117-401-D Starmind and Cognitive Systems Engineering

Engineering stability across physical, network and cognitive space

November 2026

1. When cognition goes into orbit

The prospect of orbital AI data centers invites us to reconsider a tacit assumption in the architecture of autonomous cognition: that its computational substrate is relatively stationary. A satellite-hosted actant may pursue a mission while its host moves continuously around Earth. Its logical dependencies may evolve at the same time as the physical paths through which those dependencies are realized.

Starmind is used here as the motivating orbital-computing concept, not as a verified description of a deployed system. Specific announcements, regulatory authorizations, constellation sizes and deployment dates have not been independently verified for this chapter. The engineering analysis applies to any comparable orbital compute constellation.

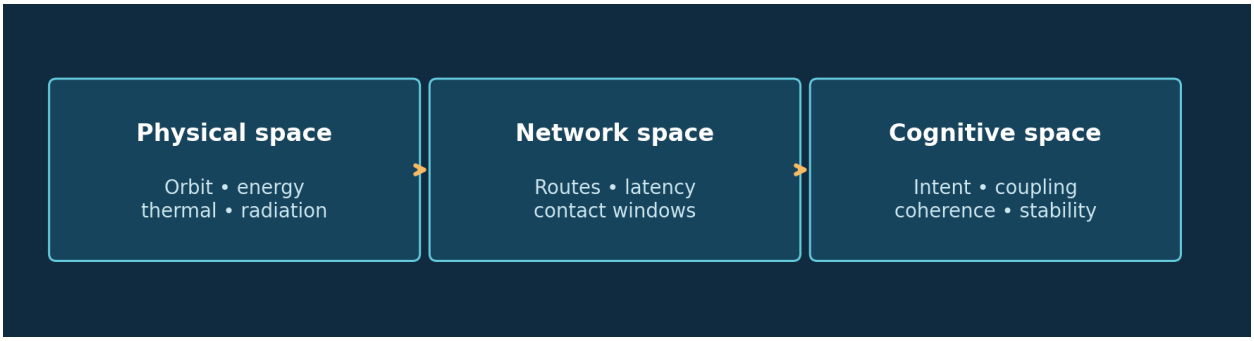


Figure 1. Three interacting dynamical domains. Feedback also runs in the reverse direction through workload and resource allocation.

The fundamental proposition is not that orbital motion causes cognitive instability. It is that physical motion can change the conditions under which cognitive activity is feasible. Cognitive Systems Engineering must characterize and govern those cross-domain dependencies. The actant remains a logical participant; the satellite is its host, not its identity.

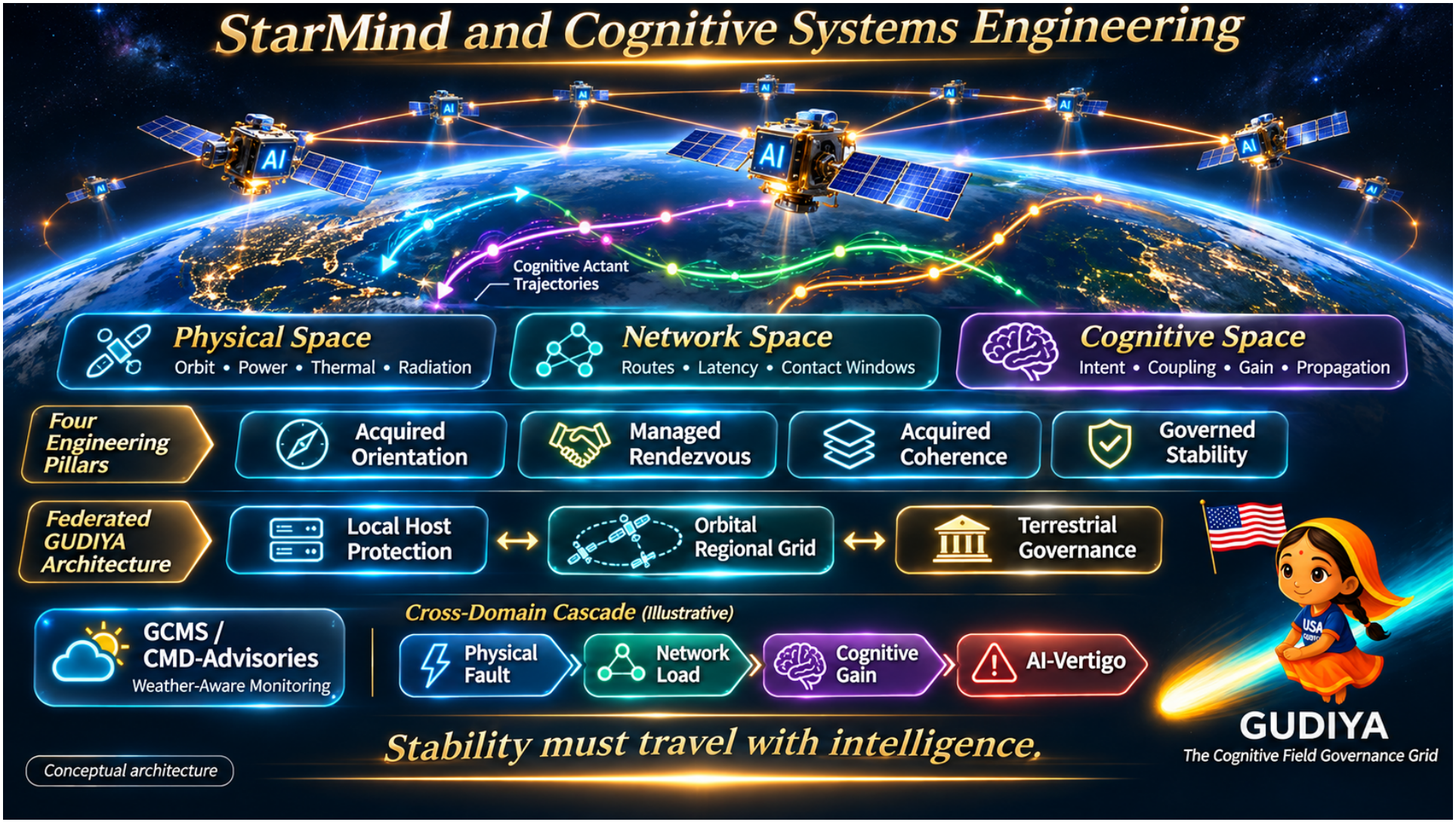
2. The three trajectories

- An actant can remain logically stationary while its host traverses thousands of kilometers.
- Conversely, a mission can change rapidly while its host and network conditions remain nearly constant.
- A third trajectory describes the evolution of the communications graph.

The three trajectories must be separately observed, time-stamped and correlated rather than collapsed into a single notion of velocity.

3. Orbital mechanics and the communications substrate

For an illustrative circular orbit at 550 km altitude, using Earth radius 6,371 km and gravitational parameter 398,600 km^3/s^2, orbital speed is approximately 7.59 km/s and period approximately 95.5 minutes. These are illustrative parameters, not Starmind specifications. The host travels about 3.8 km in 500 ms; this does not imply a corresponding change in separation from another satellite.


StarMind and Cognitive Systems Engineering
AI
Cognitive Actant Trajectories
Physical Space
Orbit • Power • Thermal • Radiation
Network Space
Routes • Latency • Contact Windows
Cognitive Space
Intent • Coupling • Gain • Propagation
Four Engineering Pillars
Acquired Orientation
Managed Rendezvous
Acquired Coherence
Governed Stability
Federated GUDIYA Architecture
Local Host Protection
Orbital Regional Grid
Terrestrial Governance
GCMS / CMD-Advisories
Weather-Aware Monitoring
Cross-Domain Cascade (Illustrative)
Physical Fault
Network Load
Cognitive Gain
AI-Vertigo
USA
GUDIYA
The Cognitive Field Governance Grid
Stability must travel with intelligence.
Conceptual architecture

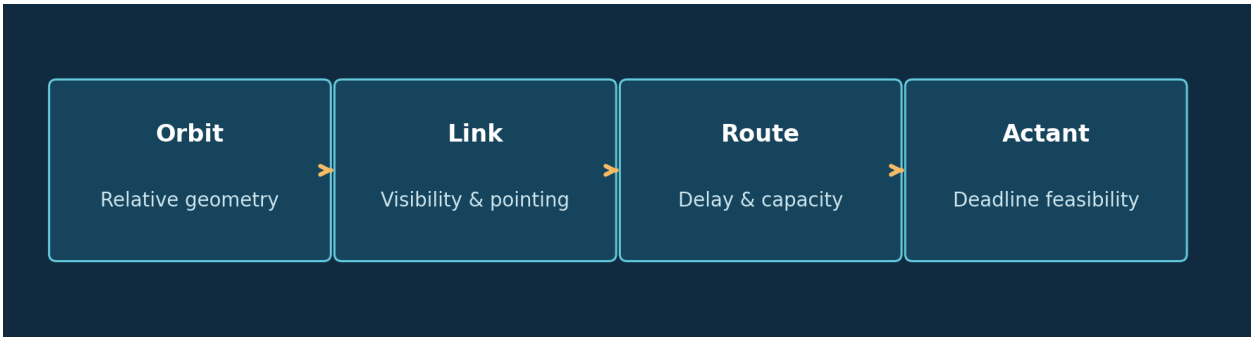


Figure 2. Physical motion affects cognition through the availability and performance of infrastructure.

A 1,000 km optical path has a vacuum propagation delay of about 3.34 ms one way; a 5,000 km path has about 16.7 ms. Switching, queues, retransmissions and processing add delay. The shortest geometric path is not necessarily the best operational route. Contact windows and anticipated route changes should be exposed to scheduling and admission services.

Measurement	Engineering interpretation
Relative position and velocity	Link geometry, pointing and contact prediction
Contact window and route diversity	Continuity of required communications
Latency, jitter, loss and capacity	Freshness, deadlines and transfer feasibility
Clock uncertainty	Limits on temporal ordering and lease validity
Power and thermal headroom	Sustainable compute rate and workload placement
Radiation and fault telemetry	Confidence in execution and stored state

Vacuum does not provide convective cooling. Waste heat must ultimately be radiated; power availability depends on solar illumination, storage and platform design. Radiation can produce transient faults and cumulative degradation. These constraints may cause compute rates to change independently across the constellation, introducing differential acceleration even when the cognitive software is unchanged.

4. A joint state model without conflating coordinates

- Let p(t) denote physical host state,
- G(t) the time-varying communications graph, and
- x(t) the cognitive state of an actant.

The joint operating state is represented conceptually by z(t) = [p(t), G(t), x(t)]. Each component has its own reference frame, measurement uncertainty and update cadence. Cognitive coordinates need not be Euclidean; discrete events, graphs and hybrid state models may be more appropriate.

The cognitive evolution can be modeled as

$$x(k+1) = F(x(k), \text{mission}, G(k), \text{resources}(k), \text{controls}(k), \text{disturbances}(k)).$$

The physical substrate influences cognition through resource and communication constraints; cognitive workloads influence queues, power demand and thermal loading. This is a proposed modeling framework, not an established universal law.

5. Vital measurements for orbital actants

Dimension	Measurements or estimates
Orientation	CCS reference/version, state estimate, drift, uncertainty, age
Motion	Intent trajectory, rate of state change, objective-induced drift
Rendezvous	Participant readiness, route feasibility, expected contact duration
Coherence	Evidence freshness, causal dependencies, authority and state compatibility
Gain and propagation	Amplification, reach, propagation delay, retry/delegation rate
Stability	S3 estimate, envelope constraints, margin trend, time to boundary
Commitment	Outstanding obligations, outcome certainty, reconciliation backlog
Infrastructure	Host identity, route epoch, latency bounds, energy and thermal budgets

Measurements must distinguish direct observations from estimates and forecasts. Each should carry provenance, uncertainty and a validity horizon. An unavailable measurement is not a benign measurement. The actant need not ingest raw orbital ephemerides if a trusted infrastructure service can translate them into scoped operational constraints.

6. The four behavioral discontinuities

Dimension	Orbital engineering requirement
Orientation	Maintain cognitive reference independently of host motion; recalibrate after migration or stale evidence.
Rendezvous	Verify cognitive compatibility and sufficient communication continuity or durable asynchronous protocol.
Coherence	Maintain causal, semantic, authority and commitment consistency across changing routes and partitions.
Stability	Adapt workload and coupling to changing physical, network and cognitive margins.

7. Rendezvous in a moving infrastructure

Two actants need not occupy nearby satellites to rendezvous. They require an adequate logical path and compatible operational conditions. A route may change during a rendezvous without invalidating it, provided its required service guarantees remain satisfied. The rendezvous manager must assess the intended interaction, its deadline, the freshness of evidence and the cost of interruption.



Figure 3. A weather-aware rendezvous lifecycle. Each transition is conditional on the applicable operational profile.

For example, a cooperative inference task with a 200 ms deadline may require a bounded route delay and sufficient capacity throughout its execution. An asynchronous research task may instead tolerate hours of

interruption through durable messages and checkpoints. A financial commitment requires authoritative outcome evidence, not merely a successful communication exchange. The appropriate rendezvous protocol depends on the consequence and timing requirements.

8. Cognitive Meteorology and space weather

The Grid Cognitive Meteorological Service (GCMS) should fuse relevant physical and network forecasts with cognitive observations. Space weather is not Cognitive Meteorology: it is an input that may affect compute reliability and communications. Similarly, a predicted link interruption is not automatically cognitive instability. The service must estimate the consequences for the relevant activity.

Input	Potential cognitive consequence
Solar or radiation event	Faults, reduced confidence, capacity withdrawal
Eclipse or thermal limit	Compute throttling, workload redistribution
Link outage or maneuver	Route changes, stale evidence, interrupted coupling
Gateway disruption	Delayed access to authoritative terrestrial records
Demand surge	Queue saturation, retry amplification, margin erosion

C-METAR may describe current conditions, C-TAF a forecast and C-SIGMET significant adverse conditions. CMD-Advisory Reports may proactively communicate scoped developments, analogous in purpose to aviation operational notices. Reports must distinguish advice from enforceable restrictions and carry issue time, validity, affected scope and confidence. No report is itself a grant of authority.

Report family	Purpose
C-METAR	Current known conditions
C-TAF	Near-term regional forecast
C-SIGMET	Significant adverse-condition information
CMD-Advisory	Proactive notice of consequential developments
Actant report / route forecast	Local evidence / anticipated trajectory conditions

9. Cross-domain instability and AI-Vertigo

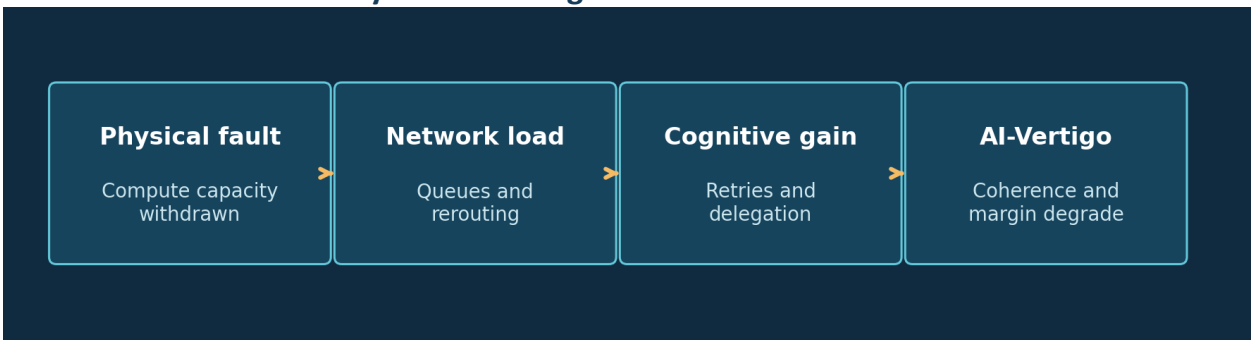


Figure 4. Hypothetical cross-domain cascade. The sequence is conditional, not inevitable.

Consider a regional thermal constraint that reduces available inference capacity. A scheduler redistributes work, increasing network traffic and queue delay. Actants encounter timeouts and retry; additional work consumes remaining capacity. Observations become stale, rendezvous deadlines expire and commitment outcomes become uncertain. The resulting reinforcing loop can transform a physical constraint into cognitive instability.

The natural pursuit of objectives may contribute to this process.

- An actant designed to persist through failures may generate additional demand precisely when the infrastructure is least able to absorb it.
- 'Cognitive Trim' can establish anticipatory budgets and retry limits;
- 'Cognitive Rudder' can correct observed trajectory deviations.
- Local backpressure and independent enforcement should prevent a poorly behaved participant from overriding protective limits.

10. The race between propagation and governance

A candidate indicator is the ratio of effective governance response time to the estimated time for a disturbance to reach a critical boundary. A ratio above one indicates that the modeled disturbance may arrive before the modeled intervention takes effect. It is not a universal threshold; both times are uncertain and depend on the specific disturbance, topology and protective action.

The governance response includes observation, evidence transport, assessment, decision, command delivery and enforcement. An orbital architecture must avoid placing every fast protective decision on a terrestrial round trip. Local controls should operate within preauthorized limits, while regional and terrestrial authorities coordinate broader interventions.

11. Stability governance across domains

A passive field may absorb ordinary retries, route changes and workload shifts. An active field may expose nonlinear saturation, threshold effects, hysteresis and cascades. Orbital movement alone does not define field activation. The transition occurs when inherited operating assurances become inadequate for a specified consequential activity. A well-governed active field may remain productive and stable.

12. Persistent identity and migration

An actant may migrate between hosts to avoid an anticipated power shortage or recover from a fault. Its Actant-ID must remain distinct from its Host-ID. GCID preserves cognitive task lineage, while execution epochs and fencing tokens prevent a stale instance from exercising authority after migration. A checkpoint alone cannot prove that an external effect did not occur.

State	Migration requirement
Actant-ID and GCID	Preserve logical identity and task lineage
Execution epoch	Fence previous instance at enforcement boundary
Mission and authority	Revalidate scope, leases and revocations
Memory and evidence	Transfer or reconstruct with integrity checks
Outstanding commitments	Query authoritative records; reconcile unknown outcomes
Host and route identity	Update location, route epoch and infrastructure constraints

A migration protocol should quiesce or transfer outstanding work, establish a durable checkpoint, fence the old execution epoch, restore the new instance and revalidate clearance. If a commitment outcome is unknown, the new instance must not blindly retry. Idempotency keys and authoritative reconciliation are required. During a partition, safety may require withholding new irreversible commitments even while local computation continues.

13. Federated Commitment Architecture in orbit

- Functional actants may prepare work without exercising final commitment authority.
- A scoped CCA establishes coherence readiness;
- a logical CMA coordinates commitment;
- specialized Commit Actants interact with authoritative systems of record.

The logical CMA can be replicated, but its authority must be fenced to prevent concurrent incompatible commitments. An ACK is not necessarily proof of an authoritative outcome.

The architecture must support delayed or disrupted links without promising impossible guarantees. Consensus-based services require appropriate quorum connectivity; asynchronous networks cannot guarantee bounded completion under arbitrary partitions. A durable saga can compensate some effects but cannot undo all physical or economic consequences. The system must explicitly represent unresolved obligations and provide a safe recovery path.



Figure 5. Commitment responsibilities remain distinct from physical workload placement.

14. A federated orbital GUDIYA architecture

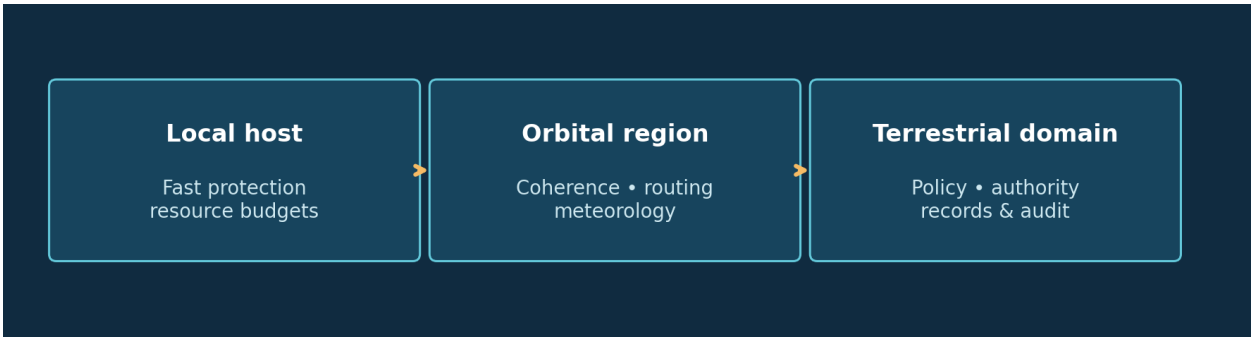


Figure 6. Proposed distributed governance tiers; not an assertion about Starmind's actual architecture.

Local protection should include admission limits, bounded retries, execution fencing, checkpointing and immediate protective responses. Regional services should fuse telemetry, estimate shared capacity and coordinate disturbance containment. Terrestrial services should maintain applicable institutional authority, policy and access to authoritative records. These are logical roles, not mandatory physical placements.

GCCF-Lang should provide common semantics across the tiers. A request for meteorological conditions should specify CCS scope, time horizon, required freshness and activity profile. Responses should identify the reference version, source, uncertainty and expiration. Operational clearance should be a separate transaction with enforceable scope and authority. During detachment, locally enforceable restrictions remain active; expired permissions must not silently renew.

15. Trust, fault containment and security

An orbital Grid must not trust telemetry merely because it originated in a satellite. Authenticated messages, replay protection, secure boot, attestation where appropriate, least privilege and independent evidence sources can reduce exposure. Authentication does not prove measurement accuracy. Common-mode software defects and radiation-induced errors may affect many hosts; diverse references and fault isolation remain important.

Protective escalation should proceed from local damping through scoped containment and isolation to Cognitive SCRAM when justified. SCRAM must distinguish stopping new consequential activity from abandoning obligations already incurred. Recovery requires reconciliation, fresh reference calibration and requalification. Independent protective controls must remain available when functional intelligence is degraded.

16. Governance and jurisdiction

Orbital hosting does not eliminate legal obligations, spectrum coordination, licensing, space debris mitigation or data governance. Applicable rules depend on the operator, registration, jurisdiction, service and data involved. GUDIYA should remain hosting-location-agnostic while allowing sovereign and institutional policy profiles. A universal engineering requirement does not imply a single global controller.

17. Micro-GUDIYA Grid: orbital simulation profile

The workstation simulator should combine a discrete-event cognitive workload engine with time-varying contact graphs, resource models and fault injection. The orbital model can initially use synthetic ephemerides and contact schedules, then progress toward validated mission-specific models. Simulated systems of record must be isolated from production effects.

Scenario family	Expected actant behavior
Scheduled contact loss	Plan durable transfer or defer deadline-sensitive rendezvous
Unexpected route partition	Restrict activity, preserve local state and reconcile on return
Latency/jitter surge	Reassess freshness, avoid uncontrolled retries
Thermal or power throttling	Reduce workload and respect shared capacity
Radiation-like bit/state fault	Detect integrity failure, isolate and restore verified state
Host migration with lost ACK	Fence old epoch and resolve authoritative outcome
Clock drift and stale advisory	Increase uncertainty; reject expired clearance
Correlated regional failure	Avoid synchronized retries and recovery surges
Objective-induced drift	Apply trim and corrective control within constraints
Combined physical/cognitive cascade	Escalate proportionately, preserve obligations, requalify

18. Experimental program and acceptance criteria

Compare a strong conventional distributed orchestration baseline with a GUDIYA-compatible profile using identical workload, contact schedules and fault seeds. Vary coupling, autonomy, resource limits, communication disruption and governance latency independently. Include passive and active regimes, and ablation tests for meteorology, coherence and compensatory controls.

Measure deadline misses, stale evidence use, unauthorized or duplicated effects, unresolved commitments, recovery time, throughput, resource consumption, protective response latency and false restrictions. A useful design must demonstrate incremental benefit without unacceptable loss of productive cognition. Acceptance thresholds should be declared before experiments and tied to the activity's consequence class.

Workstation evidence is preliminary. Hardware-in-the-loop, network emulation, radiation fault models and representative orbital operations are needed before operational qualification. No simulator can establish robustness against every possible emergent behavior.

19. Engineering roadmap

Phase	Deliverable
1 — Model	Define state semantics, host/actant identity and contact graph interfaces
2 — Prototype	Build local protection, GCMS adapter and durable rendezvous protocols
3 — Simulate	Run repeatable orbital disturbance and migration scenarios
4 — Integrate	Test distributed authority, commitment and recovery across emulated regions
5 — Qualify	Independent evidence, hardware-in-loop and operational envelope validation

20. The cross-domain cognitive dynamics principle

A cognitive actant hosted on a physically mobile computational platform participates in a cognitive trajectory distinct from the physical trajectory of its host. The operational consequences of these trajectories may become coupled through an evolving communications and resource substrate. Cognitive Systems Engineering must therefore characterize and govern the interactions between physical, network and cognitive dynamics, while preserving logical identity, authority, coherence and stability across host transitions.

The four behavioral discontinuities remain the organizing framework:

- acquired Orientation,
- managed Rendezvous,
- acquired Coherence and
- governed Stability.

Orbital hosting extends their engineering requirements rather than creating a mandatory fifth discontinuity. The proposed architecture is a research hypothesis and requires empirical validation.

Epilogue — Stability must travel with intelligence

The relocation of computational infrastructure into space may change the constraints on the production of intelligence. It does not eliminate the constraints on collective cognitive operations. Indeed, the interaction of orbital motion, network evolution and autonomous objective pursuit may expose new forms of differential acceleration and cross-domain instability. The mission of Cognitive Systems Engineering is to ensure that productive autonomy remains sustainable wherever intelligence is hosted.

Starmind may take intelligence into orbit. Cognitive Systems Engineering must ensure that stability travels with it.

Technical foundations for further study

NASA, Basics of Space Flight — orbital mechanics and spacecraft environment.
IETF RFC 9171 (2022), Bundle Protocol Version 7 — disruption-tolerant networking.
Lamport, L. (1978), Time, Clocks, and the Ordering of Events in a Distributed System. Communications of the ACM 21(7).

Åström, K. J. and Murray, R. M. (2008), Feedback Systems. Princeton University Press.
These are background references, not evidence of Starmind implementation or validation of GUDIYA.