

**Using Large Language Models to Convert Documents to Knowledge  
Graphs to Check for Completeness and Consistency**

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A Praxis submitted to

The Faculty of  
The School of Engineering and Applied Science  
of The George Washington University  
in partial satisfaction of the requirements  
for the degree of Doctor of Engineering

March 8, 2026

Praxis directed by

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The School of Engineering and Applied Science of The George Washington University certifies that [Your Name] has passed the Final Examination for the degree of Doctor of Engineering as of December 18, 2025. This is the final and approved form of the Praxis.

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## **Dedication**

In loving memory of my parents, Jack and Helen. I dedicate this work to their belief in me and the lessons they taught. From my mother, I learned what is possible through sheer determination. The memory of her returning to school to earn a master's in economics while raising our family is an inspiration that I carry with me always. From both of my parents, I received the encouragement and love of learning that made this achievement possible.

To my siblings, Gordon, Carole, and Iain, who have graciously and humorously allowed me to neglect them during this endeavor. I am deeply grateful for your patience and look forward to reconnecting now that it is complete.

To my children, Alex, Peter, and Kayla. Your unwavering support and quiet understanding have been a constant source of strength. Thank you for inspiring me to see this through.

And most importantly, to my lovely wife, Elaine. You encouraged me to start this journey, sustained me with endless coffee and patience when the mornings were early or the nights grew long, and became my partner in every sense of the word. You will now be living with the results, and I am eternally grateful. This achievement is as much yours as it is mine.

## **Acknowledgments**

I would like to express my profound gratitude to my advisor, Dr. Elabasheer, whose mentorship was instrumental in guiding this research. He showed me the way forward when the path was unclear and challenged me to think more critically. Whenever I find myself thinking I cannot multitask or overcome a challenge, I will undoubtedly hear his voice reminding me that I must—a lesson in perseverance I will carry throughout my career.

My deepest appreciation extends to all my professors at The George Washington University who taught me during this program. Their dedication to teaching and intellectual generosity created the rich academic environment and provided the abundant knowledge that were essential for this journey.

I am also deeply grateful to my West Chester University Dean, Dr. Burns, who served as a steadfast source of support. He was always available to listen to my trials and tribulations, and with a few short, insightful words, he consistently helped me untangle complex problems and understand how to proceed. His wisdom and perspective were invaluable.

A special and heartfelt thank you is reserved for my wife, Elaine. As a lawyer, her tolerance for dense text is matched only by her sharp eye for detail—both of which were indispensable gifts to this project. She patiently read every single word at least ten times, and her contribution to this work is immeasurable.

Finally, I wish to acknowledge my students. Their intellectual curiosity and enthusiasm for learning were a constant source of motivation. It was my desire to be a more effective and knowledgeable teacher for them that provided the final impetus to see this project through to its completion. You reminded me daily of why this work matters.

## **Abstract**

### **Using Large Language Models to Convert Documents to Knowledge Graphs to Check for Completeness and Consistency**

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## **Glossary of Terms**

**AI** Artificial Intelligence

**ANN** Artificial Neural Network

**API** Application Programming Interface

**API** Bidirectional Long Short-Term Memory network

**BPE** Byte Pair Encoding

**CPU** Central Processing Unit

**CRF** Conditional Random Field

**DAG** Directed Acyclic Graph

**GAT** Graph Attention Networks

**GCNN** Graph Convolutional Neural Network

**GNN** Graph Neural Network

**GPT** Generative Pre-trained Transformer

**GPU** Graphical Processing Unit

**HMM** Hidden Markov Model

**IE** Information Extraction

**IRI** Internationalized Resource Identifier

**JSON** JavaScript Object Notation

**KG** Knowledge Graph

**LLM** Large Language Model

**LSTM** Long Short-Term Memory

**MEMM** Maximum Entropy Markov Model

**ML** Machine Learning

**NER** Named Entity Recognition

**NLP** Natural Language Processing

**OWL** Web Ontology Language

**RAM** Random Access Memory

**RDF** Resource Description Framework

**RE** Relationship Extraction

**SHAP** SHapley Additive exPlanations

**SPARQL** SPARQL Protocol and RDF Query Language

**SVM** Support Vector Machine

**TN** True Negative

**TP** True Positive

**UBB** User-Based Batching

**UBS** User-Based Sequencing

**URI** Uniform Resource Identifier

**VRAM** Video Random Access Memory

**W3C** World Wide Web Consortium

**XML** eXtensible Markup Language

## **Chapter 1: Introduction**

### **1.1 Background and Research Motivation**

Ensuring document quality involves verifying completeness, consistency, and correctness (Zowghi & Gervasi, 2003). While evaluating correctness often necessitates access to knowledge external to the document and understanding the document's intent, completeness and consistency can be assessed using only the document's internal content. This research focuses on developing automated methods using Large Language Models (LLMs) to address the latter two aspects. The specific focus is on converting a large document into a knowledge graph that can be used in future research to check for document consistency and completeness.

#### **1.1.1 Background**

The increasing complexity and scale of textual documents in various domains present significant challenges to ensuring consistency and completeness. Legal codes, technical documentation, and regulatory frameworks are often drafted collaboratively over extended periods, a process that can lead to inconsistencies, redundancies, and informational gaps. Traditional manual review methods, while necessary, are labor-intensive and prone to human oversight, making automated solutions an attractive alternative. Advances in Natural Language Processing (NLP) and Artificial Intelligence (AI) have introduced new methodologies for analyzing and structuring large bodies of text, with promising applications in document validation and knowledge extraction.

At the core of modern NLP advancements are Transformer-based models

that rely on the Attention Mechanism to understand and generate text. LLMs, which build upon this foundation, can process and interpret vast amounts of textual data, although they are constrained by fixed context windows. To address this limitation, structured approaches such as knowledge graphs have emerged, enabling explicit representation of entities and relationships within documents. This research applies these technologies to Pennsylvania township laws, a domain where maintaining consistency is particularly critical. Given the size and complexity of municipal codes, inconsistencies in legal definitions, zoning regulations, and procedural rules can lead to legal disputes and financial losses. By leveraging AI-driven tools, this study aims to develop a framework for systematically analyzing and improving the consistency of legal documents.

Ensuring structural consistency and completeness in documents has been a longstanding challenge across various domains. Previous research has focused on methods to maintain internal coherence within documents (Laban et al., 2021), while other studies have explored domain-specific approaches to consistency checking (Tröls et al., 2022). In academic literature, the term coherence is often used interchangeably with consistency (Shen et al., 2021), reflecting the broader goal of ensuring logical and semantic alignment within textual content.

In 2017, a research team at Google introduced the Transformer model, a neural network architecture based entirely on the Attention Mechanism (Vaswani et al., 2017). Unlike previous sequential models, the Transformer processes all words within a given input simultaneously, allowing it to assess how each word influences others across the text. Using self-attention, this architecture captures long-range dependencies more effectively than earlier models. Despite advances in scaling Transformer-based models, they remain

constrained by a limited attention window due to memory and computational efficiency considerations.

Large Language Models are built upon the Transformer architecture and inherit its fundamental attention-based mechanisms. These models, however, are constrained by a fixed context window, which limits the amount of text they can analyze at once. As documents grow in length, they often exceed this window, preventing comprehensive processing in a single pass. Despite this limitation, document analysis does not necessarily require attending to an entire document simultaneously. Instead, LLMs can be employed to extract key entities and concepts across different sections, enabling a more focused and structured approach to consistency checking. Through the identification of entities and the analysis of their relationships, LLMs can effectively navigate large documents while maintaining efficiency.

Knowledge graphs provide a structured, human-readable representation of information, serving as an alternative to the implicit encoding of knowledge found in neural networks. A knowledge graph is a directed acyclic graph (DAG) in which nodes represent entities and edges define the relationships between them. Each node can possess attributes that enrich its descriptive properties. For instance, a node representing a car might include attributes such as color, model, or manufacturer. A useful way to conceptualize knowledge graphs is through the framework of frames, as described by Minsky (Minsky, 1974). In contrast to LLMs, which rely on statistical inference, knowledge graphs offer explicit, interpretable relationships that can be leveraged for consistency and completeness verification in structured documents.

Pennsylvania is home to over 1,200 townships of the second class, each responsible for drafting and maintaining its own set of municipal laws.

These laws regulate a wide range of local governance areas, including police services, fire departments, zoning, and land development. Over time, the cumulative nature of legal amendments introduces inconsistencies and gaps, which, if left unaddressed, can lead to legal ambiguities and enforcement challenges. Although legal professionals and municipal officials work diligently to identify and resolve these issues, the complexity of these documents—often spanning thousands of pages—renders manual review error-prone and inefficient.

A key source of complexity is the interdependence of different sections within municipal codes. For example, early sections may define zoning regulations, specifying minimum frontage, setbacks, and other boundary constraints for different zoning districts. Inconsistencies can arise, however, when later sections introduce or reference zoning areas that were never formally defined. Similar discrepancies can emerge across other regulatory provisions, necessitating careful synchronization of legal language and definitions. Ensuring consistency across these interconnected legal elements is a critical challenge that demands a more systematic and automated approach to legal document analysis.

### **1.1.2 Research Motivation**

Despite extensive research on the analysis of small documents or specific document sections, a significant gap remains in addressing the challenges of comprehensive, large-scale document analysis. The need for automated consistency and completeness checks is critical in various industries where these tasks are often performed manually, requiring substantial time and resources while still potentially yielding suboptimal results. This research aims to bridge this gap by developing an effective and efficient automated

solution.

The process for publishing local regulations in Pennsylvania townships exemplifies these challenges. After a governing body enacts a law, it is sent to an organization for compilation into the township's existing legal code. This manual and intensive process involves determining if any existing laws are affected by the new one. Even with this careful review, new laws frequently render the existing legal framework incomplete or inconsistent, thereby motivating the present research.

## **1.2 Problem Statement**

*Municipal laws in Pennsylvania Townships, authored by multiple people over time, develop inconsistencies and are incomplete (Curley, 2024; Rau, 2024; Sanders, 2024), leading to annual revenue losses of hundreds of thousands of dollars. (Bosco, 2024)*

The complexity of municipal laws in Pennsylvania townships arises from their incremental development. Ordinances and regulations are often drafted by different individuals, including elected officials, legal counsel, and administrative staff, each contributing to the evolving legal framework. This decentralized process can lead to inconsistencies in language, overlapping provisions, and unintended gaps in regulatory coverage. As laws are amended or new ones are introduced, prior statutes may not be adequately reconciled, further exacerbating these issues. Without a systematic approach to maintaining legal coherence, townships face challenges in enforcing their laws effectively and equitably.

The consequences of these inconsistencies extend beyond legal ambiguity. Incomplete or conflicting municipal laws can create loopholes that hinder a township's ability to collect fees, fines, and other sources of rev-

enue. For example, unclear zoning regulations may allow developments to proceed without appropriate permits or impact fees, and ambiguous tax ordinances can lead to disputes that reduce collections. When enforcement mechanisms are weakened by gaps in the legal framework, municipalities struggle to ensure compliance, leading to significant financial losses. These inefficiencies, compounded over time, place additional strain on local budgets and limit resources for essential public services and infrastructure improvements.

Addressing these issues requires a structured methodology for analyzing, refining, and maintaining municipal laws. Traditional legal review processes, while valuable, are labor-intensive and reactive, often identifying issues only after disputes or financial shortfalls have arisen. Advances in artificial intelligence, particularly the use of LLMs, offer a potential solution by systematically identifying inconsistencies, redundancies, and gaps within legal texts. By applying LLMs to municipal laws, townships could proactively assess their legal frameworks, thereby improving clarity, enforcement, and financial sustainability. The implementation of such an approach, however, requires careful consideration of computational constraints, document formats, and the broader applicability of AI-driven legal analysis.

### **1.3 Thesis Statement**

*An LLM-based tool to convert a document into an attributed knowledge graph can be used to check for consistency and completeness, which will allow municipal lawyers to create consistent and complete law documents, thereby preventing costly disputes and reducing revenue losses.*

The application of LLMs in legal document analysis has the potential to revolutionize municipal law by providing an automated, systematic ap-

proach to ensuring consistency and completeness. Traditional legal drafting and review processes rely heavily on human oversight and are consequently susceptible to errors, especially in laws that have evolved over time through multiple amendments and contributors. By leveraging an LLM-based tool to convert legal documents into attributed knowledge graphs, municipalities can proactively identify gaps, redundancies, and contradictions before laws are enacted or enforced. This proactive approach serves to minimize ambiguity, strengthen legal clarity, and enhance the efficiency of legal review processes.

A knowledge graph-based representation of municipal laws enables a structured, machine-readable format that facilitates logical analysis. Unlike traditional text-based legal review, which requires extensive manual effort to trace dependencies and resolve conflicts, a knowledge graph explicitly maps relationships between legal provisions, definitions, and enforcement mechanisms. This structure allows municipal lawyers to assess the inter-connectivity of legal clauses and verify their consistency against established legal principles. Furthermore, an attributed knowledge graph can highlight areas where laws are incomplete or misaligned with overarching governance policies, enabling timely revisions that improve legal coherence.

Beyond improving legal clarity, the ability to create consistent and complete municipal laws has direct financial implications. Inconsistent or incomplete regulations can lead to disputes over zoning, taxation, and permitting, often resulting in costly litigation or lost revenue from unenforceable provisions. By employing an LLM-driven tool to detect and resolve these issues at the drafting stage, municipalities can reduce legal ambiguities that might otherwise be exploited. This strengthens fiscal sustainability by preventing revenue leakage and ensuring that all applicable fees, fines, and

taxes are properly assessed and collected.

The integration of LLM-based tools into municipal lawmaking represents a transformative step toward modernizing local governance. As artificial intelligence continues to advance, municipalities that adopt such technologies will gain a significant advantage in maintaining legally sound and financially sustainable frameworks. Future research could extend this approach beyond municipal laws to other domains of legal and regulatory governance, demonstrating the broader impact of AI-driven knowledge representation on ensuring legal accuracy and reducing administrative burdens.

#### **1.4 Research Objectives**

The primary objective of this research is to develop a tool capable of automatically processing documents of any size into a coherent set of entities within a knowledge graph. This tool will leverage advanced techniques to analyze document content, identify potential entities, and provide access to the resulting knowledge graph.

The created knowledge graph will then be analyzed to determine its suitability for checking the source document for inconsistencies and incompleteness. This evaluation will involve introducing targeted issues into the source documents and subsequently demonstrating the ease with which these issues can be observed and identified within the knowledge graph representation.

#### **1.5 Research Questions**

To achieve the research objectives, the following research questions will be addressed.

**RQ1:** Can an LLM be used to convert a large document into a knowledge graph?

**RQ2:** Can an LLM be used to process multiple knowledge graphs into a typed cluster of knowledge graphs.

**RQ3:** Can a typed cluster of knowledge graphs be used to check the source document for consistency and completeness?

## 1.6 Research Hypotheses

This research will test the following hypotheses.

**H1:** An LLM can be used to convert a large document into a knowledge graph.

**H2:** An LLM can be used to process multiple knowledge graphs into a typed cluster of knowledge graphs.

**H3:** A typed cluster of knowledge graphs can be used to check the source document for consistency and completeness.

## 1.7 Research Scope and Limitations

The subsequent sections outline the scope and limitations of this study. This research employs Pennsylvania township laws as a case study to develop and evaluate an automated tool for analyzing legal documents. These publicly accessible laws, having undergone extensive manual reviews, provide a rigorous benchmark for assessing the proposed methodology. The primary focus is the construction of Knowledge Graphs that faithfully represent document structure and content, thereby laying the groundwork for future work in verifying legal consistency and completeness. This study acknowledges several inherent limitations, including computational constraints,

challenges associated with specific document formats, and a primary emphasis on textual analysis, all of which underscore the need for continued research.

### **1.7.1 Research Scope**

This study focuses on the use of Pennsylvania township laws as a case study for developing and testing an automated tool designed to analyze legal documents. These laws, publicly available in PDF and Word formats, were selected for their complexity, length, and history of multiple authorships. Having undergone rigorous manual reviews, they serve as an ideal benchmark for evaluating the effectiveness of the proposed approach. Although the primary application is in the legal domain, the methodology is designed to be adaptable for broader use across various document types.

The core of this research centers on constructing Knowledge Graphs that accurately represent the structure and content of the documents under review. These graphs will serve as a foundation for future work in verifying legal consistency and completeness. While this study will assess the suitability of the generated Knowledge Graphs for such tasks, the actual implementation of automated consistency and completeness checks is deferred to future research. This approach ensures a focused and systematic exploration of Knowledge Graph generation while establishing a foundation for subsequent advancements in automated legal analysis.

### **1.7.2 Research Limitations**

This study has several potential limitations. Computational constraints may affect the efficiency and scalability of processing large and complex legal documents. Challenges may also arise in handling specific document

formats and linguistic intricacies, particularly in ensuring accurate interpretation and structuring of legal text. Furthermore, while this research focuses on leveraging existing LLMs such as Gemini and ChatGPT, it does not involve developing specialized models tailored for knowledge graph construction. Such specialization could be an avenue for future work to reduce computational costs and energy consumption.

This research does not perform direct testing for consistency and completeness. Instead, it utilizes Pennsylvania township laws that are publicly available and have already undergone such validation, treating them as a gold standard. Future studies should explore the applicability of this approach to a broader range of legal and non-legal documents where ground-truth validation is not pre-existing.

For document handling, this research primarily uses Word documents to facilitate modifications during testing. Although the methodology is expected to be compatible with PDFs, further research is needed to confirm seamless integration and processing across different file formats.

Finally, this study is limited to textual analysis. Future work could expand upon this research by incorporating non-textual elements such as tables, formulas, images, and diagrams to achieve a more holistic document comprehension and analysis.

## **1.8 Praxis Organization**

The remainder of this research is organized into several key chapters. Chapter 2 provides a comprehensive review of the relevant literature, focusing on the creation of knowledge graphs from documents by LLMs, the processing of multiple knowledge graphs by LLMs, and the utility of knowledge graphs in ensuring document consistency and completeness. This

review also covers the process of creating and maintaining local laws in Pennsylvania. Chapter 3 delves into the statistical and machine learning methodologies employed, detailing the processes of data pre-processing, model selection, training, and evaluation. Chapter 4 presents and analyzes the results, addressing each research question and hypothesis while evaluating the performance of the proposed methodology. Finally, Chapter 5 concludes the investigation with a discussion of the key findings, contributions, and recommendations for practical applications, as well as potential avenues for future research.

## **Chapter 2: Literature Review**

### **2.1 Introduction**

The landscape of Artificial Intelligence (AI), particularly Natural Language Processing (NLP), was significantly reshaped by the groundbreaking work conducted at Google Brain, documented in the seminal paper *Attention Is All You Need* (Vaswani et al., 2017). This paper introduced the Transformer architecture, which leverages self-attention mechanisms and serves as the foundation for modern Large Language Models (LLMs). These models have demonstrated remarkable capabilities across a wide range of tasks, including text generation, summarization, translation, and question answering, often producing outputs nearly indistinguishable from human writing (Badshah & Sajjad, 2024; Verma, 2024).

Despite these advancements, LLMs possess an inherent architectural limitation: a finite context window. This window represents the maximum amount of text, measured in tokens, that a model can process simultaneously when generating a response or performing an analysis. Consequently, if critical information or dependencies within a document fall outside this fixed window, separated by a larger span of intervening text, the LLM may fail to capture the relationship or address the query accurately (Kaplan et al., 2020). This limitation poses a significant challenge when analyzing large or complex documents where understanding relies on synthesizing information across distant sections.

A promising approach to mitigate this limitation involves transforming large, unstructured documents into structured representations using Knowledge Graphs (KGs). Through the extraction of key entities, relation-

ships, and attributes from text and mapping them into a graph structure, it becomes possible to represent the document’s core semantic content in a format amenable to computational analysis (Hogan et al., 2021). Such a structure allows for querying and reasoning over the entire document’s scope, independent of an LLM’s context window constraints, potentially enabling a more focused and comprehensive analysis for tasks like ensuring information integrity.

This chapter reviews the pertinent literature underpinning this approach, beginning with an examination of the development and characteristics of Large Language Models. It focuses on their capabilities and limitations, particularly the context window constraint. Subsequently, the text delves into the principles, construction, and application of KGs as structured knowledge representations. Key techniques for populating KGs from text via Information Extraction (IE) are then discussed, followed by an exploration of the challenges associated with processing large and complex documents, especially within the legal domain. The chapter concludes by defining the critical concepts of consistency, completeness, and coherence, surveying related work, and presenting a summary that motivates the proposed research direction.

## 2.2 Large Language Models

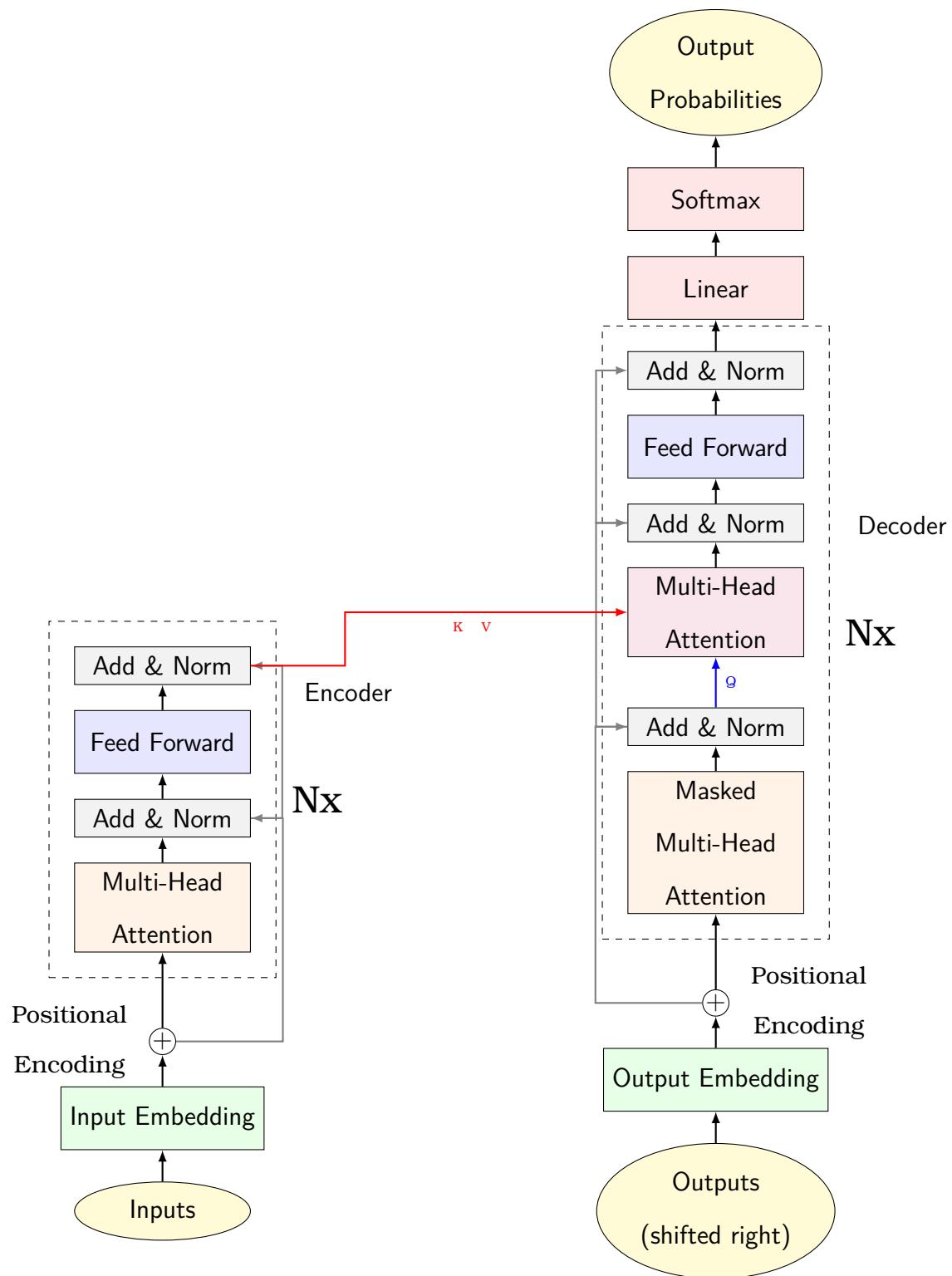
The trajectory of modern NLP took a significant turn in 2017 with the publication of *Attention Is All You Need* by Vaswani et al. (Vaswani et al., 2017). This work introduced the Transformer architecture, which relies on self-attention mechanisms to weigh the importance of different words (tokens) in an input sequence. This design enables superior handling of long-range dependencies compared to previous dominant recurrent or

convolutional architectures, thereby addressing critical bottlenecks in earlier sequence models (Turner, 2024; Zhao et al., 2023). This innovation paved the way for the development of increasingly powerful language models, such as Google's BERT, which introduced bidirectional pre-training (Gardazi et al., 2025), and OpenAI's influential Generative Pre-trained Transformer (GPT) series (Gao et al., 2023).

While research groups at numerous institutions continuously pursued improvements, the public release of OpenAI's *ChatGPT* on November 30, 2022, marked a pivotal moment. The event dramatically increased public awareness and accelerated the deployment of advanced conversational AI systems. It also catalyzed the development of competing models from major research labs, including Google's *Gemini* family, Anthropic's safety-focused *Claude* series, and Meta's open-source *Llama* family (Caruccio et al., 2024; Grattafiori et al., 2024; Team et al., 2024). The proliferation of models is evident on platforms like Hugging Face, a central repository for AI models and datasets, which reportedly surpassed one million hosted models by late 2024 (Edwards, 2025).

Functionally, LLMs process input text (a "prompt") by converting it into numerical representations called tokens, often using techniques like Byte Pair Encoding (BPE) or WordPiece (Schmidt et al., 2024). The model then uses the complex patterns learned during pre-training on vast text corpora to predict subsequent tokens autoregressively, generating a coherent and contextually relevant output. Prompts can be engineered to elicit specific behaviors, including the analysis of substantial text provided for context (in-context learning). For instance, an LLM can be prompted with a company's annual report to answer specific questions or to summarize key findings, tasks on which many current models perform reasonably well, provided the

information falls within their processing limits (Rzepka et al., 2023). The architecture of the Transformer model is depicted in Figure 2.1.



adapted from Vaswani et al. (2017)

**Figure 2.1:** The Transformer - model architecture

A fundamental limitation of LLMs, however, remains the context window size. This size, representing the maximum number of tokens the model can attend to simultaneously, is always finite, although it has increased with newer model generations (Kaplan et al., 2020; Liu et al., 2025; Ratner et al., 2022). If a document's length exceeds this limit, the LLM cannot process it in a single pass. Standard techniques involve processing the document in chunks, yet this can sever long-distance contextual links crucial for deep understanding (T. Chen et al., 2024). For example, determining if a policy defined on page one of a lengthy legal code is contradicted by regulations hundreds of pages later becomes impossible if the intervening text exceeds the context window, as the model would process these sections independently.

Furthermore, the computational cost of processing information within the context window is a significant factor. The self-attention mechanism, core to the Transformer, typically scales quadratically ( $O(n^2)$ ) with the sequence length ( $n$ ) in terms of both computation and memory requirements (Vaswani et al., 2017). Although various "efficient Transformer" variants aim to reduce this to near-linear complexity, processing long sequences still demands substantial resources (Tay et al., 2023). This scaling makes analyzing very large documents prohibitively expensive or slow for many practical applications, further motivating alternative approaches, such as KG-based structuring, for achieving comprehensive and efficient analysis.

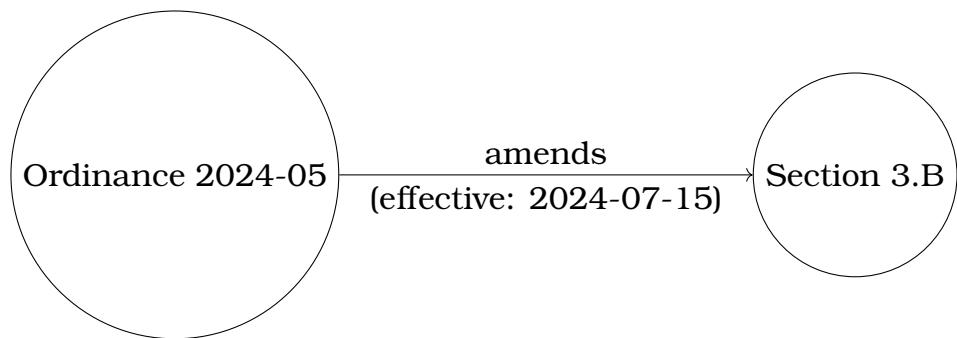
### 2.3 Knowledge Graphs

Knowledge Graphs (KGs) provide a structured paradigm for representing information, evolving from concepts in semantic networks, frame systems, and earlier AI research in symbolic knowledge representation (Hogan et al.,

2021). Formally, a KG represents knowledge as a directed labeled graph, comprising a collection of interconnected entities (nodes) and the explicitly typed relationships (edges) between them. Both nodes and edges can possess attributes or properties that store additional metadata or context (Cong, 2024; Ehrlinger & W "o ss, 2016).

The core components of a KG are as follows:

- **Nodes (Entities):** These represent real-world objects, abstract concepts, events, or specific instances of interest. Examples include persons, organizations, locations, legal statutes ('15 Pa.C.S.A. § 1502'), or defined terms ('nonconforming use'). Nodes are often identified by unique identifiers.
- **Edges (Relationships):** These represent the connections or typed relationships between pairs of nodes, such as 'works for', 'located in', 'cites', or 'amends'. Edges are typically directed from a subject node to an object node and are labeled with the relationship type.
- **Attributes (Properties):** These are key-value pairs associated with nodes or edges, providing additional details. For instance, a 'Person' node might have an 'email' attribute, or a 'cites' edge might have an 'effectiveDate' attribute.



**Figure 2.2:** Knowledge graph fragment of a legal amendment.

Pioneering work in structured knowledge includes Minsky's concept of Frames, which represented stereotypical situations using slots and relationships, thereby influencing subsequent formalisms like description logics and semantic web ontologies (Minsky, 1974).

Knowledge graphs are implemented using various technologies. The Resource Description Framework (RDF) is a W3C standard based on triples (subject-predicate-object) and is foundational to the Semantic Web. It is often queried using SPARQL and defined with ontology languages like OWL (Hitzler, Krotzsch, & Rudolph, 2009b; N. Kumar & Kumar, 2013; "RDF 1.2 Primer", 2025). Property Graphs, used in databases like Neo4j, offer a flexible model where both nodes and edges can have properties and are queried with languages like Cypher or Gremlin (Fernandes & Bernardino, 2018). Additionally, Graph Neural Networks (GNNs) are machine learning techniques that operate on graph structures to learn vector representations (embeddings), enabling tasks like link prediction and node classification (Gupta et al., 2021; Scarselli et al., 2009; K. Wang et al., 2024).

KGs are employed in diverse applications, including semantic search, recommendation systems, and enterprise data integration (Fensel et al., 2020; Hogan et al., 2021; Ji et al., 2022). Their ability to explicitly model complex relationships makes them valuable for analyzing the internal structure and integrity of large document collections.

## 2.4 Information Extraction for KG Construction

To leverage KGs for document analysis, the unstructured information within source documents must be transformed into the structured format of a graph. This process, termed KG construction, relies on Information Extraction (IE) techniques (Kolluru et al., 2020; Zhong et al., 2024). This

section covers two fundamental IE tasks: identifying nodes via Named Entity Recognition (NER) and identifying edges via Relation Extraction (RE). LLMs have shown significant promise in performing both tasks, often with minimal task-specific training data (Benjira et al., 2025).

#### 2.4.1 Named Entity Recognition

Named Entity Recognition (NER) is a primary task in information extraction that identifies and classifies named entities in text into predefined categories (Al-Moslmi et al., 2020). These categories can include standard types like persons and organizations or be extended to domain-specific entities. For building KGs, NER serves as the main mechanism for identifying the potential **nodes** of the graph. A subsequent step, Entity Linking, is often necessary to disambiguate these mentions and link them to unique identifiers (Chaurasiya et al., 2022).

NER methods have evolved significantly. Early approaches were rule-based systems that used hand-crafted rules and dictionaries, which achieved high precision but were brittle and labor-intensive (Grishman & Sundheim, 1996; Nadeau & Sekine, 2007). These were followed by statistical models like Hidden Markov Models and Conditional Random Fields, which offered better generalization (Lafferty et al., 2001). Currently, deep learning approaches, particularly Transformer-based models like BERT, have achieved state-of-the-art performance by leveraging powerful pre-trained representations (Al-Moslmi et al., 2020; Carbonell et al., 2020).

Applying NER to the legal domain requires identifying specialized entities such as specific statutes, defined legal terms, legal roles, and explicit document references (Au et al., 2022; Kalamkar et al., 2022). The unique vocabulary and complex sentence structures of legal texts necessitate that

NER models be trained or fine-tuned on legally annotated corpora to achieve high accuracy (Chalkidis et al., 2022). A robust legal NER system provides the essential building blocks for constructing a meaningful knowledge graph from legal documents.

#### 2.4.2 Relation Extraction

While NER identifies entities (nodes), Relation Extraction (RE) identifies the semantic relationships between them, which correspond to the edges in a knowledge graph (Carbonell et al., 2020; Ji et al., 2022). For instance, from the sentence "Acme Corp, headquartered in West Chester, acquired Beta Inc.," RE aims to identify relations such as 'headquarteredIn(Acme Corp, West Chester)'. This task is crucial for building the graph's structure. Work in this area includes both Closed RE, for a predefined set of relation types, and Open Information Extraction (OpenIE), which extracts relations expressed with arbitrary text (Etzioni et al., 2008).

Approaches to RE have mirrored those in NER. Early systems were rule-based, using linguistic patterns to identify relations (Hearst, 1992). Supervised statistical models followed, using classifiers trained on annotated data or data generated through distant supervision, a technique that aligns known relations from KGs with text but can introduce noise (Kambhatla, 2004; Mintz et al., 2009). Modern deep learning approaches, especially Transformer-based models, now represent the state-of-the-art (S. Kumar, 2017; Wu & He, 2019). LLMs, through prompting techniques, offer a powerful alternative capable of extracting relations with minimal task-specific fine-tuning (Chia et al., 2022).

Key challenges in RE include handling ambiguity, extracting relations that span sentences, and adapting models to new domains. In the legal

context, extracting relations such as amendments, definitions, and obligations is critical for building a KG that accurately reflects the legal framework (Dhani et al., 2021; Tauqeer et al., 2022). The structured output from NER and RE forms the basis for the constructed knowledge graph.

## 2.5 Consistency, Completeness, and Coherence

When analyzing formal document corpora such as legal codes or technical standards, quality evaluation often involves assessing internal integrity. Three key aspects of this integrity are consistency, completeness, and coherence (Umar & Lano, 2024). These concepts, while sometimes overlapping, address distinct facets crucial for ensuring documents are understandable, unambiguous, and effective.

- **Consistency:** Refers to the absence of logical contradictions within a document set (Egyed, 2006; Guo et al., 2023; Heitmeyer et al., 1996; Nentwich, 2005; Tröls et al., 2022; Yang et al., 2024; Zowghi & Gervasi, 2003). A consistent document should not contain provisions that assert mutually exclusive facts or prescribe conflicting obligations under identical conditions. Detecting such inconsistencies is vital for legal certainty and predictability (Donelson, 2019; Duck-Mayr, 2022; Rossi, 2016). Formal logic and automated reasoning techniques are often employed to check consistency in formal specifications (Brucker & Wolff, 2019; Heitmeyer et al., 1996).
- **Completeness:** Pertains to whether the document set contains all necessary information relative to its intended scope (Zowghi & Gervasi, 2003). Defining completeness is inherently challenging, as it depends on a clear specification of what should be included. In a legal context,

completeness may require that all terms are adequately defined, referenced procedures are specified, and relevant scenarios are addressed. Gaps or omissions can lead to ambiguity and disputes. Assessing completeness often requires significant domain knowledge and may involve checking against predefined templates or requirements specifications (Umar & Lano, 2024; Zowghi & Gervasi, 2003). The interpretation of completeness in KGs is also affected by the "Closed World Assumption" versus the "Open World Assumption" (Hitzler, Krötzsch, & Rudolph, 2009a; Reiter, 1978).

- **Coherence:** Relates to the overall understandability, organization, and logical flow of the presented information (Shen et al., 2021; Wang & Guo, 2014). A coherent document is well-structured, uses terminology consistently, and ensures cross-references are accurate. While related to consistency, coherence focuses more on clarity and comprehensibility for a human reader, encompassing aspects like lexical cohesion and discourse structure (Wang & Guo, 2014).

Ensuring these three qualities simultaneously in large, evolving legal codes through traditional manual review is exceptionally difficult. The volume of text, the intricate web of interdependencies, the potential for ambiguity in natural language, and the distributed nature of authorship make manual detection of subtle flaws challenging and error-prone (Beth, 2018). Computational approaches that leverage structured representations like KGs offer significant potential advantages.

A Knowledge Graph provides a structured substrate amenable to automated analysis by explicitly modeling entities and their relationships. Graph-based queries and algorithms can be designed to automatically detect potential inconsistencies, such as conflicting property values or circular

definition chains (Brucker & Wolff, 2019; Schönberg et al., 2011; Tauqeer et al., 2022; Weitl & Freitag, 2006). While perfect completeness verification is often intractable for natural language documents, KGs can help identify potential gaps by analyzing the graph’s structure for missing nodes, absent relationships, or orphaned sections (Knublauch & Kontokostas, 2017; Omran et al., 2020; Rabbani et al., 2022, 2023; Umar & Lano, 2024).

LLMs can play a role throughout this pipeline, aiding in the initial interpretation of text to populate the KG, helping to formulate complex graph queries, or summarizing the findings from the analysis for human review (Benjira et al., 2025). The KG itself, however, provides the persistent, globally coherent, and computationally tractable structure necessary for systematic integrity checks. Such a structure can overcome the context window limitations and potential lack of deterministic reasoning inherent in LLMs alone. Research exploring KGs and related AI techniques for automated integrity checking provides a foundation for this approach (Aumiller et al., 2021; Dhani et al., 2021; Heitmeyer et al., 1996; Tauqeer et al., 2022; Umar & Lano, 2024). This praxis project aims to build upon such work by investigating the practical application of LLM-driven KG construction for analyzing municipal legal codes.

## 2.6 Challenges in Analyzing Large Documents

Research in automated document processing is extensive, covering tasks like summarization, information extraction, and question answering (D. Chen et al., 2017; Gambhir & Gupta, 2017; Zhong et al., 2024). Historically, much of this research focused on relatively small documents, as they are less computationally demanding and more feasible for the human evaluation required to establish ground truth.

Many critical real-world applications, however, involve documents that are orders of magnitude larger, such as legal contracts, technical manuals, and extensive regulatory codes. Analyzing these large documents presents distinct and significant challenges:

- **Computational Resources:** Processing large volumes of text demands substantial memory, storage, and processing time. The computational complexity often scales non-linearly with document length, making naive processing of entire large documents infeasible (Vaswani et al., 2017).
- **Long-Range Dependencies:** Comprehension frequently requires capturing semantic connections or references between sections that are far apart in the document. Models with limited context windows struggle to capture these long-distance relationships accurately (Liu et al., 2025; Zhao et al., 2023).
- **Context Fragmentation:** A common technique for handling large documents involves splitting them into smaller chunks. This method, while necessary for models with fixed inputs, risks losing critical context that spans chunk boundaries, potentially leading to fragmented understanding (T. Chen et al., 2024; Qu et al., 2024).
- **Evaluation Complexity:** Assessing the quality of automated analysis on a large document is inherently difficult for human evaluators. Establishing reliable ground truth for evaluation benchmarks remains a major challenge for large-document tasks (Shaham et al., 2022).

Techniques like Retrieval-Augmented Generation (RAG) allow LLMs to leverage information from large external corpora without processing the entire

corpus in their context window (Lewis et al., 2020). RAG retrieves relevant text snippets and provides them as context to the LLM. Although powerful for knowledge-intensive tasks, standard RAG retrieves discrete, localized chunks and may not provide the holistic, structured view of the entire document that a pre-constructed Knowledge Graph can offer.

## 2.7 Challenges in Analyzing Legal Documents

Legal documents, particularly statutory codes, represent a compelling yet challenging domain for advanced document analysis techniques. They possess several intrinsic characteristics that make them difficult testbeds and valuable targets for automation:

- **Complexity and Precision:** Legal language is dense, employing specialized terminology and complex sentence structures. Ambiguity must be minimized, demanding high precision in interpretation, as misinterpretations can have significant real-world consequences (Ashley, 2017; Malik et al., 2022).
- **Volume and Interconnectedness:** Legal corpora can be vast and are highly interconnected through citations, amendments, and definitions. Understanding one part often requires understanding its relationship to many others (Beth, 2018).
- **Semi-structured Format:** Legal texts mix structured elements (e.g., sections, clauses) with unstructured natural language prose, requiring sophisticated NLP techniques to handle both.
- **Critical Need for Integrity:** The consistency, completeness, and coherence of legal documents are paramount for their function. These

qualities underpin the rule of law, ensuring predictability and enforceability. Flaws can lead to disputes, costly litigation, and erosion of public trust (Donelson, 2019; Duck-Mayr, 2022; Rossi, 2016).

The specific focus on the codified ordinances of Pennsylvania townships provides a valuable and concrete dataset. These codes exhibit realistic complexity, having often been developed over decades with multiple authorships and numerous amendments. The legislative drafting and codification process, although designed to ensure quality through multi-stage human review, can still introduce errors. Inconsistencies, incompleteness, and incoherence can persist as the code grows (Rossi, 2016). The resource-intensive and fallible nature of purely manual review motivates the exploration of computational methods to assist legal professionals in maintaining the integrity of these foundational legal documents.

## 2.8 Related Work

Research relevant to this praxis project spans several areas: utilizing LLMs for Information Extraction, applying KGs for document integrity checking, and the application of NLP to the legal domain.

**LLMs for Information Extraction and KG Construction:** The advent of powerful LLMs has advanced information extraction. Studies demonstrate the ability of models like GPT-4, often via prompting, to perform NER and RE with performance rivaling or exceeding traditional fine-tuned models, especially in specialized domains (Xu et al., 2024). Researchers have explored various techniques to mitigate LLM limitations like hallucinations and to control output structure (S. Wang et al., 2023). Several works focus on constructing KGs from text using LLMs as the primary extraction engine, developing pipelines that integrate entity identification, relation extraction,

and schema mapping, sometimes with human-in-the-loop refinement (Benjira et al., 2025; Lairgi et al., 2024).

**KGs for Document Analysis and Integrity Checking:** Beyond construction, KGs serve as a substrate for advanced document analysis, including semantic search and complex question answering (Hogan et al., 2021; Ji et al., 2022). Directly relevant to this work is the use of KGs for consistency and completeness checking. In software requirements engineering, KGs and ontologies model requirements to detect conflicts (Umar & Lano, 2024). In the Semantic Web community, technologies like SHACL (Shapes Constraint Language) provide a standard way to validate RDF KGs against predefined constraints, effectively checking aspects of data integrity (Knublauch & Kontokostas, 2017).

**AI and NLP for Legal Document Analysis:** The legal domain has been a target for AI and NLP research for decades (Ashley, 2017). Recent research applies modern NLP to tasks like legal information retrieval, case outcome prediction, and contract review (Aletras et al., 2016; Chalkidis et al., 2022; Moens, 2001). Information extraction from legal texts has received significant attention, focusing on extracting citations, legal entities, and obligations (Kalamkar et al., 2022; Tauqeer et al., 2022). Some prior work has explored automated consistency checking in legal documents, often using rule-based or logic-based approaches, but these efforts have typically focused on specific types of conflicts rather than a comprehensive KG-based approach applied to municipal codes (Rossi, 2016).

**Positioning of this Work:** This praxis project builds upon these converging lines of research. While previous work has explored LLMs for KG construction and KGs for consistency checking separately, the specific contribution here lies in the integration and practical application of modern

LLMs to construct KGs from municipal legal codes for consistency and completeness analysis. The project addresses LLM context window limitations by leveraging the KG structure for global reasoning. Unlike prior legal AI work focusing on case law or contracts, this project targets foundational legislative texts at the local government level. The "praxis" aspect emphasizes developing and evaluating a practical methodology to assist municipal professionals in maintaining the quality of their codified laws.

## 2.9 Conclusions

This chapter surveyed key literature relevant to utilizing LLMs and KGs for analyzing legal documents. The review traced the rise of LLMs from the Transformer architecture, noting their capabilities alongside their critical context window limitations (Liu et al., 2025; Vaswani et al., 2017). Knowledge Graphs were introduced as a structured paradigm capable of overcoming these limitations for global analysis (Hogan et al., 2021). The discussion covered Information Extraction as the bridge from unstructured text to structured KGs, detailing the roles of NER and RE (Xu et al., 2024).

The application was framed by defining the quality attributes of consistency, completeness, and coherence (Zowghi & Gervasi, 2003). The challenges of maintaining these qualities manually in complex legal codes motivate the need for computational assistance (Beth, 2018). This project is situated within research on LLM-driven IE, KG-based analysis, and legal AI, but is distinguished by its novel integration and practical focus on consistency and completeness checking for municipal ordinances.

The limitations of LLMs for global document understanding and the structure offered by KGs, combined with the critical need for ensuring legal code integrity, motivate the methodology of this praxis project. By

leveraging LLMs to extract information from complex legal text and mapping it into a queryable KG, this work aims to develop and evaluate a practical approach to assist in identifying potential inconsistencies and omissions. The following chapter will detail the specific methodology employed to achieve this objective.

## **Chapter 3: Methodology**

### **3.1 Introduction**

This chapter details the systematic methodology for developing and evaluating a system that leverages Large Language Models (LLMs) to convert extensive legal documents into attributed knowledge graphs (KGs) (Fensel et al., 2020; Hogan et al., 2021). As established in Chapter 1, these KGs are intended to serve as a foundation for subsequent analysis of document completeness and consistency (Umar & Lano, 2024; Zowghi & Gervasi, 2003). The challenge of managing the complexity and scale of modern textual documents, particularly in legal codification, necessitates automated solutions (Bhattacharya et al., 2019). Traditional manual review is often insufficient for ensuring comprehensive consistency in large, evolving document sets. This research posits that KGs, by providing structured representations of entities and their relationships, offer a viable approach to address these challenges (Zhong et al., 2024).

The methodology herein is designed to be rigorous and reproducible. It outlines the overall research approach, system architecture, and data sources—specifically, Pennsylvania township laws. The chapter then details the critical hyperparameters governing the system, the experimental plan for their tuning, the software tools utilized, and the multi-faceted strategy for evaluating the quality of the generated KGs in the absence of a definitive ground truth. Finally, the inherent limitations of the chosen methods and relevant ethical considerations are examined, concluding with a restatement of the research questions and hypotheses this framework aims to address.

### 3.2 Approach

The research objective is the design, implementation, and evaluation of a robust pipeline for transforming large legislative documents into queryable KGs using LLMs (Benjira et al., 2025; Lairgi et al., 2024). The long-term goal is to facilitate automated checks for consistency and completeness. The system's design prioritizes accessibility, requiring minimal specialized skill for operation. Furthermore, it enforces strict traceability, ensuring any extracted information or flagged error can be linked to a specific location in the source document. While developed using legal texts, the architecture is intended to be generalizable to other domains with large, complex corpora (Shaham et al., 2022).

#### 3.2.1 Architectural Overview

The system architecture is a multi-stage pipeline that synthesizes established practices in KG construction from text (Ji et al., 2022) with novel adaptations for the legal domain. This modular design allows for targeted optimization at each stage. The data flows through several components to manage complexity, particularly the context window limitations of LLMs (Liu et al., 2025), and to iteratively build the KG.

The architectural components are as follows:

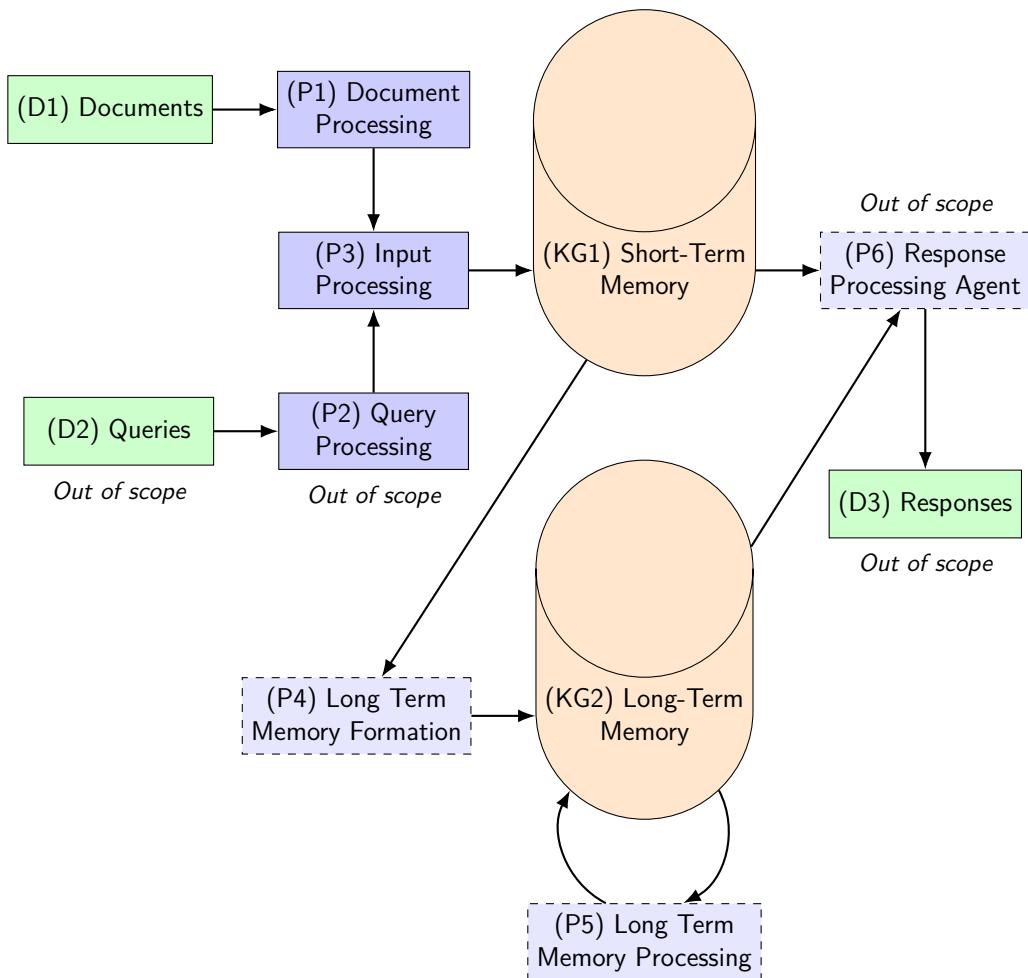
- **Document Processing:** Converts large source documents into smaller, semantically coherent segments ("chunks").
- **Input Processing:** Uses an LLM to perform Named Entity Recognition (NER) and Relation Extraction (RE) on each chunk, generating a KG fragment in JSON format.

- **Short-Term Memory (STM):** An in-memory buffer that temporarily stores these KG fragments.
- **Long-Term Memory (LTM) Formation:** A periodic process that aggregates fragments from STM, performs entity disambiguation and de-duplication, and structures the data for persistent storage.
- **Long-Term Memory (LTM):** A persistent Neo4j graph database that stores the consolidated, global KG.
- **LTM Processing:** Asynchronous operations performed periodically on the LTM to refine and enhance the global KG's structure and semantic richness.

Figure 3.1 depicts the data flow and interactions between these components. Note that query processing and response generation, while shown for architectural completeness, are out of scope for the present research.

### 3.2.2 Long Term Memory Processing Details

The LTM Processing stage iteratively refines the global KG's quality and structural integrity. Operations are performed on randomly selected subsets of the KG, allowing for gradual improvement without requiring complete reprocessing. This stage encompasses several sequential steps. First, core entities are marked with a 'DoNotChange' label to protect them from alteration by subsequent automated processes. Second, explicit ontological classifications are established by assigning 'ISA' relationships (e.g., "Ordinance\_123" 'ISA' "Ordinance") to entities, creating type hierarchies essential for semantic reasoning (Minsky, 1974; Noy & McGuinness, 2001). Third, meronymic (part-whole) relationships are modeled by assigning 'PARTOF'



**Figure 3.1:** High-Level System Architecture for Knowledge Graph Construction.

relationships (e.g., "Section\_3.B" 'PARTOF' "Article\_III"), which are critical for understanding document structure.

Subsequent steps focus on refining the type system. Synonymous or semantically equivalent entity types (e.g., "Regulation" and "Rule") are identified and merged into a single canonical type, often using LLM-generated embeddings to measure similarity (Gardazi et al., 2025). The various entity types are then organized into a coherent subsumption hierarchy (an ontology) using a combination of LLM-based classification and domain knowledge (Tian et al., 2022). Finally, the type assigned to an individual entity instance may be corrected or refined based on new evidence or a more appropriate classification within the evolving type hierarchy. This two-tiered approach, separating initial aggregation (LTM Formation) from deeper semantic refinement (LTM Processing), manages complexity by improving the KG incrementally.

### 3.3 Data

#### 3.3.1 Dataset Selection and Rationale

The primary dataset comprises the codified ordinances of various townships within the Commonwealth of Pennsylvania. This choice is predicated on several factors aligned with the research objectives. These documents are voluminous and linguistically complex, presenting a suitable challenge. Their public availability simplifies acquisition and supports open research principles. Legal codes contain rich interrelationships—such as cross-references, definitions, and amendments—that are well-suited for KG representation. The dataset directly addresses the problem of inconsistency in municipal laws identified in Chapter 1 (Curley, 2024; Rau, 2024). Fi-

nally, the researcher’s domain familiarity aids in the interpretation of legal nuances.

### **3.3.2 Data Acquisition and Pre-processing**

The township law documents will be acquired from online sources, primarily in DOCX format, which preserves structural information (e.g., heading styles) better than PDF. This structure is advantageous for developing semantically aware chunking strategies. An initial Exploratory Data Analysis (EDA) will be conducted on a representative sample to characterize document structure, length, linguistic features, and common entity types. The findings from EDA will inform the design of chunking strategies and LLM prompts. Following EDA, pre-processing will involve extracting textual content, removing irrelevant elements like headers and footers, and normalizing text based on EDA findings.

## **3.4 Hyperparameters**

The pipeline’s performance is governed by several critical hyperparameters, as detailed in Table 3.1. The choice of LLM is foundational, with candidates including models from the Google Gemini, OpenAI GPT, Anthropic Claude, and Meta Llama series. Evaluation will determine the model that yields the most accurate extraction of entities and relationships while minimizing errors like hallucinations (Rzepka et al., 2023). LLM-specific parameters such as temperature and maximum output tokens will also be tuned. To ensure consistently structured output, a JSON SCHEMA is used to constrain the model’s output, a procedural control found to be essential during initial development (Knublauch & Kontokostas, 2017).

Document chunking strategies are vital for processing large documents

within LLM context windows (Ratner et al., 2022). Three strategies will be investigated: paragraph-based chunking, staggered sliding windows, and overlapping chunks. The goal is to identify a strategy that maximizes information capture across chunk boundaries (Qu et al., 2024).

Finally, processing parameters control the execution of asynchronous consolidation and refinement. These include the STM fullness threshold (which triggers LTM Formation), the batch size for LTM Formation, the batch size for LTM Processing (number of nodes to refine per cycle), and the frequency of LTM Processing. These parameters will be tuned to achieve a practical balance between timely KG updates and manageable computational load.

*Table 3.1: Hyperparameter Experimental Design Overview.*

<b>Category</b>	<b>Specific Parameter</b>	<b>Values/Variations to be Tested</b>	<b>Rationale/Goal for Varying</b>
LLM Used	LLM Model	Gemini Pro, GPT-3.5-turbo, GPT-4/GPT-4o, Claude 3 Sonnet/Opus, Llama 3 (various sizes)	Identify LLM with optimal accuracy, reliability, and efficiency for legal text extraction and KG generation tasks.
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Table 3.1 – *Continued from previous page*

<b>Category</b>	<b>Specific Parameter</b>	<b>Values/Variations to be Tested</b>	<b>Rationale/Goal for Varying</b>
	LLM Temperature	e.g., 0.1, 0.3, 0.5, 0.7	Balance determinism/precision (for extraction) with sufficient flexibility; mitigate hallucination.
	Prompt Design	Iteratively refined prompt structures based on specific task (NER, RE, type assignment, etc.) and LLM.	Optimize LLM's understanding of the task and the desired output format (e.g., structured JSON).
Document Chunking	Strategy	Paragraph-based, Sliding Window (Staggered), Overlapping Chunks	Determine strategy that best preserves semantic context and minimizes information loss at chunk boundaries.
	Paragraphs per Chunk (for Paragraph-based)	e.g., 1, 3, 5 paragraphs	Find optimal semantic unit size that balances context with LLM input limits.

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Table 3.1 – *Continued from previous page*

<b>Category</b>	<b>Specific Parameter</b>	<b>Values/Variations to be Tested</b>	<b>Rationale/Goal for Varying</b>
	Overlap Percentage (for Overlapping Chunks)	e.g., 10%, 20%, 30%, 50%	Evaluate trade-off between context continuity and processing redundancy.
	Chunk Size (Tokens/Chars for Staggered/Over-lap)	e.g., 256, 512, 1024, 2048 tokens (adjusted based on selected LLM's context window)	Maximize local context available to LLM while adhering to its input constraints.
Processing	STM Fullness Threshold (Number of KGs)	e.g., 50, 100, 200, 500 KGs	Balance frequency of Long Term Memory Formation (LTM freshness) with processing overhead and STM memory usage.
	Long Term Memory Formation Batch Size	e.g., Process 50 KGs, 100 KGs, or 100% of STM if below threshold	Control the resource intensity and duration of individual Long Term Memory Formation cycles.

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Table 3.1 – <i>Continued from previous page</i>			
<b>Category</b>	<b>Specific Parameter</b>	<b>Values/Variations to be Tested</b>	<b>Rationale/Goal for Varying</b>
	LTM Processing Batch Size (Number of Nodes)	e.g., 100, 500, 1000, 2000 nodes	Determine optimal scope for LTM refinement cycles, balancing depth of processing with computational cost.
	Frequency of LTM Processing	e.g., After every N (e.g., 1, 5, 10) Long Term Memory Formations; Time-based (e.g., daily, weekly)	Control the overall rate of iterative refinement of the global KG in LTM.

### 3.5 Tooling

The methodology will be implemented using a standard set of tools for AI and NLP research. Python (version 3.8+) is the core programming language, selected for its extensive ecosystem of libraries, including clients for LLM APIs, frameworks like LangChain (Zhao et al., 2023), and data manipulation tools. Google Colaboratory will serve as the development environment, providing necessary computational resources (e.g., GPUs). The LTM will be implemented using Neo4j (version 5.x), a native graph database whose Cypher query language is well-suited for KG analysis (N. Kumar & Kumar, 2013). The ‘python-docx’ library will be used for parsing

input documents. Version control will be managed with Git and GitHub to ensure reproducibility.

### 3.6 Measurements

Evaluating the KG's quality is challenging due to the difficulty of establishing a "gold standard" ground truth for large legal documents (Dhani et al., 2021). The evaluation strategy is therefore multi-faceted, combining intrinsic and extrinsic measures to provide a holistic assessment of the KG's fidelity and utility, as summarized in Table 3.2.

The evaluation will assess three main areas. First, **Knowledge Graph Fit** addresses how well the KG represents the source documents. This will be measured through sample-based manual evaluation of extraction quality, calculating Precision, Recall, and F1-score against annotations created by domain-aware reviewers (Shen et al., 2021). It also includes qualitative expert review of the KG's content coverage and plausibility, verification of traceability from KG elements back to the source text, and analysis of the KG's structural integrity (e.g., node distributions, connectivity).

Second, the KG's **Suitability for C&C Analysis** will be assessed. While the implementation of C&C checking algorithms is future work, this evaluation determines if the KG is structured to support such analysis. This involves verifying the presence of requisite information types (e.g., definitions, obligations, cross-references), testing the KG's queryability for common integrity patterns (e.g., undefined terms), and a qualitative assessment of the KG's schema and ontology fitness for the legal domain.

Third, a controlled **Error Injection** experiment will be conducted. A typology of common legal document errors (e.g., conflicting definitions, broken references) will be developed. These errors will be systematically

introduced into source documents to create a synthetic ground truth (Mintz et al., 2009). The resulting KGs will be analyzed to calculate the Error Detection Rate (EDR), assessing the system's sensitivity to document flaws.

*Table 3.2: Summary of Measurement Metrics and Evaluation Methods.*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
Knowledge Graph Fit	Entity/Relation Extraction (Precision, Recall, F1-score)	Calculated against manual annotations on a sample of document chunks. Separate scores for entities (typed) and relations (typed).	Achieve high scores (e.g., target $F1 > 0.7-0.8$ , depending on the complexity of entity/relation types) on representative legal entity and relation types.
<i>Continued on next page</i>			

Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
	Content Coverage & Plausibility	Qualitative expert review of KG portions against source documents. Use of a checklist for key legal concepts and provisions.	High agreement among reviewers on the accuracy and comprehensiveness of KG representation. Key legal concepts from source documents are present and logically represented.
	Traceability	Percentage of randomly sampled KG elements (nodes/edges) that can be correctly and precisely linked back to their originating text passage(s) in the source documents.	Achieve very high traceability (e.g., target >95%), ensuring transparency and verifiability.
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Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
	KG Structural Integrity	<p>Analysis of node/edge type distributions, graph density, connectivity, presence of orphan nodes, untyped entities.</p> <p>Measure of reduction in duplicates/untyped entities after LTM processing.</p>	<p>Well-formed graph structure, logical type distributions, minimal structural anomalies.</p> <p>Demonstrable improvement in KG quality metrics as a result of LTM processing steps.</p>

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Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
Use for Consistency & Complete- ness (Suitability Assessment)	Presence of Requisite Information Types	Checklist-based evaluation: Does the KG contain entities and relationships (e.g., definitions, obligations, cross-references, effective dates) necessary for common C&C checks?	High coverage of essential information types identified as prerequisites for C&C analysis in legal texts.
<i>Continued on next page</i>			

Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
	Queryability for Integrity Patterns	<p>Ability to formulate and successfully execute Cypher queries targeting common C&amp;C patterns (e.g., undefined terms, broken references, conflicting provisions).</p> <p>Assessment of the meaningfulness of query results.</p>	KG structure and content support the execution of relevant C&C queries. Queries return plausible candidate C&C issues (validation of these issues is out of scope).

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Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
	KG Schema/Ontology Quality	Qualitative assessment of the clarity, coherence, domain-appropriateness, and completeness of the KG's type system and relationship definitions for representing legal knowledge relevant to C&C tasks.	The schema is logical, understandable, sufficiently expressive, and suitable for supporting downstream C&C applications in the legal domain.

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Table 3.2 – *Continued from previous page*

<b>Category</b>	<b>Metric</b>	<b>Definition</b>	<b>Goal</b>
Error Introduction	Error Detection Rate (EDR)	Percentage of deliberately injected document errors (from a predefined typology) that are identifiable (directly or indirectly) through analysis of the generated KG.	Achieve a high detection rate for a diverse set of introduced error types, demonstrating the KG's sensitivity to document flaws.
	Traceability of Error Indicators	For detected injected errors, can the KG elements that indicate the error be accurately traced back to the specific erroneous text in the modified source document?	High traceability for error indicators, allowing users to locate the source of potential issues identified via the KG.

### **3.7 Methodological Limitations**

This research acknowledges several limitations. The system's accuracy is dependent on the capabilities of the underlying LLM, which can hallucinate or misinterpret nuanced text (Zhao et al., 2023). Document chunking inherently risks losing context that spans across chunks (Qu et al., 2024). KG evaluation involves subjective judgment in the absence of a comprehensive ground truth, and errors in early pipeline stages can propagate (Zhong et al., 2024). The scope of this praxis is limited to textual content (excluding complex tables), and the system is developed and evaluated on Pennsylvania township laws; performance on other legal document types may vary. Finally, this work focuses on generating a KG \*suitable\* for C&C checks; the implementation of those checks is designated as future work (Zowghi & Gervasi, 2003).

### **3.8 Ethical Considerations**

The research is guided by several ethical principles. The data consists of public records, and no private or sensitive information is processed. The system is intended as an assistive tool for experts, not a replacement for human judgment; the emphasis on traceability mitigates the risk of over-reliance. The potential for LLMs to perpetuate biases present in training data is acknowledged (Zhao et al., 2023). All intellectual property will be handled according to university policy, and the principles of responsible innovation and transparency will be followed throughout the research.

### **3.9 Conclusion**

This chapter has presented a detailed methodology for developing and evaluating an LLM-based system to convert large legal documents into KGs. The objective is to create a foundation for future analysis of document consistency and completeness. The approach specifies a multi-stage pipeline, a systematic plan for hyperparameter tuning, and a multi-faceted evaluation strategy that combines quantitative metrics, qualitative reviews, and a controlled error injection experiment. By addressing inherent limitations and ethical considerations, this methodology provides a structured plan to investigate the research questions and test the hypotheses set forth in Chapter 1.

### **3.10 Research Questions**

This methodology is designed to address the following research questions:

**RQ1:** Can an LLM be used to convert a large document into a knowledge graph?

**RQ2:** Can an LLM be used to process multiple knowledge graphs into a typed cluster of knowledge graphs.

**RQ3:** Can a typed cluster of knowledge graphs be used to check the source document for consistency and completeness?

### **3.11 Research Hypotheses**

The research will test the following hypotheses:

**H1:** An LLM can be used to convert a large document into a knowledge graph.

**H2:** An LLM can be used to process multiple knowledge graphs into a typed cluster of knowledge graphs.

**H3:** A typed cluster of knowledge graphs can be used to check the source document for consistency and completeness.

## **Chapter 4: Results and Analysis**

### **4.1 Introduction**

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**Table 4.1:** Title of the table every first letter capitalized

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Something here	123	123

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$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (4.1)$$

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$$Precision = \frac{TP}{TP+FP} \quad (4.2)$$

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Table 4.2 depicts the xxxx.

**Table 4.2:** Test-2: Transformer vs. AutoTAB Performance Metrics

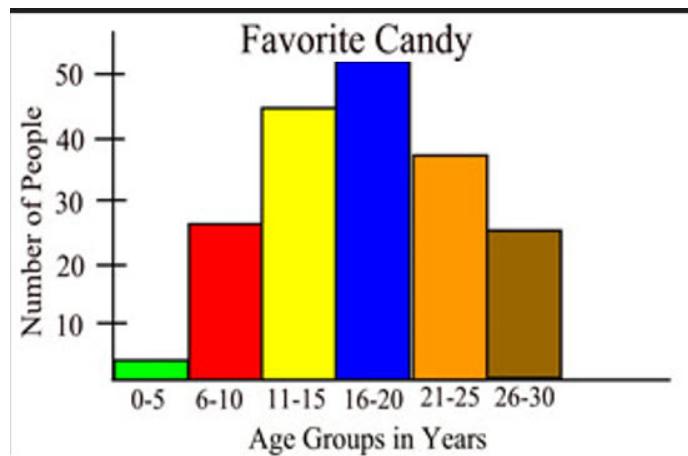
<b>Model</b>	<b>Method</b>	<b>A</b>	<b>P</b>	<b>R</b>	<b>F1</b>	<b>AUC</b>	<b>FNR</b>	<b>FPR</b>
Mod1	Sub1	<b>0.0123</b>						
	Sub2	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123
	Sub3	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123
Mod2	Sun1	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123
	Sub2	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123
	Sub3	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123

#### 4.1.1 Conclusion

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**Figure 4.1:** Histogram of XYZ

This is how to enter an equation and reference it. Equation 4.3 and 4.3 show how XYZ is implemented.

$$TE_{(pos,2i)} = \sin(pos/23^{2i/Lm}) \quad (4.3)$$

$$KN_{(pos,2i+1)} = \cos(pos/453^{2i/Lm}) \quad (4.4)$$

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***Table 4.3: My Table About Something***

<b>Reference</b>	<b>Technique</b>
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## **Chapter 5: Discussion and Conclusions**

### **5.1 Conclusion**

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### **5.2 Contribution to the Body of Knowledge**

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### **5.3 Recommendations for Future Research**

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Nothing to see here.