System Requirements Elicitation and Conceptualization for a Novel Space Robot Suspension System

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DLR

Robot Arms in Space for In-Orbit Manipulation

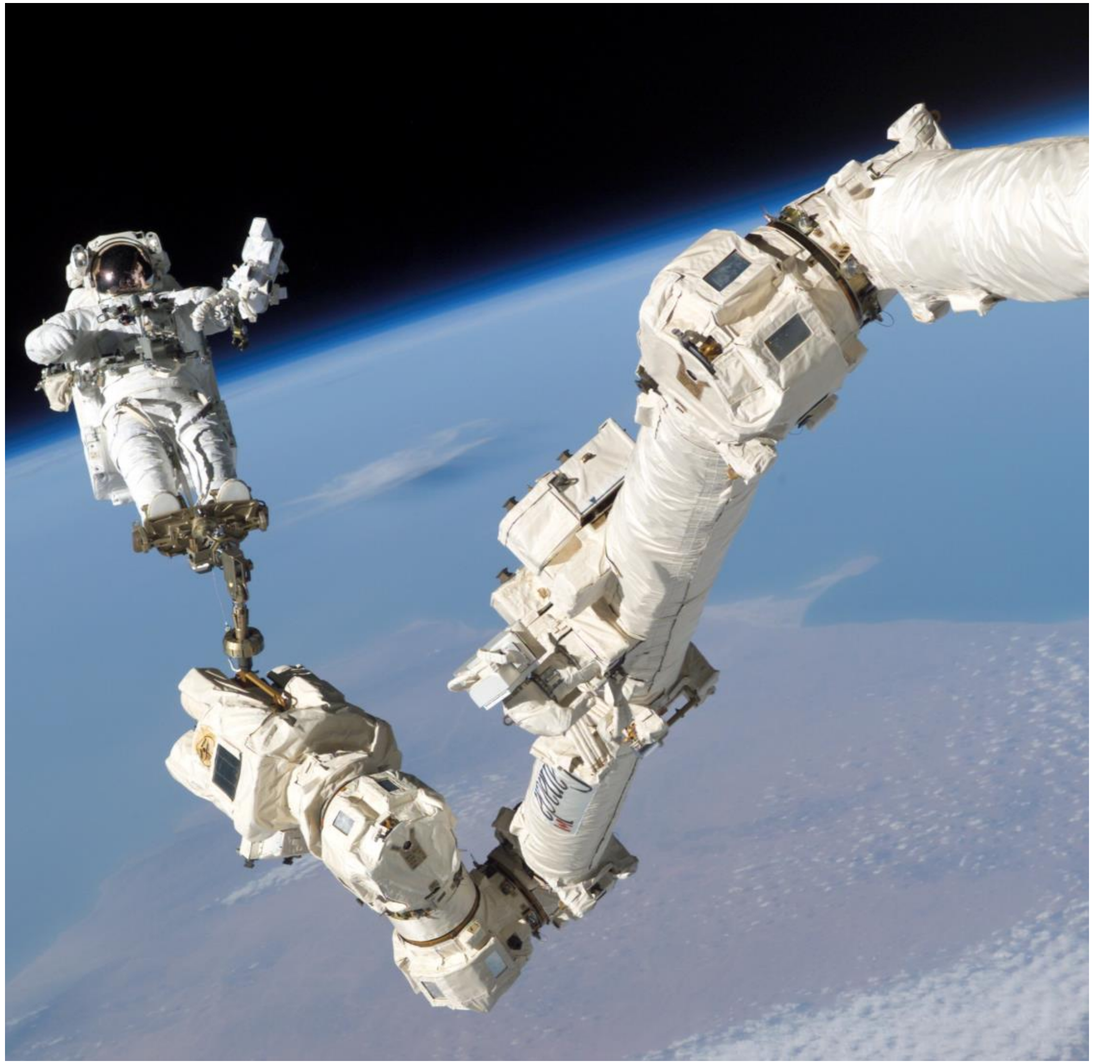
DLR

Robotic Arms in Space Exploration

- Docking Maneuvers
- Life extension, inspections and surveillance
- Change of orbit using add-on propulsion systems
- End-of-life removal from orbit

On-Ground Validation

- Some space robot non-gravity-bearing
- Suspension systems necessary



Canadarm2 (NASA)

On-Ground Validation of Space Robot I

Air Bearings [5]

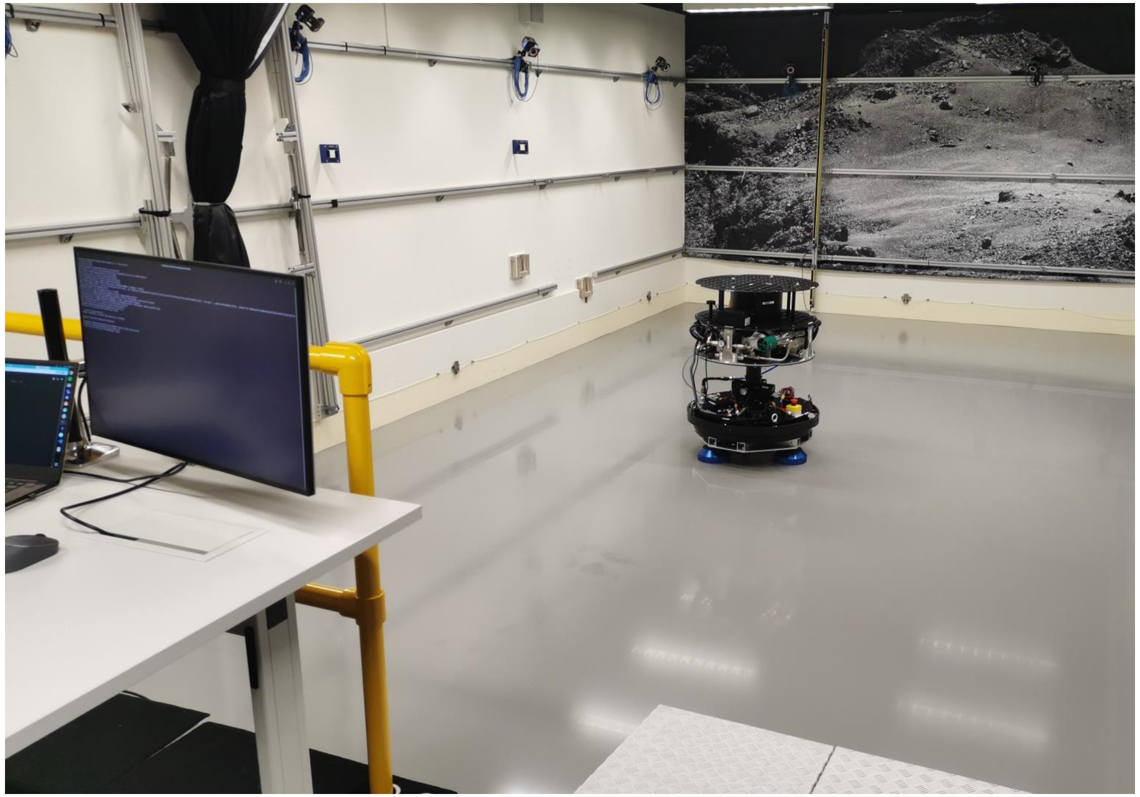
- Movements on thin layer of air
- Robot mounted on several platforms

Helium Balloons [6]

- Support solar arrays
- Large and high inertia

Neutral Buoyancy [4]

- Often used for astronaut training
- Underwater compensates for gravity



Air Bearing Test Setup at ESA ESTEC (ESA)

On-Ground Validation of Space Robot II

Free-fall/Parabolic Flights [12]

- Zero-gravity
- Short Timespan

Rail-based Suspension Systems [14]

- Gantry crane for horizontal positioning
- Vertical force applied passively or actively

Cable-Driven Parallel Suspension Systems

- Cable-Driven positioning
- Lightweight design

Rail-based suspension system: The NASA Active Response Gravity Offload System (NASA)

Core Requirements for Suspension Systems

Gravity Compensation

- Reducing Joint Torques
- Zero Gravity
- Adaptable Gravity Environment

Dynamics Analysis Capability

- High Vibration Bandwidth
- Suspension Force Observation
- Non-Invasive Testing

Geometric Flexibility

- Extended Workspace
- 6-DoF Work Envelope

Usability

- Unlimited Experiment Duration
- Compactness and Affordability
- Low Experiment Effort

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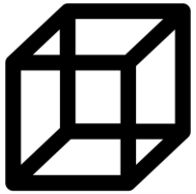

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- **6-DoF Work Envelope**

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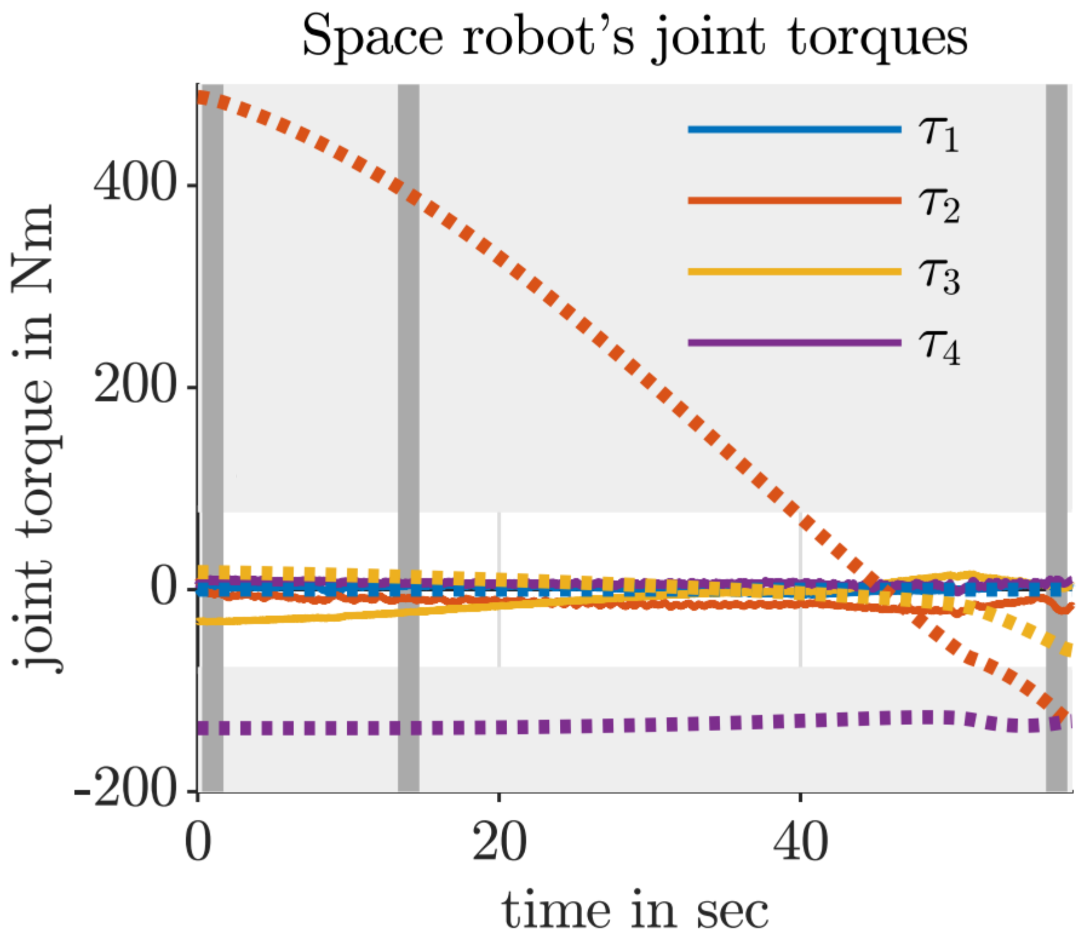
Core Requirements – Reducing Joint Torques

Space Robot

- Some space robots non-gravity-bearing
- Designed for zero gravity, but tested at Earth

Suspension System

- Should reduce the robot's joint torques



Robot joint torques with (line) and without (dotted) suspension system (DLR)

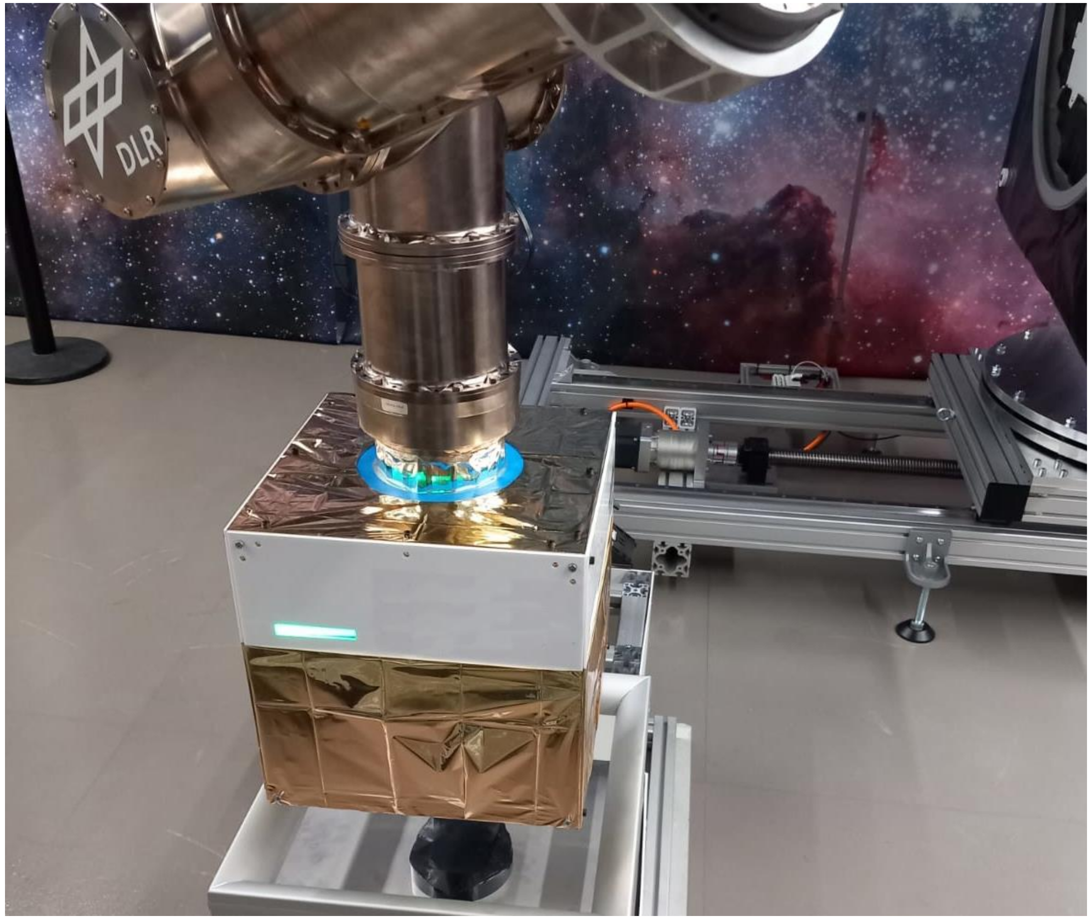
Core Requirements – 6-DoF Work Envelope

Space Robot

- Grasping, vision-based latching, rapid retraction trajectories
- 6-DoF motions necessary

Suspension System

- Suspension system should allow 6-DoF motions



6-DoF motions necessary during latching trajectories (DLR)

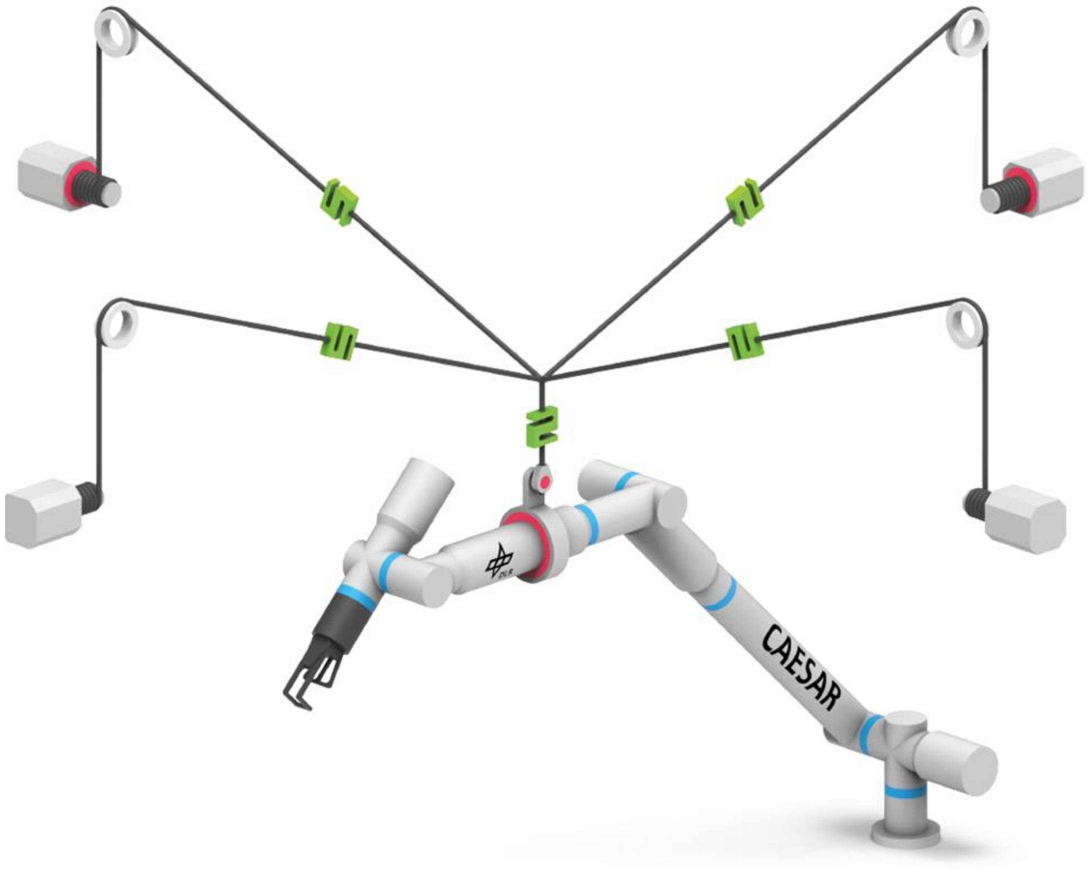
COMPARATIVE ANALYSIS

Requirement \ Suspension Concept	Air Bearing	Helium Balloons	Neutral Buoyancy	Free-falling	Rail-based	Cable-driven
Gravity Compensation						
Reducing Joint Torques	++	++	++	++	++	++
Zero Gravity	+	o	+	+	+	+
Adaptable Gravity Environment	- -	o	o	- -	++	++
Geometric Flexibility						
Extended Workspace	+	++	++	- -	+	+
6-DoF Work Envelope	- -	++	++	++	++	++
Dynamics Analysis Capability						
High Vibration Bandwidth	-	- -	- -	++[3]	-	++
Observation Capability	++	++	- -	++[3]	++	++
Non-Invasive Testing	+	+	- -	++	+	+
Usability						
Unlimited Experiment Duration	o	++	+	- -	++	++
Compactness and Affordability	o	++	- -	- -	o	+
Low Experiment Effort	+	+	- -	- -	+	+

[3] fulfilled because of zero-gravity

Discussion

- Neutral buoyancy and free-falling: most realistic zero-gravity environment
- High effort for zero-gravity -> drawbacks in the development process
- Utility of true zero-gravity is limited
- Focus less on realistic zero-gravity and more on other requirements
- Cable-driven suspension system is most promising for testing space robot



Concept of the Motion Suspension System (MSS) by the DLR

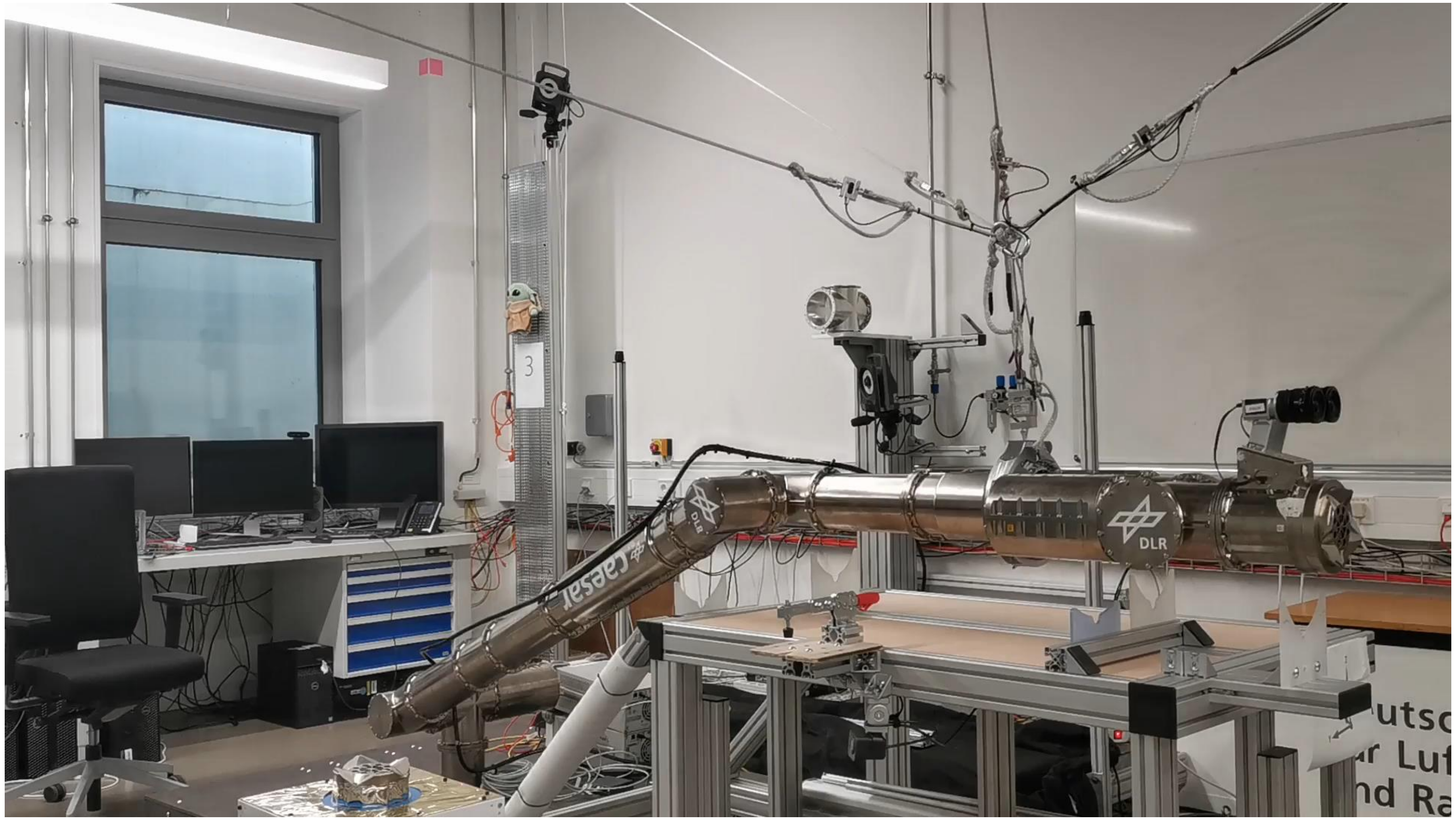
A Cable-Driven Suspension System – Motion Suspension System (MSS)

Cable-Based Mechanical Support

- Four Dyneema cables
- Direct drive motors

Reducing Joint Torques

- No real zero-gravity
- Gravity compensation is MSS + additional robotic joint torques



Space robot CAESAR by the German Aerospace Center operating with the Motion Suspension System (MSS)

Imprint/Sources

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Credits:	DLR

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