ALLEN+: Temporal Reasoning with Imperfect Information

An ontology using **composition-in-context** to reduce uncertainty in Allen's Interval Algebra.

Vagan Terziyan & Olena Kaikova, University of Jyväskylä, Finland

Temporal Data is Inherently Imperfect

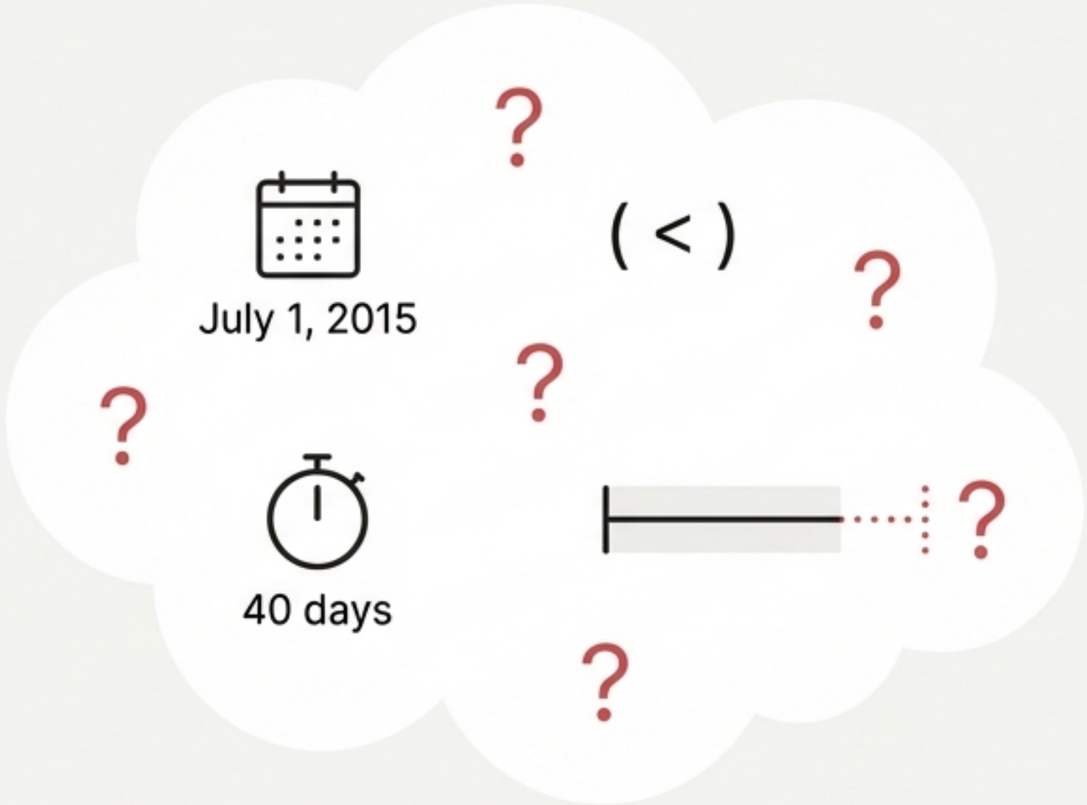
Effective automated reasoning requires tools that can handle the reality of temporal data: **it is rarely complete, precise, or consistent.**

Heterogeneous: Data comes in mixed formats—qualitative (“before,” “during”) and quantitative (“July 1, 2015,” “duration of 40 days”).

Incomplete: Timestamps may be missing start points, end points, or both.

Uncertain: Information can be vague (“sometime in August”) or relative (“longer than activity B”).

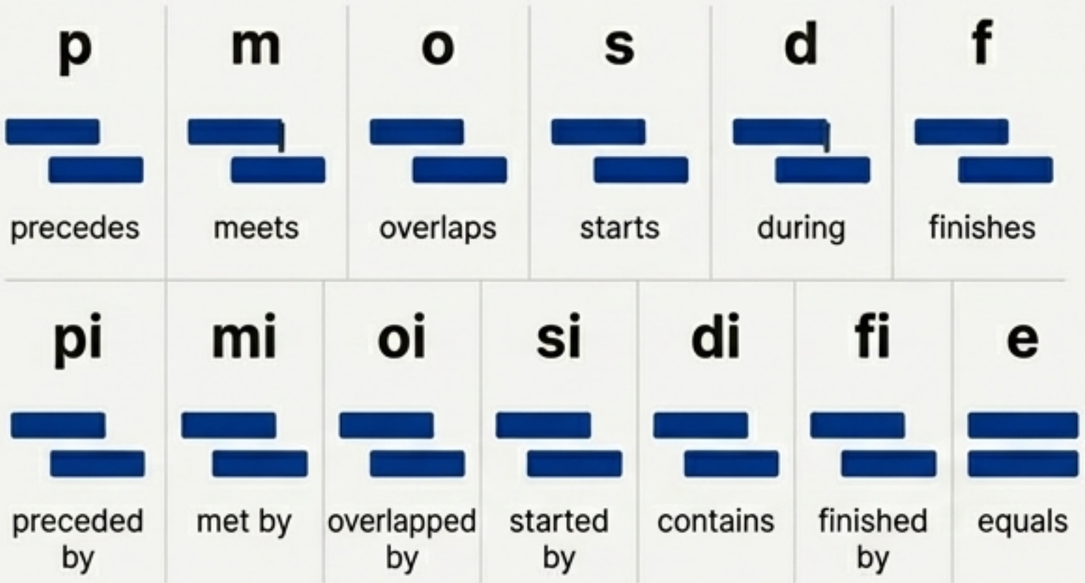
Fragmentary: Relationships between events must often be pieced together from disparate, indirect clues.



Allen's Interval Algebra: A Powerful but Flawed Standard

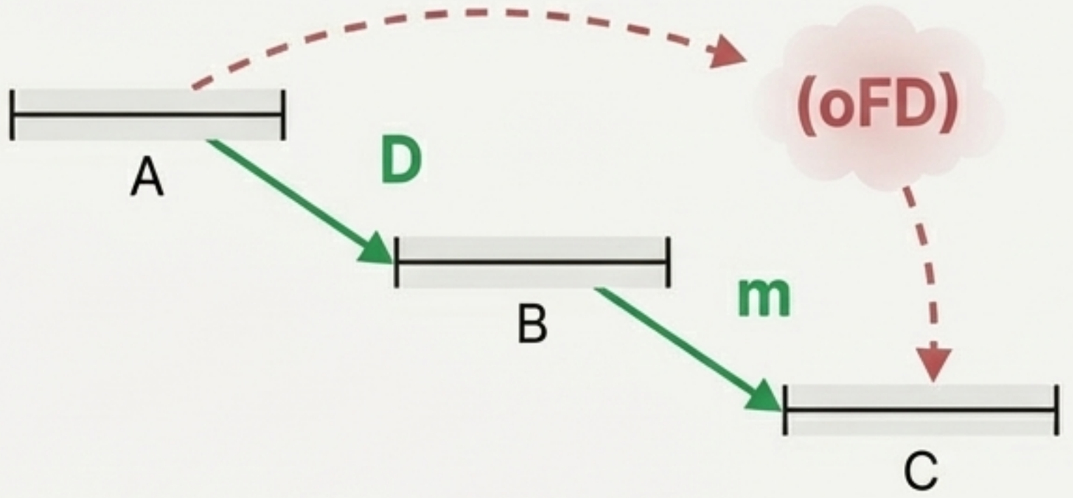
The Foundation

Allen's Algebra provides a foundational calculus for temporal reasoning, defining the 13 basic relations that can exist between two time intervals.



The Critical Flaw

The problem arises during inference. The composition of relations—determining the relationship between A and C from A-B and B-C—often results in an explosion of uncertainty.



The Composition Table Reveals an Uncertainty Epidemic

.	(p)	(m)	(o)	(D)	(s)	(e)	(S)	(d)	(f)	(M)	(P)
(p)	(p)	(p)	(p)	(p)	(p)	(e)	(p)	(pmosd)	(pmosd)	(pmosd)	***FULL***
(m)	(p)	(p)	(p)	(p)	(m)	(m)	(m)	(osd)	(osd)	(Fef)	(DSOMP)
(o)	(p)	(pmo)	(pmo)	(pmoFD)	(o)	(o)	(oFD)	(osd)	(osd)	***LONG***	(DSOMP)
(F)	(p)	(m)	(F)	(D)	(o)	(F)	(D)	(osd)	(Fef)	(DSO)	(DSOMP)
(D)	(pmoFD)	(oFD)	(D)	(D)	(oFD)	(D)	(D)	***LONG***	(DSO)	(DSO)	(DSOMP)
(s)	(p)	(pmo)	(pmo)	(pmoFD)	(s)	(s)	(seS)	(d)	(d)	(dfO)	(P)
(e)	(p)	(e)	(F)	(D)	(e)	(s)	(s)	(d)	(f)	(O)	(P)
(S)	(pmoFD)	(oFD)	(D)	(D)	(seS)	(s)	(s)	(dfO)	(O)	(M)	(P)
(d)	(p)	(pmosd)	(pmosd)	***FULL***	(d)	(d)	(dfOMP)	(u)	(d)	(dfOMP)	(P)
(f)	(p)	(osd)	(Fef)	(DSOMP)	(d)	(f)	(OMP)	(d)	(f)	(OMP)	(P)
(O)	(pmoFD)	***LONG***	(DSO)	(DSOMP)	(dfO)	(O)	(OMP)	(dfO)	(O)	(OMP)	(P)
(M)	(smoFD)	(seS)	(M)	(P)	(dfO)	(M)	(P)	(dfO)	(M)	(P)	(P)
(P)	***FULL***	(dfOMP)	(P)	(P)	(dfOMP)	(P)	(P)	(dfOMP)	(P)	(P)	(P)

A few compositions yield a single, certain outcome.

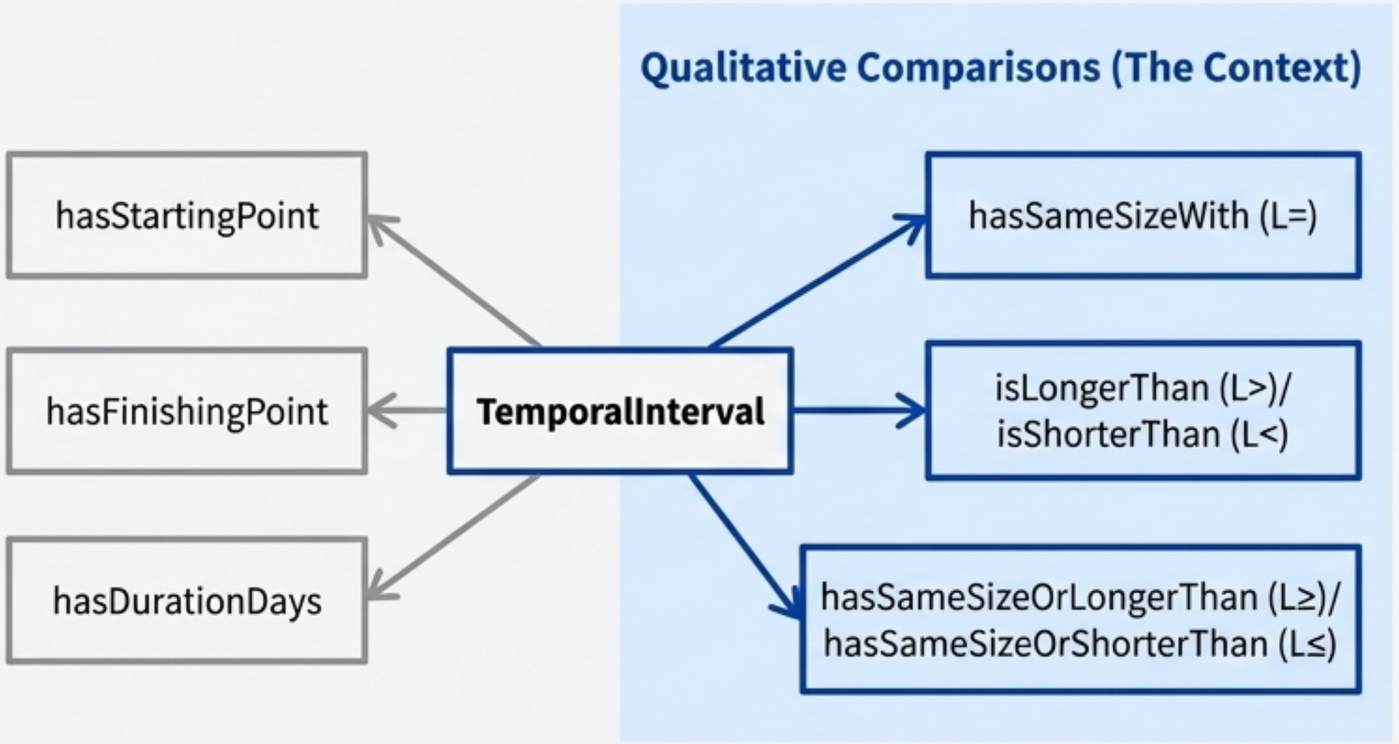
However, 72 of 169 outcomes are uncertain, containing multiple possibilities.

Chaining compositions accumulates this uncertainty, quickly rendering long-range inference useless. This is a fundamental barrier to tractability in complex scenarios.

The Solution: Building a Richer Context with ALLEN+

ALLEN+ is an OWL ontology enhanced with SWRL rules. It moves beyond basic relations by creating a comprehensive context from all available data.

- **Temporal Points & Intervals:** Standard classes for time points (`TemporalPoint`) and intervals (`TemporalInterval`).
- **Quantitative Properties:** Explicit data like `hasYear`, `hasMonth`, `hasDay`, and a calculated `hasDurationDays`.
- **Qualitative Comparisons (The Context):** A set of relations comparing interval sizes, which we will use to resolve ambiguity.



The Breakthrough: Composition-in-Context

Key idea: We refine the composition of Allen's relations by using size comparisons as a deciding context.

Standard Composition (The Fog)

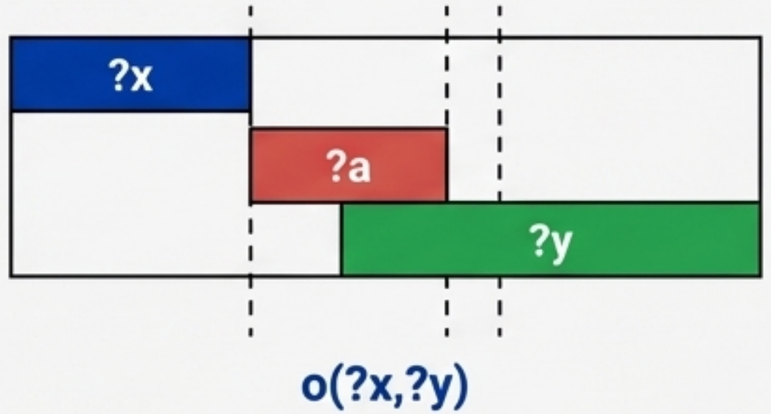
$$D \cdot m = (oFD)$$

Without context, if Interval ?x `contains` (?a) and ?a `meets` (?y), the relationship between ?x and ?y is uncertain. It could be `overlaps` (o), `finished-by` (F), or `contains` (D).

From Fog to Focus

Composition-in-Context (The Focus)

$$(D \cdot m)|_{L\leq} = o$$



But if we also know that ?x is shorter than or the same size as ?y (`L≤`), we can eliminate the possibilities where ?x must be longer (`F` and `D`). The only remaining option is `overlaps` (o).

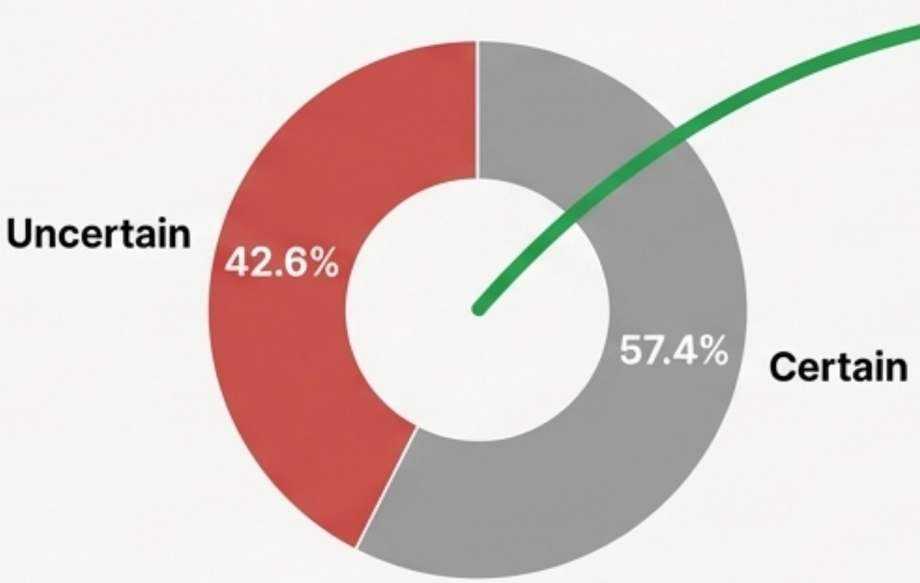
```
IF isCovering(?x, ?y) AND isMeetingWith(?y, ?z) AND hasSameSizeOrShorterThan(?x, ?z) THEN isOverlappingWith(?x, ?z)
```

A Quantifiable Leap in Certainty

20% Progress

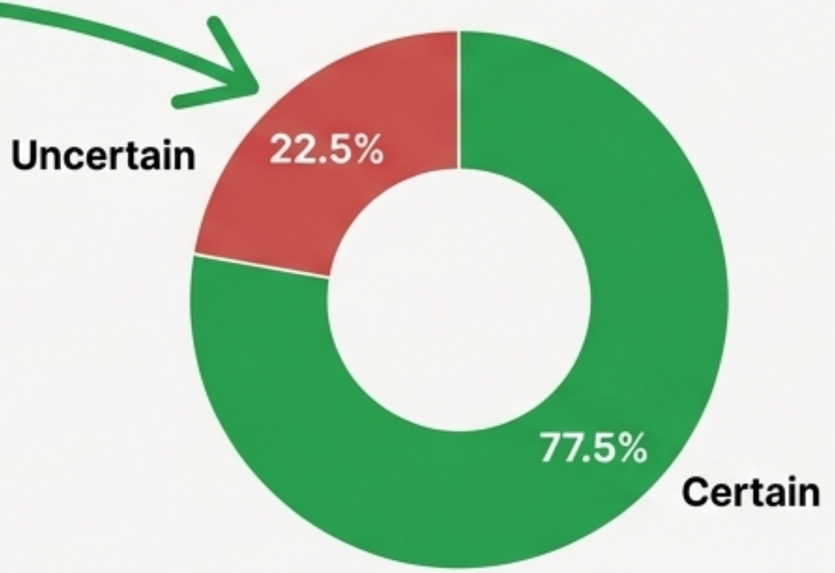
Adding context makes a 20% improvement in the overall quality of composition.

Standard Allen's Composition



72 of 169 outcomes are uncertain.

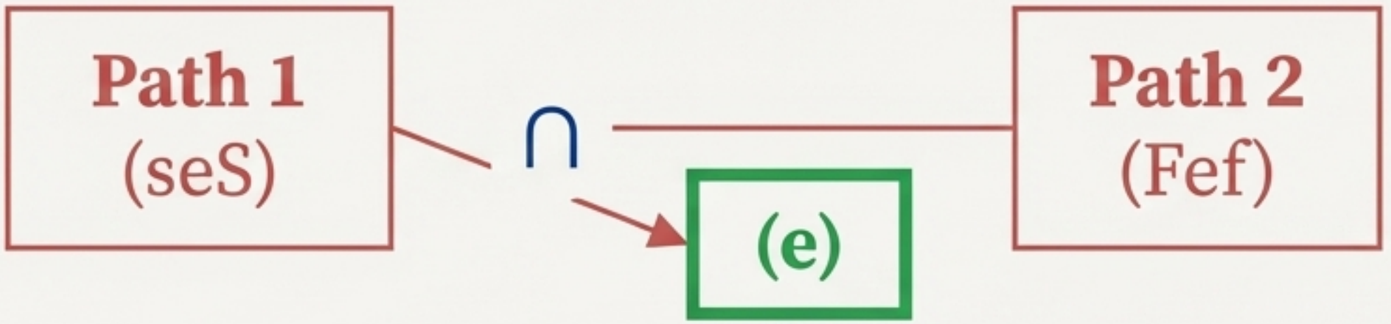
ALLEN+ Composition-in-Context



34 uncertain cases resolved,
reducing total uncertainty by half.

Advanced Technique: Intersecting Uncertainties to Find Truth

When multiple reasoning paths exist between two intervals, each might produce a different *uncertain* result. The intersection of these results can reveal a single, *certain* relation.



Example from the paper:
Path 1 yields the relation set (seS).
Path 2 yields the relation set (Fef).
The intersection (seS) ∩ (Fef) results in (e), because equals is the only relation common to both sets.

A highly simplified extract from the intersection table

ALLEN+ includes SWRL rules to automatically perform these intersections on the 12 most common uncertain results from compositions.

Case Study: Solving a Complex Planning Puzzle

We are given a plan with 5 activities (TI-1 to TI-5) and a messy set of incomplete and uncertain temporal constraints.

Initial Data

1. TI-1 starts July 1, 2015.
2. TI-2 has a duration of 214 days and finishes the same day as TI-1.
3. TI-3 has a duration of 40 days, finishes Aug 31, 2015, and isStarting TI-4.
4. TI-4 isStartedBy TI-5.
5. TI-5 is isShorterThan TI-3 and starts the same day as TI-3.

The Goal

What is the precise relationship between Activity 1 (TI-1) and Activity 5 (TI-5)? Can TI-5 occur *during* TI-1?

There is no direct chain of Allen's relations between TI-1 and TI-5. Standard composition fails.

Inference Step 1: From Fragments to Facts

The SWRL rule-set automatically enriches the initial data.

`TemporalPoint` TP-6 has date AND `isPointToPointEqual` to TP-2.

↓ **`Rule-A` (Point Equality)**

Inferred date for TP-2 is Aug 31, 2015.

Known start (TP-1) and inferred end (TP-2) of TI-1.

↓ **`Rule-B` (Duration Calculation)**

TI-1 has a duration of 62 days.

Known durations (TI-1: 62d, TI-3: 40d) AND relation (`TI-5 isShorterThan TI-3`).

↓ **`Rule-D` family (Duration Comparison)**

A complete map of size relations is created: `TI-1 isLongerThan TI-3', `TI-3 isLongerThan TI-5', etc.

We have now established a rich **context** of size comparisons, which was not present in the initial data.

Inference Step 2: Applying Context to Forge the Chain

Composition-in-context rules create the missing links between TI-1 and TI-5.

Linking TI-1 to TI-3

- **Known:** TI-1 isFinishing TI-2 and TI-2 isFinishedBy TI-3

✗ **Standard Comp.: f · F = (Fef)** (Uncertain!)

Context: TI-1 isLongerThan TI-3

↓ **Rule:** $(f \cdot F)|_{L>} = F$

✓ **Result:** TI-1 isFinishedBy TI-3 (Certain!)

Linking TI-3 to TI-5

- **Known:** TI-3 isStarting TI-4 and TI-4 isStartedBy TI-5

✗ **Standard Comp.: s · S = (seS)** (Uncertain!)

Context: TI-3 isLongerThan TI-5

↓ **Rule:** $(s \cdot S)|_{L>} = S$

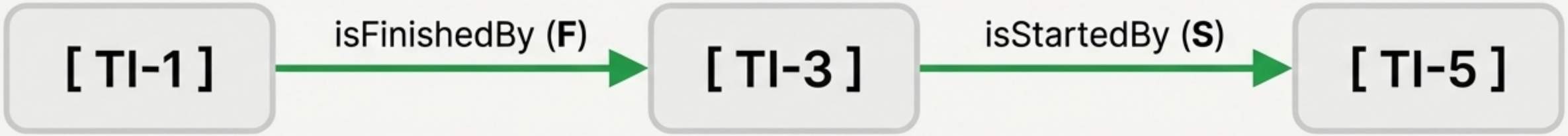
✓ **Result:** TI-3 isStartedBy TI-5 (Certain!)

Key Result: Two previously uncertain relationships have been resolved into concrete facts, creating a solid chain: TI-1 -> TI-3 -> TI-5.

Inference Step 3: The Final Composition

What is the relationship between TI-1 and TI-5?

The Chain



The Calculation

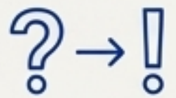
We now compose the two certain relations we just inferred: **isFinishedBy (F) · isStartedBy (S)**
→ From the standard composition table, we know: **F · S = D**

TI-1 isCovering TI-5

Yes, Activity 5 can be performed *during* Activity 1. The ALLEN+ ontology successfully navigated imperfect data to provide a definitive answer where standard methods would fail.

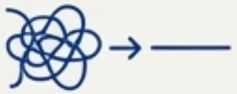
The Core Contribution: Inferring Context to Conquer Uncertainty

The unique power of ALLEN+ is not just in modeling time, but in its ability to synthesize a reliable context from imperfect, heterogeneous temporal data.



Reduces Ambiguity: Turns uncertain composition results into certain facts, making reasoning more reliable.

Leverages All Data: Seamlessly combines qualitative relations, quantitative timestamps, and duration information.



Improves Tractability: Enables solutions for complex reasoning chains that are NP-hard with standard Allen's Algebra.

Practical & Accessible: Implemented as a lightweight OWL ontology with SWRL rules, usable in standard environments like Protégé.

ALLEN+ transforms the challenge of imperfect data from a barrier into an asset, using fragments of information to bring the larger temporal picture into sharp focus.

The ontology is publicly available at: http://www.cs.jyu.fi/ai/vagan/ontologies/2014/temporal.owl