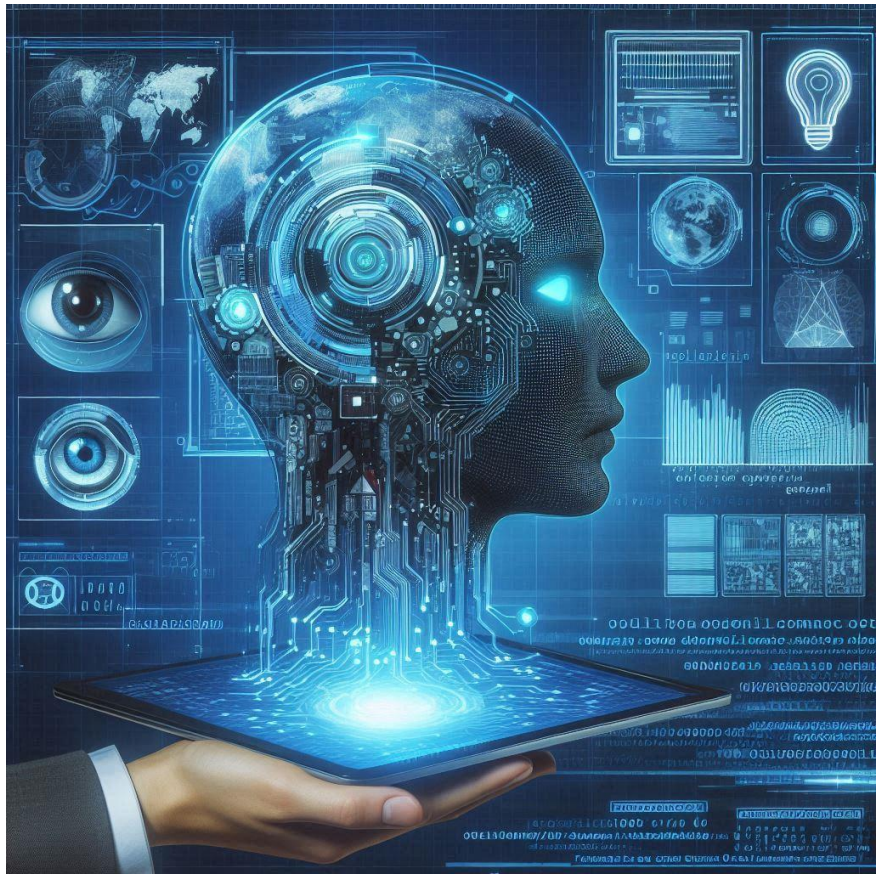
Cognitive models for low-code real-time control of digital twins based on Nephele VOs and ROS



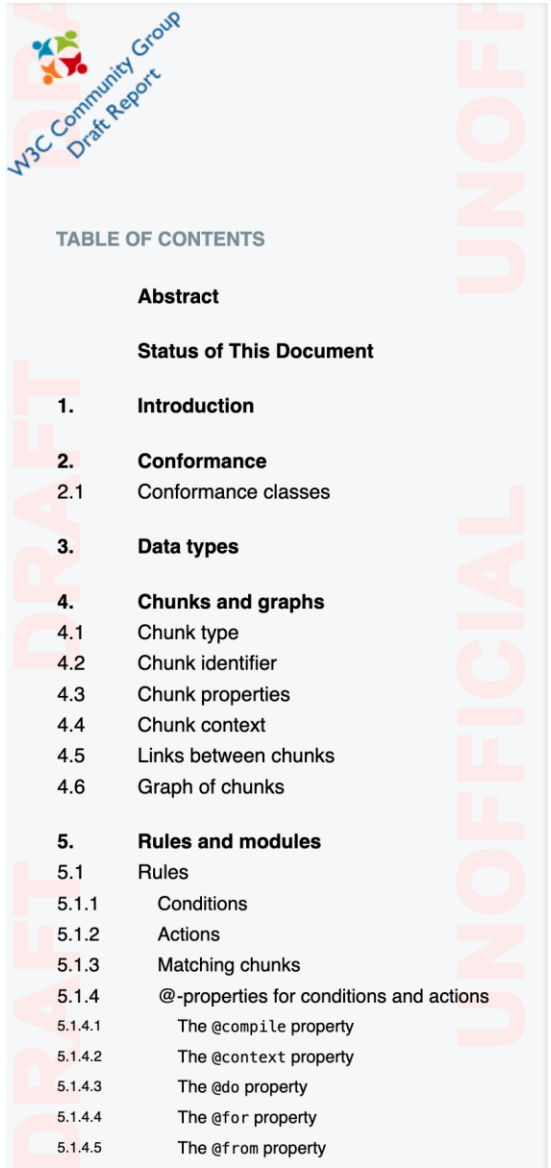
Chunks & Rules applies research in the cognitive sciences on human cognition to simplify IoT application development, layering on top of the hardware abstractions provided by Nephele virtual objects and devices using the robot operating system.

Grateful acknowledgement of support from the Nephele and SmartEdge projects under the EU Horizon Europe programme

Cognitive Approach to Low-Code Control

- *Low-code* is an approach to application development that simplifies the process of automating workflows and building applications
- Empowers professional developers and business users to create applications more efficiently
- Behaviour is described using facts and rules using a convenient syntax
- Mimics how humans execute tasks, drawing upon decades of work in the cognitive sciences
- Simple approach to specifying real-time behaviour
  - For resilience and adaptability
- Event-driven concurrent threads of behaviour using APIs exposed by resources as described in taxonomies
- Extension to distributed agents, e.g. swarms using asynchronous message exchange decoupled from underlying communications protocols
- W3C Cognitive AI CG's Chunks & Rules specification

Formal Specification from Cognitive AI CG



W3C Community Group Draft Report

TABLE OF CONTENTS

Latest published version:
https://www.w3.org/chunks/

Latest editor's draft:
https://w3c.github.io/cogai/

Editors:
François Daoust (W3C)
Dave Raggett (W3C)

Feedback:
GitHub w3c/cogai (pull requests, new issue, open issues)

Copyright © 2024 the Contributors to the Chunks and Rules Specification, published by the Cognitive AI Community Group under the W3C Community Contributor License Agreement (CLA). A human-readable summary is available.

Abstract

This specification defines a cognitive graph database model featuring chunks as collections of properties, and rules that operate on them in conjunction with highly scalable graph algorithms, together with a simple notation for serializing graphs as a convenient abstraction above RDF. The model reflects functional characteristics of human memory and cognition, including stochastic recall and the forgetting curve. Chunks & Rules provide an attractive framework for low-code real-time control of digital twins for the Internet of Things, decoupled from the details of communication technologies and standards, using asynchronous messaging that enables distributed implementations and integration with robot systems based upon ROS (the robot operating system), see [CHUNKS-LOWCODE]

Status of This Document

This specification was published by the Cognitive AI Community Group. It is not a W3C Standard nor is it on the W3C Standards Track. Please note that under the W3C Community Contributor License Agreement (CLA) there is a limited opt-out and other conditions apply. Learn more about W3C Community and Business Groups.

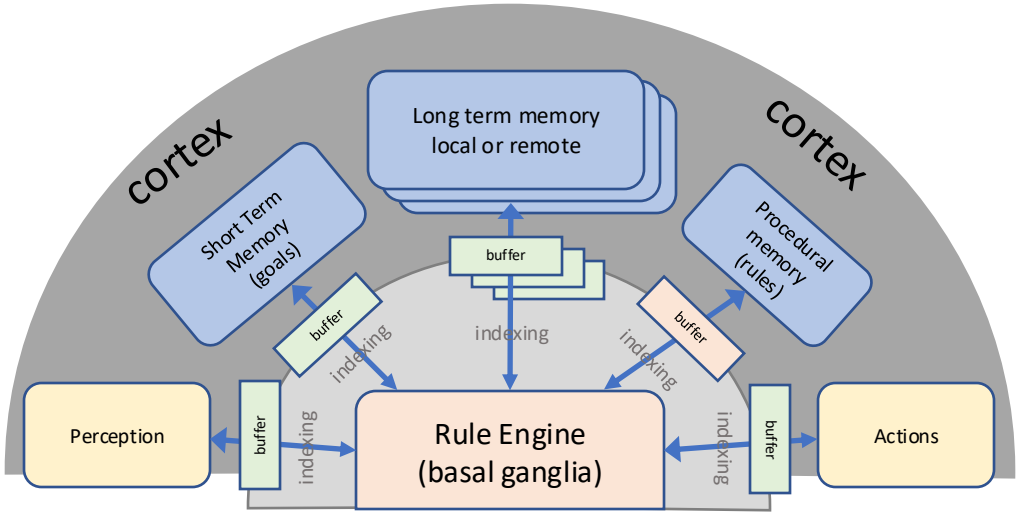
This document reflects implementation experience, but is still subject to change. Feedback is welcome through GitHub issues or on the public-cogai@w3.org mailing-list (with public archives).

GitHub Issues are preferred for discussion of this specification.

Cognitive Architecture

- Inspired by John Anderson's ACT-R
- Mimics characteristics of human cognition and memory, including spreading activation and the forgetting curve
- Asynchronous operations that enable distributed cognition
- Perception builds live models of the environment including events that trigger corresponding behaviours
- Actions expressed as intents to be realised as appropriate
  - *intent*: an aim, purpose, goal or objective
- Reasoning is decoupled from real-time control over external actions, e.g. a robot arm

Cognition – Sequential Rule Engine

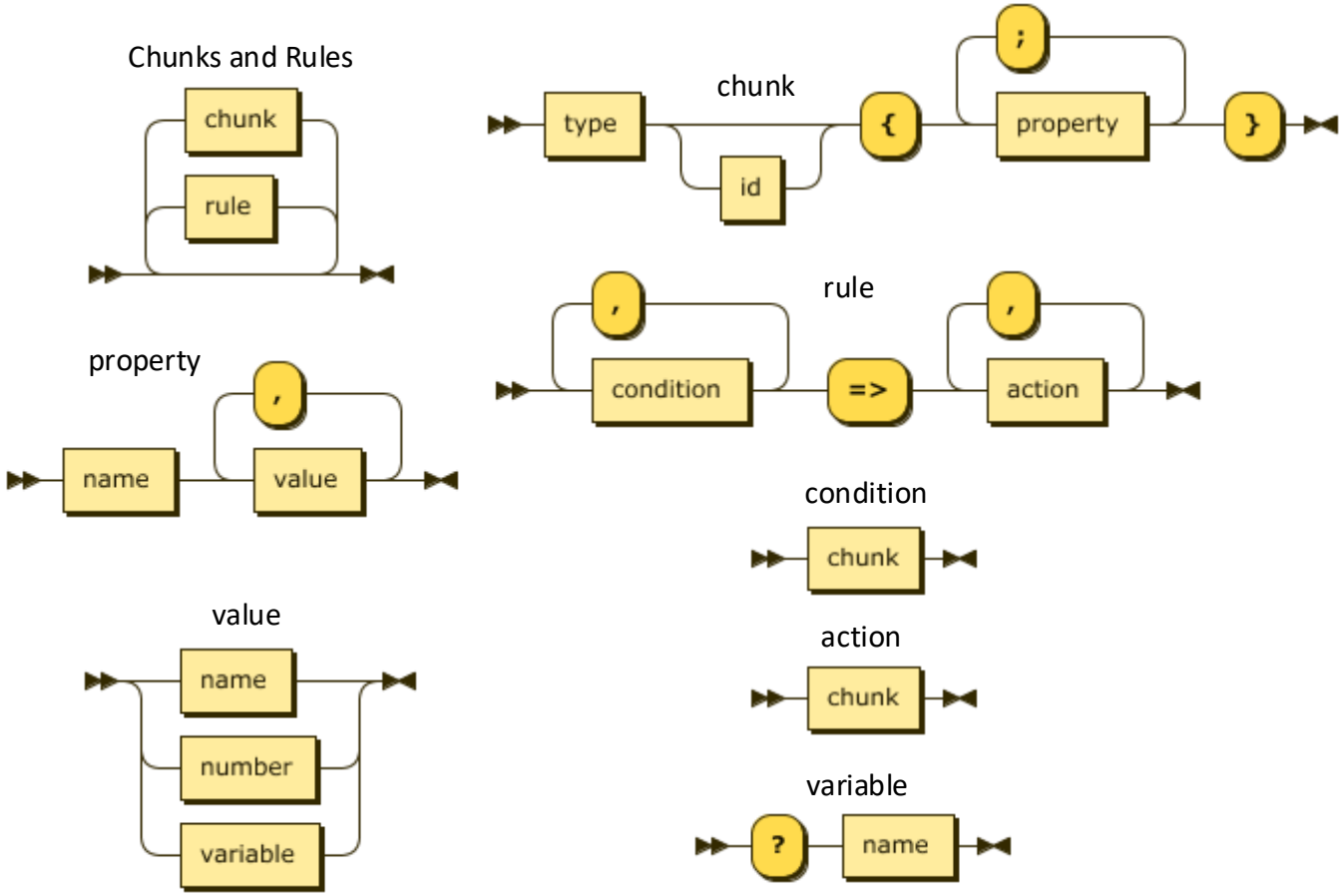


- The cortex holds a set of cognitive modules, each of which is associated with a module buffer that holds a single chunk
- Predefined asynchronous operations on buffers in analogy with REST

Chunks and Rules

web-based demos for smart homes and factories

- Chunks are sets of properties
  - Name/value pairs that correspond to a set of RDF triples with same subject
- Rule conditions and actions that specify which cognitive module buffer they apply to
- Rule variables for data binding
- Actions either directly update the buffer or invoke operations on the buffer's module, asynchronously updating the buffer
- Extensible suite of cortical operations inspired by Roy Fielding's REST

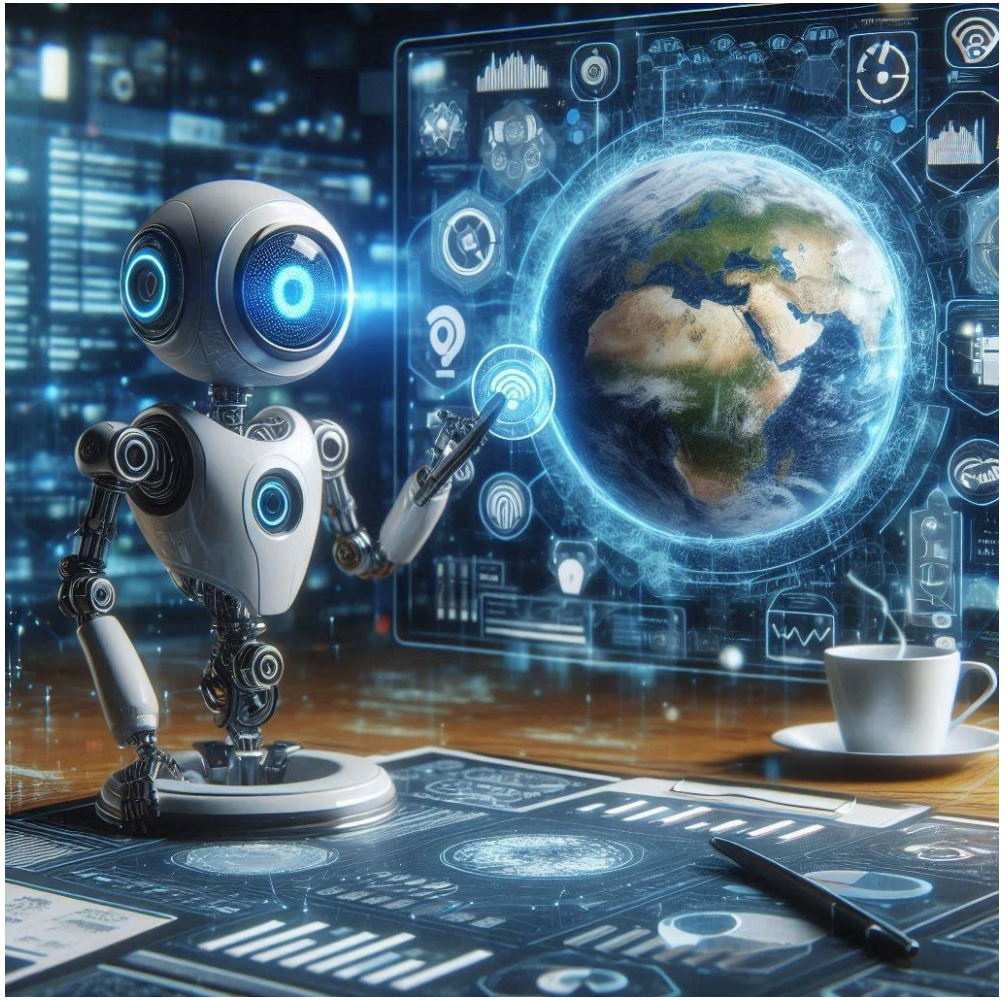


names beginning with "@" are reserved, e.g. @do for actions

See [W3C Cognitive AI Community Group]

Chunk Rules for Digital Twins

- Nephele's Virtual Objects are related to digital twins for devices, processes and even people*
- Digital Twin affordances (properties, actions, events) and semantics are described using W3C Thing Descriptions, and searchable in Thing Description Directories
- Chunk rule actions can be used to invoke the affordances exposed by digital twins
- Some glue code is needed to handle the data formats and protocols
- Complex results involve using the predefined suite of operations over chunk graphs given that module buffers are limited to single chunks

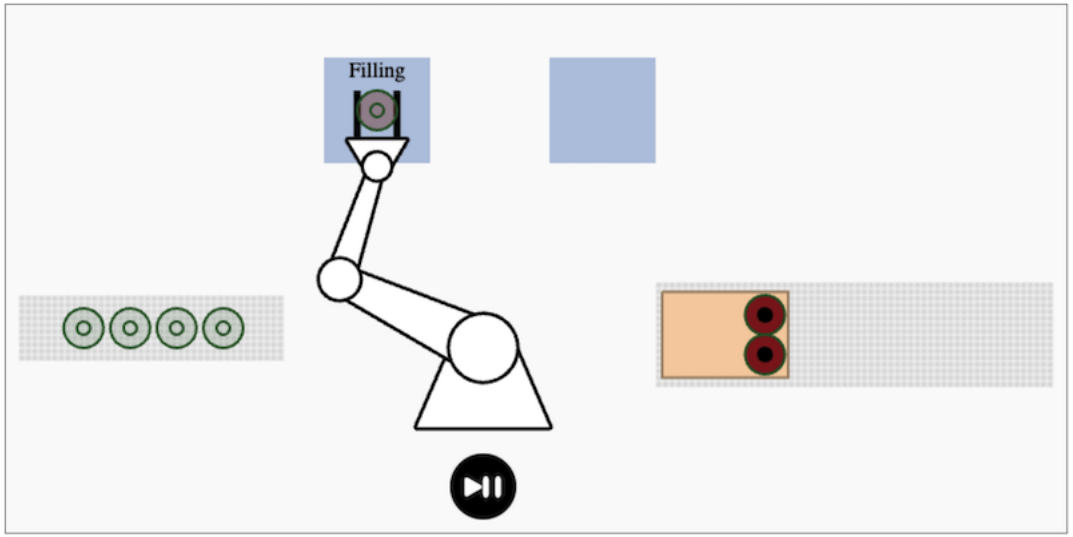


* Digital twins for people as used in healthcare applications, and for defining virtual devices as abstractions over multiple physical devices (i.e. composite virtual objects)

Chunks and Rules

- Mature JavaScript library for use in webpages or with NodeJS
- Application script declares additional operations, e.g. for robot control, layered above ROS operations
- These are implemented in JavaScript and can use real-time clock as well as networking for external messaging
- ERCIM can help with this
- Contact Dave Raggett <dsr@w3.org>

Note: rules can use variables for dynamic parameters where an object location is determined at run-time.



Factory demo: filling, capping and packing bottles of wine with real-time control over conveyor belts, filling and capping machines, and a robot arm

```
# move robot arm into position to grasp empty bottle
after {step 1} =>
   robot {@do move; x -170; y -75; angle -180; gap 30; step 2}

# grasp bottle and move it to the filling station
after {step 2} =>
   goal {@do clear},
   robot {@do grasp},
   robot {@do move; x -80; y -240; angle -90; gap 30; step 3}
```

See also smart homes demo

Robot Operating System (ROS)

ROS diffbot

- ROS is an open source software framework for robots
  - Linux, Windows, MacOS
- Strong developer community
- Message based with hardware abstraction
  - Topic based streams
  - Services with request/response
  - Nodes for message exchange
  - Shared database for parameters
- **Chunks & Rules** are a good fit for controlling ROS devices
- Using ROS topic streams to update chunk models of robots and their environment
- Using Chunk Rules to invoke ROS services
  - Delegation for planning and execution
- Using existing JavaScript libraries for integration with ROS

Swarm Intelligence

- A single cognitive agent may be used to control multiple devices
  - Factory demo: a single chunks & rules agent controls two conveyor belts, one robot arm, a bottle filling station and a bottle capping station
- Cognitive agents can fuse information from local and remote sources for situational awareness
  - Not limited to on-device sensors
- Cognitive agents can share information that other agents may find useful*
  - e.g. unexpected obstacles
- You can think of the swarm as a hive mind composed from multiple communicating cognitive agents
  - Asynchronous chunk messages
- Increased resilience and flexibility

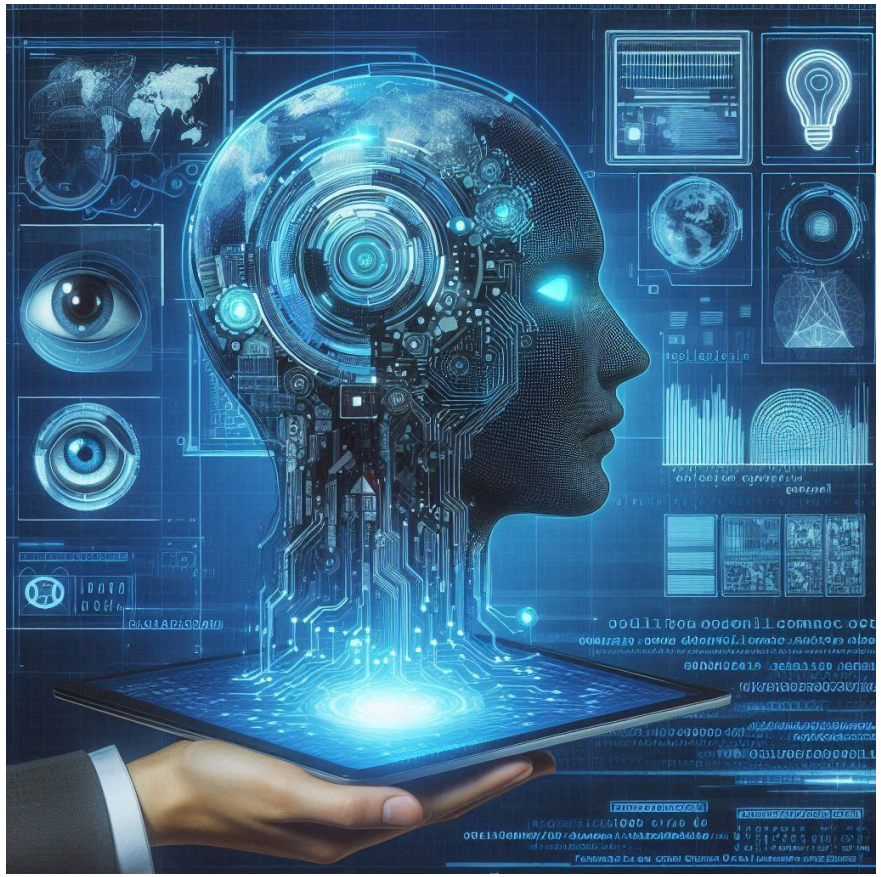
Agents can leave information in the physical or virtual environment as a form of *stigmergy*. This is a mechanism of indirect coordination through the environment, between agents or actions. The principle is that the trace left in the environment by an individual action stimulates the performance of a succeeding action by the same or different agent. Agents can also communicate directly, e.g. when they are in close proximity, or via their names or roles.

Iterative Refinement

- Cognitive rules can respond in milliseconds*, and can be complemented by faster reactions using simple reflex responses implemented at a lower level
- Application development is a collaboration between people maintaining the low-code description of high level behaviour and system programmers responsible for the glue code for the digital twins, i.e. Nephele (composite) VOs
- Development starts using a simple approach and iteratively refines it as new requirements come to light, e.g. when something unexpected occurs at run-time and needs to be handled
- That may further necessitate changes to the digital twins, e.g. to sense error conditions
- In robot use case: errors such as a bottle falling over, being only partially filled, or badly capped

* Rule execution is fast as time consuming operations are handled asynchronously

Questions?



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