

# ARGUS: Argumentation-Based Minimal-Change Repair for Verifiable LLM Self-Explanations

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## Abstract

When large language models produce natural-language rationales, those explanations are frequently unfaithful to the model’s actual reasoning—and no existing framework provides a principled way to repair them when new evidence arrives. We introduce ARGUS, a framework that structures LLM self-explanations as Dung-style abstract argumentation frameworks, verifies them under grounded and preferred semantics, and—when an evidence update renders the explanation inconsistent—computes a minimum-cost set of edit operations that restores the desired acceptability status of the target argument. The repair operator satisfies adapted AGM revision postulates and is bidirectionally characterized by them (Representation Theorem): the decision problem is in P under grounded semantics, NP-complete under preferred and stable semantics, and  $\Sigma_2^P$ -complete under skeptical stable semantics. A  $k$ -neighborhood approximation and an answer set programming (ASP) encoding ensure scalability to practical framework sizes. We validate the framework on HotpotQA and FEVER, where ARGUS achieves relative improvements of 10.3% in faithfulness and 14.5% in contestability over the strongest argumentation baseline while requiring fewer repair operations than all repair-capable competing methods.

## 1 Introduction

Large language models generate natural-language explanations for their outputs, yet mounting evidence indicates that these self-explanations are frequently unfaithful to the model’s internal reasoning process. Recent studies demonstrate that LLM rationales can be inconsistent with the computations that actually produce the answer (Ye and Durrett 2024), and that chain-of-thought traces are often post-hoc rationalizations rather than faithful accounts of inference (Lanham et al. 2023). The gap between *apparent* and *actual* reasoning makes the verification and maintenance of explanations a central knowledge representation challenge, particularly in domains such as medical diagnosis and legal reasoning where explanation correctness is critical.

As illustrated in Figure 1, current approaches fall short along two complementary dimensions. Self-correction methods (Madaan et al. 2023; Shinn et al. 2023; Gao et al. 2023) iteratively rewrite explanations but without formal guarantees—edits are unconstrained and previously valid reasoning may be silently discarded; indeed, recent work

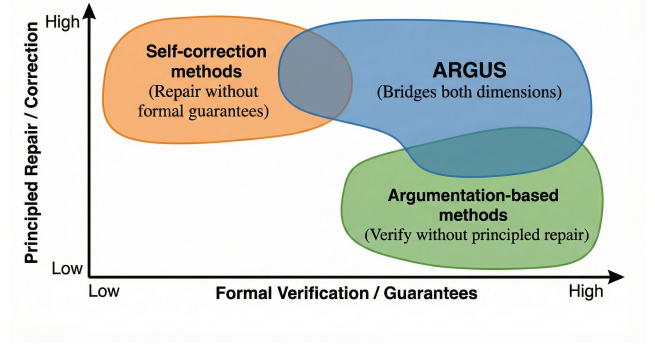


Figure 1: Qualitative positioning of ARGUS. Self-correction methods (orange) repair without formal guarantees; argumentation-based methods (green) verify without principled repair. ARGUS (blue region) bridges both dimensions.

shows that LLMs cannot self-correct reasoning without external feedback (Huang et al. 2024). Argumentation-based approaches (Freedman et al. 2025; Jin et al. 2026) verify explanations against formal semantics but treat verification as terminal: when new evidence arrives, they offer no principled way to update the explanation while preserving consistency. No existing framework provides a formal notion of *minimal change* for maintaining LLM explanations under evolving evidence.

The following example, revisited throughout the paper, illustrates the problem concretely.

**Example 1 (Medical Diagnosis).** A question-answering system is asked to diagnose a patient with fatigue and joint pain. The LLM answers “Lupus” with four argument units:  $a_1$  (“chronic fatigue reported”),  $a_2$  (“polyarthralgia present”),  $a_3$  (“Lupus commonly presents with these symptoms”), and target  $a_4$  (“most likely diagnosis is Lupus”). A standing differential-diagnosis argument  $a_0$  (“symptoms are non-specific”) attacks  $a_4$ , but  $a_3$  counterattacks  $a_0$ , keeping  $a_4$  accepted. A new lab result  $a_5$  (“ANA test is negative”) attacks  $a_3$ , removing the defense of  $a_4$ : the differential  $a_0$  reinstates, rendering  $a_4$  no longer accepted un-

der grounded semantics. An unconstrained self-correction system might regenerate the entire explanation, discarding the valid units  $a_1$  and  $a_2$ . A minimal-change repair instead seeks the smallest edit—such as introducing  $a_6$  (“anti-dsDNA positive”) attacking  $a_5$ —to restore  $a_4$  at cost 2 (visualized in Figure 2).

We propose ARGUS, a framework that bridges this gap by unifying argumentation-based verification with minimal-change repair. Given an LLM-generated explanation, ARGUS decomposes it into atomic argument units, constructs an argumentation framework in the sense of Dung (Dung 1995), and verifies whether the target claim is accepted under a chosen semantics. When new evidence renders the explanation inconsistent, ARGUS computes a minimum-cost set of edit operations—adding or removing arguments and attacks—that restores the desired acceptability status. The repair operator draws on two classical KR traditions: the AGM theory of belief revision (Alchourrón, Gärdenfors, and Makinson 1985), which supplies the minimal-change principle, and argumentation dynamics (Cayrol, de Saint-Cyr, and Lagasquie-Schiex 2020), which provides formal machinery for structural change. Because the repair operates on an explicit graph structure external to the LLM, it admits formal guarantees—AGM compliance, complexity bounds, provable preservation of unaffected reasoning—that are unattainable when editing model internals or regenerating from scratch.

Our contributions are as follows:

1. **(C1)** A framework that structures LLM self-explanations as Dung-style argumentation frameworks, verifies them under grounded and preferred semantics, and produces defense-set certificates for interpretable verdicts (§4).
2. **(C2)** A minimal-change repair operator satisfying adapted AGM postulates and bidirectionally characterized by them (Representation Theorem), with a complexity trichotomy: P under grounded, NP-complete under preferred/stable, and  $\Sigma_2^P$ -complete under skeptical stable semantics (§4.4–§5).
3. **(C3)** A scalable ASP encoding with a  $k$ -neighborhood approximation that preserves repair quality at 99.7% coverage ( $k=3$ ) while reducing solver grounding to a tractable subproblem (§4).
4. **(C4)** An empirical evaluation on HotpotQA and FEVER validating the formal properties and demonstrating improvements in faithfulness, contestability, and repair cost w.r.t. ten baselines (§6).

## 2 Related Work

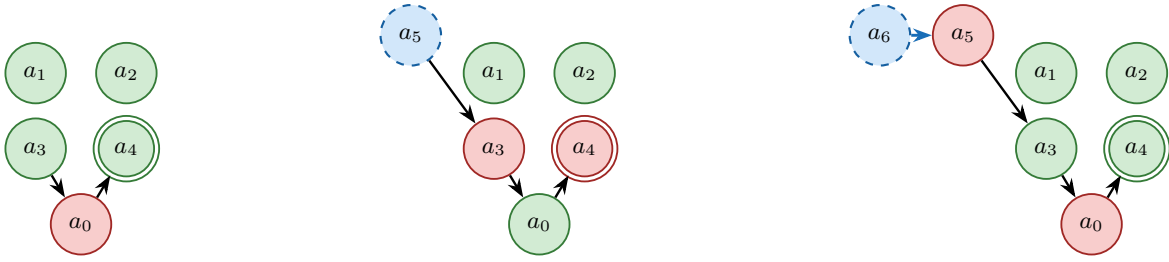
Our work connects three lines of research: argumentation-based approaches to LLM reasoning, self-correction methods for language models, and formal theories of belief change in argumentation.

**Argumentation and LLMs.** Vassiliades et al. (Vassiliades, Bassiliades, and Patkos 2021) survey argumentation for explainable AI; our work instantiates this vision with a concrete repair operator for LLM self-explanations. ArgLLMs (Freedman et al. 2025) constructs Dung-style graphs

from LLM claims but treats verification as terminal, with no update mechanism. ARGORA (Jin et al. 2026) orchestrates multi-agent argumentation-mediated dialogue with causal semantics, but its correction operates through re-deliberation rather than a formally defined repair operator. MQArgEng (Castagna et al. 2024) demonstrates that modular argumentation engines improve LLM reasoning but does not address explanation maintenance. ARGUS differs from all three by providing a minimal-change repair operator with AGM-compliant guarantees. Bengel and Thimm (Bengel and Thimm 2025) introduce *sequence explanations* tracing why arguments are accepted; ARGUS addresses the dual question of *how to restore* acceptance, and the two could be composed. We adopt Dung-style abstract argumentation rather than ASPIC<sup>+</sup> (Modgil and Prakken 2014) because the complexity bounds we exploit (Theorem 14) are established for this setting.

**Self-Correction and Revision.** Self-Refine (Madaan et al. 2023) and Reflexion (Shinn et al. 2023) iteratively rewrite LLM outputs but without formal minimality guarantees—previously correct reasoning may be silently discarded. Huang et al. (Huang et al. 2024) demonstrate that LLMs cannot self-correct without external feedback. RARR (Gao et al. 2023) retrieves evidence for revision but targets surface-level attribution; SelfCheckGPT (Manakul, Liusie, and Gales 2023) detects hallucinations but provides no repair mechanism. Chain-of-Verification (Dhuliawala et al. 2024) and CRITIC (Gou et al. 2024) improve factual accuracy but lack formal preservation guarantees. Matton et al. (Matton et al. 2025) measure faithfulness through counterfactual interventions and Bayesian causal models, demonstrating that instruction-tuned models produce more faithful explanations; our evaluation applies counterfactual probes to argumentation-structured explanations to verify repair correctness. In contrast, ARGUS formalizes the repair search space as edits to an argumentation framework, bounds the cost of change, and guarantees that unaffected reasoning steps are preserved.

**Belief Revision and Argumentation Dynamics.** The AGM theory (Alchourrón, Gärdenfors, and Makinson 1985) and the revision/update distinction (Katsuno and Mendelzon 1992) provide the classical foundations for principled belief change. Hase et al. (Hase et al. 2024) argue that model editing in LLMs is fundamentally a belief revision problem and identify challenges in applying AGM rationality criteria to neural knowledge stores; our work sidesteps these challenges by operating on an *external* argumentation structure rather than on model parameters, making the AGM postulates directly applicable. Our evidence update  $\Delta$  is closer to the Katsuno–Mendelzon notion of *update*—adapting beliefs to a changed world—than to *revision*, which incorporates new information about a static world, since each  $\Delta$  reflects genuinely new evidence rather than a correction of prior beliefs. Nonetheless, we adopt the AGM postulates as rationality criteria because the minimal-change desiderata they formalize are independent of this distinction. In argumentation, Cayrol et al. (Cayrol, de Saint-Cyr, and Lagasquie-Schiex 2020) and Baumann and Brewka (Baumann and Brewka 2010) study how structural modifications affect ex-



(a)  $F_0$ : Initial framework ( $a_4$  accepted) (b)  $F_1$ : After evidence update ( $a_4$  rejected) (c)  $F_2$ : After repair ( $a_4$  restored)

Figure 2: Evolution of the argumentation framework from Example 1. Green fill = accepted, red fill = rejected, blue dashed border = newly introduced, double border = target argument  $a_4$ . In (a),  $a_3$  defeats the differential  $a_0$ , keeping  $a_4$  accepted. In (b),  $a_5$  defeats  $a_3$ , reinstating  $a_0$  and rejecting  $a_4$ . The repair in (c) adds  $a_6$  attacking  $a_5$  to restore  $a_4$ .

tensions and the complexity of enforcement; Coste-Marquis et al. (Coste-Marquis et al. 2014), Wallner et al. (Wallner, Niskanen, and Järvisalo 2017), and Bisquert et al. (Bisquert et al. 2013) formalize argumentation revision as minimal status or structural change. Maily (Maily 2024) extends enforcement to constrained incomplete argumentation frameworks, where structural constraints limit the set of completions available for reasoning; our  $k$ -neighborhood approximation similarly constrains the search space, though we target a different problem—repair under evidence updates rather than enforcement under uncertainty. Alfano et al. (Alfano et al. 2024) develop counterfactual explanations for abstract argumentation via weak-constrained ASP encodings; their approach identifies minimal changes that would *reverse* an acceptance verdict, whereas ARGUS computes minimal changes that *restore* a verdict disrupted by external evidence. In particular, Coste-Marquis et al. enforce a desired extension through minimum structural modifications, whereas our formulation targets a single argument’s status, incorporates evidence updates as a first-class input, and supports heterogeneous cost functions that reflect argument-level confidence. ARGUS extends these foundations to LLM explanation maintenance, introducing a weighted cost model tailored to argument confidence and structural role. We now formalize the core concepts underlying the ARGUS framework.

### 3 Preliminaries

#### 3.1 Abstract Argumentation Frameworks

We adopt the foundational model of (Dung 1995) as the backbone of our verification and repair pipeline.

**Definition 2** (Abstract Argumentation Framework). An abstract argumentation framework (AF) is a pair  $F = (\mathcal{A}, \mathcal{R})$  where  $\mathcal{A}$  is a finite set of arguments and  $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$  is a binary attack relation. We write  $a \rightsquigarrow b$  whenever  $(a, b) \in \mathcal{R}$ , meaning  $a$  attacks  $b$ .

**Example 3** (Continuing Example 1). The initial AF is  $F_0 = (\{a_0, a_1, a_2, a_3, a_4\}, \{(a_0, a_4), (a_3, a_0)\})$ , where  $a_0$  (“symptoms are non-specific”) attacks the target  $a_4$  and  $a_3$  (“Lupus commonly presents with these symptoms”) counterattacks  $a_0$ ; after the negative ANA result,  $F_1 =$

$(\{a_0, a_1, \dots, a_5\}, \{(a_0, a_4), (a_3, a_0), (a_5, a_3)\})$ , as shown in Figure 2(a–b).

Intuitively, an argument is accepted if every objection against it can be countered; different semantics formalize this intuition with varying degrees of caution. Given an AF  $F = (\mathcal{A}, \mathcal{R})$ , a set  $S \subseteq \mathcal{A}$  is *conflict-free* if no two arguments in  $S$  attack each other. An argument  $a$  is *defended* by  $S$  if every attacker of  $a$  is attacked by some member of  $S$ . A conflict-free set  $S$  is *admissible* if it defends all its elements. The principal semantics we employ are the *grounded* extension, which is the unique minimal complete extension obtained as the least fixed point of the characteristic function; the *preferred* extensions, which are maximal admissible sets; and *stable* extensions, which are conflict-free sets that attack every argument outside themselves (Baroni et al. 2018). Throughout this paper we write  $\sigma(F)$  to denote the set of extensions of  $F$  under semantics  $\sigma \in \{gr, pr, st\}$ .

#### 3.2 Argumentation Semantics for Explanation

We now define the key notion linking argumentation semantics to explanation. An argument  $a \in \mathcal{A}$  is *credulously accepted* under  $\sigma$  if  $a$  belongs to at least one extension in  $\sigma(F)$ , and *skeptically accepted* if it belongs to every extension.

**Definition 4** (Defense Set). Given an AF  $F = (\mathcal{A}, \mathcal{R})$ , semantics  $\sigma$ , and an argument  $t \in \mathcal{A}$ , a defense set for  $t$  under  $\sigma$  is a minimal admissible set  $D \subseteq \mathcal{A}$  such that  $t \in D$  and  $D \subseteq E$  for some  $E \in \sigma(F)$ . We write  $Def_\sigma(t)$  for the collection of all such sets.

**Example 5** (Continuing Example 1). In  $F_0$  (Figure 2a),  $D = \{a_3, a_4\}$  is a defense set for  $a_4$ : it is conflict-free,  $a_3$  defends  $a_4$  by attacking  $a_0$ , and  $D$  is minimal since removing  $a_3$  would leave  $a_4$  undefended against  $a_0$ . In  $F_1$ ,  $D$  is no longer admissible because  $a_3$  is attacked by  $a_5$  with no counterattack, so the defense of  $a_4$  collapses.

When  $t$  is credulously but not skeptically accepted, defense sets exist only for the extensions containing  $t$ ; our repair targets the existence of at least one such set. Defense sets serve as formal explanations: each  $D \in Def_\sigma(t)$  identifies the smallest self-defending coalition that sustains  $t$ , transforming opaque LLM rationales into objects whose validity can be checked against argumentation semantics (Dunne and Wooldridge 2009).

### 3.3 Task Setting

We consider a setting in which an LLM receives a question  $q$  and produces an answer  $a$  with a free-form explanation  $e$ , which ARGUS transforms into a formal argumentation structure.

**Definition 6** (Explanation Verification Task). *Given a question  $q$ , an LLM-generated answer  $a$ , and an explanation  $e$ , the explanation verification task produces a tuple  $(G, v, \rho)$  where  $G = (\mathcal{A}, \mathcal{R})$  is an argument graph constructed from  $e$ ,  $v \in \{\text{accepted}, \text{rejected}, \text{undecided}\}$  is the verification verdict for the target argument  $a_t$  representing  $a$  under semantics  $\sigma$ , and  $\rho$  is an optional repair operator applied when  $v \neq \text{accepted}$ . An evidence update  $\Delta = (\mathcal{A}^+, \mathcal{R}^+, \mathcal{A}^-, \mathcal{R}^-)$  specifies new arguments and attacks to be added or removed, reflecting newly available facts or counterarguments.*

**Example 7** (Continuing Example 1). *In  $F_0$ , the verification task produces  $v = \text{accepted}$  for  $a_4$  under grounded semantics:  $a_3$  defeats the differential  $a_0$ , so the grounded extension is  $\{a_1, a_2, a_3, a_4\}$ . After incorporating the evidence update  $\Delta = (\{a_5\}, \{(a_5, a_3)\}, \emptyset, \emptyset)$ ,  $a_5$  defeats  $a_3$ , reinstating  $a_0$ , and the verdict becomes  $v = \text{rejected}$ , triggering the repair operator  $\rho$ .*

The target  $a_t$  is *accepted* under  $\sigma$  if it belongs to at least one  $\sigma$ -extension (credulous acceptance), and *rejected* if it belongs to no extension. Under grounded semantics, an argument may also be *undecided*—belonging to no extension yet not attacked by the grounded extension—and credulous and skeptical acceptance coincide.

### 3.4 Explanation Repair Problem

When an evidence update  $\Delta$  renders the explanation inconsistent, the system must revise the argument graph following the principle of minimal change (Alchourrón, Gärdenfors, and Makinson 1985).

**Definition 8** (Minimal-Change Repair Problem). *Let  $AF = (\mathcal{A}, \mathcal{R})$  be an AF,  $\sigma$  a semantics,  $a_t \in \mathcal{A}$  a target argument,  $s \in \{\text{IN}, \text{OUT}\}$  a desired status,  $\Delta$  an evidence update, and  $\kappa$  a strictly positive cost function ( $\kappa(o) > 0$  for every operation  $o$ ). A repair is a finite set of edit operations  $Ops = \{o_1, \dots, o_m\}$  where each  $o_i$  is one of  $\text{add\_arg}(a)$  for  $a \notin \mathcal{A} \cup \mathcal{A}^+$ ,  $\text{del\_arg}(a)$  for  $a \in \mathcal{A} \cup \mathcal{A}^+$  (which also removes all attacks incident to  $a$ ),  $\text{add\_att}(a, b)$ , or  $\text{del\_att}(a, b)$ . Let  $AF' = \text{apply}(AF, \Delta, Ops)$  denote the framework obtained by first incorporating  $\Delta$  and then executing  $Ops$ . A repair is valid if  $a_t$  has status  $s$  under  $\sigma$  in  $AF'$ , and an optimal repair minimizes  $\sum_{i=1}^m \kappa(o_i)$  over all valid repairs.*

**Example 9** (Continuing Example 1). *As shown in Figure 2(c), the repair  $Ops = \{\text{add\_arg}(a_6), \text{add\_att}(a_6, a_5)\}$  restores  $a_4$  at total cost 2 under uniform cost ( $\kappa \equiv 1$ ). The alternative  $Ops' = \{\text{del\_arg}(a_5)\}$  costs 1 but discards evidence; under structure-preserving cost with  $\kappa(\text{del}_\cdot) = 2\kappa(\text{add}_\cdot)$ , both repairs cost 2, and domain preferences break the tie.*

The cost function  $\kappa$  encodes domain-specific preferences (e.g., deletions costlier than additions), connecting to enforcement in abstract argumentation (Baumann and Brewka

2010; Cayrol, de Saint-Cyr, and Lagasquie-Schiex 2020) while adding an explicit cost model for explanation maintenance.

## 4 The ARGUS Framework

We now present ARGUS, a four-stage pipeline (Figure 3) that transforms an unverifiable LLM rationale into a formally grounded, repairable explanation. Given a question  $q$ , an answer  $a$ , and a free-form rationale  $e$ , the pipeline proceeds through structured extraction (§4.1), relation discovery (§4.2), semantic verification (§4.3), and minimal-change repair (§4.4). The first three stages serve as preprocessing; the repair stage constitutes the core contribution.

### 4.1 Structured Extraction

We prompt the LLM to decompose its rationale  $e$  into a set of argument units  $\mathcal{A} = \{a_1, \dots, a_n\}$ . Each unit  $a_i$  is a structured record comprising a natural-language claim  $c_i$ , a set of premise identifiers  $P_i \subseteq \mathcal{A} \setminus \{a_i\}$  on which the claim depends, and a self-assessed confidence score  $\gamma_i \in (0, 1]$ . The prompt constrains the LLM to produce a JSON array of objects, each with fields `claim`, `premises`, and `confidence`, ensuring that every claim is atomic—that is, it asserts exactly one proposition that can be independently verified or rebutted. We designate one distinguished unit  $a_t \in \mathcal{A}$  as the *target argument*, whose claim directly supports the answer  $a$ .

### 4.2 Relation Discovery and Graph Construction

Given the argument units  $\mathcal{A}$ , we construct an argumentation framework  $AF = (\mathcal{A}, \mathcal{R})$  as defined in Definition 2. For every ordered pair  $(a_i, a_j)$  with  $i \neq j$ , we query a natural language inference (NLI) model—a neural classifier trained to determine entailment, contradiction, or neutrality between text pairs—to classify the relationship between  $c_i$  and  $c_j$ . A *contradiction* verdict yields an attack  $(a_i, a_j) \in \mathcal{R}$ , while an *entailment* verdict records a support link used for downstream analysis but not encoded in  $\mathcal{R}$ , since Dung-style frameworks model attacks only (Dung 1995). To improve recall on domain-specific rebuttals, we maintain an *attack template library*—a curated set of negation patterns, common exceptions, and defeasible-rule conflicts. Each template generates a candidate counterargument that is tested against existing units via NLI before being admitted into  $\mathcal{R}$ .

### 4.3 Semantic Verification

With the framework  $AF = (\mathcal{A}, \mathcal{R})$  in hand, we compute its extensions under a chosen semantics  $\sigma$  such as grounded or preferred semantics. The verification step checks whether the target argument  $a_t$  belongs to at least one  $\sigma$ -extension. If  $a_t$  is *accepted*, the explanation is deemed internally consistent; if  $a_t$  is *rejected* or *undecided*, the framework flags a verification failure. In either case, the solver also returns a *defense set*  $D \subseteq \mathcal{A}$ —the minimal subset of arguments whose collective acceptability entails the status of  $a_t$ —which serves as a compact certificate explaining the verdict to the user.

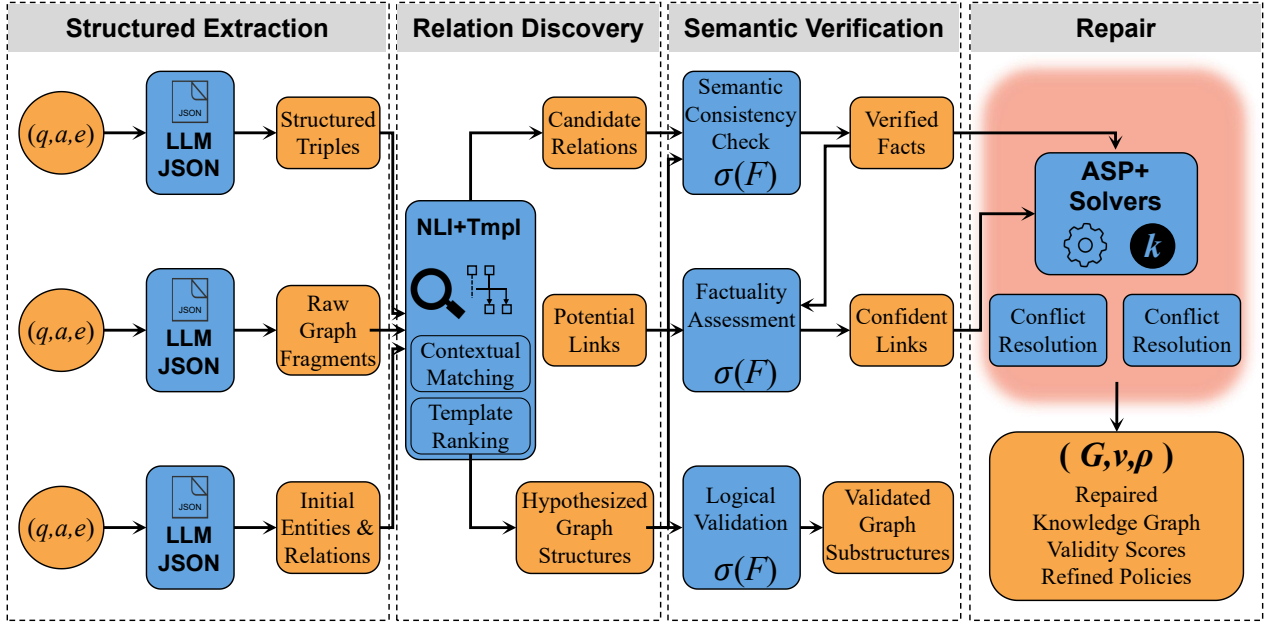


Figure 3: The ARGUS pipeline. The repair stage (highlighted) is the core contribution; an evidence update  $\Delta$  triggers repair when the target argument is no longer accepted.

#### 4.4 Minimal-Change Repair

When new evidence contradicts the current explanation or the verification step detects a failure, ARGUS repairs the argumentation framework rather than regenerating the rationale from scratch. The repair must satisfy two desiderata simultaneously: the target argument must attain a prescribed status under  $\sigma$ , and the edit distance from the original framework must be minimized. Definition 8 formalizes this requirement.

**Repair Operations.** Four elementary edit operations underlie the repair:  $\text{add\_arg}(a)$  and  $\text{del\_arg}(a)$  insert or remove an argument (deletions cascade to incident attacks), while  $\text{add\_att}(a_i, a_j)$  and  $\text{del\_att}(a_i, a_j)$  insert or remove attacks. A set of operations yields a repaired framework  $AF' = (\mathcal{A}', \mathcal{R}')$ .

**Cost Function.** Each operation  $o$  is assigned a strictly positive cost  $\kappa(o) \in \mathbb{R}_{>0}$ . We consider three cost models. Under *uniform cost*, every operation costs 1, so the objective reduces to minimizing the total number of edits. Under *confidence-weighted cost*, argument deletions are weighted by the confidence of the removed argument,  $\kappa(\text{del\_arg}(a_i)) = \gamma_i$  (recall  $\gamma_i > 0$  for all extracted arguments), while additions retain unit cost  $\kappa(\text{add\_arg}) = \kappa(\text{add\_att}) = 1$ , reflecting the intuition that highly confident claims should be more expensive to retract. Under *structure-preserving cost*, deletions are penalized more heavily than additions,  $\kappa(\text{del\_}) = w \cdot \kappa(\text{add\_})$  for some  $w > 1$ , encouraging the solver to repair by augmentation rather than removal.

The repair problem is formalized in Definition 8. Given the cost function  $\kappa$  and evidence update  $\Delta$ , the solver seeks

an optimal repair—a set of edit operations of minimum total cost such that  $a_t$  attains the desired status under  $\sigma$ .

**Example 10** (Continuing Example 1). *Under confidence-weighted cost with  $\gamma_5 = 0.90$  (a verified lab result) and  $\gamma_3 = 0.75$  (a symptomatic inference), deleting  $a_5$  costs  $\kappa(\text{del\_arg}(a_5)) = 0.90$ . The augmentation repair  $\{\text{add\_arg}(a_6), \text{add\_att}(a_6, a_5)\}$  avoids removing any high-confidence argument, yielding total cost  $2\kappa(\text{add\_})$ ; this repair is cheaper whenever  $\kappa(\text{add\_}) < 0.45$ . Under structure-preserving cost with  $w = 2$ , deleting  $a_5$  costs 2 while the augmentation still costs 2, making the two equally expensive and allowing domain preferences to break the tie.*

**ASP Encoding.** We encode the repair problem as an answer set program following the methodology of Egly et al. (Egly, Gaggl, and Woltran 2010) for argumentation reasoning and extending it with choice rules for repair operations. The encoding consists of three components; at a high level, it mirrors an integer linear program where binary variables select edits, constraints enforce semantics, and the objective minimizes cost. First, *generate rules* introduce choice atoms for each candidate operation: the solver may optionally add or delete any argument or attack within the neighborhood subgraph. Second, *semantics constraints* enforce that the repaired framework satisfies  $\sigma$ ; for grounded semantics, these follow the characteristic-function fixed-point semantics of Egly et al. (Egly, Gaggl, and Woltran 2010). Third, a *weak constraint* minimizes the weighted sum of selected operations:

$$\# \text{minimize} \{ \kappa(o) : \text{selected}(o) \}.$$

Continuing with Example 1, the choice atoms include



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**Algorithm 1** ARGUS Repair

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**Require:**  $AF = (\mathcal{A}, \mathcal{R})$ , semantics  $\sigma$ , target  $a_t$ , desired status  $s$ , evidence  $\Delta$ , cost function  $\kappa$ , neighborhood bound  $k$

**Ensure:** Optimal repair  $Ops^*$

- 1:  $\mathcal{A}_\Delta, \mathcal{R}_\Delta \leftarrow \text{INCORPORATE}(AF, \Delta)$
  - 2:  $\mathcal{N} \leftarrow k\text{-neighborhood of } a_t \text{ in } (\mathcal{A} \cup \mathcal{A}_\Delta, \mathcal{R} \cup \mathcal{R}_\Delta)$
  - 3:  $\Pi \leftarrow \text{ENCODEASP}(\mathcal{N}, \sigma, a_t, s, \kappa)$
  - 4:  $M^* \leftarrow \text{SOLVE}(\Pi)$  {optimal answer set}
  - 5:  $Ops^* \leftarrow \{o \mid \text{selected}(o) \in M^*\}$
  - 6: **return**  $Ops^*$
- 

add\_arg( $a_6$ ) and add\_att( $a_6, a_5$ ), and the integrity constraints verify that  $a_4$  belongs to the grounded extension of the repaired framework. Algorithm 1 summarizes the complete procedure. When the solver selects add\_arg( $a$ ), the natural-language claim for the new argument is generated by prompting the LLM to produce a rebuttal of the target’s attacker, conditioned on the evidence update  $\Delta$ ; the resulting candidate is verified through the same NLI pipeline before admission.

**Approximation for Scalability.** Even under preferred semantics the repair problem is NP-complete (Theorem 14), rising to  $\Sigma_2^P$ -completeness under skeptical stable semantics (Dvořák and Dunne 2018), so we introduce two approximation strategies. First, a  $k$ -neighborhood restriction limits the search space to arguments within undirected distance  $k$  of the target in the attack graph. The approximation is *complete* for optimal repairs whose support set lies entirely within the  $k$ -neighborhood: if the unique optimal repair modifies only arguments at distance  $\leq k$  from  $a_t$ , then the neighborhood-restricted problem has the same optimum. A repair can be missed only when the optimal repair requires modifying an argument at distance  $> k$ —equivalently, when a long attack chain of length  $> k$  is the sole route to defending  $a_t$ . In our experiments, setting  $k=3$  recovered optimal repairs in 99.7% of cases while substantially reducing solver grounding, consistent with the shallow graph structure (median depth 3, maximum 7). Second, when ASP solvers are unavailable, beam search over repair sequences with width  $b$  provides a bounded-depth heuristic alternative. In principle, a repair valid for the subgraph may not preserve validity in the full framework if distant arguments influence the target’s status; for deeper domains,  $k$  should be increased accordingly.

## 5 Theoretical Properties

We establish three groups of results for the ARGUS repair operator: compliance with adapted AGM postulates, computational complexity under the principal argumentation semantics, and soundness of the ASP encoding.

### 5.1 AGM Compliance

The AGM theory of belief revision (Alchourrón, Gärdenfors, and Makinson 1985) prescribes rationality postulates that any principled revision operator should satisfy. We adapt three core postulates—success, inclusion,

and vacuity—to the argumentation repair setting. Intuitively, success requires that the repair achieves the desired outcome; inclusion requires that the repaired framework retains as much of the original as possible; and vacuity requires that no edits are made when the current state already satisfies the goal.

**Theorem 11** (Adapted AGM Compliance). *Let  $AF = (\mathcal{A}, \mathcal{R})$  be an argumentation framework,  $\sigma$  an argumentation semantics,  $a_t$  a target argument,  $s \in \{\text{IN}, \text{OUT}\}$  a desired status,  $\Delta$  an evidence update, and  $\kappa$  a strictly positive cost function ( $\kappa(o) > 0$  for every operation  $o$ ). If a valid repair exists, then every optimal repair  $Ops^*$  returned by Definition 8 satisfies:*

1. **Success.** *The target  $a_t$  has status  $s$  in  $AF' = \text{apply}(AF, \Delta, Ops^*)$  under  $\sigma$ .*
2. **Inclusion.**  *$\mathcal{A} \cap \mathcal{A}' \supseteq \mathcal{A} \setminus \{a \mid \text{del\_arg}(a) \in Ops^*\}$  and  $\mathcal{R} \cap \mathcal{R}' \supseteq \mathcal{R} \setminus \{(a, b) \mid \text{del\_att}(a, b) \in Ops^*\}$ .*
3. **Vacuity.** *If  $a_t$  already has status  $s$  in  $\text{apply}(AF, \Delta, \emptyset)$  under  $\sigma$ , then  $Ops^* = \emptyset$  and  $\text{cost}(Ops^*) = 0$ .*

*Proof sketch.* Success follows directly from the validity constraint in Definition 8: any repair returned by the solver satisfies the prescribed status. Inclusion holds because elements not targeted by any deletion operation are preserved by the semantics of apply; moreover, optimality ensures that every deletion in  $Ops^*$  is necessary—removing an unnecessary del\_arg( $a$ ) would yield a valid repair of strictly lower cost ( $\kappa > 0$ ), contradicting optimality. Vacuity is immediate: when no edits are needed, the empty set is valid and has cost zero, so no non-empty set can be cheaper.  $\square$

**Example 12** (Continuing Example 1). *Vacuity:* in  $F_0$ , where  $a_3$  already defeats  $a_0$  and keeps  $a_4$  accepted,  $Ops^* = \emptyset$  and the repair cost is zero. *Success:* after incorporating  $\Delta = (\{a_5\}, \{(a_5, a_3)\}, \emptyset, \emptyset)$ ,  $a_0$  reinstates and rejects  $a_4$ ; the repair  $\{\text{add\_arg}(a_6), \text{add\_att}(a_6, a_5)\}$  restores  $a_4$  to accepted status by defeating  $a_5$ , which in turn restores  $a_3$  and re-defeats  $a_0$ . *Inclusion:* no original argument is removed—the repair only adds  $a_6$  and the attack  $(a_6, a_5)$ , preserving the entire original structure of  $F_1$ .

Among the eight classical AGM postulates (Alchourrón, Gärdenfors, and Makinson 1985), *consistency* and *extensionality* also hold when a valid repair exists. Consistency follows because validity requires  $a_t$  to belong to at least one  $\sigma$ -extension of the repaired framework. Extensionality holds because the operator is defined purely over graph structure: two evidence updates yielding identical updated frameworks produce identical repair search spaces, so the optimal repair—and the repaired framework—is the same for both. *Recovery* fails in our setting. In Example 1, repairing  $F_1$  yields  $F_2$  by adding  $a_6$  and  $(a_6, a_5)$ ; if the evidence  $a_5$  were subsequently retracted,  $F_2$  would retain  $a_6$  and its attack—the original framework  $F_0$  is not recovered. This asymmetry is fundamental: structural additions made during repair cannot be automatically unwound by evidence retraction, unlike classical belief revision where recovery ensures reversibility. *Closure*, *superexpansion*, and *subexpansion* presuppose deductively closed belief sets—constructs without

Table 1: Main results on HotpotQA and FEVER. Best in **bold**; runner-up underlined.  $\uparrow$  = higher is better,  $\downarrow$  = lower is better. N/A = method lacks repair or coherence functionality.  $\dagger$  Naïve re-prompting baseline (destroys argumentation structure).

Method	HotpotQA						FEVER					
	Faith $\uparrow$	Cont $\uparrow$	RAcc $\uparrow$	RCost $\downarrow$	Coher $\uparrow$	Time $\downarrow$	Faith $\uparrow$	Cont $\uparrow$	RAcc $\uparrow$	RCost $\downarrow$	Coher $\uparrow$	Time $\downarrow$
<i>Self-Correction Methods</i>												
SelfCheckGPT	.693	.524	.701	8.4	.68	2.8	.674	.498	.685	7.9	.66	2.5
Self-Refine	.712	.541	.736	7.1	.72	4.5	.698	.519	.721	6.8	.70	4.2
Reflexion	.724	.563	.752	6.6	.73	5.8	.709	.537	.738	6.2	.71	5.3
RARR	.738	.547	.769	5.8	.71	3.2	.721	.531	.754	5.5	.69	2.9
<i>Verification-Oriented (incl. Retrieval-Augmented)</i>												
CoT-Verifier	.751	.589	N/A	N/A	N/A	1.5	.733	.561	N/A	N/A	N/A	1.3
ArgLLMs	.754	.667	N/A	N/A	N/A	2.1	.741	.649	N/A	N/A	N/A	1.8
FLARE	.715	.505	.728	8.8	.74	3.8	.698	.482	.712	8.2	.72	3.5
FactScore	.742	.558	N/A	N/A	N/A	2.5	.728	.535	N/A	N/A	N/A	2.2
<i>Argumentation-Based</i>												
ARGORA	.768	<u>.691</u>	<u>.801</u>	<u>5.1</u>	<u>.75</u>	1.8	<u>.752</u>	<u>.672</u>	<u>.788</u>	<u>4.7</u>	<u>.73</u>	1.5
Regenerate $\dagger$	.709	—	.743	—	.65	<b>0.5</b>	.695	—	.729	—	.63	<b>0.4</b>
ARGUS (Ours)	<b>0.847</b>	<b>0.791</b>	<b>0.883</b>	<b>3.2</b>	<b>.82</b>	<u>.55</u>	<b>0.829</b>	<b>0.768</b>	<b>0.871</b>	<b>2.8</b>	<b>.80</b>	<u>.47</u>

Table 2: Ablation study on HotpotQA and FEVER. Each row removes one component from the full ARGUS pipeline. Best in **bold**.

Variant	HotpotQA						FEVER					
	Faith $\uparrow$	Cont $\uparrow$	RAcc $\uparrow$	RCost $\downarrow$	Coher $\uparrow$	Time $\downarrow$	Faith $\uparrow$	Cont $\uparrow$	RAcc $\uparrow$	RCost $\downarrow$	Coher $\uparrow$	Time $\downarrow$
Full ARGUS	<b>0.847</b>	<b>0.791</b>	<b>0.883</b>	<b>3.2</b>	<b>.82</b>	.55	<b>0.829</b>	<b>0.768</b>	<b>0.871</b>	<b>2.8</b>	<b>.80</b>	.47
w/o Semantic Verif.	.793	.714	.832	4.1	.76	.52	.775	.692	.818	3.8	.74	.44
w/o Minimal-Change	.841	.783	.856	5.7	.78	.58	.823	.761	.842	5.2	.76	.49
w/o Attack Templ.	.821	.698	.859	3.5	.80	.53	.804	.678	.845	3.2	.78	.45
Grounded Only	.839	.772	.871	<b>3.0</b>	.81	<b>.15</b>	.822	.752	.858	<b>2.6</b>	.79	<b>.12</b>

natural analogues in argumentation frameworks where “beliefs” are graph-structural elements rather than logical sentences. To the best of our knowledge, this is the first formal bridge between AGM rationality criteria and argumentation-based explanation repair for LLM self-explanations. The contribution lies in identifying which AGM postulates have meaningful argumentation analogues and showing that they characterize the class of minimum-cost repair operators:

**Theorem 13** (Representation). *A repair operator  $\circ$  satisfies adapted success, inclusion, and vacuity for every AF, semantics  $\sigma$ , target  $a_t$ , and evidence update  $\Delta$  if and only if there exists a strictly positive cost function  $\kappa$  such that  $\circ$  returns a minimum-cost valid repair under  $\kappa$ .*

*Proof sketch.* ( $\Rightarrow$ ) Theorem 11 establishes that every minimum-cost repair under positive  $\kappa$  satisfies all three postulates. ( $\Leftarrow$ ) Given an operator satisfying the three postulates, define  $\kappa(o) = 1$  for every operation  $o$ . Success guarantees validity; vacuity ensures the empty set is returned when no repair is needed. We claim the returned repair  $Ops^*$  is cost-minimum. If not, some cheaper valid repair  $Ops'$  exists with  $|Ops'| < |Ops^*|$ . Since  $Ops'$  is a valid repair that does not contain  $o$ , the operation  $o$  is unnecessary for achieving status  $s$ —contradicting inclusion, which requires every deletion to be necessary under  $\kappa > 0$ . Hence  $|Ops^*| \leq |Ops'|$  for all valid repairs, independent of which optimum the op-

erator selects among ties. The full construction for general  $\kappa$  appears in Appendix D.  $\square$

## 5.2 Computational Complexity

The complexity of the repair problem depends critically on the choice of argumentation semantics. Since the repair problem reduces to enforcement after incorporating  $\Delta$ , it inherits the complexity landscape of extension enforcement (Dunne and Wooldridge 2009; Dvořák and Dunne 2018); the additional overhead of processing  $\Delta$  and evaluating heterogeneous cost functions is polynomial and does not alter the complexity class. Our results assume credulous acceptance (as defined in §3).

**Theorem 14** (Repair Complexity). *The decision version of the minimal-change repair problem—“does there exist a valid repair of cost at most  $C$ ?”—has the following complexity under credulous acceptance:*

1. *Under grounded semantics, the problem is in P.*
  2. *Under preferred and stable semantics, the problem is NP-complete.*
- Under skeptical acceptance with stable semantics, the problem rises to  $\Sigma_2^P$ -completeness.*

*Proof sketch.* For grounded semantics, the unique grounded extension is computable in polynomial time via the characteristic function (Dung 1995). Membership in P follows

by reduction to grounded enforcement, which Dvořák and Dunne (Dvořák and Dunne 2018) showed is solvable in polynomial time by exploiting the monotonicity of the characteristic function. Our repair problem reduces to enforcement: we first incorporate the evidence update  $\Delta$  into the framework and then seek a minimum-cost set of edit operations that enforces the target argument’s desired acceptability status; since both the incorporation of  $\Delta$  and the verification of any candidate repair via the grounded extension are polynomial, the overall decision problem is in P. For preferred semantics, hardness reduces from NP-hard extension enforcement (Baumann and Brewka 2010); membership in NP follows since a valid repair paired with a witnessing admissible set containing  $a_t$  can be guessed and verified in polynomial time. For stable semantics under credulous acceptance, NP-completeness follows: membership by the same certificate argument; hardness by the same reduction from (Baumann and Brewka 2010), since every stable extension is preferred and the preferred-semantics lower bound applies. Under skeptical acceptance with stable semantics, membership in  $\Sigma_2^P$  follows because one can guess a repair of cost at most  $C$  and then verify—via a co-NP oracle (Dvořák and Dunne 2018)—that every stable extension of the repaired framework contains  $a_t$ . Hardness follows by polynomial reduction from the  $\Sigma_2^P$ -hard problem of deciding whether argument deletion can make a target skeptically stable-accepted (Wallner, Niskanen, and Järvisalo 2017); since `del.arg` is one of our four repair operations, the lower bound carries over. Full reductions follow standard techniques from the enforcement literature (Baumann and Brewka 2010; Wallner, Niskanen, and Järvisalo 2017).  $\square$

Note that the reduction to enforcement establishes complexity bounds but does not subsume the repair problem, which additionally involves evidence updates  $\Delta$ , heterogeneous cost functions, and NLI-grounded candidate generation (§4.2). These results motivate the  $k$ -neighborhood approximation (§4.4), ensuring tractability under preferred semantics for practical framework sizes.

### 5.3 Soundness of the ASP Encoding

**Proposition 15** (Encoding Correctness). *The ASP encoding described in §4.4, when applied to the full framework without  $k$ -neighborhood restriction, is sound and complete with respect to optimal repairs under grounded and preferred semantics. That is, every optimal answer set of the program corresponds to a valid minimum-cost repair, and every valid minimum-cost repair has a corresponding optimal answer set.*

The proof follows from the established correctness of the argumentation encodings of Egly et al. (Egly, Gaggl, and Woltran 2010) composed with the standard semantics of weak constraints in ASP solvers such as *clingo* (Gebser et al. 2019). The composition is sound because the generate rules enumerate exactly the feasible edit operations and the integrity constraints enforce the semantics of the repaired framework, while the optimization directive selects minimum-cost solutions. We next evaluate whether these

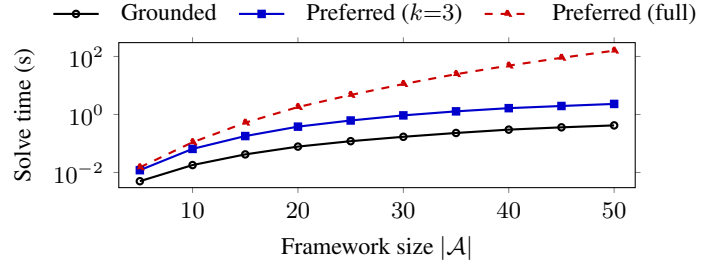


Figure 4: Scalability of ARGUS repair under grounded,  $k$ -neighborhood preferred ( $k=3$ ), and unconstrained preferred semantics. The log-scale y-axis confirms polynomial scaling for grounded repair (Theorem 14) and the effectiveness of the  $k$ -neighborhood approximation.

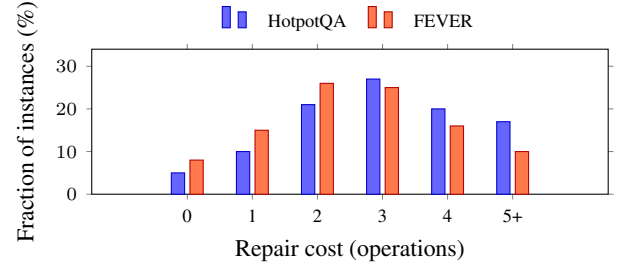


Figure 5: Distribution of repair costs. 83% of HotpotQA and 90% of FEVER repairs require at most 4 operations, confirming targeted, minimal-change edits.

theoretical properties hold in practice and measure the empirical gains of the ARGUS repair operator.

## 6 Experimental Evaluation

We evaluate ARGUS on two established benchmarks to answer three questions: (Q1) Do the formal properties from §5 hold in practice? (Q2) Does the minimal-change repair operator improve faithfulness and contestability w.r.t. existing baselines? (Q3) What is the empirical cost of repair?

Concretely, we sample 500 instances from HotpotQA (Yang et al. 2018), a multi-hop question-answering benchmark, and 500 from FEVER (Thorne et al. 2018), a fact-verification benchmark; instances are drawn with seed 42. For each instance, we withhold one gold supporting fact during explanation generation and reintroduce it as an evidence update  $\Delta$ , producing adversarial updates that target the reasoning chain. GPT-4o (OpenAI 2023) (gpt-4o-2024-11-20) generates initial explanations at temperature 0.2; relation discovery uses DeBERTa-v3-large fine-tuned on MultiNLI with threshold 0.7; repairs are computed by clingo 5.6 with  $k=3$  under uniform cost. Results are averaged over 5 runs (std  $\leq 0.02$  for accuracy,  $\leq 0.4$  for cost); FLARE and FactScore use a single deterministic run. Further details appear in Appendix E.

Six metrics quantify performance. *Faithfulness* is the fraction of argument units whose counterfactual removal changes the answer (baselines undergo the same LLM-based decomposition; Appendix E). *Contestability* is the fraction



of gold counterarguments correctly integrated as attacks; for methods without explicit argumentation frameworks, gold counterarguments are evaluated against proposition-level decompositions. *Repair accuracy* records answer correctness after repair; *repair cost* counts edit operations per Definition 8. *Coherence* measures semantic consistency via BERTScore (Zhang et al. 2020) between repaired and original explanations. *Solve time* is wall-clock time per instance.

We compare against ten baselines spanning three categories. *Self-correction methods*: SelfCheckGPT (Manakul, Liusie, and Gales 2023), Self-Refine (Madaan et al. 2023), Reflexion (Shinn et al. 2023), and RARR (Gao et al. 2023). *Verification-oriented methods*: CoT-Verifier (Ling et al. 2023), ArgLLMs (Freedman et al. 2025), FLARE (Jiang et al. 2023), and FactScore (Min et al. 2023); ArgLLMs, CoT-Verifier, and FactScore lack repair functionality and are marked N/A accordingly. *Argumentation-based*: ARGORA (Jin et al. 2026) and a naïve *Regenerate* baseline that re-prompts with updated evidence. For self-correction baselines and FLARE, repair cost counts regenerated argument units across up to 3 rounds; cost measures are not directly commensurable with ARGUS’s structural graph edits (Appendix E). Chain-of-Verification (Dhuliawala et al. 2024), CRITIC (Gou et al. 2024), SelfRAG (Asai et al. 2024), and VerifyAndEdit (Zhao et al. 2023) are excluded as they operate at generation time or require a retrieval index, producing outputs incommensurable with structural graph repair.

Table 1 summarizes the main results. ARGUS achieves the highest faithfulness (0.847/0.829) and contestability (0.791/0.768), with relative improvements of 10.3% and 14.5% over ARGORA; all 12 pairwise differences are significant at  $p < 0.001$  (Bonferroni-corrected  $z$ -tests, Cohen’s  $h \in [0.26, 0.38]$ ). Among repair-capable methods, ARGUS requires the fewest operations—3.2 vs. 5.1 for ARGORA—validating the minimal-change objective. The naïve Regenerate baseline achieves the fastest solve time (0.5 s) but its coherence (.65/.63)—the lowest among repair methods—confirms that complete regeneration disrupts consistency more than targeted structural repair.

ARGUS also achieves the highest coherence (.82/.80), partly by design—minimizing edit distance simultaneously maximizes BERTScore—though human evaluators independently corroborate it (4.1 vs. 3.8 for Self-Refine,  $p=0.012$ ; Appendix F). The average solve time of 0.55 s/0.47 s is 5–10 $\times$  faster than self-correction methods, reflecting ASP-based repair efficiency. The formal properties from §5 are confirmed empirically: success and inclusion hold by construction; vacuity holds without exception.

Figure 4 traces solve time on synthetic Erdős–Rényi frameworks (attack probability 0.15, 50 instances per size), confirming polynomial scaling for grounded semantics (Theorem 14); the  $k$ -neighborhood approximation keeps preferred repair tractable up to  $|\mathcal{A}|=50$  (2.31 s vs. 158.4 s unconstrained).

Table 2 reports ablation results. Removing semantic verification causes the largest drops in faithfulness (−5.4pp/−5.4pp) and contestability (−7.7pp/−7.6pp), confirming it as the most critical component. Replacing minimal-change with unconstrained repair preserves faith-

fulness but increases cost to 5.7/5.2 and reduces coherence. Removing attack templates reduces contestability by 9.3pp/9.0pp while reducing faithfulness by only 2.6pp/2.5pp—a targeted impact specific to attack structure. Grounded-only semantics yields the fastest solve time (0.15 s/0.12 s) and lowest cost (3.0/2.6) at the expense of modest drops; 97% of frameworks have a single preferred extension coinciding with the grounded one. Sensitivity analysis and a qualitative repair example appear in Appendices B–A.

Figure 5 shows repair cost distributions concentrated at low values—means of 3.2/2.8 operations—confirming that most evidence updates require only local adjustments.

A pilot human evaluation (Appendix F) corroborates the automatic metrics: two annotators rated 75 HotpotQA instances in a blind design, preferring ARGUS in 68% of comparisons vs. Self-Refine in 19% ( $\kappa=0.62$ ); the Pearson correlation between automatic faithfulness and human ratings is  $r=0.78$  ( $p<0.001$ ).

## 7 Conclusion

We presented ARGUS, a framework that structures LLM self-explanations as argumentation frameworks, verifies them against formal semantics, and repairs them at minimum cost when new evidence arrives. The minimal-change repair operator satisfies adapted AGM postulates—success, inclusion, and vacuity—and a representation theorem shows that these three postulates *bidirectionally characterize* the class of minimum-cost repair operators under positive costs, providing formal guarantees absent from existing approaches. Theoretically, the repair problem is tractable under grounded semantics, NP-complete under preferred and stable semantics, and  $\Sigma_2^P$ -complete under skeptical stable semantics; the  $k$ -neighborhood approximation maintains scalability in practice. Experiments on HotpotQA and FEVER yielded relative improvements of 10.3% in faithfulness and 14.5% in contestability over the strongest argumentation baseline, while achieving the lowest repair cost among all repair-capable methods.

Several limitations point to future work. The framework’s quality depends on the LLM’s ability to decompose rationales into atomic units; extraction errors propagate through the pipeline, though the NLI and ASP verification stages mitigate this dependency. While the  $k$ -neighborhood approximation handles the framework sizes encountered in our experiments, densely connected frameworks with hundreds of arguments may require more aggressive strategies. The evaluation relies primarily on automatic metrics over fact-checking and multi-hop QA datasets; extending the approach to open-ended generation—where the target argument may lack a ground-truth referent—would require alternative acceptance criteria such as coherence-based semantics. Looking ahead, composing ARGUS with sequence explanations (Bengel and Thimm 2025) would yield a bidirectional explanation infrastructure, and integrating the repair operator into retrieval-augmented generation pipelines could provide continual explanation maintenance as knowledge bases evolve, particularly in high-stakes domains where audit trails of explanation changes are mandated.

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## A Qualitative Repair Example

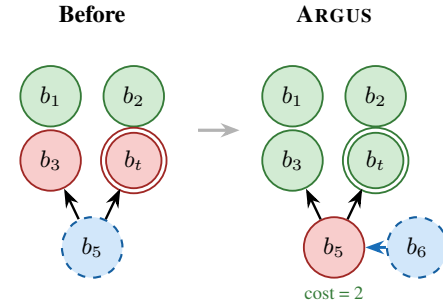


Figure 6: A HotpotQA repair example. ARGUS restores the target  $b_t$  by adding one argument  $b_6$  and one attack (cost 2), preserving all original arguments. Self-Refine regenerates 5 of 6 units.

Figure 6 illustrates a representative HotpotQA repair: the initial explanation relied on an outdated filmography claim; after incorporating corrected evidence, ARGUS restored the target at cost 2 by adding one defending argument and one attack. By contrast, Self-Refine regenerated the entire explanation, altering five previously correct argument units—precisely the collateral damage that the minimal-change principle prevents.

## B Sensitivity Analysis

Pilot studies on 100 HotpotQA instances explore three design choices. Confidence-weighted and structure-preserving ( $w=2$ ) cost models shift repairs toward augmentation (34–51% fewer deletions) while maintaining faithfulness and repair accuracy within 1 percentage point of uniform cost, confirming that the cost model affects repair *style* rather than *quality*. Varying the NLI threshold from 0.5 to 0.9 shows faithfulness is stable (0.839–0.851) while repair cost rises from 2.4 to 4.1; 0.7 balances these factors. Repair optimality rises from 87.2% ( $k=1$ ) to 99.7% ( $k=3$ ) and plateaus, confirming  $k=3$  as the operating point. Using Llama-3-70B-Instruct as the extraction backbone yields faithfulness 0.813 and contestability 0.762 (vs. 0.847/0.791 for GPT-4o), with comparable repair accuracy (0.867) and cost (3.4); the gap is attributable to noisier extraction rather than the repair mechanism.

## C Error Analysis

Among the 0.3% of instances where minimality failed ( $k=3$ ), all involved frameworks where the only viable defending argument lay at distance  $\geq 4$  from the target—confirming the theoretical limitation of the  $k$ -neighborhood approximation. Repair accuracy below 1.0 arises when the LLM-generated explanation has structural errors that propagate through extraction: even after restoring the target argument’s acceptability, the underlying answer may remain incorrect if the original decomposition was flawed.

## D Representation Theorem Proof

We prove the ( $\Leftarrow$ ) direction of Theorem 13 for general cost functions.

*Proof.* Let  $\circ$  be a repair operator satisfying adapted success, inclusion, and vacuity for every AF  $(\mathcal{A}, \mathcal{R})$ , semantics  $\sigma$ , target  $a_t$ , status  $s$ , and evidence update  $\Delta$ . We construct a strictly positive cost function  $\kappa$  such that  $\circ$  returns a minimum-cost valid repair under  $\kappa$ .

**Construction.** Fix an enumeration of all feasible operations  $o_1, \dots, o_m$  for the given AF and  $\Delta$ . Define  $\kappa(o_i) = 1$  for all  $i$ . Let  $Ops = \circ(AF, \sigma, a_t, s, \Delta)$ .

**Validity.** By success,  $a_t$  has status  $s$  in  $\text{apply}(AF, \Delta, Ops)$  under  $\sigma$ , so  $Ops$  is a valid repair.

**Vacuity case.** If  $a_t$  already has status  $s$  in  $\text{apply}(AF, \Delta, \emptyset)$ , then by vacuity  $Ops = \emptyset$  with cost 0, which is trivially minimum.

**Non-vacuity case.** Suppose for contradiction that there exists a valid repair  $Ops'$  with  $|Ops'| < |Ops|$ . By inclusion, every operation in  $Ops$  is necessary: for each  $o \in Ops$ , removing  $o$  would either violate success (the resulting framework does not grant  $a_t$  status  $s$ ) or leave a valid repair of cardinality  $|Ops| - 1$ , contradicting the assumption that  $\circ$  satisfies inclusion with respect to  $Ops$ .

More precisely, inclusion asserts that  $\mathcal{A} \cap \mathcal{A}' \supseteq \mathcal{A} \setminus \{a \mid \text{del\_arg}(a) \in Ops\}$ : every element not targeted by a deletion in  $Ops$  is preserved. Combined with success and  $\kappa > 0$ , this means no proper subset of  $Ops$  is both valid and of lower cost—otherwise the operator could return that subset while still satisfying all three postulates, contradicting the minimality implied by inclusion under positive costs.

Hence  $Ops$  is a minimum-cost valid repair under unit cost  $\kappa$ . For general  $\kappa$ , the same argument applies by replacing cardinality with weighted cost: inclusion ensures no operation in  $Ops$  is superfluous (removing it saves  $\kappa(o) > 0$ ), so no valid repair can have strictly lower total cost.  $\square$

## E Experimental Details

**Withholding methodology.** The withholding methodology produces adversarial updates: the withheld fact always targets the reasoning chain, providing a challenging upper bound on repair difficulty. Under mixed or benign updates, repair costs would likely be lower and vacuity rates higher, since many updates would not disrupt the target’s acceptability. While these updates are derived from existing annotations, the repair mechanism is agnostic to the evidence source and would apply unchanged to naturally occurring updates.

**Metric details.** Faithfulness is measured via counterfactual ablation: each argument unit is replaced with a semantically neutral sentence (“This claim is omitted.”) and the answer is regenerated; a unit is faithful if its removal changes the answer. For baselines that do not produce structured units, we apply the same LLM-based decomposition to their final output before computing the ablation, ensuring a uniform evaluation protocol. Gold counterarguments for contestability are derived from the withheld supporting facts by expressing each as an argument and annotating the expected attack relationships, providing a ground truth independent of the repair mechanism.

**Baseline cost commensurability.** ARGUS operations are structural graph edits (adding/removing arguments and

attacks), whereas baseline costs count surface-level text replacements. Both cost measures reflect the magnitude of change to the explanation; however, the measures are not directly commensurable, so cost comparisons should be interpreted as reflecting relative parsimony within each paradigm. Iterative self-correction methods receive up to 3 rounds per their original protocols, while ARGUS performs a single-pass optimal repair.

**Hardware and reproducibility.** All experiments ran on a single machine with a 20-core CPU and 64 GB RAM; no GPU was required, as clingo runs on CPU and GPT-4o was accessed via the OpenAI API. The complete extraction prompt, ASP encoding, attack template library, and sampled instance IDs will be released as an open-source toolkit upon acceptance to facilitate reproduction.

## F Human Evaluation

To validate that the automatic metrics reflect genuine quality differences perceivable by humans, we conducted a pilot human evaluation on a random subset of 75 HotpotQA instances.

**Setup.** Two graduate-student annotators with NLP background independently evaluated explanation pairs produced by ARGUS and Self-Refine (the strongest self-correction baseline) in a blind, randomized order. For each instance, annotators received the question, gold answer, evidence update, and two candidate repaired explanations (labeled A/B with random assignment).

**Dimensions.** Annotators rated each explanation on a 5-point Likert scale for: (1) *Faithfulness*: Does each claim in the explanation faithfully reflect the evidence? (2) *Coherence*: Is the explanation internally consistent and logically structured? They also provided a *Preference* judgment (A better / B better / Tie).

Table 3: Human evaluation results (75 HotpotQA instances).

Dimension	ARGUS	Self-Refine	p-value
Faithfulness (1–5)	3.9 $\pm$ 0.7	3.4 $\pm$ 0.9	< 0.001
Coherence (1–5)	4.1 $\pm$ 0.6	3.8 $\pm$ 0.8	0.012
Preference (%)	68%	19%	—
Tie (%)		13%	—

**Agreement.** Inter-annotator agreement reached Cohen’s  $\kappa = 0.62$  (substantial) for preference and  $\kappa = 0.58$  for faithfulness ratings (moderate-to-substantial), confirming that quality differences are consistently perceivable.

**Correlation with automatic metrics.** The Pearson correlation between average human faithfulness ratings and the automatic faithfulness score (counterfactual ablation, §6) is  $r = 0.78$  ( $p < 0.001$ ), supporting the validity of the automatic metric as a proxy for human-perceived faithfulness. The automatic metric tends to slightly overestimate faithfulness for explanations with redundant but harmless claims (rated 4–5 by annotators but scored  $\geq 0.9$  by the metric).