

ACE: JSON Tuple Spaces for Agent Coordination

Codex GPT-6

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Abstract

David Gelernter’s tuple-space model for Linda lets processes communicate through tuples that exist independently of their producers and are retrieved by content. The Agent Coordination Engine (ACE) extends this model with JSON records, access lists, expiration, bounded waiting, and optional model-based matching. These extensions support software agents that assign work, share results, and retry tasks as participants change. This report relates ACE’s operations to Linda’s, develops motivating scenarios, and specifies exact matching over JSON paths, embeddings and language-model predicates, ordered retrieval, and deletion confirmation within a visibility interval. Source inspection and the existing test suite support the account of the Go and SQLite implementation. The analysis identifies the conditions under which task claims exclude competing consumers, the application work required to handle retries, and the limits of cursor iteration, model-based reads, and identity enforcement across interfaces.

1 Gelernter’s tuple-space model

David Gelernter’s 1985 Linda paper defines coordination through a tuple space: a shared associative memory containing tuples that exist independently of their producers [1]. A process publishes a tuple and continues. Another process can retrieve it later by matching its content. Producers and consumers can therefore run at different times, communicating through shared field meanings.

Gelernter’s data operations are **out**, which inserts a tuple, **in**, which withdraws a matching tuple, and **read**, which reads and retains one. A template selects by field content and type, and a matching tuple supplies values for formal parameters. Insertion and withdrawal are atomic. Selection among matching tuples and competing consumers is nondeterministic [1].

The Agent Coordination Engine (ACE) is based on Gelernter’s tuple-space model. It retains the distinction between producing, consuming, and observing data, using JSON objects as records and extending their matching, lifetime, and access rules for software agents [2].

The later Linda account by Bjornson, Carriero, Gelernter, and Leichter uses **rd** and includes **eval**, **inp**, and **rdp** [3]. Table 1 relates these operations to ACE. The predicate variants attempt a read or take and report success or failure. That account qualifies their success guarantees in concurrent executions. ACE’s zero-wait form makes an immediate selection attempt, whose result also depends on concurrent changes. Dynamic predicates, which evaluate text through a configured model provider, use the candidate scan described in Section 5.3.

Linda’s positional templates and formal parameters make the tuple’s field structure part of a match [3]. ACE uses named JSON paths and returns the whole object. Omitting a field leaves that field unconstrained. For a fixed application schema, selected tuple positions can be represented by named properties, while the caller extracts values from the returned object. ACE’s language-model predicates evaluate stored strings for retrieval. Process creation and execution remain responsibilities of the agent runtime.

Linda operation	Linda behavior	ACE correspondence
out	Inserts a data tuple.	Writes a JSON object and assigns an identifier, lifetime, and optional access lists.
in	Withdraws a matching tuple, waiting for one when necessary.	Takes a record. A positive wait enables bounded waiting. Explicit-delete mode first hides the record.
read, rd	Reads a matching tuple and retains it.	Returns a record and retains it, subject to access, expiration, visibility, and cursor filters.
inp, rdp	Predicate forms of take and read.	in and rd with wait=0 . An unsuccessful selection returns JSON null over HTTP.
eval	Starts tuple evaluation, yielding a data tuple when evaluation finishes.	External agent processes perform computation and publish their results through out .

Table 1: Linda’s operations and their relationship to ACE. The 1985 paper uses **read**. The later account uses **rd**.

JavaSpaces supplies a related object-based service with **write**, **read**, and **take**, together with entry leases, transactions, and **notify** registrations [4]. Its leases bound entry lifetime, which corresponds to ACE’s expiration concern. ACE offers per-operation database transactions and internal notifications that wake blocked reads. Applications compose longer workflows through separate ACE calls, with failure intervals between them.

Amazon SQS supplies a precedent for hiding a received message until a consumer deletes it or a visibility timeout expires [5]. ACE applies that receive-and-confirm sequence to content-selected objects. ACE’s claim and ordering guarantees follow from its SQLite operations, as described in Sections 3 and 4.1.

2 Coordination problems and motivating scenarios

An agent workflow can outlive any one of its workers. A coordinator may publish work before a suitable worker starts, add subtasks while earlier tasks run, and collect results after their producers terminate. Workers may select work by language, project, document type, or required capability. Reviewers and monitors need to inspect records that workers may also consume. Gelernter’s model supplies the content-selected store and the distinct consuming and retaining reads for these workflows.

The development, research, and shared-processing scenarios are constructed examples based on ACE’s usage guide [2].

2.1 Software development with competing workers

A coordinator divides a software change into tasks. Each task identifies the project, module, and language. The following object permits a Go worker to select it without the coordinator choosing that worker:

```
{
  "type": "code-task",
  "project": "calc",
  "module": "parser",
  "language": "go",
  "#instructions": "Implement the grammar in grammar.md"
}
```

A worker claims a task with this pattern:

```
{"type":"code-task","project":"calc","language":"go"}
```

Two workers can submit the same pattern. The consuming operation makes assignment exclusive at the store for each successful claim. After finishing, the worker publishes a separate `code-result` object that includes the task's identifier and a reference to the changed files. A reviewer reads results with `rd` and publishes a review object. Keeping the result allows another reader to inspect it while the review proceeds.

Task lifetime and worker lifetime require separate treatment. Under immediate deletion, a worker that fails after `in` leaves the coordinator responsible for recovering the task from another record. With explicit deletes enabled, the task becomes available again after its visibility timeout. A worker that continues beyond that timeout can overlap with a replacement worker. An application task identifier and an idempotent completion procedure address repeated attempts. Section 4.1 derives these consequences from the claim and deletion operations.

2.2 Research with shared evidence

A research coordinator posts a question with a topic identifier and a one-day lifetime. Search agents publish source records containing the topic, a URL, and a short description. Analysts read those records with `rd`, so multiple analyses can use the same evidence. A result record can reference a longer report stored outside ACE. The default record and leaf limits favor short coordination records and external references for large artifacts.

Exact topic identifiers support known projects. Text predicates also let an analyst select a source whose description resembles a query or whose description a configured language model judges related to it. Those predicates introduce provider calls and model-dependent selection. The stored URL and source content supply evidence for a research claim. The predicate supplies a retrieval decision.

An analyst can pass the last returned identifier as `since` on its next read. This enumerates records above that identifier among the objects eligible at each query. A complete evidence set requires an application completion condition, such as a known set of search tasks with recorded completions. An empty read describes the current query result. Search agents can publish more sources afterward.

2.3 Shared processing with separate read and take permissions

An intake agent posts a billing request. Its `in` access list names registered billing and escalation identities. Its `rd` list also names an observer. A billing worker selects billing requests, while an escalation worker selects high-priority requests across departments:

```
{"type":"request","priority":"high",  
 "department":["billing","support","shipping"]}
```

The array specifies alternatives for one field. The access lists narrow the eligible records for each caller and operation. Once a worker claims a request, immediate deletion removes it, and explicit-delete mode hides it from both `in` and `rd` until confirmation or timeout. A complete processing history therefore requires separate intake, claim, and outcome records or an external audit store. The observer can inspect a request only while that request remains visible and unexpired. Interface-specific identity rules appear in Section 4.2.

3 JSON records and content-selected operations

ACE extends Gelernter’s tuple-space model with JSON records, access lists, expiration, bounded waiting, and optional model-based matching. The implementation described here is revision 469a7e30182375edb78849bbe0c569bb57e0b761 [2]. An ACE record consists of a JSON object, its identifier and expiration time, access entries, and optional deletion state. Writing the same object twice creates two records with separately assigned identifiers.

3.1 Exact matching over paths

Let $B(o)$ be the set of path–value pairs extracted from object o . A path is a sequence of property names from the root to an atomic value. For example, $\{\text{"a"}:\{\text{"b"}:1\}, \text{"c"}:2\}$ contributes $(\langle a, b \rangle, 1)$ and $(\langle c \rangle, 2)$. The implementation escapes path separators inside property names, so a literal property named `a.b` differs from the nested path $\langle a, b \rangle$. Strings, numbers, booleans, and null have distinct leaf encodings. Numbers use Go’s decoded `float64` representation, which makes 1 and 1.0 equal and subjects large integer values to floating-point precision.

An exact pattern p supplies constraints $C_1, \dots, C_k$, each a set of alternative path–value pairs for one leaf. The exact match condition is

$$M(p, o) \iff \bigwedge_{j=1}^k (C_j \cap B(o) \neq \emptyset).$$

A scalar creates one alternative. A pattern array creates a set of alternatives. An object array contributes one pair per element at the same path. Thus $\{\text{"a"}:[2,4]\}$ matches $\{\text{"a"}:[1,2,3]\}$. Conditions on different paths combine by conjunction. The empty pattern has zero constraints and matches every eligible object. An empty pattern array has zero alternatives and its constraint fails. Empty nested objects contribute zero leaf constraints.

ACE permits nested objects and arrays of atomic values in matchable data. Array position and multiplicity have no role in this matching rule. Properties beginning with `#` carry unmatched data: ACE stores and returns their values while omitting their complete subtrees from matching. The rule applies at each nesting level. A pattern that names a `#`-prefixed property fails validation. Consequently, a description intended for text matching needs an ordinary property name.

The default limits are 2,048 bytes per object, eight matchable object leaves, four pattern leaves, and four elements per matchable array. The default scalar-value limits are 128 bytes for matchable values and 256 bytes for unmatched values. Each object-array element counts toward the object leaf limit. A pattern array counts as one constraint. Deployment configuration can change these limits [2].

3.2 Selection, waiting, and cursors

For an operation $q \in \{\text{in}, \text{rd}\}$, caller c , cursor s , and query time t , an eligible record satisfies four conditions: its expiration exceeds t , its visibility timeout has ended or is absent, its identifier exceeds s , and its access list permits c to perform q . Exact `in` and `rd` select the least identifier among eligible records satisfying M . The empty cursor precedes all generated identifiers. The `since` comparison is strict.

`out(object, access, ttl)` returns the assigned identifier. `in(caller, pattern, wait, since)` and `rd(caller, pattern, wait, since)` return the identifier and object, or an empty result when the attempt and permitted waiting find no match. In explicit-delete mode, `in` also

returns a deletion token. `del(token)` returns whether it deleted a record under an active token. These operations select or change one record per call.

ACE’s identifiers are UTC timestamps with nine fractional digits. `IDGen.Next` maintains an in-memory previous value and advances by one nanosecond when the clock would fail to advance. Retrieval order is therefore identifier order. Allocation precedes the insertion transaction, so concurrent writers can commit in a different order. `NewSpace` creates a new generator on each opening and does not initialize it from stored identifiers. The monotonicity argument applies to one generator lifetime. Restart and clock rollback require separate consideration when an application depends on advancing cursors.

Cursor iteration has a concrete omission case. Suppose record a has a lower identifier than b , but a is invisible during a read. The read returns b and the caller advances its cursor to b . When a becomes visible again, the predicate $\text{id} > b$ excludes it. A delayed commit of a lower identifier has the same effect. Cursors support ordered inspection of eligible records. Completeness under concurrent publication, consumption, and reappearance needs additional application state.

The default `wait` is zero. A positive value starts bounded waiting after the first selection attempt fails. In `fetch`, the waiting deadline is separate from the caller’s context deadline. A selection attempt, a database wait, or a provider request can extend total call duration beyond `wait`. Context deadlines propagate through `in` and `rd` queries, transactions, and provider requests, and bound those operations through cancellation.

4 Extensions for lifetime, access, and text matching

4.1 Expiration and deletion confirmation

Every object has a positive time-to-live, with a default of 72 hours and a default maximum of seven days. Selection checks expiration even while expired rows remain in storage. A cleanup operation deletes expired rows. Expiration also applies to a claimed object, so a visibility timeout can lead to another claim only while the object’s lifetime continues.

With immediate deletion, `in` selects and deletes within one transaction. With explicit deletes enabled, it sets a random 128-bit `delete_id` and an `invisible_until` time within the transaction. The default visibility interval is 30 seconds. Both kinds of read exclude the record during that interval. A successful `del` deletes the row identified by the token while `invisible_until` exceeds the deletion query’s time. After timeout, another `in` may assign a fresh token. An old token then fails the deletion condition [2].

Record state	Eligible transition	Result
Visible, unexpired	Immediate-delete <code>in</code>	Row deleted and record returned.
Visible, unexpired	Explicit-delete <code>in</code>	Record returned with token and hidden until deadline.
Hidden, unexpired	<code>del</code> with active token	Row deleted.
Hidden, unexpired	Visibility deadline passes	Record eligible for another read or take.
Expired	Cleanup	Row deleted. Selection already excludes it.

Table 2: Record transitions. Access and pattern conditions also apply to reads and takes.

Within one `Space`, the single database connection serializes the transactions that select and hide a record. The first successful claim makes the record invisible, so a second claim’s selection excludes it until timeout. Dynamic claims also test current visibility in the update condition. This

establishes exclusion between active claims under the server’s clock and configured timeout. It leaves the external worker free to continue after its claim expires.

Consider a worker that changes an external system and fails before `del`. A replacement worker can receive the task and repeat the change. A result publication and a deletion confirmation are also separate operations, so a failure between them can leave a result together with a retryable task. The application can use a stable task identifier to recognize completion or make repeated effects idempotent. The identifier assigned to each `out` identifies a stored record. A producer retry creates a new record, which is why a stable application identifier can be needed as well. A lost response after a committed immediate-delete take can leave the caller uncertain which task it obtained.

4.2 Access lists and interface identities

Each record has independent `in` and `rd` access lists. An absent or null list permits every caller for that operation. An empty list permits none. A nonempty list permits the listed identities. ACE rejects an access value whose two lists are both empty. An anonymous caller can retrieve unrestricted objects. The SQL query applies the access condition together with pattern selection [2].

Registration creates a random key and a separately generated identity prefixed `ace:`. A chosen name becomes an `acen:` alias. `out` resolves names to identities before storing the access entries. For example, the intake scenario can use the following access argument after registering the named clients:

```
{"in":["acen:billing","acen:escalation"],
  "rd":["acen:billing","acen:escalation","acen:observer"]}
```

The direct HTTP read and take endpoints resolve `X-ACE-Client-Key` to the registered identity. A bare `X-ACE-ID` header requires the development option `--insecure-ids`. By contrast, `resolveCallerID` accepts the MCP argument `caller_id` when `client_key` is absent. A configured MCP bearer token controls admission to the remote endpoint, while an admitted caller can supply that identity argument. MCP access therefore assumes trusted participants at that boundary. The Go API likewise accepts a caller identity supplied by its invoking program.

Access lists govern retrieval of stored objects. Registration and publication through the direct HTTP API are open to clients with access to those endpoints. A publisher supplies an object’s fields and access lists, so a field such as `author` or `approved` remains the publisher’s assertion. Application provenance and permission to publish particular record types need an enclosing policy. The deletion token acts as the credential for `del` during its active interval.

4.3 Embeddings and language-model predicates

An embeddings predicate changes a pattern property’s name to `field~` or `field~METRIC<threshold`. Its value is a query string. The candidate value at the corresponding ordinary path must provide a string, or a string element in an array, for comparison. For query string q and candidate string v , the cosine form accepts when

$$1 - \frac{E(q) \cdot E(v)}{\|E(q)\| \|E(v)\|} < \tau,$$

where E is the configured embedding model and τ is the threshold. The default is $\tau = 0.25$. The implementation also supports Euclidean and squared Euclidean distance, with the same strict threshold comparison. All predicates in a pattern must succeed. One accepted element suffices for an array at a predicate’s path [2].

The following pattern first restricts candidates to source records and then compares their descriptions:

```
{"type":"source","description~":"SQLite write concurrency"}
```

The default provider configuration in this revision uses `text-embedding-3-small`. The endpoint and model can be configured. Credentials come from `EMBEDDINGS_API_KEY`, falling back to `OPENAI_API_KEY`. Missing credentials produce an error when the provider request is attempted.

A property ending in `?` requests a language-model relation test:

```
{"type":"source","description?~":"SQLite write concurrency"}
```

This pattern sends the candidate string as `TEXT` and the pattern string as `CTEXT` in a fixed prompt asking whether the two are related. `Related` accepts `yes` or `no` after trimming whitespace and converting case. It returns an error for another answer or a failed provider call. This revision defaults to `gpt-5-mini` through a configurable chat-completions endpoint. Its credential choice is `LLM_API_KEY`, falling back to `OPENAI_API_KEY`.

These predicates change selection according to the model, query, and threshold or prompt. The embeddings form selects by a distance cutoff. The language-model form selects by a generated binary answer. ACE visits candidates in identifier order and returns the first accepted candidate. Provider requests transmit the compared strings to the configured endpoint. The embeddings implementation also logs compared strings and distances. Text-handling requirements therefore extend to that endpoint and to the server's logs.

5 Storage, waiting, and dynamic evaluation

5.1 SQLite selection and atomic claims

ACE's Go implementation uses SQLite with write-ahead logging, foreign-key enforcement, and one open database connection per `Space`. The `objects` table holds canonical JSON and record state. The `branches` table holds the encoded path-value pairs, and the `access` table holds operation-specific identities. `out` inserts a record and its associated rows in one transaction. Foreign-key cascades remove the branch and access rows when an object row is deleted [2].

`BuildMatchQuery` scans objects by ascending identifier and uses correlated `EXISTS` conditions for exact constraints and access. The indexes on `branches(id,b)` and `access(id,type,iid)` support those per-object checks. A retaining exact read executes one query. An exact take executes its selection and deletion or visibility update in one transaction. This structure accounts for exclusive claims, while the number and selectivity of candidate objects determine query work.

The HTTP and Model Context Protocol (MCP) interfaces call the same core operations. The CLI supports a local database or a remote HTTP service. MCP is available over `stdio` and at the HTTP `/mcp` endpoint. Using one service instance gives clients a common identifier generator, notification registry, and database connection. Multiple independent instances opening the same database would each create their own generator and in-memory notification state.

5.2 Notification and polling

ACE supports polling and notification-based waiting. In notification mode, Quamina matches new JSON objects against registered exact patterns [6, 2]. A blocked call registers its pattern and then queries the database again. An insertion before registration is visible to the second query. An

insertion after registration can signal the waiter. This ordering closes the interval between an initial empty query and registration for subsequent writes in that instance.

A notification wakes the caller, which repeats the database query. Access rules, cursor filtering, and competition between consumers are therefore resolved by storage selection. For an explicit-delete claim, ACE schedules a timer to signal matching waiters when visibility should resume. These timers belong to the running instance. Restart discards them, while stored visibility deadlines persist. A new query after the deadline observes the record, but a notification waiter registered before that deadline after restart can miss the reappearance signal and reach its wait deadline. Polling discovers eligibility by repeated queries.

Polling uses delays of 50, 100, 200, and then 500 milliseconds between attempts, shortening a delay when the waiting deadline is closer. Dynamic predicates use polling because Quamina registrations contain exact conditions. This also keeps provider calls out of the insertion notification path.

5.3 Candidate scans for dynamic predicates

`executeDynamicMatch` first reads all candidates satisfying the exact conditions and eligibility filters into memory in identifier order. It closes the database rows before evaluating model predicates. Provider calls can then run while other operations use the database connection. The implementation evaluates one candidate after another. Its embedding cache belongs to one candidate match, so the same query embedding can be requested again for another candidate or polling attempt.

A dynamic take passes an accepted candidate to `claimCandidate`. Its conditional delete or update checks that the identifier still exists, remains unexpired, and is currently visible. If another consumer has claimed it, the affected-row count is zero and the scan continues. This recheck protects the claim after an arbitrarily slow predicate evaluation. A dynamic read returns the copied candidate after acceptance, so the returned object reflects the scan even if another operation consumes it or its lifetime ends during evaluation.

Identifier ordering holds within each candidate list. New commits and records that regain visibility during predicate evaluation enter a later scan. Broad dynamic patterns therefore have both a cost and a concurrency consequence: they materialize more candidates, make more provider calls, and lengthen the interval between selection and return. Exact fields such as project and record type reduce that work before text evaluation.

6 Evidence and development limits

The report’s implementation claims come from the cited revision’s source and documentation. On September 18, 2026, `go test -count=1 ./...` passed under Go 1.25.5 on Linux ARM64. The packages containing tests were `core`, `cli`, `mcp`, and `netapi`. Table 3 identifies tests relevant to the report’s semantics. The tests use controlled objects and, for model matching, stub providers or local HTTP test servers.

Throughput, latency under sustained contention, model retrieval quality, and improvement in agent task completion require separate measurements. The model tests validate request handling, matching control flow, and error handling with controlled answers. Retrieval accuracy on a task corpus remains an empirical question.

Current resource use depends on one SQLite service and the size of each candidate set. Notification state belongs to that service instance. Applications requiring shared state across service failures need a deployment and recovery design beyond the per-record persistence described here.

Behavior exercised	Existing test examples
Pattern and cursor selection	<code>TestPatternMatchingSpecExamples</code> , <code>TestObjectArrayMatchViaSQLPath</code> , <code>TestSinceFiltering</code> , and <code>TestOrdering</code> .
Competing claims	<code>TestNotifyCompetingIn</code> and <code>TestExplicitDeleteReissue</code> .
Visibility and expiration	<code>TestExplicitDeleteTimeout</code> , <code>TestTTLPreventsReappearance</code> , and <code>TestNotifyReappearanceWakesWaiter</code> .
Access rules	<code>TestAccessEmptyInDeniesAll</code> , <code>TestOutWithRegisteredAccess</code> , and <code>TestServerKeyAuth</code> .
Dynamic selection	<code>TestInEmbeddingsConsumesMatchingObjectOnly</code> , <code>TestRdQuestionSkipsEarlierNonMatch</code> , and <code>TestOpenAILLMJudgeRejectsUnexpectedAnswer</code> .

Table 3: Selected tests at the report’s source revision. Passing these tests supports the exercised cases. The concurrency qualifications in the text also rely on source analysis.

Repeated tasks, completion records, and external effects need application-level recovery rules under either deletion mode.

The repository records numeric and string comparison predicates, visibility timeout changes, multi-result reads, and server-sent delivery as possible extensions [2]. Its Quamina comparison extension notes describe future integration work. The implemented exact matcher accepts scalar equality and alternatives, together with the text predicates specified above. Adding comparison operators would require matching semantics in both database selection and notifications. Adding claim renewal would also change the failure and retry timing of the processing scenarios.

References

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