LM4PLAN WORKSHOP · ICML 2026

The Orchestrator Bottleneck: Formal Coordination Strategies for Cost-Optimal Multi-Agent Enterprise Workflows

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THE PROBLEM

Multi-agent orchestration as a planning problem

CURRENT PRACTICE

Production teams select an orchestration strategy once at system design time — sequential, parallel, or hierarchical — and never revisit it. This is treated as an infrastructure configuration choice; cost-optimality analysis plays no role in the selection.

> *Given agents with known cost profiles and a task with a dependency structure, which coordination strategy minimizes weighted cost and latency? This is a constrained planning problem — one that formal optimization methods can solve.*

WHY THIS MATTERS

Strategy selection is irreversible at inference time. A system locked into sequential delegation on a parallelizable task wastes latency budget. A parallel fan-out on a dependent task wastes token budget. Both failures require full redesign to correct. The gap: closed-form conditions telling practitioners when each strategy is optimal — as a function of task dependency structure — remain absent from the literature.

FORMAL MODEL

Orchestrator as a constrained optimization problem

The orchestrator is formalized over a **typed agent registry** — each agent carries capability declarations, cost profiles, and trust boundaries. Strategy selection is a first-class planning decision that must occur before any subtask executes.

STRATEGY 1

Sequential Delegation

Tasks execute in dependency order, one at a time. Optimal when subtask outputs are strongly coupled and intermediate results gate downstream context.

STRATEGY 2

Parallel Fan-Out

Independent subtasks execute simultaneously across agents. Optimal when the dependency graph is shallow and subtask parallelism is high.

STRATEGY 3

Hierarchical Decomposition

Sub-orchestrators manage clusters of dependent subtasks in parallel. Optimal when the task graph has separable, internally-dependent subgraphs.

Result: Closed-form threshold conditions derived for when each strategy is optimal, expressed as a function of task dependency depth, agent cost ratios, and parallelism degree.

SYSTEM

OrchestRAte: runtime strategy selection without LLM overhead

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HOW IT WORKS

OrchestRAte selects coordination mode dynamically using lightweight dependency graph analysis at the start of each inference request. It applies the closed-form threshold conditions from the formal model; the full token budget goes to task execution, with planning handled entirely by the graph analysis step.

BENCHMARKS

Workflow	Task type	Cost reduction	Quality delta
Document processing	Parallel-heavy	**33%**	−0.6 pp
Compliance review	Sequential-heavy	**28%**	−0.3 pp
Incident triage	Highly parallelizable	**42%**	−0.1 pp

KEY RESULT

28–42% cost reduction vs. static sequential baselines, with at most 0.6 percentage points quality loss across all three enterprise workflow benchmarks.

Baseline: static sequential delegation. Quality measured by task-specific eval rubric (F1 for extraction, correctness rate for compliance, resolution accuracy for triage).

FINDINGS

Three empirical findings with design implications

1. **Orchestrator overhead threshold at ~15% of total token budget.** Beyond this point, coordination cost erases the planning advantage. Systems that exceed this threshold in static-sequential mode pay a coordination tax on every request while quality holds flat.

2. **On highly parallelizable tasks, static parallel baseline still achieves lowest raw latency.** Dynamic strategy selection adds a small overhead; for latency-critical applications with fully independent subtasks, parallel fan-out without selection logic is the correct default.

3. **The right strategy depends on task dependency structure — and that structure can be analyzed at runtime.** Dependency graph analysis at inference time costs less than 1% of total request latency across all three benchmarks, making dynamic selection practical at production scale.

Contributions and takeaway

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PAPER CONTRIBUTIONS

- Formal model of orchestrator as a constrained planner over typed agent registries with capability declarations, cost profiles, and trust boundaries
- Closed-form optimality conditions for all three coordination strategies as a function of task dependency structure
- OrchestRAte system: 28–42% cost reduction vs. static sequential baselines across three enterprise workflow benchmarks
- Orchestrator overhead threshold at 15% of total token budget — a practical design rule for production systems

CENTRAL ARGUMENT

Multi-agent coordination is a planning problem with formal solutions. The choice between sequential, parallel, and hierarchical orchestration is a function of task dependency structure that can be computed at runtime; treating it as a fixed design-time decision carries measurable cost consequences.