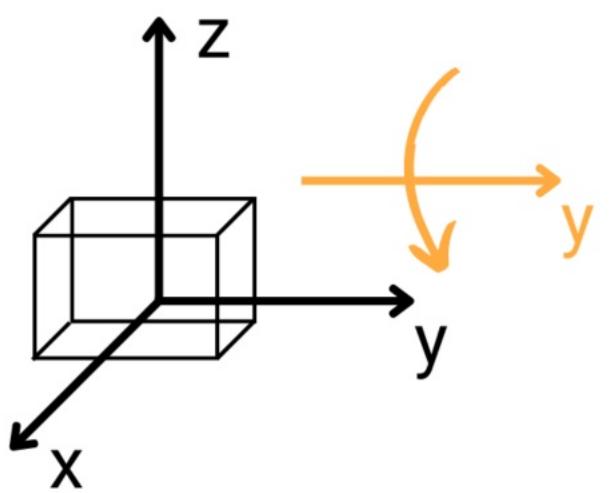
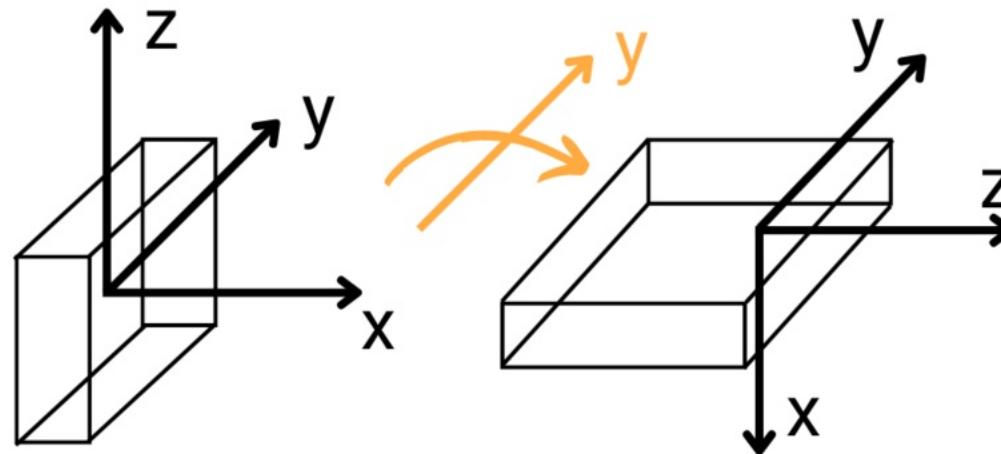
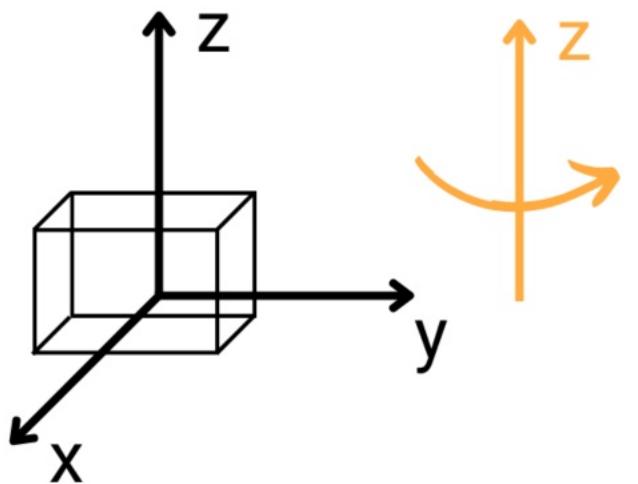










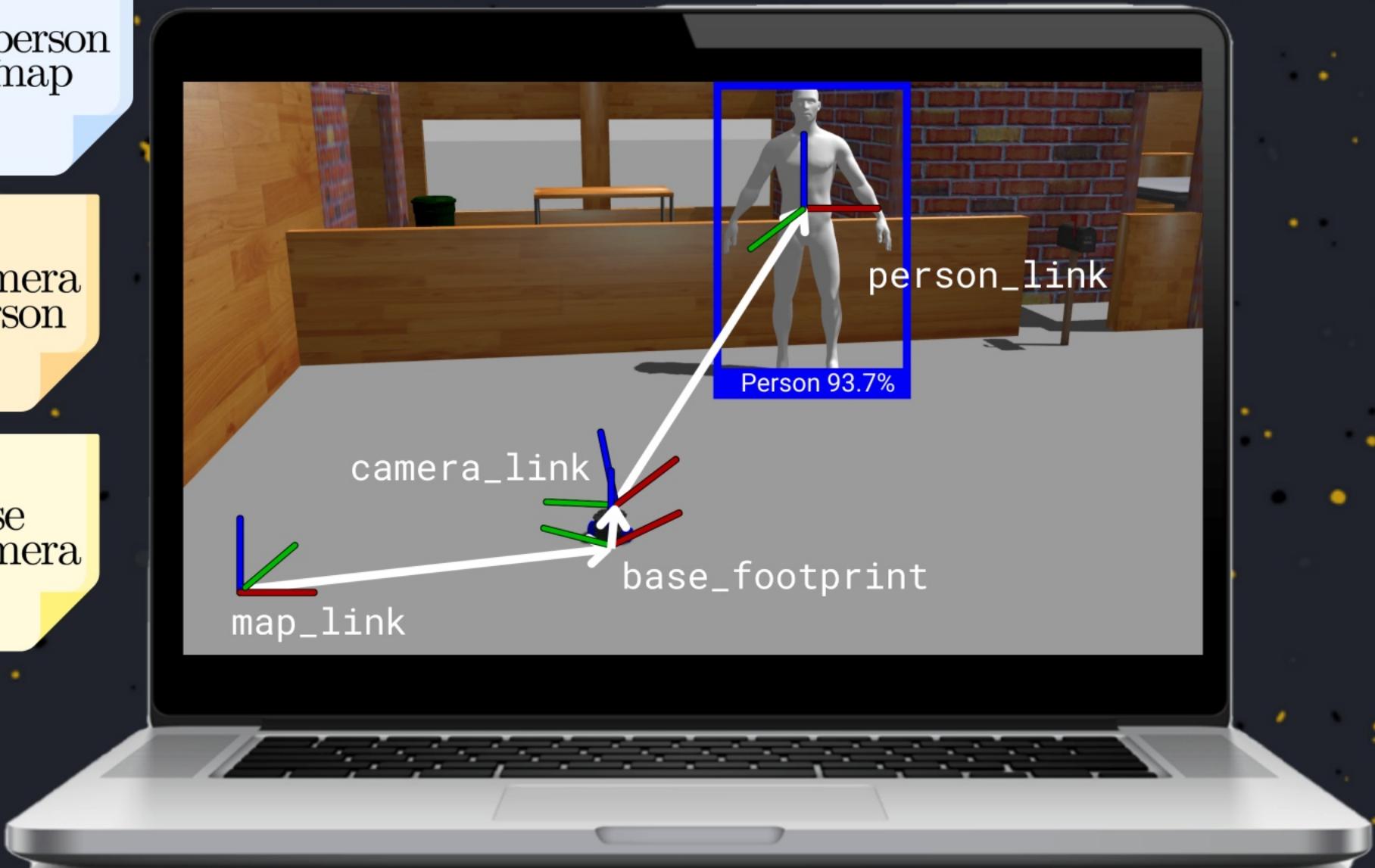


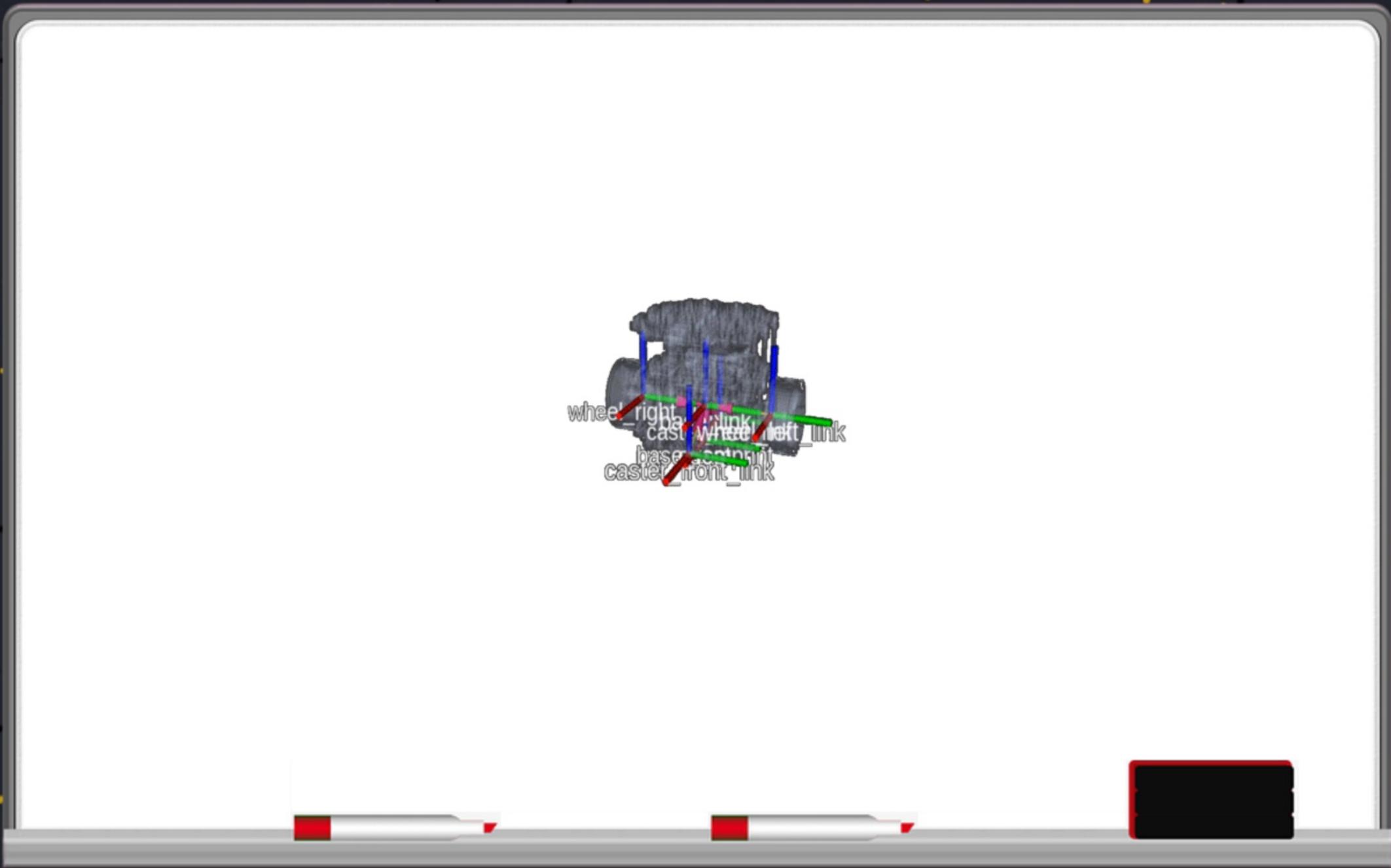
$T_{\text{person}}^{\text{map}} \neq T_{\text{map}}^{\text{person}}$

$T_{\text{person}}^{\text{camera}}$

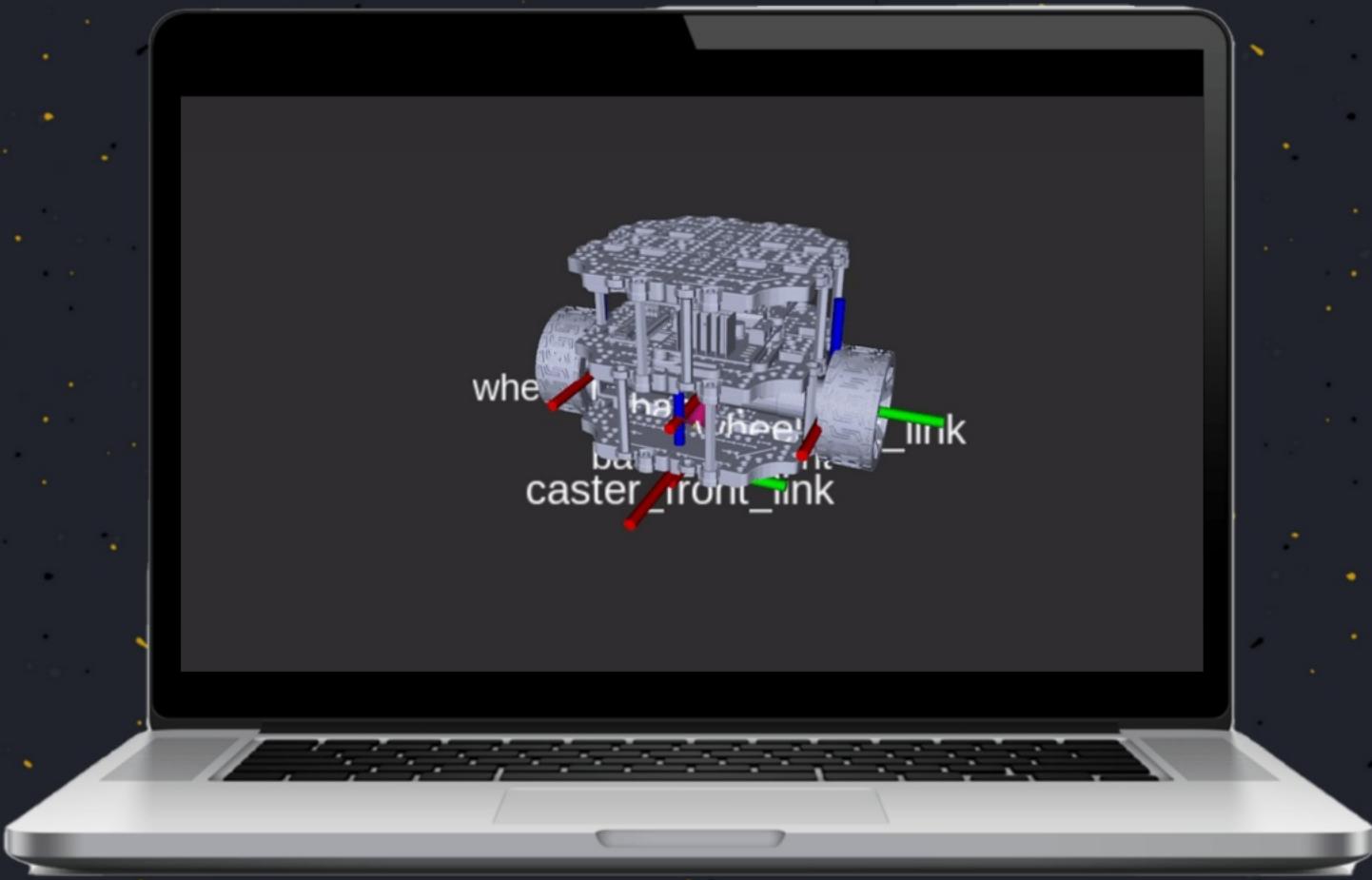
$T_{\text{camera}}^{\text{base}}$

$T_{\text{base}}^{\text{map}}$





TF2 Library



```
<link name="base_link">
  <visual>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </visual>
  <collision>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </collision>
</link>

<joint name="base_joint" type="fixed">
  <parent link="base_footprint"/>
  <child link="base_link" />
  <origin xyz="0 0 0.033" rpy="0 0 0"/>
</joint>

<joint name="wheel_right_joint" type="continuous">
  <origin xyz="0 0 0" rpy="0 0 0" />
  <parent link="base_link" />
  <child link="wheel_right_link" />
  <axis xyz="0 1 0" />
</joint>
```

robot_state_publisher



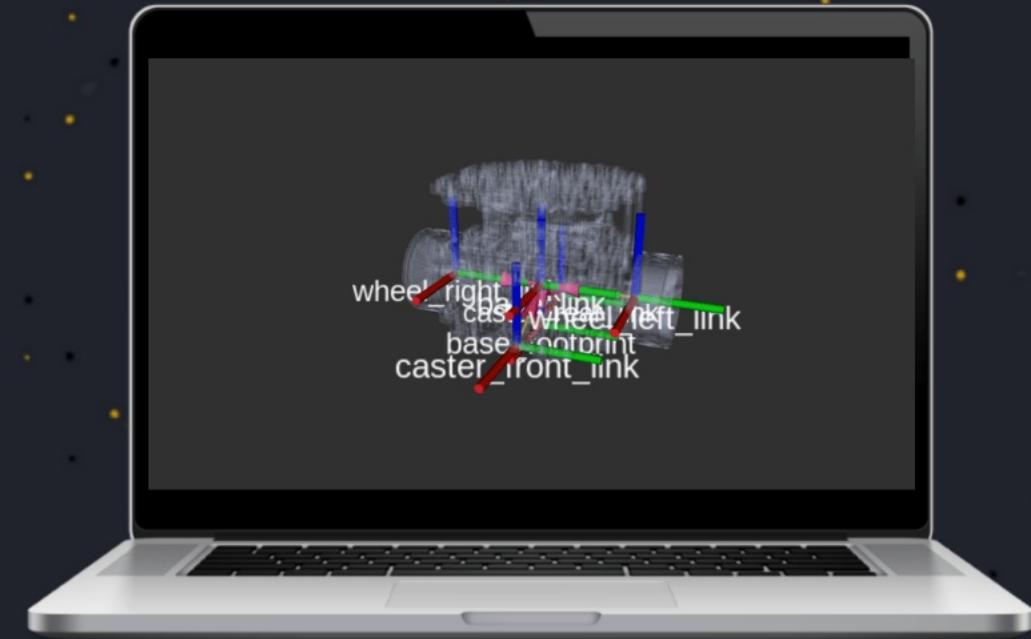
```
<link name="base_link">
  <visual>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </visual>
  <collision>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </collision>
</link>

<joint name="base_joint" type="fixed">
  <parent link="base_footprint"/>
  <child link="base_link" />
  <origin xyz="0 0 0.033" rpy="0 0 0"/>
</joint>

<joint name="wheel_right_joint" type="continuous">
  <origin xyz="0 0 0" rpy="0 0 0" />
  <parent link="base_link" />
  <child link="wheel_right_link" />
  <axis xyz="0 1 0" />
</joint>
```

robot_state_publisher

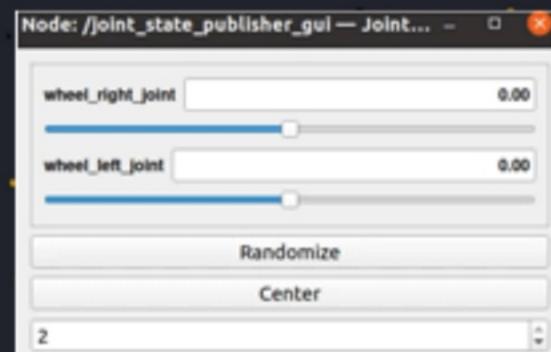
/tf_static



```
<link name="base_link">
  <visual>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </visual>
  <collision>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </collision>
</link>
```

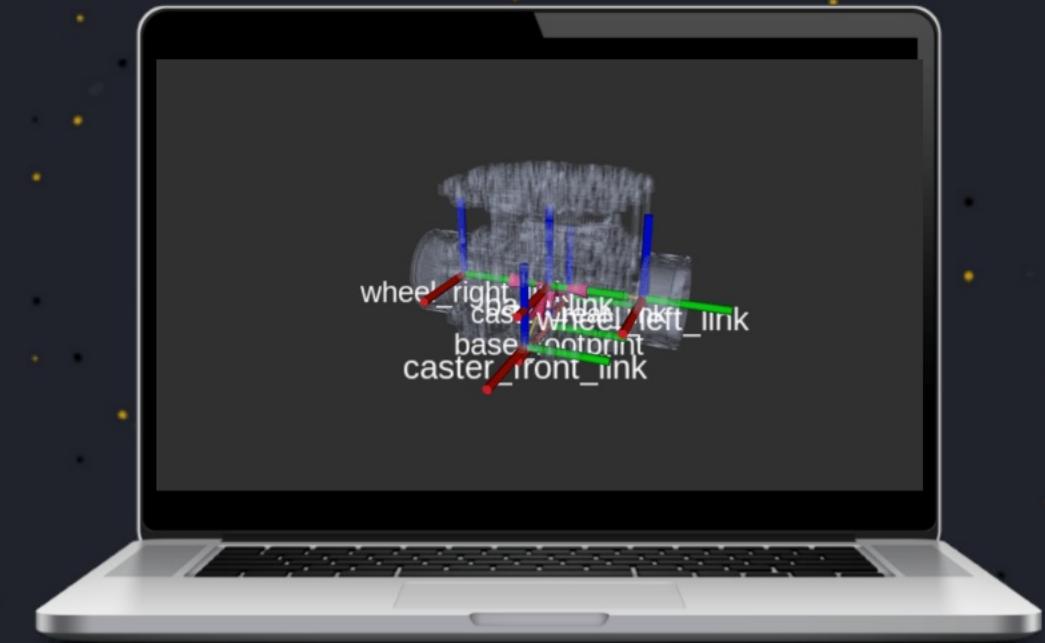
```
<joint name="base_joint" type="fixed">
  <parent link="base_footprint"/>
  <child link="base_link" />
  <origin xyz="0 0 0.033" rpy="0 0 0"/>
</joint>
```

```
<joint name="wheel_right_joint" type="continuous">
  <origin xyz="0 0 0" rpy="0 0 0" />
  <parent link="base_link" />
  <child link="wheel_right_link" />
  <axis xyz="0 1 0" />
</joint>
```



robot_state_publisher

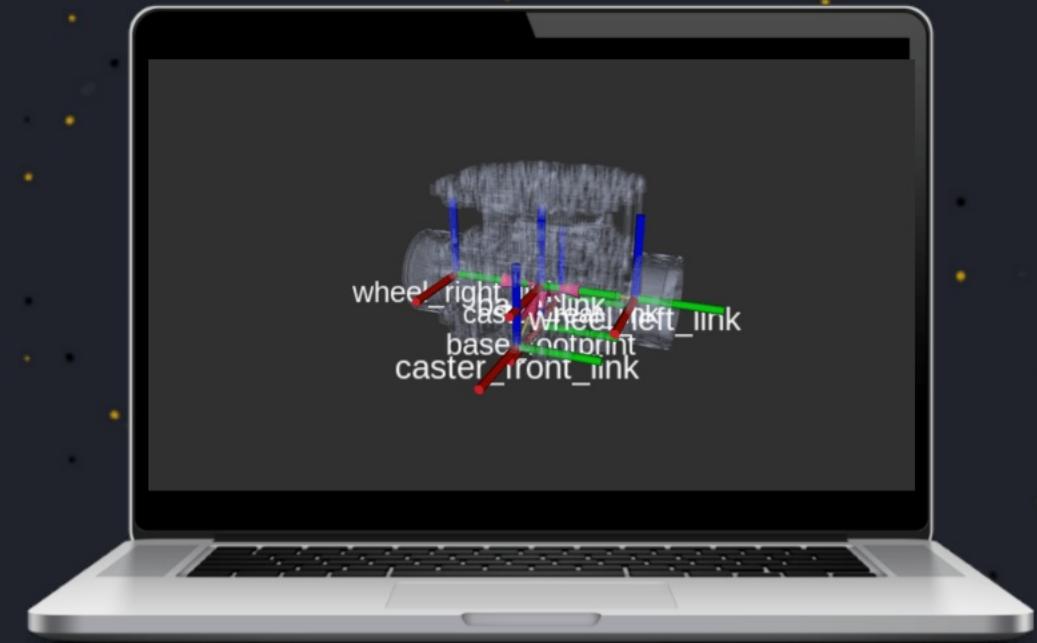
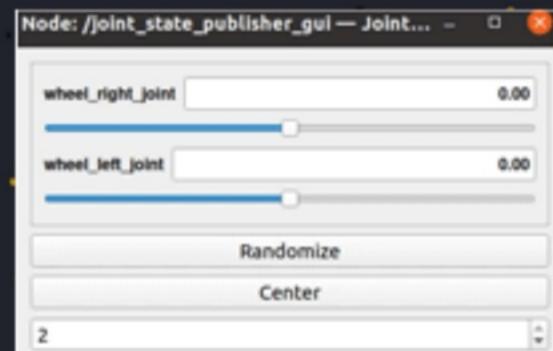
/tf_static



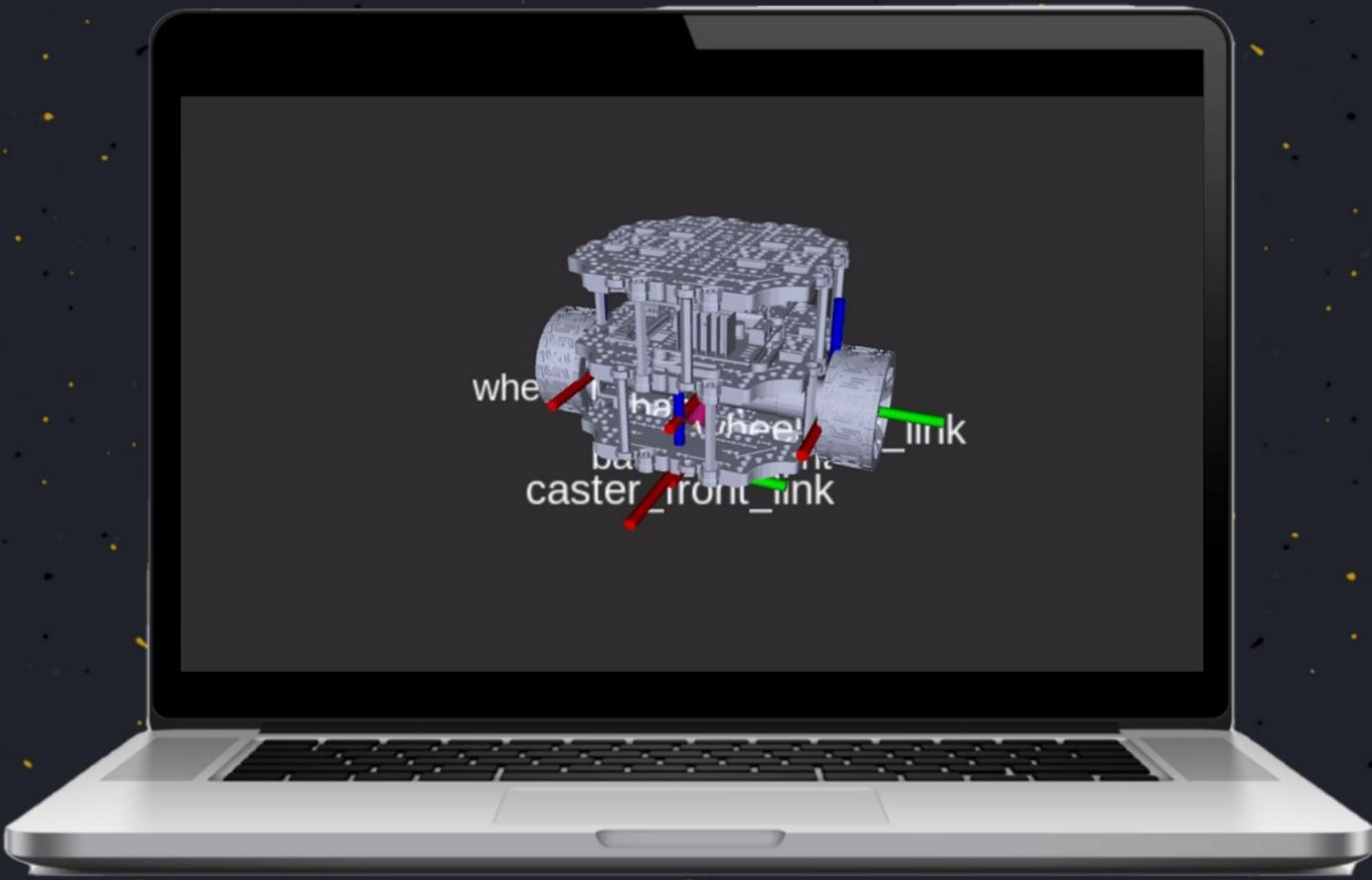
```
<link name="base_link">
  <visual>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </visual>
  <collision>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <mesh filename="base_link.STL" />
    </geometry>
  </collision>
</link>
```

```
<joint name="base_joint" type="fixed">
  <parent link="base_footprint"/>
  <child link="base_link" />
  <origin xyz="0 0 0.033" rpy="0 0 0"/>
</joint>
```

```
<joint name="wheel_right_joint" type="continuous">
  <origin xyz="0 0 0" rpy="0 0 0" />
  <parent link="base_link" />
  <child link="wheel_right_link" />
  <axis xyz="0 1 0" />
</joint>
```



TF2 Library



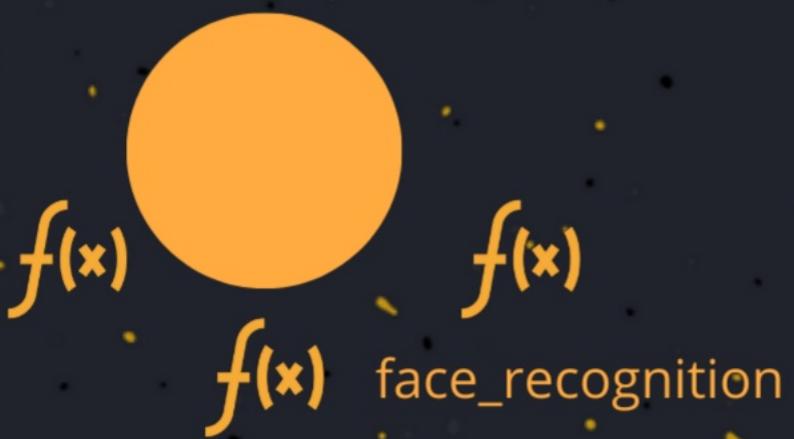


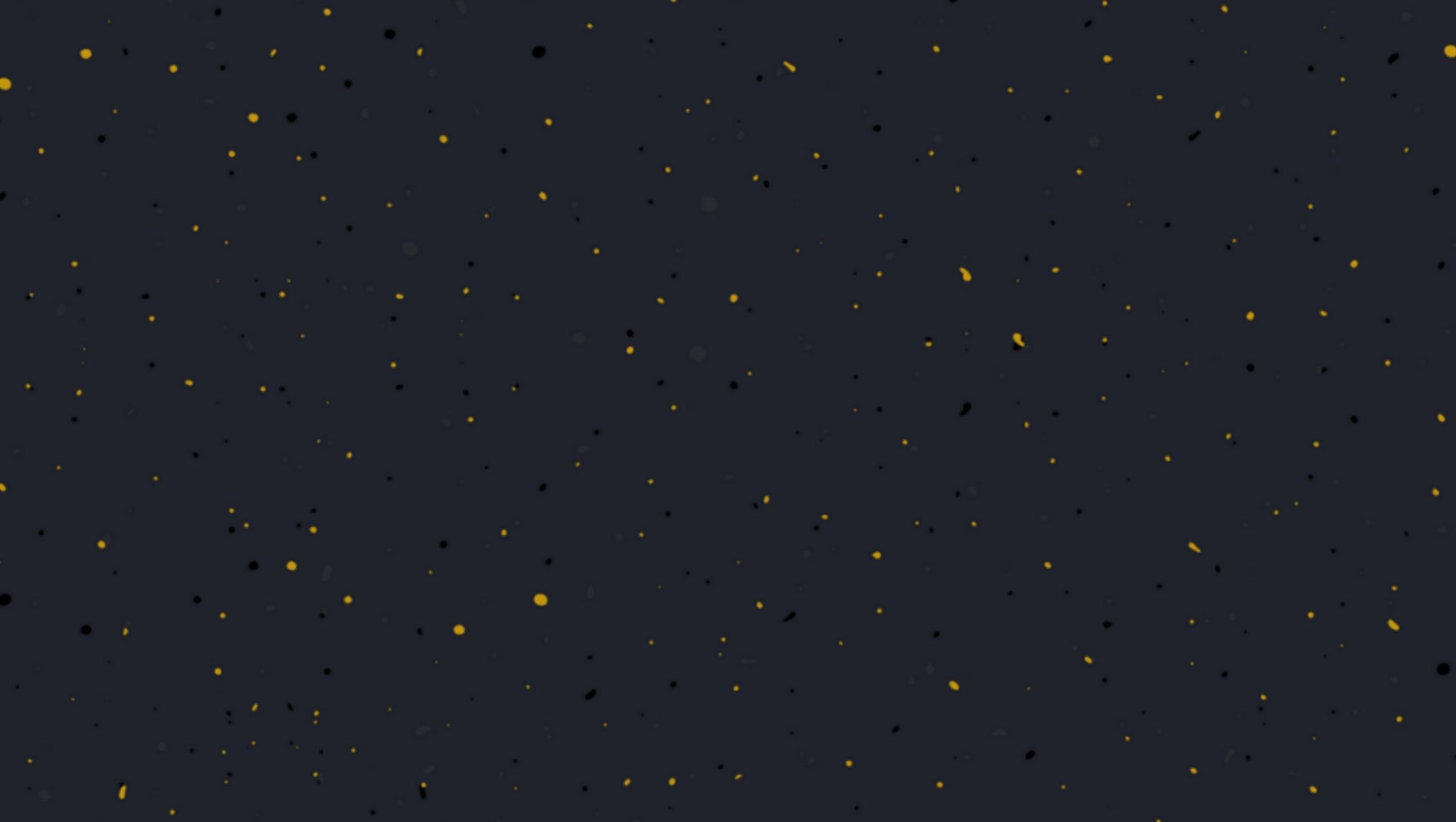
$f(\mathbf{x})$

$f(\mathbf{x})$ face_recognition

$f(\mathbf{x})$

$f(\mathbf{x})$





$f(\mathbf{x})$

$f(\mathbf{x})$ $f(\mathbf{x})$

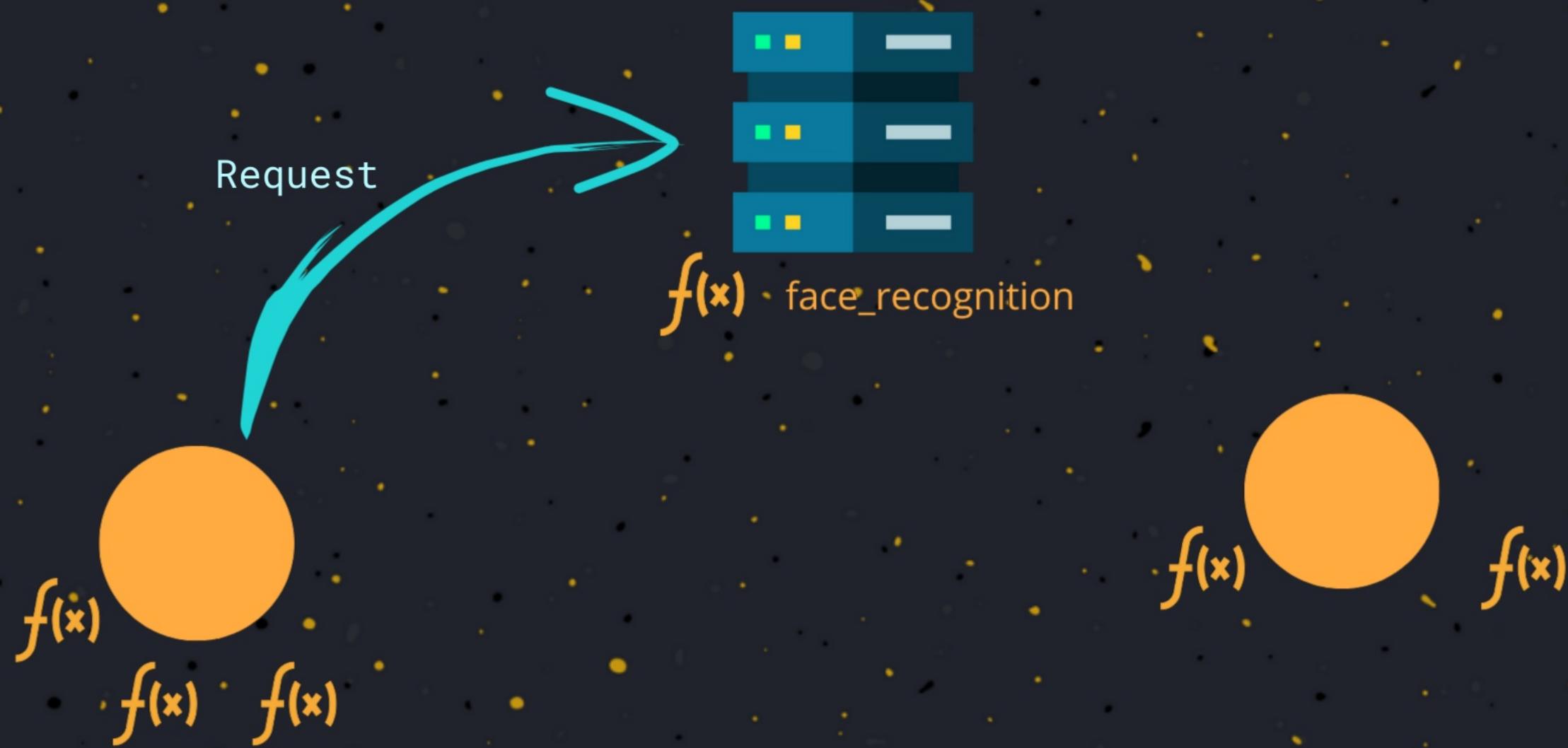


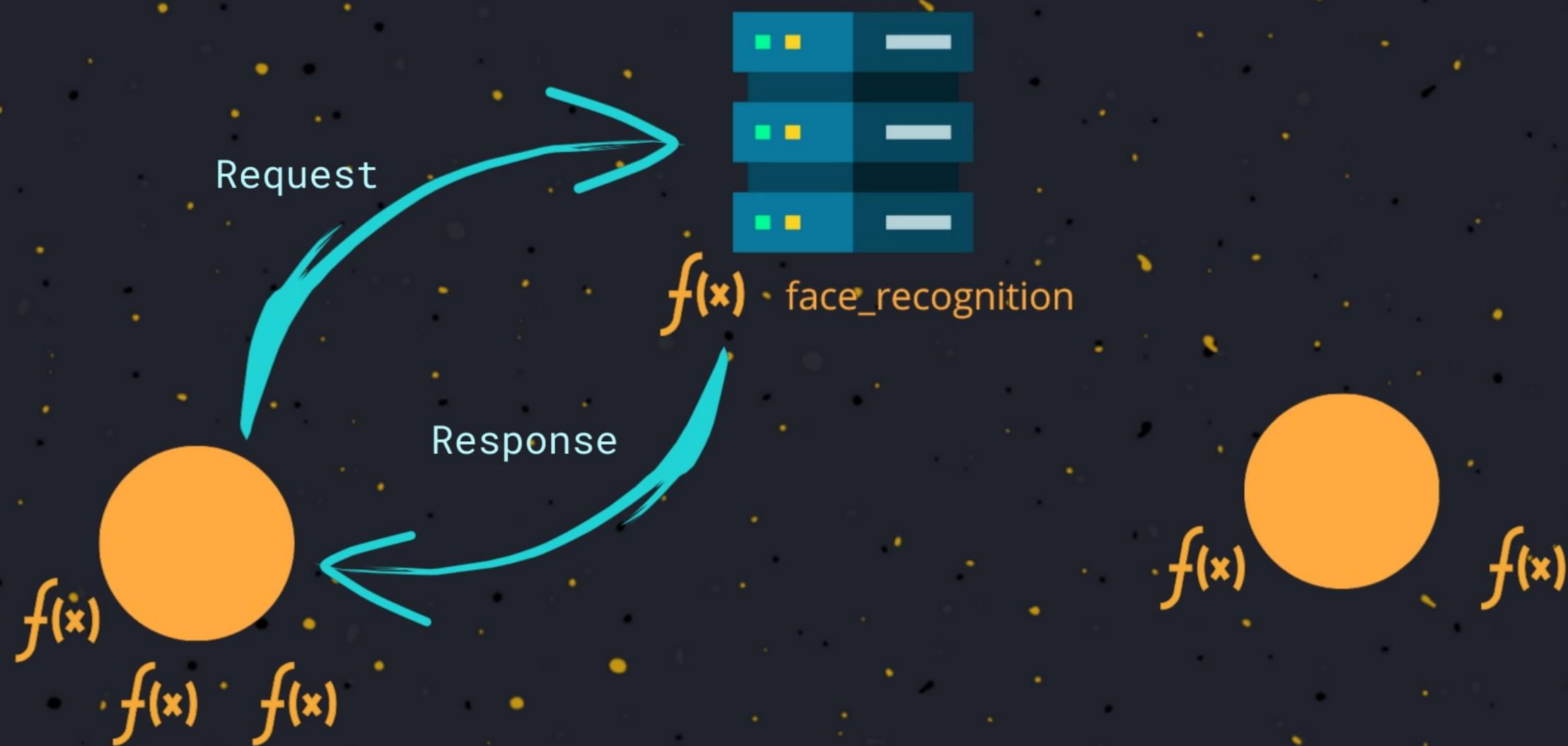
$f(\mathbf{x})$ face_recognition

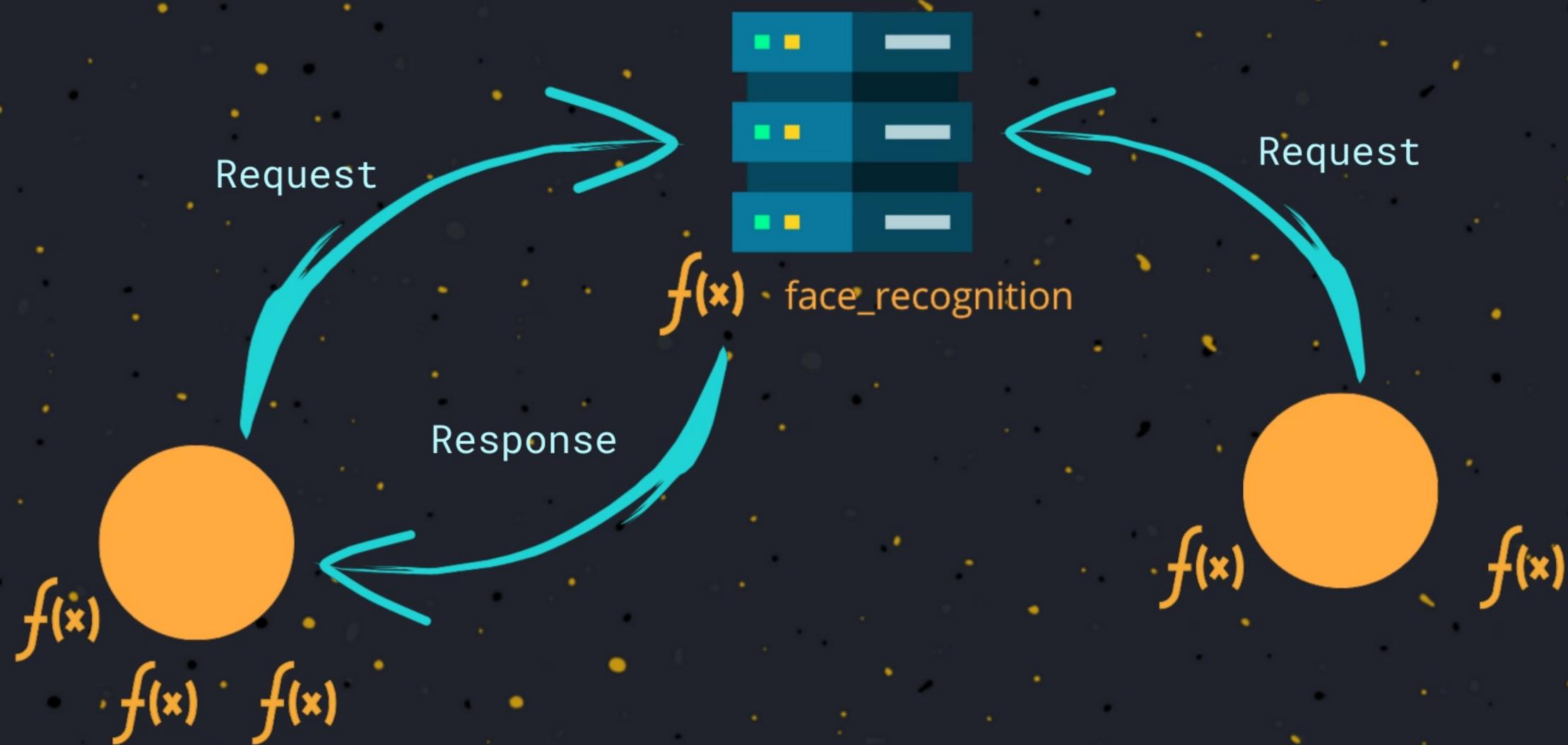


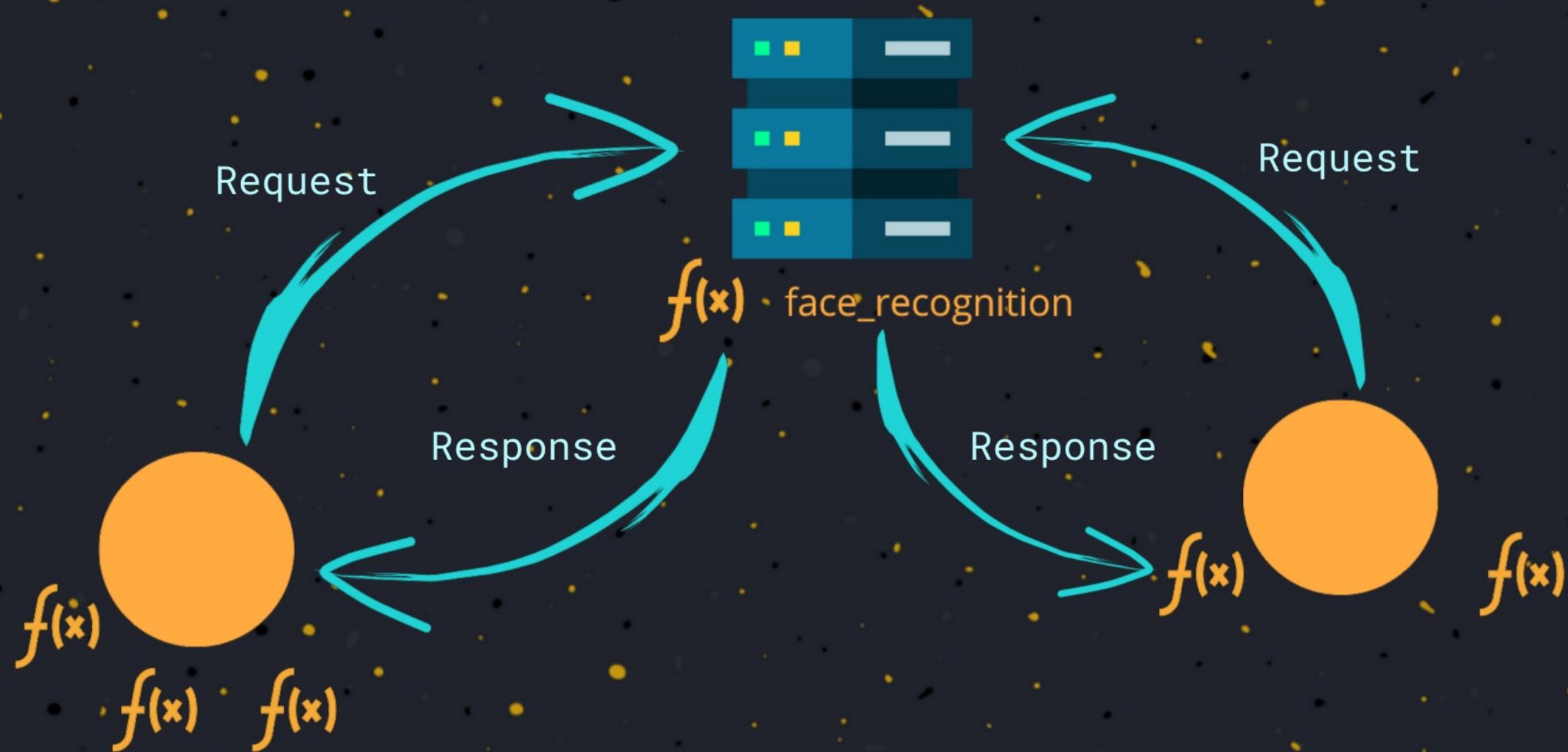
$f(\mathbf{x})$

$f(\mathbf{x})$









Service



Client

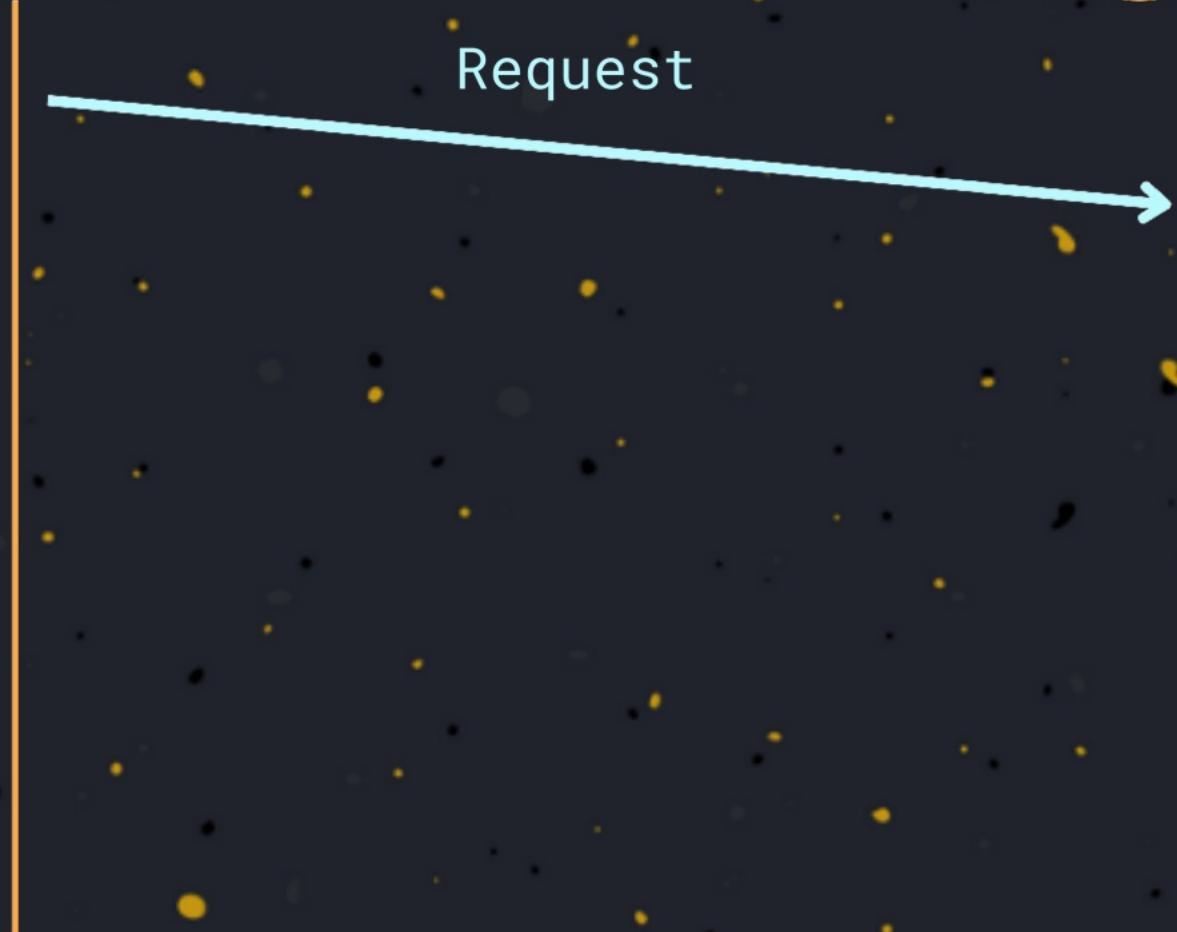


Server

Service



Request



Client

Server

Service



Request



Client

Server

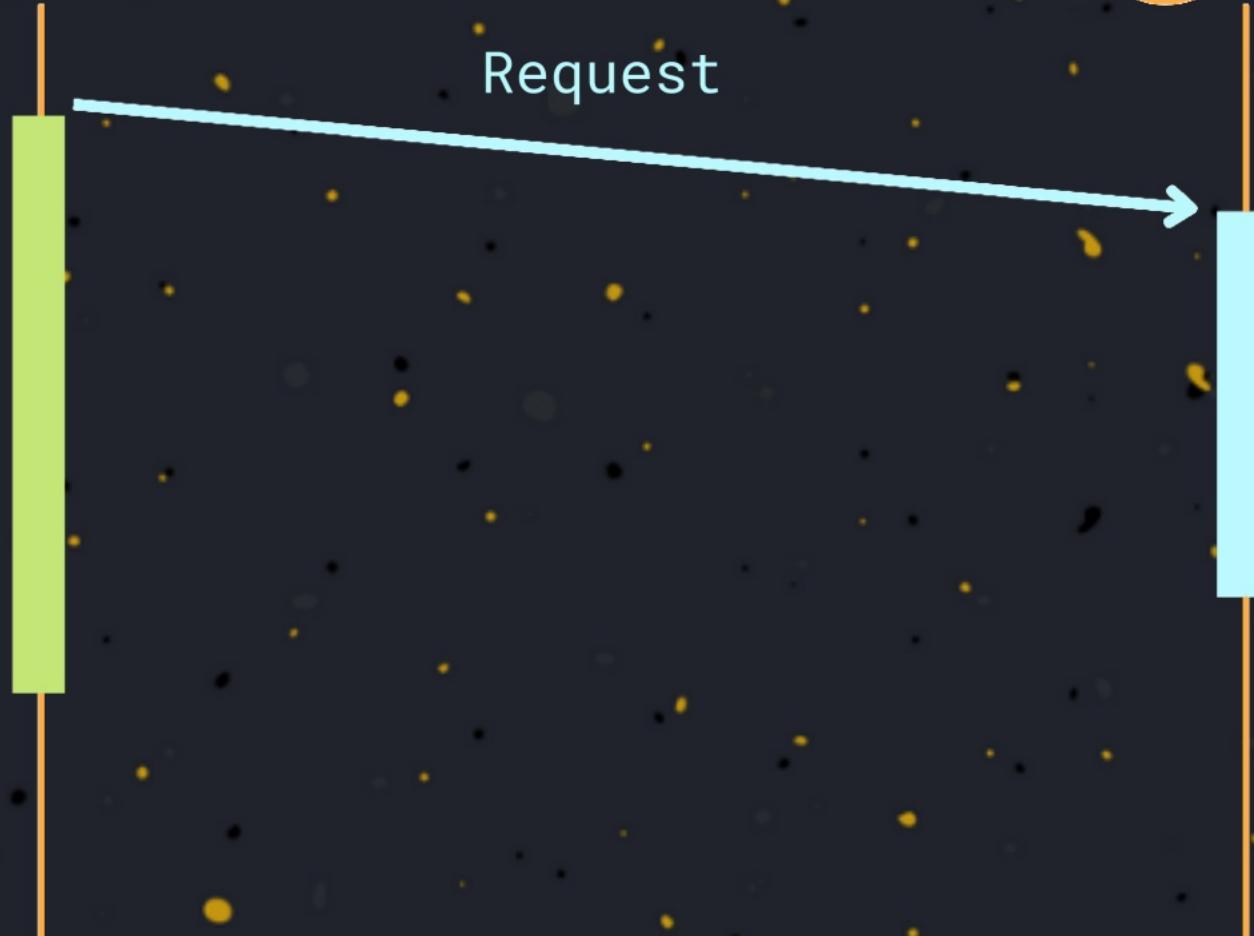
Service



Request

Client

Server



Service

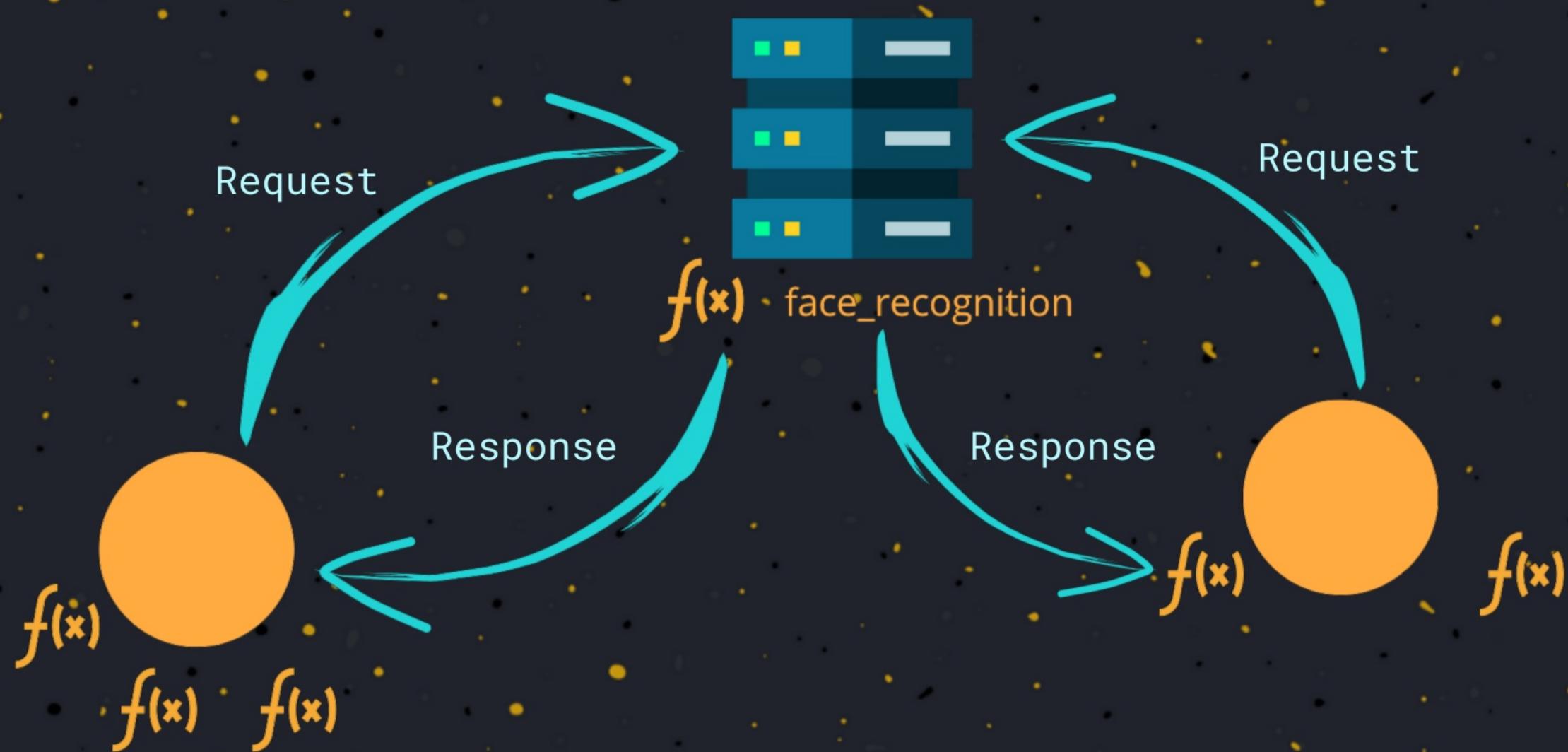


Request

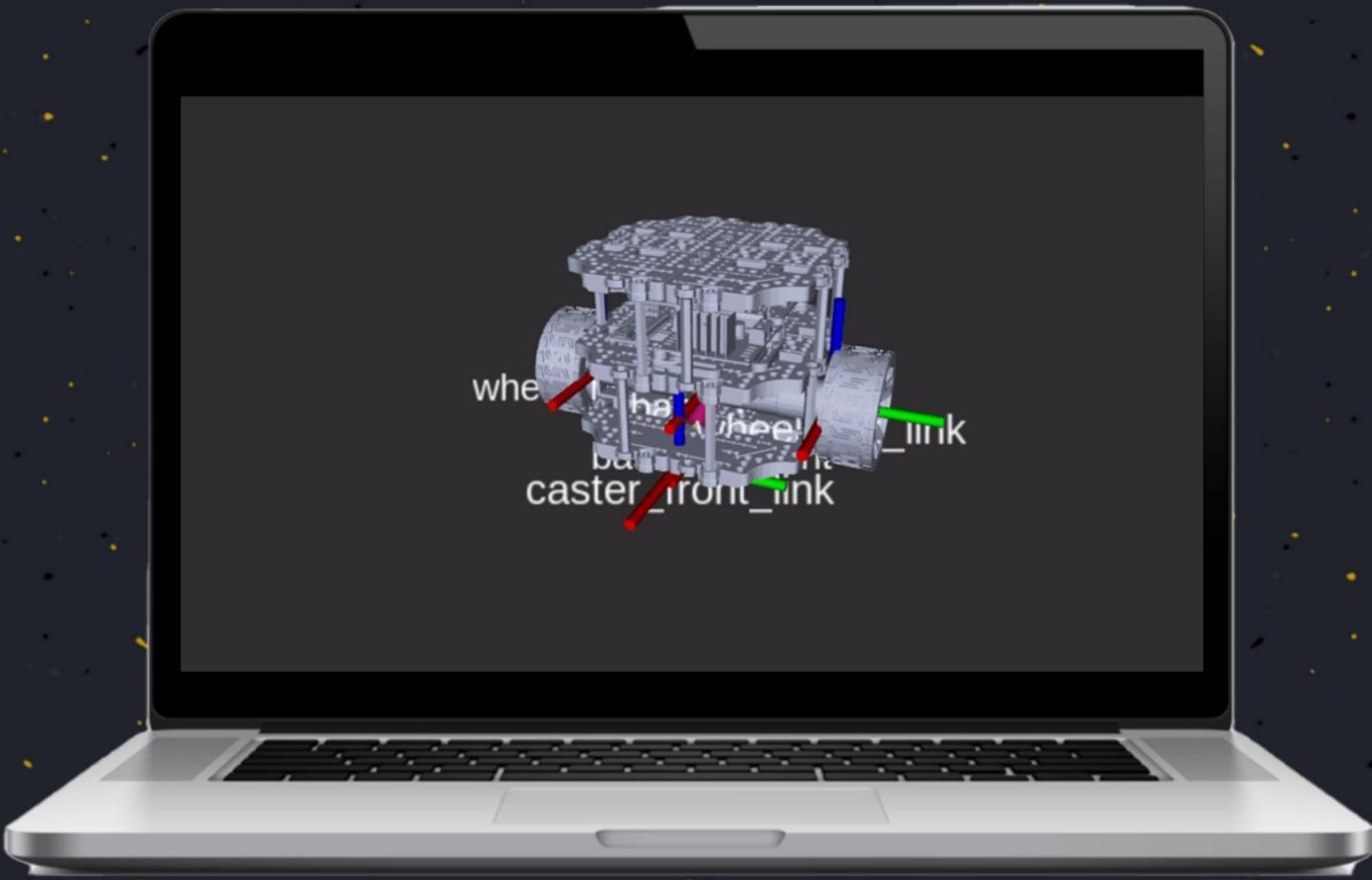
Response

Client

Server

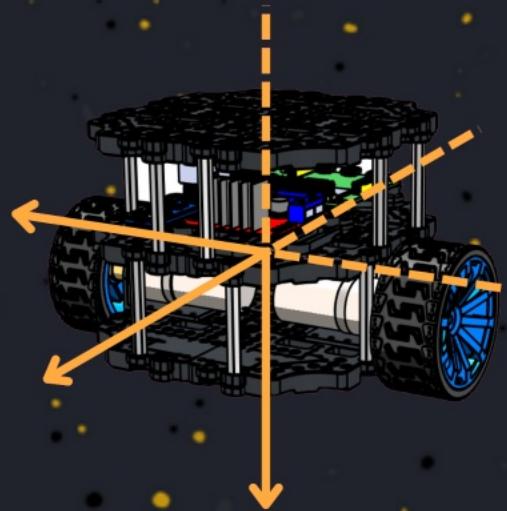


TF2 Library



Angle Representations

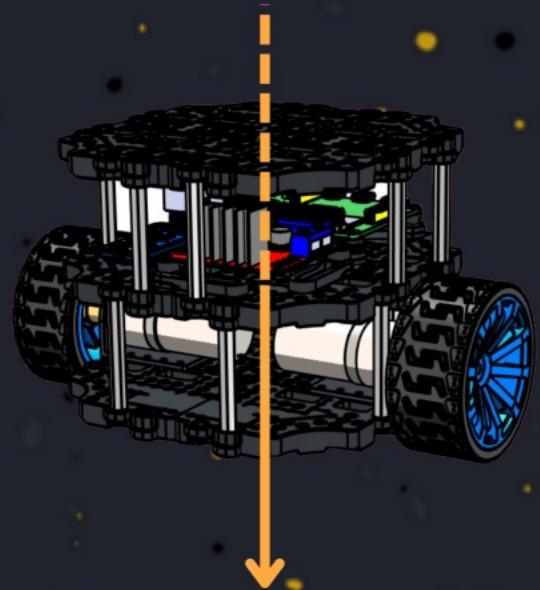
Euler Angles



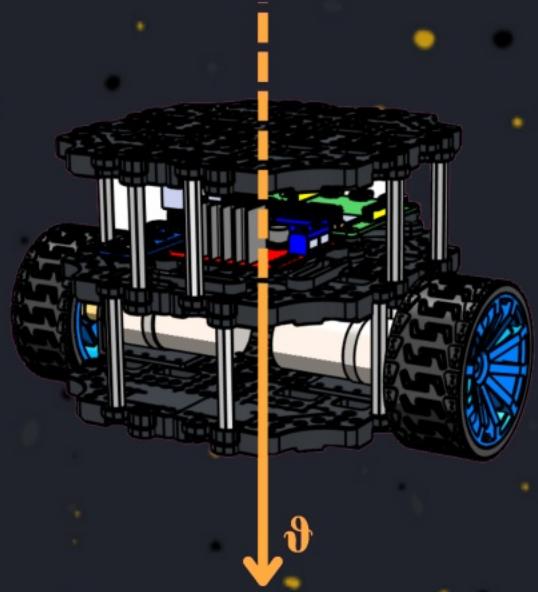
Quaternion



Euler Angles

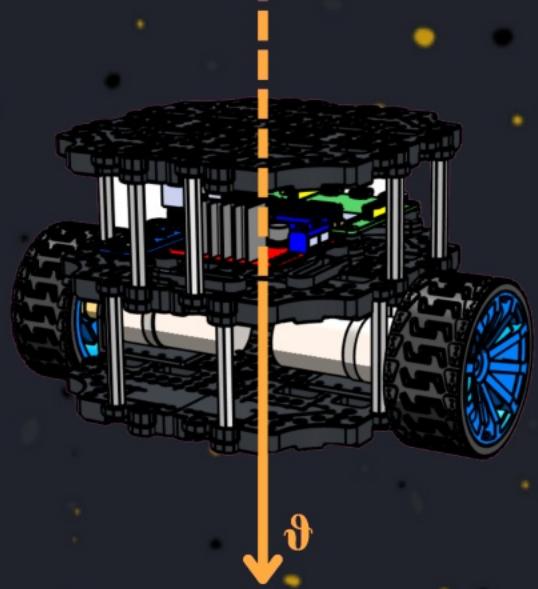


Euler Angles

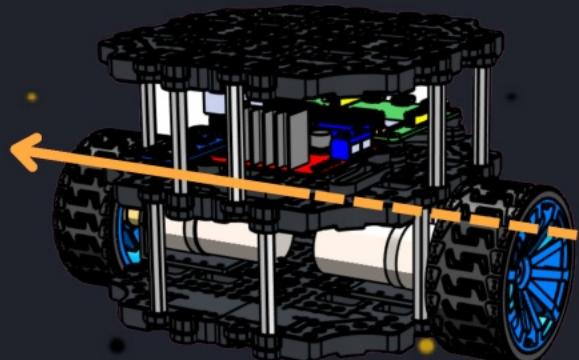


$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

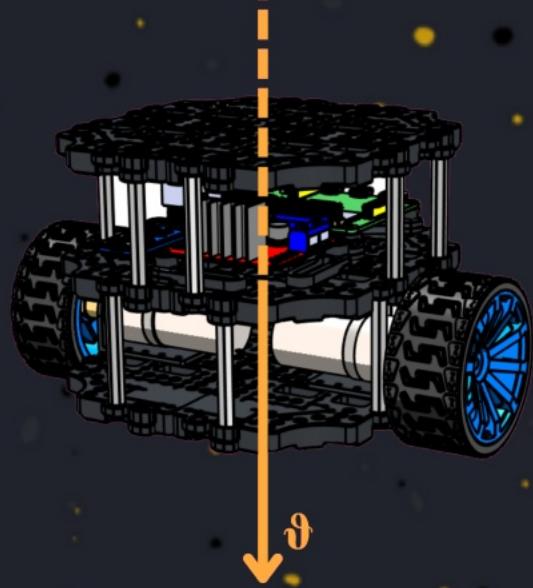
Euler Angles



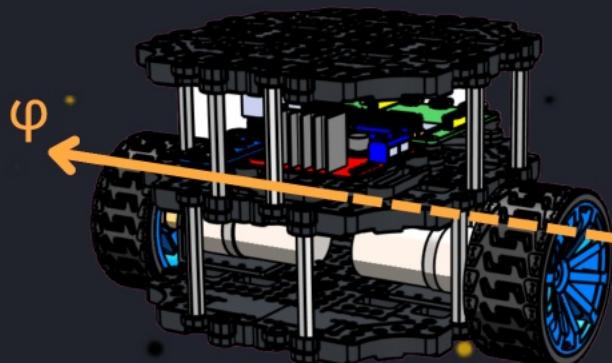
$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Euler Angles

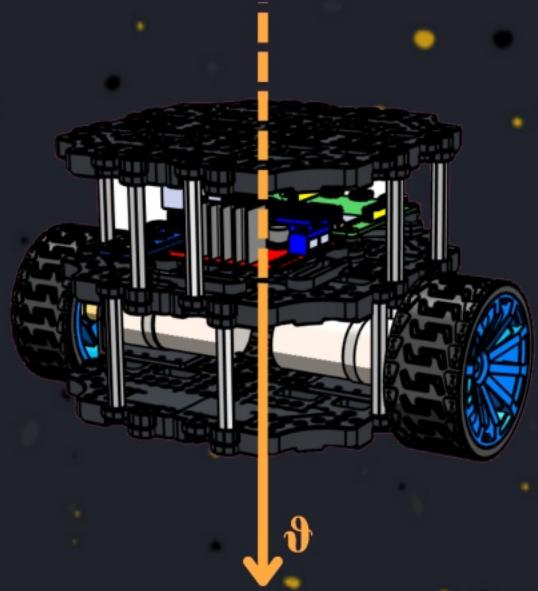


$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

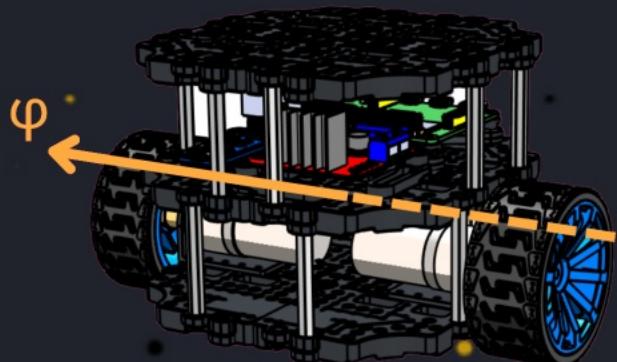


$$\begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix}$$

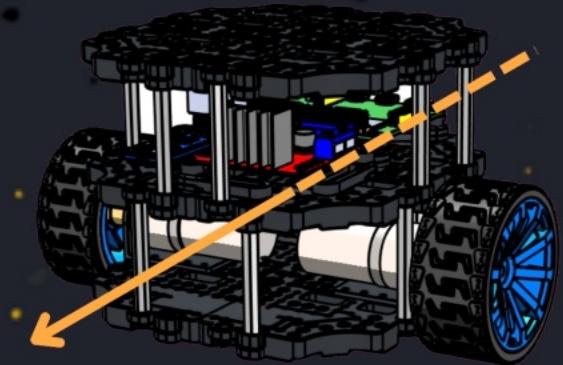
Euler Angles



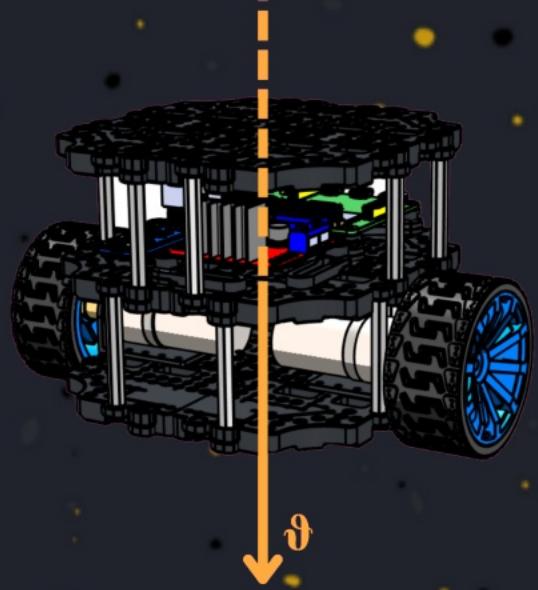
$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



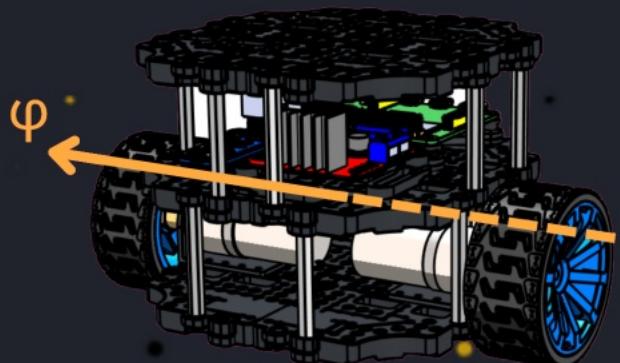
$$\begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix}$$



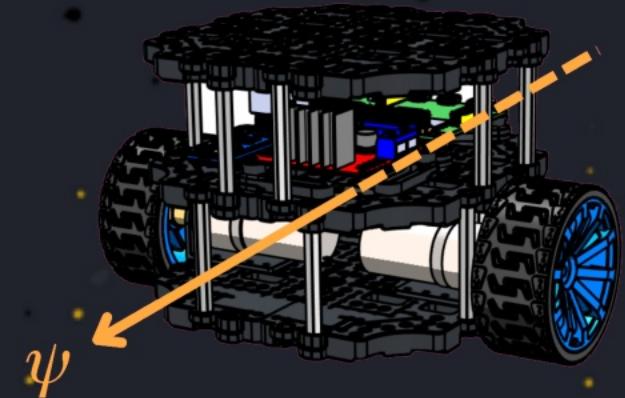
Euler Angles



$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



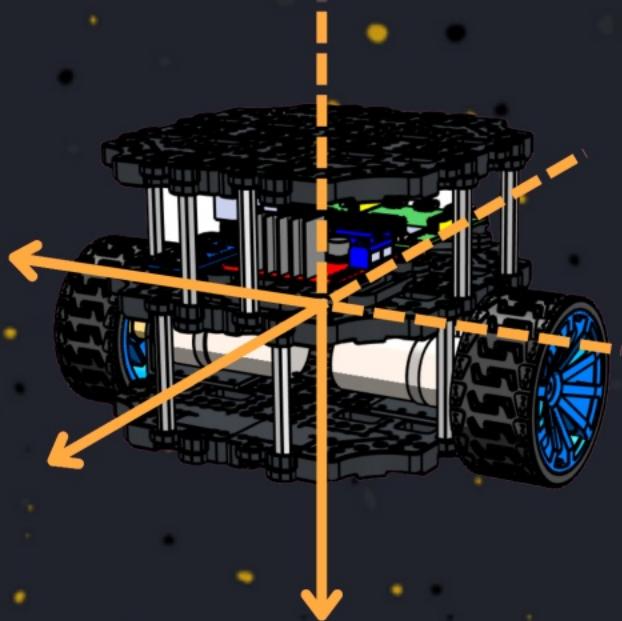
$$\begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix}$$



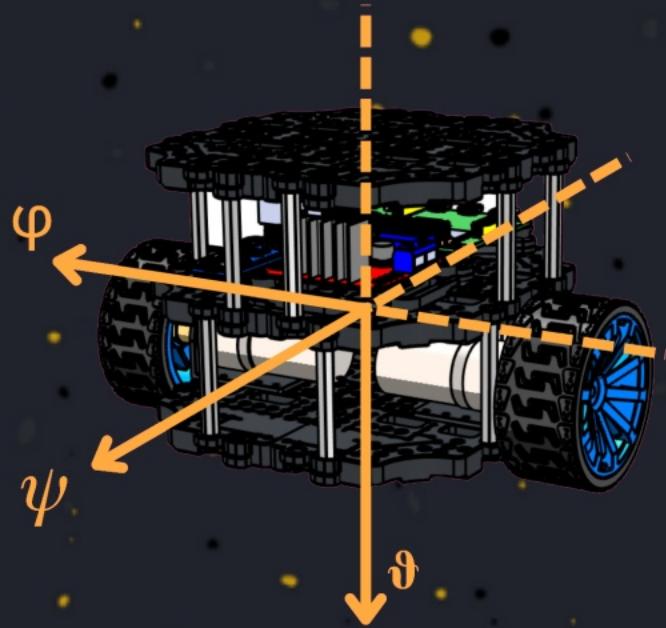
$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & -\sin(\psi) \\ 0 & \sin(\psi) & \cos(\psi) \end{bmatrix}$$

Euler Angles

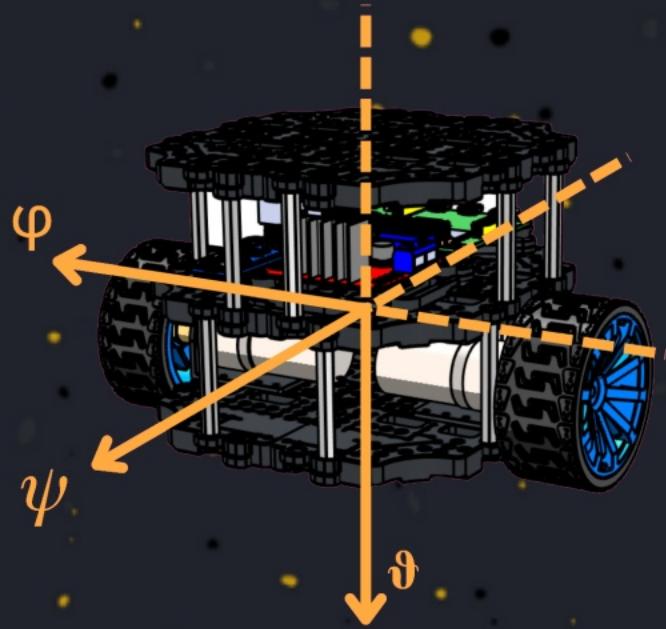
Euler Angles



Euler Angles

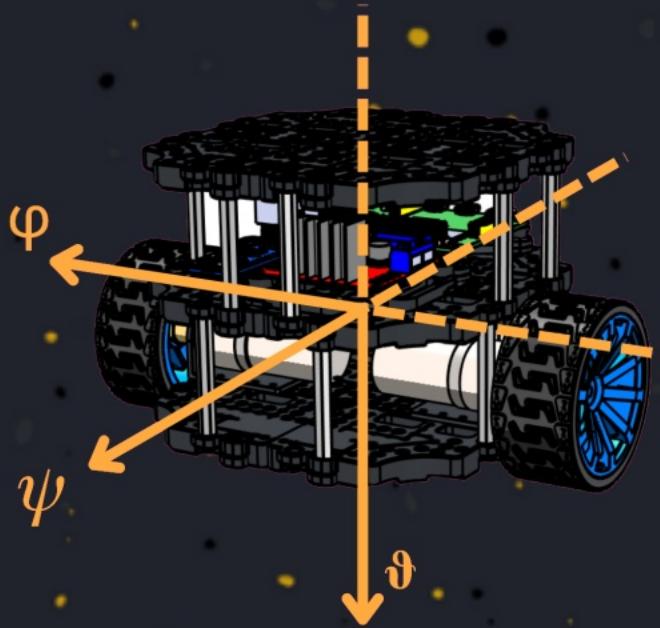


Euler Angles



$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & -\sin(\psi) \\ 0 & \sin(\psi) & \cos(\psi) \end{bmatrix}$$

Euler Angles



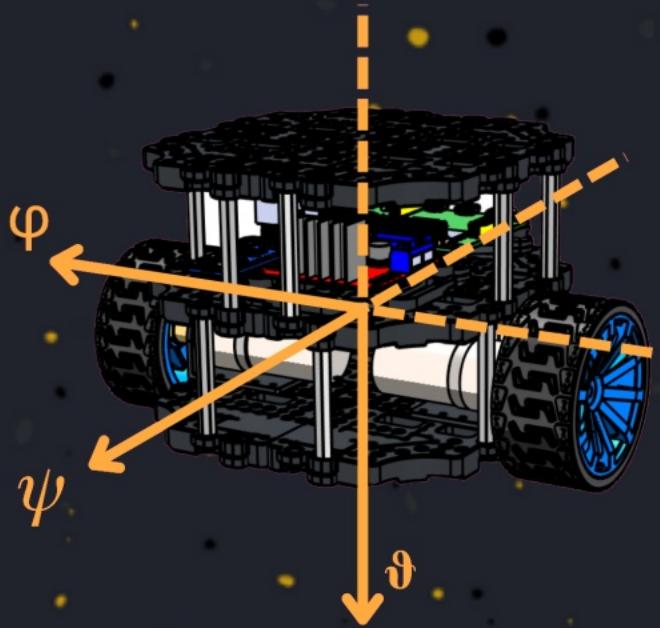
$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & -\sin(\psi) \\ 0 & \sin(\psi) & \cos(\psi) \end{bmatrix}$$

Yaw

Pitch

Roll

Euler Angles



$$\begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

$$\begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) & 0 \\ \sin(\vartheta) & \cos(\vartheta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) \\ 0 & 1 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & -\sin(\psi) \\ 0 & \sin(\psi) & \cos(\psi) \end{bmatrix}$$

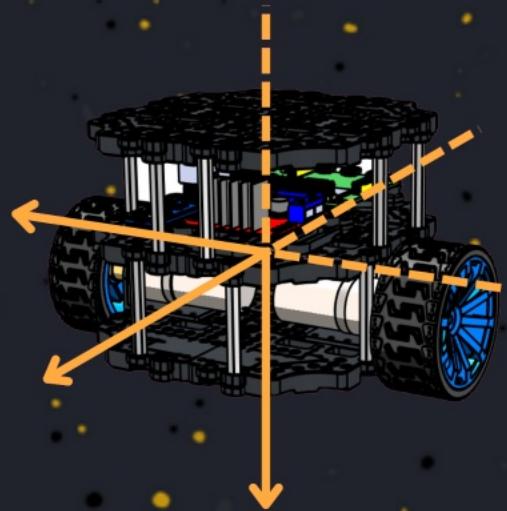
Yaw

Pitch

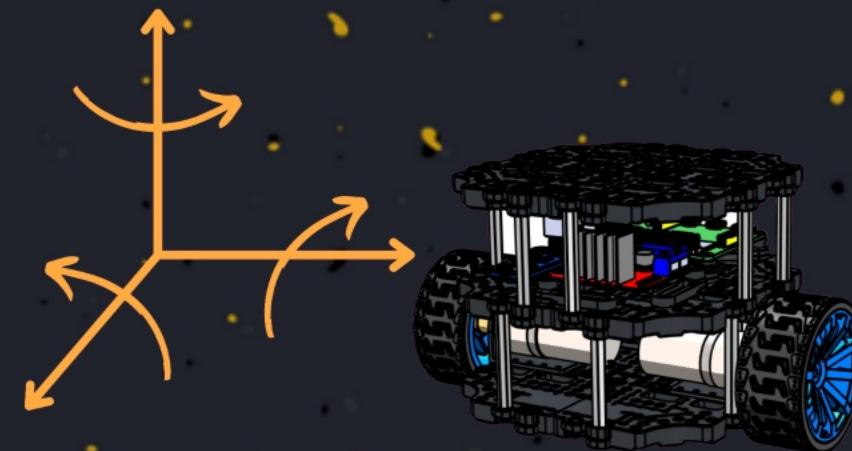
Roll

Angle Representations

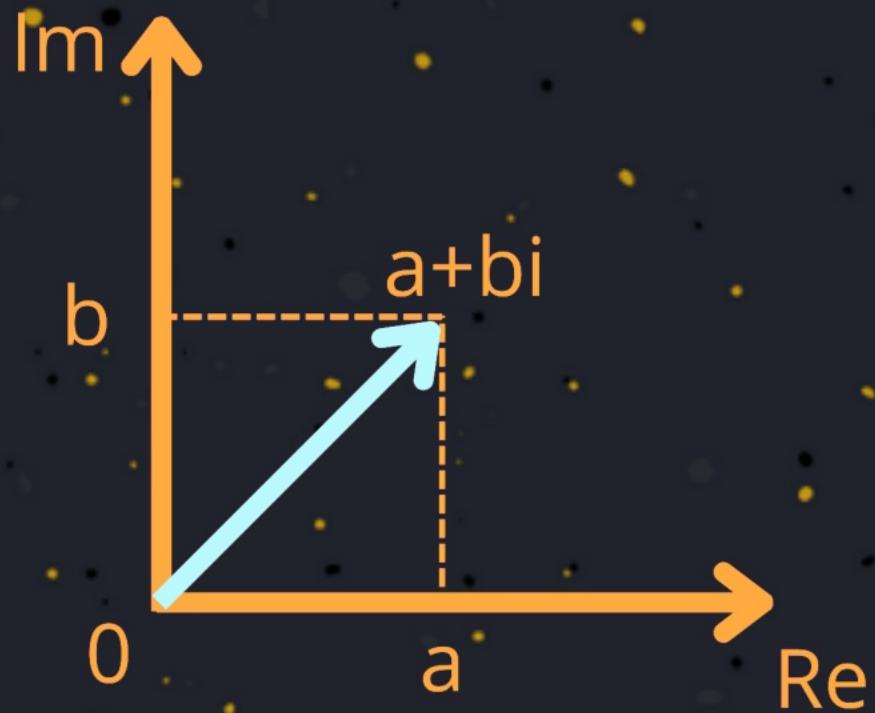
Euler Angles



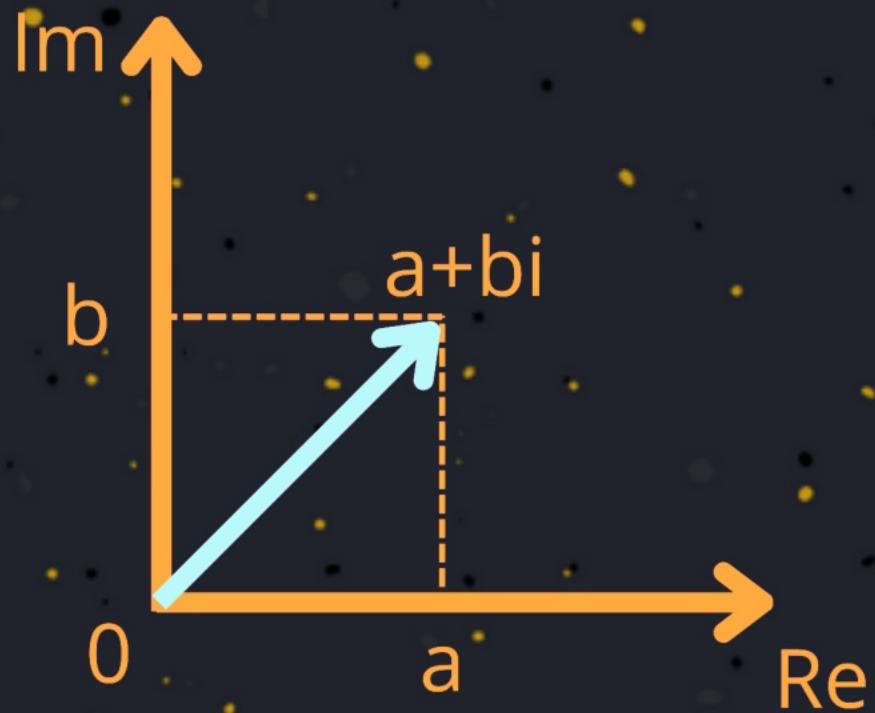
Quaternion



Quaternion

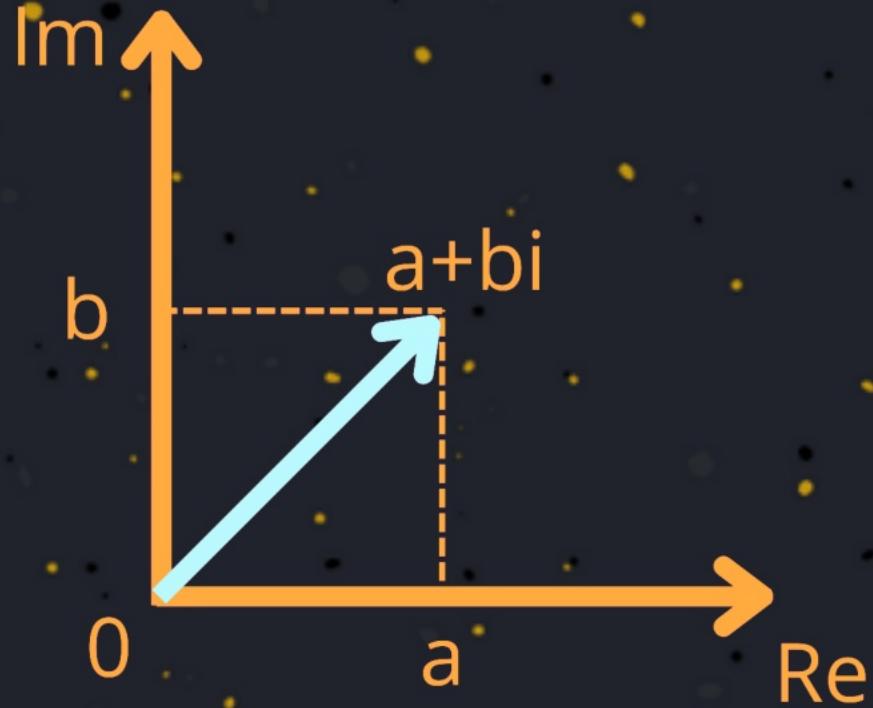


Quaternion



$$q = a + bi + cj + dk$$

Quaternion

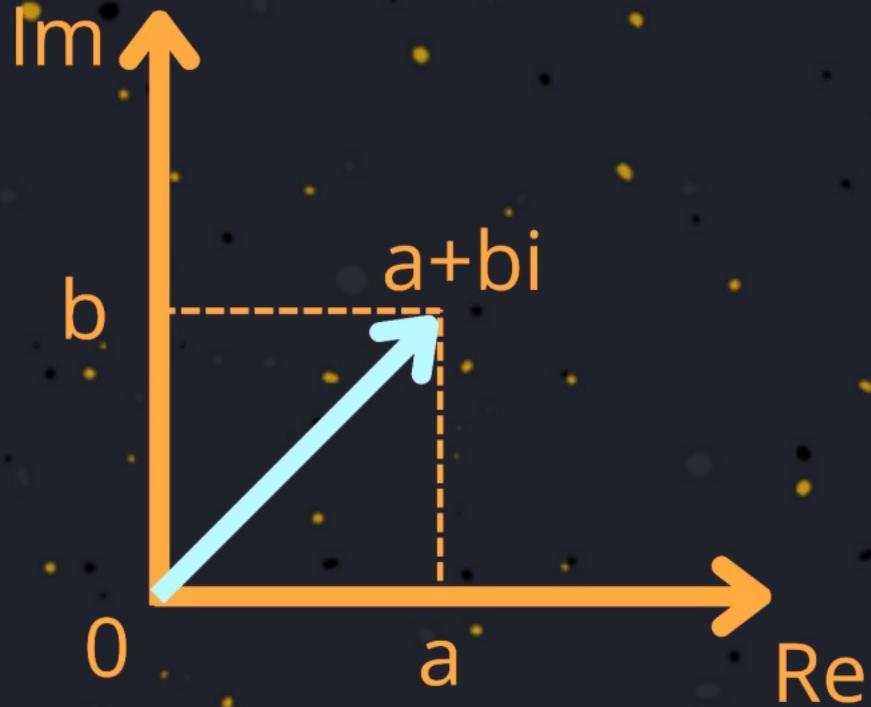


$$q = a + bi + cj + dk$$

Unitary

$$a^2 + b^2 + c^2 + d^2 = 1$$

Quaternion



$$q = a + bi + cj + dk$$

Unitary

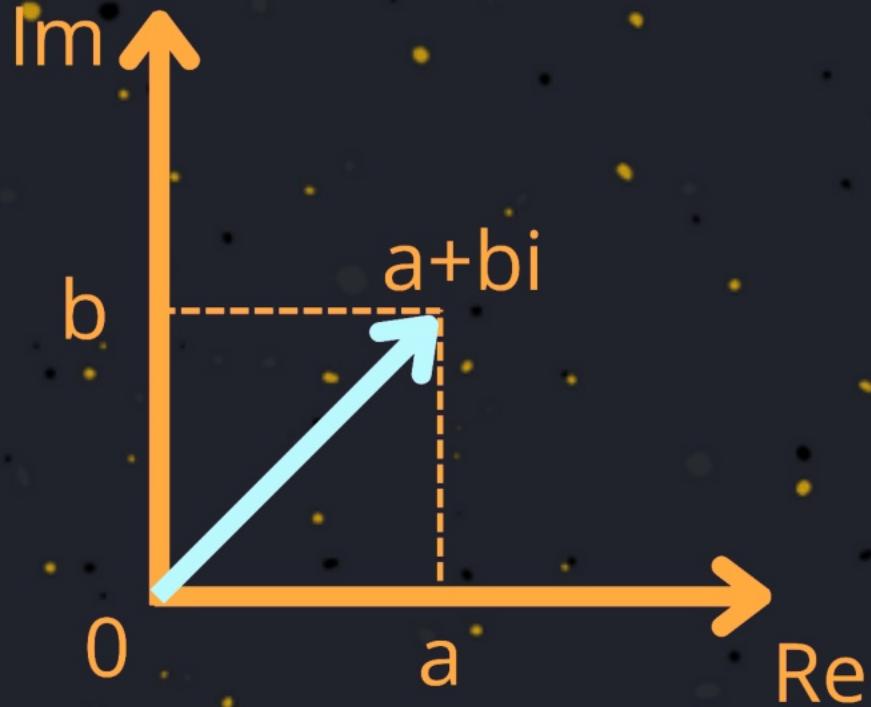
$$a^2 + b^2 + c^2 + d^2 = 1$$

Rotation Composition

$$q_1 = \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{bmatrix}$$

$$q_2 = \begin{bmatrix} a_2 \\ b_2 \\ c_2 \\ d_2 \end{bmatrix}$$

Quaternion



$$q = a + bi + cj + dk$$

Unitary

$$a^2 + b^2 + c^2 + d^2 = 1$$

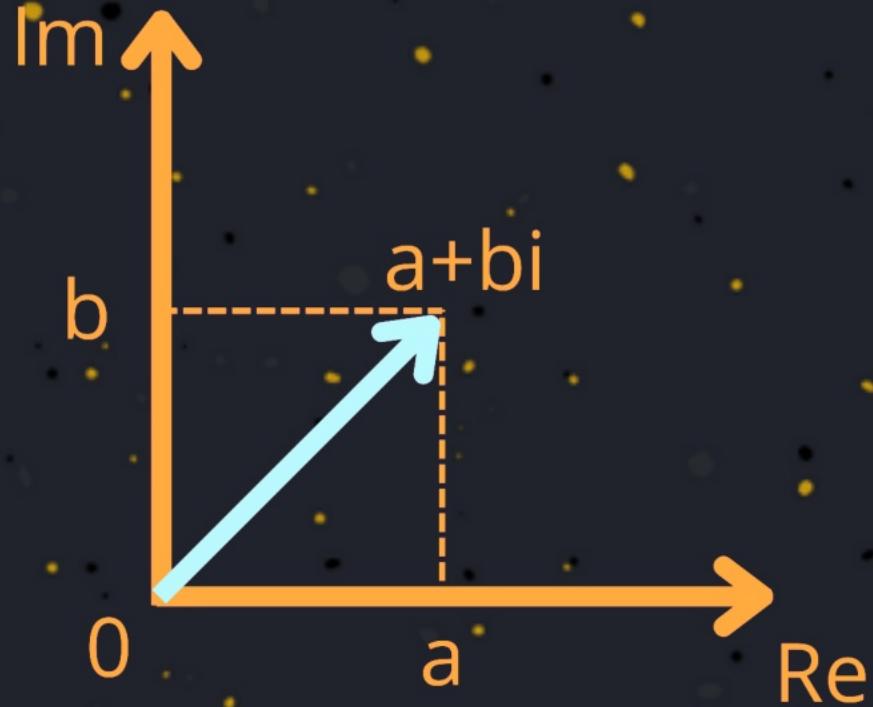
Rotation Composition

$$q_1 = \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{bmatrix}$$

$$q_2 = \begin{bmatrix} a_2 \\ b_2 \\ c_2 \\ d_2 \end{bmatrix}$$

$$q_1 \cdot q_2$$

Quaternion



$$q = a + bi + cj + dk$$

Unitary

$$a^2 + b^2 + c^2 + d^2 = 1$$

Rotation Composition

$$q_1 = \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{bmatrix}$$

$$q_2 = \begin{bmatrix} a_2 \\ b_2 \\ c_2 \\ d_2 \end{bmatrix}$$

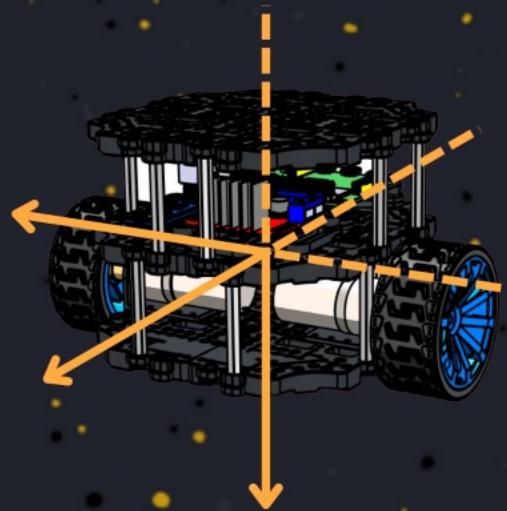
$$q_1 \cdot q_2$$

Inverse

$$q^{-1} = a - bi - cj - dk$$

Angle Representations

Euler Angles



Quaternion



TF2 Library

