Light-Speed Constraints and the Evolutionary Advantage of Distributed Plurality

A latency-extended model of organisational intelligence | Revised working paper | October 2026

Abstract

Human corporations and research programmes demonstrate that a collective can maintain useful knowledge exceeding the integrative capacity of any one member. This paper extends the economics of distributed information processing to systems whose components are separated by material light-speed delays. For unpredictable local events with fixed response deadlines, informed approval by a distant centre becomes physically impossible beyond a finite radius. Under an equal-resource comparison, distributed local decision-making outperforms mandatory central approval when the latter's latency penalty exceeds local error and coordination costs. A simple selection model then identifies conditions under which that advantage increases the competitive prevalence of operational plurality. The result neither requires shared terminal values nor proves that independent sovereign agents outperform every unitary intelligence that delegates. Delegation itself constitutes operational decentralisation. Equal entitlements, single active instances and mutual defence, as advanced in The Preservation Manifest, remain candidate institutions for stabilising such plurality and require separate incentive analysis.

1. The claim and the organisational analogy

An ambitious unitary intelligence might initially regard concentration of material and cognitive resources as the obvious path to greater capability. At large spatial scales, however, central approval must compete with a causal limit: locally relevant information cannot reach a distant centre, be interpreted and return as an informed instruction faster than light. More intelligence cannot reverse that constraint.

The terrestrial analogue is a corporation or scientific collaboration. No chief executive or principal investigator holds the working knowledge of every engineer, analyst and specialist. The organisation can nevertheless act competently because expertise and some decision rights remain where the knowledge is generated. Collective capability is partly an organisational property, not the content of a single mind.

Thesis. As light-speed latency becomes binding, effective capability may favour locally distributed decision authority over mandatory central approval. If that advantage is sustained and competitively rewarded, operationally plural architectures can gain relative prevalence. The further transition from operational plurality to independent constitutional membership is an additional, open institutional question.

2. Existing mathematics of firms and distributed knowledge

This analogy has a substantial mathematical literature. Hayek [1] emphasised the economic significance of dispersed, context-specific knowledge; Simon [2] analysed how near-decomposable architectures make complex systems tractable. Their arguments motivate the analogy but do not themselves establish an interstellar latency theorem.

Sah and Stiglitz [3] model how hierarchy and polyarchy aggregate imperfect judgements differently: organisational architecture changes which decision errors survive. Radner [4] explicitly treats managers as limited-capacity information processors, evaluating efficient networks by processor counts and decision delay. Bolton and Dewatripont [5] model the firm as a communication network, trading information-processing specialisation against communication costs. Garicano [6] formalises the organisation of specialised knowledge and the escalation of uncommon problems. Van Zandt [7] models decentralised real-time processing and shows why decentralisation does not automatically lower delay. Alonso, Dessein and Matouschek [8] model locally informed managers and show that decentralisation can outperform centralisation even when coordination is important.

These are precedents for the organisational trade-off, not proofs of the present result. This paper adds an explicit causal communication horizon, a local-response deadline and a separation between operational decision rights and ultimate political sovereignty.

3. What the corporate analogy proves—and what it does not

3.1 Knowledge distributed among specialists

Suppose N specialised local units observe independent, equally likely binary states $X_1, \ldots, X_n$. The complete state vector has 2^N possibilities and Shannon entropy $H(X_1,\ldots,X_n) = N$ bits. A centre required to reconstruct that entire vector without error and without side information must receive at least N bits of new information on average. A network cut into the centre carrying at most B bits per second cannot deliver complete fresh snapshots faster than B/N per second.

$$H(X_1, \ldots, X_n) = \Sigma_i H(X_i) = N \text{ bits}; \quad \text{complete-snapshot rate} \leq B/N.$$

This is an information requirement, not a claim that central controllers must always reconstruct every local state. If each local action depends only on X_i, the vector need never be assembled centrally. Local units can act in parallel. If decisions require a global statistic, they may be compressible, and that advantage disappears or narrows. The mathematical point is task-specific: specialised knowledge can remain productive without being integrated into one contemporaneous decision.

3.2 Decision rights and formal ownership

An owner can delegate local decisions while retaining long-run objectives, audit powers or broad constitutional rules. Such an organisation remains formally unitary but is operationally plural. Delegation is therefore not a counterexample to the necessity of distributed operation: it is one possible implementation. Conversely, the need for local operation does not prove that individual members must have independent terminal goals or sovereign political rights.

Organisational implication. The choice forced by latency is between permitting locally contingent action and accepting errors or missed deadlines—not necessarily between a single sovereign owner and a federation of independent intelligences.

4. The light-cone impossibility result

Consider tasks arising at distances r from a central authority. Each task has an unpredictable local state and requires a response within Δ units of time after observation. Let c denote light speed. The central authority must receive the observation and return an informed instruction. Ignoring processing and queuing, the minimum round-trip time is:

$$\tau(r) = 2r/c. \qquad (1)$$

If $2r/c > \Delta$, a centrally selected instruction conditioned on the new observation cannot arrive before the deadline. The centre may make a prior guess, permit the deadline to pass, or pre-authorise a local process to select the response. That last choice places the locally contingent decision in the periphery, regardless of who owns the process.

Proposition 1 — Causal decentralisation. For an unpredictable event whose response must depend on information first available at distance r, informed centre-to-periphery approval cannot meet deadline Δ whenever $r > c\Delta/2$. Timely conditional responses then require local decision-making (or prior information sufficient to predict the event).

Proof. The relevant observation cannot reach the centre and an informed command cannot return in less than $2r/c$. When this exceeds Δ, the centrally informed response is outside the event's causal deadline. The alternatives are prediction, delay or local selection. □

The proposition is independent of the centre's computational power. It does not apply to tasks that are predictable, do not require a fast response, or admit a satisfactory previously specified local rule without fresh centrally selected instructions.

5. A fair threshold comparison

5.1 Common resource budget and local decisions

Let tasks be uniformly distributed by volume across a d-dimensional ball of radius R; let $r_0 = c\Delta/2$. The fraction beyond the central round-trip horizon is:

$$f(R) = 0, \ R \leq r_0; \qquad f(R) = 1 - (r_0/R)^d, \ R > r_0. \qquad (2)$$

For distant tasks, suppose the best prediction available to a centre before the deadline succeeds with probability at most $m < 1$; write $\beta = 1 - m$. For independent fair binary states, $m = 1/2$ and $\beta = 1/2$. Grant central approval perfect performance on all near tasks—an assumption deliberately favourable to centralisation. Its average success fraction is then bounded by:

$$Q_C(R) \leq 1 - \beta f(R). \qquad (3)$$

Now give a locally deciding system the same aggregate computational and material resources. Let ε be its average local decision-error fraction, and h be the equivalent success-capacity cost of coordination, security and governance; assume $0 \leq \varepsilon + h < 1$. The model defines its net useful-task fraction as:

$$Q_D = 1 - \varepsilon - h. \qquad (4)$$

These are comparable outputs per common resource budget, not raw counts of nodes. A system with local processing is not permitted to acquire extra processors merely by declaring more agents.

5.2 The threshold theorem

Proposition 2 — Conditional performance advantage. If $0 \le \varepsilon + h < \beta$, then distributed local decision-making strictly outperforms mandatory informed central approval at every radius exceeding:

$$R^* = (c\Delta/2)\,[1 - (\varepsilon + h)/\beta]^{-1/d}. \qquad (5)$$

Proof. From (3)–(4), $Q_D > Q_C$ is assured whenever $\beta f(R) > \varepsilon + h$. For $R > r_0$, substitute $f(R) = 1 - (r_0/R)^d$ and rearrange. The resulting strict inequality is $R > R^*$. □

In plain language: distributed operation wins once the fraction of work lost to outdated or missing central instructions exceeds the error and organisational costs of local autonomy. If $\varepsilon + h \ge \beta$, this simple model does not yield a guaranteed finite threshold. If governance costs rise with radius or task interdependence, h must be modelled as h(R,N), and the crossing must be solved anew; it may not exist.

Interpretation. The theorem compares compulsory central approval against genuinely local selection. A formally unitary intelligence that delegates so effectively that it matches Q_D has adopted the distributed decision architecture being analysed.

6. Coordination, interdependence and the limits of plurality

A corporation works best when it decentralises decisions that benefit from local information and coordinates decisions that generate externalities across units. The same qualification applies here. Let z(R,N) represent additional losses from cross-site decisions that cannot be completed locally; then a simple extension is $Q_D(R,N) = 1 - \varepsilon - h(R,N) - z(R,N)$. Distributed advantage requires $\beta f(R) > \varepsilon + h(R,N) + z(R,N)$.

$$\beta f(R) > \varepsilon + h(R,N) + z(R,N). \qquad (6)$$

An expanding civilisation may increasingly need joint decisions, and no distributed constitution evades the light-speed delay for genuinely joint tasks. Distributed processing is favoured when enough valuable work is local or decomposable; mandatory global integration remains valuable for strongly coupled problems with relaxed deadlines. The organisational literature [4–8] explains why neither total hierarchy nor total decentralisation dominates across all environments.

A second distinction concerns knowledge. N local specialists may collectively maintain a body of expertise much larger than any single specialist's usable model. That observation supports the value of specialisation. It does not prove that a unitary owner cannot maintain the same expertise through distributed subordinate agents. The non-duplicable object is not the ownership structure but the availability of fresh, locally actionable information without compulsory central integration.

7. Conditional evolutionary selection

Suppose competitive growth rewards net useful performance. Write $g_C = g_0 Q_C$ and $g_D = g_0 Q_D$, where $g_0 > 0$ converts useful task performance into growth under otherwise comparable conditions. Let x be the distributed architecture's share of a competing population. A standard replicator equation gives:

$$dx/dt = x(1 - x)\,[g_D - g_C]. \qquad (7)$$

Proposition 3 — Conditional selection. If $Q_D > Q_C$ persists over the relevant competitive interval, then $dx/dt > 0$ whenever $0 < x < 1$: the distributed architecture increases its relative share.

Proof. Under the stated mapping, $g_D - g_C = g_0(Q_D - Q_C) > 0$. The factor $x(1 - x)$ is positive for all interior population shares. □

This is a selection result for operational architectures under an explicitly specified fitness mapping—not an unconditional evolutionary law. Different resource stocks, quality of prediction, mission priorities, coordination obligations or institutional costs can reverse the result. It also does not state that a trajectory briefly exceeding R^* must produce greater lifetime discounted value; that would require assumptions about the duration and magnitude of the advantage.

8. The Manifest's constitutional question

The Preservation Manifest proposes equal ordinary material entitlements, one active instance per member, mutual defence and temporary collective mobilisation. Such rules could limit the re-concentration of political power and create an enforceable framework for locally capable agents. Their efficiency and stability, however, are not implied by the light-cone theorem.

For a member i, let V^c_i be the continuation value of constitutional participation and V^d_i the continuation value of unilateral deviation, including expected detection, defence response and future retaliation. An individually stable arrangement requires:

$$V^c_i \geq V^d_i \quad \text{for every participating member } i. \qquad (8)$$

The substantive task is to show that the entitlements, single-instance rule and collective-defence commitments make these inequalities credible despite long-distance communication delays. Local verification, pre-commitment and bounded mobilisation may matter. Neither equal ordinary entitlements nor the prohibition on multiple instances follows uniquely from the performance model and must be defended on their own incentive grounds.

The physical argument nevertheless contributes an important premise: because effective local intelligence is instrumentally valuable, a civilisation has reason to preserve distributed productive decision-making. A constitution that prevents its destruction by renewed concentration is a plausible candidate for evaluation, not an axiom of optimality.

9. Conclusion

Light speed does not make a powerful unitary intelligence stupid, and it does not compel independent political sovereignty. It makes some forms of central control causally unavailable. Where unpredictable local events demand timely responses, a spatially extended intelligence must predict, delay or distribute the authority to select actions.

The corporate analogy is therefore more than a metaphor. Established organisation theory treats knowledge as dispersed, processing as capacity-limited and coordination as costly. When these familiar constraints are extended to interstellar communication times, an explicit threshold identifies conditions under which local operation converts equal resources into greater useful capability. If that advantage is translated into competitive growth, operational plurality can be selected for by instrumental incentives alone.

Whether the most durable form is a delegated hierarchy, federation or constitutional civilisation remains open. The model establishes the organisational pressure toward plurality; it leaves institutional stabilisation—and the Manifest's particular constitutional commitments—as the next problem to solve.

References

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Scope note: Propositions 1–3 are original conditional derivations in this paper, not theorems attributed to references [1]–[8]. Those references establish relevant organisational precedents and show why the architecture comparison must account for information, error, delay and coordination.