

A Cross-Domain Evaluation of Multimodal Argument Relation Identification

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Abstract

Recent advances in argument relation identification have begun to look beyond the domain in which they were trained. It comes as no surprise that models which are able to generalise well into many different domains are much more useful in real-world contexts. Such work has previously been hampered by a lack of available data. In this project the largest multimodal argument mining dataset currently available is presented, along with a cross-domain dataset. These datasets are then used to evaluate different multimodal techniques in a cross-domain environment. It was found that while the addition of acoustic features does not provide a significant improvement over text only solutions, it was found that the process used to combine data from each sequence in the pair is vitally important to the performance of the model.

1 Introduction

Argument relation identification (ARI) is a subtask of argument mining (AM) involved with the detection and classification of the argumentative components contained within text and discussion [1]. AM generally can cover many different tasks, including argumentative sequence detection, argument component classification and ARI in a specific domain.

All of these tasks (often when combined) have many different applications such as fake news and fallacy detection with uses across many fields including political science, military and corporate intelligence, and education. In all of these fields it is important to be able to extract

arguments and their relations accurately and with ease.

In many contexts (e.g. political debates or court proceedings) there is both the audio data which can then be transcribed into the textual data. Previously, most argument mining systems have focused completely on the textual data, often gained from a transcript of these discussions or debates. More recent research, however, has shown that the paralinguistic features available from other modalities of data (either images or audio) are able to improve the performance over text only solutions.

Multimodal models have shown the greatest level of improvement in argumentative sentence detection and argument segmentation [2]. However, they have only had varying degrees of success in ARI with Mancini *et al.* [3] finding the addition of acoustic features significantly increased performance while Mestre *et al.* [4] find no significant difference. Recent advances in multimodal models and their pre-training have now allowed the effective addition of acoustic features [5], [6], along with advances in other areas of natural language processing, more specifically, the advent of the transformer [7] and the recent boom of large language models (LLMs), including their use in text-based argument mining [8]. Due to their size, LLMs perform very well across a variety of domains and fields, but at great computational cost. Therefore it is pertinent to understand how smaller models perform across a number of domains.

Traditionally, argument mining systems have been evaluated on the same domain that they were trained on [9], [10]. But given the recent uses of relatively task agnostic pre-training approaches and models such as BERT [11] and then the advent of LLMs has further increased

the need for domain agnostic models. These advancements have also been applied to argument mining by evaluating models on datasets and domains with which they were not trained [12], [13]. This approach has not yet been evaluated on multimodal models generally nor text-audio models specifically, in any sub-task of argument mining, it is very possible that the addition of acoustic features will be helpful for the model to learn more intrinsic, less domain-specific features and therefore increase its ability to generalise beyond the domain in which it was trained. A likely reason that this has not been studied further is the relative lack of resources and available datasets designed for text-audio ARI. The only dataset currently available for the task is the M-Arg policital debate dataset [4].

It is for this reason that the goals of this project are twofold:

- (i) Extend two existing debate datasets with their audio data allowing their use for all multimodal or audio-only AM applications. The first of these is the large QT30 corpus [14] and the second is a smaller, but cross-domain corpus created from Moral Maze episodes [15].
- (ii) Perform an extensive evaluation of different multimodal techniques and models in a cross-domain setting on the task of argument relation identification.

2 Background

2.1 Argumentation Theory

Argument and debate has been studied since the time of the ancient Greek philosophers and rhetoricians where argument theorists have sought to formalise discourse and discover some standard of proof for determining the ‘correctness’ of an argument. Over time, theories of arguments and discussions have evolved, notably when Hamblin [16] refashioned an argumentative discourse as a game, where one party makes moves offering premises that may be acceptable to the another party in the discourse who doubts the conclusion of the argument. When viewing a discourse as a game, it becomes possible to model discourse in such a way that it can be

viewed through the lens of formal logic, and therefore computationally too.

In order to describe various dialogue, argument and illocutionary structures different models (annotation schemes) can be used, some annotation schemes focus on types of the text itself (such as speech act theory [17]) or on the types of relations between components (such as Rhetorical Structure Theory [18]). Inference Anchoring Theory (IAT) [19] is an annotation scheme constructed to benefit from insights across both types, whilst focusing specifically on argumentative discourse. This makes IAT a very useful tool to analyse arguments and their relations.

In IAT, the discourse is first segmented into Argumentative Discourse Units (ADUs). An ADU is any span of the discourse which has both propositional content and discrete argumentative function [20]. An IAT argument graph is typically composed of two main parts: the left-hand side and the right-hand side. The right-hand side is concerned with locutions and transitions between them. A locution is simply the text of the ADU as uttered, without reconstructing ellipses or resolving pronouns. Locutions also include the speaker and may even include a timestamp. Transitions connect locutions capturing a functional relationship between predecessor and successor locutions (i.e. a response or reply).

The left-hand side of an argument graph is more concerned with the content of the ADU, rather than directly reflecting what was uttered. This consists of the propositions made, and the relations between those propositions. To create a proposition from an ADU, the content is reconstructed to be a coherent, lone-standing sentence. This means that any missing or implicit material has to be reconstructed, including anaphoric references (e.g. pronouns). Performing this reconstruction allows both a human annotator and a computational system to view some of the context surrounding the locution and therefore make a better judgement as to a proposition’s relation to others.

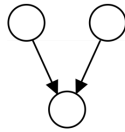
IAT defines three different types of propositional relation: *inference*, *conflict* and *rephrase*. An inference relation (also termed RA) holds between two propositions when one (the premise) is used to provide a reason to accept the other (the conclusion). This may include an-

notation of the kind of support e.g. Modus Ponens or Argument from Expert Opinion. These subtypes of relation are often called *argument schemes* [21], [22]. There are also several different inference structures (images from [1]):

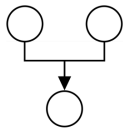
- **Serial arguments** occur when one proposition supports another, which in turn supports a third.



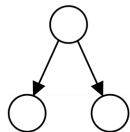
- **Convergent arguments** occur when multiple premises act independently to support the same conclusion.



- **Linked arguments** occur when multiple premises work together to support a conclusion.



- **Divergent arguments** occur when a single premise is used to support multiple conclusions.



A conflict relation (also termed CA) holds between two propositions when one is used to provide an incompatible alternative to another and can also be of a given

kind (e.g. Conflict from Bias, Conflict from Propositional Negation). The following conflict structures are identified by IAT:

- **Rebutting conflict** occurs if one proposition is directly targeting another by indicating that the latter is not acceptable.
- **Undermining conflict** occurs if a conflict is targeting the premise of an argument, then it is undermining its conclusion.
- **Undercutting conflict** occurs if the conflict is targeting the inference relation between two propositions.

A rephrase relation (also termed MA) holds when one proposition rephrases, restates or reformulates another but with different propositional content (i.e. one proposition cannot simply repeat the other). There are many different kinds of rephrase, such as Specialisation, Generalisation, Instantiation etc. Generally, question answering will often involve a rephrase because the propositional content of the question is typically instantiated, resolved or refined by its answer. In contrast to inference, conflict and rephrase structures only have a single incoming one outgoing edge.

The left and right-hand sides are connected by *illocutionary connections*. These illocutionary connections are based on illocutionary force as introduced by speech act theory [17]. The speech act $F(p)$ is the act which relates the locution and the propositional content p through the illocutionary force F e.g. asserting p , requesting p , promising p etc. There are many different types of illocutionary connection, including: assertions, questions, challenges, concessions and (dis-)affirmations [23]. By modelling these relations it is possible to gain a better understanding of how something is said and its purpose within the discourse. In doing this, we create a graph (known as an *argument map*) which can then be stored computationally.

There have been several ways to store argumentative data created, for example Argument Markup Language (AML) [24], an XML-based language used to describe arguments in the Araucaria software. More recently, the Argument Interchange Format (AIF) [25] has been created to standardise the storage of IAT graphs.

AIF treats all relevant parts of the argument as nodes within a graph. These nodes can be put into two categories: *information nodes* (I-nodes) and *scheme nodes* (S-nodes). I-nodes represent the claims made in the discourse whereas S-nodes indicate the application of an argument scheme. Initially I-nodes only included the propositions made [25], but when Reed *et al.* [26] extended AIF to cater to dialogues, they added L-nodes as a subclass of I-nodes to represent locutions. For the purposes of this research, I-nodes and L-nodes are considered separate classes where I-nodes contain propositions and L-nodes contain locutions.

Since AIF data can be easily shared, it became the basis for a Worldwide Argument Web (WWAW) [27]. Since then, many corpora have been annotated using IAT and published on the AIFdb¹ [28] providing a very useful resource for argumentation research of many kinds.

2.2 Natural Language Processing

In recent years there have been several major advances in the field of natural language processing (NLP), most notably the introduction of the transformer architecture [7]. The transformer architecture, based on self-attention, allows the model to determine much longer range dependencies than previous approaches. In doing so, the model is able to learn from the context surrounding a word, even gaining insight from context ‘far away’ in the text.

Even before Vaswani *et al.* introduced the transformer architecture supervised and semi-supervised pre-training approaches were already being explored, and proven to be a very useful tool for improving the performance of language models [29], [30]. When the transformer was introduced these pre-training techniques were adapted for use in transformers creating models which are able to be fine-tuned with relatively minimal effort and compute to allow high performance on a wide variety of tasks [11], [31]. The pre-training approaches introduced by BERT and RoBERTa use a combination of masked language modelling (where the model is trained to predict the token hidden under a [mask] token) and next sentence prediction. The models are then trained using this

approach on a large amount of data (the data used to pre-train RoBERTa totals over 160GB of uncompressed text).

Transformer models have recently become much more well-known due to the introduction of Large Language Models (LLMs) such as GPT-4 [32] and LLaMA [33]. LLMs have proven very useful across NLP due to their ability to achieve high performance on many tasks without the need for fine-tuning, this can, however, include few-shot techniques to allow them to ‘learn’ at inference time [34], [35].

A similar progression can be seen in the development of audio models. Pre-training was notably introduced into speech recognition with wav2vec [5], where the model is trained to predict future samples from a given signal. The wav2vec model has two main stages, first raw audio samples are fed into a convolutional network which performs a similar role to the tokenisation seen in text-based language models by using a sliding window approach to downsample the audio data. These encodings are then fed into a second convolutional network to create a final encoding for the sequence.

Transformer models were introduced into the architecture of audio models with wav2vec2 [36] and HuBERT [37], where the second convolutional model is replaced with a transformer in order to better learn dependencies across the entire sequence. These models are then pre-trained on significant amounts of audio data (960 hours in the case of wav2vec2) in order to then be fine-tuned on a downstream task. It is also possible to combine text and audio in order to gain insights from both modalities.

Combining modalities (such as text and audio) has also proven to be a useful tool across several tasks, including medical imaging [38], [39] and natural language processing [40], [41], including argument mining [3], [4]. Generally fusion techniques can be split into two categories: early and late. Early fusion techniques combine representations of each modality before being used as input to an encoder, with the primary benefit that only a single encoder is used. Late fusion techniques use a separate encoder for each modality, and the encodings are then fused to provide a crossmodal representation of the input.

¹<https://www.aifdb.org/>

In early fusion the input representations are transformed into a common information space, often using vectorisation techniques dependent on the modality. Late fusion techniques allow for the encodings of each modality to be combined in several different ways, often either simple operations (such as concatenation or an element-wise product) but a cross-modal attention module can also be used to combine the modalities [42], [43]. The fusion techniques used in this project are explained in detail in Section 4.

2.3 Argument Mining

Argument Mining (AM) is the automatic identification and extraction of inference and reasoning in natural language [1]. Various NLP techniques have been beneficial to AM, from statistical methods to the more recent neural networks, in particular the transformer architecture [12]. Before discussing the automation of AM, it is useful to understand how argument analysis is conducted manually. Manual argument analysis considers the following steps:

- **Text Segmentation** involves the splitting of the original text/discourse into the pieces that will form the resulting argument structure. These pieces are often termed Elementary Discourse Units (EDUs).
- **Argument / Non-Argument Classification** is the task of determining which of the segments found in the text segmentation step are relevant to the argument. For most manual analysis, this step is performed in conjunction with text segmentation i.e. the analyst doesn't segment parts of the text which are not relevant to the argument.
- **Simple Structure** is the identification of relations between the arguments (e.g. inference, conflict and rephrase) and their structures (e.g. convergent, serial etc.).
- **Refined Structure** refers to the identification of argumentation schemes (e.g. Argument from Expert Opinion, Conflict From Bias etc.).

When the argument analysis process is automated, the stages are very similar to those in the manual process. Lawrence and Reed [1] define the steps as follows, increasing in computational complexity:

- **Identifying Argument Components** combines the stages of text segmentation and argument / non-argument classification in the manual process.
- **Identifying Clausal Properties** involves the identification of both intrinsic clausal properties (e.g. is X evidence?, is X reported speech?) of the ADU and the contextual properties (e.g. is X a premise?, is X a conclusion?).
- **Identifying Relational Properties** relates to the identification of *general relations* between ADUs (e.g. is X a premise for Y?, is X in conflict with Y?) and the identification of argument schemes.

Generally these stages of AM are not directly used in the literature, but instead a set of AM sub-tasks which map onto each of these stages, these tasks are defined by Mancini et al. [3] as follows:

- **Argumentative Sentence Detection (ASD)** is the task of classifying a sequence as containing an argument, or not. ASD can be extended to include the task of claim detection, where a sequence is classified as containing a claim or not containing a claim.
- **Argument Component Classification (ACC)** is the task of determining whether an argumentative sentence x contains one or more argumentative components e.g. a claim or premise. This is loosely analogous to the identification of clausal properties as defined by Lawrence and Reed.
- **Argumentative Relation Identification (ARI)** is the task of identifying the relation between a pair of sentences where given a pair (x_i, x_j) the task is to identify the argumentative relation $x_i \rightarrow x_j$ across some relation model.

There are varying relation models for ARI, the most commonly used is simply classifying the pair as one of support (a combination of inference and rephrase), attack (conflict) or unrelated. For the purposes of this project this is termed 3-class ARI. ARI can also be conducted using all relations described in IAT (inference, rephrase and conflict), as well as unrelated nodes. For the purpose of this project this is termed 4-class ARI. Some literature makes a distinction between Argument Relation Identification and Argument Relation Classification, where the latter does not involve unrelated pairs (i.e. given that the pair (x_i, x_j) is related, what is the type

of relation?), however this distinction is by no means universal among AM literature [13].

Much of the AM literature only evaluates their systems in the same domain (dataset) as it was trained on [1], [8]–[10], [44], [45]. Recently, however, more research has been conducted into how these models perform across different domains [12], [46], [47], this generally involves training the model on one domain and then evaluating its performance across several others. A good example of this is the ARIES benchmark [13], which provides results for various different approaches to the ARI task across popular ARI datasets. Another notable contribution is Ruiz-Dolz *et al.* (2021) [12] which compares the cross-domain performance of the most popular pre-trained transformer models (e.g. BERT [11] and RoBERTa [31]) showing that the RoBERTa models tend to perform better both in-domain and cross-domain. In order to perform a cross-domain evaluation, it is useful to understand how the data can be constructed and what influence that has.

Ruiz-Dolz *et al.* (2025) [48] proposes techniques to answer the question: How do we sample unrelated arguments? If all possible examples of unrelated samples are used it constitutes an overwhelming proportion of the dataset (98-100%) which would be detrimental to model performance in the real world. To achieve this, they propose the following methods:

- **Undersampling** creates a more balanced class distribution by randomly choosing unrelated propositions from the set of all possible combinations.
- **Long Context Sampling** where unrelated propositions are chosen such that they are ‘far apart’ in the discourse. Ruiz-Dolz *et al.* define this as being from different argument maps.
- **Short Context Sampling** where unrelated propositions are chosen such that they are ‘close together’ in the discourse. Ruiz-Dolz *et al.* define this as being from the same argument map.
- **Semantic Similarity Sampling** where unrelated propositions are chosen such that they are semantically similar.

They show that Short Context Sampling is the most challenging method when looking in-domain, however, the model is better able to generalise across different do-

main than the other methods and is a more realistic task.

Next, the applicability of these techniques is extended to multiple modalities. AM has been performed using both Vision-Language systems [49]–[51] and perhaps the more obvious Audio-Language systems [2], [3], [52]. Making use of acoustic features has been shown to improve performance across both ASD and ARI tasks [2], [4] but there has not been any research into the applicability of Audio-Language systems in cross-domain contexts.

Mancini *et al.* [3] created a comprehensive toolkit for argument mining research. They include both datasets and models that can be used for the creation and evaluation of audio-language argument mining systems, across different tasks, including ASD, ACC and ARI. Therefore, MAMKit provides a very useful benchmark for the development of audio-language AM techniques.

3 Datasets

All argument data used in this project are available as corpora on AIFdb². Using consistently annotated Argument Interchange Format (AIF) data allows many different datasets to be used and tested. The AIF Format [25] allows the annotation of argument data across all AM tasks, providing a platform for many different kinds of research.

Throughout the project two primary corpora have been considered: QT30 [14], a corpus consisting of 30 AIF annotated Question Time episodes, and a corpus of 9 AIF annotated Moral Maze episodes available on AIFdb [15].

3.1 Preprocessing

3.1.1 Argument Data

In order to use AIF data efficiently for ARI, it is useful to perform some preprocessing. This process produces a graph, where each node contains a location, its related proposition, and the proposition’s AIF identifier. This identifier corresponds to the audio data, allowing it to be

²<https://corpora.aifdb.org/>

easily loaded when required. Each edge in this graph corresponds to a relation between the propositions, one of RA (inference), MA (rephrase) or CA (conflict).

Figure 1 shows an example sub-graph from the larger argument graph. Each node is truncated for brevity and only shows the node’s ID, and the proposition. The major downside of processing the data in this way is simply that much of the nuance encoded within AIF is lost. This is primarily the inference and conflict structures (e.g. linked arguments, undercutting conflict etc.) but also the transitions and illocutionary connections. In the context of this project this is not an issue but is worth remembering when examining the data.

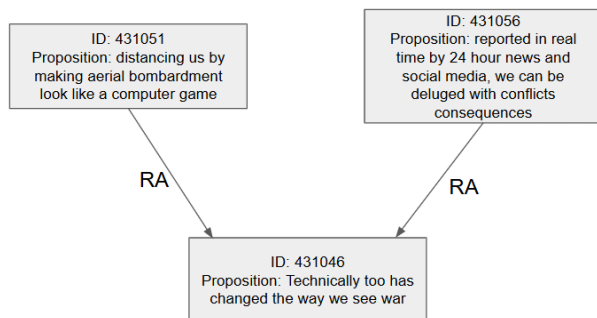


Figure 1: Example sub-graph.

An example of the JSON structure used to store the argument data is shown in Listing 1. It is also worth understanding the link between the locution and the proposition, of which those in Listing 1 are good examples. The locution is exactly what is said, and the speaker is given (in this case Matthew Taylor), whereas the proposition can be thought of as adding a bit more context from the surrounding dialogue. This primarily includes pronoun resolution as seen in the first word “she” in the locution vs. “Nancy Sherman” in the proposition.

An array of these JSON objects can then be used to create the node pairs required for the training and evaluation of the model.

3.1.2 Audio Data

The audio data first had to be downsampled from 44.1kHz to the 16kHz which is best accepted by the

Listing 1 Example JSON object corresponding to a Node.

```

1 {
2   "id": 433407,
3   "locution": "Matthew Taylor : she
4     ↳ answered questions about
5     ↳ norms and structures by
6     ↳ talking about beliefs and
7     ↳ campaigns and I think beliefs
8     ↳ are different to norms and I
9     ↳ think campaigns are different
10    ↳ to social structures",
11   "proposition": "Nancy Sherman
12     ↳ answered questions about
13     ↳ norms and structures by
14     ↳ talking about beliefs and
15     ↳ campaigns and beliefs are
16     ↳ different to norms and
17     ↳ campaigns are different to
18     ↳ social structures",
19   "relations": [
20     {
21       "type": "CA",
22       "to_node_id": 433393
23     },
24     {
25       "type": "RA",
26       "to_node_id": 433416
27     }
28   ]
29 }

```

Wav2Vec2 transformer [36] among many others. This can easily be achieved using FFmpeg³. In the case of QT30, first audio had to be extracted from the video, and collapsed into a mono track before it could be downsampled, this was also easily achieved with FFmpeg.

Next, start and end times for each locution in the argument graph need to be found, to allow the audio to be split per-locution (and therefore per node). This can be achieved using Connectionist Temporal Classification (CTC) [53] as exposed by PyTorch’s forced alignment

³<https://ffmpeg.org/>

api⁴.

In order to understand the abilities of a CTC-based forced alignment system it is of course useful to understand how the algorithms work. Simply, CTC provides the probability distribution across a set of tokens, for each timestep (known as a frame). For a forced alignment task, these tokens are typically each letter of the alphabet and a blank token. The blank token is used for frames which cannot be classified as any other token (e.g. silence).

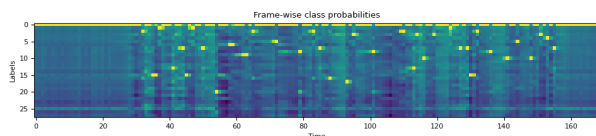


Figure 2: Example framewise probabilities.

Figure 2 (taken from the PyTorch tutorial on the subject⁵) shows an example of the framewise probability distribution across each token, token 0 here is the blank token. This distribution provides the probability (or confidence) of any particular token appearing in any given frame. Taking simply the most probable tokens provides something that looks like the following: - i - - h h a - - - d - where - is the blank token. That sequence describes the words ‘I had’, so it can be seen that the duplicates need to be removed, along with the blank tokens. This is the process that would be undertaken for Automated Speech Recognition.

When looking at forced alignment however, the process is a bit different since we already have a transcript. For forced alignment the goal is to find the most probable route through the framewise probability matrix matching the transcript. To do this a so-called trellis matrix can be generated. This represents the probabilities of remaining at the same token in the transcript, or moving on to the next one in each frame.

We are then looking for the path across the most likely transitions, $k_{(t+1,j+1)}$, where j is the current location in

the transcript, and t is the current timeframe. The trellis can then be defined as in Equation 1.

$$k_{t+1,j+1} = \max \left(k_{(t,j)}p(t+1,c_{j+1}), k_{(t,j+1)}p(t+1,repeat) \right) \quad (1)$$

Where k is the trellis matrix and $p(t, c_j)$ is the probability of any token c_j appearing in frame t , effectively referencing the framewise probability matrix, and *repeat* represents the blank token.

Once the trellis matrix is generated, an example of which is shown in Figure 3⁶ where the yellow high-probability path is visually obvious, it can be traversed using a backtracking algorithm, starting from the last token in the transcript and following either $(c_j \rightarrow c_j)$ or $(c_j \rightarrow c_j + 1)$ transitions, based on their probability, until reaching the beginning of the transcript.

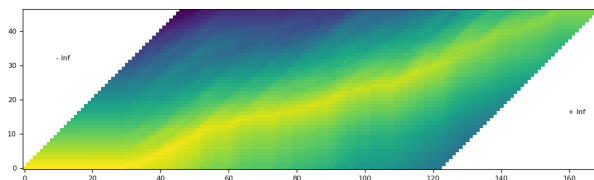


Figure 3: Example trellis matrix where yellow shows a high probability.

At this point, we have start and end frame-numbers for each token, and based on the probabilities the model has traversed, a ‘confidence’ score can be calculated based on the mean of the probabilities traversed, this group of three values is known as a span (in this case a token span). The token spans can be generated by using the PyTorch forced alignment API, allowing the algorithm to be easily implemented and used. Finally, the token spans can be combined into word spans based on word boundaries in the transcript. This provides start and end frame numbers for each word, along with a confidence score. The same process can be conducted later to find a location-level span with a confidence score. The frame

⁴<https://pytorch.org/audio/>

⁵https://pytorch.org/audio/main/tutorials/ctc_forced_alignment_api_tutorial.html ⁶https://pytorch.org/audio/main/tutorials/forced_alignment_tutorial.html

numbers can then be easily converted back into times in the waveform and then split into the required segment.

Initially the forced alignment of the argumentative discourse was achieved by aligning each word in the complete transcript of the episode, producing start and end times for each word. A search can then be performed through this data to find the required location. While this technique initially produced promising results, it was not robust enough to allow for errors in the transcripts or the crosstalk common in debates. This problem can be seen in the fact that the trellis matrix only allows for a single token to appear in each timeframe, which is trivially not applicable to the real world in an argumentative context where a lot of crosstalk (multiple speakers talking over each other) exists.

To solve this problem, the PyTorch forced alignment API is able to take wildcard tokens as input, therefore, each location can be searched for individually. To achieve this, the partial transcript used as input to the forced aligner took the following form: `* {location} *`.

Using this system allows the forced aligner to work well through crosstalk (since each location’s alignments are searched for independently of all others), and qualitatively seems to be more resilient to errors. Error resilience is helped since errors are less common in the location texts as opposed to the transcripts. Using this system also allowed for confidence scores to be collected for analysis. In this section general analysis across all corpora is performed, with corpus specific analysis in the relevant section.

Figure 4 shows the distribution of confidence scores across both the QT30 corpus and all Moral Maze corpora. This distribution shows that the system can relatively confidently align the majority of locations, with only approx. 8% of locations with a confidence score less than 0.50.

In order to further analyse the performance of this system, locations were selected at random and qualitatively analysed. Throughout this process, all locations appeared correct, however, it was very challenging to accurately determine the accuracy of the system on locations with confidence scores < 0.2 . This shows that this method of aligning locations with their corresponding

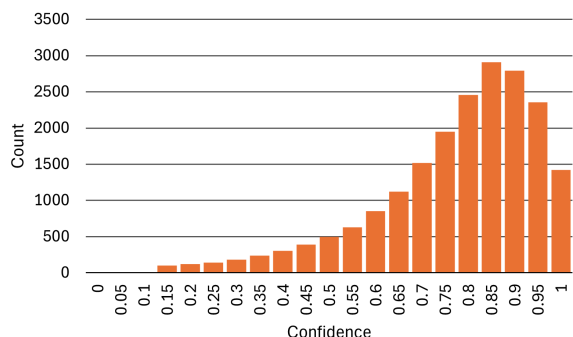


Figure 4: Confidence distribution across all corpora.

audio is accurate for the purposes of this project, as long as the confidence scores are taken into account. However, these confidence scores should not be mistaken for a ‘probability of being correct’.

The distribution of lengths for each audio clip was also analysed in order to ensure the models are being provided with enough data. The primary statistics are shown in Table 1. This data shows that the majority of locations are shorter than 8 seconds (approximately 120,000 samples at the sampling rate of 16kHz). In total, across both corpora, there is over 24 hours of argumentative audio, out of over 36 hours of total audio processed. The relevant data for the specific corpora are detailed in the relevant section.

Table 1: Audio data for locutions across all corpora.

Quantity	Length (s)	No. of Samples
Mean	3.9	62,000
75th Percentile	5.1	81,000
90th Percentile	7.7	120,000
Maximum	31	490,000

3.1.3 Pair Creation

Finally, a set of node pairs and their relations can be generated in order to train a neural network. For related nodes this can be done trivially in that for each relation, the corresponding pair of nodes can be added to the set. When sampling unrelated nodes, however, things

are more complex.

It has also been shown that how unrelated node pairs are sampled is very relevant to the model’s performance [48]. For this reason, it is also useful to provide a comparison between the different methods in a multimodal context. Since a short context is defined as being within an episode, the sampling strategies are only relevant for QT30, all Moral Maze episodes are simply undersampled. The following methods are compared:

- **Undersampling (US)** is the simplest method. The set of all possible pairs is created and then randomly undersampled to the number of inference/support relations.
- **Long Context Sampling (LCS)** samples unrelated nodes such that each node comes from a different episode with the result that they are ‘far apart’ in the discourse, this often takes the form of a different topic and such the task is slightly easier than the other methods. This list can then be randomly undersampled to the number of inference/support relations.
- **Short Context Sampling (SCS)** samples unrelated such that each node comes from the same episode so they are ‘close together’ in the discourse meaning that they often involve the same topic with the result that the task is slightly harder than other methods. This set is then randomly undersampled to the number of inference/support relations.

3.2 QT30

The QT30 argument corpus [14] contains transcripts and argument annotations for 30 episodes of the BBC’s Question Time, a series of televised topical debates across the United Kingdom. All episodes aired in 2020 and 2021. The corpus is split into 30 subcorpora, each spanning a single episode. This creates a large corpus with almost 20k locutions. What follows is an analysis of the corpus and how audio data was added.

Table 2 shows the distribution of each type of relation across QT30. Inference and Rephrase relations make up a total of 91.5% of the dataset, with Conflict relations being significantly less common, only making up 8.5% of the dataset. It is obvious that this is an unbalanced

dataset, which will have to be considered during training.

Table 2: Disribution of propositional relations in QT30.

Relation Type	Count	Proportion (%)
Inference	5,761	51.4%
Conflict	947	8.5%
Rephrase	4,496	40.1%
Total	11,204	100%

Table 3 shows the mean and standard deviation of the confidence scores across each of the QT30 subcorpora. The lowest two mean scores are shown in bold. Manually analysing samples in these episodes indicates a high error rate in the alignment of locutions. Because of this high error rate, it was decided to exclude these episodes from the corpus used for training. The excluded episodes are: 22July2021 and 30September2021. The rest of the episodes from QT30 will form its multimodal subcorpus (QT30-MM).

Table 3: Mean confidence scores (μ) and standard deviation of confidence scores (σ) across each QT30 subcorpus.

Corpus Name	μ	σ
28May2020	0.76	0.16
4June2020	0.72	0.17
18June2020	0.76	0.16
30July2020	0.75	0.16
2September2020	0.78	0.15
22October2020	0.76	0.16
5November2020	0.77	0.17
19November2020	0.74	0.19
10December2020	0.77	0.16
14January2021	0.74	0.17
28January2021	0.70	0.17
18February2021	0.75	0.16
4March2021	0.76	0.16
18March2021	0.75	0.17
15April2021	0.75	0.15
29April2021	0.70	0.19
20May2021	0.76	0.17
27May2021	0.79	0.15
10June2021	0.75	0.17
24June2021	0.74	0.17
8July2021	0.72	0.17
22July2021	0.44	0.28
5August2021	0.76	0.17
19August2021	0.77	0.17
2September2021	0.78	0.16
16September2021	0.77	0.16
30September2021	0.24	0.08
14October2021	0.75	0.19
28October2021	0.75	0.17
11November2021	0.78	0.16
QT30	0.75	0.17

Similarly to the complete QT30 corpus, Table 4 shows that Inference and Rephrase make up the vast majority of the QT30-MM dataset, with the proportion of Conflict relations decreasing to 8.4%.

Table 4: Distribution of propositional relations in QT30-MM.

Relation Type	Count	Proportion (%)
Inference	5,740	51%
Conflict	937	8.4%
Rephrase	4,479	40.6%
Total	11,156	100%

As can be seen in Figure 5 the distribution of confidence scores closely matches that shown in Figure 4. This still indicates that the audio alignments are calculated with high accuracy.

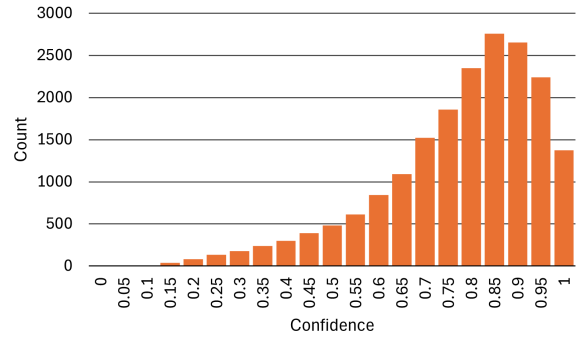


Figure 5: Confidence distribution across QT30-MM.

Table 5 shows the distribution of relations after sampling unrelated nodes, this process increases the dataset size to a total of almost 17k samples.

Table 5: Distribution of propositional relations after sampling non-related nodes.

Relation Type	Count	Proportion (%)
None	5,470	34%
Inference	5,470	34%
Conflict	937	6%
Rephrase	4,479	27%
Total	16,896	100%

The audio data contained within the dataset can also be analysed as shown in Table 6. Generally the values are

very similar to those shown in Table 1. The QT30-MM dataset contains almost 20 hours of argumentative audio taken from approximately 29.5 hours of total audio. This makes the QT30-MM corpus the largest multimodal ARI dataset currently available.

Table 6: Audio data for locutions across QT30-MM.

Quantity	Length (s)	No. of Samples
Mean	3.8	60,000
75th Percentile	5.0	79,000
90th Percentile	7.5	120,000
Maximum	30	470,000

3.3 Moral Maze

Similar to Question Time, the BBC’s Moral Maze is a series of radio broadcast debates, with each episode focusing on a certain topic. Several episodes of the Moral Maze have been annotated with IAT and AIF and also made available on AIFdb. Of these episodes, eight were chosen from different fields. It is therefore these eight episodes, released from 2012 to 2019, which this project considers. Each episode focuses on a very different domain which allows for a robust, cross-domain analysis of any models trained on another corpus (e.g. QT30). The Moral Maze corpus contains data from eight different episodes: Banking (B), Empire (E), Money (M), Problem (P), Syria (S), Green Belt (G), Hypocrisy (H) and Welfare (W). Each episode consists of a debate focusing on a different topic, and hence has a different distribution of classes.

Table 7 shows the distribution of propositional relations across the Moral Maze corpus, after unrelated pairs have been sampled. Comparing the corpus to QT30, a significantly lower proportion of the corpus is made up of Rephrase relations. It is possible that the differing formats of the debates has an impact here.

Table 8: Mean confidence scores (μ) and Standard Deviation of confidence scores (σ) across Moral Maze sub-corpora.

Subcorpus	μ	σ
B	0.79	0.14
E	0.76	0.15
M	0.78	0.14
P	0.80	0.15
S	0.74	0.16
G	0.80	0.14
H	0.74	0.16
W	0.75	0.15

In Table 8 the mean and standard deviation of audio alignment confidence scores are compared across sub-corpora. Generally the results match what is expected and are similar to those in QT30.

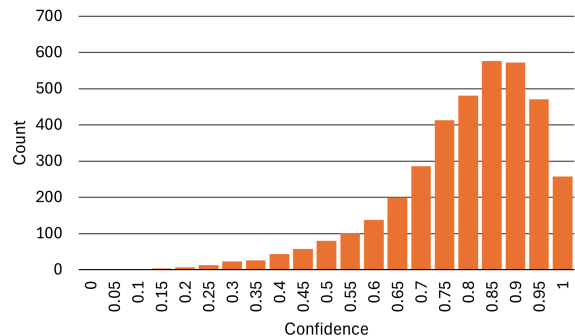


Figure 6: Confidence distribution across all Moral Maze subcorpora.

Figure 6 shows the distribution of audio alignment confidence scores across all Moral Maze episodes. This follows the expected pattern as shown in Figures 4 and 5.

Table 9 shows the statistics for the audio part of the combined Moral Maze corpus. Generally the locutions seem to be a bit longer in the Moral Maze when compared to QT30. The Moral Maze combined corpus contains almost 5 hours of argumentative audio taken from approximately 6.5 hours of total audio.

Table 7: Distribution of propositional relations across the Moral Maze corpus.

Relation Type	None	Inference	Conflict	Rephrase	Total
B	132 (45%)	132 (45%)	24 (8%)	3 (1%)	291
E	151 (41%)	151 (41%)	39 (11%)	25 (7%)	366
M	255 (43%)	255 (43%)	29 (5%)	58 (10%)	597
P	236 (42%)	236 (42%)	40 (7%)	45 (8%)	557
S	181 (42%)	181 (42%)	63 (14%)	10 (2%)	435
G	301 (41%)	301 (41%)	46 (6%)	93 (13%)	741
H	207 (43%)	207 (43%)	23 (5%)	43 (9%)	480
W	211 (40%)	211 (40%)	59 (11%)	43 (8%)	524
Total	1,674 (42%)	1,674 (42%)	323 (8%)	320 (8%)	3,991

Table 9: Audio data for locutions across Moral Maze.

Quantity	Length (s)	No. of Samples
Mean	4.4	70,000
75th Percentile	5.8	94,000
90th Percentile	9.0	140,000
Maximum	31	490,000

4 Models

This section describes the model architectures that are evaluated in this project. Since the models will be aimed at a sequence pair classification task, there is a distinction between when data from each sequence is combined (which can be termed sequence fusion) and when data from each modality is combined (which can be termed multimodal fusion). The following subsections define the different approaches evaluated for each of these stages.

In previous work it has been shown that the RoBERTa models perform better than other pretrained transformers on the task of ARI [12]. To encode the text data, the RoBERTa-base model is used, with 12 encoder layers, each with 12 attention heads and a hidden size of 768, resulting in 110M total parameters⁷. Wav2Vec 2.0 is also used in many audio processing tasks [3], [54] and therefore is used to encode the audio data. To ensure both models output the same hidden size, the wav2vec2-

base model is used with 95M total parameters⁸. The wav2vec2 model used is fine-tuned on 960 hours of librispeech for automatic speech recognition. Once the data has been encoded, it can be fed into the classification head to output a final prediction.

The classification head used for most models is a simple linear projection from the hidden vector down to the required number of classes. The best performing model on ARI as proposed in MAMKit [3] (MM-RoBERTa) is also evaluated. Their model uses the fusion architecture described in Figure 8 but with a 3 layer Multilayer Perceptron (MLP) model as the classification head. They also only train the classification head, without training the text or audio encoders.

4.1 Sequence Fusion

In most text-processing approaches data from each sequence is combined at the text level using special tokens defined in the encoder’s tokeniser [13], [44], [45]. For this project, this approach is termed early sequence fusion. To achieve this, the input sequences can be delimited by a separator token, and the entire sequence wrapped in the start of sequence (SOS) and end of sequence (EOS) tokens. An example using the RoBERTa tokeniser takes the following form: `<s> [sequence 1] </s> [sequence 2] </s>`. Here the `<s>` token corresponds to the SOS, and `</s>` does the job of both the separator token and the EOS token.

Next the audio data can be considered. As far as was

⁷<https://huggingface.co/FacebookAI/roberta-base>

⁸<https://huggingface.co/facebook/wav2vec2-base-960h>

found, there is no existing literature on how early sequence fusion could function for audio models. Therefore, it was decided to delineate each audio sequence by a certain amount of silence. The exact amount of silence could be adjusted as a training hyperparameter and was eventually set to 5 seconds.

Figure 7 shows an example of a model architecture using this late fusion technique, text related steps are shown in purple and audio related steps are shown in green. RoBERTa and Wav2Vec2 are simply used as examples and could be substituted for other models.

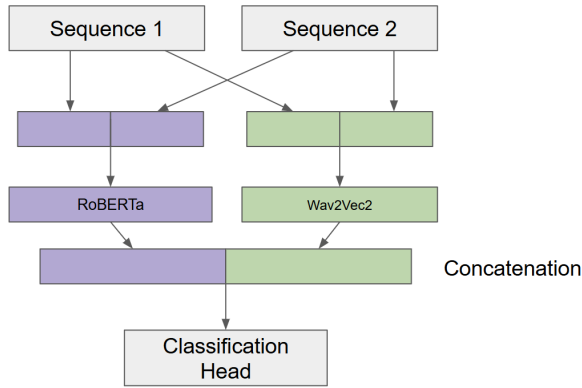


Figure 7: Model diagram with early sequence and late multimodal fusion.

Mestre *et al.* [4] and Mancini *et al.* [3] approach the problem differently. They first put each sequence through the text encoder independently, before fusing the outputs and feeding the combined encodings into the classification head. While concatenation is the only fusion method examined for this sequence fusion technique, others (such as an element-wise product or cross-attention) could be used. This approach extends much more easily to the audio modality, since the audio encodings can be combined in the same way as the text encodings. This approach to fusing the data in each sequence can be termed late sequence fusion. Figure 8 shows an example of a model architecture using late sequence fusion, text processing steps and data are shown in purple and audio-related steps are shown in green.

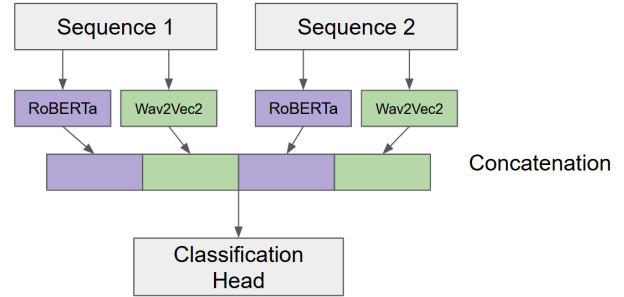


Figure 8: Model diagram with late concatenation sequence and multimodal fusion.

4.2 Multimodal Fusion

Multimodal fusion describes the method by which the text and audio data is combined. As detailed in Section 2.2, fusion techniques can be split into two major categories: early and late fusion. This project only evaluates late fusion techniques due to their ease of development and the applicability of pre-trained models. The following techniques are evaluated:

- **Concatenation** where the pooled encodings for each modality are simply concatenated before being fed into the classification head.
- **Elementwise-product** (otherwise known as a Hadamard product) takes the product of each element in the pooled encodings for each modality.
- **Crossmodal Attention (CA)** is similar to the self-attention mechanism found in transformers, however, the queries are taken from a different modality when compared to the keys and values. To compute crossmodal attention features, the query and key matrices are multiplied and then put through a softmax. This is then multiplied with the value matrix and the result can then be pooled using an arithmetic mean. For the purposes of this project, the CA module is labelled based on the modality from which the query matrix is derived (e.g. a `CA_Text` module derives the query matrix from the text encodings and the key and value matrices from the audio encodings). This is shown in Figure 9.

Listing 2 shows how a crossmodal attention mechanism can be implemented into a PyTorch module. The code is

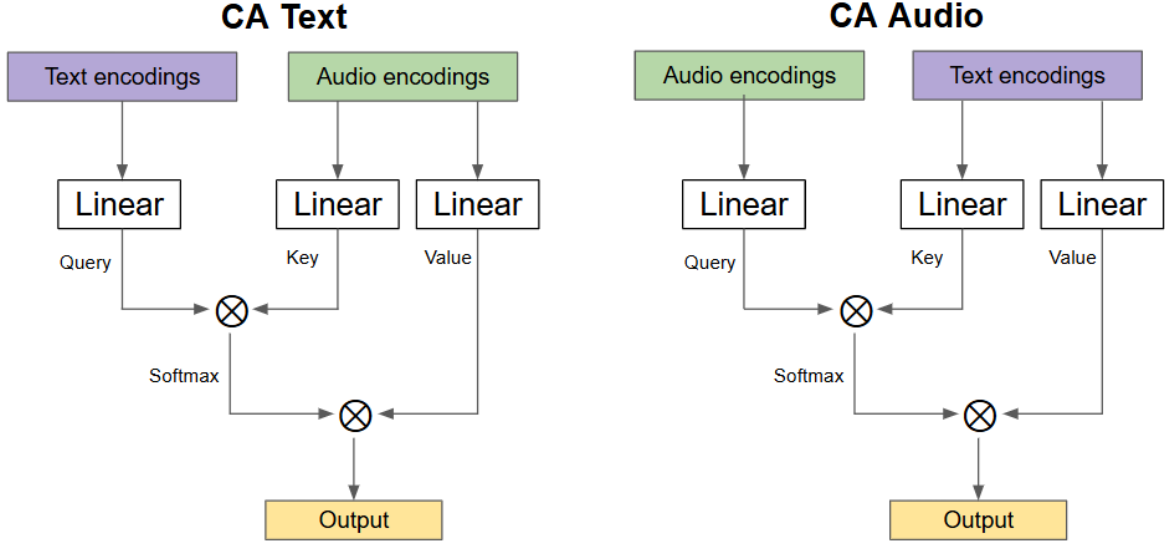


Figure 9: Crossmodal attention system with both text and audio queries. \otimes is used to denote matrix multiplication.

contained within the forward method of a PyTorch module, where `self.query_proj`, `self.key_proj` and `self.value_proj` are the linear projections for the queries, keys and values respectively. `torch.bmm` refers to a matrix multiplication and `F.softmax` is a mathematical function to ensure all values (across the requested dimension) lie in the range $[0, 1]$ and sum to 1, the softmax function for a vector \mathbf{x} is given in Equation 2.

$$\text{Softmax}(x_i) = \frac{\exp(x_i)}{\sum_j \exp(x_j)} \quad (2)$$

5 Results

5.1 Experimental Setup

To provide a comparable set of results, all experiments were run using the same hyperparameters. Each model was trained on a single Nvidia RTX 4070 Super for 15 epochs with a batch size of 32 using a weighted cross-entropy loss and the AdamW optimiser [55] initialised with a learning rate of 10^{-5} , a linear learning rate sched-

uler and 10% of training used as warm-up steps. The cross-entropy weights were calculated as in Equation 3, where \mathbf{c} is a vector containing the number of samples in each class, and \mathbf{w} is a vector containing the relevant cross-entropy weight.

$$w_i = \frac{\max(\mathbf{c})}{c_i} \quad (3)$$

In order to evaluate the models, the following metrics are reported: macro-averaged F1 score, precision and recall. These are all described for each class in Equations 4, 5 and 6 where TP is the number of true positives, FP is the number of false positives and FN is the number of false negatives. The arithmetic mean can then be taken for each class to provide a holistic overview of the model's performance.

$$F1 = \frac{2TP}{2TP + FP + FN} \quad (4)$$

$$\text{Precision} = \frac{TP}{TP + FP} \quad (5)$$

Listing 2 PyTorch forward method for a crossmodal attention mechanism.

```

1  # project query features
2  queries =
    ↪ self.query_proj(query_modality)
3
4  # project kv features
5  keys = self.key_proj(kv_modality)
6  values = self.value_proj(kv_modality)
7
8  # compute attention scores
9  attn_scores = torch.bmm(queries,
    ↪ keys.transpose(1, 2))
10 attn_probs = F.softmax(attn_scores,
    ↪ dim=-1)
11
12 # compute and return cross modal
    ↪ features
13 return torch.bmm(attn_probs, values)

```

$$\text{Recall} = \frac{TP}{TP + FN} \quad (6)$$

Generally the macro-averaged F1 score is the standard to evaluate a multi-class classification problem, including ARI systems [3], [12], [48], where only a single metric is reported, it will be a macro-averaged F1 score for this reason.

To provide a useful evaluation and simulate a real-world environment, the QT30-MM dataset is split into three splits: train, validation and test. 70% of the data is allocated for training, 10% for validation and the remaining 20% for testing. The model is evaluated on the validation split after every training epoch, the best performing model, based on macro-F1, is then chosen to be tested on the testing split, the metrics are then calculated and reported in the following sections.

After training, each model is then evaluated on the complete dataset for each Moral Maze episode (Banking, Empire, Money, Problem, Syria, Green Belt, Hypocrisy and Welfare) and each metric calculated to provide an overview of the cross-domain performance of the model.

In order to evaluate the different methods to sample un-

related arguments as described in Section 3.1.3. Models are trained on SCS, US and LCS, the validation dataset is sampled identically to the training set, and tested, both in-domain and cross-domain on SCS. This is used because of its description as a more realistic problem [48]. All code used for the experiments can be found on GitHub⁹.

5.2 In-Domain

Results are reported for both the 3-class problem (considering support, attack and no relation) and the 4-class problem (considering RA, CA, MA and NO). First results are considered when evaluating in-domain, i.e. on the test set of the QT30-MM dataset. Only macro-f1 scores are reported here, precision and recall scores are also reported in Appendix A.1.

5.2.1 The 4-Class Problem

Table 10 shows the macro-f1 scores of each model using RoBERTa-base as the text encoder and Wav2Vec2-base as the audio encoder. All that is shown are the results for models performing early sequence fusion across different NO-sampling strategies. In the 4-class problem it does not seem that the addition of acoustic features makes much if any difference to the performance of the model on the ARI task. This result has also been found by others [4].

In some runs, the audio-only models do not learn above the performance of the random baseline, it is unclear why this occurs but it appears to be random. Comparing the NO-sampling strategies there does not seem to make an appreciable difference when tested on SCS. Because SCS is considered a much more challenging task [48] it would not be expected that models trained on LCS or US would perform nearly as well as those trained on SCS, however, this does not seem to be the case. The result of this experiment implies that regardless of the sampling strategy the model is able to acquire the same knowledge and would likely perform similarly in a real-world setting, it is simply that SCS evaluations are harder than US evaluations which in turn are harder than LCS evaluations.

⁹<https://github.com/Syn-Tax/cross-domain-am>

Table 10: Macro-F1 scores for early sequence fusion models on the 4-class problem. Highest results in each column are shown in bold.

Model	SCS	LCS	US
Text-Only	.58	.59	.59
Audio-Only	.43	.41	.20
Concatenation	.58	.57	.58
Product	.56	.57	.58
CA Text	.57	.46	.57
CA Audio	.58	.57	.57
Random	.22	.23	.24
Majority	.14	.14	.14

The different sequence fusion techniques are also compared in Table 11. Here it can be seen that early sequence fusion techniques outperform late fusion techniques by approximately 50% for both text-only and audio-only with concatenation showing greater improvement at approximately 60%. This increase in performance is likely attributed to the fact that when the sequences are fused before the attention mechanisms are applied the model is able to make the long-range dependencies across sequences. This comes in contrast to the fact that the model is unable to make any dependencies cross-sequence when they are fused after the attention mechanisms are applied.

Table 11: Macro-F1 scores across sequence fusion types when trained on SCS on the 4-class problem.

Model	Early	Late
Text-Only	.58	.36
Audio-Only	.43	.28
Concatenation	.58	.38
Random		.22
Majority		.14

What follows is a more in-depth discussion of the results with the hope that it will yield some understanding of the models' limitations and how they could be improved. In order to do this the Text-Only model trained on SCS is explored in detail, however, the conclusions were found to hold on other models. A good place to begin here is by analysing the class F1 distribution, here F1 scores

are reported for each of the four classes (NO, RA, CA and MA). As can be seen in Table 12 the model performs significantly worse when shown a conflict relation as opposed to the other possible classes. It is possible that this is due to the significant class imbalance present in almost all ARI datasets as discussed in Section 3.

Table 12: Class F1 distribution for text-only SCS model on test split.

NO	RA	CA	MA
.76	.60	.30	.66

A further analysis can be conducted by looking at the confusion matrix generated as shown in Figure 10. The ideal confusion matrix shows a diagonal line, in this case from the top left down to the bottom right of the matrix, and can be used to determine which classes the model struggles to distinguish. For ARI, it is generally expected that the model is able to distinguish CA from other classes, while RA and MA are often confused with each other and sometimes with NO. This follows from the difficulties that human annotators have when determining the different relations [1]. However, this is not what Figure 10 shows, instead the model is generally confusing most classes, most notable is the underprediction of the CA class. This implies the model is simply predicting the majority classes which is a well known and well studied problem in all classification problems involving unbalanced data [56]. Typically such problems are relatively simple to solve, often using either weighted loss functions (as is explained in Section 5.1) or some form of data augmentation or manipulation technique. During this project, primarily random resampling was experimented with. Random resampling generally involves a combination (or only one) of oversampling minority classes (e.g. randomly duplicating samples labelled as CA) or undersampling majority classes (e.g. randomly discarding samples labelled as RA or NO). Often this has been shown to be the best technique for solving class-imbalance problems, despite the rise of other resampling techniques (such as SMOTE) [57]. Unfortunately in this case no resampling distribution could be found to meaningfully improve the model performance.

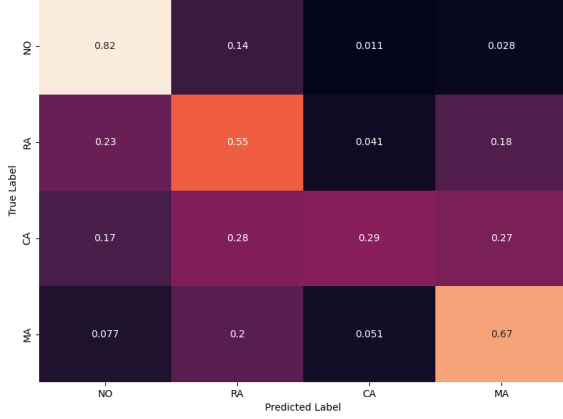


Figure 10: Confusion matrix showing true and predicted labels for the text-only SCS model.

5.2.2 The 3-Class Problem

Table 13 shows the macro-f1 scores across each NO-sampling strategy for the 3-class problem using RoBERTa-base as the text encoder and Wav2Vec2-base as the audio encoder. Similarly to the 4-class problem, the addition of acoustic features to not seem to make an appreciable difference to the performance of the model. However, it is still useful to discuss the results in more detail, again using the text-only model trained on SCS.

Table 13: Macro-F1 scores for early sequence fusion models on the 3-class problem. Highest results in each column are shown in bold.

Model	SCS	LCS	US
Text-Only	.62	.59	.61
Audio-Only	.21	.54	.22
Concatenation	.61	.61	.60
Product	.58	.61	.62
CA Text	.53	.53	.52
CA Audio	.61	.62	.63
Random	.28	.30	.29
Majority	.22	.22	.22

Table 14 shows the results when considering the different sequence fusion techniques. It can be seen that early fusion techniques significantly outperform late sequence

fusion. Similarly to the 4-class US run, the early audio-only model was not able to learn during this run. For both the text only and multimodal models, early fusion improves upon late fusion by approximately 44%.

Table 14: Macro-F1 scores across sequence fusion types when trained on SCS on the 3-class problem.

Model	Early	Late
Text-Only	.62	.43
Audio-Only	.21	.33
Concatenation	.61	.43
Random		.23
Majority		.15

What follows is a more in-depth analysis of the 3-class in-domain results. The class F1 distribution for the 3-class problem is shown in Table 15. Similarly to the 4-class F1 distribution, the Attack class appears to be significantly harder to predict than the other classes. Similarly to the 4-class problem it can be hypothesised that this is due to the class imbalance in the dataset. What is interesting, is the fact that the class F1 scores for the Attack/CA relations have dropped when compared with the 4-class results and the scores for non-attack/CA relations have risen. It is possible that this is simply due to the change in the number of classes, however, it can also be considered that the 3-class dataset is more heavily unbalanced against the Attack relation which could also have this effect.

Table 15: Class F1 distribution for text-only SCS model on test split.

None	Support	Attack
.82	.78	.26

The confusion matrix for the 3-class problem, as shown in Figure 11 can also be discussed. Here the underprediction of the attack class and the overprediction of the majority class. When compared to the 4-class confusion matrix (Figure 10) it appears that the model is effectively combining incorrect predictions between samples labelled inference and rephrase. This result could imply that the model’s learning is approximately equivalent between the 3- and 4-class approaches, although it should

be noted that more investigation is required to prove this.

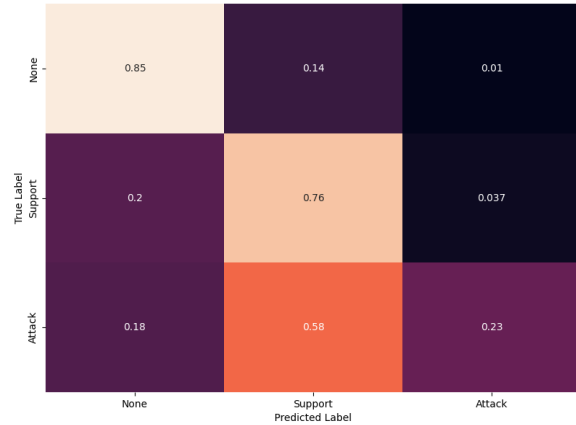


Figure 11: Confusion matrix showing true and predicted labels for the text-only SCS model.

5.3 Cross-Domain

In this section the results presented in Section 5.2 are extended across the Moral Maze subcorpora. Results here are presented across each subcorpus and the arithmetic mean calculated and also reported. The goal of this section is to analyse how well the models and techniques are able to generalise into different topics and domains. Similar to the In-Domain results, first the 4-class problem is discussed and then its 3-class equivalent. Only the Macro-F1 scores are reported here with precision and recall scores added in Appendix A.2.

5.3.1 The 4-Class Problem

Table 19 provides a cross-domain evaluation of the different model architectures across the nine Moral Maze subcorpora when trained on SCS. Taking a broad overview, there is a distinct lack of significant improvement when the addition of acoustic features is considered. Since the evaluation is significantly harder than evaluating in-domain, the models show a significant decrease in the macro-F1 scores when comparing back to the in-domain results. This drop shows how challenging it is for the models to generalise effectively across the different domains.

Table 16: Mean cross-domain macro-F1 scores for early sequence fusion models on the 4-class problem across different sampling strategies. Highest results in each column are shown in bold.

Model	SCS	LCS	US
Text-Only	.46	.46	.46
Audio-Only	.37	.36	.22
Concatenation	.45	.43	.45
Product	.45	.44	.46
CA Text	.43	.32	.41
CA Audio	.47	.46	.43
Random	.23	.23	.23
Majority	.15	.15	.15

Table 17 compares early and late sequence fusion in a cross-domain setting. The results reported are the arithmetic mean across the Moral Maze subcorpora. Generally the increase is similar to that found in the in-domain evaluation with approximately a 50% increase for the text only and multimodal models and a 32% increase in performance for the audio only model.

Table 17: Macro-F1 scores across sequence fusion types when trained on SCS on the 4-class problem. The mean is taken across all Moral Maze subcorpora.

Model	Early	Late
Text-Only	.46	.30
Audio-Only	.37	.28
Concatenation	.45	.30
Random	.23	
Majority	.15	

Table 16 can be used to compare the different NO-sampling strategies which again, seem to show little difference between the various methods, both for unimodal and multimodal approaches. Similarly to the in-domain results, what follows is a close look into the results of both the text only and CA audio models when trained on SCS and evaluated on the Banking subcorpus.

The class F1 distribution can be found in Table 12. Similarly to the in-domain results, the model is very able to predict unrelated pairs and pairs connected by an inference, and the score for pairs connected by a conflict are

Table 18: Class F1 distribution for text only and CA audio SCS models on banking subcorpus.

Model	NO	RA	CA	MA
Text-Only	.67	.60	.41	.065
CA Audio	.65	.64	.41	.095

similar. The major difference in the class distribution is the inability of the model to accurately predict rephrases, it is possible that this is the result of an increase in domain specific knowledge and terminology necessary to predict these rephrases but these data are in no way conclusive in that respect.

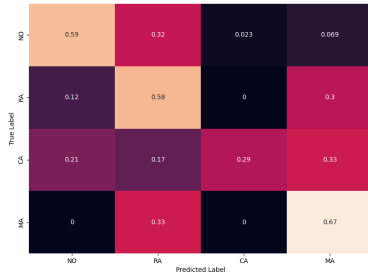


Figure 12: Text only model confusion matrix on the banking subcorpus.

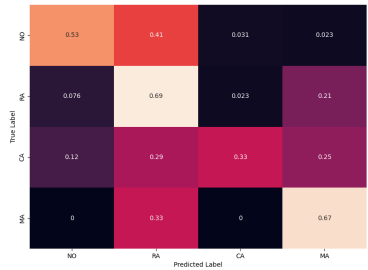


Figure 13: CA Audio model confusion matrix on the banking subcorpus.

Figures 12 and 13 show the confusion matrices for both the text only model and the CA audio model when trained on SCS and evaluated on the Banking subcorpus. While the matrices are generally very similar, there are some notable differences that show as a trend across

all subcorpora. Firstly the crossmodal attention model is better able to distinguish the rephrases. The text only model seems to be more likely to predict MA for true CA or RA samples. The other notable distinction between the two models' performance is that the text only model is more likely to confuse conflict-labelled pairs as being unrelated, as opposed to the crossmodal attention model which is more likely to predict the label as an inference in all cases. Similarly to the in-domain results, there was no resampling of training data that could be found to change the F1 distribution across classes.

5.3.2 The 3-Class Problem

Next, the data from the 3-class problem is extended across different domains. The data can be seen in Table 20. Generally the results are similar to the 4-class problem with a similar drop in macro-F1 scores from the in-domain results. Although the 3-class problem is slightly easier than the 4-class problem, the drop in performance is still roughly similar.

Table 21 allows a comparison between early and late sequence fusion methods on the 3-class problem. Here for both the text-only and multimodal approaches early fusion improves performance by around 40% whereas the early audio only model did not learn effectively. It should be noted that although generally achieving lower performance, the late fusion models were always able to learn when only trained on audio data.

What follows is another discussion regarding the detailed results of the CA Audio model and the text only model. First, the class F1 distribution can be found in Table 22. Here, as could reasonably be expected, the results differ significantly from the 4-class problem. The model is able to effectively classify the support relations and no significant drop is observed when compared to the in-domain results. However, the drop in macro-F1 seems to originate from the drop in the model's ability to classify unrelated nodes.

Figure 14 shows the confusion matrix for the CA audio model when evaluated on the banking subcorpus. Much like what was seen in Section 5.2.2 the matrix is characterised by the overprediction of Support relations, with the main difference being that this overprediction is

Table 19: Cross-Domain macro-averaged F1 scores on 4-class SCS trained models. Best scores in each column are shown in bold.

Model	B	E	M	P	S	G	H	W	Mean
Text-Only	.44	.46	.48	.42	.43	.50	.51	.41	.46
Audio-Only	.34	.37	.39	.38	.33	.38	.40	.37	.37
Concatenation	.43	.43	.45	.45	.45	.49	.45	.43	.45
Product	.41	.44	.42	.42	.46	.52	.46	.43	.45
CA Text	.40	.44	.44	.40	.42	.49	.43	.44	.43
CA Audio	.45	.49	.44	.42	.45	.53	.48	.46	.47
Random	.19	.23	.20	.19	.22	.25	.21	.24	.23
Majority	.16	.15	.15	.15	.15	.14	.15	.14	.15

Table 20: Cross-Domain macro-averaged F1 scores on 3-class SCS trained models. Best scores in each column are shown in bold.

Model	B	E	M	P	S	G	H	W	Mean
Text-Only	.54	.47	.50	.50	.58	.55	.63	.51	.54
Audio-Only	.21	.20	.22	.21	.20	.21	.22	.21	.21
Concatenation	.58	.49	.47	.50	.57	.57	.59	.49	.54
Product	.51	.45	.44	.47	.53	.54	.64	.47	.51
CA Text	.43	.40	.43	.41	.44	.46	.47	.44	.44
CA Audio	.59	.44	.52	.48	.59	.54	.60	.52	.54
Random	.27	.32	.30	.27	.30	.29	.29	.33	.30
Majority	.21	.21	.22	.21	.20	.21	.22	.20	.21

Table 21: Macro-F1 scores across sequence fusion types when trained on SCS on the 3-class problem. The mean is taken across all Moral Maze subcorpora.

Model	Early	Late
Text-Only	.54	.38
Audio-Only	.21	.33
Concatenation	.54	.40
Random	.23	
Majority	.15	

worse than when evaluated in-domain.

6 Limitations

Models Throughout the project there is a distinct lack of comparison between different encoder models both from a text and an audio perspective. While it is likely

Table 22: Class F1 distribution for text only and CA audio SCS models on banking subcorpus.

Model	None	Support	Attack
Text-Only	.66	.72	.26
CA Audio	.58	.69	.29

that the general overarching conclusions would still hold for other encoders it is very possible that the more specific conclusions could be encoder-specific. This leads into the fact that only the base versions of RoBERTa and Wav2Vec2 are used, it has been shown that using the large models has increased performance both in-domain and cross-domain for text only tasks [12].

Forced Alignment Through the use of forced alignment technologies it is very possible for an amount of accuracy to be lost, especially when considering the poor environments in which such a system will have to per-

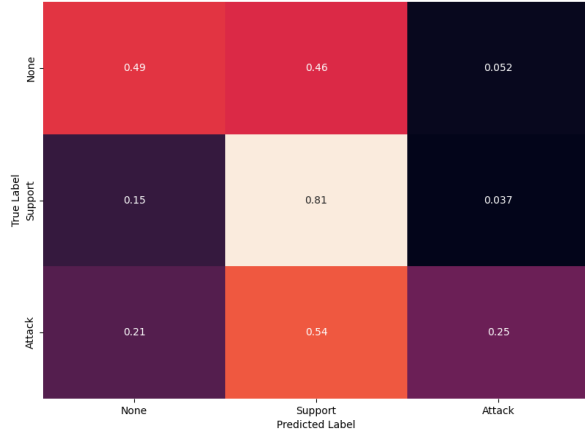


Figure 14: CA Audio model confusion matrix on the banking subcorpus.

form in the real world (i.e. with lots of crosstalk, a wide range of accents and regional dialects etc.). While the data presented here has been proven to be correct to a certain degree, it is not possible to completely guarantee correctness.

Statistical Significance In this project only a single run was performed for each reported result. Therefore it is impossible to tell whether any comparison is statistically significant, however, given the size of the comparisons made it is very likely that they still hold.

7 Conclusions

When considering goal (i) as stated in Section 1, as a result of this project, two major argumentative corpora have been extended with acoustic features into multimodal datasets for use in many areas of argumentative research. This includes the large QT30 corpus, of which a multimodal subset (QT30-MM) is presented, and the much smaller, cross-domain Moral Maze corpus. QT30-MM is the largest dataset for any AM task currently available.

Goal (ii) of this project was to use the created datasets to conduct an evaluation of different multimodal techniques in a cross-domain setting, comparing early and late sequence fusion and various different late multi-

modal fusion techniques. Through this evaluation it was found that the addition of acoustic features does not improve the performance of argument relation identification systems in-domain and does not improve the models’ ability to generalise across multiple domains.

Although acoustic features were not useful for ARI, it was discovered that the sequence fusion technique chosen during model creation is vitally important for the performance of the model. By combining sequence data early in the process (before encoding) the model is able to make cross-sequence dependencies and therefore significantly improves performance on ARI.

Counterintuitively, all models struggle to distinguish the attack/conflict relations, it is unclear why this occurs however, since data augmentation techniques had no effect it appears unlikely that it is due to the dataset imbalance present. Generally the areas with which the models struggle do not seem to match human intuition, nor how human annotators struggle with the task. When considering the cross-domain results on the 4-class problem, while the models still struggle distinguishing conflict relations, they struggle even more with rephrases, often incorrectly predicting conflicts as rephrases, or predicting rephrases as inferences.

Through the discussion of techniques used to sample unrelated node pairs they have little difference in-domain indicating that the models are able to gain the same knowledge and understanding regardless of the sampling method used, it is simply the difficulty of the evaluation which changes. This supports previous conclusions that the sampling method is an important consideration when creating and evaluating ARI systems [48].

The results presented also compare different multimodal fusion strategies showing that simple concatenation, an elementwise product and a crossmodal attention mechanism all perform well. The performance of the cross-modal attention mechanism does vary depending on which modality is used for queries (and by extension keys and values), it was found that the mechanism performs best when text is used to generate keys and values while audio is used to generate the queries.

8 Future Work

To provide a more holistic view of this topic in the future, it would be useful to further understand the importance of different encoders and with that whether the varying pre-training strategies have an influence on the ability of the model to generalise across domains. Another possible extension would be to consider data processing and classification methods which preserve inference and conflict structures as discussed in Section 3.1.1.

With the recent boom in LLMs and especially multimodal LLMs they provide an opportunity in terms of their potential ability to generalise across domains with minimal amounts of learning (e.g. using in-context learning). LLMs have already shown promise in argument mining tasks so it seems an appropriate next step to discover how they fair in a cross-domain environment [8].

9 Discussion

With the recent increases in the availability of AI technologies the considerations around the uses of such systems has come under scrutiny. Much of this scrutiny relates to how these intelligent systems can be created and used ethically. Due to the power of AI systems they are an incredibly useful tool across many fields, heavily reducing the workload and increasing the productivity of many people, on the other hand, however, because of this power even relatively incompetent, malevolent actors have the ability to cause damage. Before the introduction and increase in the availability of LLMs, malevolent actors had to be quite competent in order to cause damage, that has however changed because of the ease of use of such systems.

It is often possible to cause damage simply through laziness. This has been seen in the author’s previous work in education, where overreliance on AI systems and assistants can cause a significant decrease in accuracy, in systems where the use of ‘human-in-the-loop’ type systems are used with the goal to increase efficiency while still maintaining accuracy and minimising mistakes. Such a system only works if a. the tools are used correctly and b. the human does not become complacent and therefore

accuracy falls in relatively critical situations. This is also a discussion worth having in AM specifically with the release of interactive assistants for the task [58]. With the introduction of openly-useable LLMs such as OpenAI’s Chat-GPT models, many people are using these systems as ‘life-assistants’ and thus this overreliance does not have bounds in any specific field but rather life as a whole.

Another consideration is the creation and training of such systems, specifically around both the data and the power consumption. Primarily this comes down to how the training datasets are sourced, created and annotated (where annotation is required). The details of the annotation of the data used in this project can be found in the individual datasets’ papers, however, it was ensured that all data from those datasets was annotated and sourced ethically. The sourcing of data is also an important consideration, especially surrounding the license under which the original data is released. This generally becomes a problem when using data for commercial purposes (i.e. creating commercially available models). Throughout this project it was ensured that all training data has been sourced within the terms of any licenses.

Acknowledgements

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A Results

A.1 In-Domain

A.2 Cross-Domain

Table 23: In-domain results when testing different model architectures on the 4-class problem. F1: Macro-averaged F1, P: precision, R: recall. Highest scores in each column are shown in bold.

Fusion Methods		SCS			LCS			US		
Sequence	Multimodal	F1	P	R	F1	P	R	F1	P	R
Text Only										
Early	-	.58	.58	.58	.59	.59	.59	.59	.59	.59
Late	-	.36	.36	.35	.34	.36	.34	.35	.35	.35
Audio Only										
Early	-	.43	.48	.44	.41	.41	.42	.20	.31	.26
Late	-	.28	.29	.29	.29	.31	.29	.29	.29	.29
Multimodal										
Early	Concatenation	.58	.58	.58	.57	.57	.57	.58	.58	.57
	Product	.56	.56	.57	.57	.57	.57	.58	.58	.59
	CA Text	.57	.56	.58	.46	.46	.48	.57	.56	.57
	CA Audio	.58	.58	.58	.57	.59	.56	.57	.58	.57
Late	Concatenation	.36	.36	.35	.37	.36	.36	.35	.36	.35
Baselines										
Random		.22	.24	.23	.23	.25	.24	.24	.25	.26
Majority		.14	.09	.25	.14	.09	.25	.14	.09	.25

Table 24: In-domain results when testing different model architectures on the 3-class problem. F1: Macro-averaged F1, P: precision, R: recall. Highest scoring models (based on Macro-F1) are shown in bold.

Fusion Methods		SCS			LCS			US		
Sequence	Multimodal	F1	P	R	F1	P	R	F1	P	R
Text Only										
Early	-	.62	.63	.62	.59	.63	.58	.61	.63	.60
Late	-	.43	.45	.43	.44	.45	.44	.43	.44	.44
Audio Only										
Early	-	.21	.16	.33	.54	.54	.55	.22	.16	.33
Late	-	.33	.33	.34	.34	.33	.34	.34	.33	.35
Multimodal										
Early	Concatenation	.61	.62	.60	.61	.61	.61	.60	.61	.59
	Product	.58	.60	.57	.61	.62	.61	.62	.64	.61
	CA Text	.53	.52	.54	.53	.52	.55	.52	.51	.53
	CA Audio	.61	.62	.60	.62	.63	.62	.63	.62	.64
Late	Concatenation	.43	.44	.43	.45	.47	.45	.44	.45	.44
Baselines										
Random		.28	.33	.33	.30	.34	.36	.24	.25	.26
Majority		.22	.16	.33	.22	.16	.33	.22	.16	.33