



Cozmo: Animation pipeline for a physical robot

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Anki



COZMO®



anki®





Who are we?

Daria Jerjomina

Animation Tools Engineer at Anki

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Molly Jameson

Software Engineer at Anki

Molly@anki.com





What is this talk?





- Why keyframed animation?
- Animation export.
- Software Architecture of Cozmo.
- Accounting for real world uncertainty.
- Testing.





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anki
OVERDRIVE





What is Cozmo?



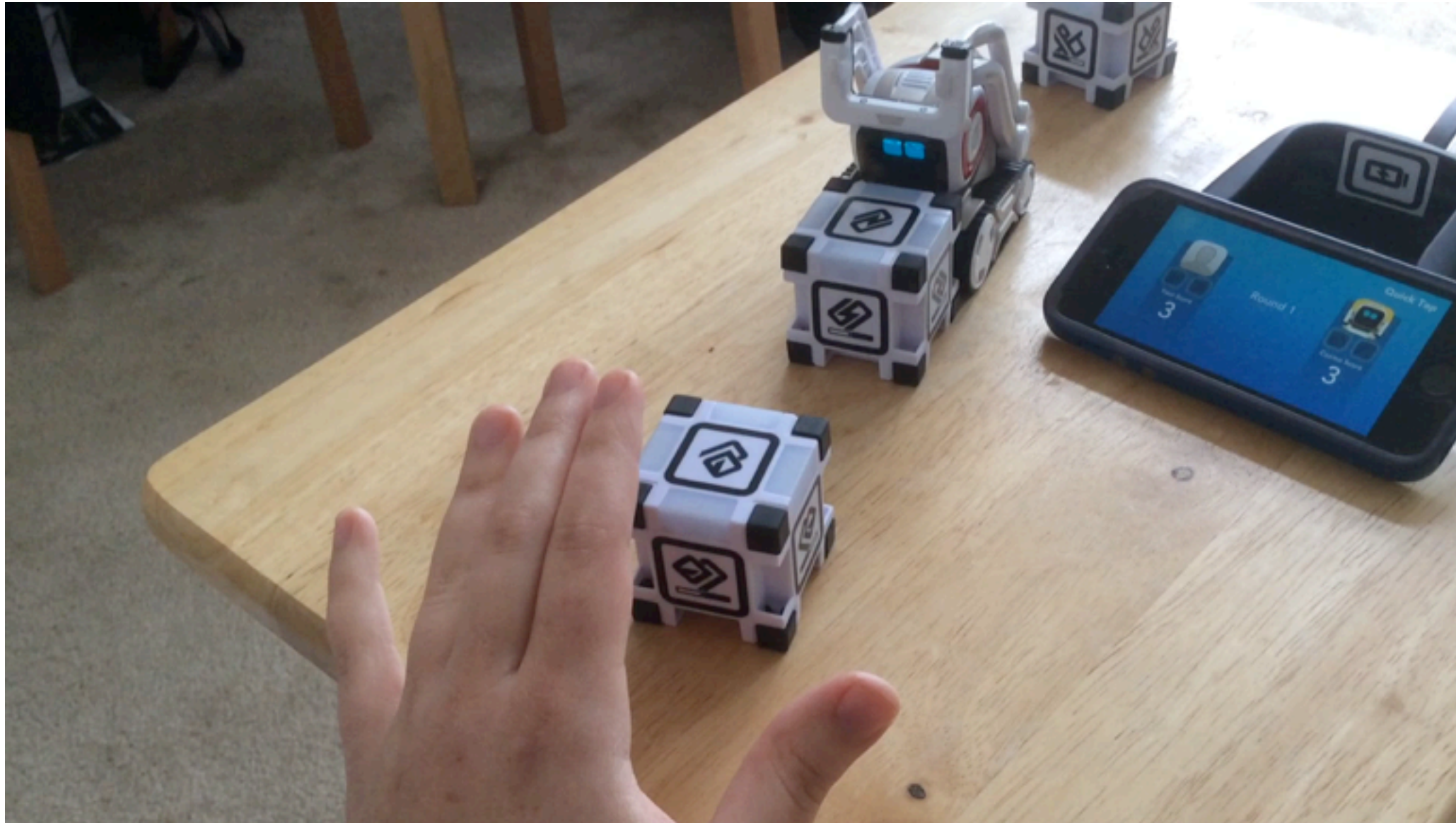
Cozmo the robot pet

The Cozmo logo is displayed in white, uppercase letters on a blue gradient background. The letters are bold and rounded, with a registered trademark symbol (®) at the top right of the 'O'.

COZMO®



Cozmo plays games





"...showing him off to new people never stops being fun"

- *Polygon*

"He's smarter, cleaner and more lovable than our hamster, plus he doesn't poop and the cat doesn't want to eat him."

- *Kotaku*

" 9/10 [...] the best smart toy of the year"

- *Slashgear*

"The way it moves and emotes is so good that it feels like you're interacting with a Pixar character instead of playing with a toy."

- *Penny-Arcade*





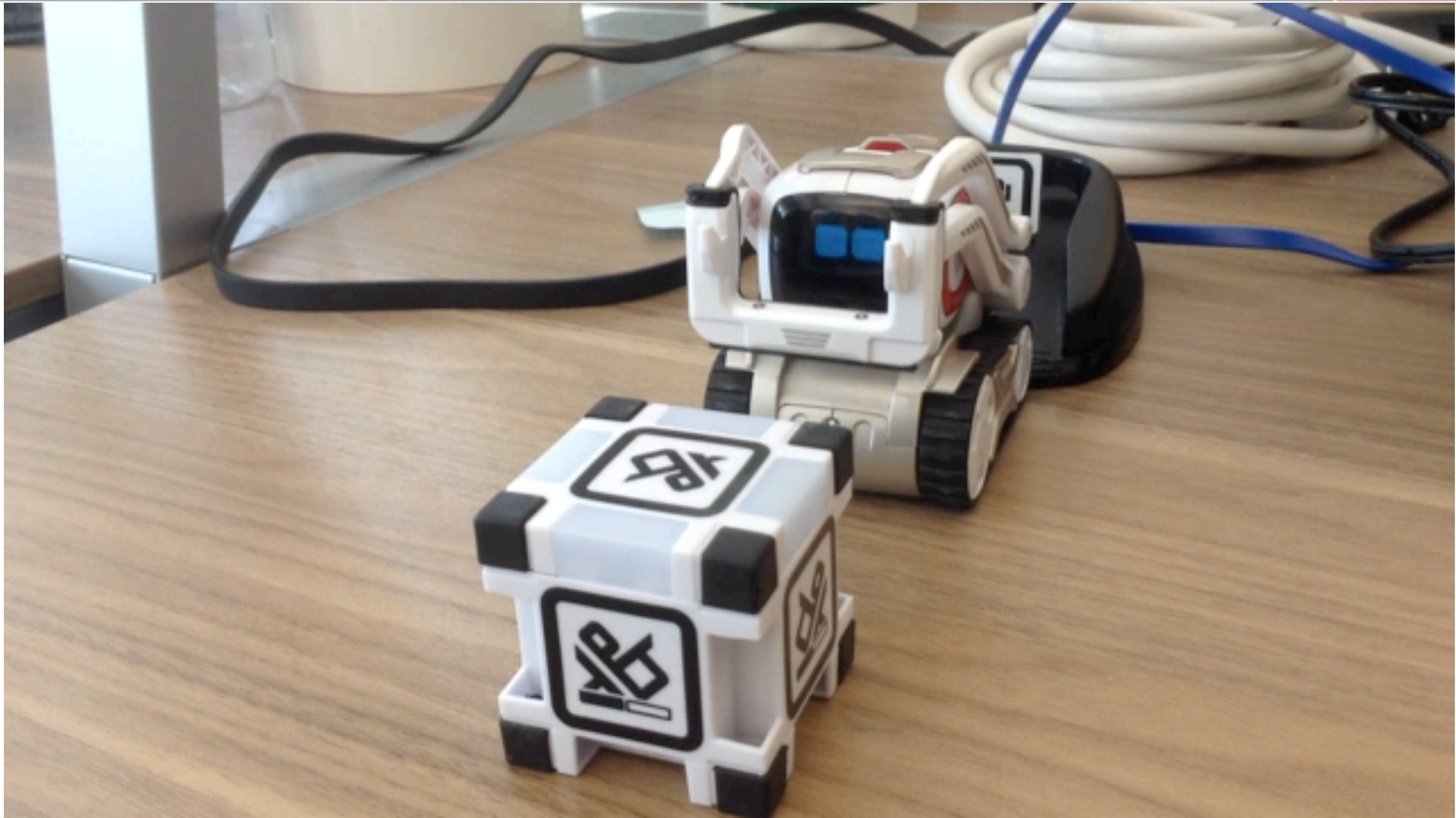
Significance of animation for Cozmo











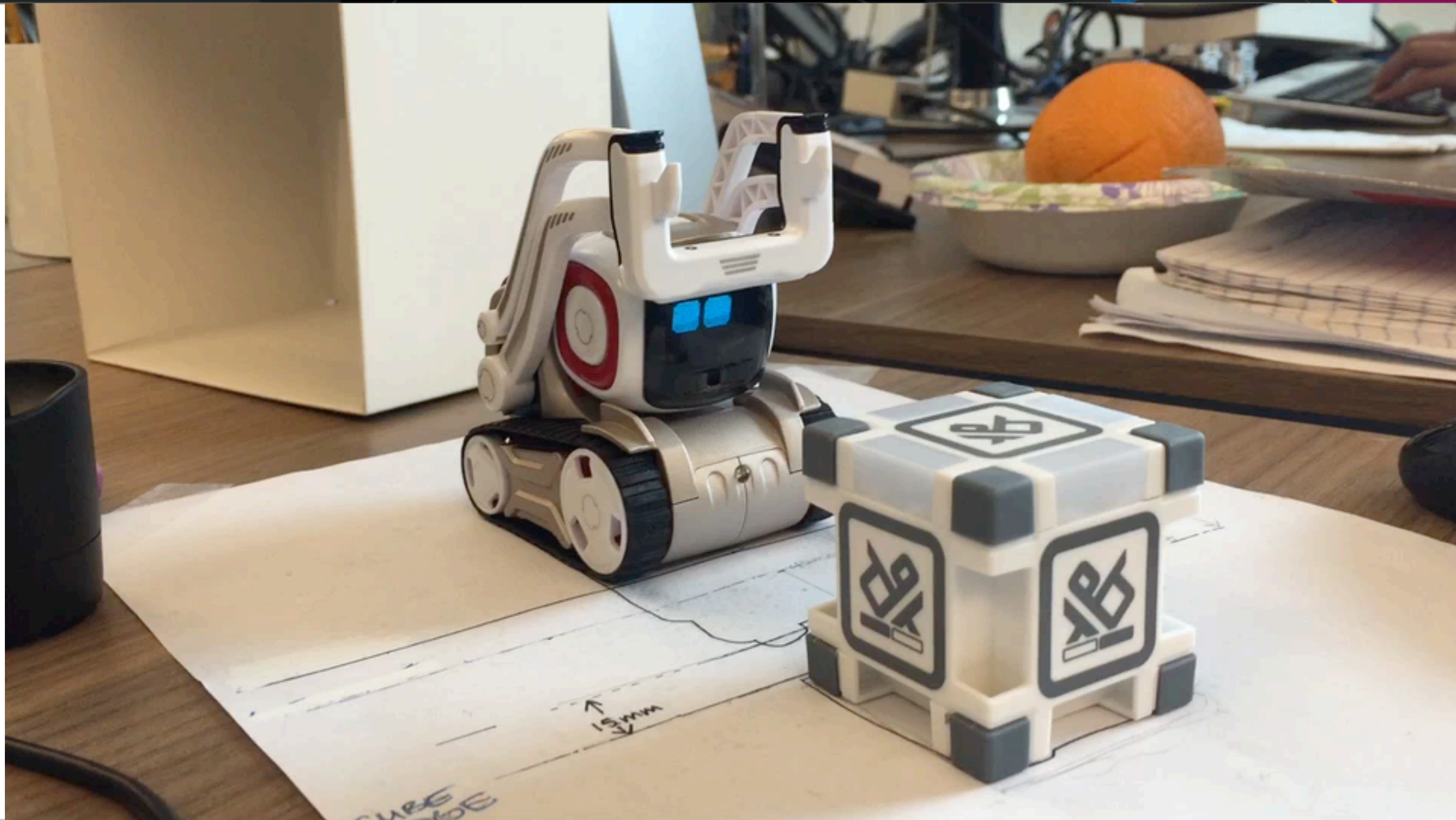
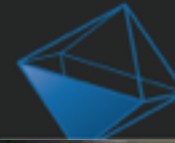


Achieving a natural, appealing motion











Transferring animation to the robot







Data exported from Maya

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"Name": "LiftHeightKeyFrame",
"heightVariability_mm": 0,
"height_mm": 67.03685588664837
},
{
"durationTime_ms": 231,
"triggerTime_ms": 3465,
"Name": "LiftHeightKeyFrame",
"heightVariability_mm": 0,
"height_mm": 82.97707085136895
},
{
"durationTime_ms": 264,
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},
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"Name": "HeadAngleKeyFrame",
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{
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"triggerTime_ms": 1155,
"Name": "HeadAngleKeyFrame",
"durationTime_ms": 627
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{
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"Name": "HeadAngleKeyFrame",
"durationTime_ms": 264
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"triggerTime_ms": 2046
}
```



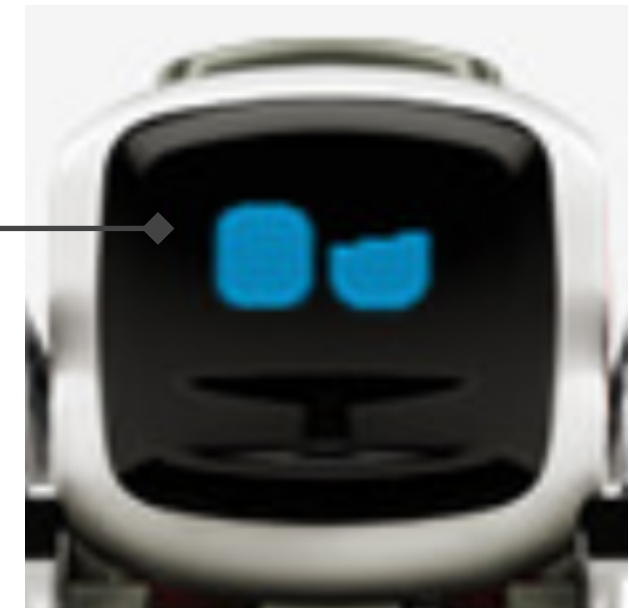


Speaker Head

Backpack

Lights

Face (eyes)



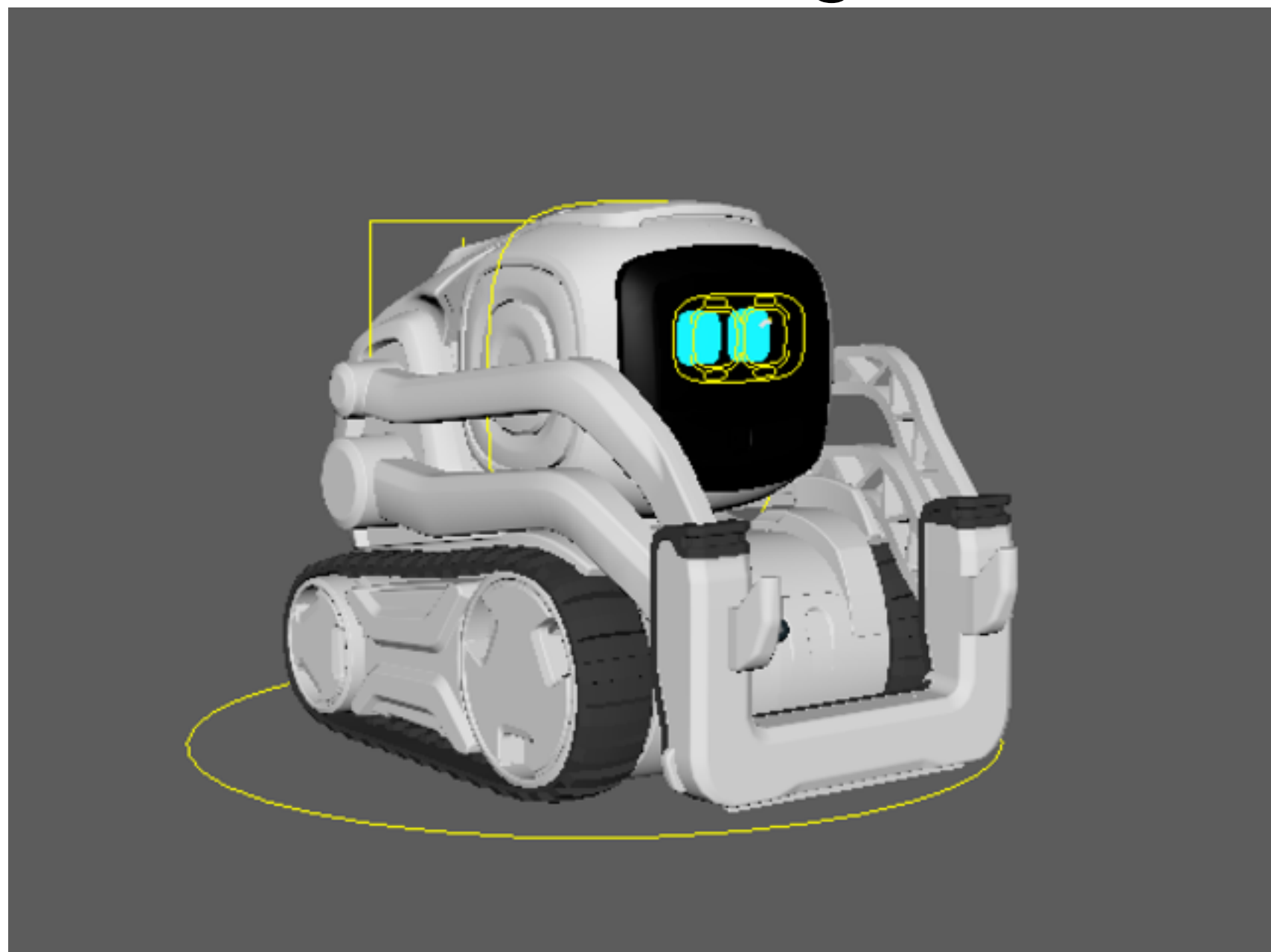
Wheels

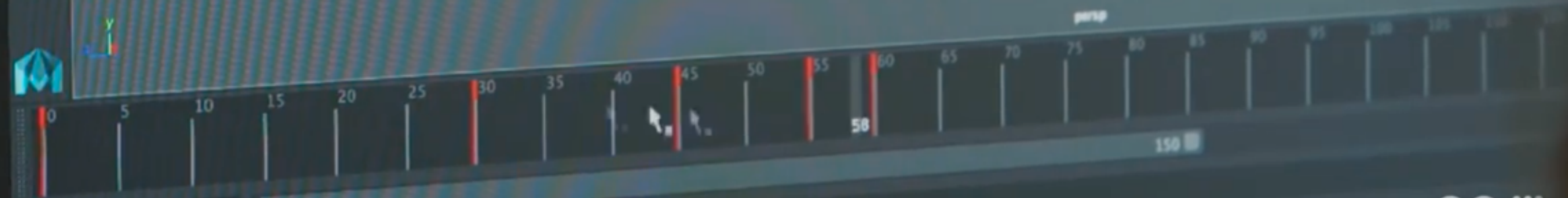
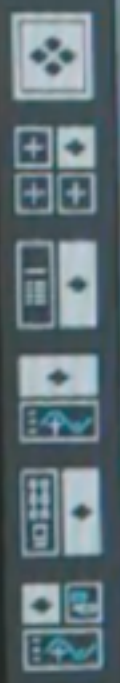
Lift





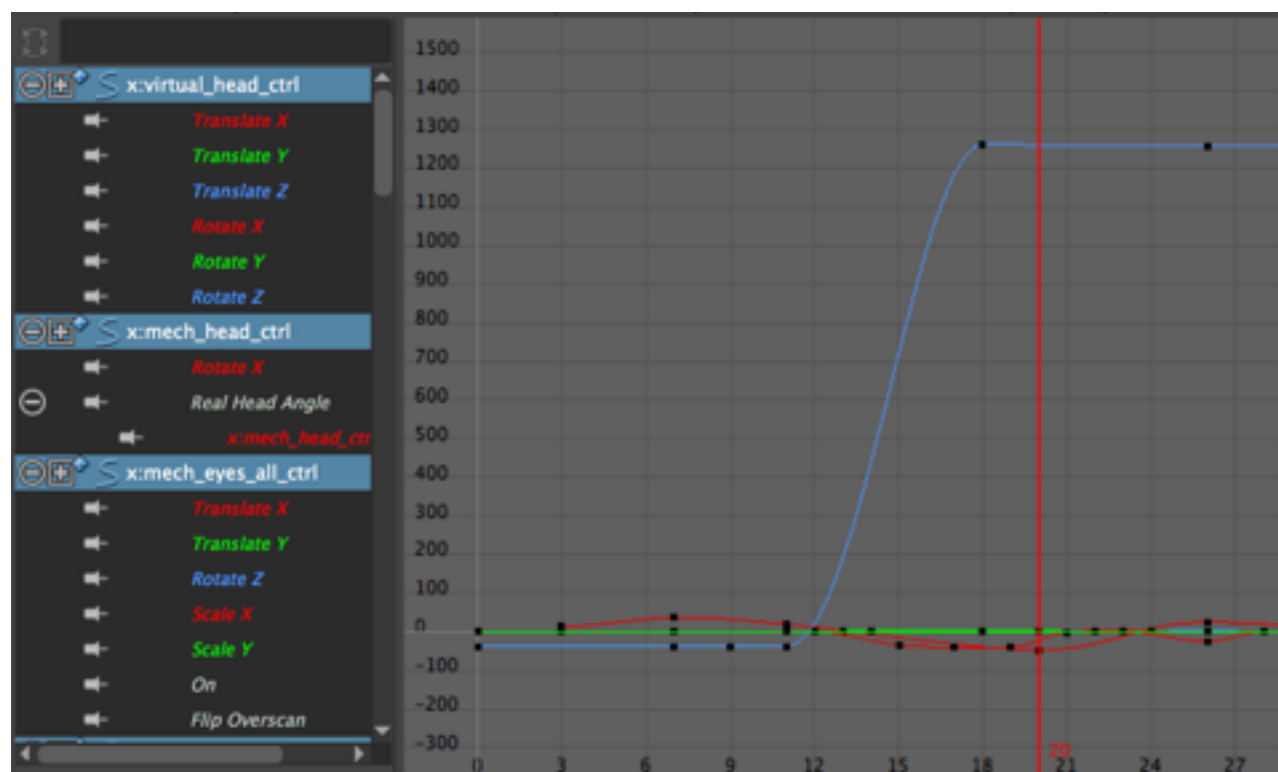
Cozmo's rig





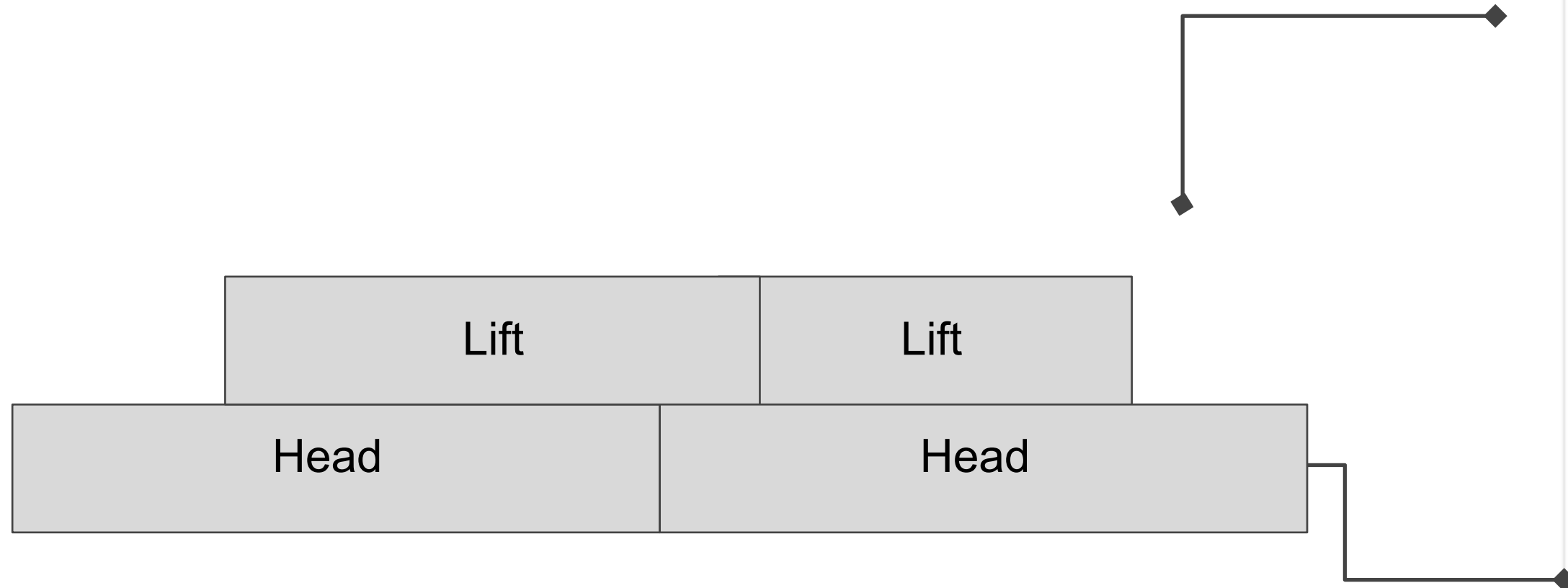
0 0 0 // Result: 1

Data Export



```
{
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{
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  "angle_deg": 15.483492851257322,
  "triggerTime_ms": 1155,
  "Name": "HeadAngleKeyFrame",
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  "Name": "HeadAngleKeyFrame",
  "durationTime_ms": 264
},
{
  "angleVariability_deg": 0,
  "angle_deg": -15.27974224090576,
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  "durationTime_ms": 264
}
```





```
{
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  "triggerTime_ms": 330,
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  "height_mm": 92.0
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{
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  "height_mm": 0.0
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{
  "angleVariability_deg": 0,
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  "triggerTime_ms": 0,
  "Name": "HeadAngleKeyFrame",
  "durationTime_ms": 1650
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{
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  "durationTime_ms": 1650
}
```

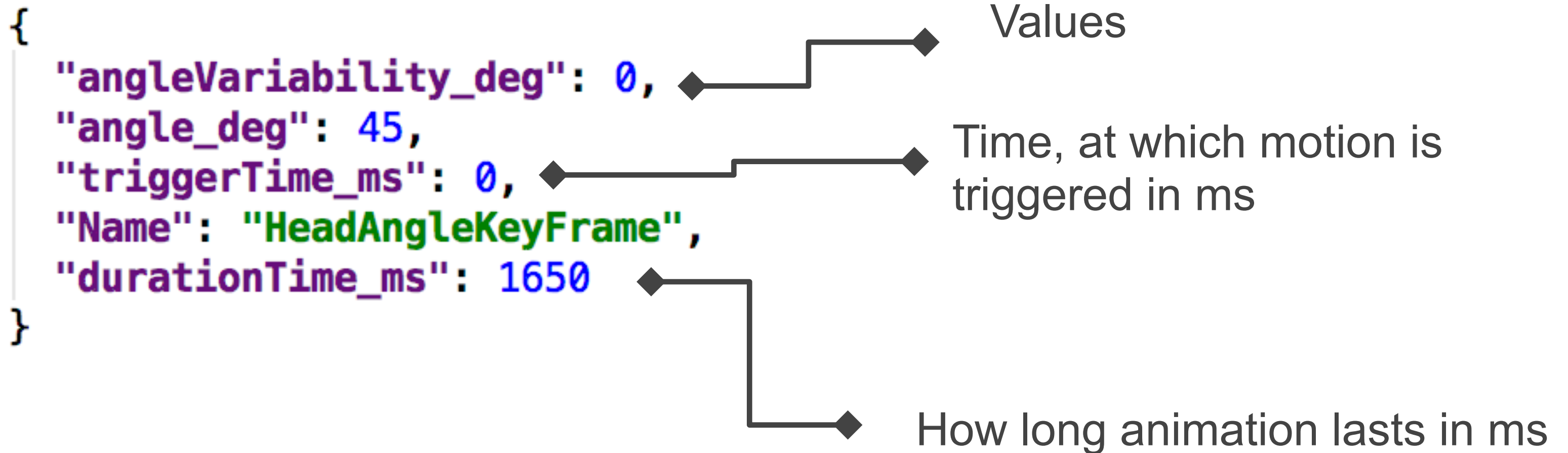



Data Export



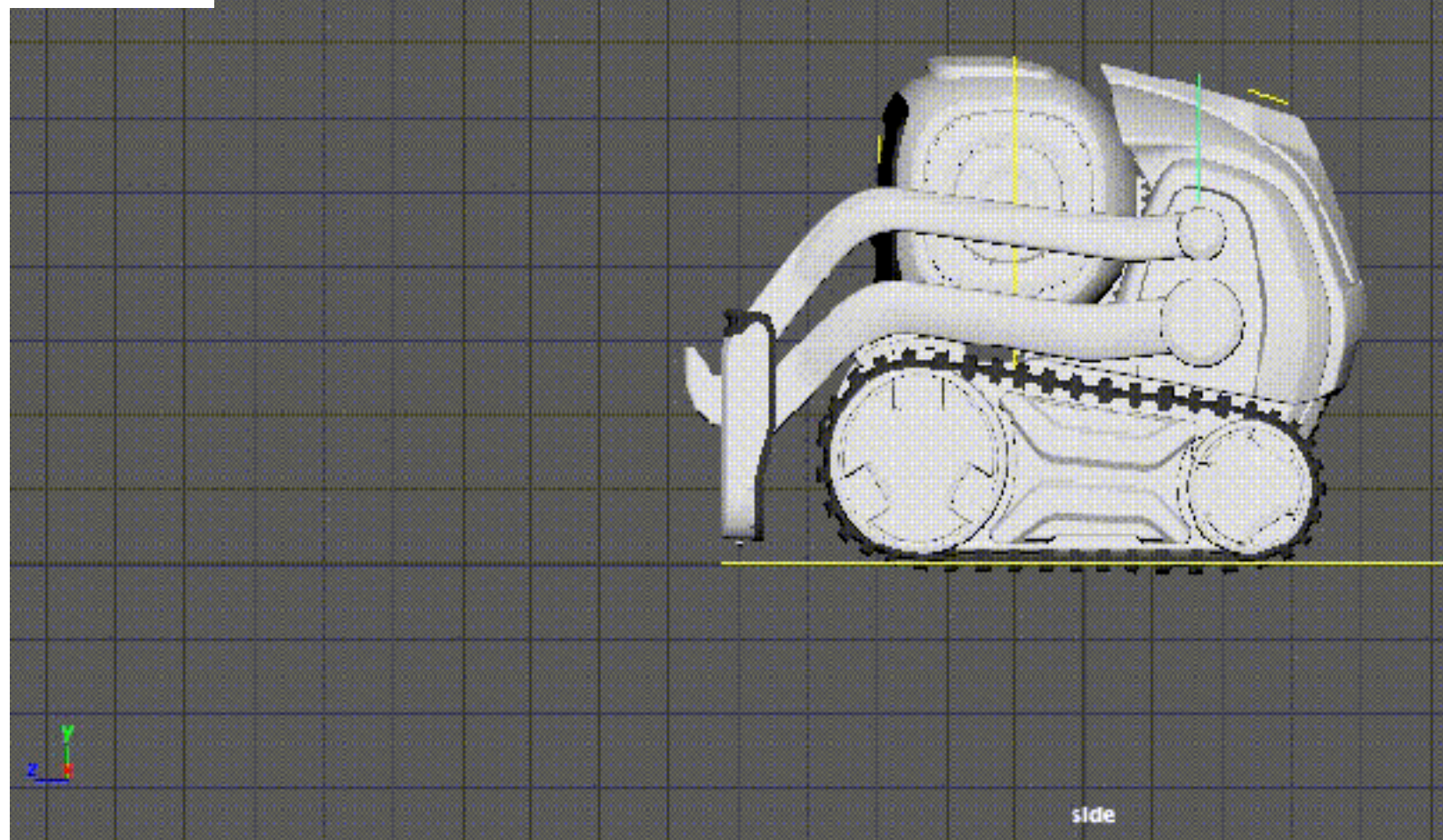


Data in form of a single node





```
{  
  "angleVariability_deg": 0,  
  "angle_deg": 45,  
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  "Name": "HeadAngleKeyFrame",  
  "durationTime_ms": 1650  
}
```





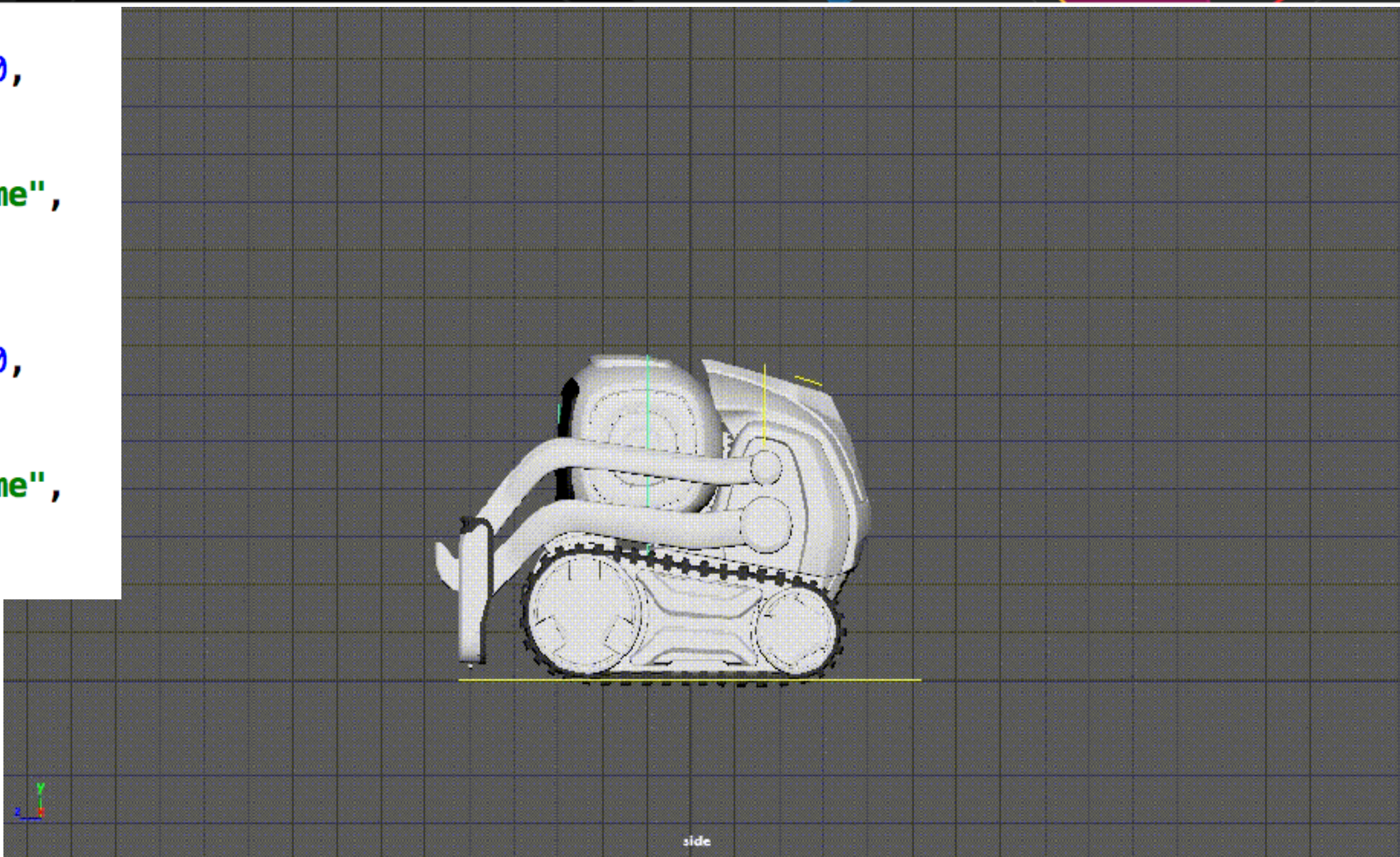
Head	Head
------	------

```
{
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  "durationTime_ms": 1650
},
{
  "angleVariability_deg": 0,
  "angle_deg": 0.0,
  "triggerTime_ms": 1650,
  "Name": "HeadAngleKeyFrame",
  "durationTime_ms": 1650
}
```



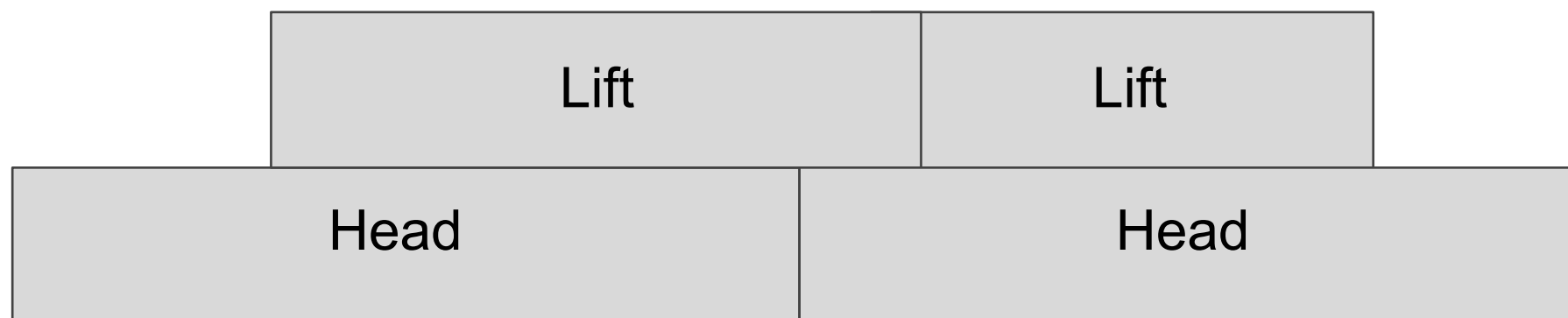


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  "Name": "HeadAngleKeyFrame",  
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  "angleVariability_deg": 0,  
  "angle_deg": 0.0,  
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  "Name": "HeadAngleKeyFrame",  
  "durationTime_ms": 1650  
}
```



side

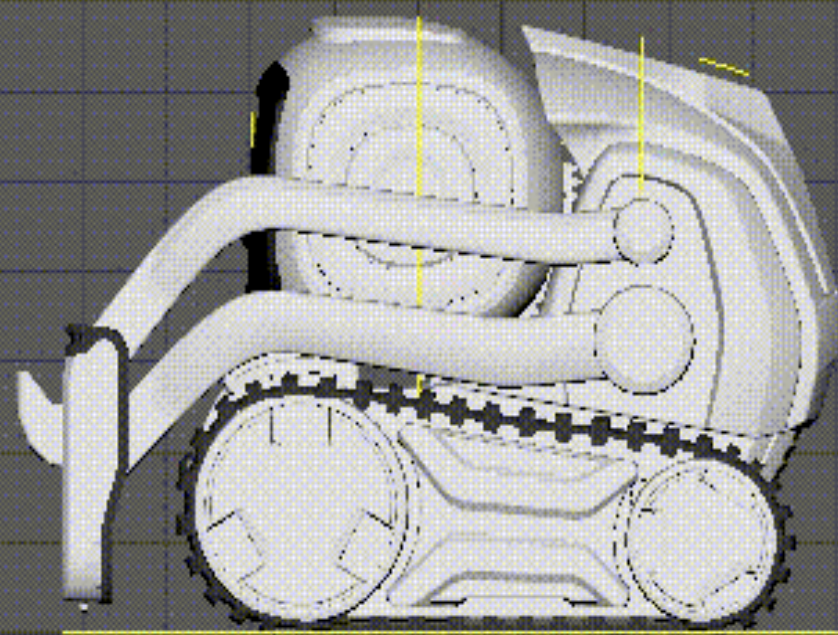




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  "durationTime_ms": 1650
}
```




```
{  
  "durationTime_ms": 990,  
  "triggerTime_ms": 330,  
  "Name": "LiftHeightKeyFrame",  
  "heightVariability_mm": 0,  
  "height_mm": 92.0  
},  
{  
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  "heightVariability_mm": 0,  
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{  
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{  
  "angleVariability_deg": 0,  
  "angle_deg": 0.0,  
  "triggerTime_ms": 1650,  
  "Name": "HeadAngleKeyFrame",  
  "durationTime_ms": 1650  
}
```





Absolute vs Relative

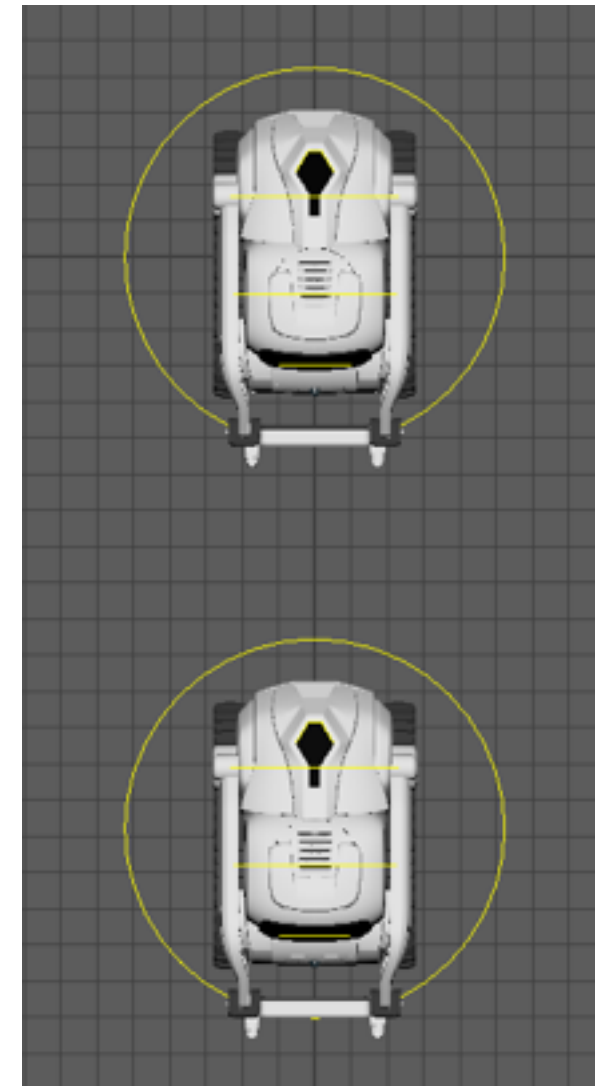
```
{  
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  "Name": "HeadAngleKeyFrame",  
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{  
  "angleVariability_deg": 0,  
  "angle_deg": 0.0,  
  "triggerTime_ms": 1650,  
  "Name": "HeadAngleKeyFrame",  
  "durationTime_ms": 1650  
}
```

```
{  
  "durationTime_ms": 297.0,  
  "speed": -303.0,  
  "triggerTime_ms": 0.0,  
  "Name": "BodyMotionKeyFrame",  
  "radius_mm": "TURN_IN_PLACE"  
},  
{  
  "durationTime_ms": 660.0,  
  "speed": 200.0,  
  "triggerTime_ms": 330.0,  
  "Name": "BodyMotionKeyFrame",  
  "radius_mm": "STRAIGHT"  
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  "speed": 793.0,  
  "triggerTime_ms": 1023.0,  
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}
```





Velocity vs Position





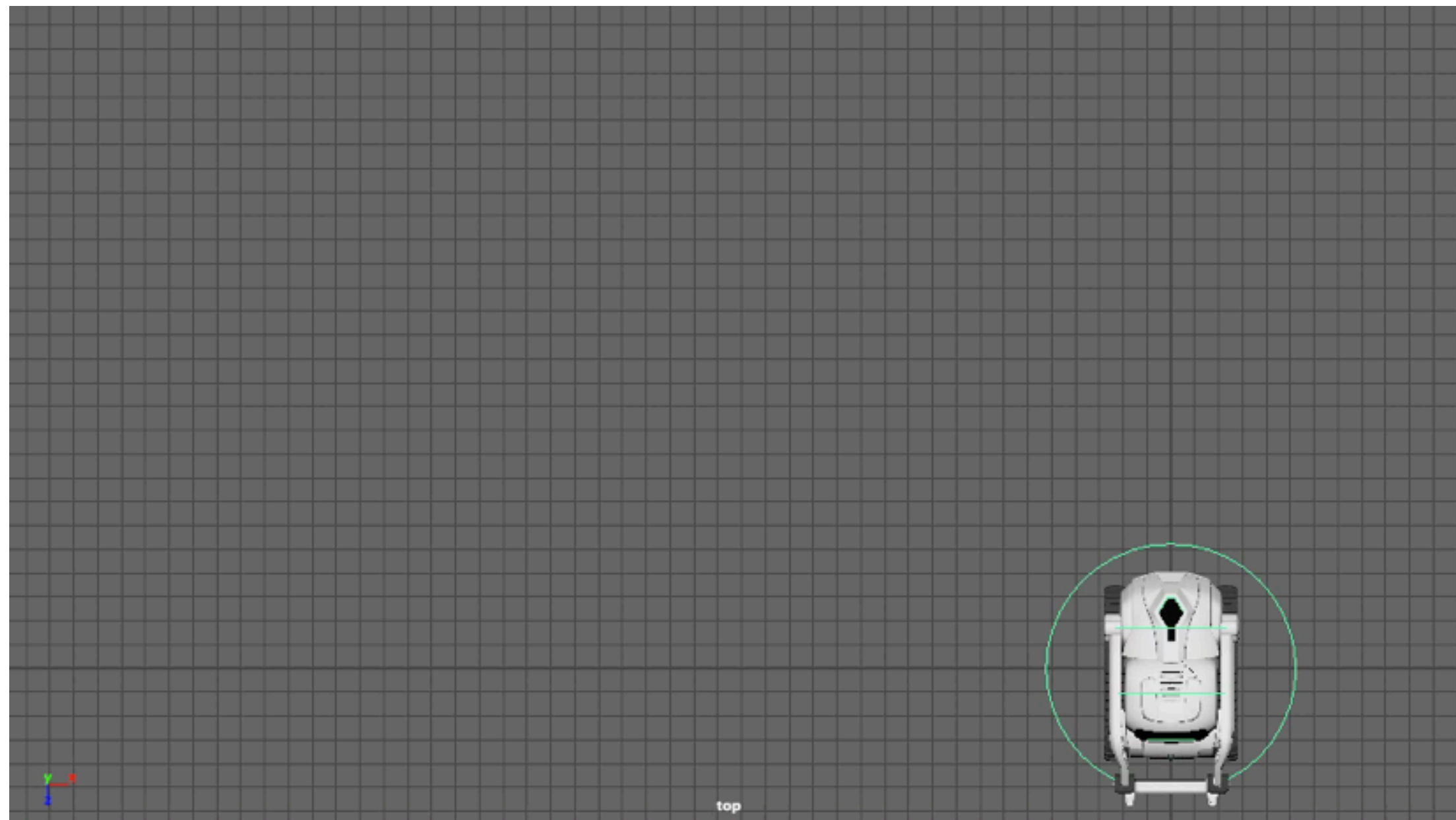
Cozmo's movement





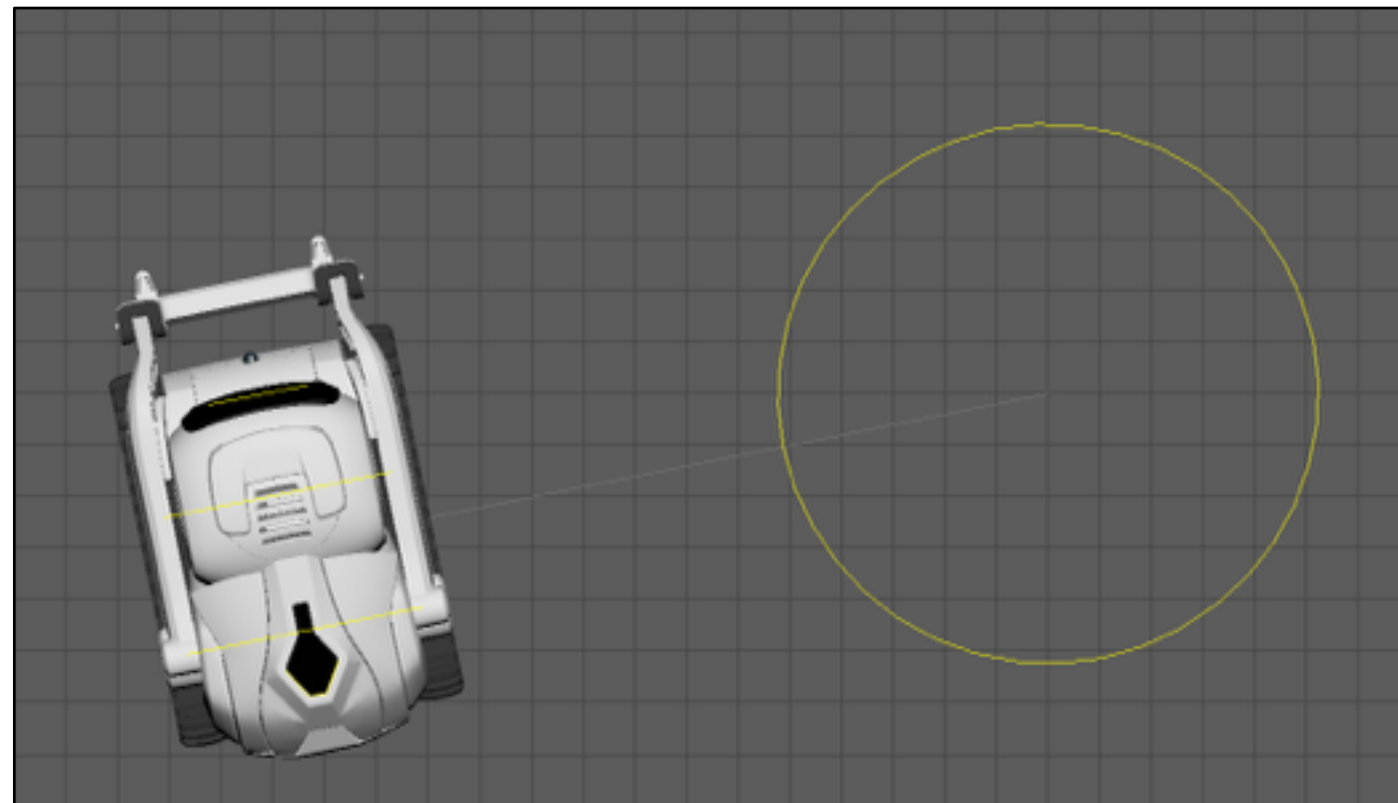
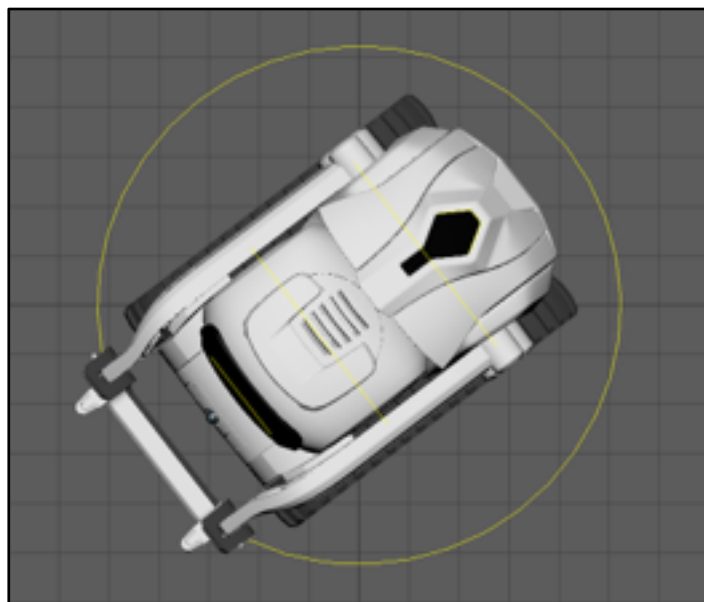
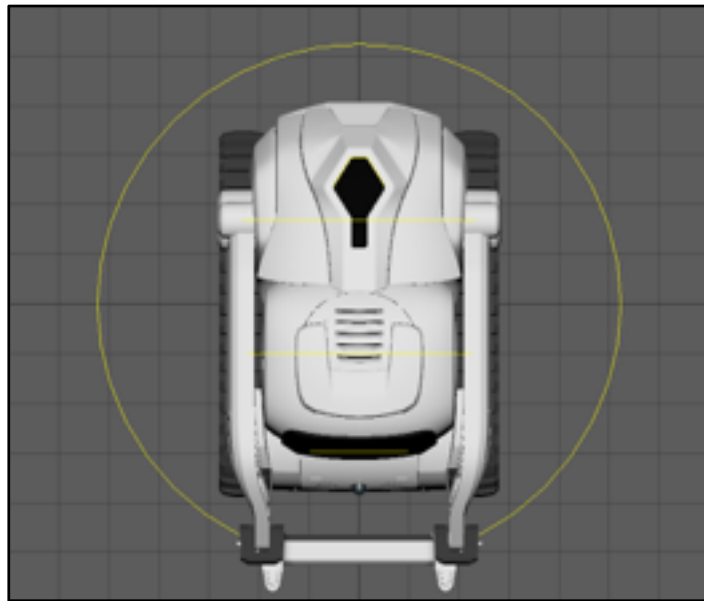
3 types of movement:

Turn in Place
Move Straight
Arc Turn



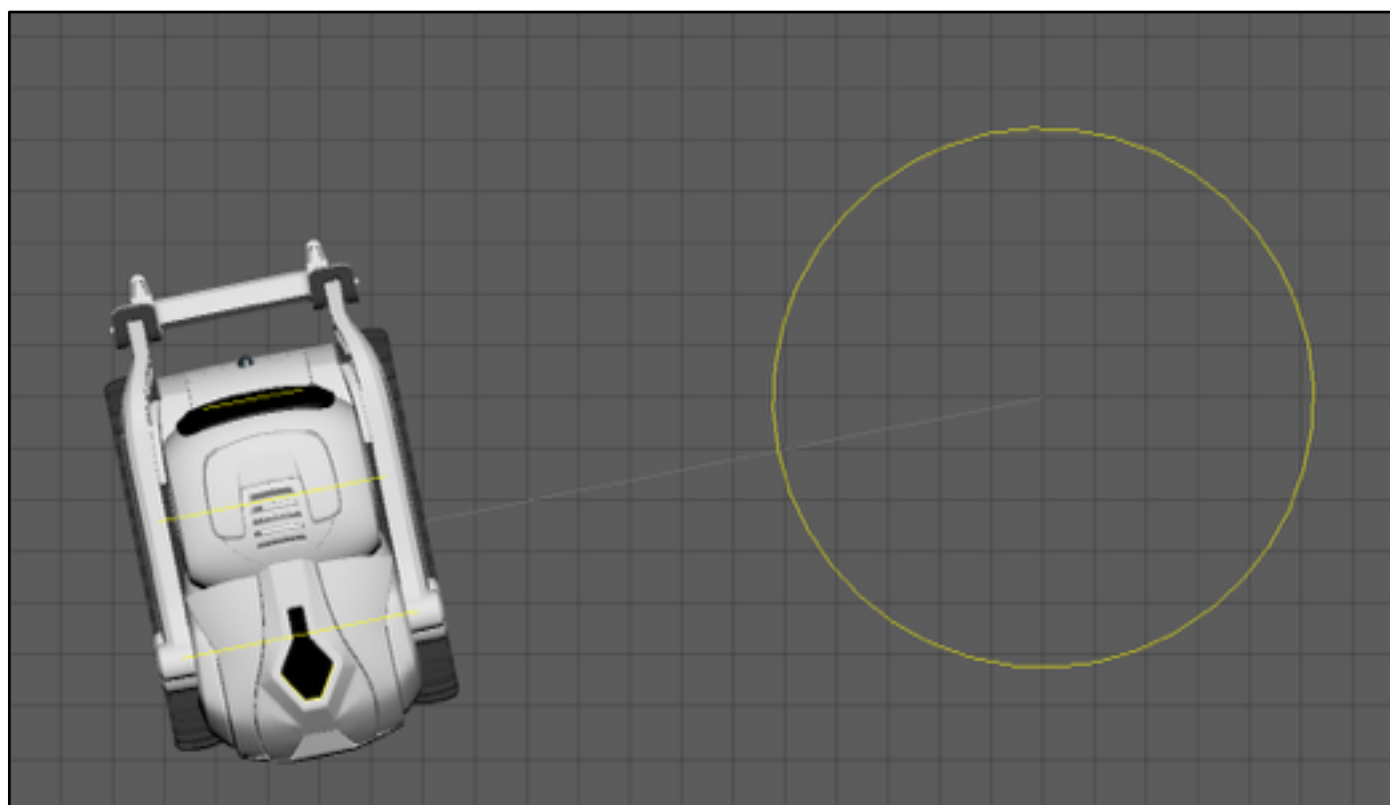
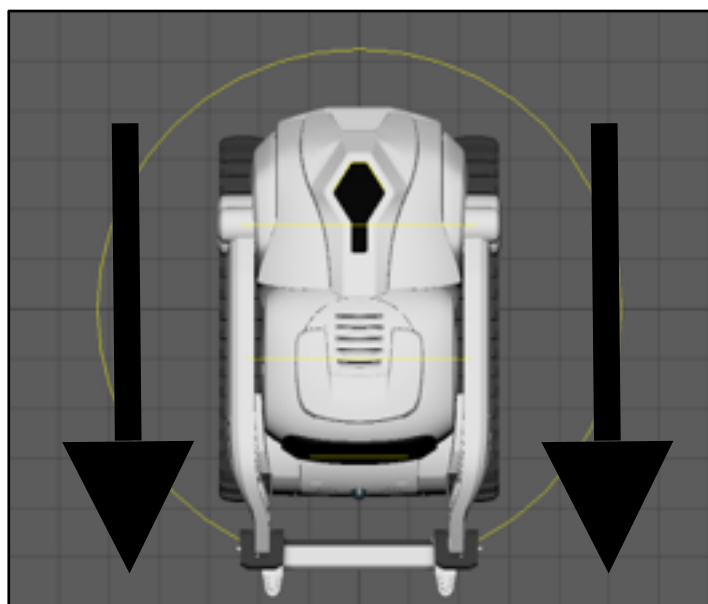


Single Axle Robot Movement



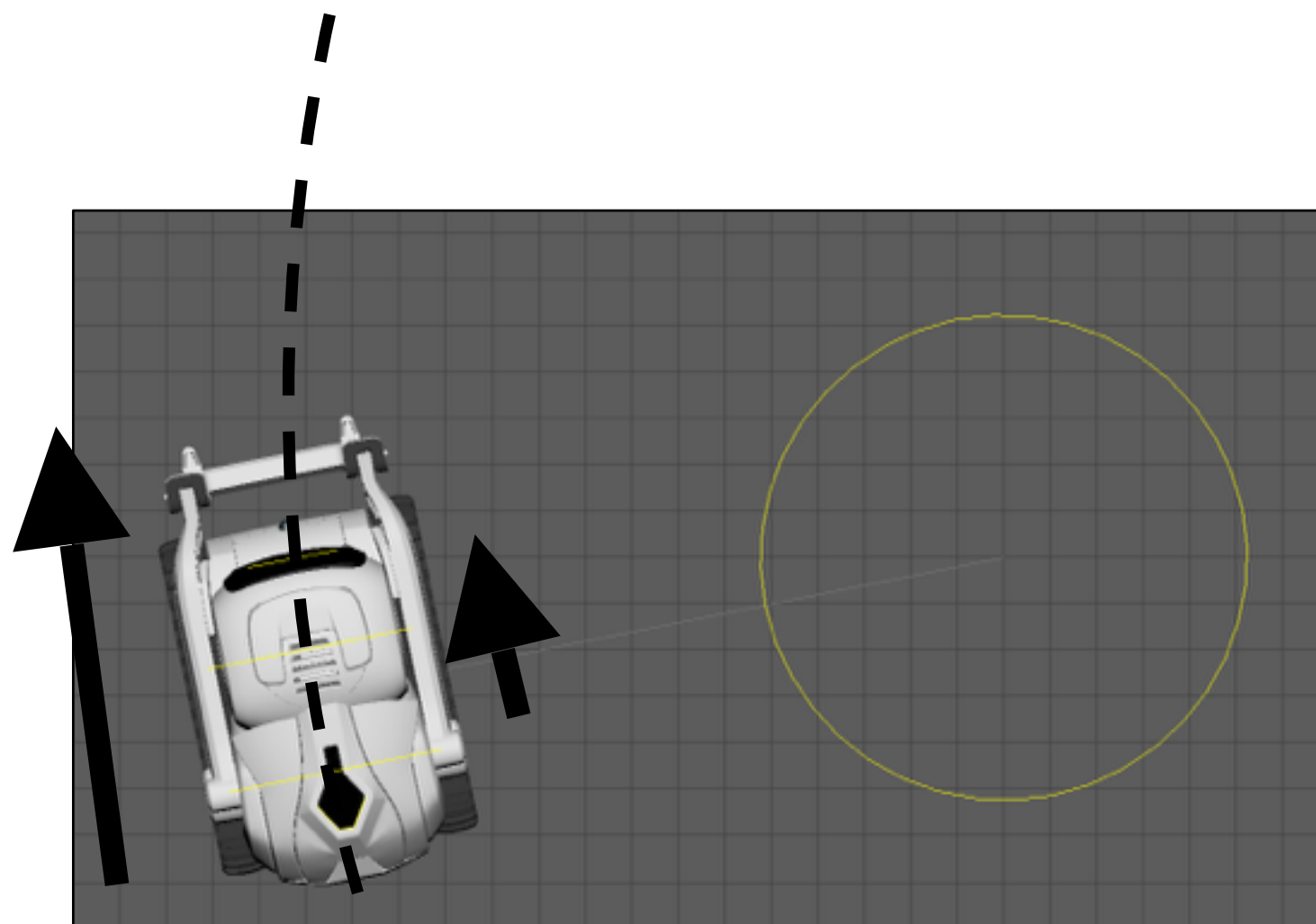
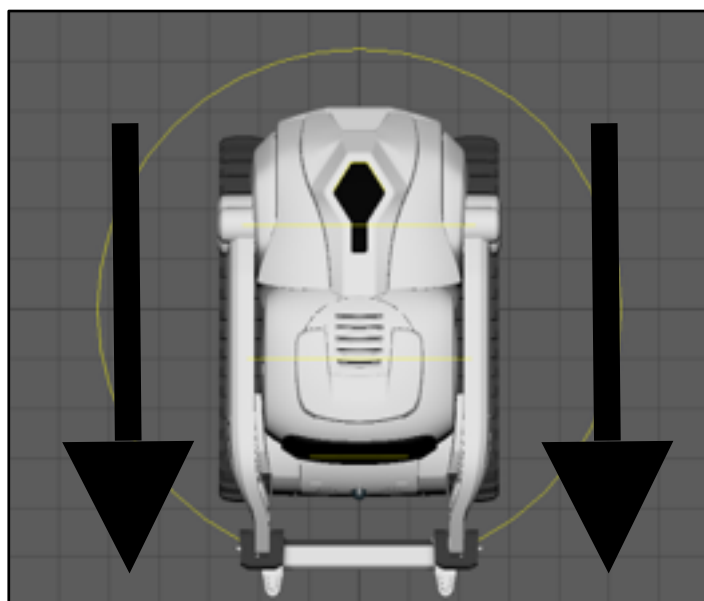


Single Axle Robot Movement



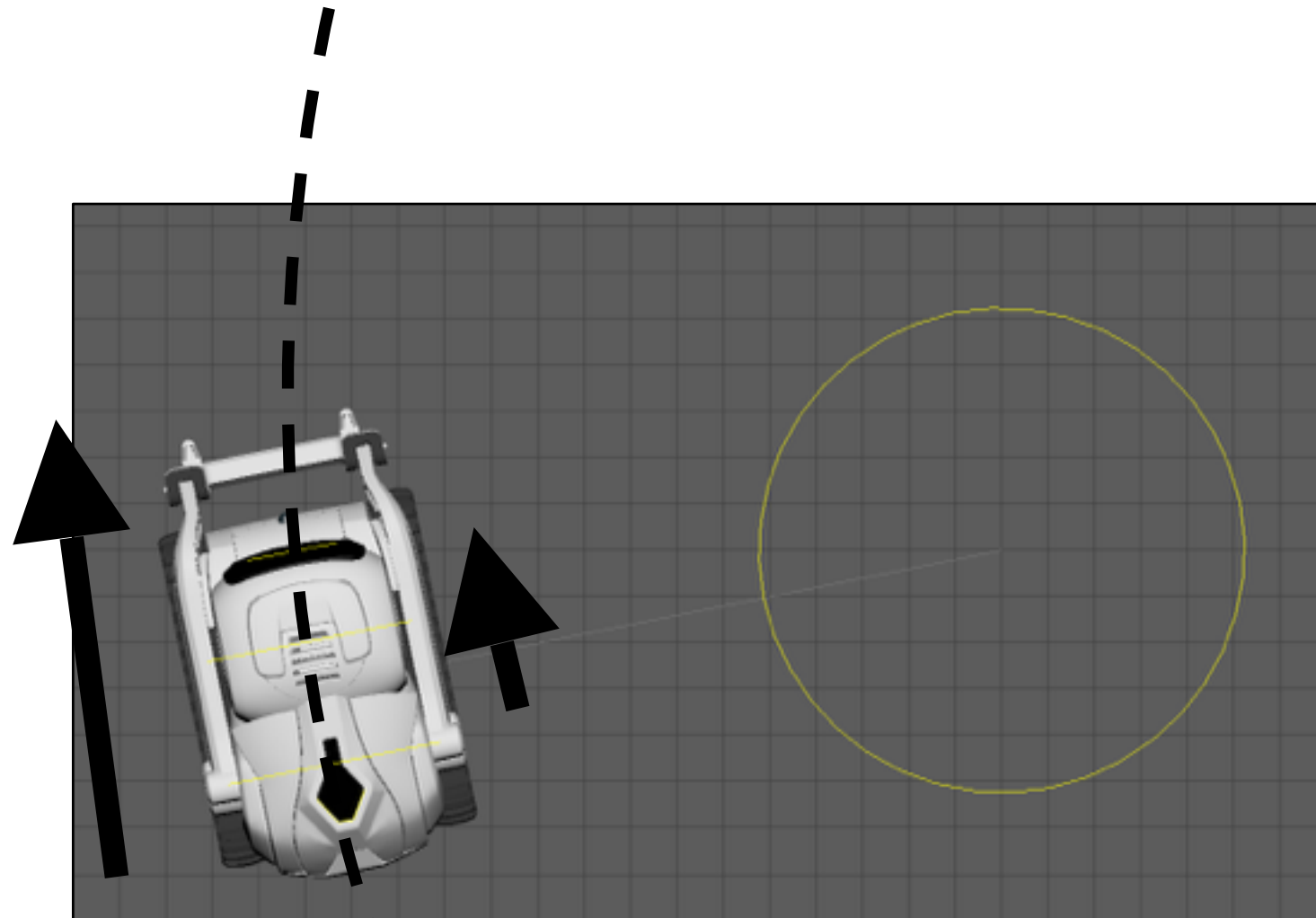
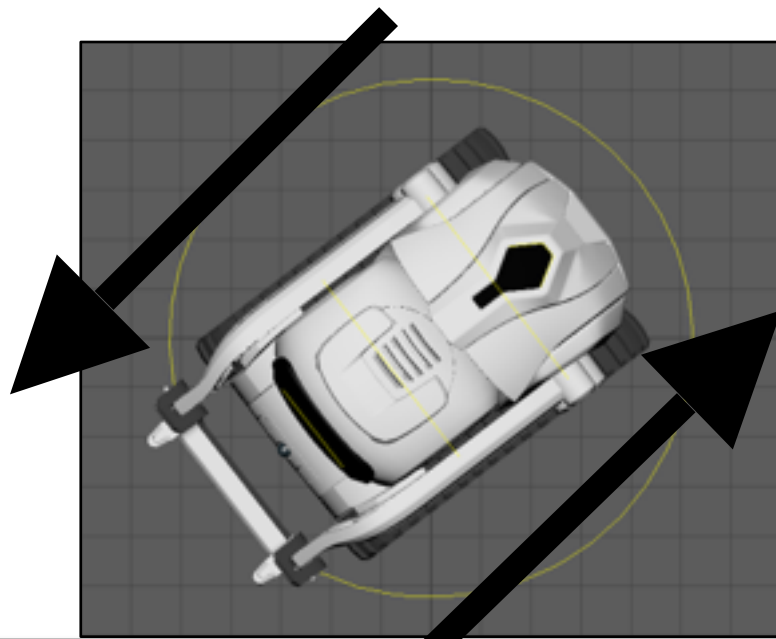
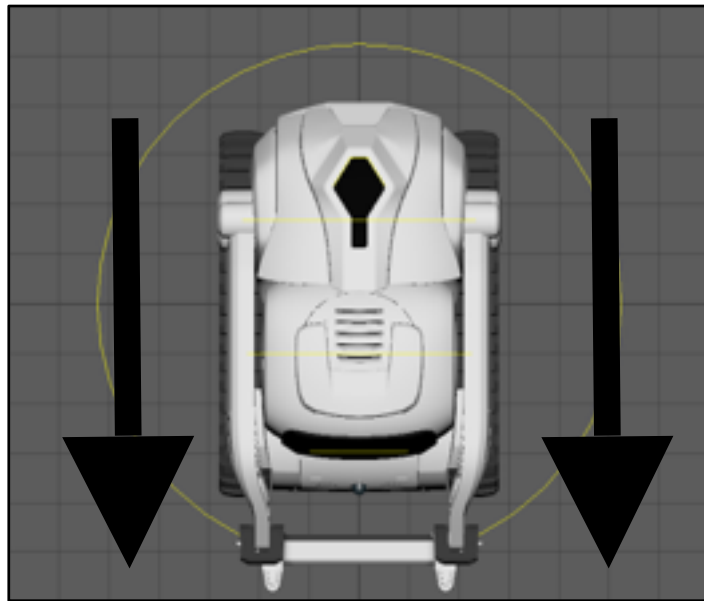


Single Axle Robot Movement





Single Axle Robot Movement

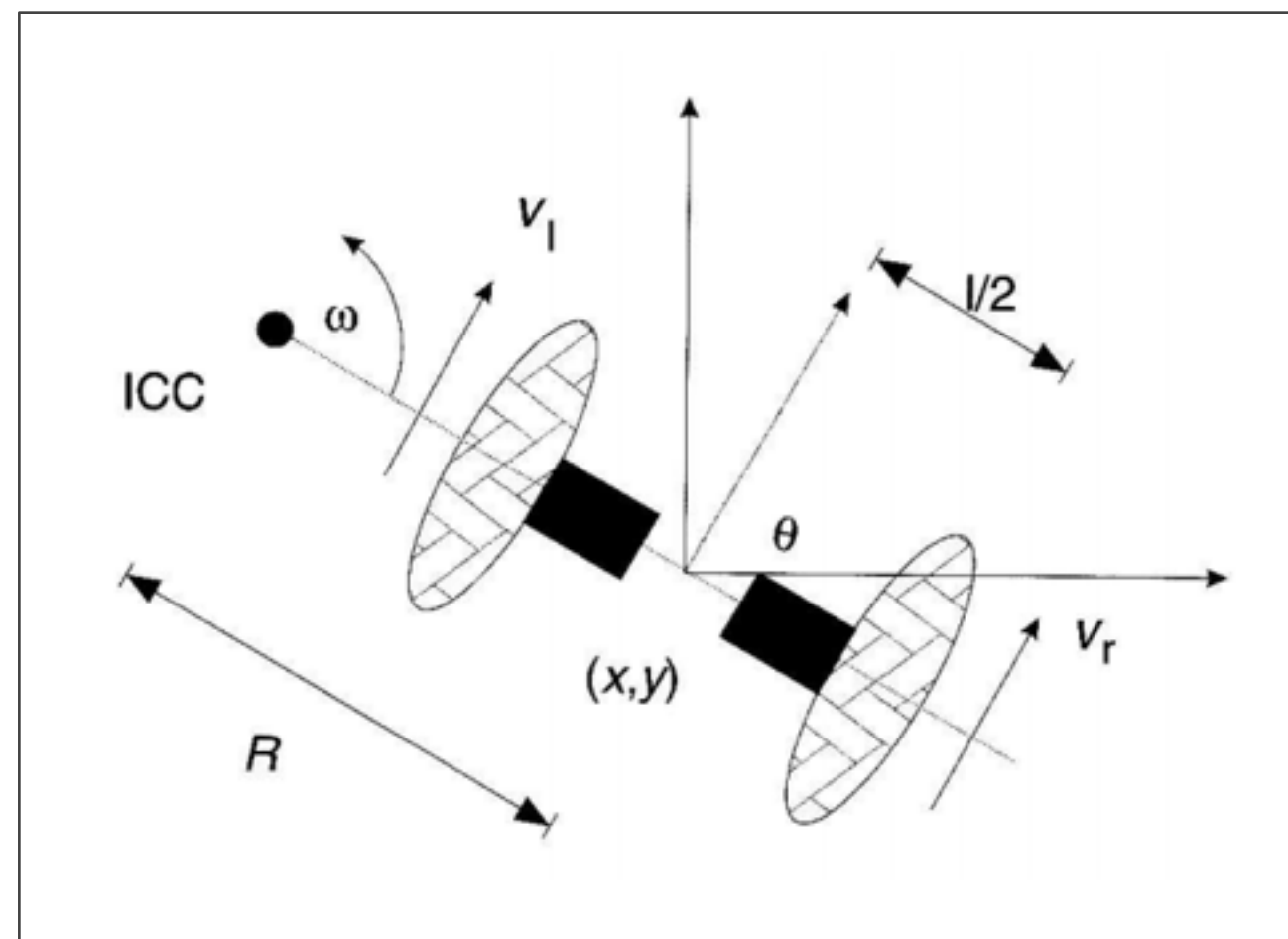
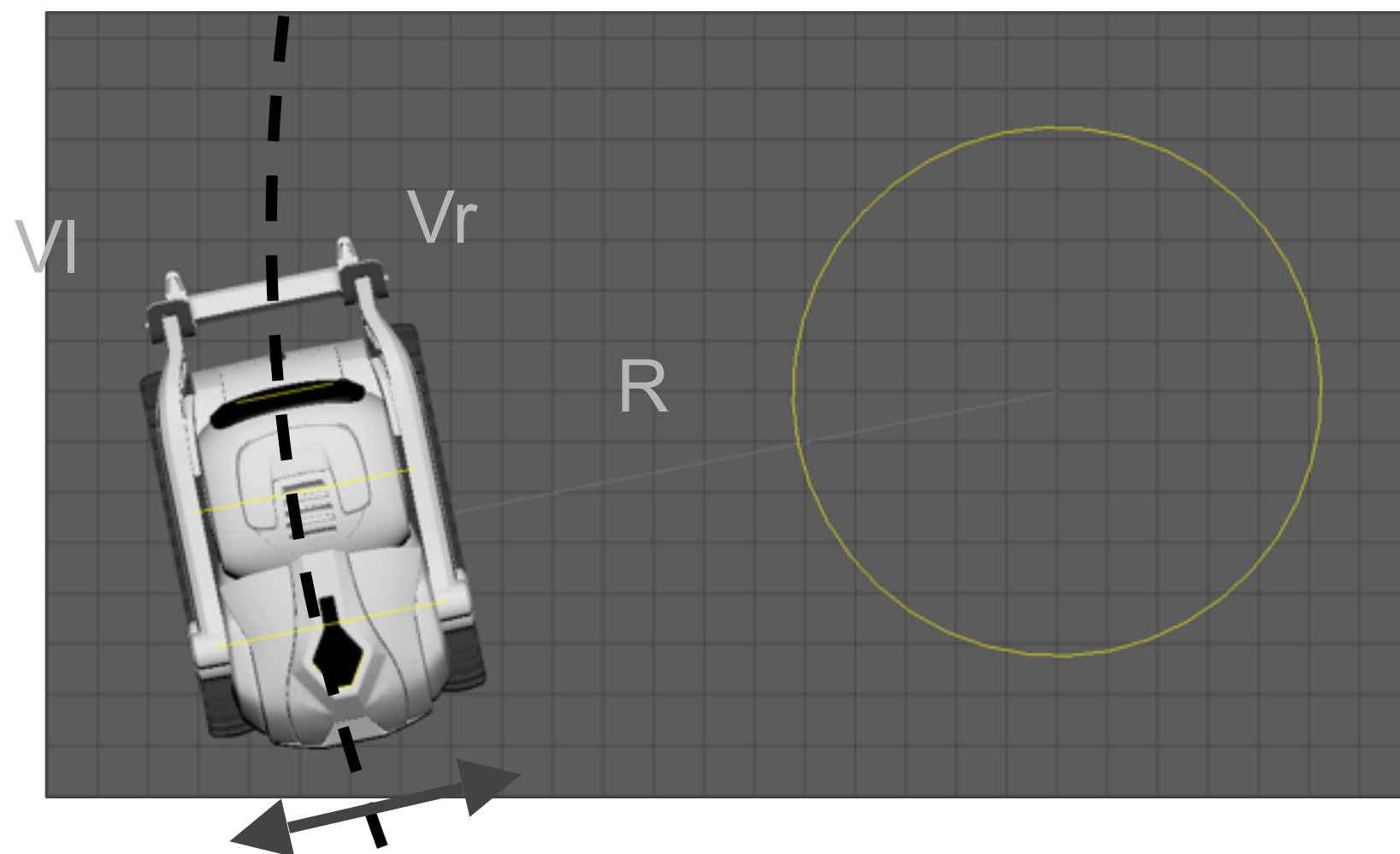




Differential Drive Kinematics

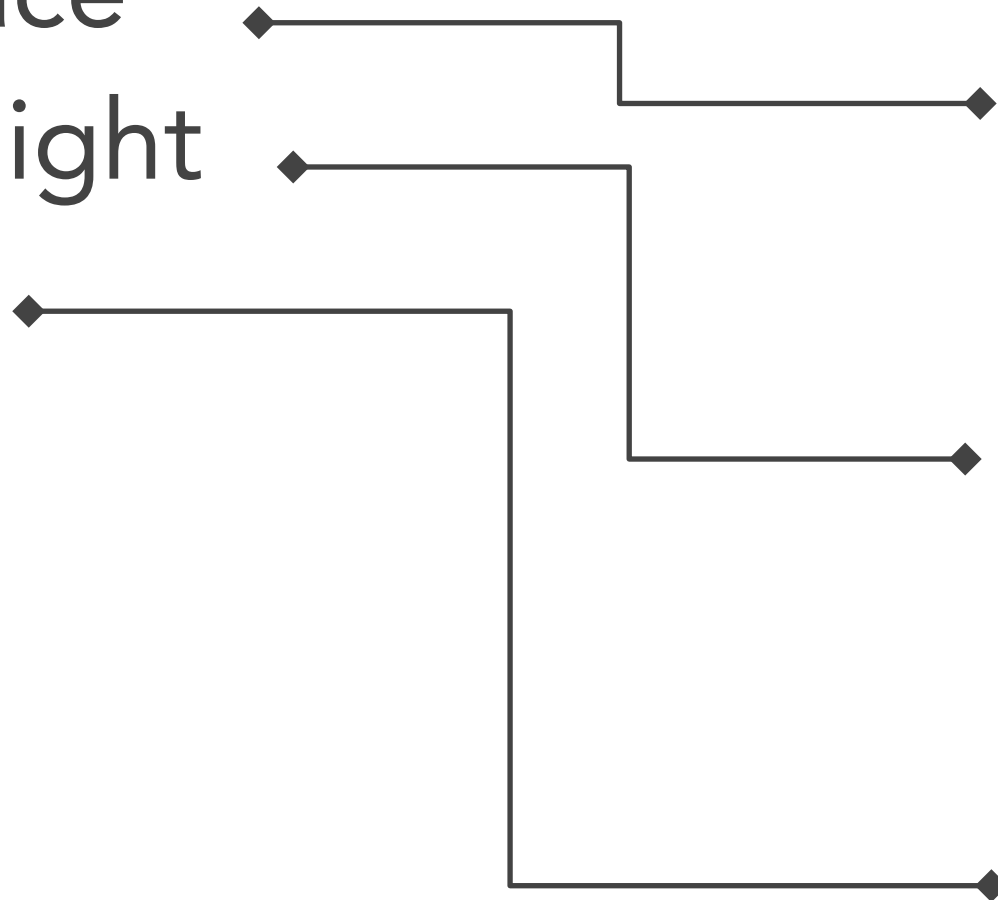
$$\omega (R + l/2) = V_r$$

$$\omega (R - l/2) = V_l$$





Turn in Place
Move Straight
Arc Turn

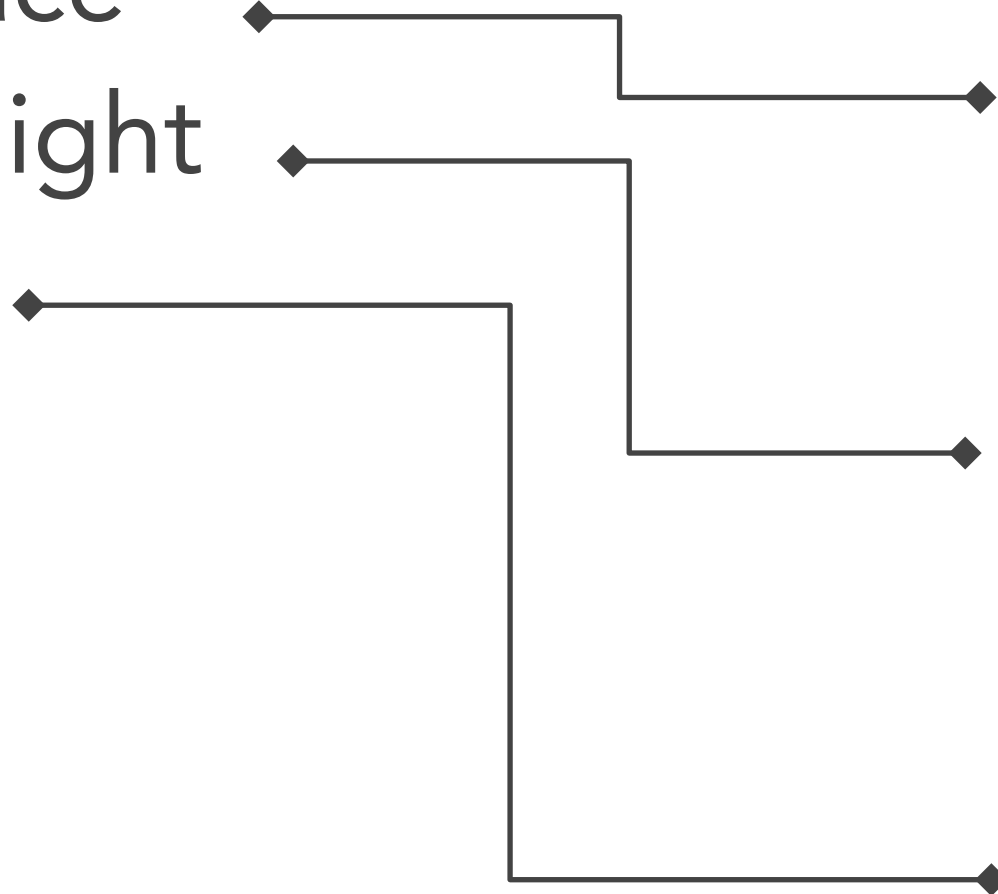


```
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{  
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}
```





Turn in Place
Move Straight
Arc Turn

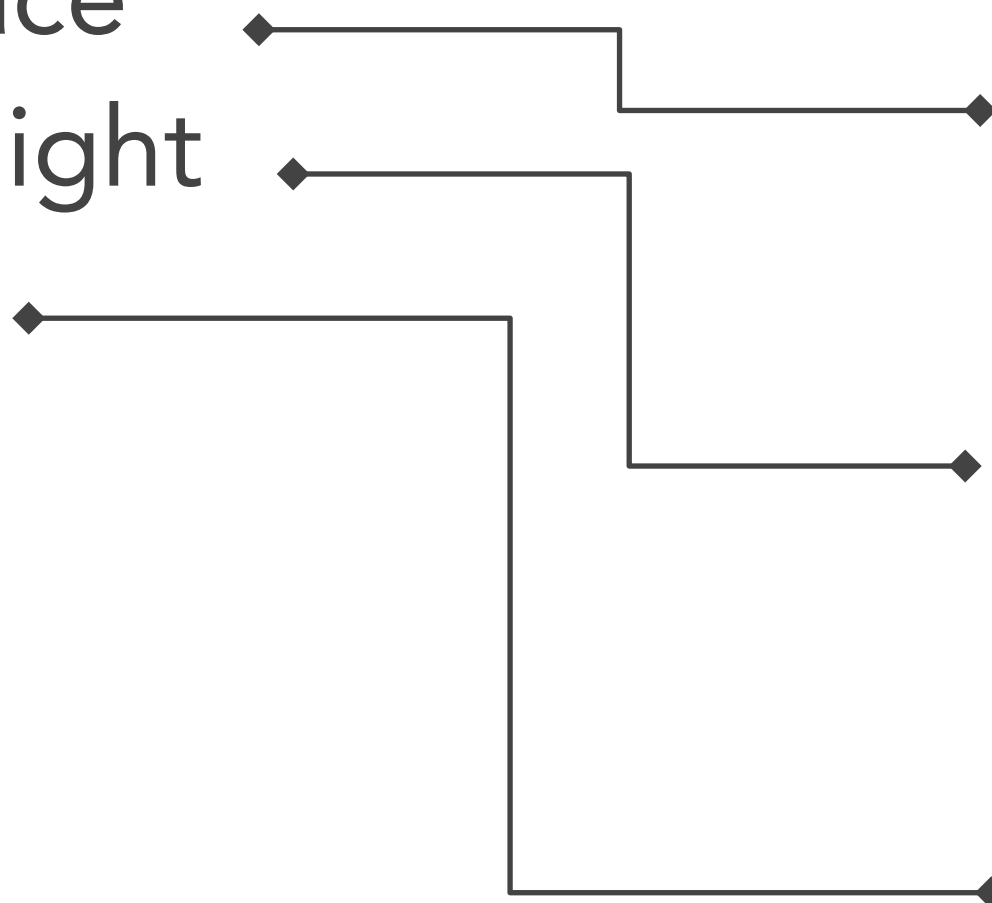


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  "radius_mm": -150.0  
}
```



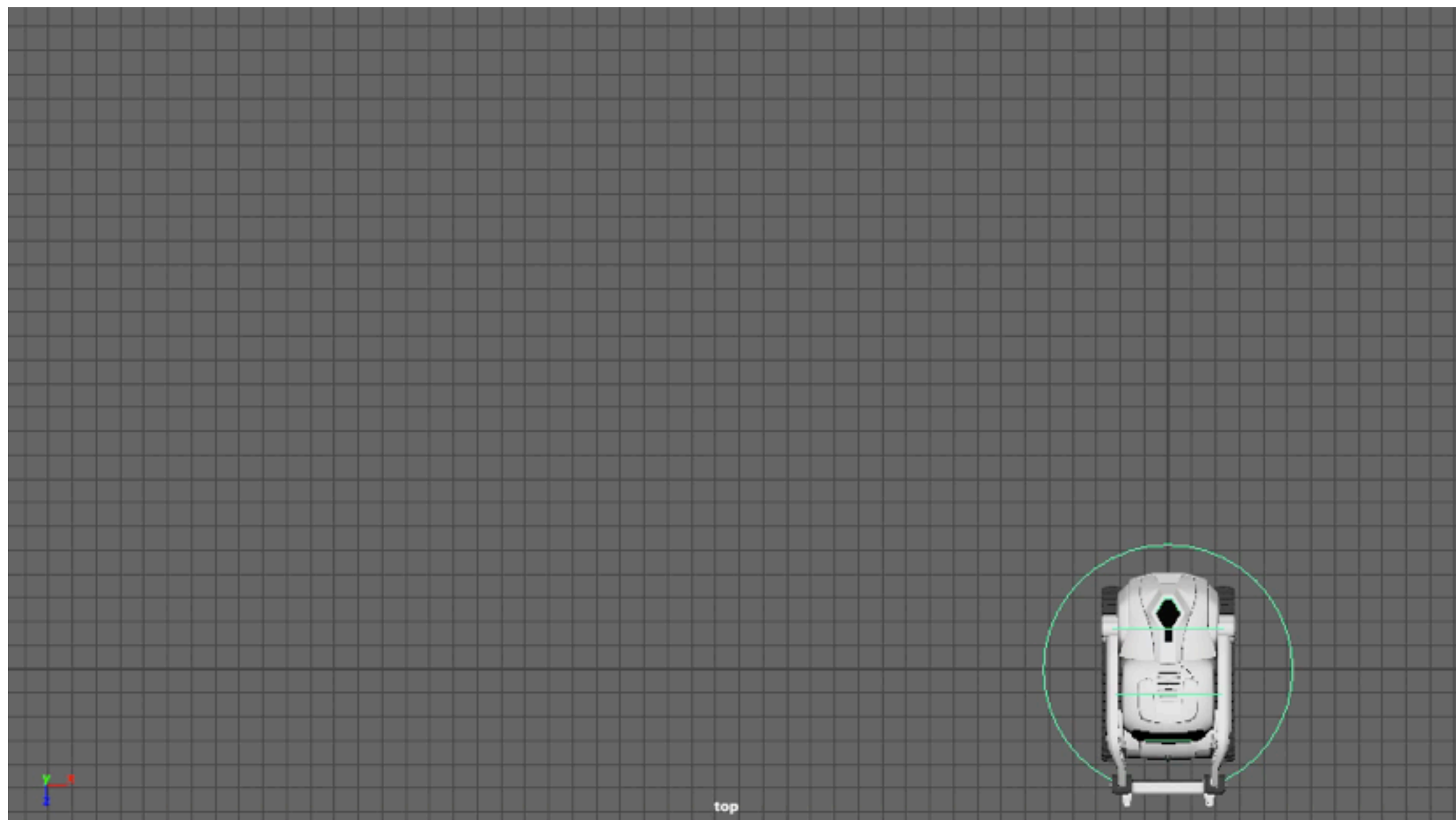


Turn in Place
Move Straight
Arc Turn



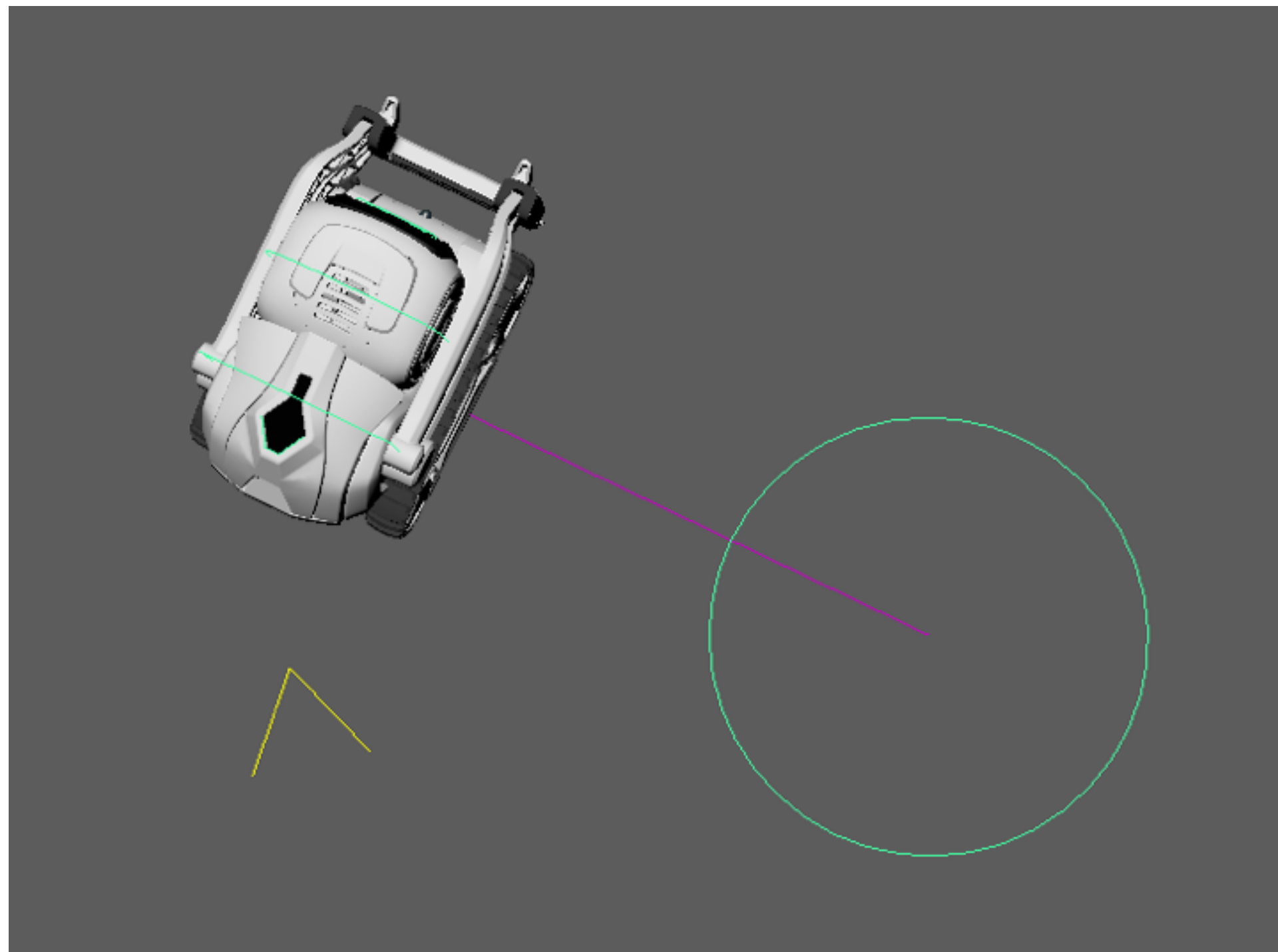
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{  
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  "Name": "BodyMotionKeyFrame",  
  "radius_mm": "STRAIGHT"  
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  "speed": 793.0,  
  "triggerTime_ms": 1023.0,  
  "Name": "BodyMotionKeyFrame",  
  "radius_mm": -150.0  
}
```





```
{
  "durationTime_ms": 297.0,
  "speed": -303.0,
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  "radius_mm": "TURN_IN_PLACE"
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{
  "durationTime_ms": 297.0,
  "speed": 793.0,
  "triggerTime_ms": 1023.0,
  "Name": "BodyMotionKeyFrame",
  "radius_mm": -150.0
}
```





Radius	-15
Forward	0
Turn	-37.531



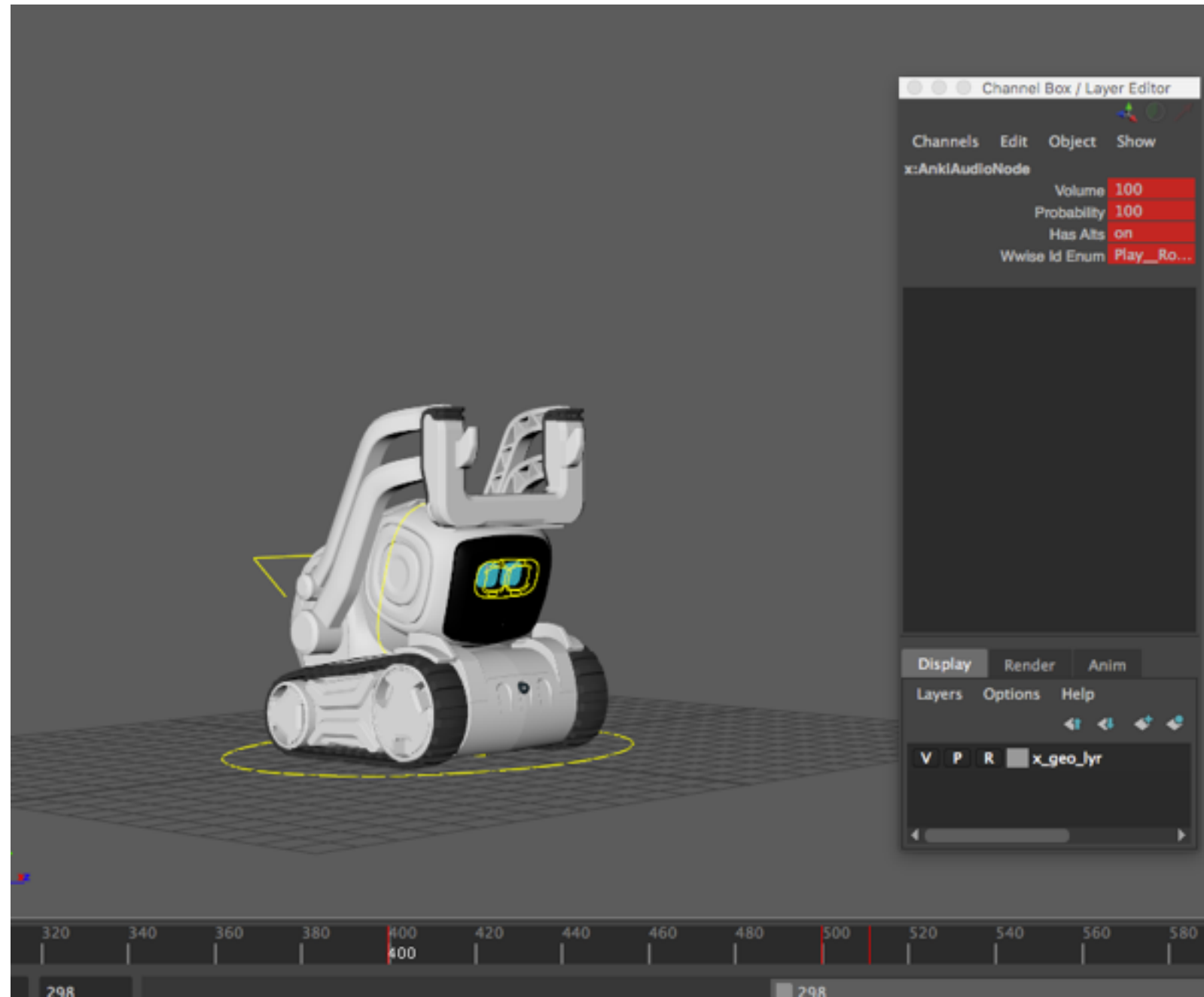


Audio





Audio



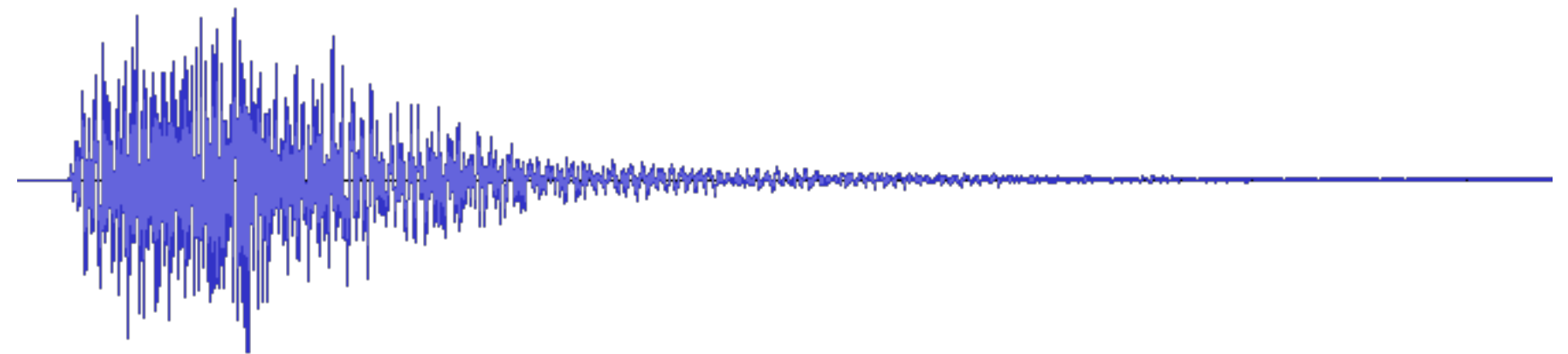
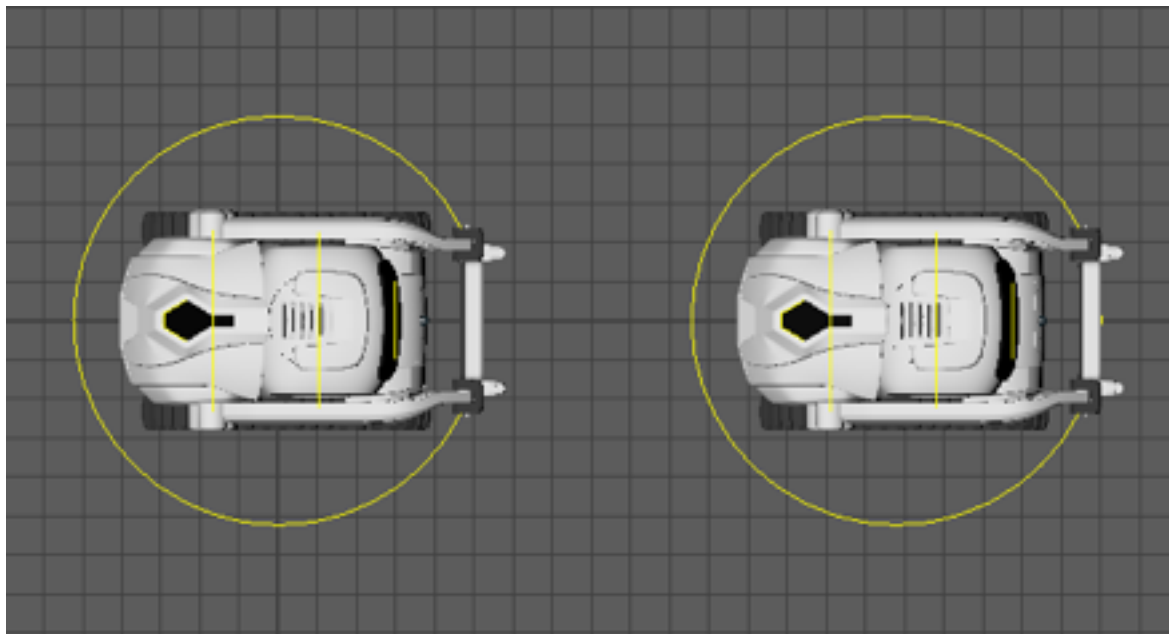
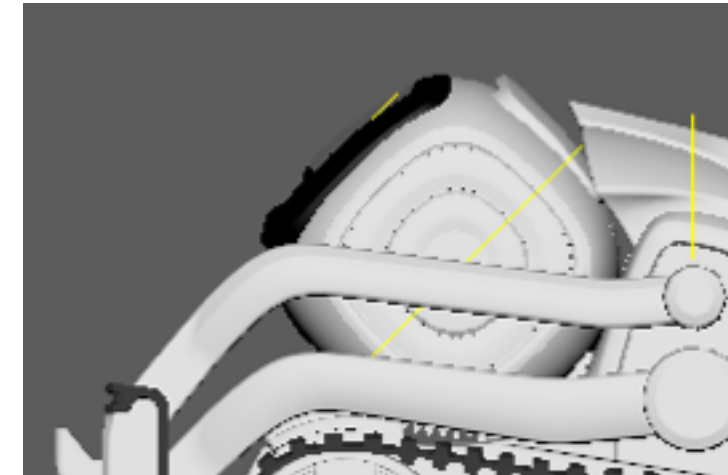


Rig and animation limitations due to physical constraints

Physical limitations

Movement

Audio





Happy accidents









Previewing animation

The screenshot displays the Cozmo development environment. On the left, a tree view shows the scene hierarchy, including CozmoWorldInfo, Viewpoint, Background, DirectionalLight, CozmoMat, and various CozmoBot and WorldComms objects. The CozmoMat object is selected, showing its properties in the 'DEF' panel. The main 3D view shows a Cozmo robot in a virtual environment with a grid floor and several small square markers. A console window at the bottom displays logs, including warnings about chunk loading and an assertion failure. A properties panel on the right shows the robot's current state, including its pose, speed, and battery level.

CozmoWorldInfo
Viewpoint
Background
DirectionalLight
CozmoMat
DEF CozmoViz_1 CozmoBot
DEF WorldComms BlockWorldComms
CozmoVizDisplay
WebotsKeyboardController
name "WebotsKeyboardController"
robotVolume 1
animationToSendName "anim_greeting_happy_03"
animationNumLoops 1
idleAnimationName "ProceduralLive"
DEV_AnimationName "ANIM_NAME"
behaviorName "DISABLED"
behaviorChooserName "Freeplay"
emotionName "WantToPlay"
emotionVal 1
userName ""
enrollToID 0
sayString "Hello"
unlockName "CubeRollAction"
activeObjectFactoryIDs
artificiallyNanant TBIE

CozmoMat (Solid)
Node Mass Position
DEF:
Transform to: <none> Export...
PROTO: Source Result
3D tools:

Console
[webotsCtrlKeyboard] HandleLoadedKnownFace: 'Stuff' (ID:18) first enrolled 3821398 seconds ago, last updated 3821387 seconds ago, last seen 3821377 seconds ago
[webotsCtrlKeyboard] HandleLoadedKnownFace: 'Bagelhead' (ID:21) first enrolled 3821351 seconds ago, last updated 3821341 seconds ago, last seen 3821341 seconds ago
[webotsCtrlGameEngine] (t:01) [Warn] EncodedImage.AddChunk.ChunkOutOfOrder (tc0020) : Expected chunk 6, got chunk 0
[webotsCtrlGameEngine] (t:01) [Warn] EncodedImage.AddChunk.UnexpectedNumberOfChunks (tc0020) : Got last chunk, expected 6 chunks but received 12 chunks
[webotsCtrlViz] (t:01) [Warn] EncodedImage.AddChunk.ChunkOutOfOrder Expected chunk 6, got chunk 0
[webotsCtrlViz] (t:01) [Info][@Unnamed] EncodedImage.AddChunk.IncompleteImage Received last chunk of invalidated image
[webotsCtrlViz] (t:01) [Warn] EncodedImage.AddChunk.UnexpectedNumberOfChunks Got last chunk, expected 6 chunks but received 12 chunks
[webotsCtrlGameEngine] (t:10) [Info][@CpuProfiler] CpuProfiler.ThreadAdded (tc0031) : Thread 1: 'VisionComponent' added
[webotsCtrlKeyboard] HandleEngineErrorCode: ImageQualityGood
[webotsCtrlGameEngine] Assertion failed: (_audioDataStream != nullptr), function SetupEnginePluginFx, file /Users/ben/Documents/Cozmo/lib/audio/source/engine/Plugins/wavePortalPlugin.cpp, line
WARNING: webotsCtrlGameEngine: The process crashed some time after starting successfully.
WARNING: 'webotsCtrlGameEngine' controller crashed.

0.00: Happy
0.00: Calm
0.00: Brave
0.00: Confident
0.00: Charged
0.00: Excited
0.00: Social
0.00: Mining
0.00: Boredom

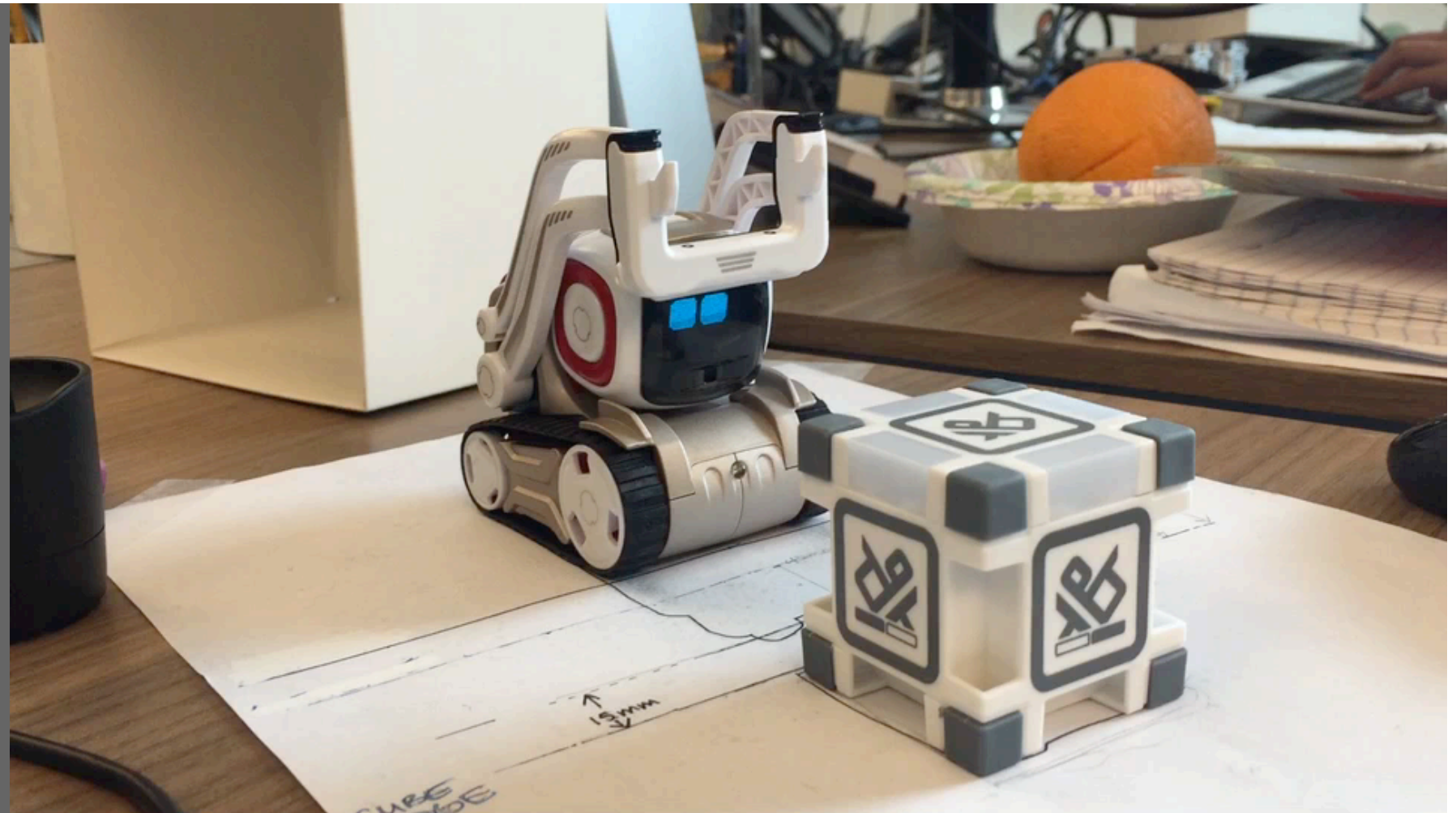
Pose: 0.0, -1.4, ang1 -2.0
Roll: 38.0 deg, Lift: 32.0 cm
Pitch: -5.5 deg (38.0 deg) 26.9 deg
Acc: 4498 -532 886.7 m/s²
Gyro: 0.0 0.1 -0.1 deg/s
Cliff: 0.0
Speed L: 0 R: -77 mm/s
Batt: 9.7 V AnimTrackLocked:
Video: 14 Hz Proc: 14 Hz
AnimBytesFree(AF): 11062(0)
Status:
ANIM(1) HEADING MOVING
Action: PlayAnimationIn_greeting_happy_03
LocalizedTo: (nothing)
WorldOrigin(21): Robot1_PoseOrigin5
Vision: DetectionMarkers*DetectionFaces*Detection
NoneBehavior
Anim: anim_greeting_happy_03
HD 10Hz Selection NoneBehavior



Previewing animation



persp





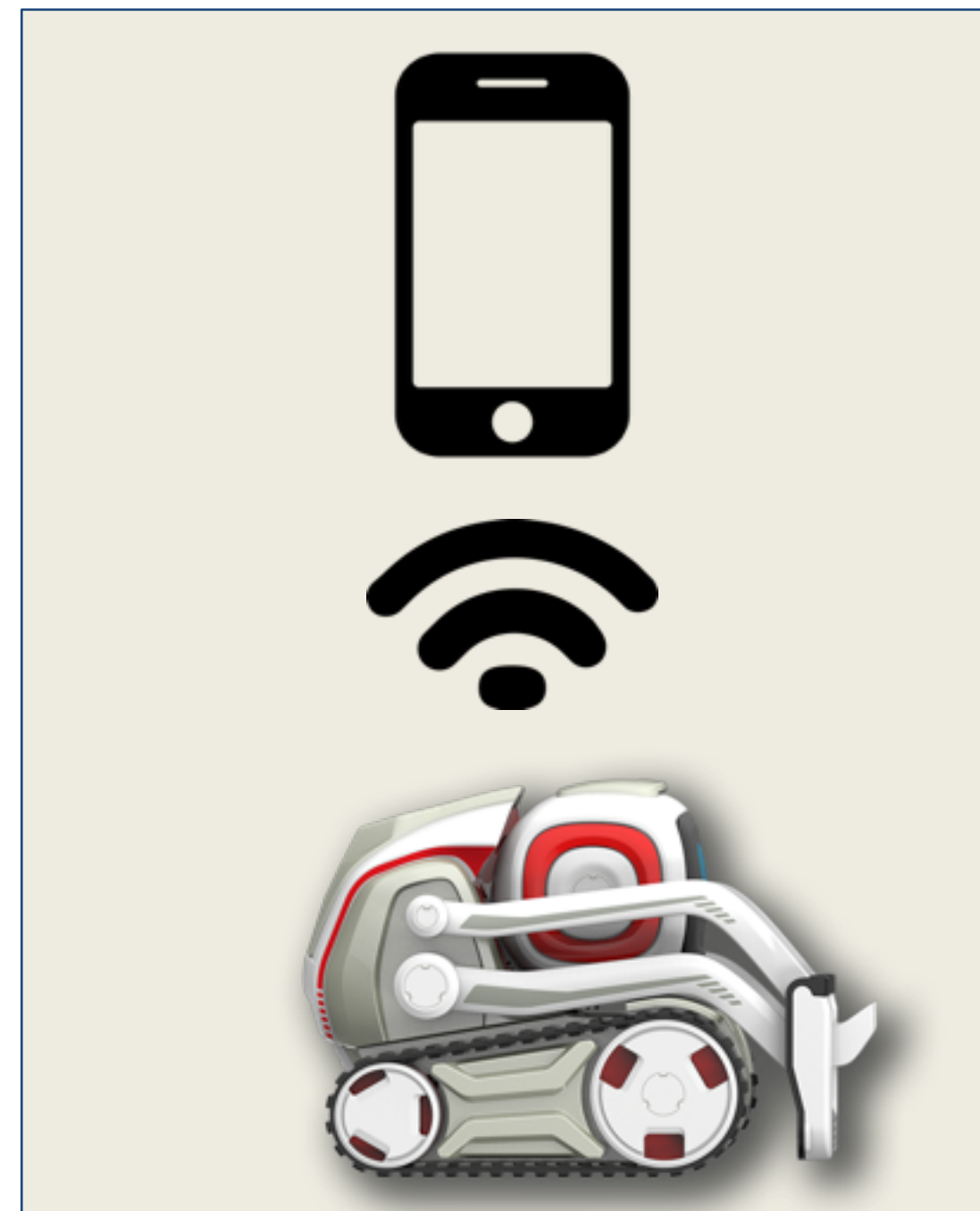
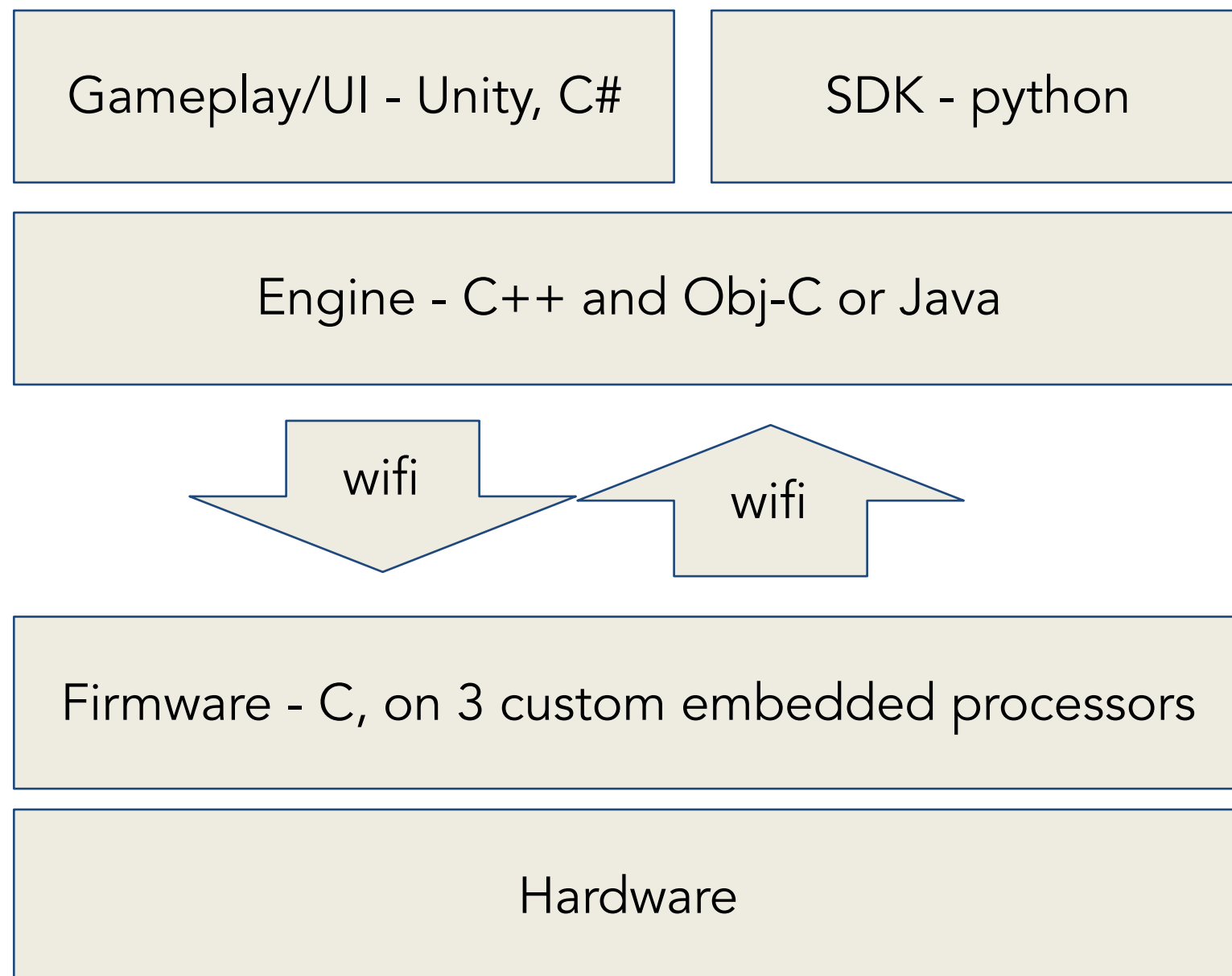
Once we have the animation data created we can then see it in the game as experienced by the player

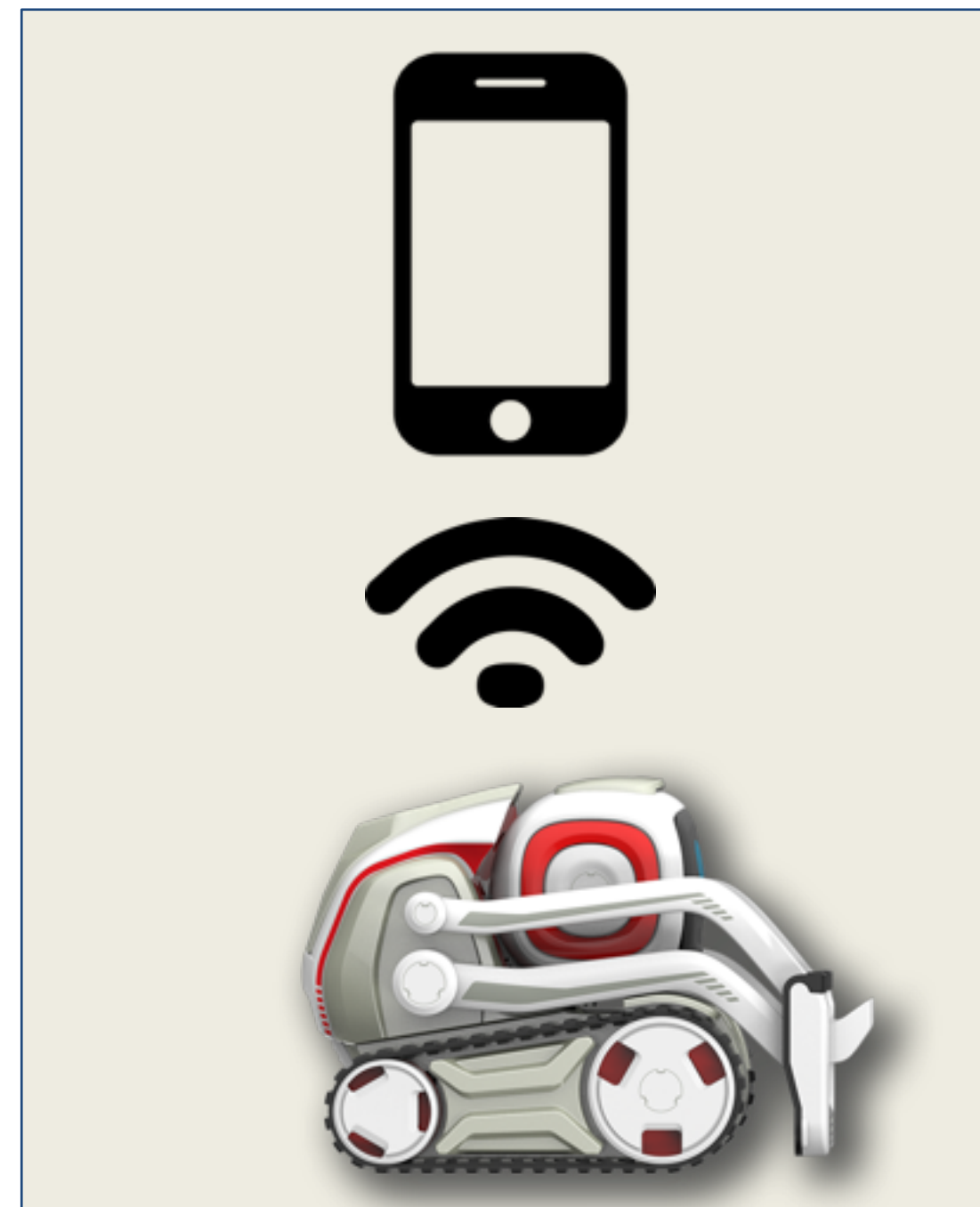
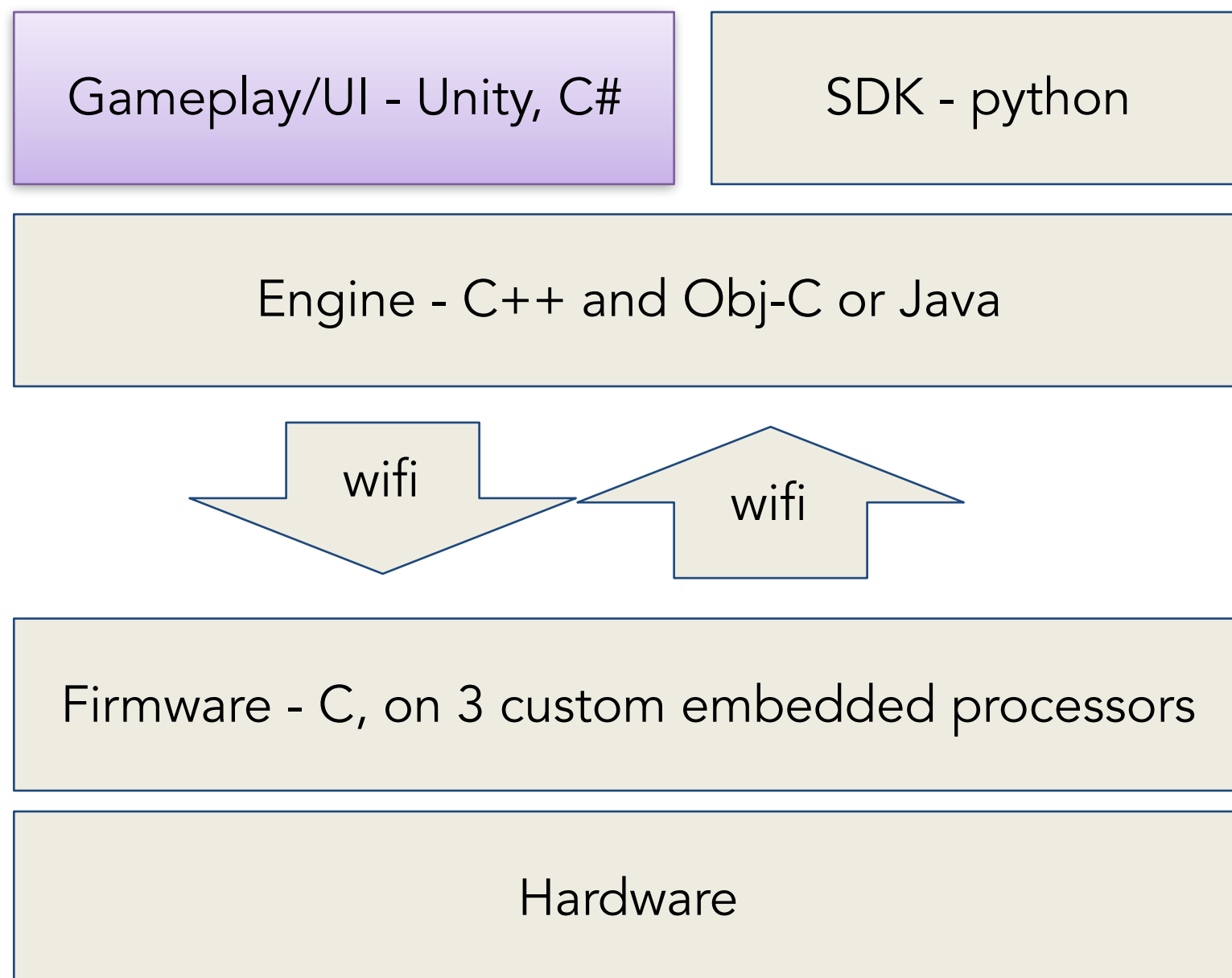


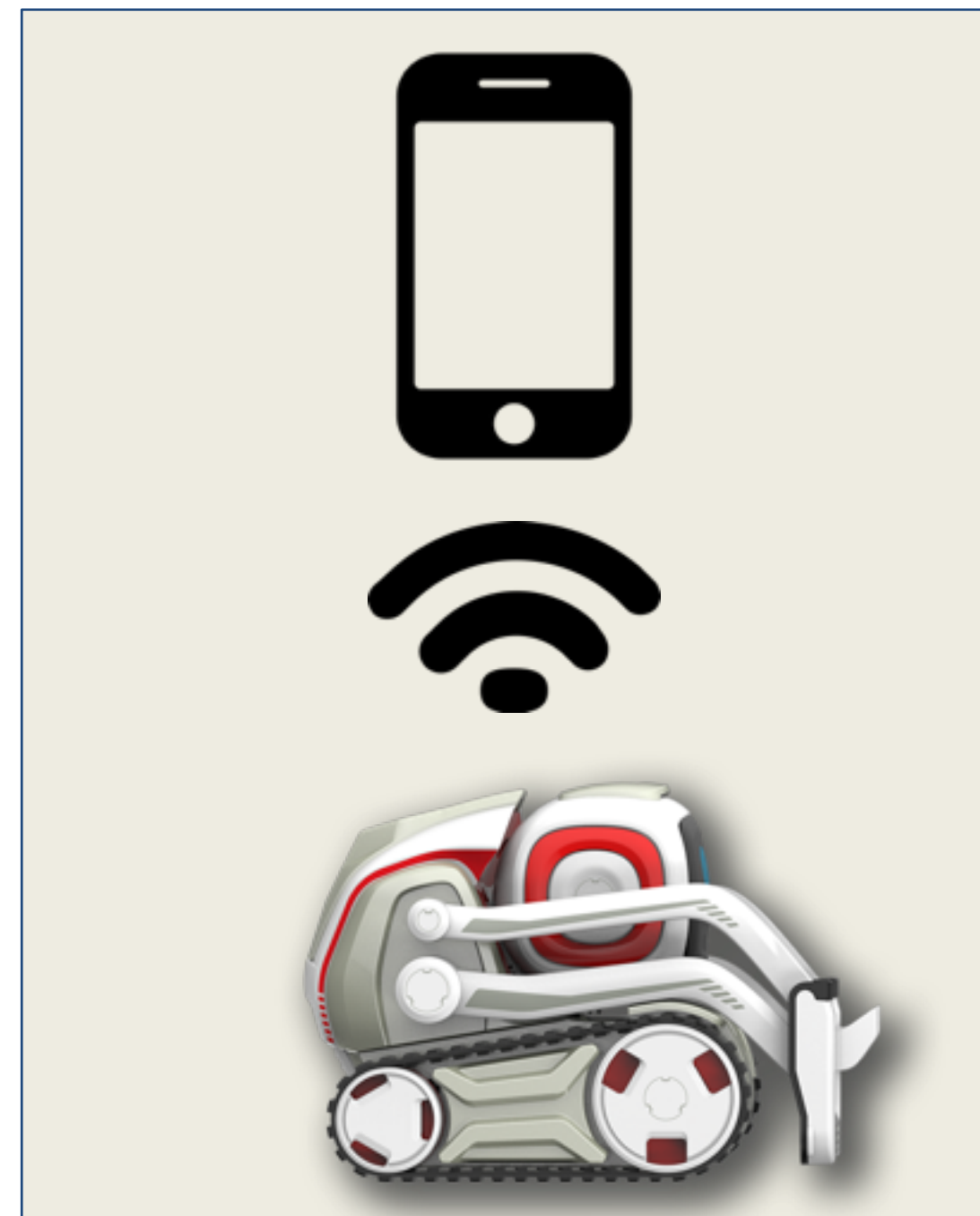
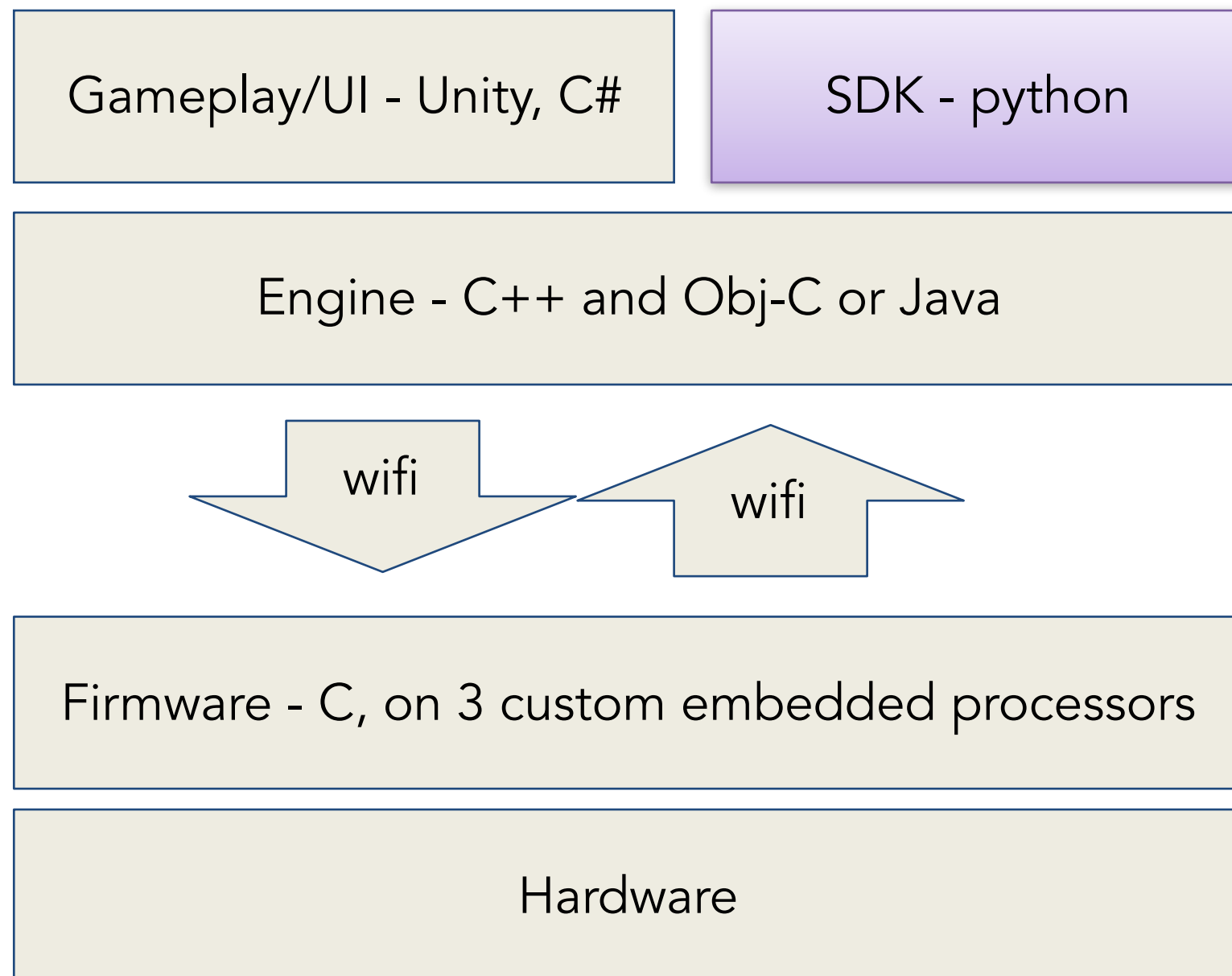


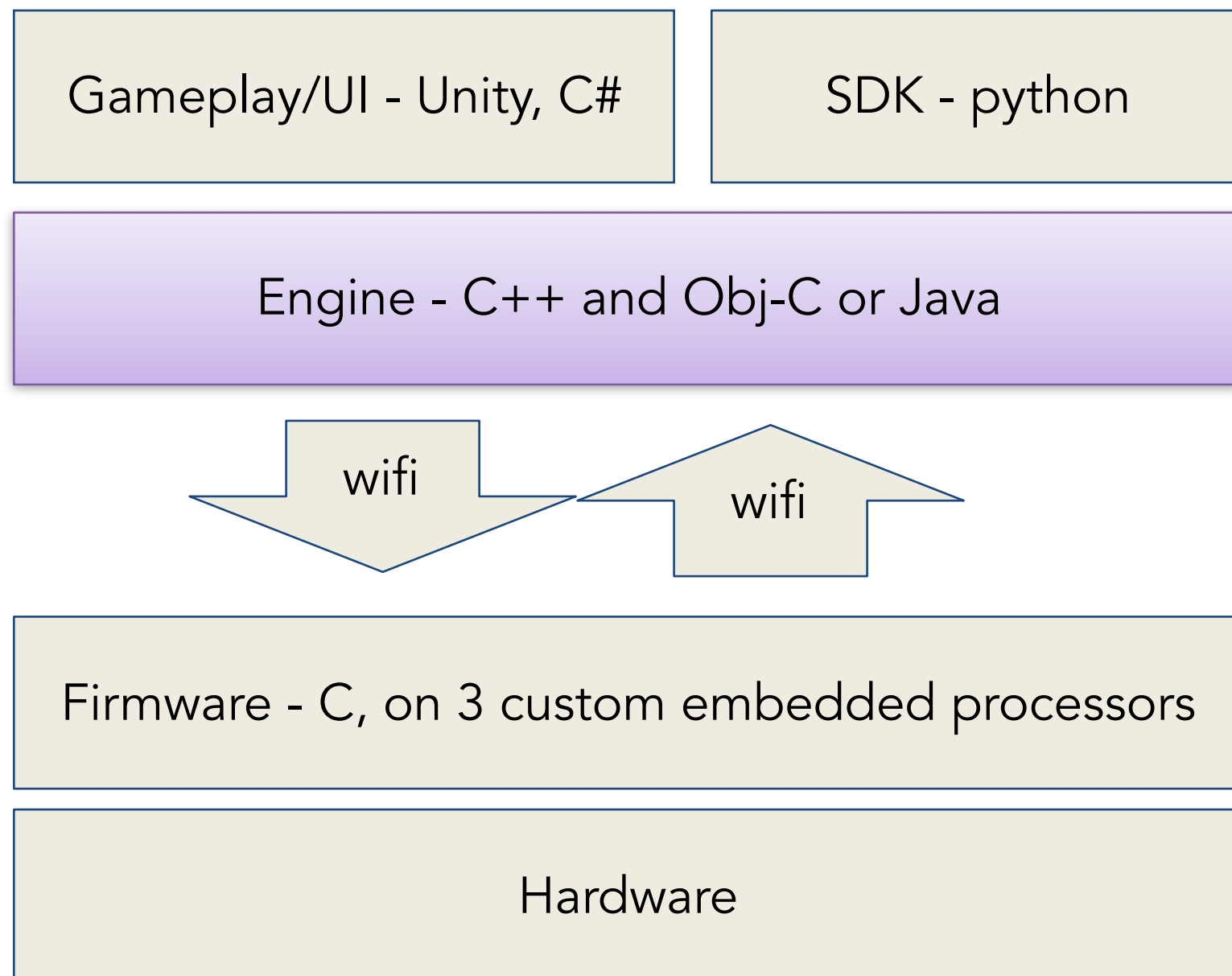
Cozmo's full stack

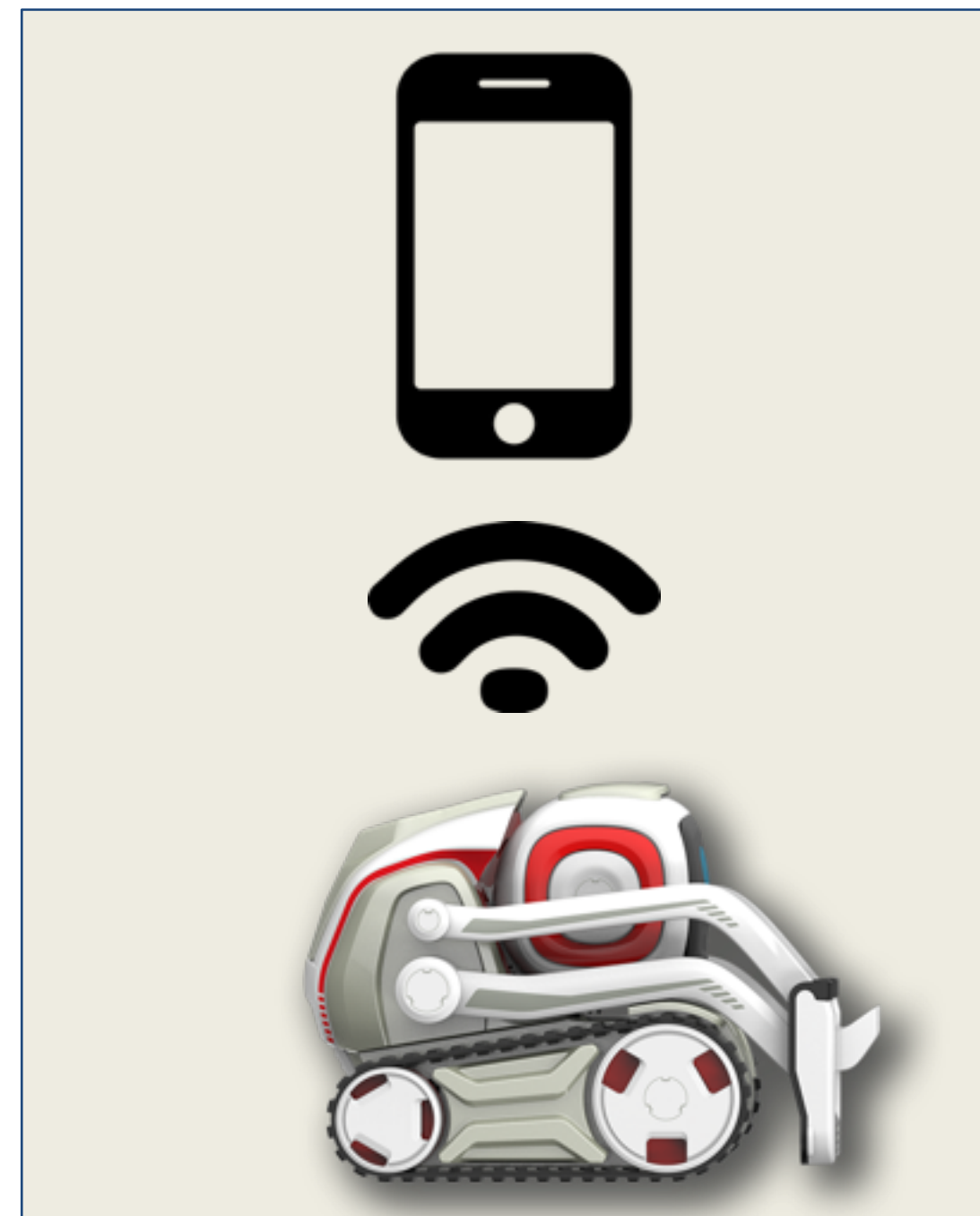
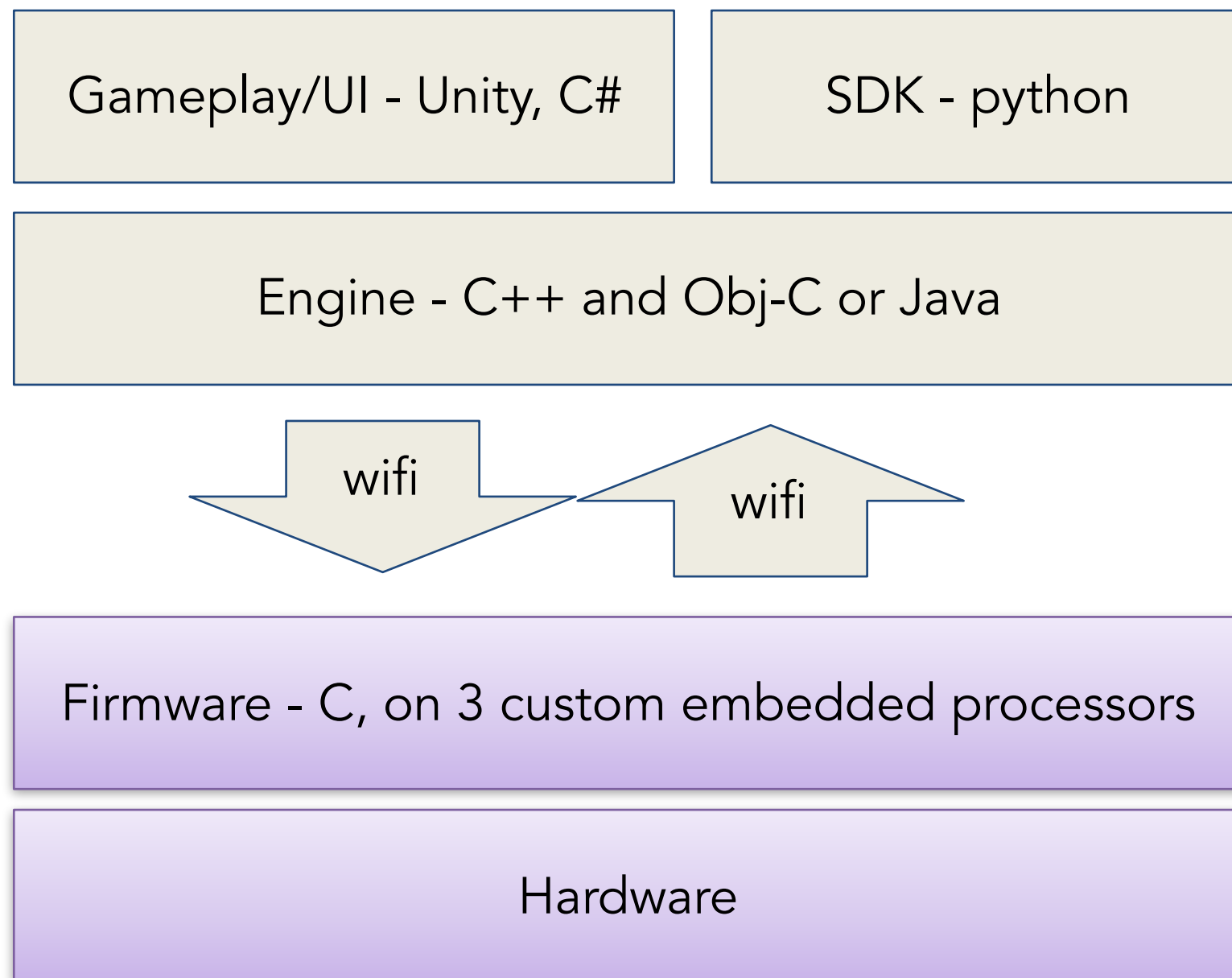






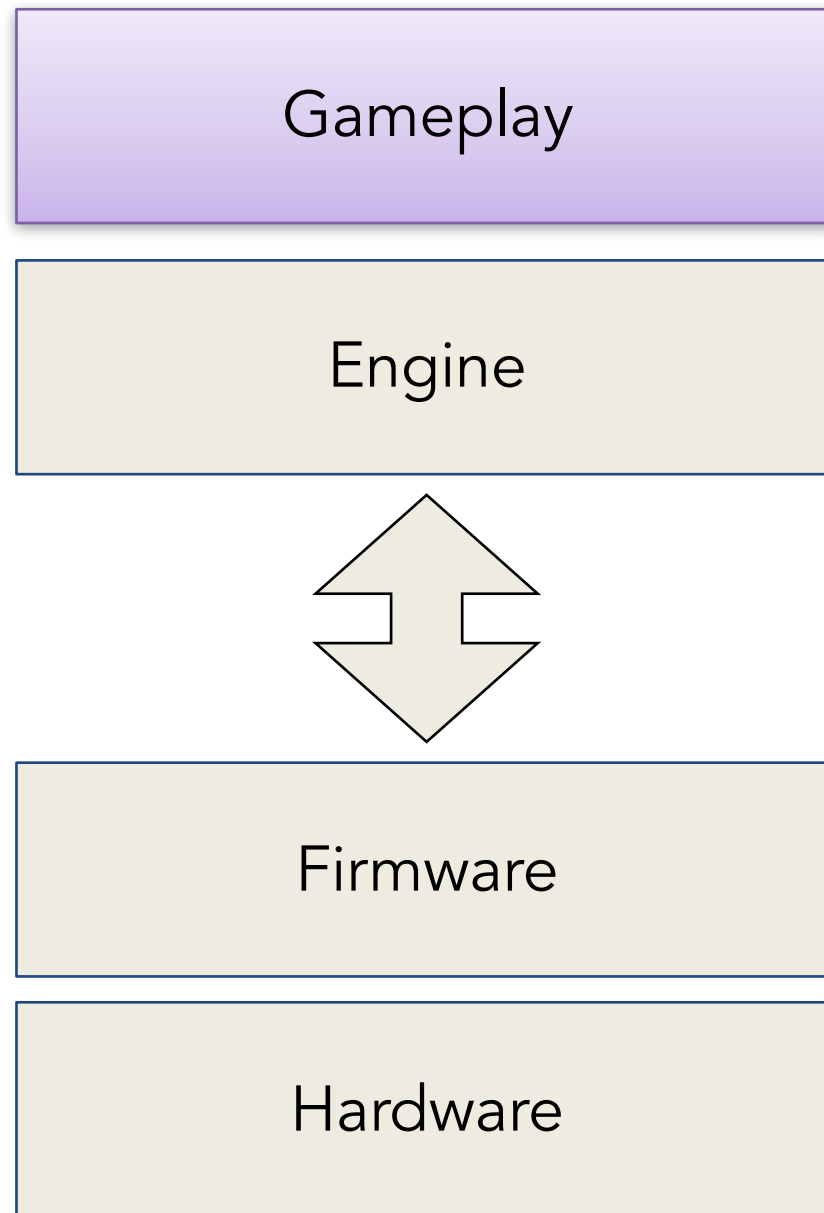








Steps to get animation playing

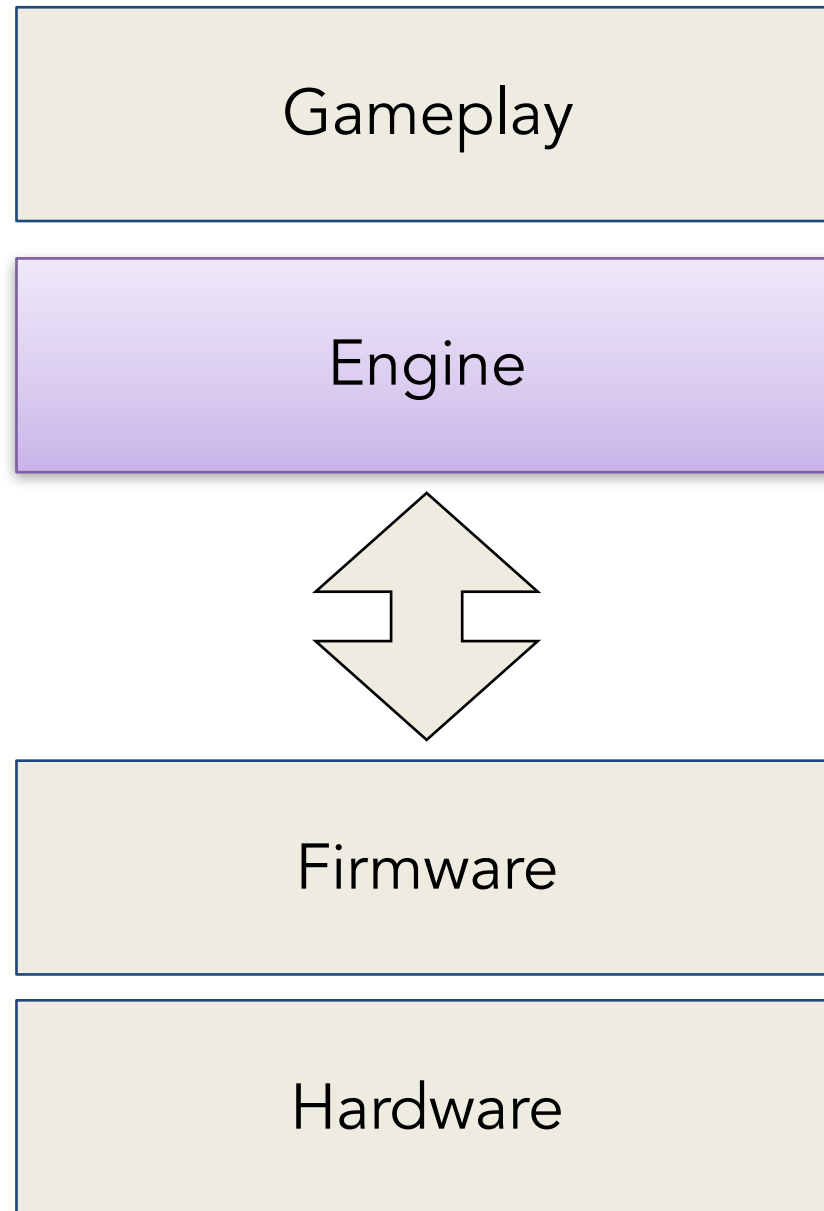


```
robot.play_anim_trigger(  
    cozmo.anim.Triggers.MajorWin)
```



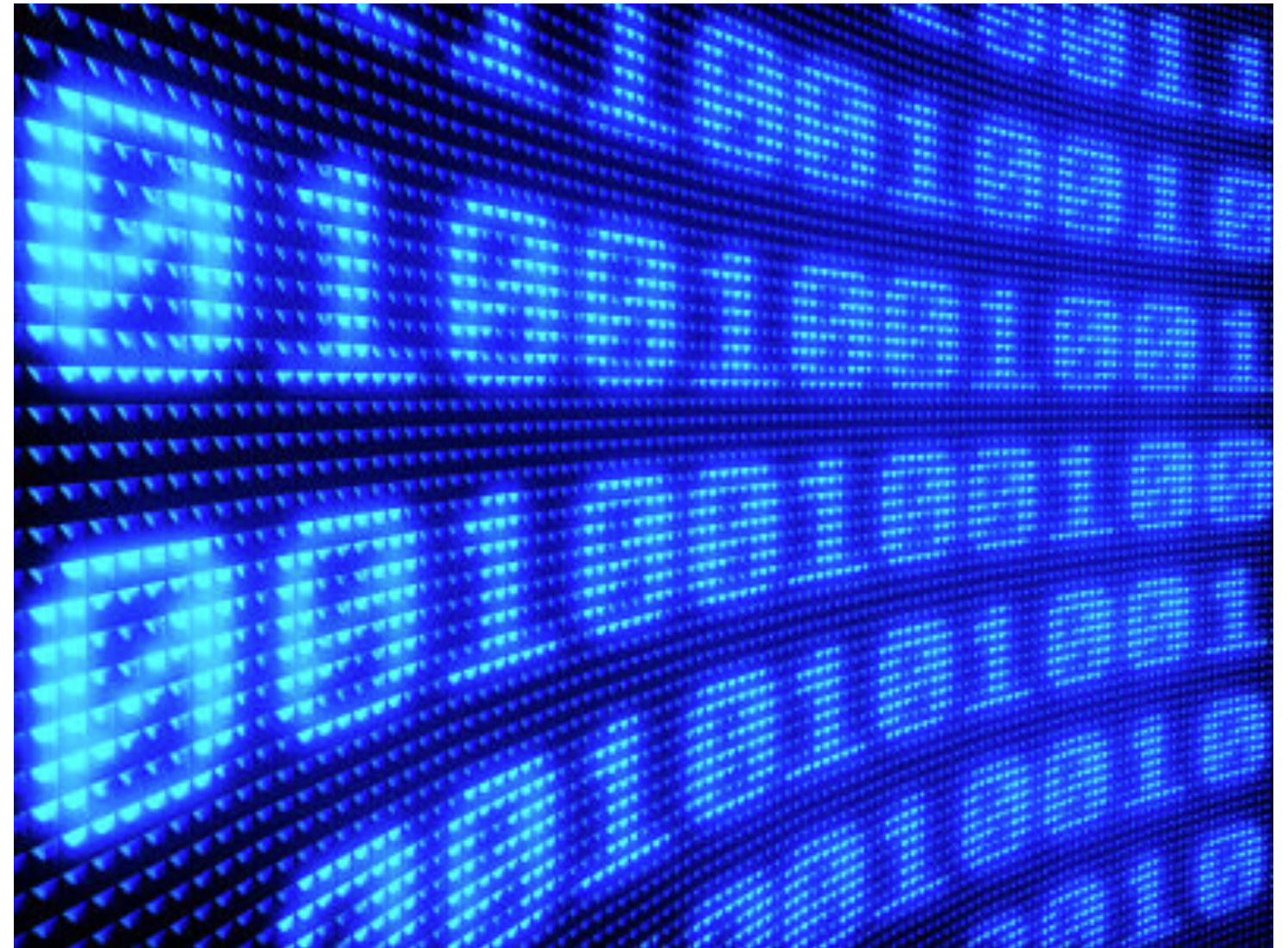
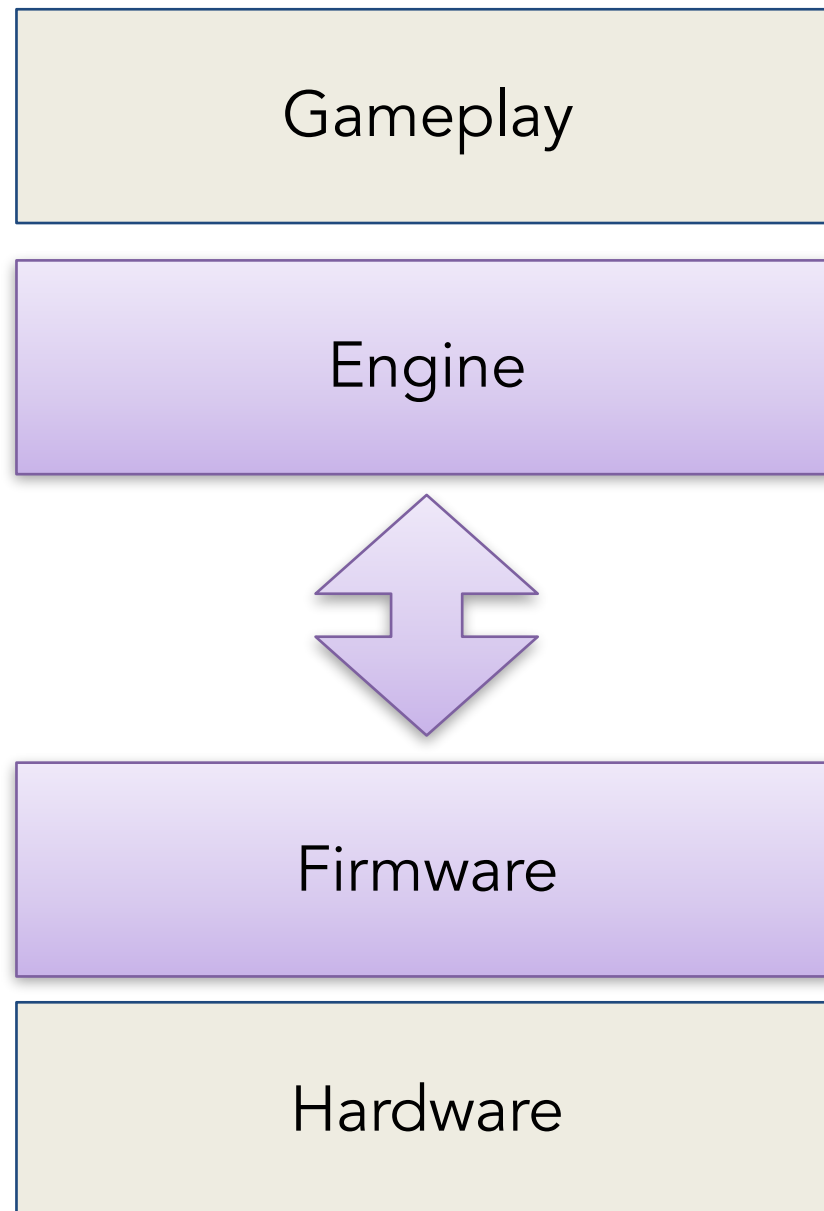


Steps to get animation playing



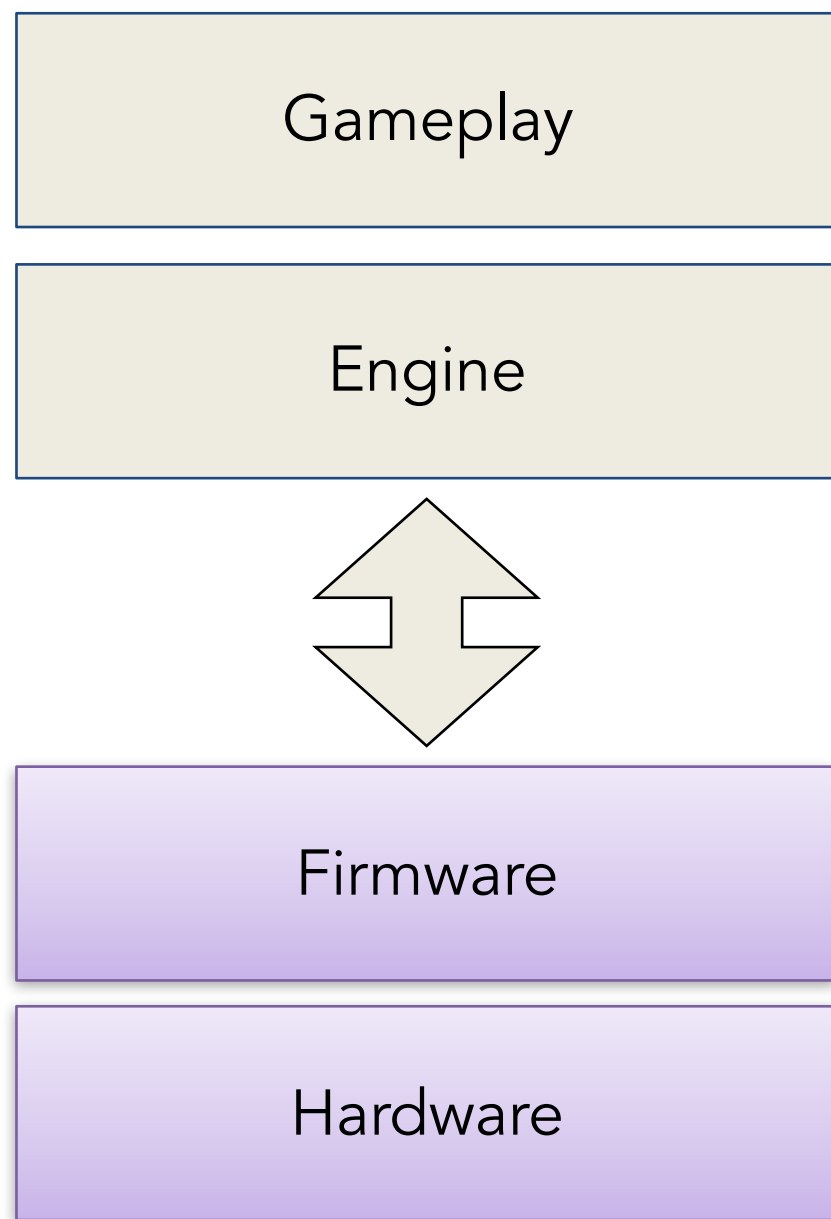


Steps to get animation playing





Steps to get animation playing







Real World Uncertainty And Lessons Learned





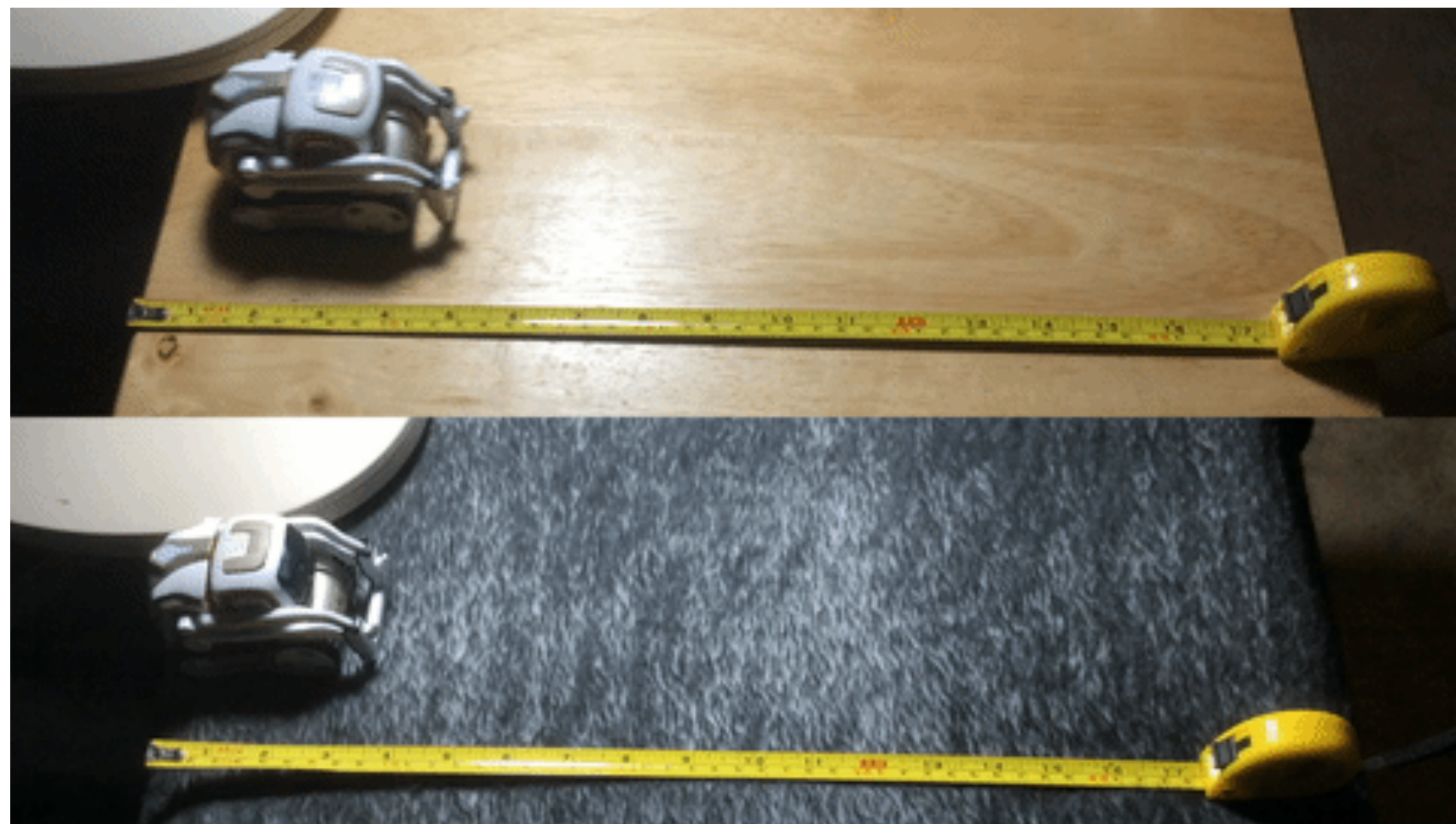
Challenge 1:
Different surfaces make the
robot move differently





Different Surface frictions mean different timing

Challenge: We'd often want things like "Cozmo drives forward for X seconds which should be Y mm at Z speed"





Different Surface frictions mean different timings

Fix: Procedural actions that can dynamically respond to where Cozmo is currently in the world.

How do we know where Cozmo is in the world?



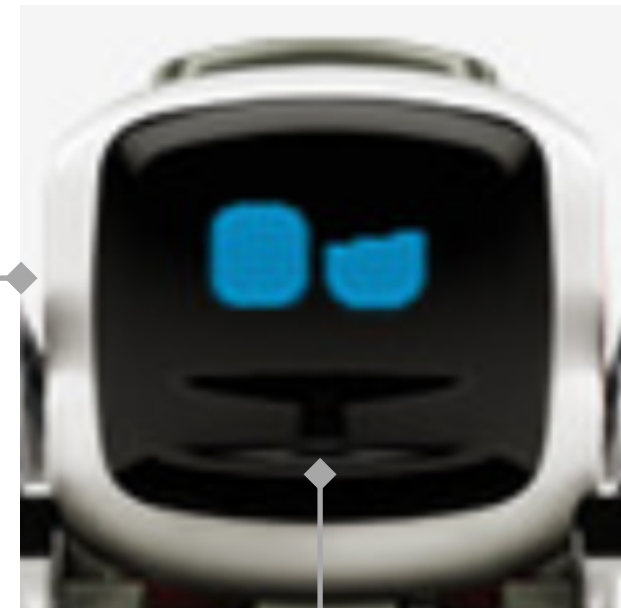


Sensors on Cozmo

wheel
encoders

IMU

Cliff Sensor



Camera

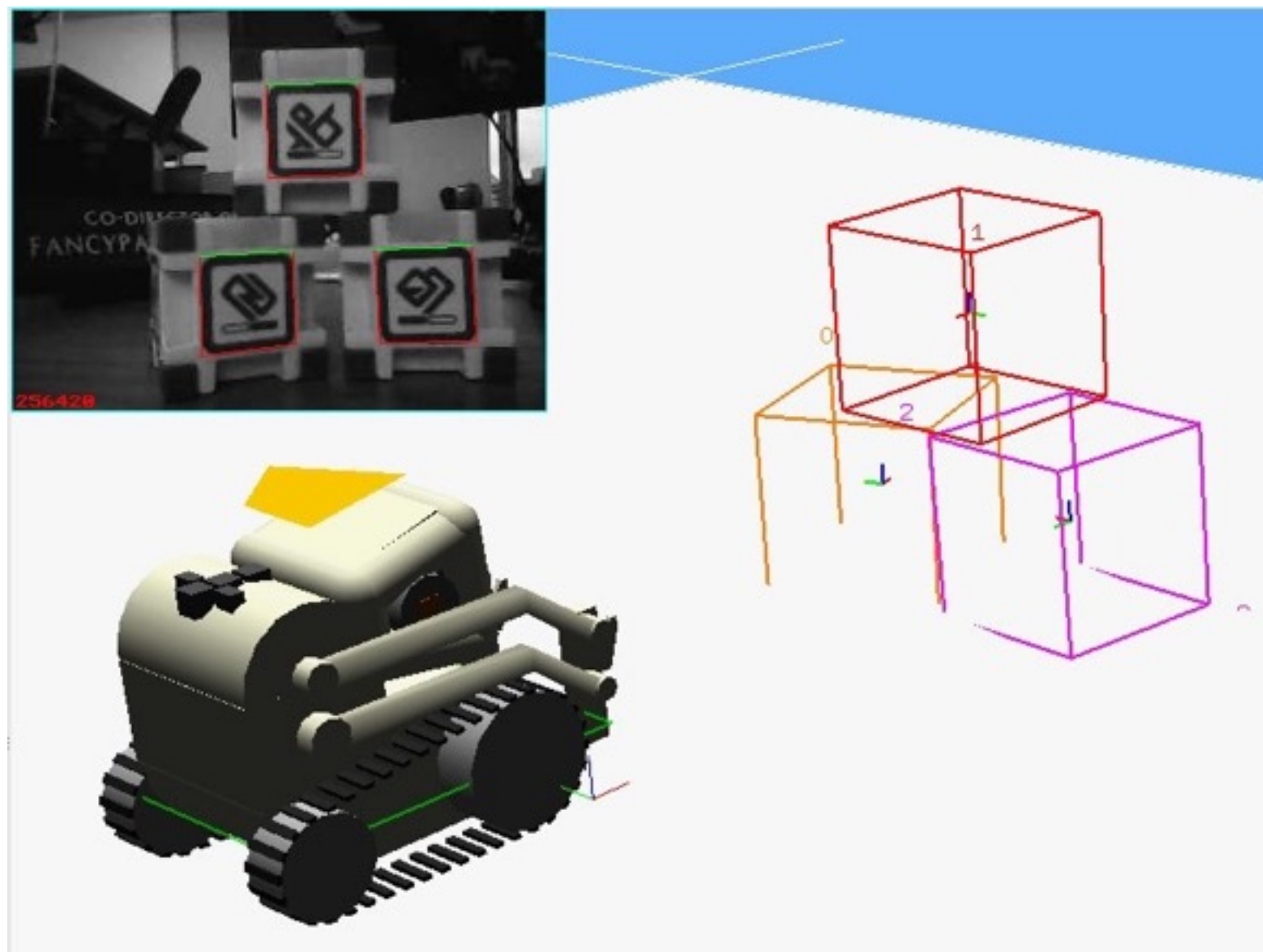




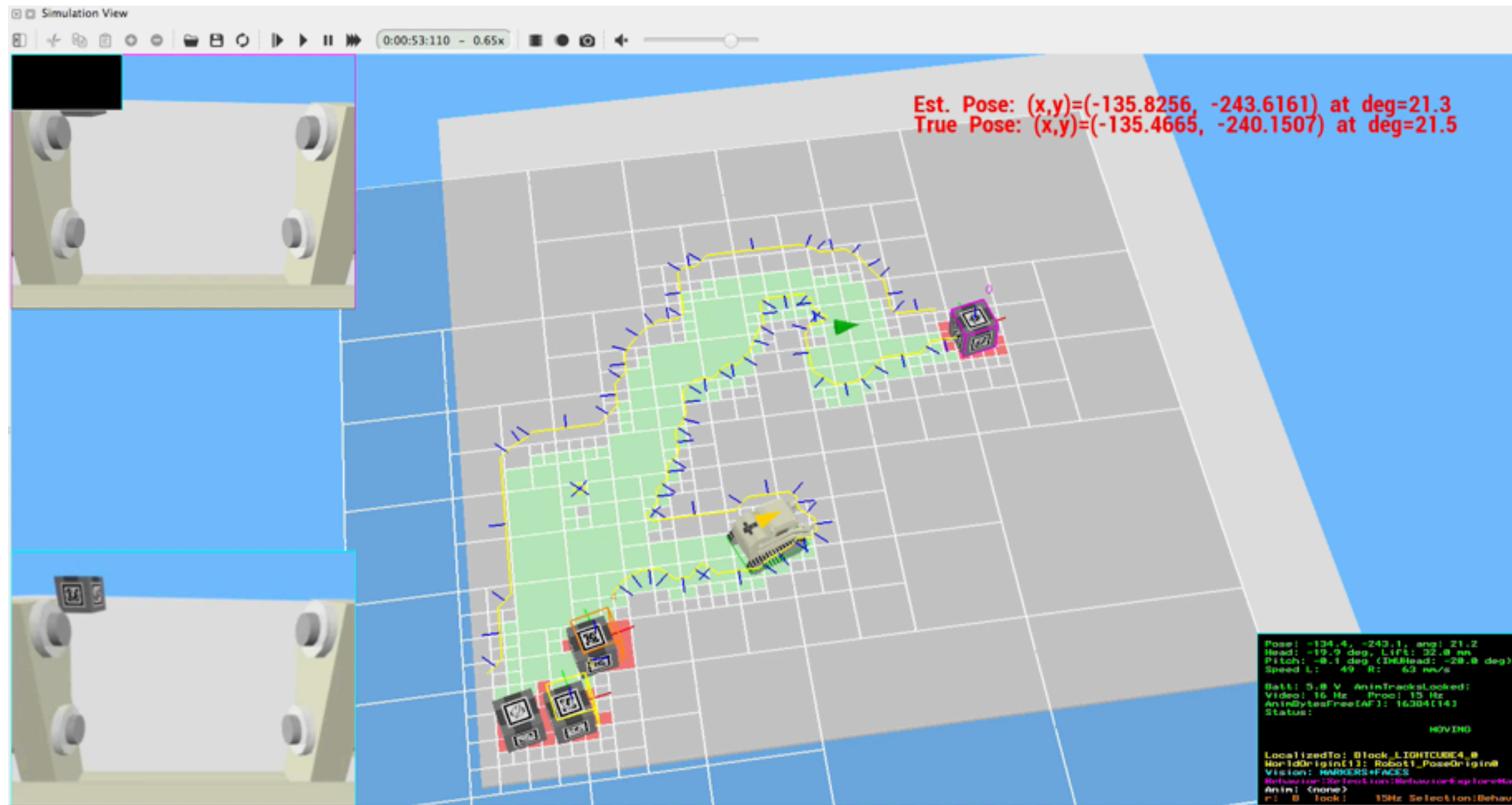
Cozmo Ecosystem

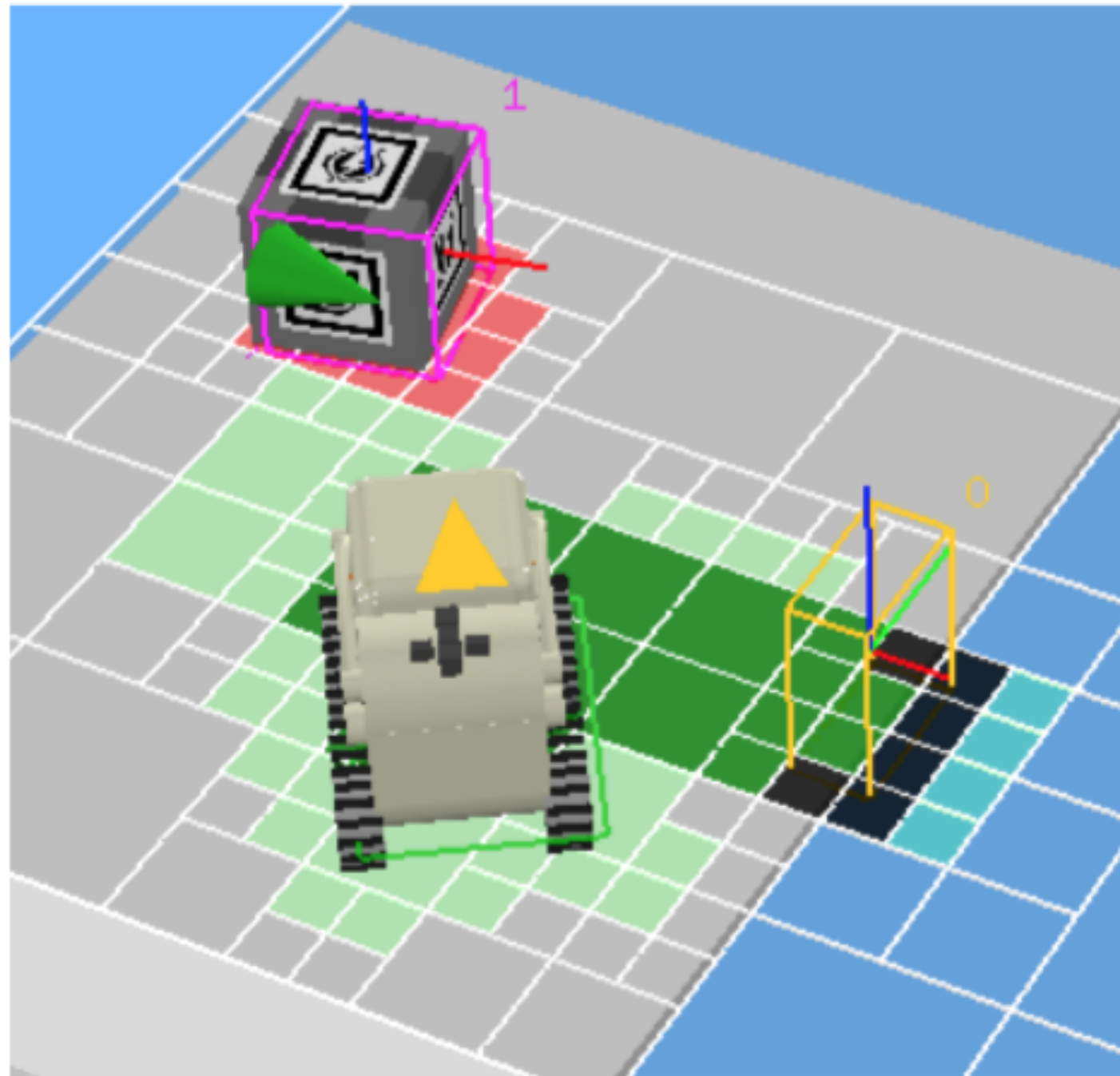


Cozmo's cubes



SLAM (simultaneous localization and mapping)







Robot Localization

How do we know where cozmo is in the world?

- Camera data of seen blocks
- Drive history
- Visible area between camera and cliffs probably obstacle free.
- Gyro + cliff sensor can feel if he's been moved by an outside force





Challenge 2: Making animations work in multiple situations





Making animations work in multiple situations

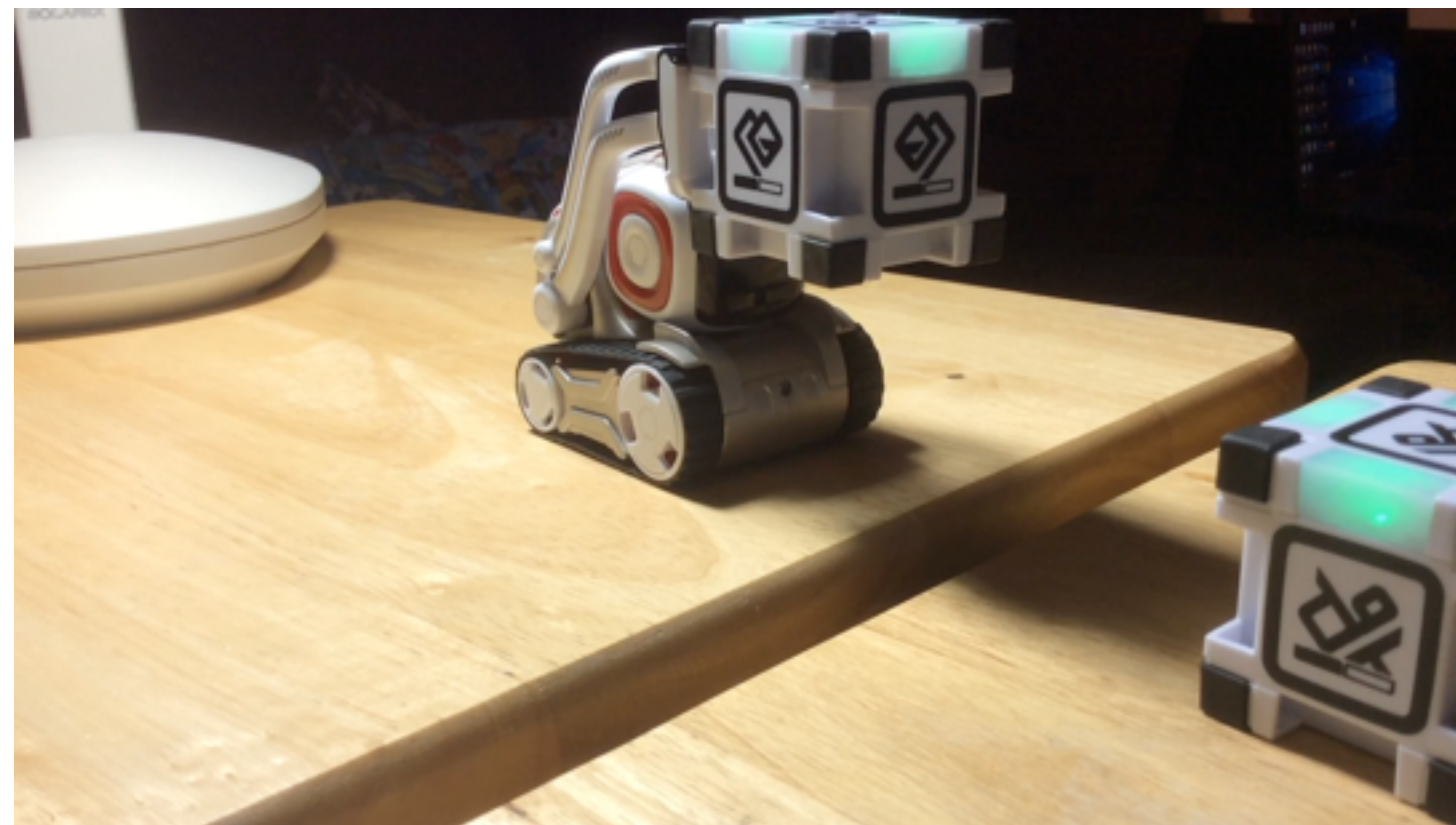
Challenge: Animations need to be flexible to play in different contexts, such as driving and driving while holding a cube.





Making animations work in multiple situations

Fix: locking important tracks we don't want to move if they are occupied





Challenge 3:

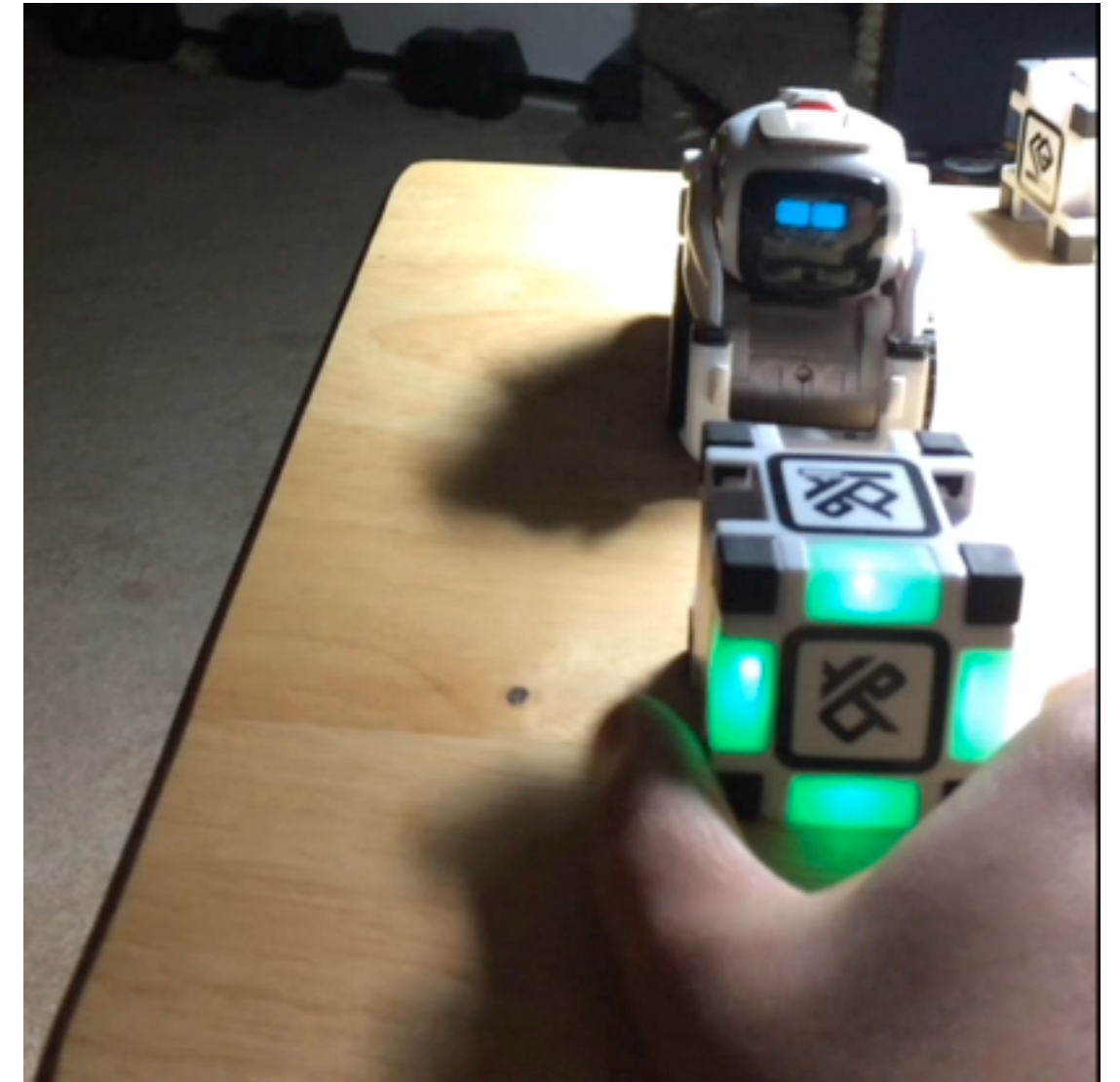
Recovering if actions unexpectedly fail





Sometimes actions fail

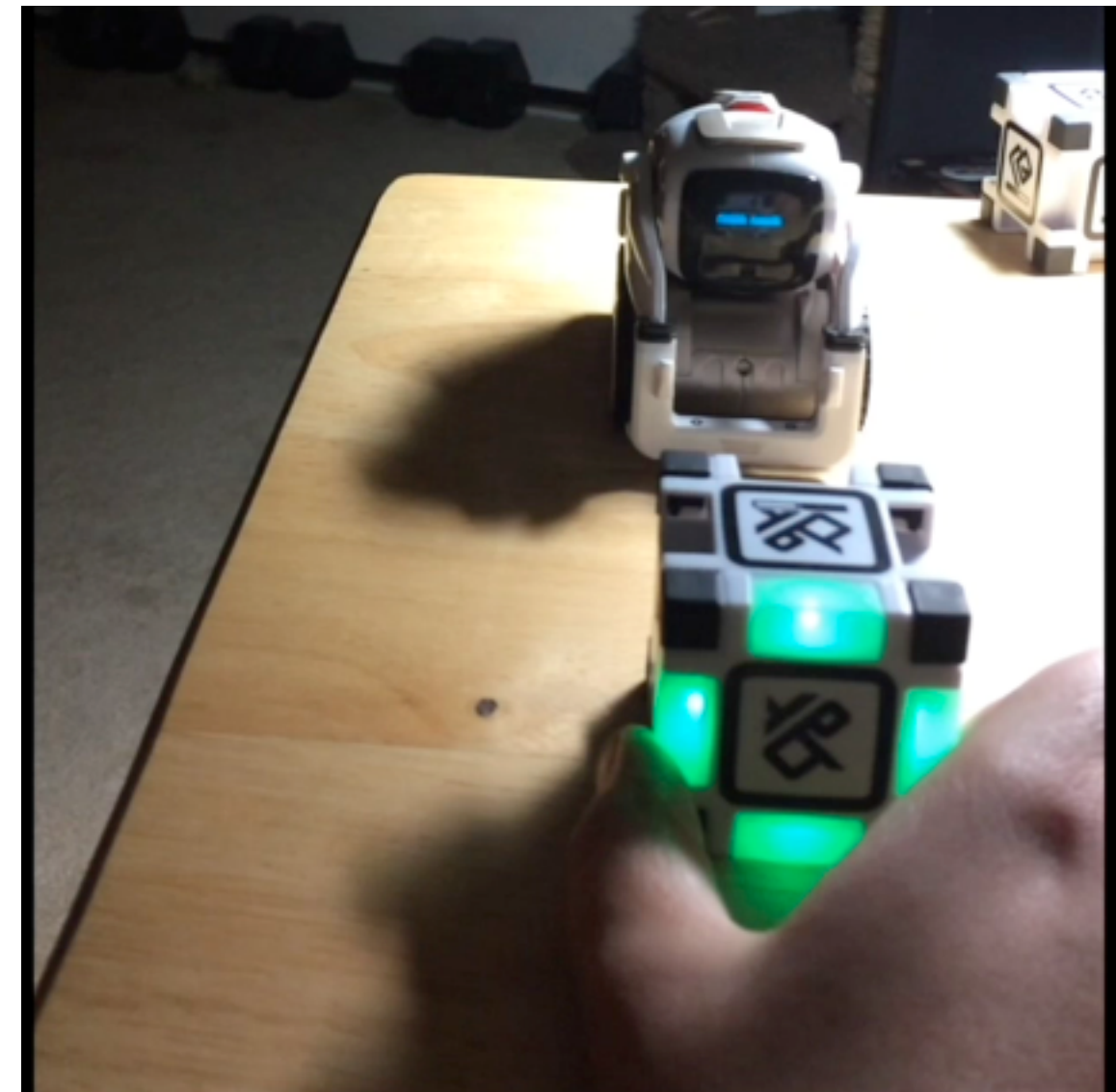
Challenge: Cozmo only has a simulated version of the world and often the real world doesn't match meaning actions can fail if something isn't where he thinks it should be.





When actions will fail, communicate a retry

Fix: Animators made failure states that demonstrated Cozmo was confused by the frustrating world making behaviors robust enough to handle several retries





Challenge 4:

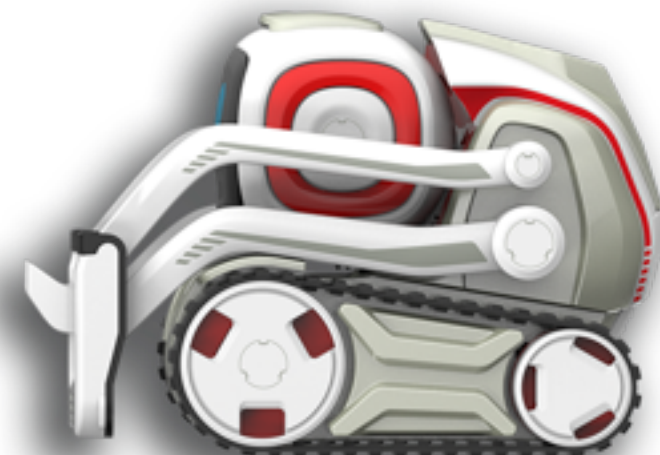
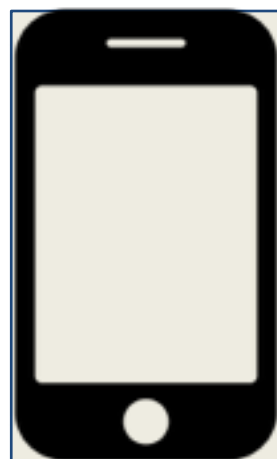
Directing the user's focus





Where is the user's focus?

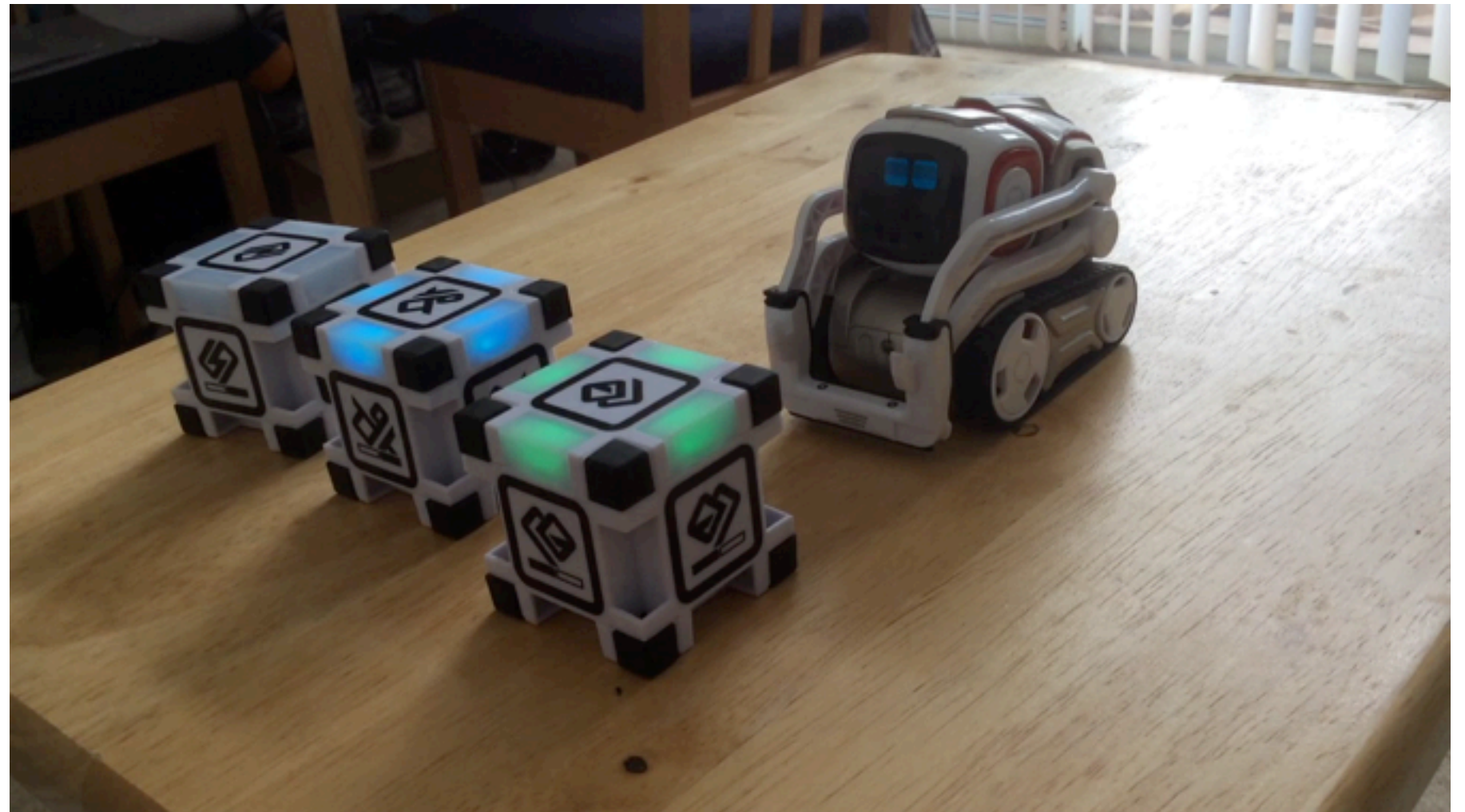
Challenge: Because we have an App with UI and a robot that can do cool stuff, the user might not be looking where we need them.





Where is the user's focus?

Fix: "Hey look at me!"
behavior when Cozmo
was about to do
something interesting
on his own





Challenges Overcome!

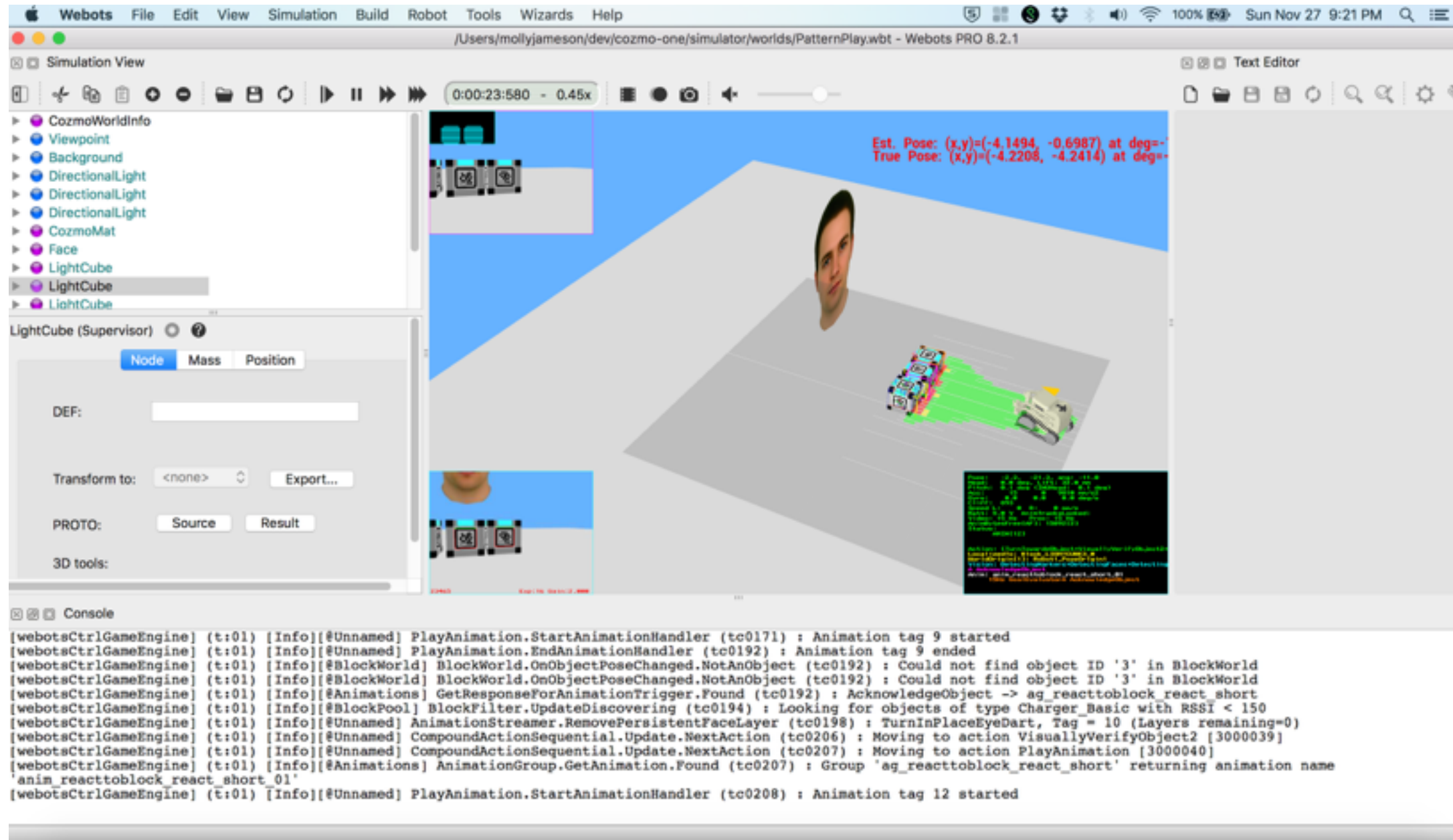


it!

... After testing



Automated Testing





Lesson Learned:

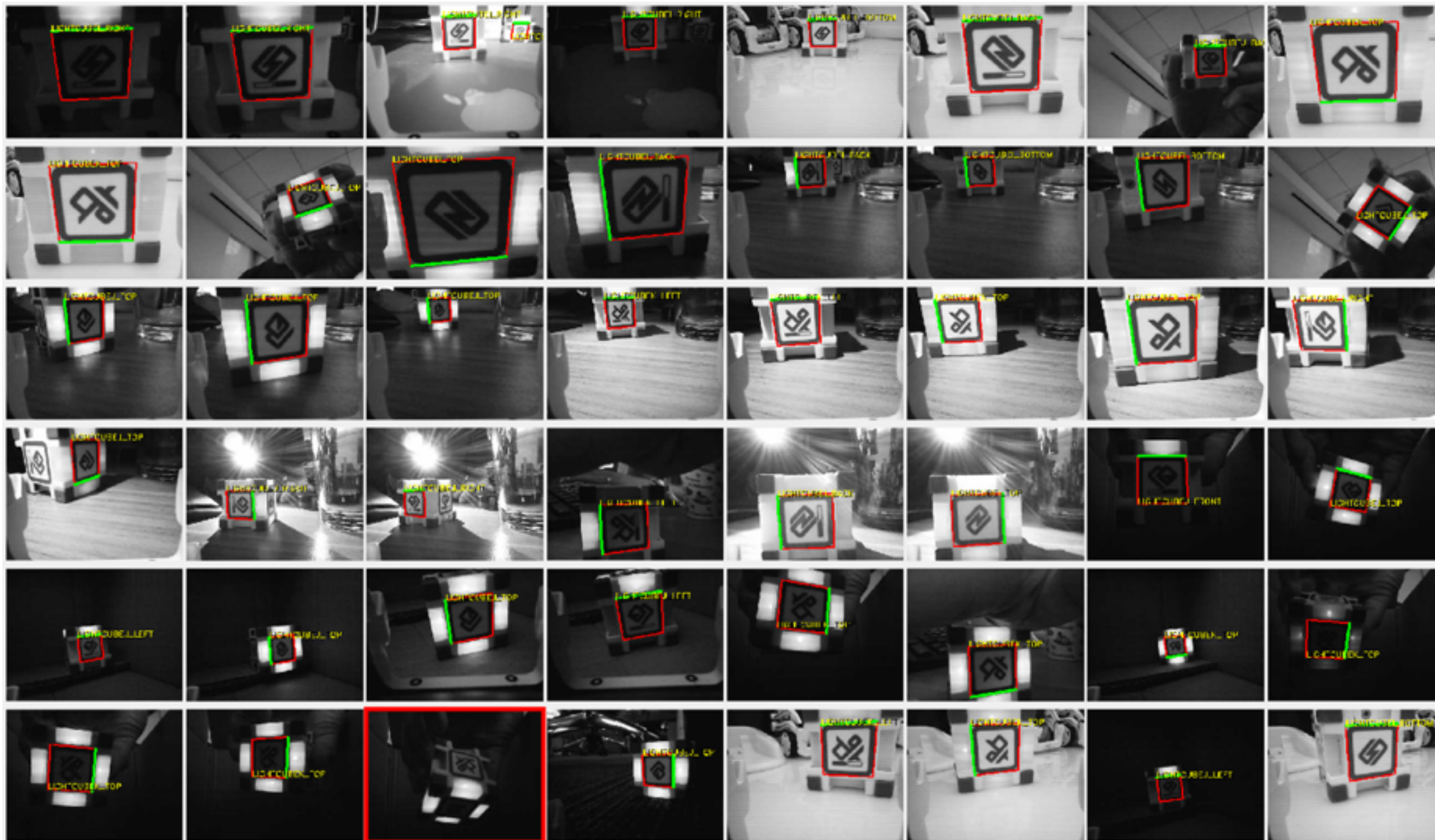
Programmers from robotics backgrounds are way more serious about automated testing than most games programmers.





Manual Testing







Message your users when in trouble





Sometimes the key to testing is getting creative



Factory Testing

2016-8-9... / K6 + V55CH3 + V56CF3
2016-8-12... / K6 + V56CH3 + V57CF3
2016-8-13... / K6 + V56CH3 + V58CF3
2016-8-18... / K6 + V58CH3 + V60CF3

Afix05

Afix05

FULL SYSTEM TEST + SENSOR CALIBRATION



Testing

- Hardware is finalized long before software (~1 year in our case) to go to factory. QA needs to be testing way sooner as a result.
- Features need to be tested across multiple robots, multiple devices, multiple environments.
- Drop testing, temperature and humidity testing.





Thanks

Nishkar Grover

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Mooly Segal

Mark Wesley

David Cerpa

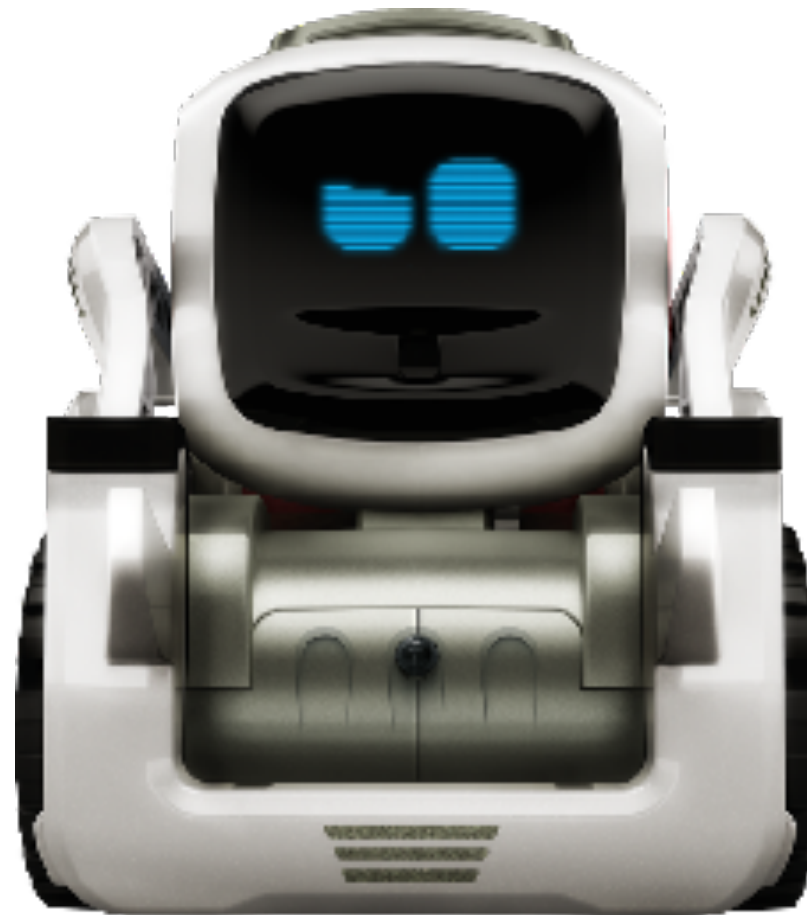
Kevin Yoon

Brad Neuman





Questions?





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