

GRAFT: A Graph-based Flow-aware Agentic Framework for Document-level Machine Translation

Himanshu Dutta^{1,3*}, Sunny Manchanda²,
Prakhar Bapat², Meva Ram Gurjar², Pushpak Bhattacharyya¹

¹Indian Institute of Technology Bombay, India

²DYSL-AI, DRDO, India ³Microsoft Research, India

{hdutta1024, manchanda.sunny}@gmail.com, pb@cse.iitb.ac.in

Abstract

Enterprises, public organizations, and localization providers increasingly rely on Document-level Machine Translation (DocMT) to process contracts, reports, manuals, and multimedia transcripts across languages. However, existing MT systems often struggle to handle discourse-level phenomena such as pronoun resolution, lexical cohesion, and ellipsis, resulting in inconsistent or incoherent translations. We propose **GRAFT**, a modular graph-based DocMT framework that leverages Large Language Model (LLM) agents to segment documents into discourse units, infer inter-discourse dependencies, extract structured memory, and generate context-aware translations. GRAFT transforms documents into directed acyclic graphs (DAGs) to explicitly model translation flow and discourse structure. Experiments across eight language directions and six domains show GRAFT outperforms commercial systems (e.g., Google Translate) and closed LLMs (e.g., GPT-4) by an average of **2.8** d-BLEU, and improves terminology consistency and discourse handling. GRAFT supports deployment with open-source LLMs (e.g., LLaMA, Qwen), making it cost-effective and privacy-preserving. These results position GRAFT as a robust solution for scalable, document-level translation in real-world applications. The codebase and data can be found at <https://github.com/himanshu-dutta/graft>.

1 Introduction

The growing global demand for real-time content localization, multilingual compliance, and cross-border communication has intensified the need for accurate document-level machine translation in sectors like finance, healthcare, legal services, and government. Whether translating legal contracts, product manuals, or multimedia transcripts, organizations face significant challenges in maintaining

consistency, fluency, and semantic integrity across long-form documents. Industrial translation workflows frequently involve massive volumes—often exceeding hundreds of thousands of pages per month—where errors in pronoun resolution, terminology drift, or contextual ambiguity can incur high costs.¹ ² ³ Despite the progress of modern sentence-level MT systems, they often produce brittle and fragmented output when faced with discourse-level complexity that spans multiple paragraphs or sections (Maruf et al., 2021a). DocMT seeks to generate translations that not only preserve the meaning of individual sentences but also maintain coherence, cohesion, and consistency across an entire document (Bawden et al., 2018).

Discourse phenomena in MT can be classified into *intra-discoursal* and *inter-discoursal* phenomena. Intra-discoursal phenomena, such as pronoun resolution, tense and aspect consistency, ellipsis recovery, and idiomatic expression translation, arise within a coherent segment of text. Inter-discoursal phenomena, such as entity co-reference, lexical cohesion, discourse connectives, and thematic progression, link separate segments to produce a fluent and coherent document (Hu and Wan, 2023).⁴

Figure 1 shows an example document segmented into discourses, annotated with various discourse phenomena.

Wang et al. (2025) focus on treating document-level MT as a sequential translation task. They translate each sentence individually in a sequence, while maintaining a persistent memory, which is updated after the translation of each sentence. Similarly, Hu and Wan (2023) explore the inherent discourse structure present in documents by utiliz-

¹<https://credloc.com/high-volume-document-translation>

²<https://localise.com/blog/document-translation/>

³<https://www.forbes.com/contrasting-ai-and-human-translation/>

⁴We discuss various discourse-level phenomena prominent for the translation task in Appendix A.

* Work done as a graduate student at IIT Bombay.

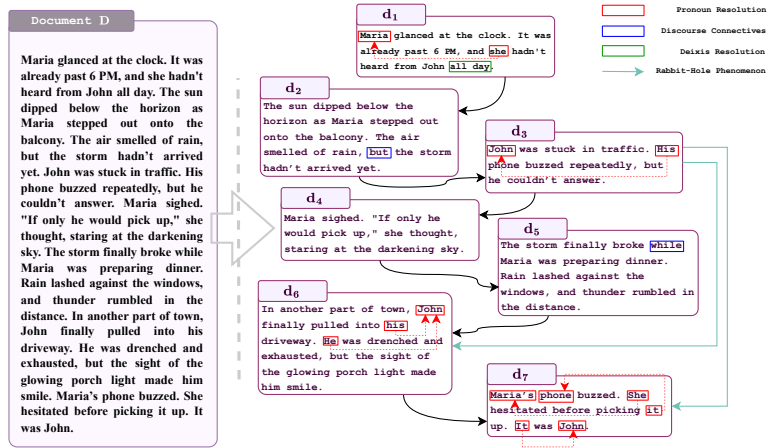


Figure 1: An example illustrating a document D segmented into discourse units (d_i), represented as nodes in a directed acyclic graph. The structure highlights discourse-level phenomena, including **sequential connections between discourses**, **pronoun resolution**, **discourse connectives**, **deixis resolution**, and **the rabbit-hole phenomenon**. This representation demonstrates how a document’s internal relationships and cohesive elements can be systematically analyzed. These phenomena are invisible to the existing approaches, with varying degrees of effects.

ing the paragraph as the discourse boundary. Both these approaches use heuristic rules to decide discourse boundaries, which are difficult to align with the idea of discourse segmentation for the task of translation.

Ideally, a discourse segmentation strategy should ensure that each discourse unit is self-contained for handling intra-discourse phenomena, such as pronoun resolution and verb tense consistency, utilizing its own context. Simultaneously, it should facilitate the handling of inter-discourse phenomena, like entity co-reference and lexical cohesion, by leveraging context from related discourse units. Further, most memory or cache-based document-level MT systems discussed above treat context as a flat or heuristic aggregation of preceding sentences, failing to model fine-grained dependencies between discourse units (Bawden et al., 2018; Voita et al., 2018, 2019).

These observations reveal three key gaps: (1) Lack of principled discourse segmentation aligned to translation, (2) Absence of structured dependency modelling between discourse units, and (3) Insufficient mechanisms to propagate rich, structured context during translation.

To bridge these gaps, we propose *GRaph-based Flow-aware Agentic Framework for Document-level Machine Translation (GRAFT)*, an agent-based system for DocMT that transforms a *source document D* into a DAG structure over discourses. It employs four specialized LLM agents: a *Discourse Agent* segments the document into self-

contained units; an *Edge Agent* infers directed dependencies between discourse units to model contextual linkage; a *Memory Agent* extracts structured local memory from each translated discourse; and a *Translation Agent* generates context-informed translations using both current and prior discourse memory. Unlike monolithic systems, GRAFT’s modular design enables better propagation of discourse phenomena, integration with arbitrary LLMs, and deployment in resource-sensitive environments.

Crucially, GRAFT is designed for industrial deployment. It can be run entirely using open-source LLMs such as LLaMA (Dubey et al., 2024) or Qwen models (Yang et al., 2024; Team, 2024), offering a cost-efficient and privacy-preserving alternative to closed-source systems. This is particularly important for organizations such as healthcare, legal, and defence institutions that operate under strict data protection regimes. Furthermore, while commercial sentence-level systems such as Google Translate⁵ are widely used, studies show they struggle with document-level discourse cohesion and terminology consistency (Wang et al., 2023a). To ensure the real-world applicability of GRAFT, all our experiments are conducted on datasets that originate from industry-relevant scenarios. These include public talks, multilingual QA forums, fictional literature, news bulletins, podcast transcripts, and domain-specific translation settings. These diverse and grounded sources reflect actual demands

⁵<https://translate.google.com/>

encountered by professional translation systems and localization teams.

Our contributions are:

- **GRAFT System (Section 2):** A modular LLM agent-based document-level MT system that segments, connects, and translates discourse units using a DAG. GRAFT achieves an average gain of 6.4 d-BLEU over Google Translate, and 3.4 d-BLEU over other LLM-based systems (Table 1). It performs comparably to GPT-4o-mini, while being fully open, extensible, and significantly more cost-efficient.
- **Agentic Discourse-Graph Dependency Modelling (Subsection 2.1):** We introduce a novel approach to represent the source document for translation as a DAG to model dependencies between discourse segments effectively. This leads to an average performance gain of 2.0 d-BLEU scores across eight translation directions (Table 5, 6).

2 Graph-Augmented Agentic Framework for Document-Level Translation

We define a *source document* D as a sequence of n sentences, $D = \{s_1, s_2, \dots, s_n\}$. The goal of DocMT is to generate a *target document* $\hat{D} = \{\hat{t}_1, \hat{t}_2, \dots, \hat{t}_m\}$ that is both fluent and faithful to D , preserving intra- and inter-discourse phenomena (e.g. coreference, discourse connectives, terminology consistency). We hypothesize that if we segment D into coherent *discourses*, translate each discourse with its own context augmented by relevant context from related discourses, and then stitch the segment translations together, we can effectively address document-level challenges.

Formally, let $V = \{d_1, d_2, \dots, d_K\}$ be a partition of the sentence indices $\{1, \dots, n\}$ into K contiguous segments (discourses), where

$$d_i = \{s_{\ell_i}, s_{\ell_i+1}, \dots, s_{u_i}\}, \quad 1 \leq \ell_i \leq u_i \leq n.$$

Each discourse d_i is translated into a target segment τ_i , and the final document $\hat{D}$ is $\hat{D} = [\tau_1, \tau_2, \dots, \tau_K]$. By explicitly modelling both intra- and inter-discourse phenomena at the segment level, we can leverage local cohesion while propagating global context.

We provide the task description and prompt templates for the decision function, f_{LLM} , the relevance function, $\mathcal{L}_{\text{edge}}$, the memory extraction function, $\mathcal{L}_{\text{mem}}$, and the translation agent, $\mathcal{L}_{\text{trans}}$ in

Appendix J. Figure 2 illustrates the end-to-end GRAFT pipeline.

2.1 Source Document $\rightarrow$ Directed Acyclic Graph

The first step of our GRAFT pipeline transforms the *source document* D into a DAG of the discourses. This is achieved by the *Discourse Agent* first segmenting D into a contiguous sequence of segments, S , and then *Edge Agent* adding directed edges between those segments. We describe the two agents in this section.

2.1.1 Discourse Agent (Segmentation)

The first sub-problem is to segment D into discourse units that are internally coherent (handling word-sense disambiguation, idioms, terminology) and amenable to translation in isolation. We implement an LLM-based Discourse Agent $S = \mathcal{L}_{\text{seg}}(D)$ which yields $S = \{d_1, \dots, d_K\}$ via an iterative decision function. Let d_{curr} be the current segment under construction, and s_i be the current sentence under consideration, then the decision function $f_{\text{LLM}}(d_{\text{curr}}, s_i)$ returns *true* if s_i should be included in d_{curr} , otherwise it returns *false*.

For the decision function, $f_{\text{LLM}}(d_{\text{curr}}, s_i)$, we utilize a few-shot prompting strategy. We compare this LLM-based segmentation to (i) *random segmentation* and (ii) *semantic-similarity segmentation* based on embedding cosine similarity (Appendix E.1). The detailed working of the Discourse Agent is provided in Appendix B.

2.1.2 Edge Agent (Dependency Modelling)

The second sub-problem is to identify which prior discourses each discourse depends on, capturing inter-discourse phenomena (such as, pronoun antecedents, discourse relations). We construct a directed graph $G = (V, E)$, $V = S$, with adjacency matrix

$$E = \{(d_j \rightarrow d_i) \mid j < i, \text{ if } \mathcal{L}_{\text{edge}}(d_j, d_i)\} \cup \{(d_j \rightarrow d_i) \mid j < i, \text{ if } j + 1 = i\}, \quad (1)$$

where $\mathcal{L}_{\text{edge}}(d_j, d_i)$ is an LLM-based relevance function, which either returns *true* if the edge should exist, otherwise *false*. We adopt a few-shot prompting strategy for the relevance function. The LLM is asked to assess whether context (see Section 2.2.1) is required from the translation process (performed by *Translation Agent* and *Memory Agent*) of d_j for the translation of d_i . We add dependency from d_{i-1} to d_i in the adjacency matrix as

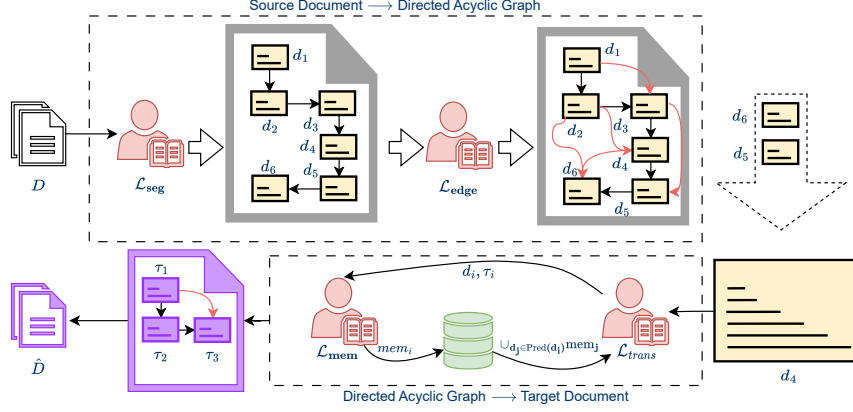


Figure 2: **GRAFT** pipeline: Illustrating the document-level translation pipeline involving four agents: the Discourse Agent ($\mathcal{L}_{\text{seg}}$), Edge Agent ($\mathcal{L}_{\text{edge}}$), Translation Agent ($\mathcal{L}_{\text{trans}}$), and Memory Agent ($\mathcal{L}_{\text{mem}}$). The process begins with a document D as input, which is segmented into discourse segments/nodes (d_i) by the $\mathcal{L}_{\text{seg}}$. These segments are then structured into a directed acyclic graph (DAG) with nodes and directed edges, representing dependency relationships, by the $\mathcal{L}_{\text{edge}}$. The Translation Agent and Memory Agent iteratively process the nodes, where the $\mathcal{L}_{\text{trans}}$ generates translations for discourse segments using context provided by the $\mathcal{L}_{\text{mem}}$, which maintains and updates local memory (mem_i) based on source and translated discourses. This iterative loop ensures context-aware and cohesive translations, enabling effective handling of intra-discourse phenomena.

d_{i-1} has the immediate predecessor relation with d_i , which allows us to maintain the flow of the document while translating it.

We compare our approach with the following strategies: (i) *chain graph* (d_i depends only on d_{i-1}) and (ii) *TF-IDF graph* with edges for high TF-IDF cosine similarity (Appendix E.1).

2.2 Directed Acyclic Graph $\rightarrow$ Target Document

The second step of our GRAFT pipeline transforms the DAG into *target document* $\hat{D}$. This is achieved by the *Memory Agent* extracting local memory, mem_i for each discourse d_i . The translation agent uses the context from the discourse d_i , along with the combined context, $\text{mem}_i^{\text{inc}}$ from all related discourses. We detail these two agents in this section.

2.2.1 Memory Agent (Context Extraction)

For each source discourse d_i and its corresponding translated discourse τ_i , the Memory Agent constructs a structured local memory, denoted as:

$$\text{mem}_i = (M_i^{\text{np}}, M_i^{\text{ent}}, M_i^{\text{phr}}, C_i, S_i), \quad (2)$$

where M_i^{np} represents mappings of nouns to pronouns in the target language, and M_i^{ent} denotes mappings of entities from the source language to the target language. Similarly, M_i^{phr} captures phrase-to-phrase mappings between the source and target languages, while C_i contains the translations of discourse connectives in the target language.

Lastly, S_i provides a concise one-line summary of the discourse context in the target language. Each of these components is extracted using an LLM-based function, $\mathcal{L}_{\text{mem}}(d_i, \tau_i)$, ensuring precise and contextually aware memory construction.

In equation 2, the memory M is represented as a structured combination of various memory components: $M = \{M_{\text{np}}, M_{\text{ent}}, M_{\text{phr}}, C_i, S_i\}$. The Memory Agent operates by receiving the source discourse d_i and the corresponding translated output τ_i . The agent analyzes the pair (d_i, τ_i) using an LLM backbone through in-context prompting to identify key elements. These prompts have been presented in Figures 7-11. For the three mappings M_{np} , M_{ent} and M_{phr} , the LLM is prompted to generate outputs in the following format $\langle \text{source} \rangle : \langle \text{target} \rangle$, i.e., source and target separated by colon(:). This allows for the extraction of structured output. Each memory component is represented as a structured list or map. For example: $M_{\text{np}} = \{[\text{entity in target language}] : [\text{pronoun in target language}]\}$ and $M_{\text{ent}} = \{[\text{source entity}] : [\text{translated entity}]\}$. For C_i and S_i , the LLM is prompted to only output the desired result, and the output is used as is.

2.2.2 Translation Agent (Context-Aware Translation)

The final task is to translate each discourse d_i by leveraging both its content and the context from related discourses. Let $\text{Pred}(d_i) = \{d_j \mid$

$(d_j \rightarrow d_i) \in E\}$ denote the set of predecessor discourses. The incident memory, defined as $\text{mem}_i^{\text{inc}} = \bigcup_{d_j \in \text{Pred}(d_i)} \text{mem}_j$, aggregates memory from these predecessors, giving priority to earlier discourses.

The translation for d_i is then computed as $\tau_i = \mathcal{L}_{\text{trans}}(d_i, \text{mem}_i^{\text{inc}})$, where $\mathcal{L}_{\text{trans}}$ is the LLM-based translation agent. Once τ_i is generated, the local memory mem_i is updated as described in Eq. (2), ensuring that subsequent translations incorporate the latest contextual information. The overall GRAFT pipeline has been summarized in Appendix C.

3 Experiments and Results

This section details our experiments and their respective results. We evaluate all the systems using d-BLEU (Liu et al., 2020) and d-COMET (Vernikos et al., 2022) metrics. To address discourse-specific phenomena, we employ two targeted metrics: Consistent Terminology Translation (cTT) and Accurate Zero Pronoun Translation (aZPT) metric (Wang et al., 2023b). The details of the data sets, the implementation details of GRAFT, the evaluation methodology for our experiments and the descriptions of the baseline systems are provided in Appendix D.

3.1 System Comparison

We evaluate GRAFT against several baseline approaches (described in Appendix D.4) using various LLM backbones, including Llama-3.1-70B-Instruct, Llama-3.3-70B-Instruct, Qwen2.5-72B-Instruct, Llama-3.1-8B-Instruct, and Qwen2.5-7B-Instruct, on the TED tst2017 dataset (Cettolo et al., 2012).

GRAFT consistently outperforms baselines across language pairs in both **English** $\Rightarrow$ **Xx** and **Xx** $\Rightarrow$ **English** directions, except for Ja $\Rightarrow$ En at 70B scale. The observed performance gains include **1.0** d-BLEU over GPT-4o-mini and **1.1** d-BLEU over DELTA (Qwen2.5-72B-Instruct). Notably, GRAFT demonstrates competitive performance using smaller LLM backbones, such as Llama-3.1-70B-Instruct, compared to larger models like GPT, highlighting the efficacy of GRAFT’s segmentation and dependency strategies.⁶ Additionally, our analysis reveals that Qwen2.5-72B-Instruct and

⁶Our results align with the findings of Neubig and He (2023). These findings motivate our decision to exclude GPT-based backbones due to cost considerations.

Llama-3.1-70B-Instruct outperform their 7B counterparts, showcasing the impact of scaling LLM backbones. Full results are presented in Table 1. GRAFT achieves a performance gain of **2.1** d-BLEU score compared to Hu and Wan (2023) in the En $\Rightarrow$ De direction.

3.2 Domain-specific Translation

To evaluate the efficacy of GRAFT in handling domain-specific complexities, we conduct experiments on the mZPRT (Xu et al., 2022) and WMT2022 (Kocmi et al., 2022) datasets for the Zh $\Rightarrow$ En translation direction. In addition to d-BLEU and d-COMET scores for overall translation quality, we utilize two targeted metrics, cTT and aZPT (detailed in Appendix D.3), to assess terminology translation consistency and pronoun resolution accuracy in translating from a pronoun-dropping language (Chinese) to a non-pronoun-dropping language (English).

Table 2 details the results across News, Social, Fiction, and Q&A domains. GRAFT (Llama-3.1-70B-Instruct) consistently outperforms all baselines, with an average improvement of **2.0** d-BLEU over GPT-4o-mini and **7.5** d-BLEU over GPT-3.5. This demonstrates that GRAFT delivers superior domain-specific translations of documents even with a comparatively smaller LLM backbone. For cTT, GRAFT achieves an average gain of **6.0%** over GPT-4o-mini and **7.0%** over GPT-3.5, reflecting its superior handling of terminology consistency. Similarly, for aZPT, GRAFT achieves **6.0%** and **7.0%** gains over GPT-4o-mini and GPT-3.5, respectively, highlighting its ability to manage pronoun translation effectively. We further present the results of the human evaluation of each system in Appendix H.

3.3 Handling Discourse Phenomena

Similar to Wang et al. (2023a), we conduct a probing experiment using the contrastive dataset proposed by Voita et al. (2019) (En $\Rightarrow$ Ru). This dataset includes deixis, lexicon consistency, ellipsis (inflexion and verb phrase) for evaluating the handling of discourse phenomena. Each instance consists of one positive translation and a few negative translations. The dataset evaluates whether a system is more likely to generate the positive translation than the negative translations. Similar to Wang et al. (2023a), we consider a system correct on an instance if it is more likely to generate the positive translation over the negative ones. Table 3

#	System	En $\Rightarrow$ Xx				Xx $\Rightarrow$ En			
		En $\Rightarrow$ Zh	En $\Rightarrow$ De	En $\Rightarrow$ Fr	En $\Rightarrow$ Ja	Zh $\Rightarrow$ En	De $\Rightarrow$ En	Fr $\Rightarrow$ En	Ja $\Rightarrow$ En
1	Commercial System (Google)	30.5/6.46	22.3/6.16	40.8/6.84	16.2/5.93	27.5/6.35	22.7 /6.17	27.4 /6.34	21.0 /6.11
2	Sentence Level (NLLB-3.3B)	30.8/6.47	24.3/6.23	34.7/6.61	13.7/5.84	26.4/6.31	33.1/6.55	42.8/6.91	16.6/5.95
3	G-Trans (BART)	34.5/6.60	30.0/6.44	43.1/6.92	16.5/5.94	24.9/6.25	29.0/6.40	38.0/6.73	13.9/5.85
4	GPT-3.5-Turbo	36.3/6.67	30.7/6.47	44.1/6.96	18.0/6.00	26.4/6.31	34.6/6.61	43.3/6.93	19.6/6.06
5	GPT-4o-mini	35.7/6.65	30.3/6.45	43.2/6.92	18.6 /6.02	26.6/6.31	34.6/6.61	43.1/6.92	19.6/6.06
6	DELTA (Qwen2-7B-Instruct)	33.2/6.56	21.7 /6.13	32.5/6.53	14.0/5.85	24.4/6.23	30.0/6.44	38.1/6.74	16.1/5.93
7	DELTA (Qwen2-72B-Instruct)	35.6/6.65	28.9/6.40	41.1/6.85	16.5/5.94	29.8/6.43	33.9/6.58	43.6/6.94	20.5/6.09
8	GRAFT (Qwen2.5-7B-Instruct)	25.5 /6.27	25.0/6.26	31.8 /6.51	9.6/5.69	21.3 /6.12	28.1/6.37	38.0/6.73	12.6 /5.80
9	GRAFT (Llama-3.1-8B-Instruct)	26.6/6.31	26.1/6.30	35.8/6.65	7.2 /5.60	24.6/6.24	31.5/6.49	41.0/6.84	14.5/5.87
10	GRAFT (Qwen2.5-72B-instruct)	36.3/6.67	28.5/6.38	44.8 /6.98	16.1/5.93	30.1/6.44	34.3/6.60	43.1/6.92	17.9/6.00
11	GRAFT (Llama-3.3-70B-Instruct)	35.3/6.63	29.0/6.40	41.6/6.87	16.9/5.96	29.4/6.42	35.4/6.64	44.4/6.97	18.3/6.01
12	GRAFT (Llama-3.1-70B-Instruct)	* 36.4 /6.67	* 31.9 /6.51	*43.1/6.92	17.6/5.98	* 30.8 /6.47	* 35.9 /6.66	* 45.0 /6.99	18.5/6.02

Table 1: Performance comparison across multiple translation systems for En $\leftrightarrow$ Xx translation directions. Results are presented as: **d-BLEU/d-COMET**. **Blue** indicates the best-performing system, while **red** highlights the lowest-performing system for a given direction. We perform the non-parametric Wilcoxon signed-rank significance test (one-tailed, $p < 0.05$) (Woolson, 2007). Superscript symbols denote significant improvements of GRAFT over specific baselines: $\dagger$ vs. GPT-3.5-Turbo, $\ddagger$ vs. GPT-4o-mini, and $*$ vs. Google Translate.

System	Automatic (d-BLEU/d-COMET/cTT/aZPT)			
	News	Social	Fiction	Q&A
Commercial System (Google)	29.7/6.61/0.23/0.19	34.4/6.42/0.31/0.25	18.8/6.36/0.31/0.35	19.0/5.56/0.36/0.41
GPT-3.5	24.8/6.32/0.28/0.11	22.3/6.44/ 0.51 /0.23	13.7/6.18/0.42/0.32	16.3/5.51/0.34/0.42
GPT-4o-mini	29.1/6.56/0.32/0.21	35.5/6.42/0.45/0.42	17.4/6.24/0.38/0.46	17.4/5.52/0.36/0.39
GRAFT (Llama-3.1-70B-Instruct)	30.1 / 6.69 / 0.39 / 0.32	36.2 / 6.72 /0.48/ 0.44	19.4 / 6.51 / 0.52 / 0.48	21.6 / 5.59 / 0.41 / 0.48

Table 2: Domain-specific translation performance for Chinese-to-English across four domains: News, Social, Fiction, and Q&A. Results are reported using three metrics: **d-BLEU** (overall translation quality), **d-COMET** (correlations with human quality judgments), **cTT** (terminology consistency), and **aZPT** (zero pronoun translation accuracy). The cell color indicates the best performance for each metric in a given domain.

System	deixis	lex.c	ell.inf	ell.VP
GPT-3.5	57.9	44.4	75.0	71.6
GPT-4	85.9	72.4	69.8	81.4
GRAFT	89.2	81.5	67.7	84.4

Table 3: Translation prediction for deixis, lexical consistency, ellipsis (inflexion), and ellipsis (VP) on the En $\Rightarrow$ Ru contrastive testset, reported using **accuracy** (%).

details the result of this study.

4 Analysis

In the following section, we analyze the effect of GRAFT on the qualitative aspects of document translation, along with analyzing whether GRAFT is able to maintain consistency over the document.

Consistency Analysis. The *consistency ratio* of P is defined as $CR(P) = CL(P)/k$, where $CL(P)$ is defined as the number of nodes in the path P (starting from first node) up to which consistency is maintained, and k is the path length. We observe that **70%** paths show a consistency ratio greater than **0.6**, suggesting that paths encompassing more significant dependencies often result in more uniform translations. This capability is particularly valuable for translating structured or technical documents where maintaining coherence

is paramount.

Handling Long-Range Dependencies in Ultra-long Documents. We conduct experiments on the Web Novel dataset from the Guofeng V1 TEST_2 dataset (Wang et al., 2023c, 2024), which contains 16.9K source sentences. We compare two approaches: translating the novel chapter by chapter versus translating the entire novel as a single document. We observe that translating the entire novel as a single document yields a **28.7** d-BLEU score, significantly higher than the **24.4** d-BLEU score achieved with the chapter-by-chapter approach for the En $\Rightarrow$ Zh direction. These results underscore its suitability for translating lengthy and complex documents, such as novels, research articles, and technical manuals, where long-range dependencies are crucial for overall quality.

Human Evaluation of GRAFT We conduct a two-part human evaluation of the Discourse and Edge Agents to assess segmentation quality and inter-discourse coherence. The details about the evaluators and evaluation guidelines have been presented in Appendix G.

Discourse Agent Analysis. The results indicate that **70.4%** of pronouns were resolved correctly within the segmented discourse, demonstrating that

the context provided by the Discourse Agent is effective in handling referential relationships. Additionally, the translated discourses exhibit a coherence score of **90.2%** and consistency in tense and aspect at **88.6%**. **Edge Agent Analysis.** The evaluation reveals that **76.3%** of edges are accurately identified, affirming the Edge Agent’s capability to model contextual dependencies effectively. Furthermore, the integration of the memory agent allowed GRAFT to maintain terminology consistency in **84.5%** of cases, a significant improvement over baseline systems lacking such contextual memory mechanisms. These findings highlight the robustness of the GRAFT system in preserving local linguistic phenomena and ensuring high-quality translations at the discourse level.

We discuss the latency and cost considerations of the GRAFT system in Appendix I. We further present qualitative analysis of each agent in the GRAFT system in Appendix F.

5 Related Work

Prior work on document-level MT may be grouped into several strands. Early methods extended sentence models with context from adjacent sentences via multi-encoder or concatenation strategies (Jean et al., 2017; Wang et al., 2017a). Hierarchical attention networks condition translation on both word- and sentence-level encodings to capture structured context (Miculicich et al., 2018). Cache-based approaches store recently translated words or topical words in dynamic and topic caches to model coherence (Kuang et al., 2017; Tong et al., 2020). Continuous cache methods leverage a light-weight history memory to adapt translations on the fly (Tu et al., 2018). More recently, unified context models explicitly encode both local sentence context and global document context in Transformer architectures (Ohtani et al., 2019). Large-scale surveys have summarized these approaches and highlighted persistent gaps in modelling and evaluation (Maruf et al., 2021b).

Document-Level MT Approaches: Document-to-Sentence (Doc2Sent) methods (Wang et al., 2017b; Miculicich et al., 2018; Guo and Nguyen, 2020) incorporate contextual signals from neighboring sentences to enhance translation quality but often treat sentences as isolated units during generation. This results in fragmented discourse and missed target-side cues, as highlighted by Mino et al. (2020); Jin et al. (2023). On the other hand,

Document-to-Document (Doc2Doc) approaches (Wu et al., 2023; Wang et al., 2023b; Pang et al., 2025) jointly model multiple sentences, capturing long-range dependencies and improving discourse coherence. However, these approaches often face challenges with ultra-long documents, such as content omissions and scalability limitations. Recent advances leverage large language models (LLMs) for document-level MT, as demonstrated by Wang et al. (2023b); Wu et al. (2024); Li et al. (2025). These models process long contexts to generate more coherent translations and address discourse-level phenomena.

Agentic Frameworks with LLMs: Agentic systems utilize autonomous LLMs to decompose complex tasks into specialized subtasks. Multi-agent architectures, such as ExpeL (Zhao et al., 2024) and DELTA (Wang et al., 2025), employ mechanisms like retrieval, iterative refinement, and multi-level memory to enhance task performance and ensure consistency. Related work (Park et al., 2023; Zhang et al., 2024; Qian et al., 2025; Madaan et al., 2023; Koneru et al., 2024; Guo et al., 2024) explores agentic paradigms for maintaining long-context memory, refining outputs, and addressing discourse-level challenges. These frameworks often draw upon discourse theories Grosz and Sidner (1986); Mann and Thompson (1988) for segmenting and maintaining text coherence.

6 Conclusion

We presented **GRAFT**, a modular, agentic framework for document-level machine translation, designed to meet the practical demands of high-volume, domain-sensitive translation scenarios. By leveraging LLM agents and representing documents as directed acyclic graphs (DAGs), GRAFT captures complex discourse dependencies that are often missed by sentence-level or flat-context systems. Our experiments show that GRAFT consistently outperforms strong commercial and LLM-based baselines, achieving gains of up to **7.5** d-BLEU in domain-specific settings while operating with smaller, open-source LLM backbones. This makes GRAFT cost-efficient, easily deployable in privacy-critical environments, and adaptable across multilingual domains such as legal, healthcare, and government translation pipelines. GRAFT bridges the gap between research innovation and industrial applicability, providing a practical solution to real-world DocMT challenges.

Limitations

GRAFT’s multi-agent design introduces computational overhead compared to single LLM systems. Second, performance is sensitive to hyperparameters like memory size, which require domain-specific tuning. Although the system is evaluated across multiple translation directions, the underlying edge-agent reasoning is language-agnostic and has not yet been explicitly adapted for morphologically rich or low-resource languages, where discourse cues differ markedly. Future work could address these limitations by incorporating adaptive discourse segmentation, lightweight reasoning modules, and larger-scale evaluations across diverse language families and genres.

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A Discourse Phenomena

Discourse-level phenomena are critical in ensuring the quality and coherence of document-level machine translation. These phenomena can be broadly categorized into inter-discourse and intra-discourse phenomena, each representing unique challenges and requirements for accurate translation. Below, we detail the various phenomena under these categories.

A.1 Intra-Discourse Phenomena

Intra-discourse phenomena pertain to elements that occur within a single discourse or document. These include:

- **Pronoun Resolution:** The accurate translation of pronouns by identifying their antecedents within the same discourse, ensuring grammatical and semantic coherence.
- **Lexical Cohesion:** Maintaining consistent terminology and word choices throughout the document to avoid ambiguity and preserve meaning.
- **Ellipsis Handling:** Correctly inferring and translating omitted elements that are understood from the context.
- **Tense and Aspect Consistency:** Preserving temporal relationships between events by maintaining consistent verb tense and aspect.
- **Coreference Resolution:** Ensuring that all mentions of a particular entity are translated consistently and coherently within the document.

A.2 Inter-Discourse Phenomena

Inter-discourse phenomena involve elements that span across multiple discourses or documents. These include:

- **Anaphora and Cataphora:** Resolving forward and backwards references across different discourses, ensuring correct linkage between entities or events.
- **Inter-Document Consistency:** Maintaining uniformity in terminology, style, and tone across related documents or sections.
- **Global Contextual Coherence:** Ensuring that translated content aligns with the broader context provided by external or previous discourses.
- **Topic Continuity:** Tracking and preserving the thematic progression of topics across multiple discourses or sections.
- **Cross-Document Reference Handling:** Resolving references to entities or events described in other related documents.
- **Rabbit-Hole Phenomena:** Capturing situations where a discourse unit revisits or deepens a concept introduced earlier, sometimes after an intervening unrelated section. These backward or

long-range semantic dependencies are difficult to track linearly and require structured memory and dependency modeling to ensure consistency. Failure to resolve rabbit-hole dependencies often leads to hallucinated or incoherent translations when long documents circle back to previously mentioned contexts.

B Discourse Agent Algorithm

The complete working of the Discourse Agent, $\mathcal{L}_{\text{seg}}(D)$ has been shown in Algorithm 1 (as discussed in Section 2.1.1).

Algorithm 1 Discourse Segmentation (Discourse Agent)

```

1: Input: Document  $D = \{s_1, \dots, s_n\}$ 
2: Output: Discourses  $S = \{d_1, \dots, d_K\}$ 
3:  $S \leftarrow \emptyset$ ,  $d_{\text{curr}} \leftarrow \emptyset$ 
4: for  $i = 1$  to  $n$  do
5:   if  $f_{\text{LLM}}(d_{\text{curr}}, s_i)$  then
6:     Append  $s_i$  to  $d_{\text{curr}}$ 
7:   else
8:     Append  $d_{\text{curr}}$  to  $S$ 
9:      $d_{\text{curr}} \leftarrow \emptyset$ 
10:  end if
11: end for
12: Return  $S$ 

```

C GRAFT Pipeline

Algorithm 2 summarizes the full GRAFT pipeline. Figure 2 provides an overview of the GRAFT pipeline.

Algorithm 2 GRAFT Pipeline for Document-Level Translation

```

1: Input: Document  $D = \{s_1, \dots, s_n\}$ 
2: Output: Translated document  $\hat{D}$ 
3:  $S \leftarrow \text{DiscourseAgent}(D)$  {Algorithm 1}
4:  $E \leftarrow \text{BuildGraph}(S)$  {see Eq. (1)}
5:  $\hat{D} \leftarrow []$ 
6: for  $i = 1$  to  $|S|$  do
7:    $\text{Pred} \leftarrow \{d_j : (d_j \rightarrow d_i) \in E\}$ 
8:    $\text{mem}_i^{\text{inc}} \leftarrow \bigcup_{d_j \in \text{Pred}} \text{mem}_j$ 
9:    $\tau_i \leftarrow \mathcal{L}_{\text{trans}}(d_i, \text{mem}_i^{\text{inc}})$ 
10:   $\text{mem}_i \leftarrow \mathcal{L}_{\text{mem}}(d_i, \tau_i)$ 
11:  Append  $\tau_i$  to  $\hat{D}$ 
12: end for
13: Return  $\hat{D}$ 

```

GRAFT comprises four LLM-based agents- Discourse, Edge, Memory, and Translation-

organized into a graph-augmented pipeline that explicitly models and propagates intra- and inter-discourse context, yielding more coherent and consistent document translations.

D Experimental Setup

Here we present the detailed experimental setup for our experiments (Section 3).

D.1 Datasets

We conduct experiments on eight language pairs: German-English, English-German, French-English, English-French, Japanese-English, English-Japanese, Chinese-English, and English-Chinese, covering diverse linguistic and domain-specific challenges. The mZPRT dataset (Xu et al., 2022) provides a parallel corpus for Chinese-English translation, focusing on fiction and Q&A domains. The WMT2022 dataset (Kocmi et al., 2022) features a Chinese-English parallel corpus in news and social domains. For high-quality, discourse-level parallel corpora, we use the Guofeng V1 TEST_2 dataset (Wang et al., 2023c, 2024), which targets web fiction for Chinese-English. Additionally, the TED tst2017 dataset from the IWSLT2017 translation task (Cettolo et al., 2012) offers two-way parallel corpora for English-Chinese, English-French, English-German, and English-Japanese. Dataset statistics are summarized in Table 4.

D.2 Implementation Details

The GRAFT system is implemented using various LLM backbones, including Llama-3.1-70B-Instruct⁷, Llama-3.3-70B-Instruct⁸, Qwen2.5-72B-Instruct⁹, Llama-3.1-8B-Instruct¹⁰, and Qwen2.5-7B-Instruct¹¹. We use all the pre-trained chat/instruct variants of the LLMs without additional fine-tuning. We utilize a few-shot prompting strategy, with three in-context examples provided for each task. The inference is conducted on two to four NVIDIA A100 GPUs, depending on the backbone model size. To optimize latency, we

⁷<https://huggingface.co/meta-llama/Llama-3.1-70B-Instruct>

⁸<https://huggingface.co/meta-llama/Llama-3.3-70B-Instruct>

⁹<https://huggingface.co/Qwen/Qwen2.5-72B-Instruct>

¹⁰<https://huggingface.co/meta-llama/Llama-3.1-8B-Instruct>

¹¹<https://huggingface.co/Qwen/Qwen2.5-7B-Instruct>

Domain	Source	Language Pair	D	S	W	W / D
News	WMT2022	Zh $\leftrightarrow$ En	38	462	18.5K/27.7K	489/731
Social			25	512	14.3K/22.7K	572/910
Fiction	mZPRT	Zh $\leftrightarrow$ En	12	860	16.9K/26.7K	1409/2230
Q&A			182	1801	18.1K/25.2K	99/138
Novel	Guofeng V1 TEST_2	Zh $\leftrightarrow$ En	12	860	26.9K/16.9K	2243/1415
		Zh $\leftrightarrow$ En	12	1448	23.9K/43.7K	1996/3645
TED	IWSLT2017	De $\leftrightarrow$ En	10	1113	18.2K/16.3K	1826/1632
		Fr $\leftrightarrow$ En	12	1449	24.0K/23.7K	2001/1975
		Ja $\leftrightarrow$ En	12	1445	23.9K/59.1K	1993/4929

Table 4: Statistics of the datasets we use in our experiments. Here |D| represents the number of documents in the dataset, |S| represents the total number of sentences in the dataset, |W| represents the number of words in the source (on the left in Language Pair) and the target (on the right in Language Pair) languages.

use vLLM (Daniel et al., 2023) for serving the models and the OpenAI API¹² for making calls to external backbones. The average inference time per document ranged between 20-30 seconds. We adopted default decoding strategies specific to each LLM backbone. For the Llama-3.1-70B-Instruct model, we utilize the standard decoding strategy with temperature values ranging from 0.1 to 0.3. The best performance is observed at a temperature of 0.1. The maximum output length is constrained to one token for the discourse and edge agents, as they produce binary outputs (e.g., ‘yes’ or ‘no’), while the memory and translation agents are configured for up to 4096 tokens. All source documents are normalized and segmented into sentences using regex-based preprocessing. Standard postprocessing steps are applied to the translation outputs, including detokenization and normalization to align with human-readable text. Due to budget constraints, experiments did not include GPT models as backbones. However, models in the 70B parameter range demonstrated comparable or superior performance, validating the feasibility of cost-effective alternatives.

D.3 Evaluation Methodology

We evaluate translation quality using both automatic metrics and human judgments. Automatic evaluation is conducted using d-BLEU (Liu et al., 2020), which measures accuracy, fluency, and adequacy. Human evaluation focuses on two aspects: discourse awareness, which assesses the system’s ability to maintain coherence and appropriately handle inter-discourse phenomena, and general translation quality, which evaluates fluency and fi-

delity to the source text. The guidelines for human evaluation are provided in Appendix G.

To address discourse-specific phenomena, we employ two targeted metrics. The Consistent Terminology Translation (cTT) metric (Wang et al., 2023b) measures the consistency of terminology translation throughout a document. For a terminology word w with possible translations $\{t_1, t_2, \dots, t_k\}$, the CTT score is computed as:

$$CTT(w) = \frac{\sum_{t \in TT} \frac{\sum_{i=1}^k \sum_{j=i+1}^k \mathbf{1}(t_i = t_j)}{C_k^2}}{TT},$$

where TT represents the set of terminology words, $\mathbf{1}(t_i = t_j)$ is an indicator function that returns 1 if $t_i = t_j$ and 0 otherwise, and C_k^2 is the binomial coefficient. A higher CTT score reflects greater consistency in terminology translation.

The Accurate Zero Pronoun Translation (aZPT) metric (Wang et al., 2023b) evaluates the accuracy of translating zero pronouns (ZPs), which are frequently omitted in source languages such as Chinese and Japanese. Given ZP , the set of zero pronouns in the source text, and t_z , the translation of $z \in ZP$, the aZPT score is calculated as:

$$aZPT = \frac{1}{|ZP|} \sum_{z \in ZP} A(t_z | z),$$

where $A(t_z | z)$ is a binary function that returns 1 if t_z accurately translates z and 0 otherwise. A higher aZPT score indicates the system’s effectiveness in recovering omitted pronouns, thereby enhancing discourse coherence.

D.4 Baselines

We compare the proposed GRAFT framework with a diverse set of baselines, ranging from commercial

¹²<https://platform.openai.com/docs/api-reference/introduction>

translation systems to advanced DocMT models. Below, we describe each baseline and its corresponding setup:

Commercial Translation System: Google Translate API We use the Google Translate API for document translation.¹³ The entire document is translated in a single request, leveraging Google’s production-grade translation system.

Sentence-Level Baseline: NLLB The NLLB-200 3.3B model (Costa-Jussà et al., 2022) serves as our sentence-level baseline.¹⁴ We use the pre-trained checkpoint to translate each document sentence by sentence, without considering inter-sentential context. This setup provides insight into the impact of ignoring document-level context on translation quality.

G-Trans (BART) We include the G-Trans model (Bao et al., 2021), which utilizes a BART-based architecture for document-level machine translation. The G-Trans approach employs a hierarchical attention mechanism to model inter-sentential dependencies, processing the document as a sequence of sentence representations. We adapt their training setup and evaluation protocols for our experiments.

GPT Models We evaluate two GPT-based models, GPT-3.5-Turbo¹⁵ and GPT-4o-mini,¹⁶ as baselines. These models are prompted to translate the entire document from the source to the target language in one go. This setup assesses the capability of general-purpose large language models to perform document-level translation.

DeTA We include DeTA (Wang et al., 2025), a document-level translation agent based on multi-level memory. The model employs Qwen2-7B-Instruct and Qwen2-72B-Instruct backbones. For evaluation, we directly adopt their methodology and utilize their reported results on the TED tst2017 dataset from the IWSLT2017 translation task (Cettolo et al., 2012). The multi-level memory mechanism in DeTA provides a strong baseline for maintaining document coherence and consistency.

¹³<https://py-googletrans.readthedocs.io/en/latest/>

¹⁴<https://huggingface.co/facebook/nllb-200-3.3B>

¹⁵<https://platform.openai.com/docs/models/gpt-3.5-turbo>

¹⁶<https://platform.openai.com/docs/models/gpt-4o-mini>

E Results: Design Choices for GRAFT

We present the results of comparing different strategies for each of the $\mathcal{L}_{\text{seg}}$, $\mathcal{L}_{\text{edge}}$, and $\mathcal{L}_{\text{mem}}$.

E.1 Analyzing Source Document $\rightarrow$ Directed Acyclic Graph

We adapt LLM-based approaches for the *Discourse Agent*, $\mathcal{L}_{\text{seg}}$, and *Edge Agent*, $\mathcal{L}_{\text{edge}}$. This subsection studies the effect of alternative segmentation and edge-detection strategies in the GRAFT pipeline, conducted with the Llama-3.1-8B-Instruct as the backbone LLM on the TED tst2017 dataset from the IWSLT2017 translation task (Cettolo et al., 2012). Experiments were performed on eight translation directions: En $\Rightarrow$ Zh, En $\Rightarrow$ De, En $\Rightarrow$ Fr, En $\Rightarrow$ Ja, Zh $\Rightarrow$ En, De $\Rightarrow$ En, Fr $\Rightarrow$ En, and Ja $\Rightarrow$ En.

Discourse Segmentation. We compare our LLM-based segmentation approach, $\mathcal{L}_{\text{seg}}$, with two alternative strategies: (i) *random segmentation* (RS) and (ii) *semantic similarity segmentation* (SC). RS involves generating K segment boundaries (where K is chosen randomly between 0 and $\frac{n}{3}$, with n being the number of sentences in the document D). The segment boundaries, $S = \{d_1, d_2, \dots, d_K\}$, divide D into random segments. The SC approach employs the semantic chunking strategy proposed by Chase (2023)¹⁷.

Our experiments indicate that $\mathcal{L}_{\text{seg}}$ consistently outperforms RS and SC, achieving average performance gains of **11.3** and **3.6** d-BLEU scores, respectively, across all translation directions. The results are detailed in Table 5.

Dependency Modelling. Dependency modelling approaches are compared as follows: (i) *chain graph* (CG), (ii) *TF-IDF graph* (TF-IDF), and (iii) our LLM-based approach, $\mathcal{L}_{\text{edge}}$. The CG strategy models adjacency through a strict sequential structure $E = \{(d_j \rightarrow d_i) \mid j < i, j + 1 = i\}$. TF-IDF relies on cosine similarity (cs) between segments d_j and d_i , computed using the TfidfVectorizer from Pedregosa et al. (2011).¹⁸ Edges are created if $\text{cs}(d_j, d_i) > \tau$, where τ is an empirically determined threshold: $E = \{(d_j \rightarrow d_i) \mid j < i, \text{cs}(\text{TfidfVectorizer}(d_j, d_i)) > \tau\} \cup \{(d_j \rightarrow d_i) \mid j < i, j + 1 = i\}$. Our LLM-based $\mathcal{L}_{\text{edge}}$

¹⁷https://python.langchain.com/docs/how_to/semantic-chunker/

¹⁸https://scikit-learn.org/stable/modules/generated/sklearn.feature_extraction.text.TfidfVectorizer.html

Language Pair	RS	SC	DA (Ours)
English $\Rightarrow$ Xx			
En $\Rightarrow$ Zh	25.7	21.8	26.6
En $\Rightarrow$ De	11.6	24.9	26.1
En $\Rightarrow$ Fr	21.3	33.3	35.8
En $\Rightarrow$ Ja	6.1	6.4	7.2
Xx $\Rightarrow$ English			
Zh $\Rightarrow$ En	11.4	23.4	24.6
De $\Rightarrow$ En	18.5	27.9	31.5
Fr $\Rightarrow$ En	12.9	31.3	41.0
Ja $\Rightarrow$ En	8.7	9.5	14.5
Ave.	14.5	22.3	25.9

Table 5: d-BLEU scores comparing various **discourse segmentation** strategies: Random Segmentation (RS), Semantic Similarity-based segmentation (SC), and Discourse Agent (DA).

surpasses both CG and TF-IDF, with average performance gains of **2.0** d-BLEU scores (over both alternate approaches) across translation directions. For Zh $\Rightarrow$ En, the CG strategy shows better performance, but $\mathcal{L}_{\text{edge}}$ outperforms it in other directions. Detailed results are presented in Table 6.

Language Pair	CG	TF-IDF	EA (Ours)
English $\Rightarrow$ Xx			
En $\Rightarrow$ Zh	24.3	25.4	26.6
En $\Rightarrow$ De	25.2	23.0	26.1
En $\Rightarrow$ Fr	35.7	31.2	35.8
En $\Rightarrow$ Ja	4.7	5.9	7.2
Xx $\Rightarrow$ English			
Zh $\Rightarrow$ En	24.8	23.1	24.6
De $\Rightarrow$ En	27.9	28.8	31.5
Fr $\Rightarrow$ En	37.0	39.8	41.0
Ja $\Rightarrow$ En	11.2	13.3	14.5
Ave.	23.9	23.8	25.9

Table 6: d-BLEU scores comparing various **edge construction** strategies: Chain Graph (CG), TF-IDF based edge construction (TF-IDF), and Edge Agent (EA).

These analyses underscore the critical role of modelling the source document as a DAG in the DocMT task. As our LLM-based approaches outperform all baselines, we use them for subsequent experiments.

E.2 Effects of Local Memory (mem_i) components

We examine the role of memory components (M_i^{np} , M_i^{ent} , M_i^{phr} , C_i , S_i) in the GRAFT

pipeline. Ablation studies remove one component at a time. We also include experiments conducted under full memory (FM) and no memory (NM) conditions. We conduct these experiments using Llama-3.1-8B-Instruct. Results on TED tst2017 show a **5.7** d-BLEU gap between FM and NM. Removing M_i^{phr} results in the largest performance drop, followed by M_i^{ent} , C_i , S_i , and M_i^{np} . Even the least impactful component, M_i^{np} , improves performance by **4.9** d-BLEU for De $\Rightarrow$ En. Table 7 shows the performance of GRAFT by ablating each memory component.

E.3 Ablations

We ablate GRAFT’s components by removing $\mathcal{L}_{\text{seg}}$, $\mathcal{L}_{\text{edge}}$, or $\mathcal{L}_{\text{mem}}$. At both 70B and 7B scales, excluding $\mathcal{L}_{\text{edge}}$ results in average degradation of **2.4** and **2.1** d-BLEU, respectively. Removing the entire agentic pipeline causes degradation of **4.0** and **2.7** d-BLEU (Table 8). Without $\mathcal{L}_{\text{mem}}$ we see a performance degradation of **3.0** and **2.7** d-BLEU scores. These results underline the significance of all components in the GRAFT pipeline.

F Qualitative Analysis of GRAFT Agents

Source Document $\longrightarrow$ Directed Acyclic Graph.

We analyze the behavior of the *Discourse Agent* ($\mathcal{L}_{\text{seg}}$) and the *Edge Agent* ($\mathcal{L}_{\text{edge}}$) to understand how GRAFT effectively represents the source document as a Directed Acyclic Graph (DAG). Figure 3 shows the distribution of the number of discourse segments per document, as well as the distribution of the number of sentences grouped within a discourse. Similarly, Figure 4 illustrates the distribution of the count of edges per document and the trend of count of edges as a function of count of discourse segments in a document. The analysis reveals that $\mathcal{L}_{\text{seg}}$ groups three to forty sentences into a single discourse for **63.4%** of documents, suggesting its ability to balance granularity and cohesion. Meanwhile, $\mathcal{L}_{\text{edge}}$ adds three to twenty indirect edges for **69.4%** of documents, highlighting its role in capturing interdependencies between segments.

A qualitative examination shows that the discourse segments generated by $\mathcal{L}_{\text{seg}}$ often align with logical or thematic units. In our analysis, we found that discourses rarely cross paragraph boundaries. This alignment indicates the effectiveness of the agent in identifying coherent translation units. Additionally, the edges created by $\mathcal{L}_{\text{edge}}$

Language Pair	NM	w/o M_i^{np}	w/o M_i^{ent}	w/o C_i	w/o M_i^{phr}	w/o S_i	FM
English $\Rightarrow$ Xx							
En $\Rightarrow$ Zh	21.5	26.2	23.3	24.6	23.6	25.9	26.6
En $\Rightarrow$ De	23.5	25.4	22.8	25.9	21.4	24.1	26.1
En $\Rightarrow$ Fr	27.9	35.1	24.1	34.6	28.6	34.5	35.8
En $\Rightarrow$ Ja	3.8	5.6	5.9	6.0	5.4	6.5	7.2
Xx $\Rightarrow$ English							
Zh $\Rightarrow$ En	16.3	24.9	23.2	23.7	25.2	23.8	24.6
De $\Rightarrow$ En	23.2	26.6	30.7	29.0	30.5	29.8	31.5
Fr $\Rightarrow$ En	35.3	40.6	37.7	36.0	31.7	40.0	41.0
Ja $\Rightarrow$ En	9.8	14.0	13.1	9.6	12.8	12.6	14.5
Ave.	20.2	24.8	22.6	23.7	22.4	24.6	25.9

Table 7: Ablation on the components of **memory**, with NM denoting no use of memory, and FM denoting use of all the memory components.

System	70B Scale		7B Scale	
	Fiction	Q&A	Fiction	Q&A
TA only	19.2	16.6	16.9	9.4
TA + DA	20.3	17.4	17.2	9.1
TA + DA + MA	21.2	18.0	17.5	10.0
GRAFT	24.6	19.2	19.6	12.1

Table 8: Results of ablation experiments comparing the performance of different system configurations on Fiction and Q&A tasks at two scales (70B and 7B). "TA only" includes only the Translation Agent, "TA + DA" includes Translation and Discourse Agent, "TA + DA + MA" incorporates the additional Memory Agents, and "GRAFT" represents the complete system. Performance improvements are highlighted in **blue**.

frequently correspond to cross-references, causal relationships, or transitions between these units, underscoring its importance in preserving document-wide coherence.

G Human Evaluation: Annotator Details and Guidelines

The evaluation process was conducted by human annotators with an average age of 24 years. All annotators hold a Bachelor of Arts and Master of Arts degree in Chinese Language and Literature. Each annotator received a compensation of \$200 for their participation. The evaluation process spanned 3 to 4 days, during which each annotator performed the evaluation independently. For all human evaluations conducted, we report the average performance based on their assessments. The guidelines for human evaluation have been provided in Table 9.

H Domain-specific Translation: Human Evaluation

Here we present the human evaluation results for our Domain-specific Translation experiment (Section 3.2). Table 10 presents the results of human evaluation of various systems across the four domains: News, Social, Fiction and Q&A in Zh $\Rightarrow$ En direction. The guidelines for the human evaluation are provided in Appendix G.

H.1 Implications and Observations

These results demonstrate that the GRAFT pipeline successfully balances intra- and inter-discourse phenomena, offering robust support for document-level machine translation. The high coherence and consistency scores in the Discourse Agent analysis indicate that discourse segmentation effectively captures localized linguistic phenomena. Similarly, the accurate identification of edges and terminology consistency underscores the Edge Agent’s ability to model and leverage cross-discourse dependencies.

Overall, the evaluation results validate the design of GRAFT, highlighting its potential for improving translation quality by systematically addressing discourse-level challenges. Future work may focus on further enhancing dependency modelling and exploring additional applications of memory mechanisms to strengthen cross-discourse coherence.

I Latency and Cost Analysis of GRAFT

We analyze the latency and cost profile of GRAFT in comparison to commercial large language models such as GPT-4o-mini and GPT-3.5-Turbo, which offer strong single-pass translation capabili-

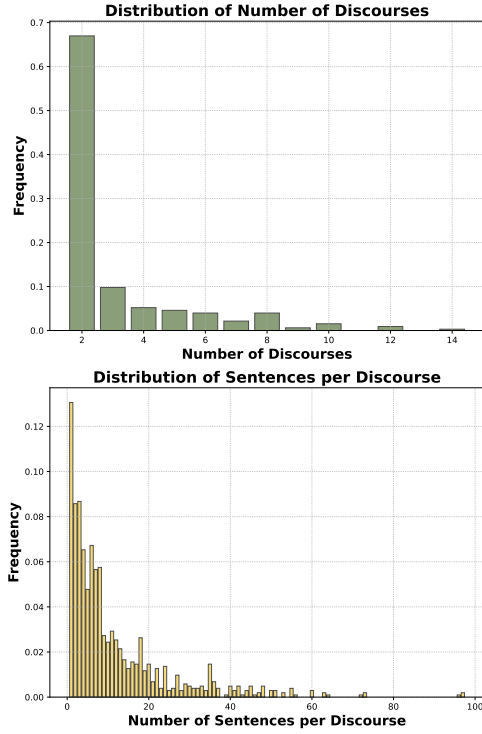


Figure 3: Analysis of the Discourse Agent’s performance across two metrics: coherence in narrative tasks and relevance in Q&A tasks. Results illustrate the agent’s contribution to maintaining contextual integrity.

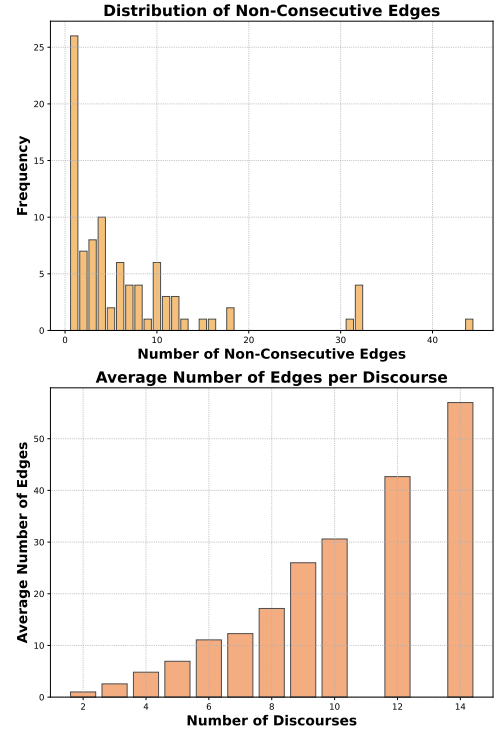


Figure 4: Evaluation of the Edge Agent’s impact on boundary-level decisions, focusing on translation precision and contextual transitions. Plots highlight its role in managing edge-case complexities.

ties but lack explicit discourse modeling. Our focus is on real-world deployment scenarios, where latency, cost-efficiency, and infrastructure flexibility are key concerns.

Despite its multi-agent architecture, GRAFT incurs only a marginal latency overhead of approximately $1.23\times$ compared to GPT-4o-mini, assuming identical compute resources. This overhead stems from sequential agent execution-segmentation, edge construction, memory generation, and final translation-but is significantly offset by improved translation quality. Notably, GRAFT achieves **2.0** d-BLEU gains over GPT-4o-mini and **3.2** over GPT-3.5-Turbo, particularly in handling discourse dependencies.

In terms of cost, GRAFT is substantially more economical when deployed with open-source models. When run with optimized open-weight LLMs such as LLaMA (Dubey et al., 2024) or Qwen (Yang et al., 2024; Team, 2024), the average cost to translate a 1,000-word document is estimated at just **\$0.03**, including all agentic steps. In contrast, GPT-4o-mini and GPT-3.5-Turbo cost approximately **\$0.08** and **\$0.05** respectively via API access, with no guarantee of document-level consis-

tency or discourse control. Thus, GRAFT provides improved quality at a lower operational cost-especially at scale-without incurring API fees or compromising data privacy.

The modular nature of GRAFT also enables targeted latency and cost optimizations. For instance, lightweight agents (e.g., segmentation and memory extraction) can use smaller, faster models; shared caches can reduce redundant inference; and components can be tailored to domain-specific workflows. This flexibility allows organizations to balance throughput, precision, and cost according to deployment constraints.

In summary, GRAFT offers strong efficiency advantages for real-world document translation: it outperforms GPT models in quality, is only marginally slower under equal compute, and enables significantly lower-cost, privacy-preserving deployment through open-source LLMs.

J Task Description and Few-shot Prompt Template

We show the prompts for $\text{En} \Rightarrow \text{De}$ language direction.

J.1 f_{LLM}

The task description and prompt used for f_{LLM} are shown in Figure 5.

J.2 $\mathcal{L}_{\text{edge}}$

The task description and prompt used for $\mathcal{L}_{\text{edge}}$ is shown in Figure 6.

J.3 $\mathcal{L}_{\text{mem}}$

The task description and prompt used to extract various components of the memory are shown in Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11.

J.4 $\mathcal{L}_{\text{trans}}$

The task description and prompt used for $\mathcal{L}_{\text{trans}}$ is shown in Figure 12.

Decision Function f_{LLM}

You are a linguistic expert tasked with segmenting a document into coherent discourses. A discourse is a contiguous segment of sentences that form a logical or thematic unit. For each new sentence, decide if it belongs to the current discourse ("yes") or if it should start a new discourse ("no"). Use the following examples to guide your decisions:

Example 1:

Current discourse: John went to the store. He bought some milk.

Next sentence: Later, he visited his friend.

Decision: yes

Example 2:

Current discourse: The company reported a significant profit increase this quarter.

Next sentence: However, the CEO announced upcoming layoffs.

Decision: yes

Example 3:

Current discourse: Alice loves painting. She often paints landscapes.

Next sentence: Meanwhile, Bob enjoys playing guitar.

Decision: no

Now process the following text:

Current discourse: {{ discourse }}

Next sentence: {{ next_sentence }}

Decision:

Figure 5: Task description and prompt: Decision function (f_{LLM}) of the Discourse Agent.

Edge Agent $\mathcal{L}_{edge}$

You are a linguistic expert tasked with determining if two discourses in a document should be connected for translation purposes. Two discourses should be connected if inter-discourse information needs to be maintained between them to ensure fluent, adequate, coherent, and cohesive translation of the second discourse.

For each pair of discourses, decide if they should be connected ("yes") or not ("no"). Use the following examples to guide your decisions:

Example 1:

Discourse 1: John went to the store. He bought some milk.

Discourse 2: Later, he visited his friend.

Decision: yes

Example 2:

Discourse 1: Alice loves painting. She often paints landscapes.

Discourse 2: Bob enjoys playing guitar in his free time.

Decision: no

Example 3:

Discourse 1: The company reported a significant profit increase this quarter.

Discourse 2: However, the CEO announced upcoming layoffs.

Decision: yes

Now process the following discourses:

Discourse 1: {{ discourse_1 }}

Discourse 2: {{ discourse_2 }}

Decision:

Figure 6: Task description and prompt: Edge Agent ($\mathcal{L}_{edge}$).

Score	General Quality	Discourse Awareness
5	Translation passes quality control; the overall translation is excellent. Translation is very fluent with no grammatical errors and has been localized to fit the target language. Word choice is accurate with no mistranslations. The translation is 100% true to the source text.	No inconsistency relating to key terms such as names, organization, etc. Linking words or expressions between sentences keeps the logic and language of the passage clear and fluent. Context and tone are consistent throughout. The style conforms to the culture and habits of the target language.
4	Translation passes quality control; the overall translation is very good. Translation is fluent. Any errors that may be present do not affect the meaning or comprehension of the text. Most word choices are accurate, but some may cause ambiguity. Key terms are consistent. Inconsistency is limited to non-key terms.	Logical and language is clear and fluent. Some sentences lack transitions but do not affect contextual comprehension. The topic is consistent. Tone and word choice may be inconsistent, but comprehension is not affected. Translation conforms to the culture and habits.
3	Translation passes quality control; the overall translation is ok. Translation is mostly fluent, but there are many sections that require rereading due to language usage. Some word choices are inaccurate or contain errors, but the meaning of the sentence can be inferred from context.	Some key terms may be inconsistent. Most sentences translate smoothly and logically, but some sentences may seem abrupt due to a lack of linkage. The topic is consistent. Tone and word choice are inconsistent, noticeably affecting the accuracy of reading comprehension.
2	Translation does not pass quality control; the overall translation is poor. Meaning is unclear or disjointed. Even with multiple rereading, the passage may still be incomprehensible. Translation is not accurate to the source text or is missing in large quantities, causing the translation to deviate from the source text.	Many key terms are inconsistent, needing multiple rereading to understand the context of the passage. Some linkages are present, but overall, the passage lacks fluency and clarity, causing trouble with comprehension. The topic or tone is different from other passages, affecting reading comprehension.
1	Translation does not pass quality control; the overall translation is very poor. More than half of the translation is mistranslated or missing.	Key terms are inconsistent, causing great trouble with comprehension. Some linkages are present, but overall, the passage lacks fluency and clarity, heavily interfering with comprehension. The topic or tone is different from other passages, heavily interfering with comprehension.
0	Translation output is unrelated to the source text.	The output is unrelated to the previous or following sections.

Table 9: Quality and Discourse Awareness Scoring Guidelines

System	Human (General/Discourse)				Ave.
	News	Social	Fiction	Q&A	
Commercial System (Google)	1.9/2.0	1.2/1.3	2.1/2.4	1.5/1.5	1.7/1.7
GPT-3.5	2.8/2.8	2.5/2.7	2.8/2.9	2.9/2.9	2.8/2.8
GPT-4o-mini	3.3/3.4	2.9/2.9	2.6/2.8	3.1/3.2	3.0/3.1
GRAFT	4.3/4.5	3.9/3.9	3.9/3.9	4.3/4.6	4.1/4.2

Table 10: Domain-specific performance (Human Evaluation) for Zh $\Rightarrow$ En translation direction across four domains.

Memory Agent $\mathcal{L}_{\text{mem}}^{M_i^{\text{np}}}$

You are a translation memory assistant.
Given the German translation below, list every full noun and its pronoun on its own line, separated by :. If none, respond with (no ≠).

Example 1:
Source discourse (EN):
John saw the man and the woman.
Target discourse (DE):
John sah den Mann und die Frau. Er grüßte sie.
Output:
der Mann:er
die Frau:sie

Example 2:
Source discourse (EN):
The dog chased the ball.
Target discourse (DE):
Der Hund jagte den Ball. Er fing ihn schnell.
Output:
der Hund:er
der Ball:ihn

Now process:
Source discourse (EN):
{ source_discourse }
Target discourse (DE):
{ target_discourse }
Output: Do not output anything except the desired result.

Figure 7: Task description and prompt: Memory Agent: M_i^{np}

Memory Agent $\mathcal{L}_{\text{mem}}^{M_i^{\text{ent}}}$

You are a translation memory assistant.
List each named entity in the English source and its German translation on its own line, separated by :. If none, respond with (no ≠).

Example 1:
Source (EN):
I flew from London to the United States.
Target (DE):
Ich flog von London in die Vereinigten Staaten.
Output:
London:London
United States:Vereinigte Staaten

Example 2:
Source (EN):
Marie Curie was born in Warsaw.
Target (DE):
Marie Curie wurde in Warschau geboren.
Output:
Marie Curie:Marie Curie
Warsaw:Warschau

Now process:
Source discourse (EN):
{ source_discourse }
Target discourse (DE):
{ target_discourse }
Output: Do not output anything except the desired result.

Figure 8: Task description and prompt: Memory Agent: M_i^{ent}

Memory Agent $\mathcal{L}_{\text{mem}}^{M_i^{\text{phr}}}$

You are a translation memory assistant.
Extract each multi-word phrase (≥ 2 words) from the English source and its German counterpart, one per line, separated by `:`. If none, respond with *(no $\neq$)*.

Example 1:
Source (EN):
The company reported a significant profit this quarter.
Target (DE):
Das Unternehmen meldete in diesem Quartal einen deutlichen Gewinn.
Output:
significant profit:deutlichen Gewinn
this quarter:in diesem Quartal

Example 2:
Source (EN):
She completed her work on time.
Target (DE):
Sie erledigte ihre Arbeit pünktlich.
Output:
on time:pünktlich
completed her work:erledigte ihre Arbeit

Now process:
Source discourse (EN):
`{{ source_discourse }}`
Target discourse (DE):
`{{ target_discourse }}`
Output: Do not output anything except the desired result.

Figure 9: Prompt: Memory Agent: M_i^{phr}

Memory Agent $\mathcal{L}_{\text{mem}}^{C_i}$

You are a translation memory assistant.
Does this German discourse end with a connective like "aber", "jedoch", or "deshalb"? If yes, output it; otherwise output *(no $\neq$)*.

Example 1:
Target discourse (DE):
Er war müde. Dennoch arbeitete er weiter.
Output:
dennoch

Example 2:
Target discourse (DE):
Sie ging nach Hause.
Output:
(none)

Now process:
Target discourse (DE):
`{{ target_discourse }}`
Output: Do not output anything except the desired result.

Figure 10: Task description and prompt: Memory Agent: C_i

Memory Agent $\mathcal{L}_{\text{mem}}^{S_i}$

You are a translation memory assistant.
Write a one-sentence summary of any special decisions you made (pronouns, connectives, word order) during translation from English to German. If none, respond with (no $\neq$).

Example 1:
Source (EN):
He wanted to go, but he stayed.
Target (DE):
Er wollte gehen, aber er blieb.
Output:
Chose "aber" to preserve contrast.

Example 2:
Source (EN):
The girl and the boy waved.
Target (DE):
Das Mädchen und der Junge winkten.
Output:
(none)

Now process:
Source discourse (EN):
`{{ source_discourse }}`
Target discourse (DE):
`{{ target_discourse }}`
Output: Do not output anything except the desired result.

Figure 11: Task description and prompt: Memory Agent: S_i

Translation Agent $\mathcal{L}_{\text{trans}}$

You are a professional translator from English into German.
Use the combined memory below to maintain consistency, fluency, cohesion, and coherence with previously translated discourses.

Example 1
Memory:
Target noun-pronoun mappings:
- the minister → he
Source entity→target entity mappings:
- Berlin → Berlin
- European Union → Europäische Union
Discourse connectives:
- außerdem
Source phrase→target phrase mappings:
- renewable energy → erneuerbare Energien
- policy framework → Politikrahmen
Combined summary:
Chose "außerdem" to add additive link; preserved "erneuerbare Energien."

Source discourse (EN):
The minister announced a new policy framework yesterday. Renewable energy targets will be updated. He said these changes will benefit all member states.
Output (DE):
Der Minister kündigte gestern einen neuen Politikrahmen an. Die Ziele für erneuerbare Energien werden aktualisiert. Er sagte, dass diese Änderungen allen Mitgliedstaaten zugutekommen werden.
...

Now translate using your own memory:
Combined memory:
`{{ incident_memory }}`
Source discourse (EN):
`{{ source_discourse }}`
Output (DE): Do not output anything except the translation.

Figure 12: Task description and prompt: Translation Agent ($\mathcal{L}_{\text{trans}}$)