Machine Learning In Finance at KDD 2025

August 4, 2025
8:00 – 12:00


TORONTO
KDD2025

RESEARCH TRACK

A Hybrid Framework for Financial Regulatory Compliance

Integrating LLMs and SMT Solver for Automated Legal Analysis

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Financial Companies are Facing Compliance Violations

A Case in Taiwan: Capital Adequacy Violation in a Major Insurance Company (2024)

The company was prohibited from entering new transactions with related parties until legal compliance is restored.

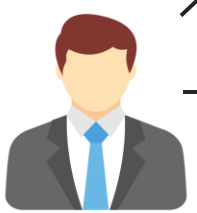
In July 2024, a Taiwanese life insurance company was penalized for failing to meet the legal **Capital Adequacy Ratio (CAR) – 111.09%** and **Net Worth Ratio – 2.97%** at the end of 2023.

Despite submitting multiple improvement plans—including asset reclassification, private equity issuance, and subordinated debt—the company could not guarantee that its CAR would reach the statutory level within the 2024 fiscal year.

The regulator concluded that the improvement plan was **incomplete and uncertain**, and therefore enforced a restriction.

Traditional Financial Compliance Analysis

Financial Expert



Our CAR is currently only **111.09%**, while the legal threshold is **200%**. We've proposed six plans, but they still won't bring us up to the required level. In addition, our **net ratio rate is 2.97%**, which is also below the legal standard of **3%**. What changes can we make to become compliant?

Law requirement

Company status

…

There are many conditions to consider

- **Large volumes of complex legal provisions**

  Time-consuming to read and difficult to interpret.

- **Interconnected and overlapping regulations**

  Creates a high barrier to entry for beginners.

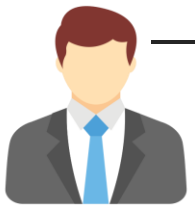
Complex laws, unfamiliar terms, too much to read.

Many rules to meet, zero tolerance for errors.

Using LLM on Financial Compliance Analysis

Our CAR is currently only **111.09%**, while the legal threshold is **200%**. We've proposed six plans, but they still won't bring us up to the required level. In addition, our **net ratio rate is 2.97%**, which is also below the legal standard of **3%**. What changes can we make to become compliant?

To achieve compliance, consider capital injection, risk asset reduction, or optimizing asset allocation. Review plan assumptions and stress-test alternatives to close CAR and net ratio gaps effectively.



However, due to current operational difficulties, we're unable to adjust our **net ratio rate and self capital too much**. But we also don't want to accept the penalty.

Given current operational constraints, we are unable to increase net capital immediately. To bridge the compliance gap and avoid further regulatory action under Article 143-6, we propose a set of capital-light strategies: rebalancing high-risk assets to improve the CAR denominator, optimizing capital efficiency through the disposal of non-core holdings, reassessing key assets to enhance recognized capital, and pursuing approval for subordinated debt or other Tier 2 instruments in compliance with regulatory requirements.

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Challenges on Using LLM on Financial Compliance Analysis

Logic Consistency

- Large Language Models (LLMs) may produce answers that appear plausible but are logically incoherent or legally incomplete, potentially giving users an illusion of correctness.
- *It is needed to guarantee the outcome does (or does not)* ***satisfy the constraints***

Constraint Adjustment and Optimization

- In real-world cases, additional restrictions on companies, e.g., the capital or net ratio can be changed only within a very limited adjustment, need to take into account.
- *A feasible solution needs to be adjusted to fit the company's needs*

To find a valid and feasible suggestion, we propose neural symbolic compliance that integrates LLM with an SMT solver to leverage formal constraint solving to financial compliance.

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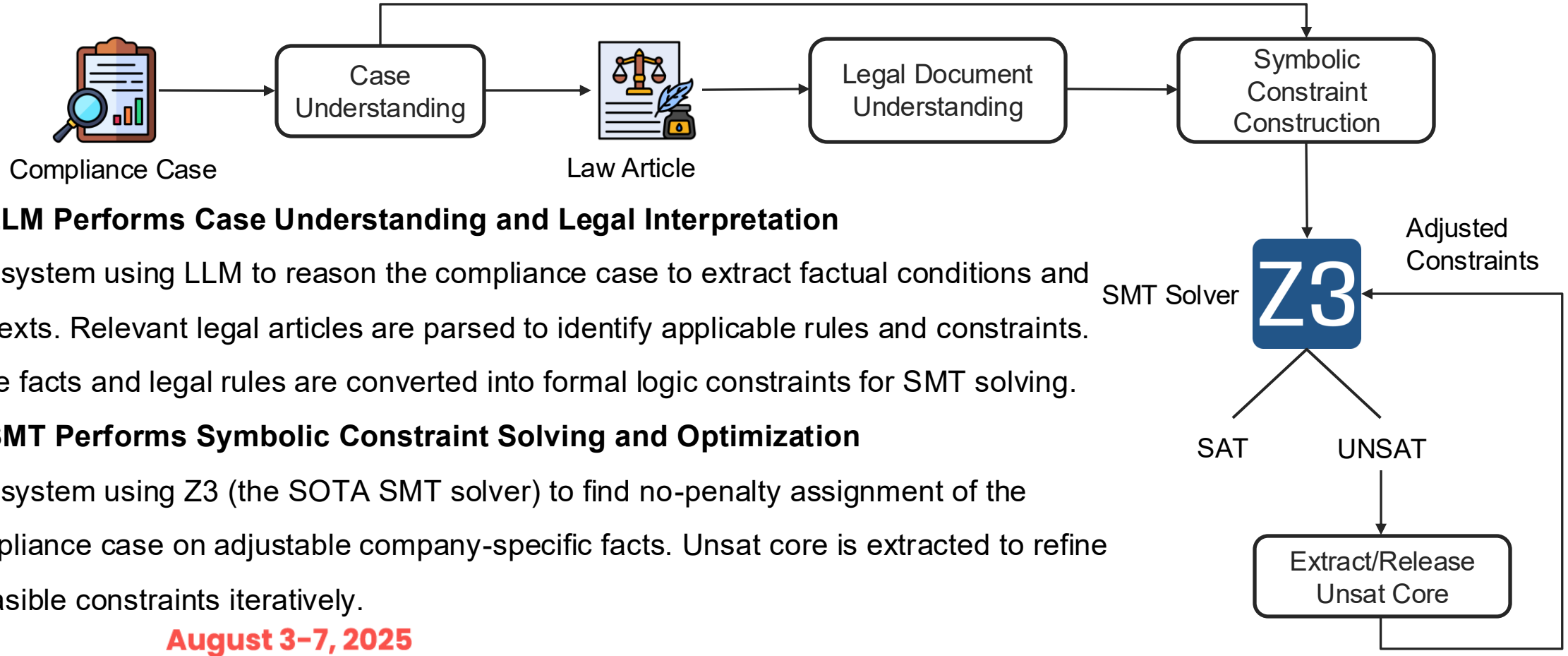
The Neural Symbolic Framework - LLM + SMT



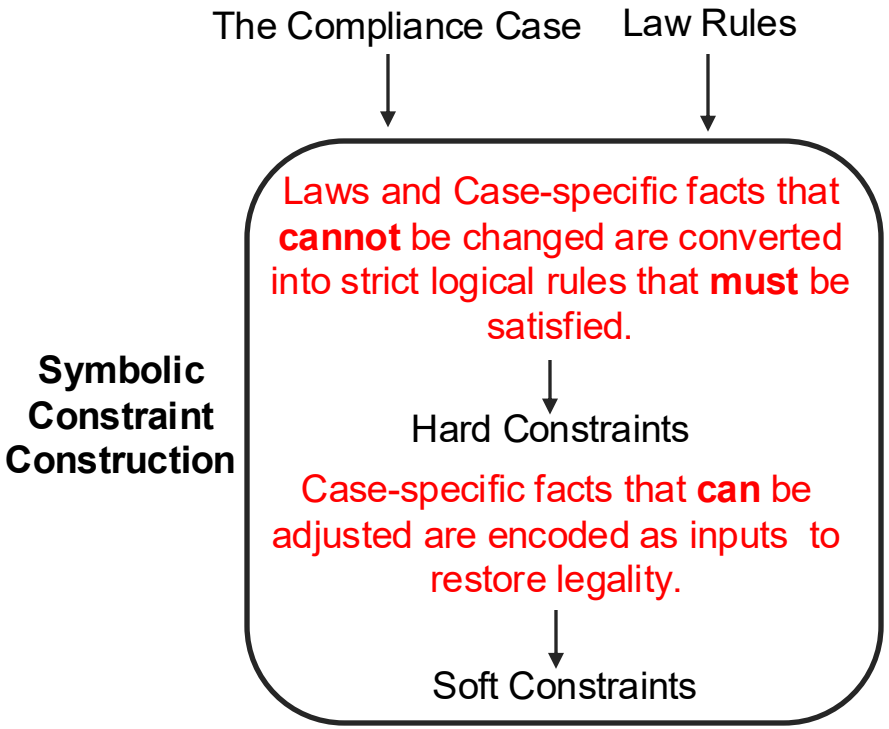
- **LLM Performs Case Understanding and Legal Interpretation**

The system using LLM to reason the compliance case to extract factual conditions and contexts. Relevant legal articles are parsed to identify applicable rules and constraints. Case facts and legal rules are converted into formal logic constraints for SMT solving.

- **SMT Performs Symbolic Constraint Solving and Optimization**

The system using Z3 (the SOTA SMT solver) to find no-penalty assignment of the compliance case on adjustable company-specific facts. Unsat core is extracted to refine infeasible constraints iteratively.

Our Neural Symbolic Framework - LLM + SMT



Legal Rule: (Hard Constraints)

$$\text{final\_CAR} \geq 200$$
$$\text{net\_worth\_ratio} \geq 3$$

$$\text{capital\_grade} = \begin{cases} 1 & \text{if final\_CAR} \geq 200 \wedge \text{net\_worth\_ratio} \geq 3 \\ 2 & \text{if final\_CAR} \geq 150 \\ 3 & \text{if final\_CAR} \geq 50 \\ 4 & \text{otherwise} \end{cases}$$

$$\text{penalty} = \begin{cases} 1 & \text{if capital\_grade} \in \{2,3,4\} \\ 0 & \text{if capital\_grade} = 1 \end{cases}$$

If penalty = 1, then apply:

- **If capital_grade = 2:**
  - stop_new_products
  - restrict_fund_use
  - limit_remuneration
  - other_measures
- **If capital_grade = 3:**
  - All grade 2 measures, and
  - remove_officer, suspend_offic
- **If capital_grade = 4:**
  - All grade 3 measures, and
  - enact_article149

$$\text{pre\_self\_capital} = \text{tier1\_unrestricted} + \text{tier1\_restricted} + \text{tier2\_capital}$$
$$\text{risk\_capital} = \text{asset\_risk} + \text{insurance\_risk} + \text{interest\_rate\_risk} + \text{other\_risk}$$
$$\text{pre\_CAR} = \left(\frac{\text{pre\_self\_capital}}{\text{risk\_capital}}\right) \times 100$$
$$\text{final\_CAR} = \left(\frac{\text{pre\_self\_capital} + \text{added\_capital}}{\text{risk\_capital}}\right) \times 100$$
$$\text{improvement\_plan} = \text{final\_CAR} - \text{pre\_CAR}$$

$$\text{base\_improvement} = \left(\frac{\text{added\_capital\_base}}{\text{risk\_capital}}\right) \times 100$$
$$\text{private\_improvement} = \left(\frac{\text{added\_capital\_private}}{\text{risk\_capital}}\right) \times 100$$
$$\text{improvement\_plan} = \text{base\_improvement} + \text{private\_improvement}$$

Domain-Specific Restrictions: (Hard Constraints)

$$\text{penalty} = 0,$$
$$\text{net\_worth\_ratio} \geq 3 \times 0.99, \qquad \text{net\_worth\_ratio} \leq 3 \times 1.01,$$
$$\text{pre\_self\_capital} \geq 150 \times 0.97, \qquad \text{pre\_self\_capital} \leq 150 \times 1.03.$$

Adjustable Compliance Case Facts: (Soft Constraints)

$$\text{pre\_CAR} = 150,$$
$$\text{improvement\_plan} = 30.4,$$
$$\text{final\_CAR} = \text{pre\_CAR} + \text{improvement\_pla}$$
$$\text{base\_improvement} = 17.9,$$
$$\text{private\_improvement} = 12.5,$$
$$\text{risk\_capital} = 100,$$

$$\text{capital\_grade} = \begin{cases} 1, & \text{if final\_CAR} \geq 200 \wedge \text{net\_worth\_ratio} \geq 3, \\ 2, & \text{if final\_CAR} \geq 150, \\ 3, & \text{if final\_CAR} \geq 50, \\ 4, & \text{otherwise,} \end{cases}$$

$$\text{has\_signed\_contract} = \text{False},$$
$$\text{has\_schedule\_detail} = \text{False},$$
$$\text{has\_complete\_plan} = \text{False}.$$

The Z3 optimization solver checks whether no-penalty assignment on adjustable case facts (soft constraints) is feasible.

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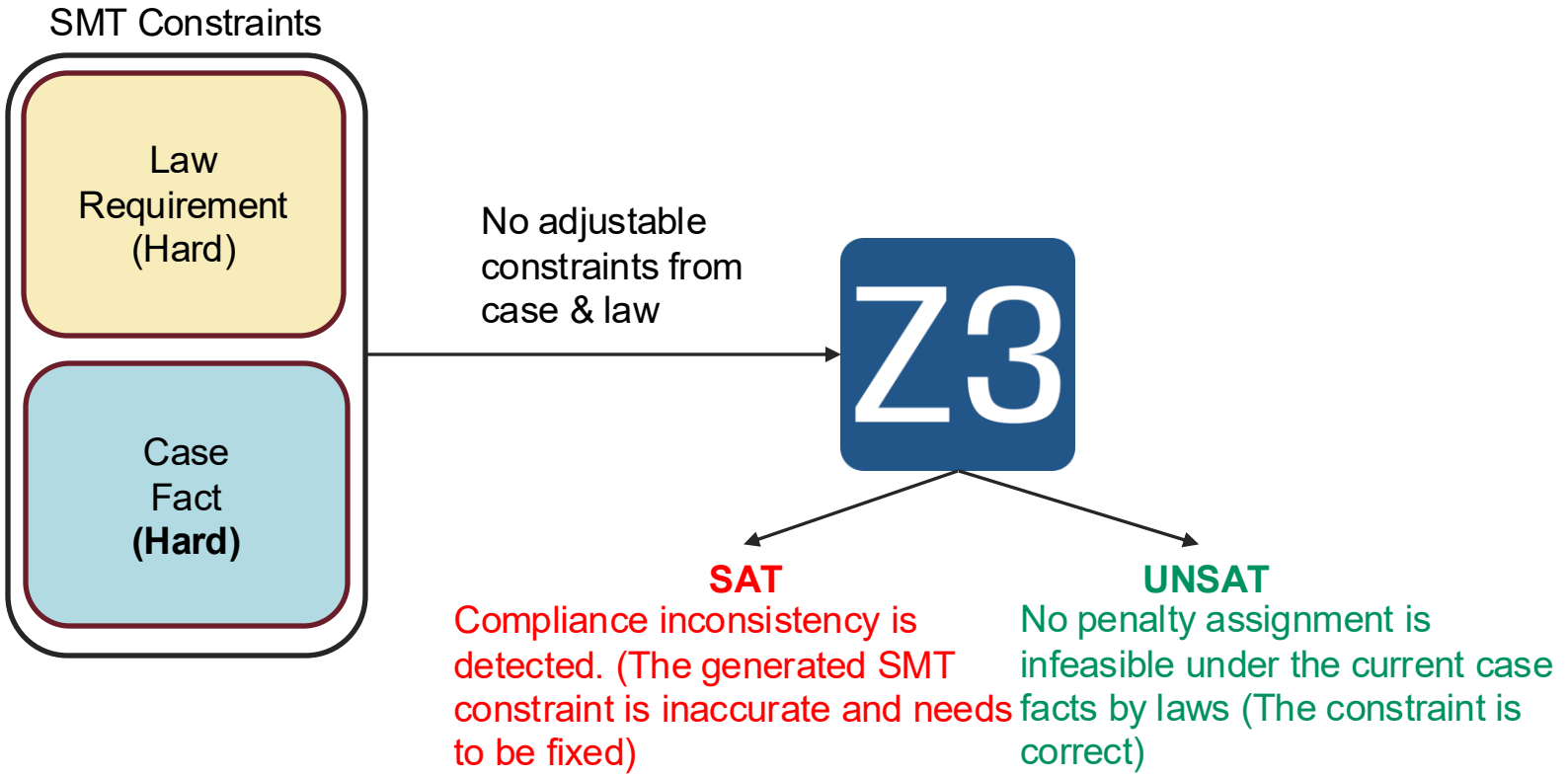
SMT Constraint Validation

Check SMT Constraint Accuracy
-We put all case facts in hard constraints and check whether it is satisfiable under no-penalty condition
- Since no adjustable facts can be used to restore legality, the constraint must be UNSAT for illegal cases



Method	Accuracy	Running Time Per Case
Neural Symbolic Framework	0.8621	36.85s

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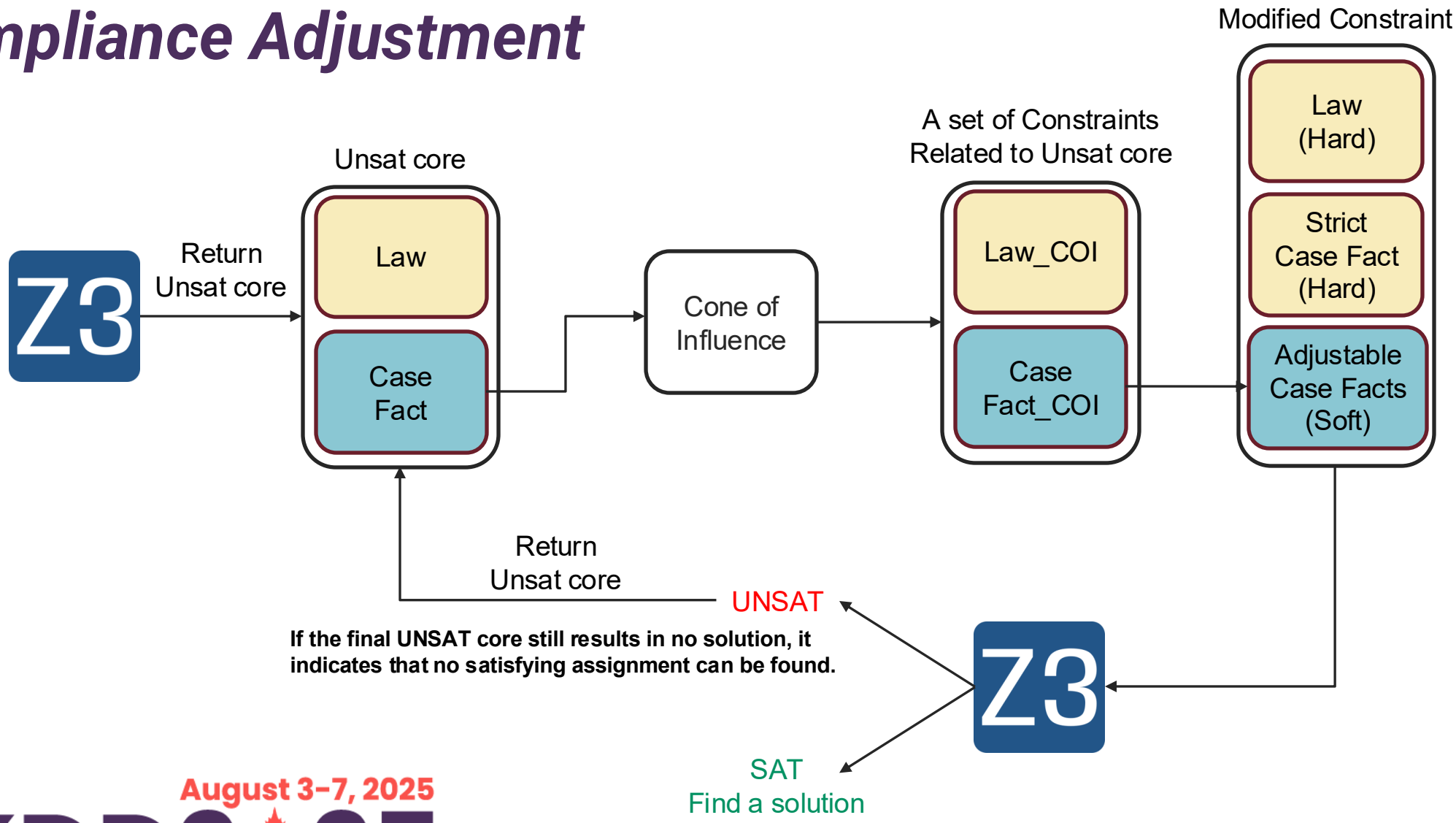
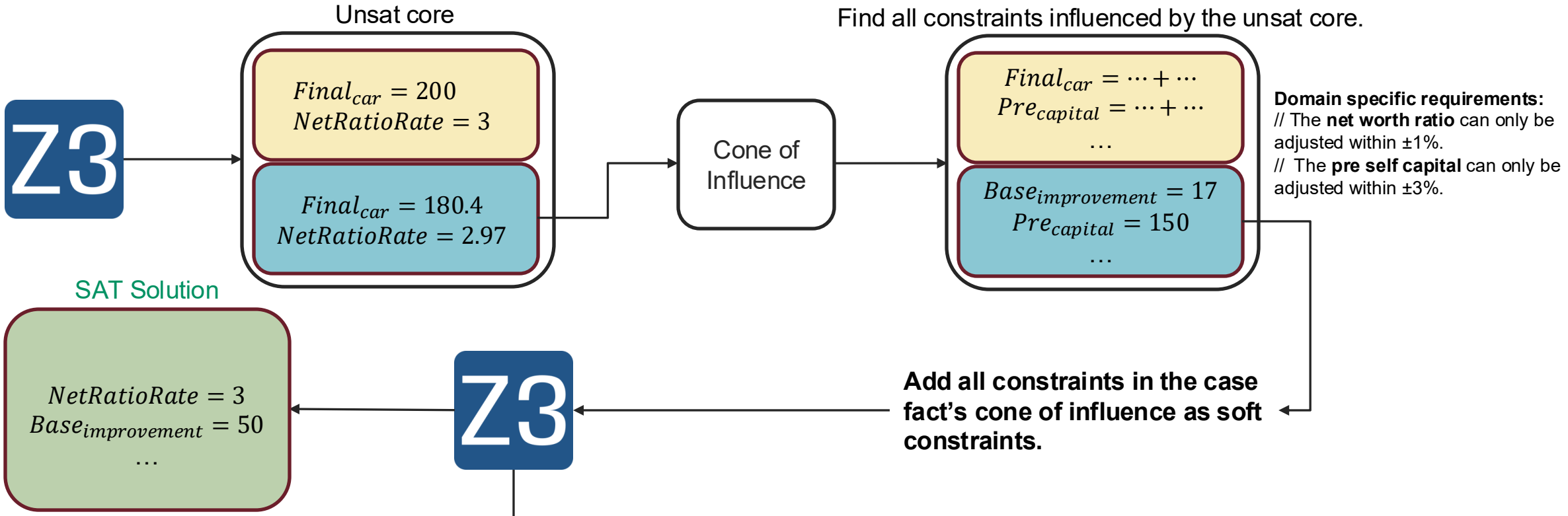
Compliance Adjustment



Cone of Influence - COI

COI gives us the “impact zone” of the violation — and tells us what conditions are needed to restore legality. We use the example on page 1.



If there are Domain specific requirements as hard constraints:

They are always included in the **Strict Case Facts**.

So when **no adjustable variables can be selected from the unsat core**,

Z3 cannot find any feasible legal assignment under such tightly constrained conditions.

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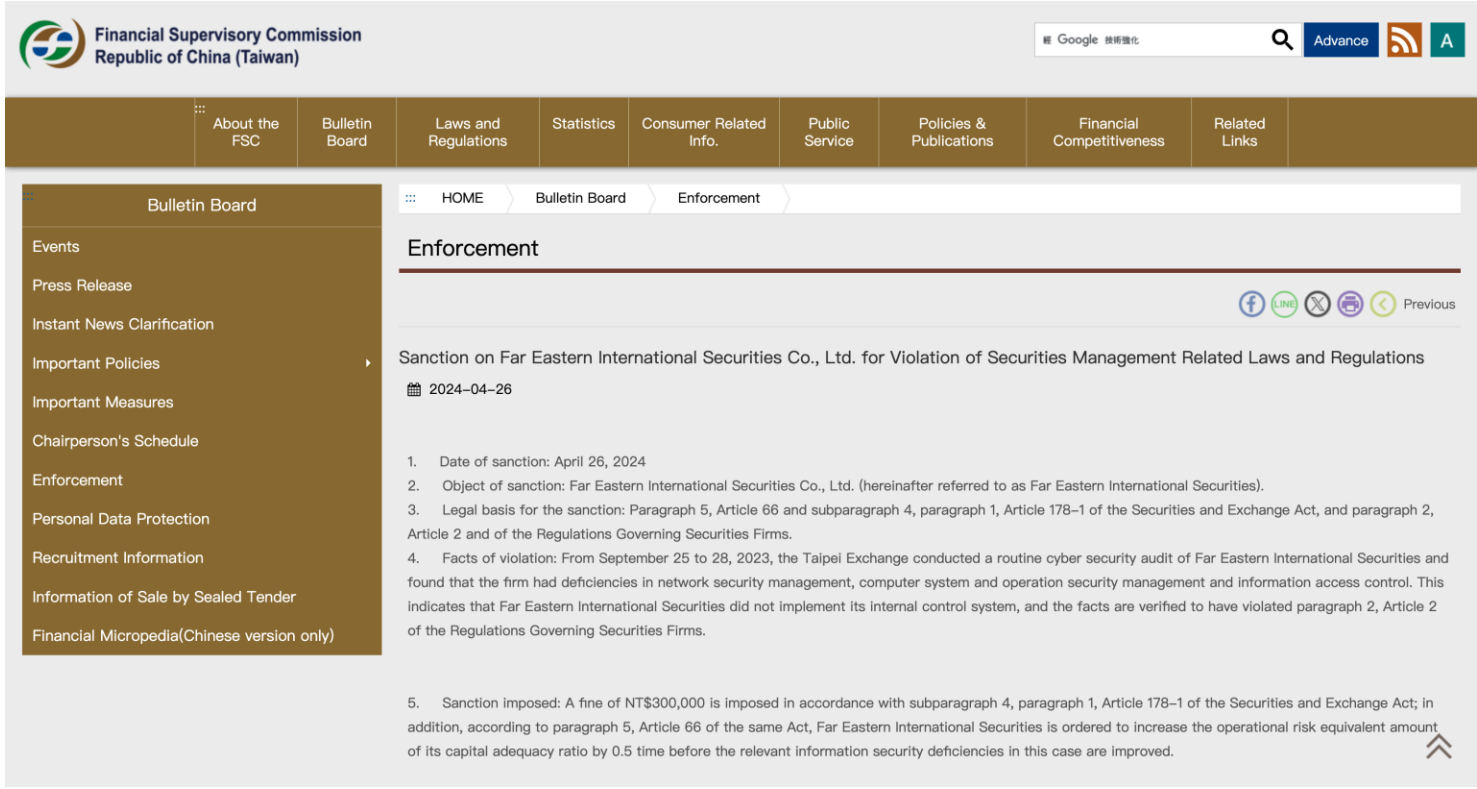
Evaluation against LLM

Evaluation on LLM+SMT:

We examine 87 regulatory cases from the Financial Supervisory Commission (FSC) of Taiwan.

Our system reports **24 UNSAT cases that include additional hard constraints**—strict company specific case facts or restrictions, and make the system conclude no adjustable solution to restore legality.

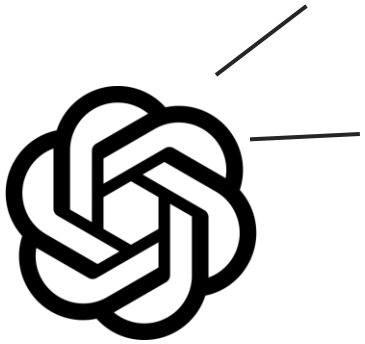
We also report **63 SAT cases** with feasible solutions on adjustable facts to restore legality of these compliance.



Evaluation against LLM

Evaluation on LLM:

We also compare how the LLM performs against these cases. **For each case, the LLM is given the compliance, related legal documents, strict company restrictions, and is open to internet. The LLM reports 13 (SAT and valid suggestions), 5 (SAT but invalid suggestions), and 45 (UNSAT, false negatives) out of 63 SAT cases, and 16 (UNSAT) and 8 (SAT but invalid suggestions) out of 24 UNSAT cases.**



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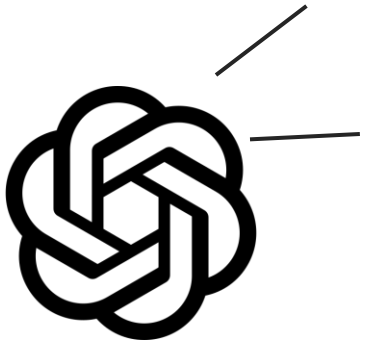
Soft Constraints (based on LLM suggestions):

$$\text{risk\_capital} \leq 100(Rebalance high - risk assets to improve CAR)$$
$$added\_capital\_base \geq 0(Dispose of non - core holdings to inject capital)$$
$$pre\_self\_capital \geq 150(Reassess asset valuations to enhance recognition)$$
$$tier2\_capital \geq 0(Apply for subordinated debt/Tier 2 instruments)$$

This is, in fact, an unsatisfiable case—but the LLM incorrectly assumes a feasible solution exists and proposes a misleading adjustment plan.

Evaluation against LLM

Here is an another example: A Financial Holdings was fined NT$10 million by Taiwan's Financial Supervisory Commission for poor corporate governance and ineffective internal controls. Senior executives improperly shared confidential company information with a major shareholder who held no official position. The chairman's salary was reduced by 30% for six months due to supervisory failures. **This case does not involve any additional domain-specific requirements.**



Although the company has established internal controls and related governance mechanisms on paper, the effectiveness of their implementation is questionable. It is recommended to conduct a thorough gap analysis between documented policies and actual practices, reinforce enforcement and monitoring mechanisms, and ensure that all personnel—especially senior executives—are regularly trained on compliance expectations and information governance boundaries.

Soft Constraints (based on LLM suggestions):

`has_internal_control_system` = true	(*Internal control framework is formally established*)
`internal_control_effective` = true	(*Control systems are theoretically functioning*)
`subsidiary_management_controls` = true	(*Oversight mechanisms for subsidiaries are in place*)
`mechanism_shareholder_comm` = true	(*Established protocols for major shareholder communication*)
`mechanism_info_provision_control` = true	(*Controls for information dissemination are documented*)
`mechanism_conflict_litigation` = true	(*Conflict-of-interest and litigation protocols exist*)

In this case, the LLM's suggestion successfully reduced the penalty to zero.

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Conclusion

We propose a novel Neural Symbolic Compliance that combines LLM reasoning and SMT Solving capabilities for financial compliance analysis, advancing formal reasoning and constraint-based repair in compliance automation.

Our empirical evaluation on 87 real-world cases shows that LLM+SMT offers significant advantages on legal understanding and feasible solution findings compared to pure LLM reasoning.

Our framework prototype

Full paper

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Future Work

- The current implementation is tailored to cases in **Taiwan.**
- The LLM+SMT framework is **jurisdiction-agnostic**.

Module	Purpose	Requires Modification?
RAG Corpus	Retrieve relevant legal text and precedents	**Yes** (replace with local corpus)
Prompt Template	Control query format and language context	**Yes** (adjust language and legal phrasing)
Clause Parser	Map legal clauses to logical templates	**Partial** (redefine parsing patterns)
Legal Mapping Dictionary	Link clause labels to statutes	**Yes** (update to target jurisdiction)
Z3 Rule Engine	Enforce symbolic legal constraints	**No** (fully reusable)
SMT Relaxation Loop	Perform minimal correction search	**No** (domain-agnostic logic)
Gradio UI	Provide user interface	**No** (language-localizable)

THANK YOU!

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