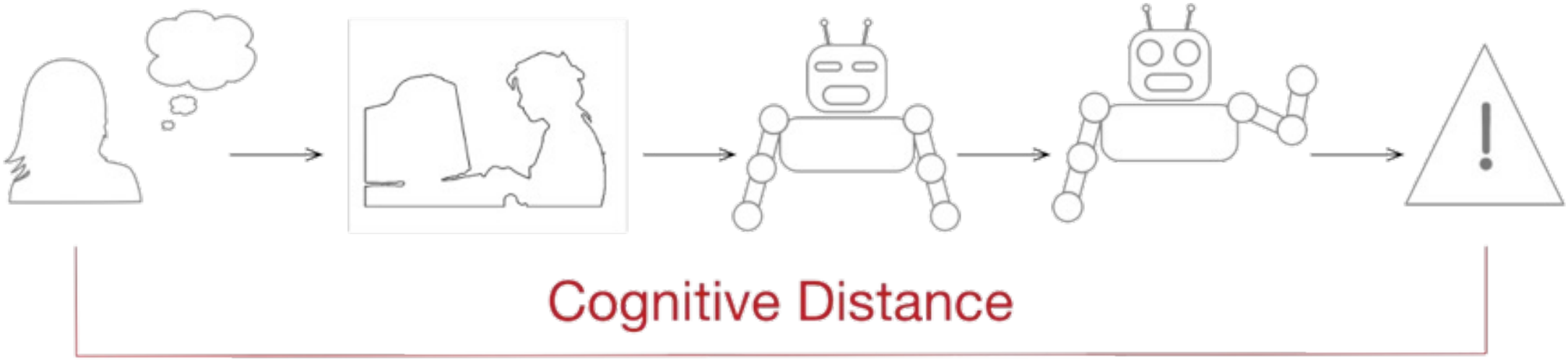
Contextual visualizations for debugging collaborative robots

Emil Stubbe Kolvig-Raun
Thor Malmby Jørgin
Miguel Campusano

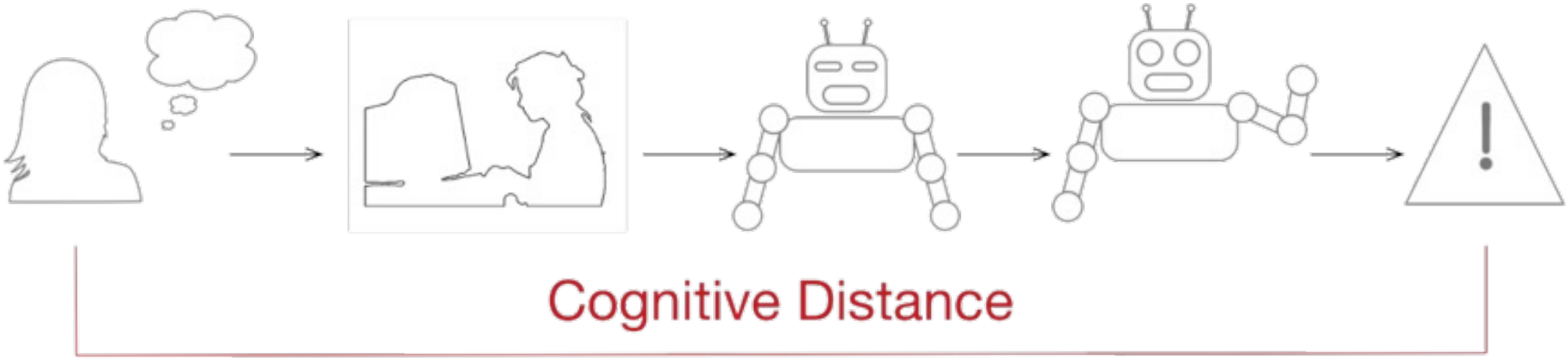
SDU Software Engineering

Development cycle



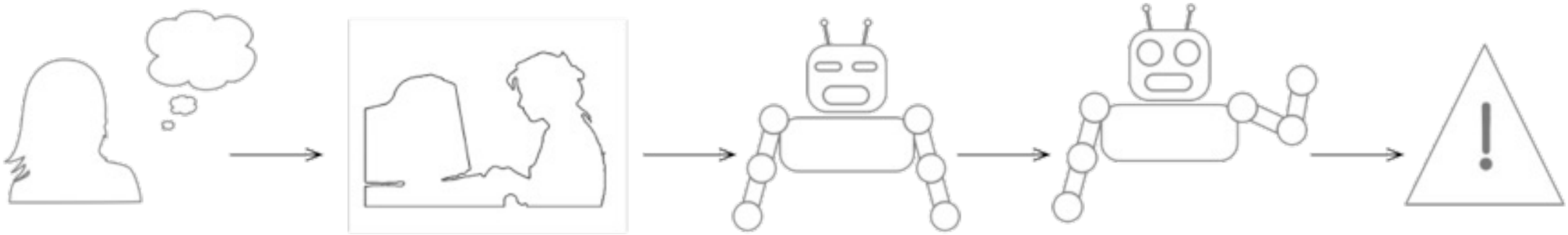
Robotic development process is *long & slow*

Development cycle



Errors! => + Cycles => + Complex

Development cycle



Errors! => - Cycles => - Complex

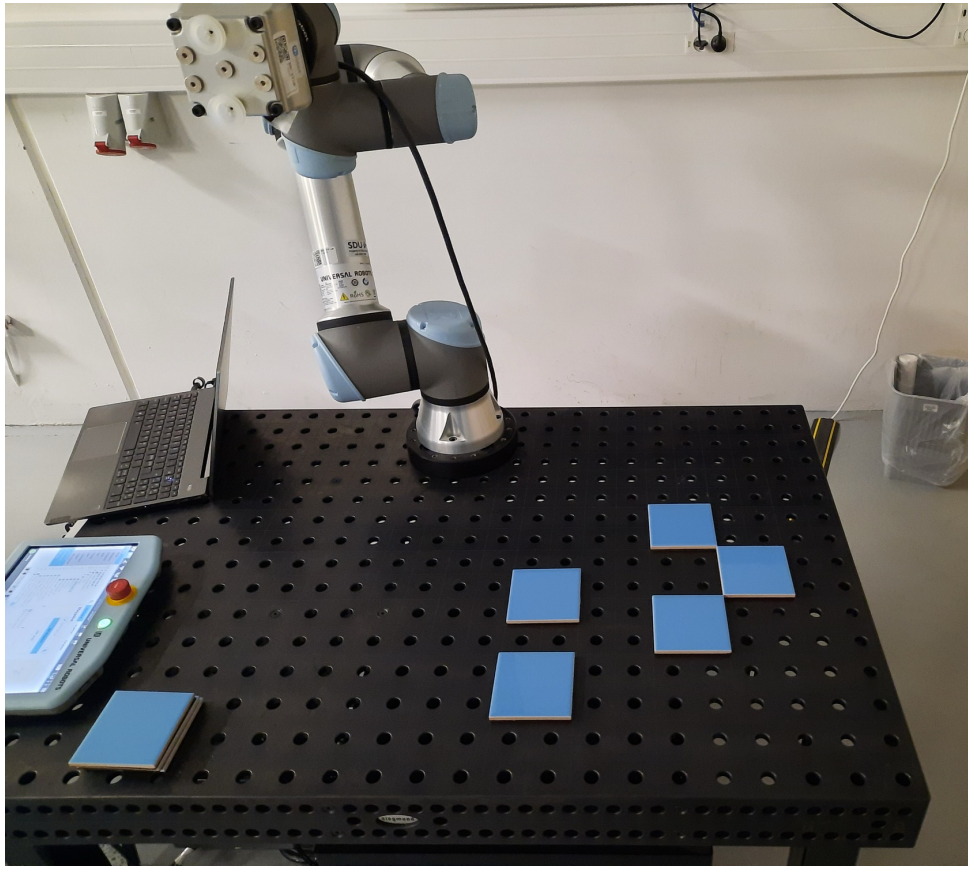
Collaborative Robot: Cobots

Direct human-robot interaction

Close proximity with humans

Evaluation

- Continuous visual inspection
- Long working shifts



Collaborative Robot: Cobots

Direct human-robot interaction

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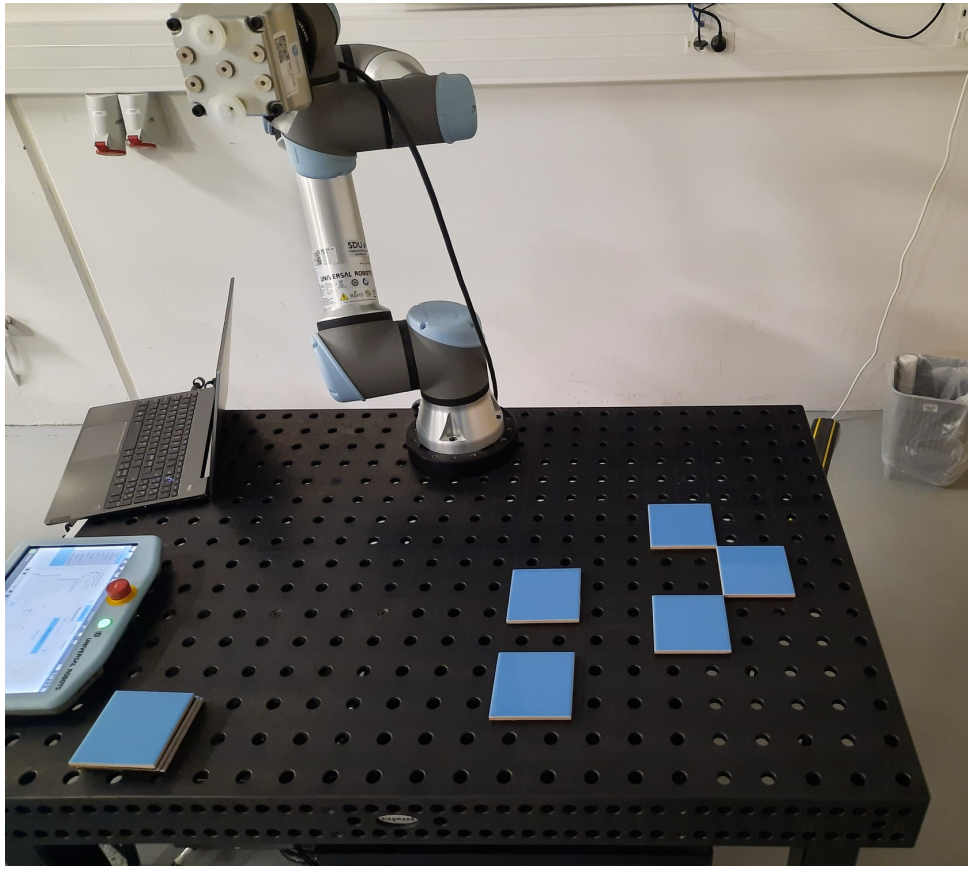
Evaluation

~~Continuous visual inspection~~

~~Long working shifts~~

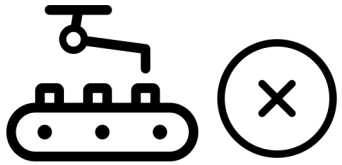
Inspect data a posteriori

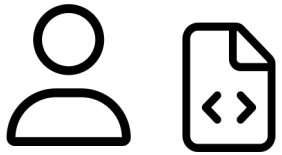


Meaningful feedback

Dev programs, but…

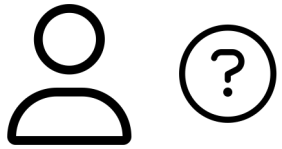
Robot behavior fails





Robot presents data…

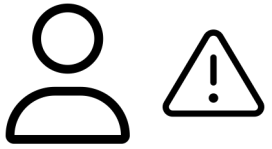
Data is difficult to follow



Put data into context…

Dev has information

Dev can debug the behavior



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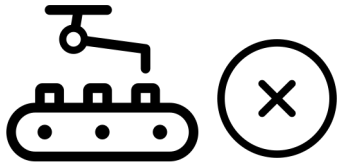

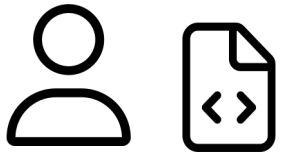

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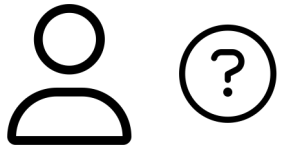

Put data into **context**…

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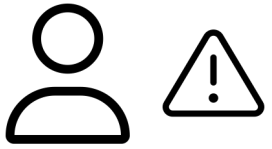

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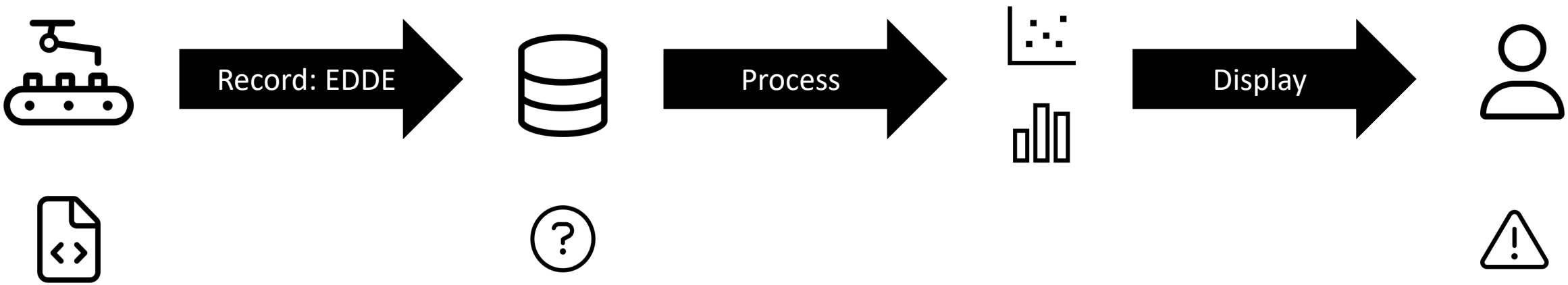
Methodology



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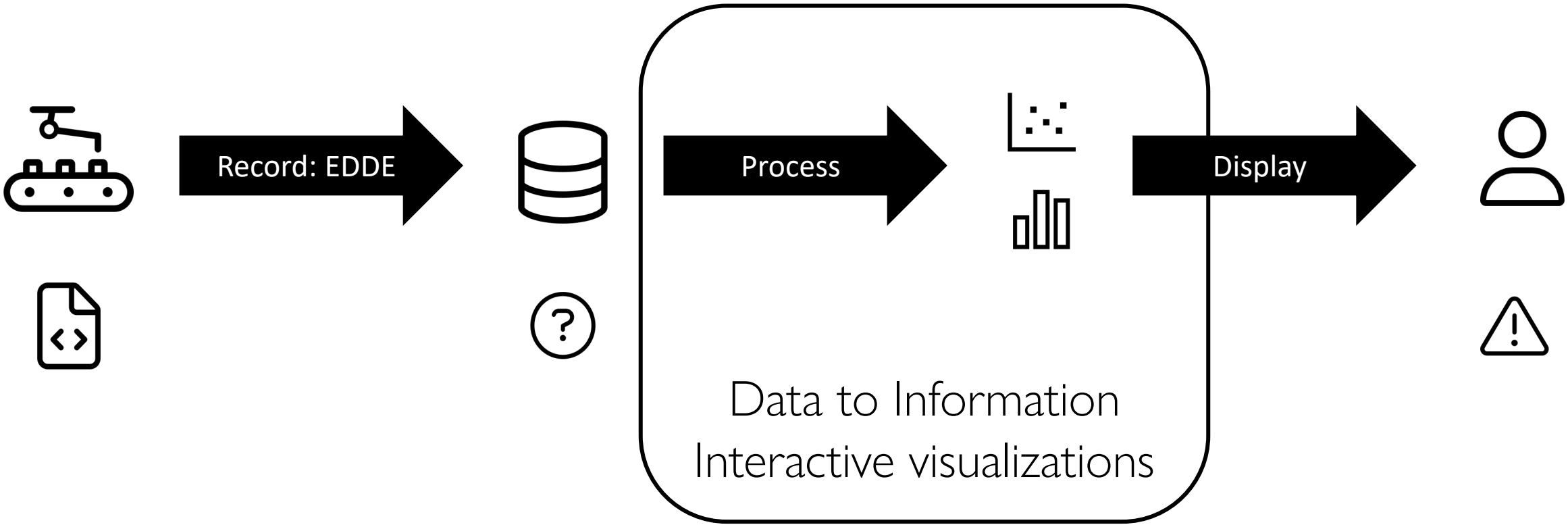


Cobot application: pick-and-place

Pick-and-Place

One of the most (if not the most) common application

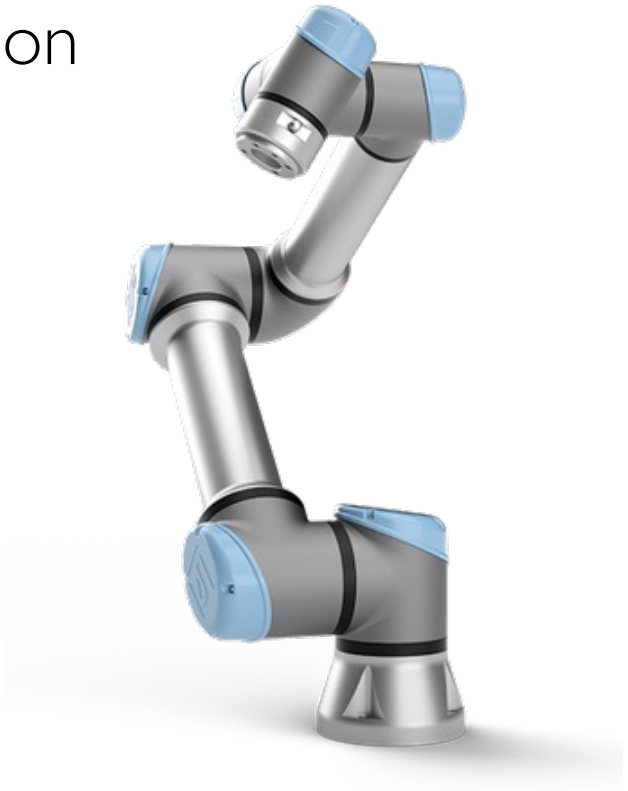
Machine Tending

Assembly

Material Handling

Palletizing

…



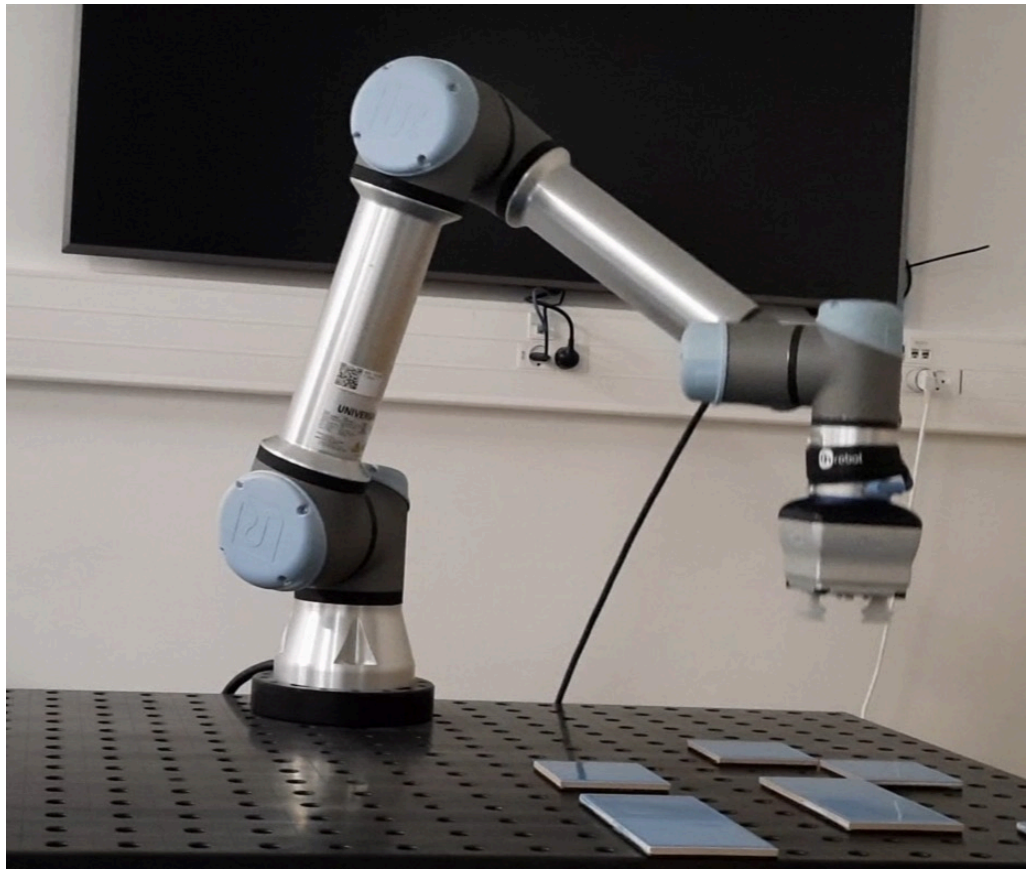
Experimental set-up

Context

- Pick-and-place application
- UR5 + vacuum gripper

Data

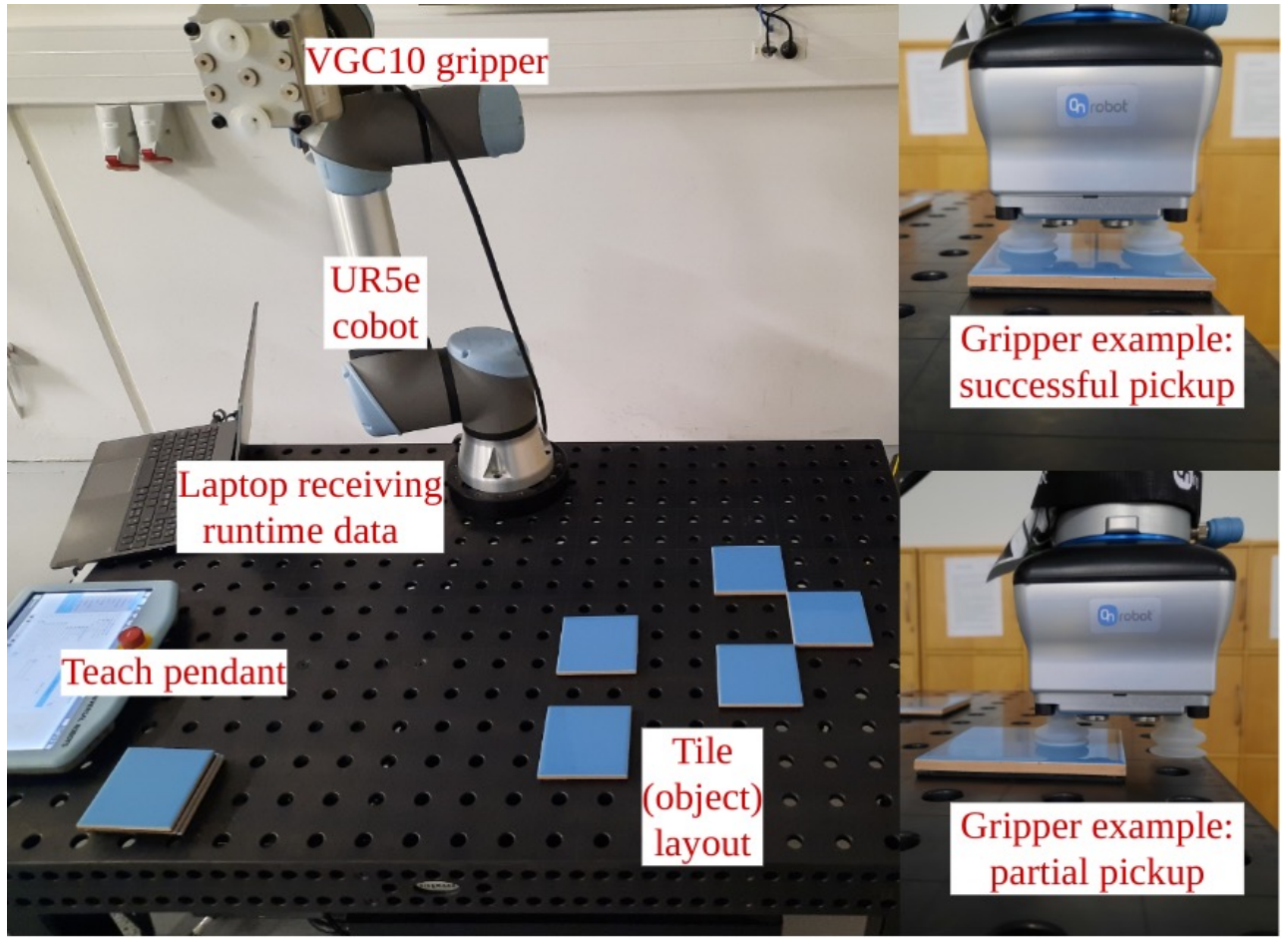
- Execution time
- Runtime state
- CSV file: 244 x runtime state



Experimental set-up

Data

	A	B	C	D	E	
1	protective_stop	robot_epoch	execution_time	current_thread	current_line	current_line_str
2	00022{No data to export...}					
3	0	9217.71	0.721271		1	NaN
4	0	9217.71	0.816936		497	script%
5	0	9217.71	0.851135		1343	script%on_rtde_feed_open()
6	0	9217.71	0.958728		253	script%ifnoton_rtde_feed_opened
7	0	9217.72	0.952559		1345	state%on_set_rtde_watchdog(updateHz=0.2)
8	0	9217.72	0.8589		1347	state%on_dataProcess_thrd=runon_dataProcess_thread()
9	0	9217.72	0.777228		304	state%whileon_dataProcess_running
10	0	9217.72	0.982163		306	script%on_dataRead()
11	0	9217.73	0.804719		708	state%on_robot_TCP_offset=TCP_offset
12	0	9217.73	0.963384		319	state%on_set_rtde_watchdog(updateHz=ON_INIT_WATCHDOG_HZ)
13	0	9217.73	0.759107		400	control%if(vg_index==ON_DI_DUAL)
14	0	9217.74	0.852695		1382	script%vg_timeout=vg_timeout+1
15	0	9217.74	0.800591		400	control%if(vg_index==ON_DI_DUAL)
16	0	9217.74	0.829715		1382	script%vg_timeout=vg_timeout+1



Context

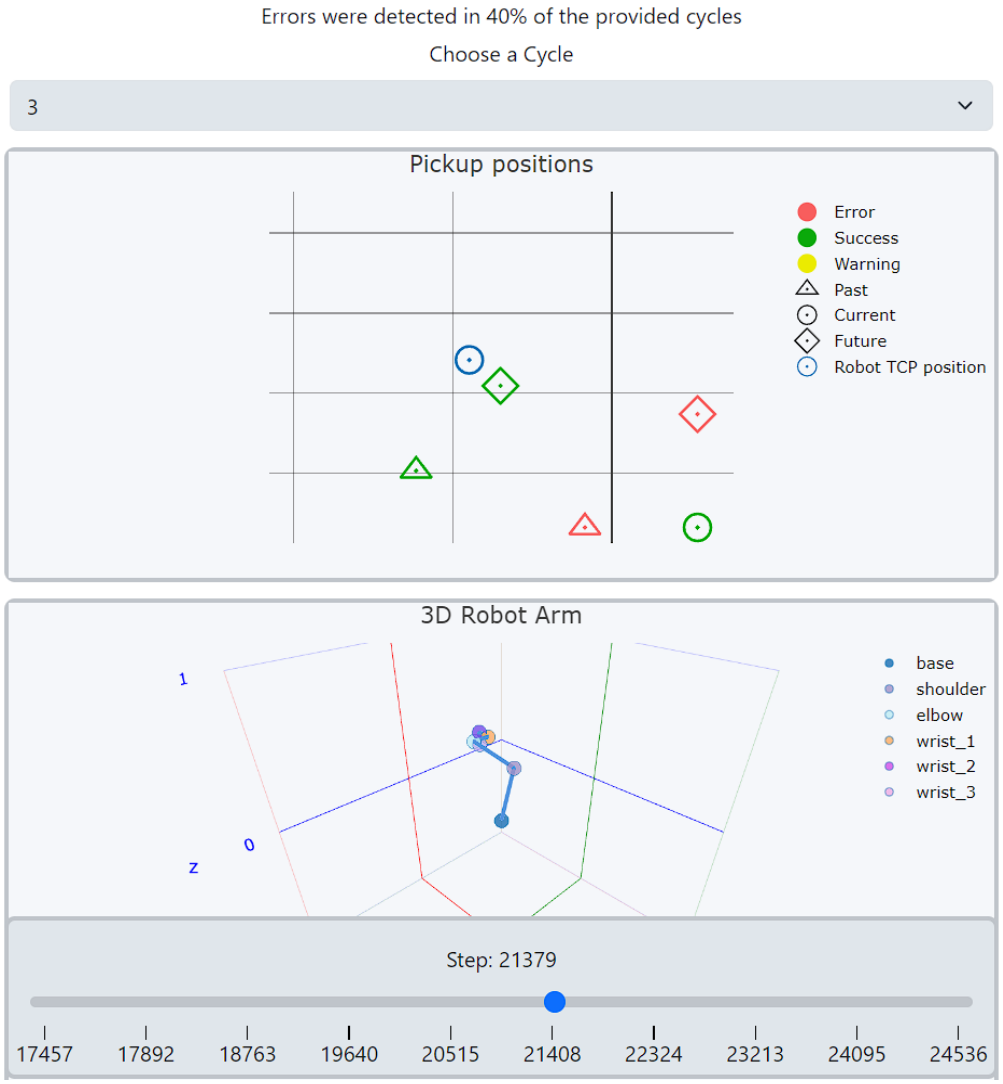
Visualizations: Objects and Robot

2D Position of objects

Current / Past / Future

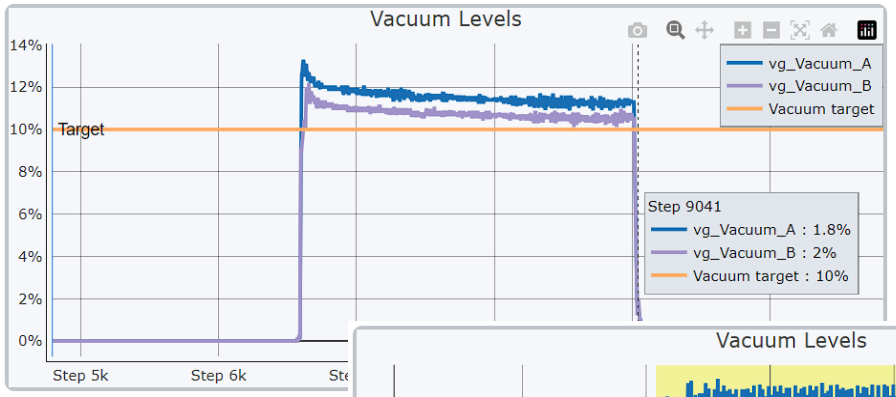
Success / Error / Warning

3D Robotic arm configuration

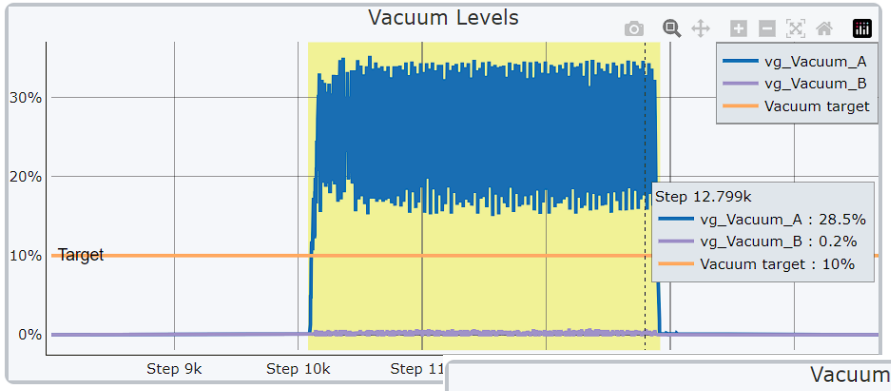


Visualizations: Vacuum level

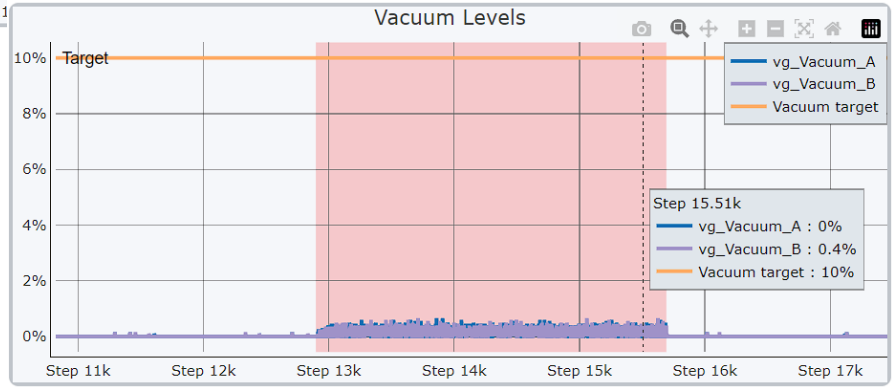
Success pick-up



Partial grasping



Error pick-up



Visualizations: Source code

Source code

- Together with all visualizations
- Highlight *current* execution line

script

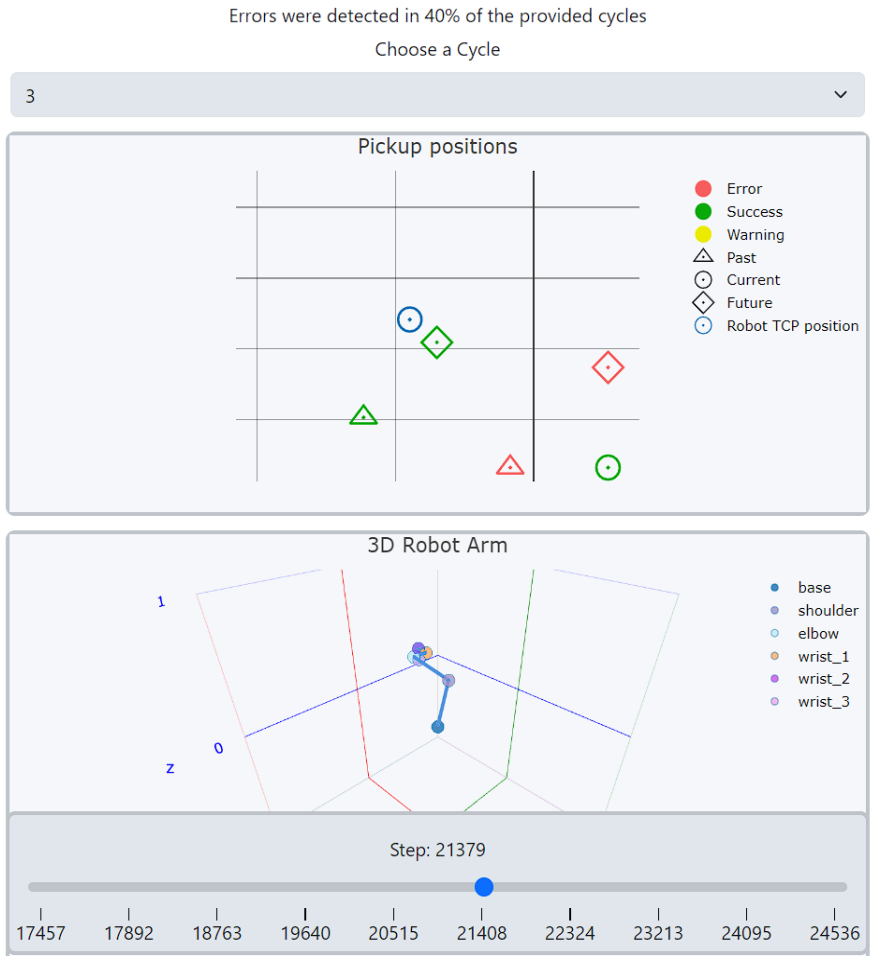
```
136   vg10_grip(2, vacuum_level, 0, False)
137
138   # Lift up to stand clear
139   pickup_pose[2] = travel_height
140   movel(pickup_pose, a=move_acceleration, v=move_speed)
141
142   # Move to the final/dropoff position (Should be movej, but because of qnear shenanigan
143   movel(dropoff_pose, r=0.1)
144
145   dropoff_lowered = dropoff_pose
146   dropoff_lowered[2] = dropoff[2]
147   # Move straight down to drop off the item
148   movel(dropoff_lowered)
149
150   # Open the tool
151   #popup("Drop the vacuum here!", "Dropping off the tile", False, False, True)
152
153   # channel, timeout, autoidle, toolindex
154   # Channel: 0 = A, 1 = B, 2 = Both
155   # timeout is how long the command waits for the vacuum to drop, before giving an error
156       # it is given in seconds : 0.6 = 600 ms
157   # autoidle :
158       # Whether the release valve should be automatically turned off when the release is
159       # and the robot has moved 5 cm away from the release position
160   # tool index is only applicable if more than one gripper is mounted
161   vg10_release(2, 0.6)
```

Visualizations: Interactive through time

Choose

- Cycle
- Step within cycle

Visualizations update with time

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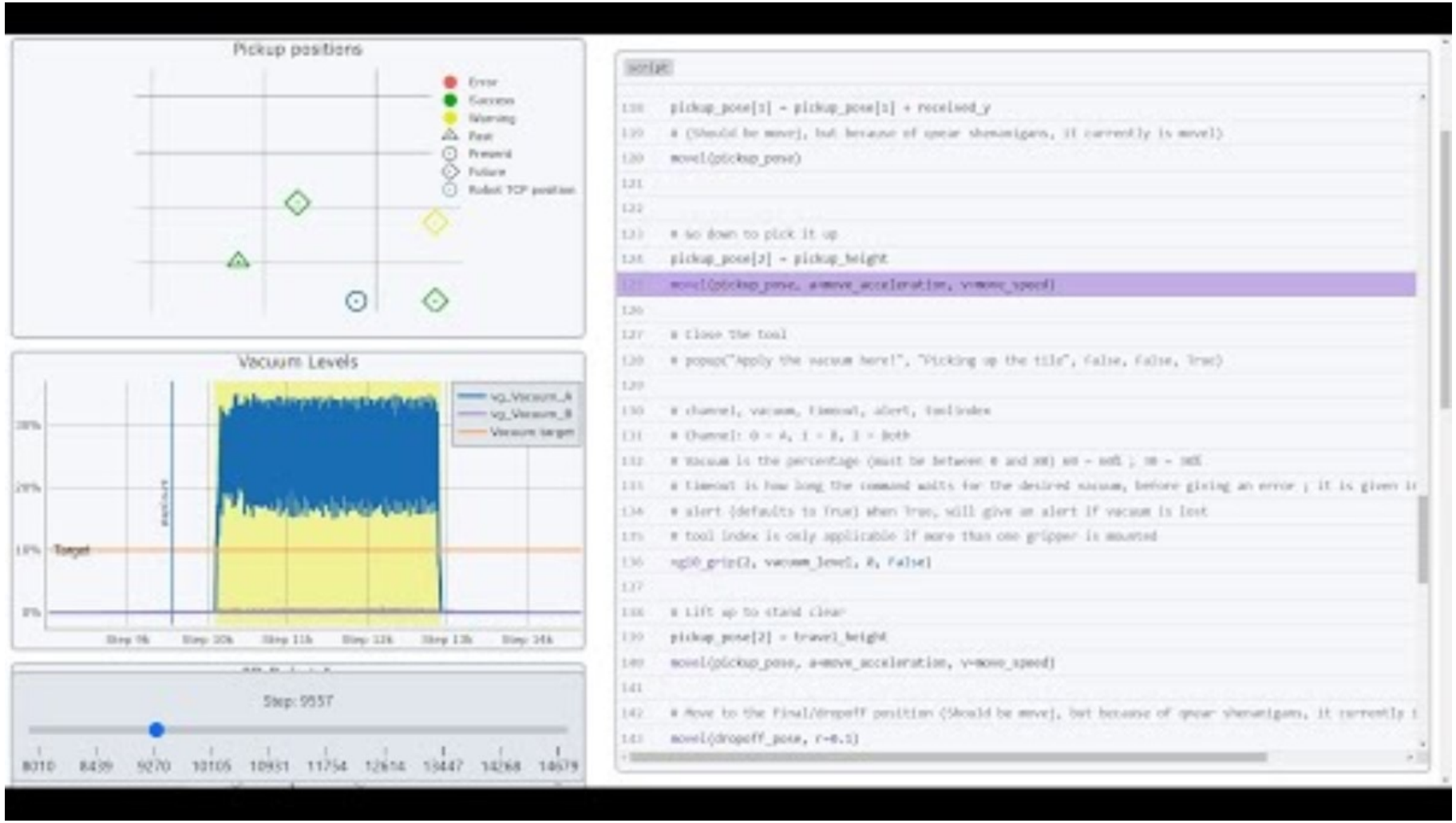
Robotic arm



https://youtu.be/FffedGoe-fU

Conclusions

Conclusions

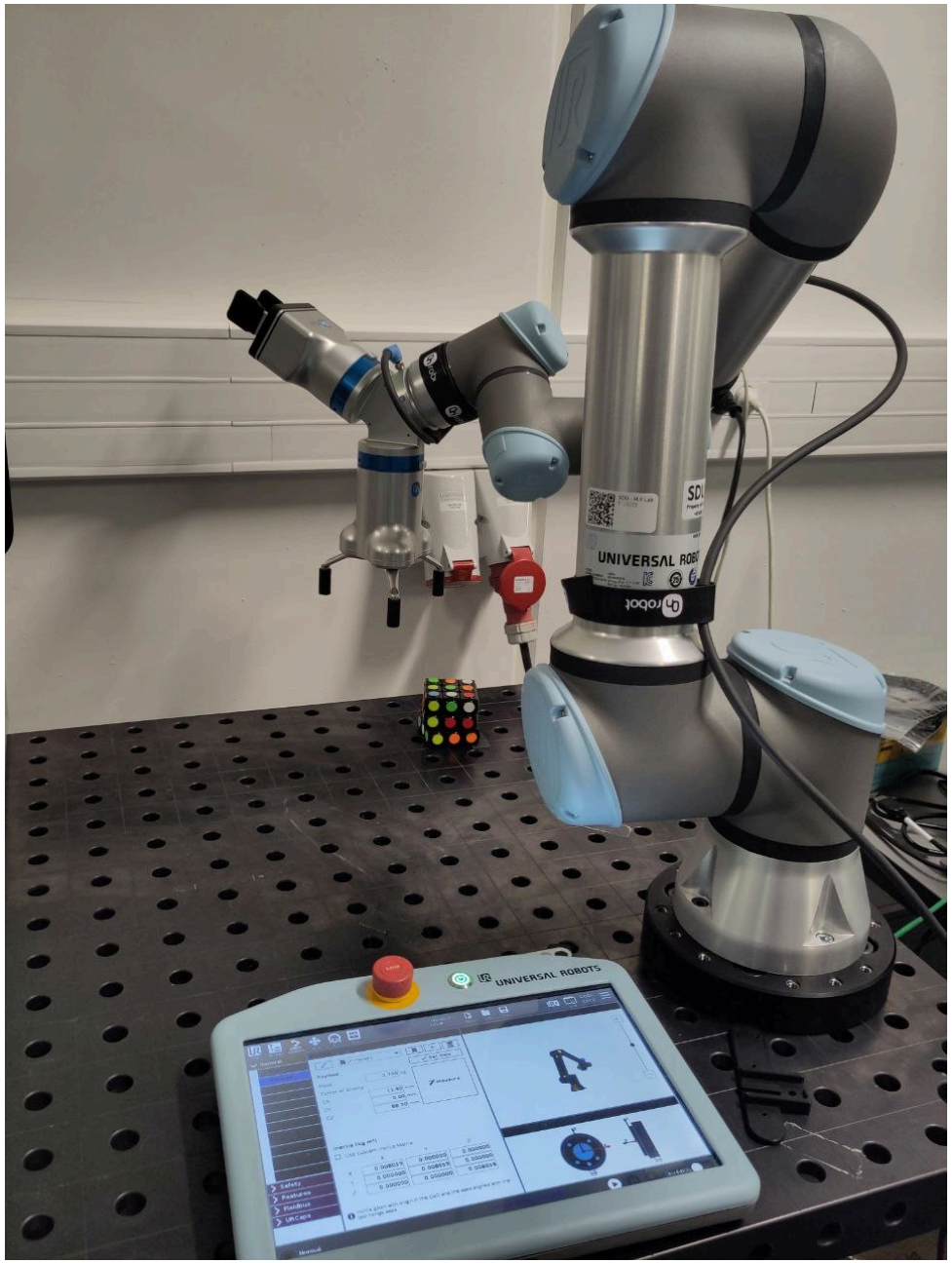
Visualizations in context: quickly assess the behavior of the robot

Quickly assess if the robot is behaving correctly

Debugging via meaningful feedback and interaction

Future Work

- Evaluation
  - Try with real users/operators
- Use cases: more contexts
  - Different (common) cobotic applications
- Data Management
  - Handling large data volume (7.4MB / 1 min)
- External sensors
  - Cameras, …



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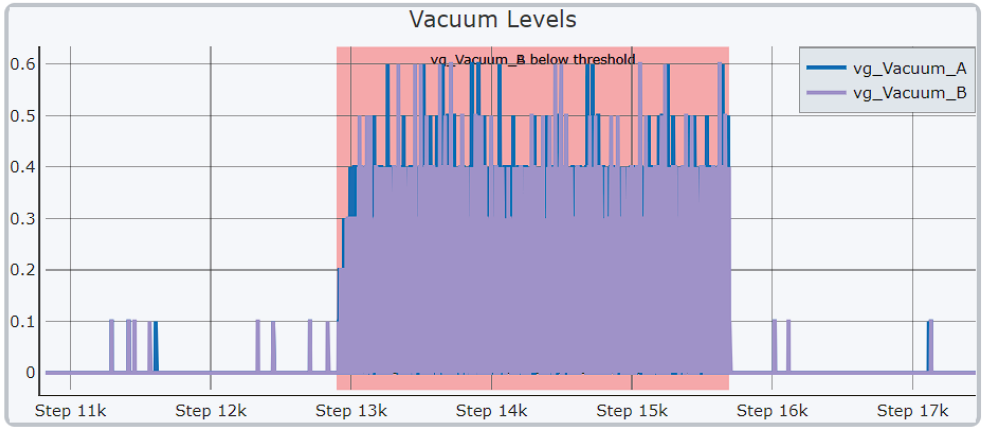

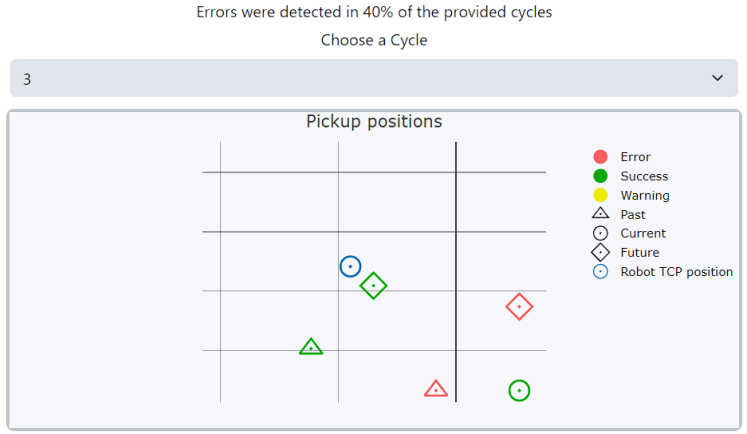

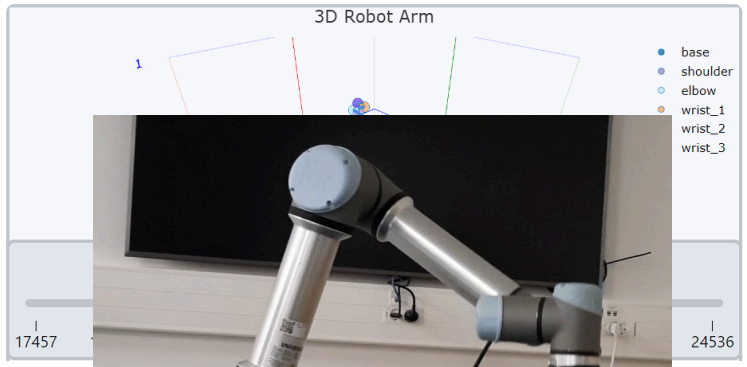

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