Data-to-text Generation with Neural Planning

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2021

Abstract

In this thesis, we consider the task of data-to-text generation, which takes non-linguistic structures as input and produces textual output. The inputs can take the form of database tables, spreadsheets, charts, and so on. The main application of data-to-text generation is to present information in a textual format which makes it accessible to a layperson who may otherwise find it problematic to understand numerical figures. The task can also automate routine document generation jobs, thus improving human efficiency. We focus on generating long-form text, i.e., documents with multiple paragraphs. Recent approaches to data-to-text generation have adopted the very successful encoder-decoder architecture or its variants. These models generate fluent (but often imprecise) text and perform quite poorly at selecting appropriate content and ordering it coherently. This thesis focuses on overcoming these issues by integrating content planning with neural models. We hypothesize data-to-text generation will benefit from explicit planning, which manifests itself in (a) micro planning, (b) latent entity planning, and (c) macro planning. Throughout this thesis, we assume the input to our generator are tables (with records) in the sports domain. And the output are summaries describing what happened in the game (e.g., who won/lost, . . . , scored, etc.).

We first describe our work on integrating fine-grained or micro plans with data-to-text generation. As part of this, we generate a micro plan highlighting which records should be mentioned and in which order, and then generate the document while taking the micro plan into account.

We then show how data-to-text generation can benefit from higher level latent entity planning. Here, we make use of entity-specific representations which are dynamically updated. The text is generated conditioned on entity representations and the records corresponding to the entities by using hierarchical attention at each time step.

We then combine planning with the high level organization of entities, events, and their interactions. Such coarse-grained macro plans are learnt from data and given as input to the generator. Finally, we present work on making macro plans latent while incrementally generating a document paragraph by paragraph. We infer latent plans sequentially with a structured variational model while interleaving the steps of planning and generation. Text is generated by conditioning on previous variational decisions and previously generated text.

Overall our results show that planning makes data-to-text generation more interpretable, improves the factuality and coherence of the generated documents and reduces redundancy in the output document.

Acknowledgements

Foremost I like to thank my advisor Mirella Lapata. A substantial share of my learning as a PhD student is due to her. I will always appreciate the clarity she had of the big picture of the thesis. Our weekly research meetings helped me take stock, discuss new ideas and prioritise my tasks. Her support was even more crucial during the Covid pandemic. I am thankful for the funding for the months when the thesis took longer than planned.

I also like to thank Adam Lopez for the helpful discussions and Ivan Titov for providing constructive feedback during my first-year review. I thank my examiners, Rico Sennrich and Michael Elhadad, for examining the thesis and viva and providing constructive feedback.

I like to thank Li Dong, Jonathan Mallinson, Yang Liu, Laura Perez, Yumo Xu, Rui Cai, Tom Sherborne, Tom Hosking, Parag Jain, Nelly Papalampidi, Hao Zheng, Reinald Kim Amplayo, and Yao Fu for the many insightful discussions during our weekly group meetings. I also had a great time collaborating with Li, Jonathan, and Yao.

I also like to thank Shashi Narayan, Joshua Maynez, and Ryan McDonald at Google Research London for their wholehearted support during my research internship.

I like to thank my friends who made the PhD journey enjoyable. Spandana, Annie, and Shashi gave us a warm welcome to Edinburgh. Mihaela and Aurora gave us all possible help for settling here. Ameya and Vinit were always there when I needed them. Ruchit made my stay in London memorable. I have enjoyed my conversations with Anoop and Litton on topics related to research and otherwise. The coffee walks with Jerin have been a great way to unwind.

I like to thank my family, parents, in-laws, brother, and sister, who have always wished the best for me. This PhD journey would not have been possible without the support of Arya, who has stood by me throughout, and our two gems Vedika and Dhyan, who fill the canvas of life with vivid colors.

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

(*Ratish Surendran Puduppully*)

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Chapter 1

Introduction

1.1 Motivation

Data-to-text generation broadly refers to the task of automatically producing textual output from non-linguistic input (Reiter and Dale, 2000; Gatt and Krahmer, 2018). The input may be databases of records, spreadsheets, expert system knowledge bases, simulations of physical systems, etc.

Data-to-text generation has two vital uses: improving access to information and automating document generation tasks (Reiter and Dale, 2000). The information available in spreadsheets and database tables may vary in format, size, granularity, etc. This disparity can restrict access to such data to trained experts. Expressing such information in textual form can make it accessible to laypersons too. In the second scenario, document generation often needs to be performed by people whose main job is unrelated. For example, doctors need to create notes of patient details, their symptoms, diagnosis, and prescriptions. Software developers spend a considerable amount of their time writing comments and documentation of their code. Data-to-text generation can automate part of this document generation task and improve the efficiency of their job.

Figure 1.1 contains tables with statistics related to the weather forecast for a week (22 - 28 October 2021) and hourly weather forecast for 22 October 2021 for Halifax, Nova Scotia, Canada from the webpage of Environment Canada `https://weather.gc.ca/canada_e.html`. Table 1.1 contains the corresponding weather forecast for 22 October 2021 for two times of the day: morning and night. A data-to-text generation system that produces such textual weather forecasts has to perform multiple tasks. It has to select specific values of the attributes from the rows. For example, such attribute values include a high temperature of $21°C$, a southwest wind of speed 30 km/h, a gust

Halifax, NS

No Alerts in effect

Current Conditions

Past 24 hours | Weather Radar | Satellite | Lightning

17°C
°C | °F

Observed at: **Halifax Stanfield Int'l Airport**
Date: **11:00 AM ADT Friday 22 October 2021**

Condition: **Mostly Cloudy**
Pressure: **101.4 kPa**
Tendency: **Falling**

Temperature: **16.8°C**
Dew point: **15.9°C**
Humidity: **94%**

Wind: **S 14 km/h**
Visibility: **11 km**

Forecast

Hourly Forecast | Air Quality | Alerts | Jet Stream

Fri 22 Oct	Sat 23 Oct	Sun 24 Oct	Mon 25 Oct	Tue 26 Oct	Wed 27 Oct	Thu 28 Oct
21°C 30% Chance of showers	17°C 60% Chance of showers or drizzle	11°C A mix of sun and cloud	11°C A mix of sun and cloud	14°C 30% Chance of showers	12°C 60% Chance of showers	13°C A mix of sun and cloud
Tonight	**Night**	**Night**	**Night**	**Night**	**Night**	
14°C 60% Chance of showers or drizzle	10°C 60% Chance of showers	4°C Cloudy periods	6°C Cloudy	8°C 60% Chance of showers	4°C 60% Chance of showers	

Hourly Forecast - Halifax

No Alerts in effect

Date/Time (ADT)	Temp. (°C)	Weather Conditions	Likelihood of precip	Wind (km/h)	Humidex
22 October 2021					
12:00	17	Cloudy	Nil	SW 30 gust 50	*
13:00	18	Cloudy	Nil	SW 30 gust 50	*
14:00	20	Chance of showers	Low	SW 30 gust 50	25
15:00	21	Chance of showers	Low	SW 30 gust 50	26
16:00	20	Chance of showers	Low	SW 30 gust 50	25
17:00	19	Chance of showers	Low	SW 30 gust 50	*
18:00	18	Partly cloudy	Nil	SW 30 gust 50	*
19:00	17	Partly cloudy	Nil	SW 30 gust 50	*
20:00	15	Partly cloudy	Nil	SW 30 gust 50	*
21:00	14	Mainly cloudy	Nil	VR 5	*
22:00	14	Mainly cloudy	Nil	VR 5	*
23:00	15	Mainly cloudy	Nil	VR 5	*

Figure 1.1: The tables show the weather forecast for seven days between 22 - 28 October 2021 (top) and the hourly forecast for 22 October 2021 (bottom) for Halifax, Nova Scotia, Canada. The information is accessed from the webpage of Environment Canada.

Day/Night	Text Forecast
Day	Becoming a mix of sun and cloud this afternoon with 30 percent chance of showers later this afternoon. Wind southwest 30 km/h gusting to 50. High 21. Humidex 26. UV index 3 or moderate.
Night	Partly cloudy. 60 percent chance of showers or drizzle overnight. Fog patches developing near midnight. Wind southwest 30 km/h gusting to 50 becoming light this evening. Low 14.

Table 1.1: Textual weather forecast corresponding to Figure 1.1 for October 21 morning and night. It focuses on specific attribute values from the table, including a high temperature of 21°C, a southwest wind of speed 30 km/h, a gust of 50 km/h, etc. In addition, it orders the attributes in a coherent sequence, such as the description of sun/cloud followed by showers, wind speed, etc.

of 50 km/h, etc. In addition, it has to order the attributes in a coherent sequence, such as the description of sun/cloud followed by showers, wind speed, etc.

Data-to-text generation systems have been used to create such textual weather forecasts for the past couple of decades. For example, Goldberg et al. (1994) created a system that generates such textual weather forecasts from an input of weather statistics. It is also multilingual, producing outputs in two languages: English and French. This work is part of a larger body of work that investigates techniques for generating weather forecasts for a geographical point or a larger area (Reiter, 2017; Sripada et al., 2002; Reiter et al., 2005; Sripada et al., 2005; Turner et al., 2008; de Oliveira et al., 2016).

Early work in data-to-text generation has focused on pipeline architectures with different modules, each performing a specific task (Reiter and Dale, 2000). The modules are responsible for tasks such as determining the structure and content of a document, deciding content words for describing concepts and relations, aggregating content into sentences, generating referring expressions, and deciding the morphology, rules of syntax to generate the surface forms. Chapter 2 contains more details on these modules. These modules are often hand-crafted by taking input from domain experts. Applying such a model to a different domain requires substantial rework creating an impetus for the development of statistical approaches in pipeline systems or end-to-end statis-

tical models to overcome this challenge (Liang et al. 2009; Angeli et al. 2010; Konstas and Lapata 2013, inter alia). As statistical models learn the weights of features from data, they can be more easily adapted to different domains, however, the features need to be manually defined. In recent times, the application of neural networks for data-to-text generation has become popular (Wiseman et al. 2017; Lebret et al. 2016; Mei et al. 2016, inter alia). Neural approaches do away with feature engineering and are often learnt end-to-end from the examples containing instances of input paired with output text. The success of neural networks has also been due to advances in computing power, including advancements in graphical processing units (GPU), which are highly optimised for parallel operations on matrices in neural networks. Concurrently, large-scale datasets have been developed, which has made it feasible for the automatic extraction of features from the data.

1.2 Thesis Contributions

Despite producing overall fluent text, neural systems have difficulty capturing long-term structure and generating documents more than a few sentences long. Wiseman et al. (2017) show that neural text generation techniques perform poorly at content selection, they struggle to maintain inter-sentential coherence, and more generally a reasonable ordering of the selected facts in the output text. Additional challenges include avoiding redundancy and being faithful to the input. Interestingly, comparisons with rule-based methods show that neural techniques do not fare well on metrics of content selection recall and factual output generation (i.e., they often hallucinate statements which are not supported by the facts in the database).

A content plan provides information about the content and structure of the output document. We hypothesize that explicitly modeling content planning should help in alleviating some of the issues with the neural models. The reasons for our hypothesis include the prevalence of planning components in pre-neural pipeline architectures. Expecting the neural decoder to perform content selection, generate fluent text, maintain inter-sentential coherence in the document, and stay faithful to the input table, all at the same time, is too much of an ask. We believe that content planning can serve as an intermediate stage between the input and output. Content plans should enable the decoder to focus on the less challenging tasks of predicting tokens conformant to the plan.

The contributions of the thesis include:

- We propose different variants of content planning, including fine-grained planning (micro planning), latent entity planning, coarse-grained planning (macro planning), and variational sequential planning.

- We show that planning improves factuality and coherence and reduces repetition in the generated text.

- Content planning makes the model interpretable as the content plans can be inspected to understand model behavior and errors.

1.3 Thesis Outline

The rest of the thesis is divided into chapters based on the following topics:

Background In Chapter 2, we discuss specific examples of data-to-text architectures that have been adopted over the years. We go over typical input and output for such systems, which we classify into rule-based, statistical, and neural network-based. We further divide these models into two categories: models focusing on individual components or those that are end-to-end. We also introduce a baseline encoder-decoder neural architecture for data-to-text generation, which we will later extend and modify in order to enable planning. In addition, we describe the metrics used to evaluate model output.

Micro Planning Micro planning generally involves deciding on specific words to describe concepts and relations, generating referring expressions, and aggregating content into sentences (Reiter and Dale, 2000). We introduce neural micro planning in Chapter 3. We propose modifications to contemporary neural encoder-decoder models, which inject planning in the generation process. Specifically, we develop a model which learns a micro plan from the input and conditions on it to generate the output document. We operationalize micro plans as a sequence of records from the input table. For training the micro planner, we extract oracle micro plans from game summaries following an information extraction (IE) approach. Specifically, we adopt the IE model introduced in Wiseman et al. (2017), which identifies candidate entity (i.e., player, team,and city) and value (i.e., number or string) pairs that appear in the text, and then predicts the type (aka relation) of each candidate pair. Given the output

of an IE system, a micro plan consists of (entity, value, record type) tuples in their order of appearance in a game summary.

Latent Entity Planning Micro planning, however, requires fine-grained record level supervision for training. It assumes the availability of a highly precise and broad coverage IE tool. Such high quality IE may be difficult to obtain for some datasets or domains. In Chapter 4, we explore how to perform data-to-text generation by inducing latent plans which operate at a higher level than records, such as entities. Our model creates entity-specific representations which are dynamically updated. Text is generated by conditioning on the data input and entity memory representations using hierarchical attention at each time step.

Macro Planning Unfortunately, the approach of latent entity planning does not handle events, which are often present in data-to-text generation tasks, in particular those in the sports domain. In Chapter 5, we introduce neural macro planning, which combines planning with the high level organization of entities *and* events. Macro planning reconceptualizes the input in terms of paragraph plans to facilitate *document-level* planning. In the sports domain, paragraphs typically mention entities (e.g, players important in the game), key events (e.g., scoring a run), and their interaction. And most of this information is encapsulated in the statistics accompanying game summaries. We thus define paragraph plans such that they contain verbalizations of entity and event records. Macro planning advocates the use of macro plans for improving the organization of document content and structure. A macro plan is a sequence of paragraph plans, and each paragraph plan corresponds to a document paragraph. In the first stage of our model, the macro planner produces a macro plan from the input of a set of paragraph plans. In the second stage, the surface realisation module generates the text conditioned on the predicted macro plan.

Variational Sequential Planning With macro planning, the input to data-to-text generation is no longer a complicated table but a sequence of paragraph plans. Thus macro planning allows us to treat data-to-text generation as a sequence-to-sequence learning problem. Macro plans, however, tend to be long, and thus challenging for the attention mechanism during text generation. Moreover, the model introduced in Chapter 5 predicts a macro plan by conditioning on the input, without making use of information present in the summary. We remedy these problems by introducing variational

sequential planning in Chapter 6. We infer latent plans sequentially with a structured variational model while interleaving the steps of planning and generation. Text is generated by conditioning on previous variational decisions and previously generated text.

Part of the content covered in the thesis have been earlier presented in Puduppully et al. (2019a) (Chapter 3), Puduppully et al. (2019b) (Chapter 4), Puduppully and Lapata (2021) (Chapter 5), Puduppully et al. (2022) (Chapter 6).

Chapter 2

Background

In this chapter, we will look first into earlier work in data-to-text generation, and discuss the characteristics of datasets used in this field. We will then study a baseline neural encoder-decoder model for data-to-text generation, which will form the foundation of our own work. We will finally review the metrics which we use to evaluate the model output.

2.1 Fundamentals of Data-to-text Generation

Reiter and Dale (2000) define the input to a data-to-text generation system as a 4-tuple $\langle k, c, u, d \rangle$, where, k is knowledge source, c is the communicative goal, u is the user model, and d is the discourse history[1].

The knowledge source represents the information available to the data-to-text system and can be a database, table, knowledge base, etc. Information in the knowledge source can be in turn numeric or textual. The communicative goal indicates the goal to be achieved by the output of an invocation of the data-to-text system. An example of a communicative goal could be to generate a weather forecast for a given day or a month. The user model indicates the specification of the intended audience of the data-to-text system. For example, the data-to-text system of Portet et al. (2009) produces summaries of neonatal intensive care unit data tailored in terms of the vocabulary and the requisite amount of detail for disparate classes of users, including nurses, junior doctors, and parents. The discourse history stores previous interactions of the user

[1]Reiter and Dale (2000) and other earlier work use the term Natural Language Generation (NLG) to mean data-to-text generation. However, in recent times NLG has come to encompass text-to-text generation tasks too. These include text summarization, sentence simplification, paraphrasing, etc. So, we use the term data-to-text generation to mean that the input is non-linguistic data.

with the data-to-text system. In the context of a dialog system, it is also similar to dialog history. The discourse history starts empty and will accumulate over interactions with the system. It stores entity mentions and can help generate pronouns and referring expressions.

The output of a data-to-text system is text. The text can be in English or other languages too. For example, FOG (Goldberg et al., 1994) produces weather forecasts in two languages: English and French. The output may also contain information to help render the text onto a device, such as HTML markup for rendering webpages. It can also include discourse information such as the division of the text into paragraphs, sections, and so on.

2.2 The Architecture of Data-to-text Systems

Reiter and Dale (2000) propose a pipeline architecture for data-to-text generation. It adopts separate stages for *document planning*, *micro planning*, and *linguistic realisation*. Document planning determines the document's content and structure organizing it into discourse. Micro planning involves aggregating content into sentences, deciding specific words to describe concepts and relations, and generating referring expressions. Linguistic realisation applies the rules of syntax, morphology, and orthographic processing to generate surface forms.

In this section, we extend from Konstas (2014) and classify earlier architectures into three types of systems: rule-based ones, those making use of statistical models, and those based on neural models.

Rule-based individual components Early work in data-to-text generation made use of hand-built content selection components (Kukich, 1983; McKeown, 1992; Reiter and Dale, 1997). Many early content planners have been based on theories of discourse coherence (Hovy, 1993; Scott and de Souza, 1990a). Other work has relied on generic planners (Dale, 1988) or schemas (Duboue and McKeown, 2002). In all cases, content plans are created manually, sometimes through corpus analysis (Duboue and McKeown, 2001). A few researchers (Mellish et al., 1998; Karamanis, 2004) adopt a generate-and-rank architecture where a large set of candidate plans is produced and the best one is selected according to a ranking function. There have been multiple systems developed for surface realisation (Elhadad and Robin, 1996; Bateman, 1997; Lavoie and Rainbow, 1997). Among these, Elhadad and Robin (1996) propose a grammar

known as SURGE (Systemic Unification Realization Grammar of English) based on the Functional Unification Formalism (FUF) (Elhadad, 1989). The SURGE grammar processes the output of the micro planner to generate text in the English language.

Rule-based end-to-end Goldberg et al. (1994) create one of the first end-to-end systems for data-to-text generation. Their system called FOG generates weather forecasts in two languages (English and French) based on weather statistics.

Statistical individual components There have also been instances of content selection components learnt from data (Barzilay and Lapata, 2005; Duboue and McKeown, 2001, 2003; Kim and Mooney, 2010). For example, Barzilay and Lapata (2005) propose an approach that learns to perform content selection by considering all the entities together in a table and not in isolation from each other. They show that such collective content selection captures the contextual relationships between the entities, thus improving the accuracy of content selection. In addition, statistical approaches have been applied to sentence planning (Stent et al., 2004; Walker et al., 2001, 2002). Specifically, Stent et al. (2004) learn a ranker for sentence plans from training data of sentence plans paired with the human ratings of their corresponding sentences generated using RealPro (Lavoie and Rainbow, 1997).

Statistical end-to-end Langkilde and Knight (1998) propose a model for generating sentences from meaning representations called abstract meaning representations (AMR). The AMR structure is first converted to word lattices. Following this, a corpus-based statistical model with word bigram information is used for the linguistic decisions to transform the word lattices to sentences.

Belz (2008) proposes a model which comprises two stages. The first stage is a base generator containing rules for the specific domain and task. The second stage is responsible for choosing between the rules based on probabilities learnt from the training dataset. They evaluate on the SUMTIME-METEO corpus (Sripada et al., 2002), which pairs numerical marine weather forecast data with human written weather forecasts.

Liang et al. (2009) model text generation as a hierarchical process of selection of records, fields in records, and words to describe the fields. Their system learns the alignment of records (and their fields) with segments of output text. They train the model following the unsupervised approach of Expectation Maximization (EM)

(Dempster et al., 1977).

Angeli et al. (2010) extend Liang et al. (2009) for the task of data-to-text generation. They propose an end-to-end model which factorizes generation as a sequence of local decisions. These decisions include record selection, selecting fields in the record, and choosing a template to verbalise the selected fields. These decisions are governed by a set of features learnt with a log-linear classifier.

Konstas and Lapata (2013) incorporate content plans represented as grammar rules operating on the document level. They experiment with a dataset of weather forecasts (Liang et al., 2009). The model relies on the EM algorithm (Dempster et al., 1977) to learn the weights of the grammar rules after tokens are aligned to database records as a preprocessing step.

Early Neural Approaches The majority of neural approaches extend the sequence-to-sequence approach of Sutskever et al. (2014). Wen et al. (2015) augment LSTM (Hochreiter and Schmidhuber, 1997) decoder with an additional gate, which performs the task of sentence planning. They run their experiments on the task of generating a sentence given input of meaning representations (MR) in the restaurant domain. Lebret et al. (2016) make use of a conditional neural language modeling (Bengio et al., 2003) approach for generating biographies on the WikiBio dataset (Lebret et al., 2016).

Some neural approaches adopt the sequence-to-sequence approach of Sutskever et al. (2014) enhanced with attention (Luong et al., 2015a). Dušek and Jurčíček (2016) train two models: one to generate a linearized sentence plan, and another to generate a sentence. The input to their models is MR. Likewise, Wiseman et al. (2017) adopt this approach for the task of generating game summaries from a table of statistics. We describe its architecture in more detail in Section 2.4.

2.3 Datasets

Several datasets have been proposed to study data-to-text generation. We primarily categorize them here according to the length of the output text. These include datasets with short outputs (i.e., fewer than 100 tokens) and datasets with long outputs (i.e., more than 100 tokens).

Data-to-text with short outputs Earlier datasets for data-to-text generation include BAGEL (Mairesse et al., 2010) and San Fransisco (SF) (Wen et al., 2015) datasets,

Name	#examples	Document length	Domain	Input type	Content Selection
BAGEL (Mairesse et al., 2010)	202	sentence	Restaurant	MR	No
SF (Wen et al., 2015)	10.2K	sentence	Restaurant	MR	No
RoboCup (Chen and Mooney, 2008)	1.9K	sentence	Soccer game simulation	MR	No
WeatherGov (Liang et al., 2009)	22.1K	sentence	Weather	MR	Yes
E2E (Novikova et al., 2017a)	50K	sentence	Restaurant	MR	Yes
WikiBio (Lebret et al., 2016)	728K	sentence	Biography	Infobox	Yes
DocWikiBio (Perez-Beltrachini and Lapata, 2018)	210K	4 sentences	Biography	Infobox	Yes
ToTTo (Parikh et al., 2020)	134K	sentence	Sports, Countries, etc.	Table	Yes
ROTOWIRE (Wiseman et al., 2017)	4.9K	document (337 tokens)	NBA games	Table	Yes
MLB (Ours)	26.3K	document (542 tokens)	MLB games	Table	Yes
German ROTOWIRE (Hayashi et al., 2019)	723	document (323 tokens)	NBA games	Table	Yes

Table 2.1: Statistics of different datasets for data-to-text generation. We include the count of examples (#examples), length of the output document, domain, type of input, and the need for content selection.

which pair MR with single sentence reference text in the restaurant or hotels domain. BAGEL contains 202 examples, whereas SF dataset contains 10.2K examples. RoboCup (Chen and Mooney, 2008) is another dataset, which contains pairs of soccer game simulation states and their commentary. The size of RoboCup dataset is 1.9K examples. Table 2.1 contains the statistics of the different datasets.

Liang et al. (2009) created the WeatherGov dataset, which pairs weather statistics with short text snippets describing a weather forecast. This dataset contains an order

Flat MR	Natural Language Reference
name[Loch Fyne], eatType[restaurant], food[French], priceRange[less than £20], familyFriendly[yes]	Loch Fyne is a family-friendly restaurant providing wine and cheese at a low cost
	Loch Fyne is a French family friendly restaurant catering to a budget of below £20.
	Loch Fyne is a French restaurant with a family setting and perfect on the wallet.

Table 2.2: Example from the E2E dataset (Novikova et al., 2017a) showing a flattened meaning representation (MR) and three natural language references. The references differ in the content selection of the attributes.

of magnitude larger number of examples (22.1K). However, it is now known that the weather forecasts were not produced by a human annotator but by a template system followed by post-editing (Reiter, 2017).

Novikova et al. (2017a) created the E2E dataset where the input is a MR in the restaurant/hotel domain, and the reference text describes the MR. An example from this dataset is shown in Table 2.2. Highlights of this dataset, compared to the earlier datasets, include the need for content selection among the attributes in the MR and diverse vocabulary in the reference text. The size of E2E dataset is 50K examples.

Lebret et al. (2016) introduced the WikiBio dataset, which contains Wikipedia infoboxes paired with a single-sentence biography from its corresponding Wikipedia article. An infobox is a table of attributes and their values. Table 2.3 shows an example from the dataset. The dataset contains 728K samples. Perez-Beltrachini and Lapata (2018) proposed an extension to the WikiBio dataset where the output biography can be multi-sentence text (an average of 4 sentences and 100 tokens). This dataset size is 210K.

Parikh et al. (2020) created a dataset for the controlled generation of text. The input is a table from Wikipedia in which some of the cells are highlighted. The task is to describe the highlighted cells in the context of the table. Table 2.4 contains an example from the dataset. The size of the dataset is 134K.

Table		Summary
Frederick Parker-Rhodes		
Born	21 November 1914 Newington, Yorkshire	Arthur Frederick Parker-Rhodes (21 November 1914 – 2 March 1987) was an English linguist, plant pathologist, computer scientist, mathematician, mystic, and mycologist, who also introduced original theories in physics.
Died	2 March 1987 (aged 72)	
Nationality	British	
Known for	Contributions to computational linguistics, combinatorial physics, bit-string physics, plant pathology, and mycology	
Scientific career		
Fields	Mycology, Plant Pathology, Mathematics, Linguistics, Computer Science	
Author abbrev. (botany)	Park.-Rhodes	

Table 2.3: An example from the WikiBio dataset (Lebret et al., 2016) with Wikipedia infobox and its corresponding single-sentence biography

Data-to-text with longer outputs Creating summaries of sports games has been a topic of interest since the early beginnings of generation systems (Robin, 1994; Tanaka-Ishii et al., 1998). A few recent datasets focus on long document generation in the sports domain, and typically consist of pairs of game statistics and their corresponding game summaries. We describe these datasets in more detail in the following sections since they form the basis of all the experiments reported in this thesis.

2.3.1 ROTOWIRE

ROTOWIRE (Wiseman et al., 2017) is a dataset of NBA basketball game summaries, paired with corresponding box-score tables. The statistics of the dataset are shown in Table 2.8. The summaries are professionally written, relatively well structured, and long (337 words on average). The summaries are targeted towards fantasy basketball fans. The number of record types is 39, the average number of records is 628, the vocabulary size is 11.3K words, and the token count is 1.6M. The dataset is ideally suited for document-scale generation. Table 2.5 contains an example of ROTOWIRE dataset.

Table Title Roger Craig (American Football)

Section Title National Football League Statistics

	Rushing					Receiving				
Year	Team	Att	Yds	Avg	TD	Rec	Yds	Avg	TD	Reference text
1983	SF	176	725	4.1	8	48	427	8.9	4	
1984	SF	155	649	4.2	7	71	675	9.5	3	
1985	SF	214	1,050	4.9	9	92	1,016	11.0	6	Craig finished
1986	SF	204	830	4.1	7	81	624	7.7	0	his eleven NFL
1987	SF	215	815	3.8	3	66	492	7.5	1	seasons with
1988	SF	310	1,502	4.8	9	76	534	7.0	1	8,189 rushing
1989	SF	271	1,054	3.9	6	49	473	9.7	1	yards, 566
1990	SF	141	439	3.1	1	25	201	8.0	0	receptions for
1991	LA	162	590	3.6	1	17	136	8.0	0	4,911 receiving
1992	MIN	105	416	4.0	4	22	164	7.5	0	yards
1993	MIN	38	119	3.1	1	19	169	8.9	1	
Career		1,991	8,189	4.1	56	566	4,911	8.7	17	

Table 2.4: An example from the ToTTo dataset (Parikh et al., 2020). It shows a table from Wikipedia with a few cells highlighted in yellow. The task is to generate a one-sentence description of the highlighted cells in context of the table.

2.3.2 MLB

In this thesis we also created a new dataset for major league baseball (MLB) (see example in Table 2.6 and statistics of the dataset in Table 2.8). The MLB dataset contains pairs of MLB game statistics and their human written summaries. The summaries are obtained from the ESPN website[2]. Compared to ROTOWIRE, MLB summaries are longer (approximately by 50%) and the input records are richer and more structured (with the addition of play-by-play). Moreover, the MLB dataset is five times larger in terms of data size (i.e., pairs of tables and game summaries). Table 2.6 shows (in a table format) the scoring summary of a MLB game, a play-by-play summary with details of the most important events in the game recorded chronologically (i.e., in which play), and a human-written summary.

For MLB we created a split of 22,821/1,739/1,744 instances. Game summaries were tokenized using NLTK (Bird et al., 2009) and hyphenated words were separated. Sentences containing quotes were removed as they included opinions and non-factual

[2]http://www.espn.com/mlb/recap?gameId={gameid}

TEAM	WIN	LOSS	PTS	FG_PCT	RB	AST	...
Pacers	4	6	99	42	40	17	...
Celtics	5	4	105	44	47	22	...

PLAYER	H/V	AST	RB	PTS	FG	CITY	...
Jeff Teague	H	4	3	20	4	Indiana	...
Miles Turner	H	1	8	17	6	Indiana	...
Isaiah Thomas	V	5	0	23	4	Boston	...
Kelly Olynyk	V	4	6	16	6	Boston	...
Amir Johnson	V	3	9	14	4	Boston	...
...	...	...	...	...	...	...	

PTS: points, FT_PCT: free throw percentage, RB: rebounds, AST: assists, H/V: home or visiting, FG: field goals, CITY: player team city.

The Boston Celtics defeated the host Indiana Pacers 105-99 at Bankers Life Fieldhouse on Saturday. In a battle between two injury-riddled teams, the Celtics were able to prevail with a much needed road victory. The key was shooting and defense, as the Celtics outshot the Pacers from the field, from three-point range and from the free-throw line. Boston also held Indiana to 42 percent from the field and 22 percent from long distance. The Celtics also won the rebounding and assisting differentials, while tying the Pacers in turnovers. There were 10 ties and 10 lead changes, as this game went down to the final seconds. Boston (5–4) has had to deal with a gluttony of injuries, but they had the fortunate task of playing a team just as injured here. Isaiah Thomas led the team in scoring, totaling 23 points and five assists on 4–of–13 shooting. He got most of those points by going 14–of–15 from the free-throw line. Kelly Olynyk got a rare start and finished second on the team with his 16 points, six rebounds and four assists.

Table 2.5: Example of game statistics and summary for ROTOWIRE dataset. The tables on the left contain team scores (top) and player scores (bottom). Collectively they are called box-score. The game summary describes relevant statistics from the table in a coherent manner.

statements unrelated to the input tables. Sometimes MLB summaries contain a "Game notes" section with incidental information which was also removed. We have released the dataset publicly[3].

2.3.3 German ROTOWIRE

To study data-to-text generation in a multilingual setting, the organizers of the Workshop on Neural Generation and Translation (WNGT) 2019 shared task on "Document-Level Generation and Translation" (Hayashi et al., 2019) created the German ROTOWIRE dataset. For this, they selected a subset of human written summaries from the English ROTOWIRE and asked professional translators to translate the summaries into German. Note that this dataset is considerably smaller than its English counterpart and

[3] https://github.com/ratishsp/mlb-data-scripts

TEAM	Inn1	Inn2	Inn3	Inn4	...	R	H	E	...
Orioles	1	0	0	0	...	2	4	0	...
Royals	1	0	0	3	...	9	14	1	...

BATTER	H/V	AB	R	H	RBI	TEAM	...
C. Mullins	H	4	2	2	1	Orioles	...
J. Villar	H	4	0	0	0	Orioles	...
W. Merrifield	V	2	3	2	1	Royals	...
R. O'Hearn	V	5	1	3	4	Royals	...
...	...	...	...	...	...	...	

PITCHER	H/V	W	L	IP	H	R	ER	BB	K	...
A. Cashner	H	4	13	5.1	9	4	4	3	1	...
B. Keller	V	7	5	8.0	4	2	2	2	4	...
...	...	...	...	...	...	...				

Inn1: innings, R: runs, H: hits, E: errors, AB: at-bats, RBI: runs-batted-in, H/V: home or visiting, W: wins, L: losses, IP: innings pitched, ER: earned runs, BB: walks, K: strike outs.

KANSAS CITY, Mo. – Brad Keller kept up his recent pitching surge with another strong outing. Keller gave up a home run to the first batter of the game – Cedric Mullins – but quickly settled in to pitch eight strong innings in the Kansas City Royals' 9–2 win over the Baltimore Orioles in a matchup of the teams with the worst records in the majors. Keller (7–5) gave up two runs and four hits with two walks and four strikeouts to improve to 3–0 with a 2.16 ERA in his last four starts. Ryan O'Hearn homered among his three hits and drove in four runs, Whit Merrifield scored three runs, and Hunter Dozier and Cam Gallagher also went deep to help the Royals win for the fifth time in six games on their current homestand. With the scored tied 1–1 in the fourth, Andrew Cashner (4–13) gave up a sacrifice fly to Merrifield after loading the bases on two walks and a single. Dozier led off the fifth inning with a 423-foot home run to left field to make it 3-1. The Orioles pulled within a run in the sixth when Mullins led off with a double just beyond the reach of Dozier at third, advanced to third on a fly ball and scored on Trey Mancini's sacrifice fly to the wall in right. The Royals answered in the bottom of the inning as Gallagher hit his first home run of the season...

BATTER	PITCHER	SCORER	EVENT	TEAM	INN	RUNS	...
C. Mullins	B. Keller	-	Home run	Orioles	1	1	...
H. Dozier	A. Cashner	W. Merrifield	Grounded into DP	Royals	1	1	...
W. Merrifield	A. Cashner	B. Goodwin	Sac fly	Royals	4	2	...
H. Dozier	A. Cashner	-	Home run	Royals	4	3	...
...	...	...	...	...	...	...	...

Table 2.6: MLB statistics tables and game summary. The tables summarize the performance of the two teams and of individual team members who played as batters and pitchers as well as the most important events (and their actors) in each play.

MLB.

TEAM	WIN	LOSS	PTS	FG_PCT	RB	AST	…
Jazz	3	2	97	46	41	18	…
Mavericks	0	4	81	43	36	18	…

PLAYER	H/V	AST	RB	PTS	FG	CITY	…
George Hill	H	4	6	25	9	Utah	…
Rodney Hood	H	3	7	22	9	Utah	…
Joe Johnson	H	4	5	13	5	Utah	…
Harrison Barnes	V	1	2	14	6	Dallas	…
Wesley Matthews	V	2	1	12	4	Dallas	…
…	…	…	…	…	…	…	

PTS: points, FT_PCT: free throw percentage, RB: rebounds, AST: assists, H/V: home or visiting, FG: field goals, CITY: player team city.

Die Utah Jazz besiegten am Mittwoch in der Vivint Smart Home Arena die Dallas Mavericks mit 97 - 81 . Die Jazz (2 - 2) gewannen nach einem langsamen Saisonstart (0 - 2) ihre zweite Partie in Folge . Ein Sieg , den sie ihrem exzellenten Backcourt der Starting Five zu verdanken haben . Point Guard der Startformation George Hill erzielte das zweite Mal in Folge mehr als 20 Punkte , war mit 25 Punkten Topscorer der Mannschaft und fügte dem noch sechs Rebounds und vier Assists bei . Rodney Hood , startender Shooting Guard , steuerte 22 Punkte und sieben Rebounds bei . Gemeinsam verwerteten sie 6 von 10 Versuchen von der Dreierlinie . Den Sieg holten die Jazz mit 12 Treffern bei 25 Versuchen auch von der Dreipunkt-Linie . Die Mavericks (0 - 3) hatten von der Dreipunkt-Linie nicht so viel Erfolg . Bei 26 Versuchen trafen sie nur 7-mal und starteten so mit ihrer dritten Niederlage in Folge in diese Saison . . . .

Table 2.7: An example from German ROTOWIRE dataset. The sports statistics are paired with human written summaries in German language.

2.4 Baseline Encoder-Decoder Models

In this section, we introduce a baseline encoder-decoder model, which is a generalization of the sequence-to-sequence model of Sutskever et al. (2014). It relaxes the requirement that the input is a sequence of tokens. Instead, the input can be an unordered set or a table of records in our case (see, for example, Table 2.5 left-hand-side). Such an encoder-decoder model was adopted by Wiseman et al. (2017) for data-to-text generation.

Each record r_j has four features for ROTOWIRE including the type of the record ($r_{j,1}$; e.g., LOSS, CITY), entity ($r_{j,2}$; e.g., Pacers, Miles Turner), value ($r_{j,3}$; e.g., 11, Indiana), and whether a player is on the home- or away-team ($r_{j,4}$; see column H/V in Table 2.5), represented as $\{r_{j,k}\}_{k=1}^{4}$. The output y is a document containing words $y = y_1 \cdots y_{|y|}$ where $|y|$ is the document length. Let $r = \{r_j\}_{j=1}^{|r|}$ denote a table of input records and y the output text.

	RW	MLB	DE-RW
Vocab Size	11.3K	38.9K	9.5K
# Tokens	1.5M	14.3M	234K
# Instances	4.9K	26.3K	723
# Record Types	39	53	39
Avg Records	628	565	628
Avg Length (tokens)	337.1	542.1	323.6

Table 2.8: Dataset statistics for ROTOWIRE (RW), MLB and German ROTOWIRE (DE-RW) including vocabulary size, number of tokens, number of instances (i.e., table-summary pairs), number of record types, average number of records and average summary length.

2.4.1 Record Encoder

The input to this model is a table of unordered records, each represented as features $\{r_{j,k}\}_{k=1}^{4}$. Following previous work (Yang et al., 2017; Wiseman et al., 2017), we embed features into vectors, and then use a multilayer perceptron to obtain a vector representation $\mathbf{r}_j$ for each record:

$$\mathbf{r}_j = \text{ReLU}(\mathbf{W}_r[\mathbf{r}_{j,1};\mathbf{r}_{j,2};\mathbf{r}_{j,3};\mathbf{r}_{j,4}] + \mathbf{b}_r)$$

where $[;]$ indicates vector concatenation, $\mathbf{W}_r \in \mathbb{R}^{n\times 4n}, \mathbf{b}_r \in \mathbb{R}^n$ are parameters, and ReLU is the rectifier activation function.

2.4.2 Text Generation

The probability of output text y conditioned on input table r is modeled as:

$$p(y|r) = \prod_{t=1}^{|y|} p(y_t|y_{<t}, r)$$

where $y_{<t} = y_1 \ldots y_{t-1}$. We use the encoder-decoder architecture with an attention mechanism (Bahdanau et al., 2015; Luong et al., 2015a) to compute $p(y|r)$.

The text decoder is based on a recurrent neural network with LSTM (Hochreiter and Schmidhuber, 1997) units. The decoder is initialized to the average of the record vectors, $\text{avg}(\{r_j\}_{j=1}^{|r|})$. At decoding step t, the input of the LSTM unit is the embedding of the previously predicted word y_{t-1}. Let $\mathbf{d}_t$ be the hidden state of the t-th LSTM unit.

The probability of predicting y_t from the output vocabulary is computed via:

$$\beta_{t,j} \propto \exp(\mathbf{d}_t^\intercal \mathbf{W}_b \mathbf{r}_j) \tag{2.1}$$

$$\mathbf{q}_t = \sum_{j=1}^{|r|} \beta_{t,j} \mathbf{r}_j$$

$$\mathbf{d}_t^{att} = \tanh(\mathbf{W}_d[\mathbf{d}_t; \mathbf{q}_t])$$

$$p_{gen}(y_t|y_{<t}, r) = \text{softmax}_{y_t}(\mathbf{W}_y \mathbf{d}_t^{att} + \mathbf{b}_y) \tag{2.2}$$

where $\sum_{j=1}^{|r|} \beta_{t,j} = 1$, $\mathbf{W}_b \in \mathbb{R}^{n \times n}$, $\mathbf{W}_d \in \mathbb{R}^{n \times 2n}$, $\mathbf{W}_y \in \mathbb{R}^{n \times |\mathcal{V}_y|}$, $\mathbf{b}_y \in \mathbb{R}^{|\mathcal{V}_y|}$ are parameters, and $|\mathcal{V}_y|$ is the output vocabulary size.

We further augment the decoder with a copy mechanism, i.e., the ability to copy words directly from the *value* portions of records in the table (i.e., $\{r_j\}_{j=1}^{|r|}$). The tokens in the game summaries representing player or team names and numbers are often infrequent compared to the other vocabulary tokens. In addition, the names and numbers occur in similar contexts. Thus their word embeddings are either not well learnt or they learn similar representations (Luong et al., 2013; Harris, 1954). In such a scenario, softmax_{y_t} operation over $|\mathcal{V}_y|$ vocabulary will often be inaccurate for entity names and numbers. As $|r| \ll |\mathcal{V}_y|$, copy attention allows the model to predict entity names and numbers with higher accuracy. There are two copy mechanisms proposed in earlier work: joint (Gu et al., 2016) and conditional copy methods (Gulcehre et al., 2016a). Specifically, we introduce a variable $u_t \in \{0, 1\}$ for each time step to indicate whether the predicted token y_t is copied ($u_t = 1$) or not ($u_t = 0$). The probability of generating y_t is computed by:

$$p(y_t|y_{<t}, r) = \sum_{u_t \in \{0,1\}} p(y_t, u_t|y_{<t}, r)$$

where u_t is marginalized out.

Joint Copy The probability of copying from record values and generating from the vocabulary is globally normalized:

$$p(y_t, u_t|y_{<t}, r) \propto$$
$$\begin{cases} \sum_{y_t \leftarrow r_j} \exp(\mathbf{d}_t^\intercal \mathbf{W}_b \mathbf{r}_j) & u_t = 1 \\ \exp(\mathbf{W}_y \mathbf{d}_t^{att} + \mathbf{b}_y) & u_t = 0 \end{cases}$$

where $y_t \leftarrow r_j$ indicates that y_t can be copied from r_j, $\mathbf{W}_b$ is shared as in Equation (2.1), and $\mathbf{W}_y, \mathbf{b}_y$ are shared as in Equation (2.2).

Conditional Copy The variable u_t is first computed as a switch gate, and then is used to obtain the output probability:

$$p(u_t = 1|y_{<t}, r) = \text{sigmoid}(\mathbf{w}_u \cdot \mathbf{d}_t + b_u)$$
$$p(y_t, u_t|y_{<t}, r) =$$
$$\begin{cases} p(u_t|y_{<t}, r) \sum_{y_t \leftarrow r_j} \beta_{t,j} & u_t = 1 \\ p(u_t|y_{<t}, r) p_{gen}(y_t|y_{<t}, r) & u_t = 0 \end{cases}$$

where $\beta_{t,j}$ and $p_{gen}(y_t|y_{<t}, r)$ are computed as in Equations (2.1) to (2.2), and $\mathbf{w}_u \in \mathbb{R}^n, b_u \in \mathbb{R}$ are parameters.

2.4.3 Training and Inference

The model is trained to maximize the log-likelihood of the gold output text given the table records:

$$\max \sum_{(r,y)\in\mathcal{D}} \log p(y|r)$$

where $\mathcal{D}$ represents training examples (input records and game summaries). During inference, the output for input r is predicted by:

$$\hat{y} = \arg\max_{y'} p(y'|r)$$

where y' represents output text candidates. We utilize beam search to approximately obtain the best results.

2.5 Evaluation

2.5.1 Automatic Evaluation

BLEU For automatic evaluation, we make use of BLEU (Papineni et al., 2002). It compares candidate output with reference summary and produces a score between 1 and 100. It matches n-grams between the two texts, considering matches from unigram till 4-grams. These matching n-grams are used to compute a weighted average of modified n-gram precision. Furthermore, BLEU has a recall based component called brevity penalty (BP), which penalises outputs shorter than the reference length. BP operates at the corpus statistic level and is computed using decayed exponential comparison of the candidate summary length and the reference summary length. More

formally, BLEU is computed using the following formula:

$$\text{BLEU} = \text{BP}.\exp(\sum_{n=1}^{N} w_n \log p_n) \tag{2.3}$$

where p_n is the modified n-gram precision, $\sum_n w_n = 1$, and BP is the Brevity Penalty.

Information Extraction based Evaluation BLEU has been shown to correlate well with human evaluation for single sentence output (Papineni et al., 2002). However, for longer texts such as documents, BLEU focuses primarily on measuring fluency. It does not evaluate if the candidate output selects relevant content from the table or orders it coherently (Wiseman et al., 2017). For a more rigorous automatic evaluation of longer model outputs, we adopt the Information Extraction (IE) approach introduced in Wiseman et al. (2017). It identifies candidate entity (i.e., player, team, and city) and value (i.e., number or string) pairs that appear in the text and then predicts the type (aka relation) of each candidate pair. For instance, in the document in Table 2.5, the IE system might identify the pair "Jeff Teague, 20" and then predict that their relation is "PTS", extracting the record (Jeff Teague, 20, PTS). Wiseman et al. (2017) create a dataset to train such an IE system automatically by determining word spans in the text that could represent entities (i.e., by matching them against players, teams, or cities in the input table) and numbers. They then consider each entity-number pair in the same sentence and search for matching entity-number pairs in the input table. If there is a match, the pair is assigned the corresponding record type or otherwise labeled "none" to indicate unrelated pairs. They consider the task of prediction of the record type as a multi-class classification problem. They use an ensemble of convolutional and bidirectional LSTM models.

A bug in the code of Wiseman et al. (2017) excluded number words from the output summary. We corrected the bug and retrained their IE system on the training portion of the ROTOWIRE corpus. This resulted in greater recall for the relations extracted from the summaries. On held-out data it achieved 94% accuracy, and recalled approximately 80% of the relations licensed by the records.

We trained our own IE system for MLB. Box and line scores in MLB are identical in format to ROTOWIRE and pose no particular problems to the IE system. However, it is difficult to extract information from play-by-play and match it against the input tables. Consider the sentences *Ryan O'Hearn homered* or *Keller gave up a home run* from Table 2.6 where we can identify entities (Ryan O'Hearn, Keller) and record types (home-run-batter, home-run-pitcher) but no specific values. We created a dummy value

of -1 for such cases and the IE system was trained to predict the record type of entity value pairs such as (Ryan O'Hearn, -1) or (Keller, -1).

Wiseman et al. (2017) define three metrics based on the output of the IE system described above. Let $\hat{y}$ be the gold summary and y the model output.

- ***Relation Generation*** (RG) measures the precision and count of relations extracted from y that also appear in records r.

- ***Content Selection*** (CS) measures the precision and recall of relations extracted from y that are also extracted from $\hat{y}$.

- ***Content Ordering*** (CO) measures the complement of the normalized Damerau-Levenshtein (DL) distance (Brill and Moore, 2000) between the sequences of relations extracted from y and $\hat{y}$.

  The DL distance for two strings p and s with lengths i and j respectively is computed recursively as follows (Boytsov, 2011):

$$C_{i,j} = \min \begin{cases} 0 & i = j = 0 \\ C_{i-1,j} + 1 & i > 0 \\ C_{i,j-1} + 1 & j > 0 \\ C_{i-1,j-1} + \mathbb{1}[p_{[i]} \neq s_{[j]}] & i, j > 0 \\ C_{i-2,j-2} + 1 & p_{[i]} = s_{[j-1]}, p_{[i-1]} = s_{[j]} \text{ and } i, j > 1 \end{cases}$$

  where $\mathbb{1}[x] = 1$ if x is true, and 0 otherwise.

  Each recursive call corresponds to one of the following cases:

  - $C_{i-1,j} + 1$ corresponds to deletion of $p_{[i]}$
  - $C_{i,j-1} + 1$ corresponds to deletion of $s_{[j]}$
  - $C_{i-1,j-1} + \mathbb{1}[p_{[i]} \neq s_{[j]}]$ checks for match between the characters $p_{[i]}$ and $s_{[j]}$
  - $C_{i-2,j-2} + 1$ corresponds to transposition of characters $p_{[i]}$, $p_{[i-1]}$ with $s_{[j]}$ and $s_{[j-1]}$

2.5.2 Human Evaluation

We also asked participants to assess model output in terms of relation generation, grammaticality, coherence, and conciseness. We conducted our study on the Amazon Mechanical Turk (AMT) crowdsourcing platform, following best practices for human evaluation in NLG (van der Lee et al., 2019). Specifically, to ensure consistent ratings, we required crowdworkers to have an approval rating greater than 98% and a minimum of 1,000 previously completed tasks. Raters were restricted to English speaking countries (i.e., US, UK, Canada, Ireland, Australia, or NZ). Participants were allowed to provide feedback on the task or field questions (our interface accepts free text).

We performed two types of studies aiming to assess a) whether the generated text is faithful to the input table and b) whether it is well-written. In our first study, we presented crowdworkers with sentences randomly selected from summaries along with their corresponding box score (and play-by-play in case of MLB) and asked them to count supported and contradicting facts (ignoring hallucinations, i.e., unsupported facts). We did not require crowdworkers to be familiar with NBA or MLB. Instead, we provided a cheat sheet explaining the semantics of box score tables. In addition, we provided examples of sentences with supported/contradicting facts. Appendix A contains additional details of the experimental setup for human evaluation for factuality estimation.

Our second study evaluated the quality of the generated summaries. We presented crowdworkers with a pair of summaries and asked them to choose the better one in terms of the three metrics:

- ***Grammaticality*** (is the summary written in well-formed English?),
- ***Coherence*** (is the summary well structured and well organized and does it have a natural ordering of the facts?) and
- ***Conciseness*** (does the summary avoid unnecessary repetition including whole sentences, facts or phrases?).

We provided example summaries showcasing good and bad output. For this task, we required that the crowdworkers be able to comfortably comprehend NBA/MLB game summaries. We elicited preferences with Best-Worst Scaling (Louviere and Woodworth, 1991; Louviere et al., 2015), a method shown to be more reliable than rating scales. The score of a system is computed as the number of times it is rated best minus the number of times it is rated worst (Orme, 2009). The scores range from -100

(absolutely worst) to +100 (absolutely best). Appendix B contains additional details of the experimental setup for human evaluation for quality estimation.

2.6 Summary

In this chapter, we discussed what makes a data-to-text system in terms of input, output and model architecture. We reviewed architectures adopted by earlier systems focusing on rule-based approaches, statistical models and neural networks. We also presented a baseline encoder-decoder neural architecture for data-to-text generation. In addition, we described datasets often used for the development of data-to-text generation systems and introduced the metrics used to evaluate model output.

In the next chapter, we show how to inject micro planning in the neural model introduced in Section 2.4. Specifically, we learn a micro plan from the input and condition on it to generate the output document. We operationalize micro plans as a sequence of records from the input table.

Chapter 3

Micro Planning

In the previous chapter, we looked into the earlier work in data-to-text generation, discussed the datasets we plan to use in our experiments, and automatic metrics for the evaluation of model output. We have also seen examples of earlier architectures for data-to-text generation, which adopt a pipeline approach with separate stages for document planning, micro planning, and surface realisation. The neural approaches do away with individual modules, instead they train a model to perform data-to-text generation in an end-to-end manner.

Micro planning involves deciding specific words to describe concepts and relations, generating referring expressions, and aggregating content into sentences (Reiter and Dale, 2000). In this chapter, we show how to inject micro planning in contemporary neural models. Our model learns a micro plan from the input and conditions on the micro plan in order to generate the output document. We operationalize micro plan as a sequence of records from the input table. An explicit micro planning mechanism has at least three advantages for multi-sentence document generation: it is a fine-grained representation of the document, thereby enabling the decoder to concentrate on the less challenging task of surface realization; it makes the process of data-to-text generation more interpretable by generating an intermediate representation; and reduces redundancy in the output, since it is less likely for the micro plan to contain the same information in multiple places.

We train our micro planning and surface realisation modules jointly using neural networks and evaluate model performance on the ROTOWIRE (Wiseman et al., 2017) and MLB datasets. Automatic and human evaluation show that micro planning improves generation considerably over competitive baselines.

TEAM	WIN	LOSS	PTS	FG_PCT	RB	AST	...
Pacers	4	6	99	42	40	17	...
Celtics	5	4	105	44	47	22	...

PLAYER	H/V	AST	RB	PTS	FG	CITY	...
Jeff Teague	H	4	3	20	4	Indiana	...
Miles Turner	H	1	8	17	6	Indiana	...
Isaiah Thomas	V	5	0	23	4	Boston	...
Kelly Olynyk	V	4	6	16	6	Boston	...
Amir Johnson	V	3	9	14	4	Boston	...
...	...	...	...	...	...	...	

PTS: points, FT_PCT: free throw percentage, RB: rebounds, AST: assists, H/V: home or visiting, FG: field goals, CITY: player team city.

The Boston Celtics defeated the host Indiana Pacers 105-99 at Bankers Life Fieldhouse on Saturday. In a battle between two injury-riddled teams, the Celtics were able to prevail with a much needed road victory. The key was shooting and defense, as the Celtics outshot the Pacers from the field, from three-point range and from the free-throw line. Boston also held Indiana to 42 percent from the field and 22 percent from long distance. The Celtics also won the rebounding and assisting differentials, while tying the Pacers in turnovers. There were 10 ties and 10 lead changes, as this game went down to the final seconds. Boston (5–4) has had to deal with a gluttony of injuries, but they had the fortunate task of playing a team just as injured here. Isaiah Thomas led the team in scoring, totaling 23 points and five assists on 4–of–13 shooting. He got most of those points by going 14–of–15 from the free-throw line. Kelly Olynyk got a rare start and finished second on the team with his 16 points, six rebounds and four assists.

Table 3.1: Example of data-records and document summary for ROTOWIRE dataset

3.1 Problem Formulation

The input to our model is a table of records (see Table 3.1 left hand-side). Let M be the number of features in each record. For example, in ROTOWIRE, each record r_j has four features including its type ($r_{j,1}$; e.g., LOSS, CITY), entity ($r_{j,2}$; e.g., Pacers, Miles Turner), value ($r_{j,3}$; e.g., 11, Indiana), and whether a player is on the home- or away-team ($r_{j,4}$; see column H/V in Table 3.1), represented as $\{r_{j,k}\}_{k=1}^{M}$. The output y is a document containing tokens $y = y_1 \cdots y_{|y|}$ where $|y|$ is the document length. The overall architecture of our model consists of two stages: (a) *micro planning* operates on the input records of a database and produces a micro plan specifying which records are to be verbalized in the document and in which order (see Table 3.2) and (b) *text generation* produces the output text given the micro plan as input; at each decoding step, the generation model attends over vector representations of the records in the micro plan.

Let $r = \{r_j\}_{j=1}^{L}$ denote a table of input records where $L = |r|$, and y the output text. We model $p(y|r)$ as the joint probability of text y and micro plan z, given input r. We further decompose $p(y,z|r)$ into $p(z|r)$, a micro planning phase, and $p(y|r,z)$, a text

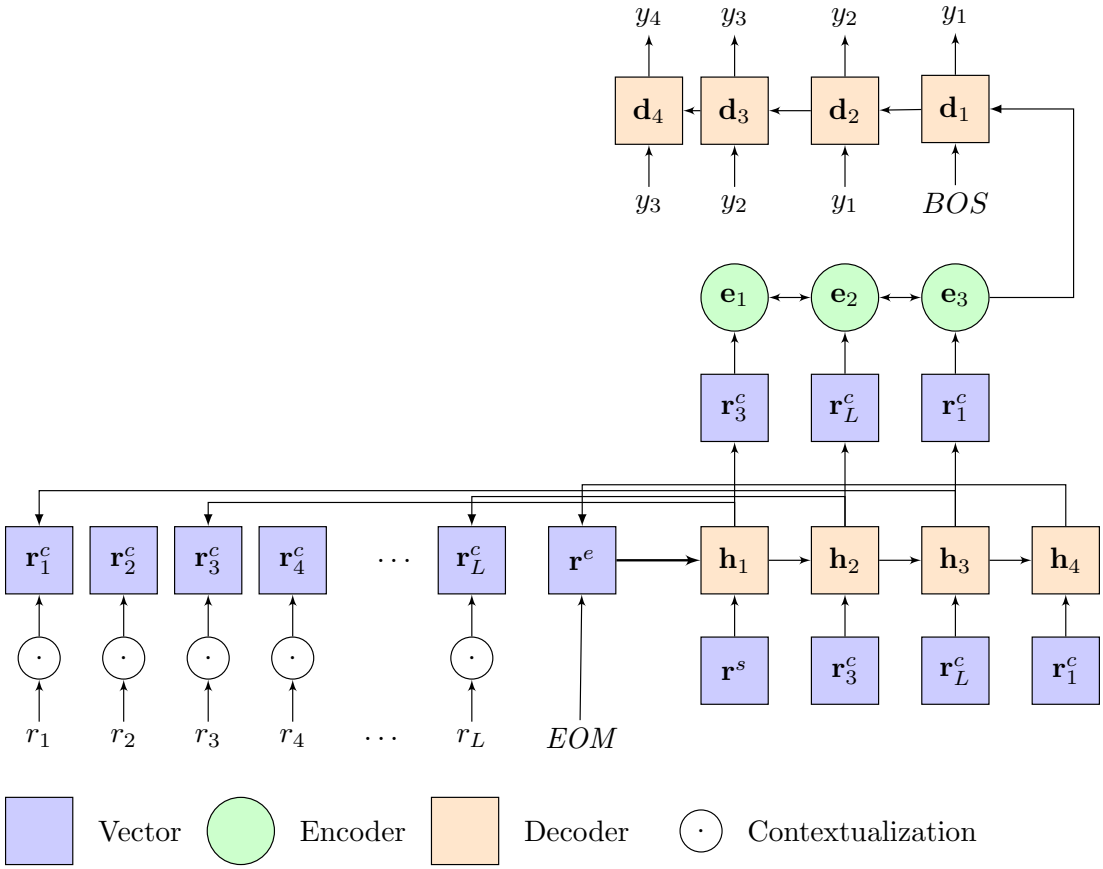

Figure 3.1: Overall model.The input to the model is table of records $r = \{r_j\}_{j=1}^{L}$ (bottom left of the figure) and output is text $y = y_1 y_2 y_3 \ldots$ (top right of the figure). The table of records is passed through a contextualization mechanism (illustrated in Figure 3.2) and produces the contextualized outputs $r^c = \{r^c_j\}_{j=1}^{L}$. The output of micro planning points to r_3, r_L, and r_1 (see Equations (3.5) and (3.6)). *EOM* is end of micro plan token. Micro planning stops when the decoder points to *EOM*. The micro plan is encoded using Bidirectional LSTM to produce representations e_1, e_2, e_3. Game summary $y = y_1 y_2 y_3 \ldots$ is generated using another LSTM with attention and copy mechanism (Equation 3.9).

generation phase (Figure 3.1):

$$p(y|r) = \sum_z p(y,z|r) = \sum_z p(z|r)p(y|r,z) \tag{3.1}$$

In the following we explain how the components $p(z|r)$ and $p(y|r,z)$ are estimated.

3.1.1 Record Encoder

The input to our model is a table of *unordered* records, each represented as features $\{r_{j,k}\}_{k=1}^{M}$. Following previous work (Yang et al., 2017; Wiseman et al., 2017),

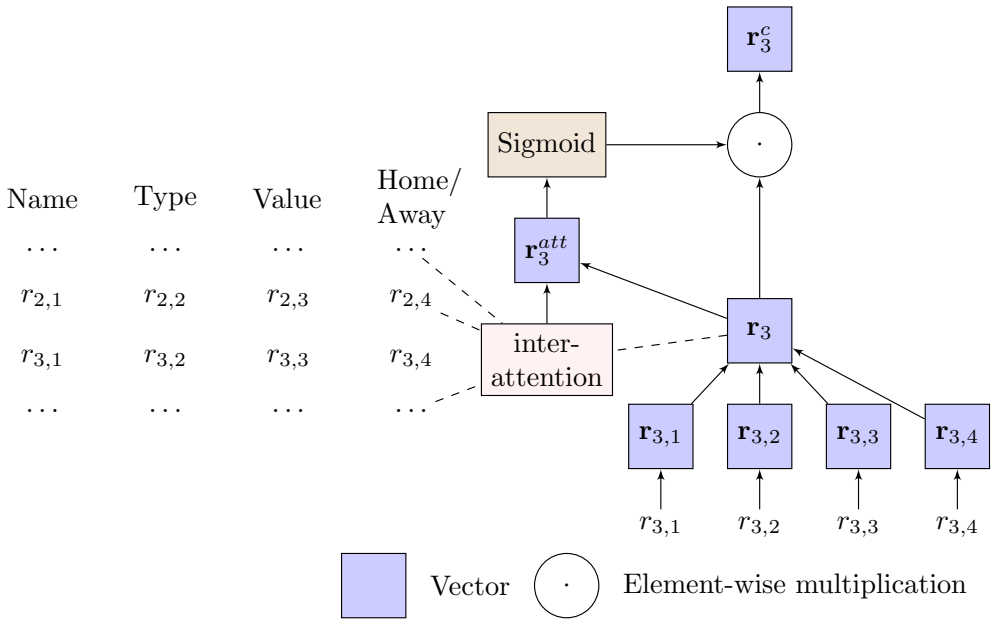

Figure 3.2: Contextualization for micro planning. $r_{3,1}$, $r_{3,2}$, $r_{3,3}$ and $r_{3,4}$ are the four features of the record r_3 in ROTOWIRE. Computation of $\mathbf{r}_3$ is detailed in Equation (3.2), $\mathbf{r}_3^{att}$ in Equation (3.3), and $\mathbf{r}_3^c$ in Equation (3.4). $\mathbf{r}_3^c$ represents the contextualized representation of r_3.

we embed features into vectors by making use of word embeddings, and then use a multilayer perceptron to obtain a vector representation $\mathbf{r}_j$ for each record:

$$\mathbf{r}_j = \text{ReLU}(\mathbf{W}_r[\mathbf{r}_{j,1};\mathbf{r}_{j,2};\mathbf{r}_{j,3};\ldots;\mathbf{r}_{j,M}] + \mathbf{b}_r) \tag{3.2}$$

where $[;]$ indicates vector concatenation, $\mathbf{W}_r \in \mathbb{R}^{n \times Mn}, \mathbf{b}_r \in \mathbb{R}^n$ are parameters, and ReLU is the rectifier activation function.

3.1.2 Contextualization

The context of a record can be useful in determining its importance vis-a-vis other records in the table. For example, in ROTOWIRE if a player scores many points, it is likely that other meaningfully related records such as field goals, three-pointers, or rebounds will be mentioned in the output summary. To better capture such dependencies among records, we make use of the contextualization mechanism as shown in Figure 3.2.

We first compute the attention scores $\alpha_{j,k}$ over the input table and use them to

obtain an attentional vector $\mathbf{r}_j^{att}$ for each record r_j:

$$\begin{aligned}\alpha_{j,k} &\propto \exp(\mathbf{r}_j^{\intercal}\mathbf{W}_a\mathbf{r}_k)\\ \mathbf{c}_j &= \sum_{k\neq j}\alpha_{j,k}\mathbf{r}_k\\ \mathbf{r}_j^{att} &= \mathbf{W}_g[\mathbf{r}_j;\mathbf{c}_j]\end{aligned} \tag{3.3}$$

where $\mathbf{W}_a \in \mathbb{R}^{n\times n}, \mathbf{W}_g \in \mathbb{R}^{n\times 2n}$ are parameter matrices, and $\sum_{k\neq j}\alpha_{j,k} = 1$.

We next apply the contextualization gating mechanism to $\mathbf{r}_j$, and obtain the new record representation $\mathbf{r}_j^c$ via:

$$\begin{aligned}\mathbf{g}_j &= \text{sigmoid}\left(\mathbf{r}_j^{att}\right)\\ \mathbf{r}_j^c &= \mathbf{g}_j \odot \mathbf{r}_j\end{aligned} \tag{3.4}$$

where $\odot$ denotes element-wise multiplication, and gate $\mathbf{g}_j \in [0,1]^n$ controls the amount of information flowing from $\mathbf{r}_j$. In other words, each element in $\mathbf{r_j}$ is weighed by the corresponding element of the contextualization gate $\mathbf{g}_j$.

3.1.3 Micro Planning

In our generation task, the output text is long but follows a canonical structure. In ROTOWIRE, for example, game summaries typically begin by discussing which team won/lost, following with various statistics involving individual players and their teams (e.g., who performed exceptionally well or under-performed), and finishing with any upcoming games. We hypothesize that generation would benefit from an explicit plan specifying both *what to say* and *in which order*. Our model learns such micro plans from training data. However, notice that ROTOWIRE (see Table 3.1) and most similar data-to-text datasets do not naturally contain micro plans. Fortunately, we can obtain these relatively straightforwardly following an information extraction approach (which we explain in Section 3.2).

Suffice it to say that plans are extracted by mapping the text in the summaries onto entities in the input table, their values, and types (i.e., relations). A plan is a sequence of pointers with each entry pointing to an input record $\{r_j\}_{j=1}^{L}$. An excerpt of a plan is shown in Table 3.2. The order in the plan corresponds to the sequence in which entities appear in the game summary. Let $z = z_1 \ldots z_{|z|}$ denote the micro planning sequence. Each z_k points to an input record, i.e., $z_k \in \{r_j\}_{j=1}^{L}$. Given the input records, the

probability $p(z|r)$ is decomposed as:

$$p(z|r) = \prod_{k=1}^{|z|} p(z_k|z_{<k}, r) \tag{3.5}$$

where $z_{<k} = z_1 \dots z_{k-1}$.

Since the output tokens of the micro planning stage correspond to positions in the input sequence, we make use of Pointer Networks (Vinyals et al., 2015). The latter use attention to point to the tokens of the input sequence rather than creating a weighted representation of source encodings. As shown in Figure 3.1, given $\{r_j\}_{j=1}^{L}$, we use an LSTM decoder to generate tokens corresponding to positions in the input. The first hidden state of the decoder is initialized by $\text{avg}(\{\mathbf{r}_j^c\}_{j=1}^{L})$, i.e., the average of record vectors. At decoding step k, let $\mathbf{h}_k$ be the hidden state of the LSTM. We model $p(z_k = r_j|z_{<k}, r)$ as the attention over input records:

$$p(z_k = r_j|z_{<k}, r) \propto \exp(\mathbf{h}_k^\intercal \mathbf{W}_c \mathbf{r}_j^c) \tag{3.6}$$

where the probability is normalized to 1, and $\mathbf{W}_c$ are parameters. Once z_k points to record r_j, we use the corresponding vector $\mathbf{r}_j^c$ as the input of the next LSTM unit in the decoder.

3.1.4 Text Generation

The probability of output text y conditioned on micro plan z and input table r is modeled as:

$$p(y|r, z) = \prod_{t=1}^{|y|} p(y_t|y_{<t}, z, r) \tag{3.7}$$

where $y_{<t} = y_1 \dots y_{t-1}$. We use the encoder-decoder architecture with an attention mechanism to compute $p(y|r, z)$.

We first encode the micro plan z into $\{\mathbf{e}_k\}_{k=1}^{|z|}$ using a bidirectional LSTM. Because the micro plan is a sequence of input records, we directly feed the corresponding record vectors $\{\mathbf{r}_j^c\}_{j=1}^{L}$ as input to the LSTM units, which share the record encoder with the first stage.

The text decoder is also based on a recurrent neural network with LSTM units. The decoder is initialized with the hidden states of the final step in the encoder. At decoding step t, the input of the LSTM unit is the embedding of the previously predicted word y_{t-1}. Let $\mathbf{d}_t$ be the hidden state of the t-th LSTM unit. The probability of predicting y_t from the output vocabulary is computed via:

$$\beta_{t,k} \propto \exp(\mathbf{d}_t^\intercal \mathbf{W}_b \mathbf{e}_k) \tag{3.8}$$

Value	Entity	Type	H/V
Boston	Celtics	TEAM-CITY	V
Celtics	Celtics	TEAM-NAME	V
105	Celtics	TEAM-PTS	V
Indiana	Pacers	TEAM-CITY	H
Pacers	Pacers	TEAM-NAME	H
99	Pacers	TEAM-PTS	H
42	Pacers	TEAM-FG_PCT	H
22	Pacers	TEAM-FG3_PCT	H
5	Celtics	TEAM-WIN	V
4	Celtics	TEAM-LOSS	V
Isaiah	Isaiah_Thomas	FIRST_NAME	V
Thomas	Isaiah_Thomas	SECOND_NAME	V
23	Isaiah_Thomas	PTS	V
5	Isaiah_Thomas	AST	V
4	Isaiah_Thomas	FGM	V
13	Isaiah_Thomas	FGA	V
Kelly	Kelly_Olynyk	FIRST_NAME	V
Olynyk	Kelly_Olynyk	SECOND_NAME	V
16	Kelly_Olynyk	PTS	V
6	Kelly_Olynyk	REB	V
4	Kelly_Olynyk	AST	V
...	...	...	...

Table 3.2: Micro plan for the game summary in Table 3.1. It contains a sequence of records, with each record containing four features: Value, Entity, Type and Home(H)/Visiting(V) side. The sequence of records in micro plan aligns with the their description in the game summary.

$$\begin{aligned} \mathbf{q}_t &= \sum_k \beta_{t,k} \mathbf{e}_k \\ \mathbf{d}_t^{att} &= \tanh(\mathbf{W}_d[\mathbf{d}_t; \mathbf{q}_t]) \\ p_{gen}(y_t|y_{<t}, z, r) &= \text{softmax}_{y_t}(\mathbf{W}_y \mathbf{d}_t^{att} + \mathbf{b}_y) \end{aligned} \tag{3.9}$$

where $\sum_k \beta_{t,k} = 1$, $\mathbf{W}_b \in \mathbb{R}^{n \times n}, \mathbf{W}_d \in \mathbb{R}^{n \times 2n}, \mathbf{W}_y \in \mathbb{R}^{n \times |\mathcal{V}_y|}, \mathbf{b}_y \in \mathbb{R}^{|\mathcal{V}_y|}$ are parameters,

and $|\mathcal{V}_y|$ is the output vocabulary size.

We further augment the decoder with a copy mechanism, i.e., the ability to copy words directly from the *value* portions of records in the micro plan (i.e., $\{z_k\}_{k=1}^{|z|}$). We experimented with joint (Gu et al., 2016) and conditional copy methods (Gulcehre et al., 2016a). See Section 2.4.2 in Chapter 2 for details on the differences between the two mechanisms.

Following Gulcehre et al. (2016a) and Wiseman et al. (2017), if y_t appears in the micro plan during training, we assume that y_t is copied (i.e., $u_t = 1$).[1]

3.1.5 Training and Inference

Our model is trained to maximize the log-likelihood of the gold[2] micro plan given table records *r and* the gold output text given the micro plan and table records:

$$\max \sum_{(r,z,y)\in\mathcal{D}} \log p\,(z|r) + \log p\,(y|r,z)$$

where $\mathcal{D}$ represents training examples (input records, plans, and game summaries). During inference, the output for input r is predicted by:

$$\hat{z} = \arg\max_{z'} p(z'|r)$$
$$\hat{y} = \arg\max_{y'} p(y'|r,\hat{z})$$

where z' and y' represent micro plan and output text candidates, respectively. For each stage, we utilize beam search to approximately obtain the best results.

3.2 Experimental Setup

Data We performed experiments on two datasets. The first one is ROTOWIRE (Wiseman et al., 2017) which contains NBA basketball game statistics matched with human-written summaries. In addition, we experiment with MLB dataset which contains baseball statistics and corresponding human-authored summaries obtained from the ESPN website.

[1] Following previous work (Gulcehre et al., 2016a; Wiseman et al., 2017) we learn whether y_t can be copied from candidate z_k by applying supervision during training. Specifically, we retain z_k when the record entity and its value occur in same sentence in y.

[2] Strictly speaking, the micro plan is silver standard since it was not created by an expert but is the output of a fairly accurate IE system.

For MLB, the value of M in Equation (3.2) is 6, and for ROTOWIRE it is 4. The first four features are similar in both datasets and include value, entity, record type whether a player is on the home- or away- team. MLB has two additional features which include the inning of play ($r_{j,5}$; e.g., 9, 7, and -1 for records in the box score), and play index, a unique play identifier for a set of records in a play ($r_{j,6}$; e.g., 0, 10, and -1 for records in the box score).

Micro Plan Extraction We extracted micro plans from the game summaries following an information extraction (IE) approach. Specifically, we followed the IE system introduced in Wiseman et al. (2017) which identifies candidate entity (i.e., player, team, and city) and value (i.e., number or string) pairs that appear in the text, and then predicts the type (aka relation) of each candidate pair. See Section 2.5.1 for the details of the IE system.

Given the output of the IE system, a micro plan for ROTOWIRE simply consists of (entity, value, record type, h/v) tuples in their order of appearance in a game summary (the content plan for the summary in Table 3.1 is shown in Table 3.2). Player names are pre-processed to indicate the individual's first name and surname (see Isaiah and Thomas in Table 3.2); team records are also pre-processed to indicate the name of team's city and the team itself (see Boston and Celtics in Table 3.2).

We trained our own IE system for MLB. The IE system does not capture attributes such as inning and team scores in play-by-play as it is difficult to deterministically match these against corresponding spans in text. On MLB, the system achieved 83.4% precision and 66.7% recall (on held out data). We expect the relatively low IE recall on MLB to disadvantage our micro planning model which relies on accurate content plans.

Training Configuration We validated model hyperparameters on the development set. We did not tune the dimensions of word embeddings and LSTM hidden layers; we used the same value of 600 reported in Wiseman et al. (2017). We used one-layer pointer networks during micro planning, and two-layer LSTMs during text generation. Input feeding (Luong et al., 2015b) was employed for the text decoder. We applied dropout (Zaremba et al., 2014)) at a rate of 0.3. Models were trained for 25 epochs with the AdaGrad optimizer (Duchi et al., 2011)); the initial learning rate was 0.15, learning rate decay was selected from $\{0.5, 0.97\}$, and the batch size was 5. For text decoding, we made use of truncated Backpropagation through time (BPTT) (Williams

and Peng, 1990) and set the truncation size to 100, i.e. we divide the the summary into blocks of size equal to the truncation size, and backpropagate the gradients to the encoder parameters and to the start of the current block. We set the beam size to 5 during inference. All models are implemented in OpenNMT-py (Klein et al., 2017a).

3.3 Results

Automatic Evaluation We evaluated model output using the metrics defined in Wiseman et al. (2017) and introduced in Chapter 2. The idea is to employ a fairly accurate IE system on the gold and automatic summaries and compare whether the identified relations align or diverge.

Automatic Evaluation for ROTOWIRE Our results on the ROTOWIRE development set are summarized in Table 3.3. We compare our Neural Content Planning model (NCP for short) against the two encoder-decoder (ED) models presented in Wiseman et al. (2017) with joint copy (JC) and conditional copy (CC), respectively. In addition to our own re-implementation of these models, we include the best scores reported in Wiseman et al. (2017) which were obtained with an encoder-decoder model enhanced with conditional copy. Table 3.3 also shows results when NCP uses oracle micro plans (OR) as input. In this case, we use the micro plans extracted using the IE approach in Section 3.2 as z in Equation 3.7 instead of the predicted micro plan. In addition, we report the performance of a template-based generator (Wiseman et al., 2017) which creates a document consisting of eight template sentences: an introductory sentence (who won/lost), six player-specific sentences (based on the six highest-scoring players in the game), and a conclusion sentence. See Table 3.11 for an example.

As can be seen, NCP improves upon vanilla encoder-decoder models (ED+JC, ED+CC), irrespective of the copy mechanism being employed. In fact, NCP achieves comparable scores with either joint or conditional copy mechanism which indicates that it is the micro planner which brings performance improvements. Overall, NCP+CC achieves best content selection and content ordering scores in terms of BLEU. Compared to the best reported system in Wiseman et al. (2017), we achieve an absolute improvement of approximately 12% in terms of relation generation; content selection precision also improves by 5% and recall by 15%, content ordering increases by 3%, and BLEU by 1.5 points. The results of the oracle system (NCP+OR) show that content selection and ordering do indeed correlate with the quality of the micro plan and

Model	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
TEMPL	54.29	99.92	26.61	59.16	14.42	8.51
WS-2017	23.95	75.10	28.11	35.86	15.33	14.57
ED+JC	22.98	76.07	27.70	33.29	14.36	13.22
ED+CC	21.94	75.08	27.96	32.71	15.03	13.31
NCP+JC	33.37	87.40	32.20	48.56	17.98	14.92
NCP+CC	33.88	87.51	33.52	51.21	18.57	16.19
NCP+OR	21.59	89.21	88.52	85.84	78.51	24.11

Table 3.3: Automatic evaluation on ROTOWIRE development set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), and BLEU.

that any improvements in our planning component would result in better output. As far as the template-based system is concerned, we observe that it obtains low BLEU and CS precision but scores high on CS recall and RG metrics. This is not surprising as the template system is provided with domain knowledge which our model does not have, and thus represents an upper-bound on content selection and relation generation. We also measured the degree to which the game summaries generated by our model contain redundant information as the proportion of non-duplicate records extracted from the summary by the IE system. 84.5% of the records in NCP+CC are non-duplicates compared to Wiseman et al. (2017) who obtain 72.9% showing that our model is less repetitive.

We further conducted an ablation study with the conditional copy variant of our model (NCP+CC) to establish whether improvements are due to better contextualization (CX) and/or micro planning (CP). We see in Table 3.4 that contextualization and micro planning individually contribute to performance improvements over the baseline (ED+CC), and accuracy further increases when both components are taken into account. In addition we evaluated these components on their own (independently of text generation) by comparing the output of the planner (see $p(z|r)$ in Equation 3.5) against micro plans obtained using the IE system (see row NCP in Table 3.4). Compared to the full system (NCP+CC), content selection precision and recall are higher (by 4.5% and 2%, respectively) as well as content ordering (by 1.8%). In another

Model	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
ED+CC	21.94	75.08	27.96	32.71	15.03	13.31
CX+CC	24.93	80.55	28.63	35.23	15.12	13.52
CP+CC	33.73	84.85	29.57	44.72	15.84	14.45
NCP+CC	33.88	87.51	33.52	51.21	18.57	16.19
NCP	34.46	—	38.00	53.72	20.27	—

Table 3.4: Ablation results on ROTOWIRE development set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), and BLEU.

Model	RG		CS		CO	Aggregation	BLEU
	#	P%	P%	R%	DLD%	#	
TEMPL	**54.23**	**99.94**	26.99	**58.16**	14.92	7.71	8.46
WS-2017	23.72	74.80	29.49	36.18	15.42	**4.78**	14.19
NCP+JC	34.09	87.19	32.02	47.29	17.15	6.61	14.89
NCP+CC	34.28	87.47	**34.18**	51.22	**18.58**	5.95	**16.50**

Table 3.5: Automatic evaluation on ROTOWIRE test set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (R%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), count of records aggregated into a sentence, and BLEU.

study, we used the CS and CO metrics to measure how well the generated text follows the micro plan produced by the planner (instead of arbitrarily adding or removing information). We found out that NCP+CC generates game summaries which follow the micro plan closely: CS precision is higher than 85%, CS recall is higher than 93%, and CO higher than 84%. This reinforces our claim that higher accuracy in the micro planning phases will result in further improvements in text generation.

The test set results in Table 3.5 follow a pattern similar to the development set. NCP achieves higher accuracy in all metrics including relation generation, content selection, content ordering, and BLEU compared to Wiseman et al. (2017).

In our model, we consider input as a table of unordered records. Thus our model is agnostic to the order of the records at the input. To empirically verify this, we conduct an experiment where we randomly shuffle the records at the input. We observe that the

MLB	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
TEMPL	59.93	97.96	22.82	68.46	10.64	3.81
ED+CC	18.69	92.65	62.29	51.36	25.93	9.55
NCP+CC	17.70	88.01	59.76	55.23	26.87	9.43

Table 3.6: Automatic evaluation on MLB development set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), and BLEU.

MLB	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
TEMPL	**59.93**	**97.96**	22.82	**68.46**	10.64	3.81
ED+CC	18.69	92.19	**62.01**	50.12	25.44	**9.69**
NCP+CC	17.93	88.11	60.48	55.13	**26.71**	9.68

Table 3.7: Automatic evaluation on MLB test set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (R%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), and BLEU.

resultant micro plan is identical to the one before.

Study of Aggregation for ROTOWIRE The metrics we have studied so far, such as RG, CS, and BLEU, focus on evaluating the verbalisation of records from the micro plan to the generated text. Thus, these metrics mainly evaluate the content aspect of micro planning (Reiter and Dale, 1997; Section 3.3.1). We now study aggregation, which is related to the structural side of micro planning. Aggregation decides the division of content into structures such as sentences and paragraphs. Aggregation also involves the task of ordering information within a sentence. Here, we study the aggregation and packaging of information into a single sentence.

Reiter and Dale (1997) (Section 5.3.1) define the unit on which aggregation applies as an informational element. For our study, we consider a record as the informational element, as we define the record as the unit of our micro plan. Furthermore, Reiter and Dale (1997) (Section 5.3.1) define different types of aggregation such as simple

conjunction (combining informational elements using conjunction such as 'and') and conjunction via shared participants (realising shared content only once in an aggregation). The aggregation operation we observe in the ROTOWIRE dataset primarily falls in the category of conjunction via shared participants; the shared participant, in our case, is a team or a player entity. Consider an example of the sentence "Isaiah Thomas led the team in scoring, totaling 23 points and five assists on 4–of–13 shooting." from the summary in Table 3.1. This sentence aggregates information of multiple informational elements such as points, assists, attempted field goals, and managed field goals for player Isaiah Thomas.

We adopt the following formulation to compute aggregation on the NCP+CC model output:

$$\text{Aggegation} = \frac{\text{Count of extracted records}}{\text{Count of sentences with at least one extracted record}} \tag{3.10}$$

From Table 3.5, we see that TEMPL has a high aggregation value of 7.71. This means, on average, about 7.7 records are aggregated into a sentence in TEMPL for the ROTOWIRE dataset. A high aggregation value indicates that information is densely packed into a sentence. It is not surprising that TEMPL has a high aggregation value, as it does not perform any content selection, and it includes a large number of facts from the table. Compared to TEMPL, the neural models have lower aggregation values.

Automatic Evaluation for MLB Our results for MLB development set are summarized in Table 3.6. We compare our NCP model against the ED+CC model as it was shown to be better than ED+JC model for ROTOWIRE dataset. In addition, we report the performance of a template-based generator for MLB. It consists of an opening sentence about the two teams playing the game. It then describes statistics of pitchers (innings pitched, runs and hits given etc.) followed by a description of play-by-play (home run, single, double, triple etc.). Table 3.16 contains an example.

NCP+CC achieves better CS recall, CO than ED+CC, comparable BLEU, and lower RG P%. The test set results in Table 3.7 follow a pattern similar to the development set. As discussed in Section 3.2, the low recall of IE used for training the micro planner hurts the performance of the NCP+CC model in MLB.

Human-Based Evaluation We conducted two human evaluation experiments using the Amazon Mechanical Turk (AMT) crowdsourcing platform as detailed in Chapter 2. The first study assessed relation generation by examining whether improvements in

relation generation attested by automatic evaluation metrics are indeed corroborated by human judgments. We did not require crowdworkers to be familiar with NBA or MLB. Instead, we provided a cheat sheet explaining the semantics of box score tables. In addition, we provided examples of sentences with supported/ contradicting facts. For ROTOWIRE, we compared our best performing model (NCP+CC), with gold reference summaries (Gold), a template system (TEMPL) and the best model of Wiseman et al. (2017) (WS-2017). For MLB, we compared NCP+CC with ED+CC, Gold, and TEMPL. AMT workers were asked to identify supporting and contradicting facts mentioned in each sentence. We randomly selected 30 games from the test set. Each sentence was rated by three workers. Altogether 49 crowdworkers participated in this study.

The left two columns in Table 3.8 contain the average number of supporting and contradicting facts per sentence as determined by the crowdworkers, for each model. The template-based system has the highest number of supporting facts, even compared to the human gold standard. TEMPL does not perform any content selection, it includes a large number of facts from the database and since it does not perform any generation either, it exhibits a few contradictions. On ROTOWIRE, compared to WS-2017 and the Gold summaries, NCP+CC displays a larger number of supporting facts. All models are significantly[3] different in the number of supporting facts (#Supp) from TEMPL (using a one-way ANOVA with post-hoc Tukey HSD tests). NCP+CC is significantly different from WS-2017 and Gold. With respect to contradicting facts (#Cont), Gold and TEMPL are not significantly different from each other but are significantly different from the neural systems (WS-2017, NCP+CC). On MLB, NCP+CC yields a number of supporting facts comparable to Gold, but significantly lower than ED+CC and TEMPL. Contradicting facts are significantly higher for NCP+CC compared to ED+CC, TEMPL and Gold.

In the second experiment, we assessed the generation quality of our model. For this task, we required that the crowdworkers be able to comfortably comprehend NBA/ MLB game summaries. We elicited judgments for the same 30 games used in the first study. For each game, participants were asked to compare summaries from the candidate systems. We arranged every 4-tuple of competing summaries into 6 pairs. Every pair was shown to three crowdworkers, who were asked to decide which summary was *best* and which one was *worst* according to three three criteria: *Grammaticality*, *Coherence*, and *Conciseness*. Altogether 46 crowdworkers participated in this study.

[3]Using a one-way ANOVA with post-hoc Tukey HSD; $p \leq 0.05$.

ROTOWIRE	#Supp	#Contra	Gram	Cohere	Concise
Gold	2.98*	0.28*	11.78*	16.00*	13.78*
TEMPL	6.98*	0.21*	-0.89	-4.89*	1.33*
WS-2017	3.19*	1.09	-4.22*	-4.89*	-6.44
NCP+CC	4.90	0.90	-2.44	-2.44	-3.55

MLB	#Supp	#Contra	Gram	Coher	Concis
Gold	2.81	0.15*	9.26	11.85	-20.74
TEMPL	3.98*	0.04*	-20.37*	-17.0	21.11
ED+CC	3.24*	0.40*	6.30	6.30	-1.48
NCP+CC	2.86	0.88	4.81	-1.11	1.11

Table 3.8: Average number of supporting (#Supp) and contradicting (#Contra) facts in game summaries and *best-worst scaling* evaluation (higher is better) for grammaticality (Gram), Coherence (Cohere), and Conciseness (Concise) for ROTOWIRE (top) and MLB (bottom) datasets. Systems significantly different from NCP+CC are marked with an asterisk * (using a one-way ANOVA with posthoc Tukey HSD tests; $p \leq 0.05$)

The results of the second study are summarized in Table 3.8. On ROTOWIRE, Gold summaries were perceived as significantly better compared to the automatic systems across all criteria (again using a one-way ANOVA with post-hoc Tukey HSD tests). NCP+CC was perceived as significantly more grammatical than WS-2017 but not compared to TEMPL which does not suffer from fluency errors since it does not perform any generation. NCP+CC was perceived as significantly more coherent than TEMPL and WS-2017. The template fares poorly on coherence, its output is stilted and exhibits no variability. With regard to conciseness, the neural systems are significantly worse than TEMPL, while NCP+CC is significantly better than WS-2017. By design the template cannot repeat information since there is no redundancy in the sentences chosen to verbalize the summary.

As far as MLB is concerned, NCP+CC is comparable to Gold, TEMPL and ED+CC on Coherence and Conciseness. On Grammaticality, NCP+CC is comparable to Gold and ED+CC, and significantly better than TEMPL.

Taken together, our results show that micro planning improves data-to-text generation across metrics and systems on ROTOWIRE. On MLB dataset, the low recall of IE used for training the micro planner hurts the performance of the NCP+CC model.

3.4 Qualitative Examples

We show output summaries for NCP+CC for the ROTOWIRE dataset in Tables 3.10 and 3.13 and their corresponding predicted micro plans in Tables 3.9 and 3.12. We see a strong alignment between the records in the micro plan and the tokens in the output summary.

Table 3.15 contains an example of output summary for the MLB dataset with its predicted micro plan in Table 3.14. We see an alignment between the records in the micro plan and the tokens in the output summary. However, the model hallucinates a block of text not supported by the micro plan. The primary reason for this is that the MLB micro planner has been trained using oracle micro plans, which suffer from lower recall for relations. The poor coverage of IE for the MLB dataset is responsible for this.

3.5 Summary

In this chapter, we studied an approach for neural micro planning for data-to-text generation. Experimental results on ROTOWIRE dataset (based on automatic metrics and judgment elicitation studies) demonstrate that generation quality improves both in terms of the number of relevant facts contained in the output text, and the order according to which these are presented. Positive side-effects of micro planning are additional improvements in the grammaticality, and conciseness of the generated text.

Training a micro planner, however, requires fine-grained supervision in the form of oracle micro plans during training, which necessitates an Information Extraction (IE) model with high coverage and precision. Such supervision using Information Extraction is hard to obtain for other datasets such as MLB. In the next chapter, we propose a latent entity planning architecture for data-to-text generation which addresses these concerns. Specifically, the latent plans operate at the level of entities which is a higher level than records. In addition, we avoid using any supervision to train the plans. Our model creates entity-specific representations which are dynamically updated. Text is generated conditioned on the data input and entity memory representations using hierarchical attention at each time step.

Value	Entity	Type	H/V
Washington	Wizards	TEAM-CITY	H
Wizards	Wizards	TEAM-NAME	H
92	Wizards	TEAM-PTS	H
Denver	Nuggets	TEAM-CITY	V
Nuggets	Nuggets	TEAM-NAME	V
85	Nuggets	TEAM-PTS	V
8	Wizards	TEAM-WINS	H
13	Wizards	TEAM-LOSSES	H
8	Nuggets	TEAM-WINS	V
15	Nuggets	TEAM-LOSSES	V
Bradley	Bradley_Beal	FIRST_NAME	H
Beal	Bradley_Beal	SECOND_NAME	H
8	Bradley_Beal	FGM	H
15	Bradley_Beal	FGA	H
John	John_Wall	FIRST_NAME	H
Wall	John_Wall	SECOND_NAME	H
5	John_Wall	FGM	H
14	John_Wall	FGA	H
15	John_Wall	PTS	H
7	John_Wall	REB	H
5	John_Wall	AST	H
3	John_Wall	STL	H
1	John_Wall	BLK	H
Jusuf	Jusuf_Nurkic	FIRST_NAME	V
Nurkic	Jusuf_Nurkic	SECOND_NAME	V
13	Jusuf_Nurkic	PTS	V
7	Jusuf_Nurkic	REB	V
1	Jusuf_Nurkic	AST	V
Jameer	Jameer_Nelson	FIRST_NAME	V
Nelson	Jameer_Nelson	SECOND_NAME	V
10	Jameer_Nelson	PTS	V
8	Jameer_Nelson	AST	V
4	Jameer_Nelson	REB	V
2	Jameer_Nelson	STL	V
36	Jameer_Nelson	MIN	V

Table 3.9: Predicted micro plan corresponding to the predicted game summary in Table 3.10. It contains a sequence of records, with each record containing four features: Value, Entity, Type and Home(H)/Visiting(V) side. The sequence of records in micro plan aligns with the their description in the game summary.

The **Washington Wizards** defeated the visiting **Denver Nuggets 92-85** at Verizon Center on Monday. The Wizards (**8-13**) came into this game winners of five of their last eight games, but the Wizards (**8-15**) jumped out to a 10-point lead at the end of the first quarter. **Bradley Beal** led the way for the Wizards with a game-high **26** points on **8-of-15** shooting from the field. **John Wall** shot **5-of-14** from the field on his way to **15** points, to go along with **seven** rebounds, **five** assists, **three** steals and **one** block. **Jusuf Nurkic** chipped in **13** points, **seven** rebounds and **one** assist. **Jameer Nelson** filled out the stat sheet with **10** points, **eight** assists, **four** rebounds and **two** steals in **36** minutes. As a team, it was a forgettable shooting night for the Nuggets, as the team shot just 46 percent from the field. Next up, the Nuggets play the second game of a back-to-back when they host the Denver Nuggets on Wednesday, while the Wizards host the Portland Trail Blazers on Friday.

Table 3.10: NCP+CC model output for ROTOWIRE corresponding to the micro plan in Table 3.9. The tokens in summary corresponding to the records in the micro plan are bold faced. We see a strong alignment between the records in micro plan and the game summary in the model output. In addition, the model output exhibits coherent ordering of facts.

The Washington Wizards (8-13) defeated the Denver Nuggets (8-15) 92-85. Bradley Beal scored 26 points (8-15 FG, 4-7 3PT, 6-6 FT) to go with 3 rebounds. Nikola Jokic scored 17 points (6-10 FG, 0-0 3PT, 5-7 FT) to go with 11 rebounds. Markieff Morris scored 15 points (5-12 FG, 0-0 3PT, 5-5 FT) to go with 3 rebounds. John Wall scored 15 points (5-14 FG, 0-4 3PT, 5-6 FT) to go with 7 rebounds. Danilo Gallinari scored 14 points (3-11 FG, 1-8 3PT, 7-9 FT) to go with 4 rebounds. Jusuf Nurkic scored 13 points (6-6 FG, 0-0 3PT, 1-2 FT) to go with 7 rebounds. The Washington Wizards' next game will be at home against the Dallas Mavericks, while the Denver Nuggets will travel to play the Bulls.

Table 3.11: Example of template model output corresponding to the example in Table 3.10. We see that the template output is stilted and exhibits no variability.

Value	Entity	Type	H/V
Golden_State	Warriors	TEAM-CITY	V
Warriors	Warriors	TEAM-NAME	V
104	Warriors	TEAM-PTS	V
Boston	Celtics	TEAM-CITY	H
Celtics	Celtics	TEAM-NAME	H
88	Celtics	TEAM-PTS	H
10	Warriors	TEAM-WINS	V
2	Warriors	TEAM-LOSSES	V
6	Celtics	TEAM-WINS	H
6	Celtics	TEAM-LOSSES	H
Klay	Klay_Thompson	FIRST_NAME	V
Thompson	Klay_Thompson	SECOND_NAME	V
28	Klay_Thompson	PTS	V
12	Klay_Thompson	FGM	V
21	Klay_Thompson	FGA	V
Kevin	Kevin_Durant	FIRST_NAME	V
Durant	Kevin_Durant	SECOND_NAME	V
23	Kevin_Durant	PTS	V
10	Kevin_Durant	REB	V
7	Kevin_Durant	AST	V
2	Kevin_Durant	STL	V
Stephen	Stephen_Curry	FIRST_NAME	V
Curry	Stephen_Curry	SECOND_NAME	V
16	Stephen_Curry	PTS	V
8	Stephen_Curry	AST	V
Draymond	Draymond_Green	FIRST_NAME	V
Green	Draymond_Green	SECOND_NAME	V
11	Draymond_Green	PTS	V
8	Draymond_Green	REB	V
8	Draymond_Green	AST	V
Isaiah	Isaiah_Thomas	FIRST_NAME	H
Thomas	Isaiah_Thomas	SECOND_NAME	H
4	Isaiah_Thomas	FGM	H
12	Isaiah_Thomas	FGA	H
18	Isaiah_Thomas	PTS	H
Avery	Avery_Bradley	FIRST_NAME	H
Bradley	Avery_Bradley	SECOND_NAME	H
17	Avery_Bradley	PTS	H
10	Avery_Bradley	REB	H

Table 3.12: Predicted micro plan corresponding to the predicted game summary in Table 3.13. It contains a sequence of records, with each record containing four features: Value, Entity, Type and Home(H)/Visiting(V) side. The sequence of records in micro plan aligns with the their description in the game summary.

The **Golden State Warriors** defeated the **Boston Celtics 104-88** at TD Garden on Friday. The Warriors (**10-2**) came into this game winners of five of their last six games, but the Warriors (**6-6**) were able to pull away in the second half. **Klay Thompson** led the way for the Warriors with **28** points on **12-of-21** shooting, while **Kevin Durant** added **23** points, **10** rebounds, **seven** assists and **two** steals. **Stephen Curry** added **16** points and **eight** assists, while **Draymond Green** rounded out the box score with **11 points**, **eight** rebounds and **eight** assists. For the Celtics, it was **Isaiah Thomas** who shot just **4-of-12** from the field and finished with **18** points. **Avery Bradley** added **17** points and **10** rebounds, while the rest of the Celtics combined to score just seven points. Boston will look to get back on track as they play host to the 76ers on Friday.

Table 3.13: NCP+CC model output for ROTOWIRE corresponding to the micro plan in Table 3.12. The tokens in summary corresponding to the records in the micro plan are bold faced. We see a strong alignment between the records in micro plan and the game summary in the model output. In addition, the model output exhibits coherent ordering of facts.

Value	Entity	Type	Inning	H/V	Play Id
Shin-Soo	Shin-Soo_Choo	first_name	-1	HOME	-1
Choo	Shin-Soo_Choo	last_name	-1	HOME	-1
pl_double_batter	Shin-Soo_Choo	pl_double_batter	8	bottom	4
Cleveland	Indians	team_city	-1	HOME	-1
Indians	Indians	team_name	-1	HOME	-1
3	Indians	team_runs	-1	HOME	-1
Chi_White_Sox	White_Sox	team_city	-1	AWAY	-1
White_Sox	White_Sox	team_name	-1	AWAY	-1
2	White_Sox	team_runs	-1	AWAY	-1
Matt	Matt_Thornton	first_name	-1	AWAY	-1
Thornton	Matt_Thornton	last_name	-1	AWAY	-1
1	Matt_Thornton	p_w	-1	AWAY	-1
1	Matt_Thornton	p_l	-1	AWAY	-1
pl_double_batter	Shin-Soo_Choo	pl_double_batter	8	bottom	4
Jensen	Jensen_Lewis	first_name	-1	HOME	-1
Lewis	Jensen_Lewis	last_name	-1	HOME	-1
2	Jensen_Lewis	p_w	-1	HOME	-1
0	Jensen_Lewis	p_l	-1	HOME	-1
Chris	Chris_Perez	first_name	-1	HOME	-1
Perez	Chris_Perez	last_name	-1	HOME	-1
0	Chris_Perez	p_er	-1	HOME	-1
Jake	Jake_Peavy	first_name	-1	AWAY	-1
Peavy	Jake_Peavy	last_name	-1	AWAY	-1
7	Jake_Peavy	p_ip1	-1	AWAY	-1
1/3	Jake_Peavy	p_ip2	-1	AWAY	-1
2	Jake_Peavy	p_r	-1	AWAY	-1
4	Jake_Peavy	p_h	-1	AWAY	-1
3	Jake_Peavy	p_bb	-1	AWAY	-1
3	Jake_Peavy	p_so	-1	AWAY	-1
Jake	Jake_Westbrook	first_name	-1	HOME	-1
Westbrook	Jake_Westbrook	last_name	-1	HOME	-1
2	Jake_Westbrook	p_r	-1	HOME	-1
5	Jake_Westbrook	p_h	-1	HOME	-1
7	Jake_Westbrook	p_ip1	-1	HOME	-1

Table 3.14: Predicted micro plan corresponding to the predicted game summary in Table 3.15 for MLB dataset. It contains a sequence of records, with each record containing six features: Value, Entity, Type, Inning, Home(H)/Visiting(V) side and Play Id.

CLEVELAND – **Shin-Soo Choo** and the **Cleveland Indians** got a clutch hit from Shin-Soo Choo . Choo hit a tiebreaking RBI **double** in the **eighth** inning , and the Indians beat the Chicago White Sox **3 - 2** on Tuesday night for their fifth straight win . The White Sox have won six of seven and are a season - high seven games over .500 . Choo **doubled** off **Matt Thornton** (**1 - 1**) with one out in the eighth and Choo followed with a double to the gap in left - center . **Jensen Lewis** (**2 - 0**) pitched a scoreless eighth and **Chris Perez** worked the ninth for his first save . **Jake** Westbrook pitched **7 1/3** innings , allowing **two** runs and **four** hits , walking **three** and striking out **three** . The right - hander , who had won his previous three starts , struck out six and walked two . Peavy allowed two runs and four hits in seven innings . He struck out five and walked two . The White Sox took a 2 - 1 lead in the fifth when Westbrook walked the bases loaded with one out , but got out of the jam by striking out Kosuke Fukudome . The White Sox tied it in the sixth on a two - out , bases - loaded walk to Jason Giambi . The White Sox took a 2 - 1 lead in the sixth on a bases - loaded walk to Jason Giambi and a sacrifice fly by Jason Giambi . **Westbrook** gave up **two** runs and **five** hits in **seven** innings . He struck out five and walked two . Westbrook has allowed at least one run in each of his last five starts .

Table 3.15: NCP+CC model output for MLB corresponding to the micro plan in Table 3.14. The tokens in summary corresponding to the records in the micro plan are bold faced. The model makes an error in reproducing the scores of *Jake Peavy* as that of *Jake Westbrook*. In addition, it hallucinates a block of text (highlighted in red) not supported by the micro plan. The primary reason for this is that the MLB micro planner has been trained using oracle micro plans, which suffer from lower recall for relations. The poor coverage of IE for the MLB dataset is responsible for this.

The Cleveland Indians defeated the Chi White Sox White Sox 3 - 2 . Jake Westbrook (0 - 1) allowed 2 runs , 5 hits and 3 walks in 7 innings . Chris Perez (0 - 1) allowed 0 runs , 0 hits and 0 walks in 1 innings . Jensen Lewis (2 - 0) allowed 0 runs , 0 hits and 0 walks in 1 innings . Matt Thornton (1 - 1) allowed 1 runs , 2 hits and 1 walks in 2/3 innings . Jake Peavy (0 - 0) allowed 2 runs , 4 hits and 3 walks in 7 1/3 innings . Alexei Ramirez hit 1 RBI double in the sixth . Alex Rios hit 1 RBI double in the seventh . Asdrubal Cabrera hit 1 RBI homer in the eighth . Shin-Soo Choo hit 1 RBI double in the eighth .

Table 3.16: Example of template model output corresponding to the example in Table 3.15. We see that the template output is stilted and exhibits no variability.

Chapter 4

Latent Entity Planning

In the previous chapter, we looked into how micro planning can be applied for data-to-text generation. Given a table as input, micro planning predicts a sequence of records which is utilised by the text generation module to create the game summary. Micro planning, however, requires fine-grained record level supervision for training. It assumes or requires the availability of a highly precise and broad coverage Information Extraction tool. Such supervision may be difficult to obtain for some datasets or domains. In this chapter, we explore how we can perform data-to-text generation by inducing *latent* plans which operate at a higher level than records, such as entities.

4.1 Motivation

Figure 4.1 is an example from the MLB dataset containing statistics related to the game and its summary. We are interested in the generation of descriptive texts such as the game summary. Descriptive texts are often characterized as "entity coherent" which means that their coherence is based on the way *entities* (also known as domain objects or concepts) are introduced and discussed in the discourse (Karamanis et al., 2004). Without knowing anything about baseball or how game summaries are typically written, a glance at the text in Figure 4.1 reveals that it is about a few entities, namely players who had an important part in the game (e.g., Brad Keller, Hunter Dozier) and their respective teams (e.g., Orioles, Royals). The prominent role of entities in achieving discourse coherence has been long recognized within the linguistic and cognitive science literature (Kuno, 1972; Chafe, 1976; Halliday and Hasan, 1976; Karttunen, 1976; Clark and Haviland, 1977; Prince, 1981), with Centering Theory (Grosz et al., 1995) being most prominent at formalizing how entities are linguistically realized and

TEAM	Inn1	Inn2	Inn3	Inn4	...	R	H	E	...
Orioles	1	0	0	0	...	2	4	0	...
Royals	1	0	0	3	...	9	14	1	...

BATTER	H/V	AB	R	H	RBI	TEAM	...
C. Mullins	H	4	2	2	1	Orioles	...
J. Villar	H	4	0	0	0	Orioles	...
W. Merrifield	V	2	3	2	1	Royals	...
R. O'Hearn	V	5	1	3	4	Royals	...
...	...	...	...	...	...	...	

PITCHER	H/V	W	L	IP	H	R	ER	BB	K	...
A. Cashner	H	4	13	5.1	9	4	4	3	1	...
B. Keller	V	7	5	8.0	4	2	2	2	4	...
...	...	...	...	...	...	...				

Inn1: innings, R: runs, H: hits, E: errors, AB: at-bats, RBI: runs-batted-in, H/V: home or visiting, W: wins, L: losses, IP: innings pitched, ER: earned runs, BB: walks, K: strike outs.

KANSAS CITY, Mo. – **Brad Keller** kept up his recent pitching surge with another strong outing. **Keller** gave up a home run to the first batter of the game – **Cedric Mullins** – but quickly settled in to pitch eight strong innings in the Kansas City **Royals**' 9–2 win over the Baltimore **Orioles** in a matchup of the teams with the worst records in the majors. **Keller** (7–5) gave up two runs and four hits with two walks and four strikeouts to improve to 3–0 with a 2.16 ERA in his last four starts. **Ryan O'Hearn** homered among his three hits and drove in four runs, **Whit Merrifield** scored three runs, and **Hunter Dozier** and **Cam Gallagher** also went deep to help the **Royals** win for the fifth time in six games on their current homestand. With the scored tied 1–1 in the fourth, **Andrew Cashner** (4–13) gave up a sacrifice fly to **Merrifield** after loading the bases on two walks and a single. **Dozier** led off the fifth inning with a 423-foot home run to left field to make it 3-1. The **Orioles** pulled within a run in the sixth when **Mullins** led off with a double just beyond the reach of **Dozier** at third, advanced to third on a fly ball and scored on **Trey Mancini**'s sacrifice fly to the wall in right. The **Royals** answered in the bottom of the inning as **Gallagher** hit his first home run of the season...

BATTER	PITCHER	SCORER	EVENT	TEAM	INN	RUNS	...
C. Mullins	B. Keller	-	Home run	Orioles	1	1	...
H. Dozier	A. Cashner	W. Merrifield	Grounded into DP	Royals	1	1	...
W. Merrifield	A. Cashner	B. Goodwin	Sac fly	Royals	4	2	...
H. Dozier	A. Cashner	-	Home run	Royals	4	3	...
...	...	...	...	...	...	...	...

Figure 4.1: MLB statistics tables and game summary. The tables summarize the performance of the two teams and of individual team members who played as batters and pitchers as well as the most important events (and their actors) in each play. Recurring entities in the summary are boldfaced and colorcoded, singletons are shown in black.

distributed in texts.

In this chapter, we propose an entity-centric neural architecture for data-to-text generation. Instead of treating entities as ordinary tokens, we create entity-specific representations (i.e., for players and teams) which are dynamically updated as text is

[*John*]$_1$ wanted to go to [*the coffee shop*]$_2$ in [*downtown Copenhagen*]$_3$. [*He*]$_1$ was told that [*it*]$_2$ sold [*the best beans*]$_4$.

Figure 4.2: The figure shows an example from Ji et al. (2017). It makes use of dynamic entity representations for language modeling and coreference resolution. In this example, it tracks the coreferent mention of entity "John" as "He". As a language model, it predicts that the text "was told that" will be followed by coreferent "it" coreferring to the entity "the coffee shop". The language model then predicts the token "sold", and a new entity mention "the best beans". At each time step during decoding, the model selects an entity conditioned on the LSTM hidden state of the decoder and distance features computed over each of the previously generated entity mentions. The model conditions on the neural representation of this selected entity to predict coreferent mentions or new mentions of entities. The neural representation of the selected entity is dynamically updated as text is generated.

being generated. Our model generates descriptive texts with a decoder augmented with a *memory cell* and a *processor* for each entity. At each time step in the decoder, the processor computes an updated representation of the entity as an interpolation between a candidate entity memory and its previous value. Processors are each a gated recurrent neural network and parameters among them are shared. The model generates text by hierarchically attending over entity memory cells *and* the records corresponding to them. If we consider the entity with the highest attention weight during each decoding step, then the list of such entities forms a latent entity plan.

4.2 Related Work

A variety of coherence theories have been developed over the years (e.g., Mann and Thomson 1988; Grosz et al. 1995) and their principles have found application in many symbolic text generation systems (e.g., Scott and de Souza 1990b; Kibble and Power 2004). Modeling entities and their communicative actions has also been shown to improve system output in interactive storytelling (Cavazza et al., 2002; Cavazza and Charles, 2005) and dialogue generation (Walker et al., 2011).

More recently, the benefits of modeling entities explicitly have been demonstrated in various tasks and neural network models. Ji et al. (2017) make use of dynamic entity

Context	All of a sudden, [*Emily*]$_1$ walked towards [*the dragon*]$_2$.
Current Sentence	[*Seth*]$_3$ yelled at [*her*]$_1$ to get back but _____

Figure 4.3: Figure shows an example from Clark et al. (2018). The model extends Ji et al. (2017) to support story generation. The model conditions on a selected entity representation (and the decoder LSTM hidden state) to generate the entity mentions. In this example, the gold reference reads as "Seth yelled at her to get back but she ignored him". The model conditions on the selected entity (Emily) representation and the decoder LSTM hidden state to generate the mention "she" and other continuing words.

representations for language modeling and coreference resolution (example in Figure 4.2). At each time step during decoding, the model selects an entity conditioned on the the LSTM hidden state of the decoder and distance features computed over each of the previously generated entity mentions. The model conditions on neural representation of this selected entity to predict coreferent mentions or new mentions of entities. The neural representation of the selected entity is dynamically updated as text is generated.

Clark et al. (2018) extend Ji et al. (2017) for text generation by adding entity context as input to the decoder (example in Figure 4.3). Specifically, the model conditions on the entity representation of a selected entity (and the decoder LSTM hidden state) to generate the entity mentions. Both Ji et al. (2017) and Clark et al. (2018) condition on a *single* entity at a time, while we dynamically represent and condition on *multiple* entities in parallel.

Kiddon et al. (2016) make use of a neural checklist model with fixed entity representations to handle coverage and coherence of recipe generation (example in Figure 4.4). The input to the model is the name of the recipe ("Pico de gallo") and a list of items in the recipe ("chopped tomatoes", "onion", "jalapenos", ...). The model maintains a soft checklist ($\in [0, 1]$) of items in the recipe. It updates entry in the checklist if mentions of a recipe item have been generated. At each time step during decoding, the model interpolates between decoder hidden state, attention over list of new recipe items and attention over list of used recipe items to predict the next token. The lists of new and used recipe items are updated based on the the checklist values.

Bosselut et al. (2018) model actions and their effects on entities for the same task of

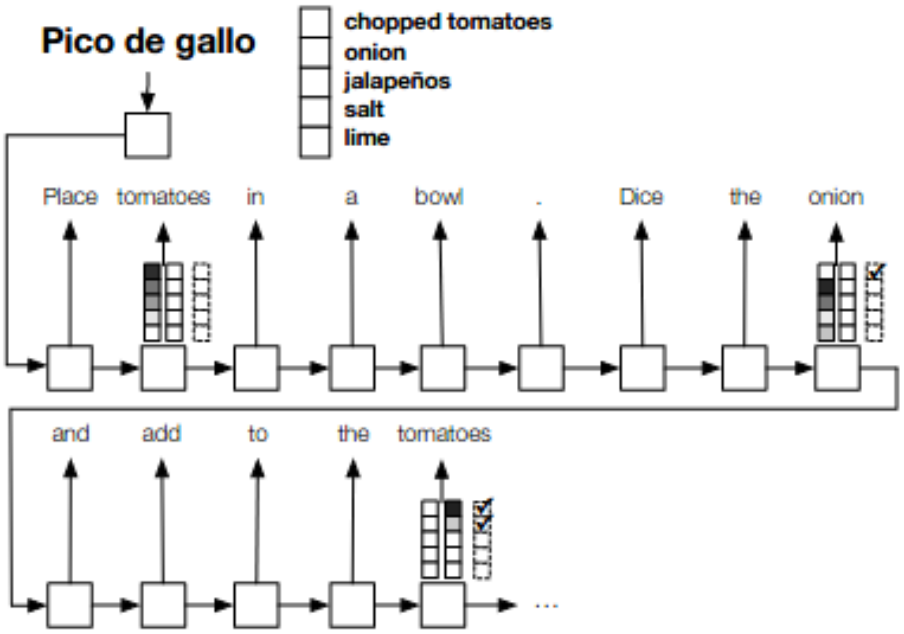

Figure 4.4: The figure shows an example from Kiddon et al. (2016). The model uses a neural checklist model with fixed entity representations to handle coverage and coherence of recipe generation. The input to the model is the name of the recipe ("Pico de gallo") and a list of items in the recipe ("chopped tomatoes", "onion", "jalapenos", ...). The model maintains a soft checklist ($\in$ [0, 1]) of items (dashed columns) in the recipe. If mentions of a recipe item have been generated, the model updates its entry in the checklist. At each time step during decoding, the model interpolates between decoder hidden state, attention over a list of new recipe items (first column), and attention over a list of used recipe items (middle column) to predict the next token. The lists of new and used recipe items are updated based on the checklist values.

recipe generation (example in Figure 4.5). It models actions such as *wash* and *cut* and their effects on entities such as *tomato*. Given a statement "wash and cut the tomatoes", the model extracts the entity representation of tomato $\bar{e}$ and updates it by applying a composition ($\bar{f}$) of learnt functions f_{wash} and f_{cut} representing the wash and cut actions, respectively. The entity representation of tomato can later be queried to determine its state of cleanliness and shape. During generation, the model conditions on the hidden state of decoder and the entity representations to predict the next token. However, in contrast to our work, they keep entity representations fixed during generation.

Henaff et al. (2017) make use of dynamic entity representations in machine reading. Entity representations are scored against a query vector to directly predict an output

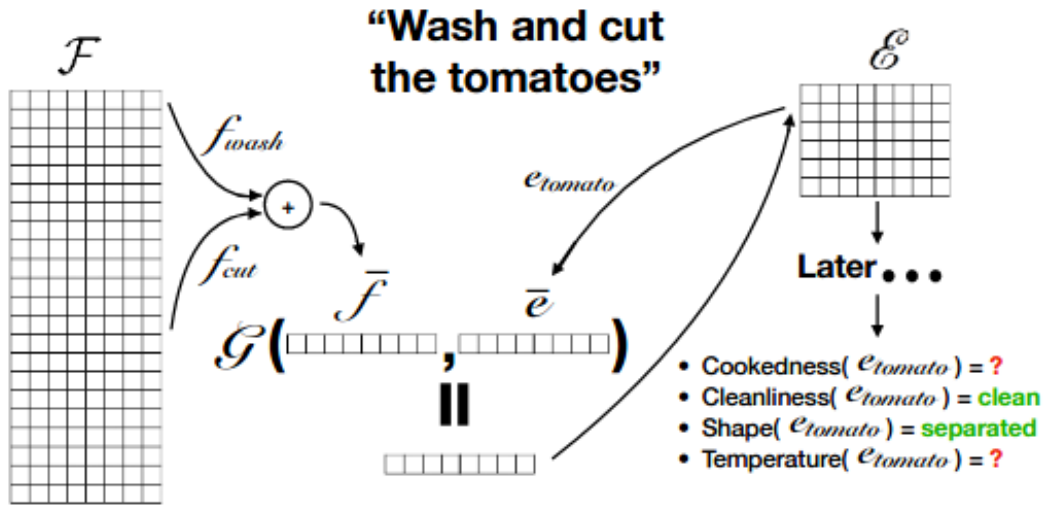

Figure 4.5: The figure shows an example from Bosselut et al. (2018). They model actions such as *wash* and *cut* and their effects on entities such as *tomato*. Given a statement "wash and cut the tomatoes", the model extracts the entity representation of tomato $\bar{e}$ and updates it by applying a composition ($\bar{f}$) of learnt functions f_{wash} and f_{cut} representing the wash and cut actions, respectively. The entity representation of tomato can later be queried to determine its state of cleanliness and shape.

class or combined as a weighted sum followed by softmax over the vocabulary. We make use of a similar entity representation model, extend it with hierarchical attention and apply it to data-to text generation. The hierarchical attention mechanism was first introduced in Yang et al. (2016a) as a way of learning document-level representations. We apply attention over records and subsequently over entity memories.

4.3 Encoder-Decoder with Conditional Copy

The input to our model is a table of records (see Figure 4.1). Records in turn have features, represented as $\{r_{j,l}\}_{l=1}^{M}$ where M is the number of features in each record. Examples of features are values ($r_{j,1}$; e.g., 8.0, Baltimore) or entities ($r_{j,2}$; e.g., Orioles, C. Mullins). The model output y is a document containing tokens $y = y_1 \cdots y_{|y|}$ where $|y|$ is the document length. Similar to the previous chapter, we embed features into vectors, and then use a multilayer perceptron to obtain a vector representation $\mathbf{r}_j$ for each record:

$$\mathbf{r}_j = \text{ReLU}(\mathbf{W}_r[\mathbf{r}_{j,1}; \mathbf{r}_{j,2}; ...; \mathbf{r}_{j,M}] + \mathbf{b}_r) \tag{4.1}$$

where $[;]$ indicates vector concatenation, $\mathbf{W}_r \in \mathbb{R}^{n \times nM}, \mathbf{b}_r \in \mathbb{R}^n$ are parameters, and ReLU is the rectifier activation function.

Let $\{\mathbf{e}_j\}_{j=1}^{|r|}$ denote the output of the encoder. We use an LSTM decoder to compute the probability of each target word, conditioned on previously generated words, and on $\mathbf{e}_j$. In the case of ROTOWIRE, we follow previous work (Wiseman et al., 2017 and Chapter 3) and consider $\mathbf{e}_j = \mathbf{r}_j$. The first hidden state of the decoder is initialized by the average of the record vectors, $\text{avg}(\{\mathbf{e}_j\}_{j=1}^{|r|})$.

In the case of MLB, information encoded in play-by-play is sequential. Recall, that it documents the most important events in a game in chronological order. To account for this, we encode MLB records into $\{\mathbf{e}_j\}_{j=1}^{|r|}$ with a Bidirectional LSTM. We impose an ordering on records in the box score i.e., home team followed by away team, followed by home team players and away team players, which is in turn followed by play-by-play where records are naturally ordered by time. The decoder is initialized with the concatenation of the hidden states of the final step of the encoder.

At time step t, the input to the decoder LSTM is the embedding of the previously predicted word y_{t-1}. Let $\mathbf{d}_t$ denote the hidden state of the t-th LSTM unit. We compute attention scores $\alpha_{t,j}$ over the encoder output $\mathbf{e}_j$ and obtain dynamic context vector $\mathbf{q}_t$ as the weighted sum of the hidden states of the input:

$$\begin{aligned} \alpha_{t,j} &\propto \exp(\mathbf{d}_t^\intercal \mathbf{W}_a \mathbf{e}_j) \\ \mathbf{q}_t &= \sum_j \alpha_{t,j} \mathbf{e}_j \\ \mathbf{d}_t^{att} &= \tanh(\mathbf{W}_c[\mathbf{d}_t; \mathbf{q}_t]) \end{aligned} \tag{4.2}$$

where $\mathbf{W}_a \in \mathbb{R}^{n \times n}, \sum_j \alpha_{t,j} = 1$, $\mathbf{W}_c \in \mathbb{R}^{n \times 2n}$, and $\mathbf{d}_t^{att}$ is the attention vector.

The probability of output text y conditioned on the input table r is modeled as:

$$p_{gen}(y_t | y_{<t}, r) = \text{softmax}_{y_t}(\mathbf{W}_y \mathbf{d}_t^{att} + \mathbf{b}_y) \tag{4.3}$$

where $\mathbf{W}_y \in \mathbb{R}^{|\mathcal{V}_y| \times n}$, $\mathbf{b}_y \in \mathbb{R}^{|\mathcal{V}_y|}$ are parameters and $|\mathcal{V}_y|$ is the output vocabulary size.

As in Chapter 3, we further augment the decoder with a copy mechanism i.e., the ability to copy *values* from the input; copy implies $y_t = r_{j,1}$ for some t and j (e.g., *Royals, Orioles, 9, 2* in the summary in Figure 4.1 are copied from r). We use the conditional copy method proposed in Gulcehre et al. (2016a) where a binary variable is introduced as a switch gate to indicate whether y_t is copied or not (Section 2.4.2 in Chapter 2).

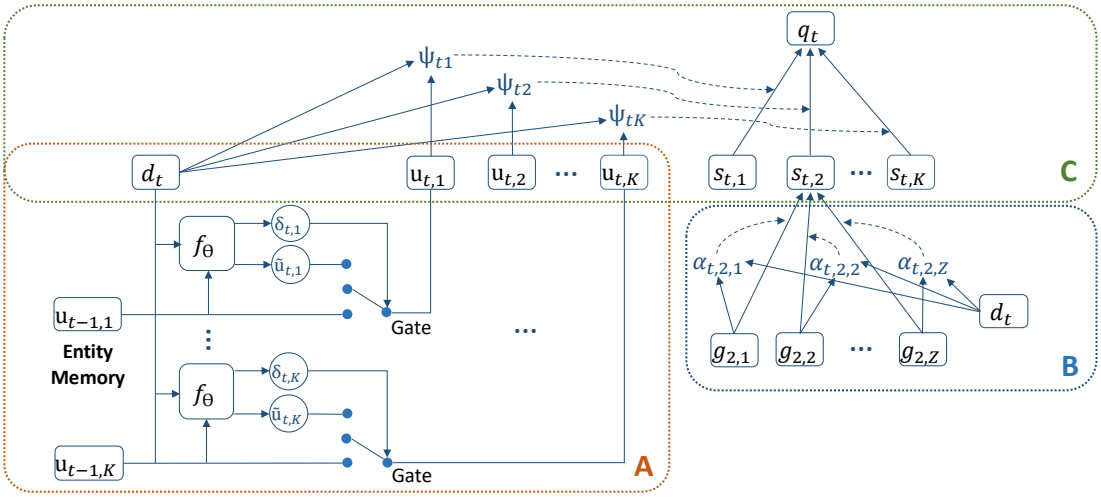

Figure 4.6: Diagram of entity memory network (block A) and hierarchical attention (blocks B and C). Module f_θ represents update equations (4.6)–(4.8) where θ is the set of trainable parameters. The gate represents the entity memory update (Equation (4.9)). Block B covers Equations (4.10) and (4.11), and block C Equations (4.12) and (4.13).

4.4 Entity Memory and Hierarchical Attention

We extend the basic model from Section 4.3 with entity memory and hierarchical attention. Figure 4.6 provides a schematic overview of our architecture.

4.4.1 Entity Memory

In order to render the model entity-aware, we compute $\mathbf{x}_k$ as an average of record representation for each unique entity k (i.e., one of $r_{j,2}$ values):

$$\mathbf{x}_k = \sum_j (\mathbb{1}[r_{j,2} = k]\mathbf{r}_j) / \sum_j \mathbb{1}[r_{j,2} = k] \tag{4.4}$$

where $\mathbb{1}[x] = 1$ if x is true, and 0 otherwise.

We initialize $\mathbf{u}_{t=-1,k}$, the memory representation of an entity at time $t = -1$, as:

$$\mathbf{u}_{t=-1,k} = \mathbf{W}_i \mathbf{x}_k \tag{4.5}$$

where $\mathbf{u}_{t=-1,k} \in \mathbb{R}^p$, p is the entity memory size and $\mathbf{W}_i \in \mathbb{R}^{p \times n}$.

To capture the fact that discourse in descriptive texts may shift from one entity to the next, e.g., some entities may be salient in the beginning of the game summary (see Brad Kelly in the text in Figure 4.1), others only towards the end (see Dozier in

Figure 4.1), and a few throughout (e.g., references to teams), we update entity representations at each time step during decoding. We use gate γ_t to indicate whether there should be an update in the entity representation:

$$\gamma_t = \sigma(\mathbf{W}_d \mathbf{d}_t + \mathbf{b}_d) \tag{4.6}$$

where $t >= 0$, σ is the sigmoid function, $\mathbf{W}_d \in \mathbb{R}^{p \times p}$, and $\mathbf{b}_d \in \mathbb{R}^p$.

We also compute $\delta_{t,k}$, the extent to which the entity representation should change, and $\tilde{\mathbf{u}}_{t,k}$, the memory of the candidate entity:

$$\delta_{t,k} = \gamma_t \odot \sigma(\mathbf{W}_e \mathbf{d}_t + \mathbf{b}_e + \mathbf{W}_f \mathbf{u}_{t-1,k} + \mathbf{b}_f) \tag{4.7}$$

$$\tilde{\mathbf{u}}_{t,k} = \mathbf{W}_g \mathbf{d}_t \tag{4.8}$$

where $\odot$ denotes element-wise multiplication, $\mathbf{W}_e, \in \mathbb{R}^{p \times n}$, $\mathbf{W}_f \in \mathbb{R}^{p \times p}$, $\mathbf{b}_e, \mathbf{b}_f \in \mathbb{R}^p$, and $\gamma_t, \delta_{t,k} \in [0,1]^p$ (see block A in Figure 4.6).

An element in gate γ_t will have value approaching 1 if an update in any $\mathbf{u}_{t-1,k}$ is required. The value of an element in gate $\delta_{t,k}$ will approach 1 if the corresponding value of the element in $\mathbf{u}_{t-1,k}$ changes. Equation (4.9) computes the update in entity memory as an interpolation over the gated representation of the previous value of the entity memory and the candidate entity memory:

$$\mathbf{u}_{t,k} = (1 - \delta_{t,k}) \odot \mathbf{u}_{t-1,k} + \delta_{t,k} \odot \tilde{\mathbf{u}}_{t,k} \tag{4.9}$$

where $\mathbf{u}_{t,k}$ represents entity k at time t.

Previous work (Henaff et al., 2017; Ji et al., 2017; Clark et al., 2018) employs a normalization term over $\mathbf{u}_{t,k}$. We empirically found that normalization hurts performance and hence did not include it in our model.

4.4.2 Hierarchical Attention

We hypothesize that our generator should first focus on entities (e.g., the main players and their teams) and then on the records corresponding to theses entities (e.g, player performance in the game). Our model implements this view of text generation via a hierarchical attention mechanism which we explain below. We also expect that focusing on entities first should improve the precision of the texts we generate as the entity distribution will constrain the probability distribution of records corresponding to each entity.

To better understand the hierarchical attention mechanism, we can view the encoder output $\mathbf{e}_j$ as a 2-dimensional array $\mathbf{g}_{k,z}$ where $k \in [1,K]$ represents entities and $z \in$

$[1,Z]$ represents records of entities and there is a one-to-one correspondence between positions j and k,z. We compute attention over $\mathbf{g}_{k,z}$, the encoder output, as:

$$\alpha_{t,k,z} \propto \exp(\mathbf{d}_t^\intercal \mathbf{W}_a \mathbf{g}_{k,z}) \tag{4.10}$$

where $\mathbf{W}_a \in \mathbb{R}^{n \times n}$, $\sum_z \alpha_{t,k,z} = 1$ (see block B in Figure 4.6). We compute the entity context as:

$$\mathbf{s}_{t,k} = \sum_z \alpha_{t,k,z} \mathbf{g}_{k,z} \tag{4.11}$$

while attention over entity vectors $\mathbf{u}_{t,k}$ is:

$$\Psi_{t,k} \propto \exp(\mathbf{d}_t^\intercal \mathbf{W}_h \mathbf{u}_{t,k}) \tag{4.12}$$

with $\mathbf{W}_h \in \mathbb{R}^{n \times p}$, $\sum_k \Psi_{t,k} = 1$. And the encoder context $\mathbf{q}_t$ (see block C in Figure 4.6) is computed as follows:

$$\mathbf{q}_t = \sum_k \Psi_{t,k} \mathbf{s}_{t,k} \tag{4.13}$$

We feed $\mathbf{q}_t$ into Equation (4.2) and compute $p_{gen}(y_t|y_{<t}, r)$, the probability of generating output text y conditioned on records r, as shown in Equation (4.3).

We experimented with feeding $\sum_k \Psi_{t,k} \mathbf{u}_{t,k}$ as input context along the lines of Clark et al. (2018); however, results on the development dataset degraded performance, and we did not pursue this approach further.

We note that in our decoder, we have a hierarchical attention over entity representations and the records corresponding to the entities. This attention over entity representations constitutes a (latent) entity plan if we consider the mode of the attention distributions.

4.5 Training and Inference

Our training objective maximizes the log likelihood of output text given an input table of records:

$$\max \sum_{(r,y) \in \mathcal{D}} \log p\,(y|r)$$

where $\mathcal{D}$ is the training set consisting of pairs of record tables and output game summaries. During inference, we make use of beam search to approximately obtain the best output $\hat{y}$ among candidate outputs y':

$$\hat{y} = \arg\max_{y'} p(y'|r)$$

4.6 Experimental Setup

Data We performed experiments on two datasets. The first one is ROTOWIRE (Wiseman et al., 2017) which contains NBA basketball game statistics matched with human-written summaries. In addition, we experiment with MLB dataset which contains baseball statistics and corresponding human-authored summaries obtained from the ESPN website.

Information Extraction For automatic evaluation, we make use of the Information Extraction (IE) approach proposed in Wiseman et al. (2017) and introduced in Chapter 2.

Training Configuration Model hyperparameters were tuned on the development set. We used the AdaGrad optimizer (Duchi et al., 2011) with an initial learning rate of 0.15, decayed by 0.97 for every epoch after the 4th epoch. We used truncated BPTT (Williams and Peng, 1990) of length 100 and made use of input feeding (Luong et al., 2015b). All models were implemented on a fork of OpenNMT-py (Klein et al., 2017a).

System Comparisons We compared our model with: (1) **TEMPL** is a template-based generator; we reused TEMPL from Wiseman et al. (2017) for ROTOWIRE and Chapter 3 for MLB. (2) **ED+CC** is the encoder-decoder model with conditional copy from Section 4.3 and the best performing system in Wiseman et al. (2017); (3) **NCP+CC** is the best performing system using micro planning; it generates content plans by making use of Pointer Networks (Vinyals et al., 2015) to point to the input e_j; the resultant content plans are then encoded using a BiLSTM followed by an LSTM decoder with an attention and copy mechanism.

4.7 Results

Automatic Evaluation We first discuss the results of automatic evaluation using the IE metrics defined in Wiseman et al. (2017) and introduced in Chapter 2. In addition, we also report BLEU (Papineni et al., 2002) with the gold summaries as reference.

Table 4.1 (top) summarizes our results on the ROTOWIRE test set. We report results for our latent entity planning model (ENT), the best system of Wiseman et al. (2017)

RW	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
TEMPL	**54.23**	**99.94**	26.99	**58.16**	14.92	8.46
WS-2017	23.72	74.80	29.49	36.18	15.42	14.19
NCP+CC	34.28	87.47	34.18	51.22	18.58	**16.50**
ENT	30.11	92.69	**38.64**	48.51	**20.17**	16.12

MLB	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
TEMPL	**59.93**	**97.96**	22.82	**68.46**	10.64	3.81
ED+CC	18.69	92.19	**62.01**	50.12	25.44	9.69
NCP+CC	17.93	88.11	60.48	55.13	**26.71**	9.68
ENT	21.35	88.29	58.35	61.14	24.51	**11.51**

Table 4.1: Evaluation on ROTOWIRE (RW) and MLB test sets using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%) and recall (R%), content ordering (CO) in complement of normalized Damerau-Levenshtein distance (DLD%), and BLEU.

(WS-2017) which is an encoder-decoder model with conditional copy, and NCP+CC. We see that ENT achieves scores comparable to NCP+CC, but performs better on the metrics of RG precision, CS precision, and CO. ENT achieves substantially higher scores in CS precision compared to WS-2017 and NCP+CC; CS recall is worse for ENT compared to NCP+CC mainly because the latter model is trained to first create an explicit micro plan with good coverage of what to say.

Table 4.1 (bottom) also presents our results on MLB (test set). Note that ED+CC is a reimplementation of Wiseman et al.'s (2017) encoder-decoder model (with conditional copy) on MLB. We see that ENT achieves highest BLEU amongst all models and highest CS recall and RG count amongst neural models. The RG precision of ENT is lower than ED+CC. Inspection of model output revealed that on MLB, ED+CC tends to focus on one or two players getting most of the facts about them right, whereas ENT sometimes gets the coreference wrong, and thus lower RG precision. The TEMPL system scores highest on RG precision and count, and CS recall on both datasets. This is because TEMPL can make use of domain knowledge which is not available to the neural models. TEMPL performs poorly on MLB in terms of BLEU, in fact it is considerably worse compared to the similar template system on ROTOWIRE (see

RW	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
ED+CC	22.68	79.40	29.96	34.11	16.00	14.00
+Hier	30.76	93.02	33.99	44.79	19.03	14.19
+Dyn	27.93	90.85	34.19	42.27	18.47	15.40
+Gate	31.84	91.97	36.65	48.18	19.68	15.97

MLB	RG		CS		CO	BLEU
	#	P%	P%	R%	DLD%	
ED+CC	18.69	92.65	62.29	51.36	25.93	9.55
+Hier	19.02	93.71	62.84	52.12	25.72	10.38
+Dyn	20.28	89.19	58.19	58.94	24.49	10.85
+Gate	21.32	88.16	57.36	61.50	24.87	11.13

Table 4.2: Ablation results on ROTOWIRE (RW) and MLB development set using relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%) and recall (R%), content ordering (CO) in normalized Damerau-Levenshtein distance (DLD%), and BLEU.

Table 4.1). This suggests that the task of creating MLB game summaries is hard, even for a template system which does not perform any sophisticated generation.

Ablation Experiments We further examined how individual model components contribute to the quality of the generated summaries. To assess the impact of hierarchical attention (Section 4.4.2) over ED+CC, we report the performance of a stripped-down variant of our model without dynamic entity memory. Specifically, the entity memory was kept static and set to $\mathbf{u}_{t=-1,k}$ (see Equation (4.5)). In this model, attention over entity vectors is:

$$\Psi_{t,k} \propto \exp(\mathbf{d}_t^{\intercal} \mathbf{W}_h \mathbf{u}_{t=-1,k}) \tag{4.14}$$

We next examined the contribution of dynamic memory, by adding it to this model without the gate γ_t (i.e., we set γ_t to one) and Equation (4.7) then becomes:

$$\delta_{t,k} = \sigma(\mathbf{W}_e \mathbf{d}_t + \mathbf{b}_e + \mathbf{W}_f \mathbf{u}_{t-1,k} + \mathbf{b}_f) \tag{4.15}$$

Finally, we obtain our final ENT model, by incorporating the update gate mechanism.

The results of the ablation study are shown in Table 4.2. We compare ED+CC against variants "+Hier", "+Dyn" and "+Gate" corresponding to successively adding

The **Houston Rockets** (18–5) defeated the **Denver Nuggets** (10–13) 108–96 on Tuesday at the Toyota Center in Houston. The **Rockets** had a strong first half where they out–scored … The **Rockets** were led by **Donatas Motiejunas**, who scored a game–high of 25 points … **James Harden** also played a factor in the win, as he went 7–for … Coming off the bench, **Donatas Motiejunas** had a big game and finished with 25 points … The only other player to reach double figures in points was **Arron Afflalo**, who came off the bench for 12 points … Coming off the bench, **Arron Afflalo** chipped in with 12 points … The **Nuggets**' next game will be on the road against the Boston Celtics on Friday, while the **Nuggets** will travel to Boston to play the Celtics on Wednesday.
The **Houston Rockets** (18–5) defeated the **Denver Nuggets** (10–13) 108–96 on Monday at the Toyota Center in Houston. The **Rockets** were the superior shooters in this game, going … The **Rockets** were led by the duo of **Dwight Howard** and **James Harden**. **Howard** shot 9–for–11 from the field and … **Harden** on the other hand recorded 24 points (7–20 FG, 2–5 3Pt, 8–9 FT), 10 rebounds and 10 assists, The only other Nugget to reach double figures in points was **Arron Afflalo**, who finished with 12 points (4–17 FG,… The **Rockets**' next game will be on the road against the New Orleans Pelicans on Wednesday, while the **Nuggets** will travel to Los Angeles to play the Clippers on Friday.

Table 4.3: Examples of model output for NCP+CC (top) and ENT (bottom) on ROTOWIRE. Recurring entities in the summaries are boldfaced and colorcoded, singletons are shown in black.

hierarchical attention, dynamic memory, and the update gate mechanism. On both datasets, hierarchical attention, improves relation generation, content selection, and BLEU. Dynamic memory and the update gate brings further improvements to content selection and BLEU.

Because it conditions on entities, ENT is able to produce text displaying nominal coreference which is absent from the outputs of ED+CC and WS-2017. We present an example in Table 4.3 where entities *Dwight Howard* and *James Harden* are introduced and then later referred to as *Howard* and *Harden*. We also see that while generating the last sentence about the next game, ENT is able to switch the focus of attention from one team (*Rockets*) to the other (*Nuggets*), while NCP+CC verbalises *Nuggets* twice.

Human-Based Evaluation As detailed in Chapter 2, we also evaluated our model by asking humans to rate its output in terms of relation generation, coherence, grammaticality, and conciseness. For ROTOWIRE, we compared ENT against NCP+CC, Gold, and TEMPL. We did not compare against WS-2017 or ED+CC, since we have seen in previous chapter that NCP+CC is superior to these models in terms of automatic and human-based evaluation. For MLB, we compared ENT against NCP+CC, ED+CC, Gold, and TEMPL.

ROTOWIRE	#Supp	#Contra	Gram	Coher	Concis
Gold	2.98*	0.28*	4.07*	3.33	-10.74*
TEMPL	6.98*	0.21*	-3.70*	-3.33*	17.78*
NCP+CC	4.90	0.90	-3.33*	-3.70*	-3.70
ENT	4.77	0.80	2.96	3.70	-3.33

MLB	#Supp	#Contra	Gram	Coher	Concis
Gold	2.81	0.15*	1.24*	3.48*	-9.33*
TEMPL	3.98*	0.04*	-10.67*	-7.30*	8.43*
ED+CC	3.24*	0.40	0.22*	-0.90*	-2.47*
NCP+CC	2.86	0.88*	0.90*	-1.35*	-1.80*
ENT	2.86	0.52	8.31	6.07	5.39

Table 4.4: Average number of supporting and contradicting facts in game summaries and *best-worst scaling* evaluation (higher is better) on ROTOWIRE and MLB datasets. Systems significantly different from ENT are marked with an asterisk * (using a one-way ANOVA with posthoc Tukey HSD tests; $p \leq 0.05$).

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In the first study, participants were presented with sentences randomly selected from the game summary (test set) together with corresponding box and line score tables and were asked to count supporting and contradicting facts in these sentences. We did not require crowdworkers to be familiar with NBA or MLB. Instead, we provided a cheat sheet explaining the semantics of box score tables. In addition, we provided examples of sentences with supported/contradicting facts. We evaluated 30 summaries and 4 sentences per summary for each of ROTOWIRE and MLB. We elicited 5 responses per summary. Altogether 137 crowdworkers participated in this study.

As shown in Table 4.4, on ROTOWIRE, ENT yields a comparable number of supporting and contradicting facts to NCP+CC (the difference is not statistically significant). TEMPL has the highest number of supporting facts, even relative to gold summaries, and very few contradicting facts. This is expected as TEMPL output is mostly factual, it essentially parrots statistics from the tables. On MLB, ENT yields a number of supporting facts comparable to Gold and NCP+CC, but significantly lower than ED+CC and TEMPL. Contradicting facts are significantly lower for ENT compared to NCP+CC, but comparable to ED+CC and higher than TEMPL and Gold.

We also evaluated the quality of the generated summaries. For this task, we re-

quired that the crowdworkers be able to comfortably comprehend NBA/ MLB game summaries. We presented participants with two summaries at a time and asked them to choose which one is better in terms of *Grammaticality*, *Coherence*, and *Conciseness*. We divided the four competing systems (Gold, TEMPL, NCP+CC, and ENT) into six pairs of summaries for ROTOWIRE and the five competing systems (Gold, TEMPL, ED+CC, NCP+CC, and ENT) into ten pairs for MLB. We elicited judgments for 30 test summaries for ROTOWIRE and MLB; each summary was rated by 3 participants. Altogether 145 crowdworkers participated in this study.

As shown in Table 4.4, on ROTOWIRE Gold receives highest scores in terms of Grammaticality, which is not unexpected. ENT comes close, achieving better scores than NCP+CC and TEMPL, even though our model only enhances the coherence of the output. Participants find ENT on par with Gold on Coherence and better than NCP+CC and TEMPL whose output is stilted and exhibits no variability. In terms of Conciseness, TEMPL is rated best, which is expected since it does not contain any duplication, the presented facts are mutually exclusive; ENT is comparable to NCP+CC and better than Gold.

As far as MLB is concerned, ENT achieves highest scores on Grammaticality and Coherence. It is rated high on Conciseness also, second only to TEMPL whose scores are lowest on Grammaticality and Coherence. Perhaps surprisingly, Gold is rated lower than ENT on all three metrics; we hypothesize that participants find Gold's output too verbose compared to the other systems. Recall that MLB gold summaries are relatively long, the average length is 542 tokens compared to ROTOWIRE whose summaries are almost half as long (see Table 2.8). The average length of output summaries for ENT is 327 tokens.

Taken together, our results show that ENT performs better than comparison systems on both ROTOWIRE and MLB.

4.8 Qualitative Examples

Table 4.5 contain examples of model outputs for ROTOWIRE, and Table 4.6 contains model outputs for MLB. Because it conditions on entities, ENT is able to produce text displaying nominal coreference compared to other models.

Template
The **Atlanta Hawks** (44 - 30) defeated the **Detroit Pistons** (39 - 35) 112 - 95 . **Paul Millsap** scored 23 points (8 - 13 FG , 3 - 4 3PT , 4 - 5 FT) to go with 9 rebounds . **Tobias Harris** scored 21 points (10 - 20 FG , 1 - 3 3PT , 0 - 0 FT) to go with 10 rebounds . **Andre Drummond** scored 19 points (7 - 11 FG , 0 - 0 3PT , 5 - 9 FT) to go with 17 rebounds . **Kent Bazemore** scored 17 points (7 - 9 FG , 3 - 5 3PT , 0 - 0 FT) to go with 4 rebounds . **Aron Baynes** scored 15 points (5 - 6 FG , 0 - 0 3PT , 5 - 6 FT) to go with 7 rebounds . **Al Horford** scored 13 points (6 - 15 FG , 1 - 5 3PT , 0 - 0 FT) to go with 5 rebounds . The **Atlanta Hawks** ' next game will be at home against the Dallas Mavericks, while the **Detroit Pistons** will travel to play the Bulls .
ENT
The **Atlanta Hawks** (44 - 30) defeated the **Detroit Pistons** (39 - 35) 112 - 95 on Monday at the Palace of Auburn Hills . The **Hawks** got off to a quick start in this one , out - scoring the **Pistons** 27 - 15 in the first quarter alone . The **Hawks** were the superior shooters in this game , going 45 percent from the field and 38 percent from the three - point line , while the **Pistons** went 39 percent from the floor and just 24 percent from beyond the arc . The **Hawks** were led by the duo of **Paul Millsap** and **Andre Drummond** . **Millsap** finished with 23 points (8 - 13 FG , 3 - 4 3Pt , 4 - 5 FT) , nine rebounds and four blocked shots , while **Drummond** had 19 points (7 - 11 FG , 5 - 9 FT) , 17 rebounds and two blocked shots . It was his second double - double in a row , as he 's combined for 45 points and 19 rebounds over his last two games . He 's now averaging 15 points and 7 rebounds on the season . **Jeff Teague** was the other starter to reach double figures in points , as he finished with 12 points (3 - 13 FG , 2 - 3 3Pt , 4 - 4 FT) and 12 assists . The **Hawks** ' next game will be at home against the Cleveland Cavaliers on Friday , while the **Pistons** will travel to Los Angeles to play the Clippers on Friday .

Table 4.5: Example game summaries from the template-based system and our ENT model for ROTOWIRE. Recurring entities in the summaries are boldfaced and color-coded, singletons are shown in black.

Template
The **Tampa Bay Rays** defeated the **Oakland Athletics** 13 - 4 . **Jason Isringhausen** (0 - 0) allowed 0 runs , 1 hits and 0 walks in 1 innings . **Jeff Niemann** (4 - 3) allowed 4 runs , 8 hits and 0 walks in 8 innings . **Sean Gallagher** (1 - 2) allowed 9 runs , 3 hits and 5 walks in 2 1/3 innings . **Kevin Cameron** (0 - 0) allowed 0 runs , 0 hits and 1 walks in 2 innings . **Gio Gonzalez** (0 - 0) allowed 4 runs , 6 hits and 3 walks in 3 2/3 innings . **Jason Bartlett** hit 2 RBI single in the first . **Orlando Cabrera** hit 1 RBI homer in the third Athletics . **Akinori Iwamura** hit 2 RBI single in the third . **Jason Bartlett** hit 1 RBI triple in the fifth . **Akinori Iwamura** hit 1 RBI single in the fifth . **Jason Bartlett** hit 2 RBI single in the sixth . **Jack Cust** hit 2 RBI homer in the eighth Athletics .
ENT
ST. PETERSBURG , Fla. - - **Jason Bartlett** and the **Tampa Bay Rays** finally found a way to beat the **Oakland Athletics** . **Bartlett** had a career - high five RBIs , **Jeff Niemann** pitched eight strong innings and the **Rays** beat the **Oakland Athletics** 13 - 4 on Tuesday night . **Bartlett** had a two - run single in the first and added a two - run single in the third to help the **Rays** take a 6 - 1 lead . **Bartlett** had a two - run single in the third and a two - run single in the sixth . **Jack Cust** hit a two - run homer in the eighth for the **A 's** , who have won five of six . The **A 's** scored six runs off **Sean Gallagher** (1 - 2) , who gave up a career - high nine runs - - seven earned - - and three hits in 2 1/3 innings . **Niemann** (4 - 3) gave up four runs , three earned , and eight hits in eight innings . The right - hander struck out three and did not walk a batter for the second time this season . The right - hander is 4 - 0 in six career starts against the **A 's** . **Orlando Cabrera** hit a solo homer in the third for the **A 's** , who have lost four of five . Oakland starter **Gio Gonzalez** gave up four runs and six hits in 3 2/3 innings . The right - hander struck out six and walked three . The right - hander was coming off a 1 - 0 loss to the **A 's** in his previous start , when he gave up six runs in 4 1/3 innings of a 10 - 0 loss to the **A 's** . The **A 's** took a 1 - 0 lead in the first when **Ben Zobrist** drew a bases - loaded walk and **Bartlett** had a two - run single .

Table 4.6: Example game summaries from the template-based system and our ENT model for MLB. Recurring entities in the summaries are boldfaced and colorcoded, singletons are shown in black.

ST. PETERSBURG , Fla. - - Jason Bartlett and the Tampa Bay Rays finally found a way to beat the Oakland Athletics . Bartlett had a career - high five RBIs , Jeff Niemann pitched eight strong innings and the Rays beat the Oakland Athletics 13 - 4 on Tuesday night . Bartlett had a two - run single in the **first** and added a two - run single in the **third** to help the Rays take a 6 - 1 lead . Bartlett had a two - run single in the **third** and a two - run single in the **sixth** . Jack Cust hit a two - run homer in the **eighth** for the A 's , who have won five of six . The A 's scored six runs off Sean Gallagher (1 - 2) , who gave up a career - high nine runs - - seven earned - - and three hits in 2 1/3 innings . Niemann (4 - 3) gave up four runs , three earned , and eight hits in eight innings . The right - hander struck out three and did not walk a batter for the second time this season . The right - hander is 4 - 0 in six career starts against the A 's . Orlando Cabrera hit a solo homer in the **third** for the A 's , who have lost four of five . Oakland starter Gio Gonzalez gave up four runs and six hits in 3 2/3 innings . The right - hander struck out six and walked three . The right - hander was coming off a 1 - 0 loss to the A 's in his previous start , when he gave up six runs in 4 1/3 innings of a 10 - 0 loss to the A 's . The A 's took a 1 - 0 lead in the **first** when Ben Zobrist drew a bases - loaded walk and Bartlett had a two - run single .

Table 4.7: Example game summary of ENT model for MLB. The example is the same as that of Table 4.6 but with events highlighted. We see that the ordering of events exhibits low coherence.

4.9 Summary

In this chapter, we presented a latent entity planning neural model for data-to-text generation, which creates entity-specific representations (that are dynamically updated) and generates text using hierarchical attention over the input table and entity memory. Extensive automatic and human evaluation on two benchmarks, ROTOWIRE and MLB, show that our model outperforms competitive baselines and manages to generate plausible output which humans find coherent, concise, and factually correct.

The work presented in this chapter, however, does not handle events in the MLB dataset. Table 4.7 shows an output of ENT for the MLB dataset. The events are highlighted in the example with bold font. We find that the ordering of events exhibits low coherence. Events are salient constituents of the MLB dataset, and we realize that without special provisions for handling events, the results will be deficient. In addition, while this work provides for latent chaining of entities during decoding, it will be beneficial to have a planning process that handles both entities *and* events.

In the next chapter, we study macro planning, where we first plan a coarse-grained or macro plan, followed by text generation. The macro plan comprises a sequence of paragraph plans, where each paragraph plan describes the entities or events to be discussed in the corresponding output paragraph.

Chapter 5

Macro Planning

In Chapter 3, we have seen how micro planning can benefit text generation. Micro planning involves a two stage approach of first predicting a fine-grained content plan, followed by text generation. We have seen that micro planning works well for the ROTOWIRE dataset but not for the MLB dataset. The primary reason for this is micro planning requires oracle micro plans during training, which necessitates an Information Extraction (IE) model with high coverage and precision. Such Information Extraction is easier to run on datasets such as ROTOWIRE, as the entities along with the values can be detected with simple pattern matching. In the case of MLB, as discussed in Chapter 4, the IE has lower precision and coverage, as the entity and value pairs cannot be easily detected with simple pattern matching. Consequently, supervision for oracle micro plans is difficult to obtain for MLB. One approach might be to forego IE altogether following the latent entity planning approach proposed in Chapter 4 which focuses on entities and how they are organized throughout the document, and achieves better results than micro planning. Unfortunately, it does not handle events in the MLB dataset.

In this chapter, we propose *macro planning*, which combines planning with the high level organization of entities *and* events.

5.1 Motivation

We focus on macro planning, the high-level organization of information and how it should be presented which we argue is important for the generation of long, multi-paragraph documents (see text (C) in Figure 5.1 which is an example from MLB dataset).

(A)

TEAM	Inn1	Inn2	Inn3	Inn4	…	TR	TH	E	…
Orioles	1	0	0	0	…	2	4	0	…
Royals	1	0	0	3	…	9	14	1	…

BATTER	H/V	AB	BR	BH	RBI	TEAM	…
C.Mullins	H	4	2	2	1	Orioles	…
J.Villar	H	4	0	0	0	Orioles	…
W.Merrifield	V	2	3	2	1	Royals	…
R.O'Hearn	V	5	1	3	4	Royals	…
…	…	…	…	…	…	…	

PITCHER	H/V	W	L	IP	PH	PR	ER	BB	K	…
A.Cashner	H	4	13	5.1	9	4	4	3	1	…
B.Keller	V	7	5	8.0	4	2	2	2	4	…
…	…	…	…	…	…	…	…	…		

Inn1: runs in innings, TR: team runs, TH: team hits, E: errors, AB: at-bats, RBI: runs-batted-in, BR: batter runs, BH: batter hits, H/V: home or visiting, W: wins, L: losses, IP: innings pitched, PH: hits given, PR: runs given, ER: earned runs, BB: walks, K: strike outs, INN: inning with (T)op/(B)ottom, PL-ID: play id.

(C)

KANSAS CITY, Mo. – Brad Keller kept up his recent pitching surge with another strong outing. <P> Keller gave up a home run to the first batter of the game – Cedric Mullins – but quickly settled in to pitch eight strong innings in the Kansas City Royals' 9–2 win over the Baltimore Orioles in a matchup of the teams with the worst records in the majors. <P> Keller (7–5) gave up two runs and four hits with two walks and four strikeouts to improve to 3–0 with a 2.16 ERA in his last four starts. <P> Ryan O'Hearn homered among his three hits and drove in four runs, Whit Merrifield scored three runs, and Hunter Dozier and Cam Gallagher also went deep to help the Royals win for the fifth time in six games on their current homestand. <P> With the score tied 1–1 in the fourth, Andrew Cashner (4–13) gave up a sacrifice fly to Merrifield after loading the bases on two walks and a single. Dozier led off the fifth inning with a 423-foot home run to left field to make it 3-1. <P> The Orioles pulled within a run in the sixth when Mullins led off with a double just beyond the reach of Dozier at third, advanced to third on a fly ball and scored on Trey Mancini's sacrifice fly to the wall in right. <P> …

(B)

BATTER	PITCHER	SCORER	ACTION	TEAM	INN	PL-ID	SCORE	…
C.Mullins	B.Keller	-	Home run	Orioles	1-T	1	1	…
H.Dozier	A.Cashner	W.Merrifield	Grounded	Royals	1-B	3	1	…
W.Merrifield	A.Cashner	B.Goodwin	Sac fly	Royals	4-B	5	2	…
H.Dozier	A.Cashner	-	Home run	Royals	5-B	1	3	…
…	…	…	…	…	…	…	…	…

(D)

```
V(B.Keller)<P>V(B.Keller) V(C.Mullins) V(Royals) V(Orioles)<P>V(B.Keller)<P>
V(R.O'Hearn) V(W.Merrifield) V(H.Dozier) V(C.Gallagher) <P>V(4-B, 5-B) <P>
V(6-T)<P>
```

Figure 5.1: MLB statistics tables and game summary. Tables summarize the performance of teams and individual team members who played as batters and pitchers as well as the most important actions (and their actors) in each play (Tables (A) and (B)). Macro plan for the game summary is shown at the bottom (Table (D)). <P> indicates paragraph delimiters. There is a plan for every paragraph in the game summary (correspondence shown in same color). ; <V(entity)> verbalizes entities, while <V(inning-T/B)> verbalizes events related to the top/bottom side of an inning (explained in Section 5.3.1).

Problematically, modern datasets like MLB and ROTOWIRE (Wiseman et al., 2017) do not naturally lend themselves to document planning as there is no explicit link between the summary and the content of the game (which is encoded in tabular form).

V(Orioles), V(Royals),	V(Royals) V(Orioles), V(Orioles)
V(C.Mullins), V(J.Villar),	V(C.Mullins), V(Orioles) V(J.Villar),
V(R.O'Hearn), V(A.Cashner),	V(Royals) V(W.Merrifield), V(Royals)
V(B.Keller), V(H.Dozier),	V(R.O'Hearn), V(Orioles) V(A.Cashner),
V(W.Merrifield), ...,	V(Royals) V(B.Keller), ...,
V(1-T), V(1-B), V(2-T),	V(C.Mullins) V(Royals) V(Orioles),
V(2-B), V(3-T), V(3-B), ...	V(J.Villar) V(Royals) V(Orioles), ...

Figure 5.2: The set of candidate paragraph plans are grouped into two types: plans describing a single entity/event or their combinations.

In other words, the underlying plans are *latent*, and it is not clear how they might be best represented, i.e., as sequences of records from a table, or simply words. Nevertheless, game summaries through their segmentation into paragraphs (and lexical overlap with the input) give clues as to how content might be organized. Paragraphs are a central element of discourse (Chafe, 1979; Longacre, 1979; Halliday and Hasan, 1976), the smallest domain where coherence and topic are defined and anaphora resolution is possible (Zadrozny and Jensen, 1991). We therefore operationalize the macro plan for a game summary as a *sequence* of *paragraph* plans.

Although resorting to paragraphs describes the summary plan at a coarse level, we still need to specify individual paragraph plans. In the sports domain, paragraphs typically mention entities (e.g, players important in the game), key events (e.g., scoring a run), and their interaction. And most of this information is encapsulated in the statistics accompanying game summaries (see Tables (A) and (B) in Figure 5.1). We thus define paragraph plans such that they contain verbalizations of entity and event records (see plan (D) in Figure 5.1). Given a *set* of paragraph plans and their corresponding game summary (see Figure 5.2 and summary (C) in Figure 5.1), our task is twofold. At training time, we must *learn* how content was selected in order to give rise to specific game summaries (e.g., how input Figure 5.2 led to plan (D) for summary (C) in Figure 5.1), while at test time, given input for a new game, we must first predict a macro plan for the summary and then generate the corresponding document.

We present a two-stage approach where macro plans are induced from training data (by taking the table and corresponding summaries into account) and then fed to the text generation stage. Aside from making data-to-text generation more interpretable, the task of generating a document from a macro plan (rather than a table) affords greater control over the output text and plays to the advantage of encoder-decoder architec-

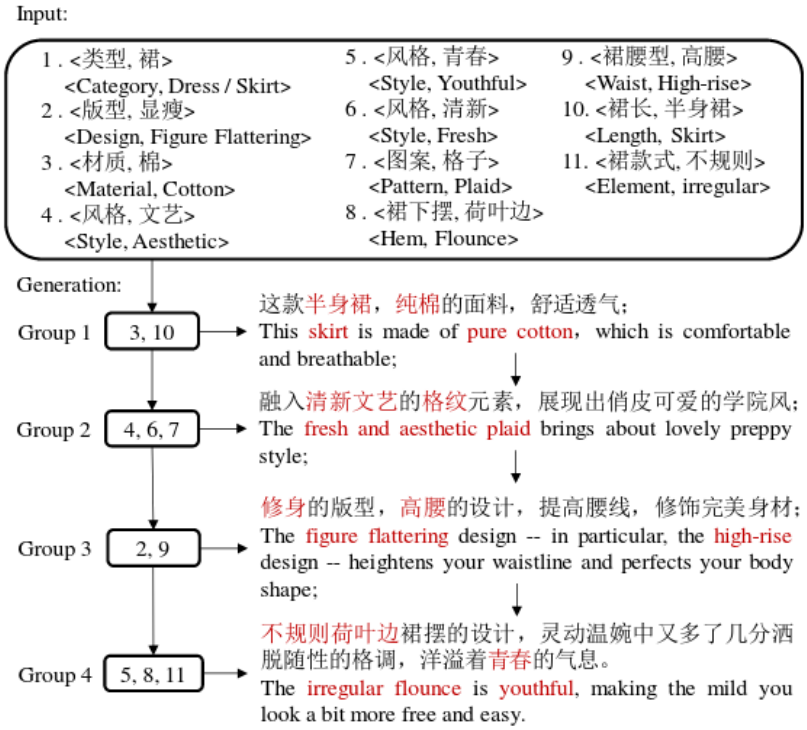

Figure 5.3: Example from Planning-based Hierarchical Variational Model (Shao et al., 2019). The input is a set of attribute-value pairs. The model predicts a plan comprising a sequence of units, with each unit containing a subset of attribute-value pairs. Next, each sentence is generated from its corresponding unit and the previously generated sentences.

tures which excel at modeling sequences. We evaluate model performance on the ROTOWIRE (Wiseman et al., 2017) and MLB benchmarks. Experimental results show that our plan-and-generate approach produces output which is more factual, coherent, and fluent compared to existing state-of-the-art models.

5.2 Related Work

Recently, various attempts have been made to improve neural generation models (Wiseman et al., 2017) based on the encoder-decoder architecture (Bahdanau et al., 2015) by adding various planning modules. Shao et al. (2019) introduce a Planning-based Hierarchical Variational Model. The input to their task is a set of attribute-value pairs (example in Figure 5.3). They predict a content plan comprising a sequence of units, where each unit contains a subset of attribute-value pairs to be covered in a sentence.

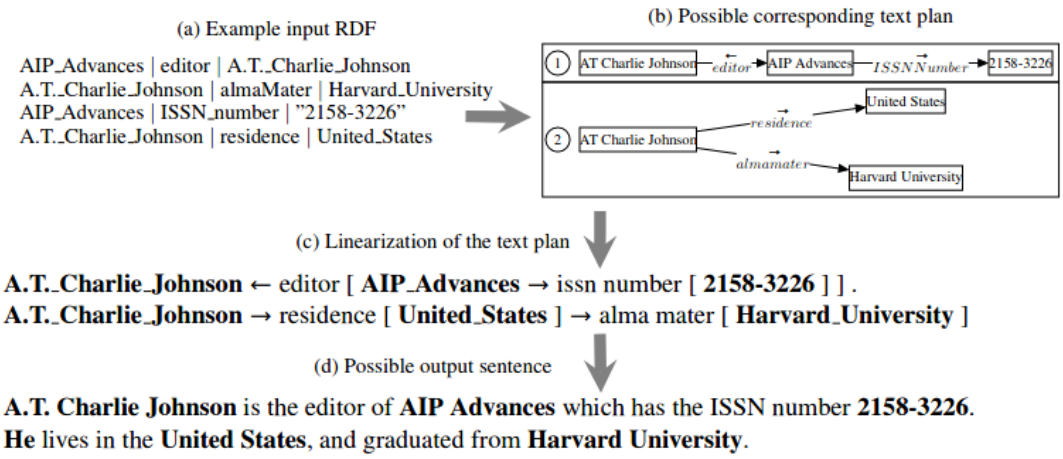

Figure 5.4: Example from Moryossef et al. (2019). The input is set of RDF ⟨ Subject, Object, Predicate ⟩ triples. A document plan is viewed as a sequence of sentence plans. Each sentence plan is a subset of tuples in a specific order. Sentence plans are realized separately into sentences, followed by a postprocessing step which generates referring expressions.

A sentence is generated conditioned on the plan unit, and the previously generated sentences. In their case, input items are a relatively small list of attribute-value pairs (~28) and the output document is also short (~110 words).

There have also been attempts to incorporate neural modules in a pipeline architecture for data-to-text generation. Moryossef et al. (2019) develop a model with a symbolic text planning stage followed by a neural realization stage (example from their paper in Figure 5.4). They experiment with the WebNLG dataset (Gardent et al., 2017) which consists of RDF ⟨ Subject, Object, Predicate ⟩ triples paired with corresponding text. Their document plan is a sequence of sentence plans which in turn determine the division of facts into sentences and their order. Along similar lines, Castro Ferreira et al. (2019) propose an architecture comprising multiple steps including ordering the tuples, organizing tuples into sentences, lexicalization, referring expression generation, and surface realization. They evaluate their model also on the WebNLG dataset. Both approaches show the effectiveness of pipeline architectures, however, their task does not require content selection and the output texts are relatively short (24 tokens on average).

Although it is generally assumed that task-specific parallel data is available for model training, Laha et al. (2019) do away with this assumption and present a three-stage pipeline model which learns from monolingual corpora. They first convert the

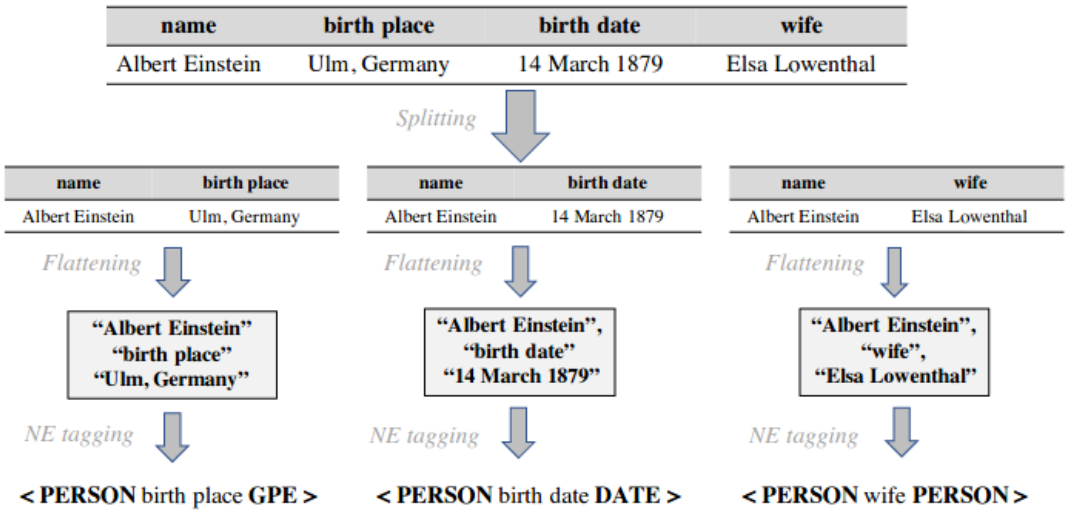

Figure 5.5: In Laha et al. (2019), the input table is first converted to a set of tuples.

input to a form of tuples (example in Figure 5.5), which in turn are expressed in simple sentences (Table 5.1 (top)), followed by the third stage of merging simple sentences to form more complex ones by aggregation and referring expression generation (Table 5.1 (bottom)). They also evaluate on data-to-text tasks which have relatively short outputs (26 tokens on average).

Our work also attempts to alleviate deficiencies in neural data-to-text generation models. In contrast to previous approaches (Moryossef et al., 2019; Laha et al., 2019), we place emphasis on *macro planning* and create plans representing high-level organization of a document including both its content *and* structure. We share with previous work (e.g., Moryossef et al. 2019) the use of a two-stage architecture. We show that macro planning can be successfully applied to *long* document data-to-text generation resulting in improved factuality, coherence, and fluency without any postprocessing (e.g., to smooth referring expressions) or recourse to additional tools (e.g., parsing or information extraction).

5.3 Problem Formulation

We hypothesize that generation based on plans should fare better compared to generating from a set of records, since macro plans offer a bird's-eye view, a high-level organization of the document content and structure. We also believe that macro planning will work well for long-form text generation, i.e., for datasets which have multi-paragraph

Input	Output
⟨ PERSON birth place GPE ⟩	⟨ PERSON was born in GPE ⟩
⟨ PERSON birth date DATE ⟩	⟨ PERSON has birthday on DATE ⟩
⟨ PERSON wife PERSON ⟩	⟨ PERSON is the wife of PERSON ⟩

Operation	Input	Output
Aggregation	Albert Einstein was born in Ulm, GermanyAlbert. Einstein has birthday on 14 March 1879.	Albert Einstein was born in Ulm, Germany and has birthday on 14 March 1879.
Referring expression generation	Albert Einstein was born in Ulm, Germany and has birthday on 14 March 1879. Elsa Lowenthal is the wife of Albert Einstein.	Albert Einstein was born in Ulm, Germany and has birthday on 14 March 1879. Elsa Lowenthal is the wife of him.

Table 5.1: In the second stage in Laha et al. (2019) (top table), the tuples are converted to simple sentences. In the third stage (below table), individual sentences are converted to more complex ones by aggregation (first row) and referring expression generation (second row).

target texts, a large vocabulary space, and require content selection.

We assume the input to our model is a set of paragraph plans $\mathcal{E} = \{e_i\}_{i=1}^{|\mathcal{E}|}$ where e_i is a paragraph plan. We model the process of generating output summary y given $\mathcal{E}$ as a two step process, namely the construction of a macro plan x based on the set of paragraph plans, followed by the generation of a summary given a macro plan as input. We now explain how the set $\mathcal{E}$ is obtained and each step is realized. We discuss our model considering mainly an example from the MLB dataset but also touch on how the approach can be straightforwardly adapted to ROTOWIRE (Wiseman et al., 2017).

5.3.1 Macro Plan Definition

A macro plan consists of a sequence of paragraph plans separated by a paragraph discourse marker <P>, i.e., $x = e_1$ <P> $e_2 \ldots$ <P> e_k where $e_1, e_2, e_k \in \mathcal{E}$. A paragraph plan e_i in turn is a sequence of entities and events describing the game. By *entities* we mean individual players or teams and the information provided about them in box score statistics (see rows and column headings in Figure 5.1 Table (A)), while *events* refer to information described in play-by-play (see Table (B)). In baseball, plays are grouped

in half-innings. During each half of an inning, a team takes its turn to bat (the visiting team bats in the top half and the home team in the bottom half). An example macro plan is shown at the bottom of Figure 5.1. Within a paragraph plan, entities and events are verbalized into a *text sequence* along the lines of Saleh et al. (2019). We make use of special tokens for the <TYPE> of record followed by the value of record from the table. We retain the same position for each record type and value. For example, batter *C.Mullins* from Figure 5.1 would be verbalized as <PLAYER>C.Mullins <AB>4
2 <BH>2 <RBI>1 <TEAM>Orioles <POS>CF <AVG>.317 <PUTOUT>6. For the sake of brevity we use shorthand <V(C.Mullins)> for the full entity.

Paragraph Plan for Entities For a paragraph containing entities, the corresponding plan will be a verbalization of the entities in sequence. For paragraphs with multiple mentions of the same entity, the plan will verbalize an entity only once and at its first position of mention. Paragraph "*Keller gave up a home run ... the teams with the worst records in the majors*" from the summary in Figure 5.1 describes four entities including *B. Keller*, *C. Mullins*, *Royals* and *Orioles*. The respective plan is the verbalization of the four entities in sequence: <V(B.Keller)> <V(C.Mullins)> <V(Royals)> <V(Orioles)>, where V stands for verbalization and <V(B. Keller)> is a shorthand for <PLAYER>B.Keller <W>7 <L>5 <IP>8 <POS>P
0 <BH>0 <RBI>0 <AB>0 <AST>2 <PH>4 <PR>2 <ER>2 <BB>2 <K>4 <HRA>1 <NP>114 <PK>74 <ERA>3.26 <WINNING-PITCHER>true <BF>30 <OUTS>24 <BS>2, <V(Royals)> is a shorthand for the team <TEAM>Royals <TR>9 <TH>14 <E>1, and so on.

Paragraph Plan for Events A paragraph may also describe one or more events. For example, the paragraph "*With the score tied 1–1 in the fourth ... 423-foot home run to left field to make it 3-1*" discusses what happened in the bottom halves of the *fourth* and *fifth* innings. We verbalize an event by first describing the participating entities followed by the plays in the event. Entities are described in the order in which they appear in a play, and within the same play we list the batter followed by the pitcher, fielder, scorer, and basemen. The paragraph plan corresponding to the bottom halves of the *fourth* and *fifth* inning is <V(4-B, 5-B)>. Here, <V(4-B, 5-B)> is a shorthand for <V(W.Merrifield)> <V(A.Cashner)> <V(B.Goodwin)> <V(H.Do zier)> ... <V(4-B,1)> <V(4-B,2)> <V(4-B,3)> <V(4-B,4)> <V(4-B,5)> <V(4-B,6)> <V(5-B,1)> <V(5-B,2)> <V(5-B,3)> <V(5-B,4)> <V(5-B,5)>. The entities <V(W.Merrifield)>, <V(A.Cashner)>, <V(B.Goodwin)>, and <V(H.Dozier)>

correspond in turn to *W. Merrifield*, *A. Cashner*, *B. Goodwin*, and *H. Dozier* while <V(5-B,1)> refers to the first play in the bottom half of the fifth inning (see the play-by-play table in Figure 5.1) and abbreviates the following detailed plan: <INN>5 <HALF>B <BATTING>Royals <PITCHING>Orioles <PL-ID>1 <PBYP-RUNS> 1 <PBYP-RBI> 1 <PBYP-OUTS> 0 <PBYP-BALLS> 0 <PBYP-STRIKES> 0 <BATTER>H.Dozier <PITCHER>A. Cashner <ACTION>Home-run <SCORES> Royals-3-Orioles-1, etc.

The procedure described above is not specific to MLB and can be ported to other datasets with similar characteristics such as ROTOWIRE. However, ROTOWIRE does not provide play-by-play information, and as a result there is no event verbalization for this dataset.

5.3.2 Macro Plan Construction

We provided our definition for macro plans in the previous sections, however, it is important to note that such macro plans are not readily available in data-to-text benchmarks like MLB and ROTOWIRE (Wiseman et al., 2017) which consist of tables of records r paired with a gold summary y (see Tables (A)–(C) in Figure 5.1). We now describe our method for obtaining macro plans x from r and y.

Similar to Moryossef et al. (2019), we define macro plans to be conformant with gold summaries such that (1) they have the same splits into paragraphs — entities and events within a paragraph in y are grouped into a paragraph plan in x; and (2) the order of events and entities in a paragraph and its corresponding plan are identical. We construct macro plans by matching entities and events in the summary to records in the tables. Furthermore, paragraph delimiters within summaries form natural units which taken together give rise to a high-level document plan.

We match entities in summaries with entities in tables using exact string match, allowing for some degree of variation in the expression of team names (e.g., *A's* for *Athletics* and *D-backs* for *Diamondbacks*). Information pertaining to innings appears in the summaries in the form of ordinal numbers (e.g., *first*, *ninth*) modifying the noun *inning* and can be relatively easily identified via pattern matching (e.g., in sentences like "*Dozier led off the **fifth** inning*"). However, there are instances where the mention of innings is more ambiguous (e.g., "*With the scored tied 1–1 in the **fourth**, Andrew Cashner (4-13) gave up a sacrifice fly*"). Here the mention of *fourth* refers to the fourth inning. However, the text doesn't mention explicitly that it is an inning.

We could disambiguate such mentions manually and then train a classifier to learn to predict whether an inning is mentioned. Instead, we explore a novel annotation-free method which makes use of the pretrained language model GPT2 (Radford et al., 2019). Specifically, we feed the context preceding the ordinal number to GPT2 (i.e., the current paragraph up to the ordinal number and the paragraph preceding it) and if *inning* appears in the top 10 next word predictions, we consider it a positive match. On a held out dataset, this method achieves 98% precision and 98% recall at disambiguating inning mentions.

To resolve whether the summary discusses the top or bottom side of an inning, we compare the entities in the paragraph with the entities in each half-inning (play-by-play Table (B) in Figure 5.1) and choose the side with the greater number of entity matches. For instance, *Andrew Cashner*, *Merrifield* and *fourth* inning uniquely resolves to the bottom half of the *fourth* inning.

5.3.3 Paragraph Plan Construction

Figure 5.1 shows the macro plan we obtain for game summary (C). Importantly, macro plan (D) is the outcome of a content selection process after considering several candidate paragraph plans as input. So, what are the candidate paragraph plans which give rise to macro plan (D)? To answer this question, we examined the empirical distribution of paragraph plans in MLB and ROTOWIRE (training portion). Interestingly, we found that ~79% of the paragraph plans in MLB refer to a single event or a single player (and team(s)). In ROTOWIRE, ~92% of paragraphs are about a single team or a single player (and team(s)) or a pair of players.

Based on this analysis, we assume that paragraph plans can be either one (verbalized) entity/event or a combination of at most two. Under this assumption, we explicitly enumerate the set of candidate paragraph plans in a game. For the game in Figure 5.1, candidate paragraph plans are shown in Figure 5.2. The first table groups plans based on individual verbalizations describing the team(s), players, and events taking place in specific innings. The second table groups pairwise combinations thereof. In MLB, such combinations are between team(s) and players. In ROTOWIRE, we also create combinations between players. Such paragraph plans form set $\mathcal{E}$ based on which macro plan x is constructed to give rise to game summary y.

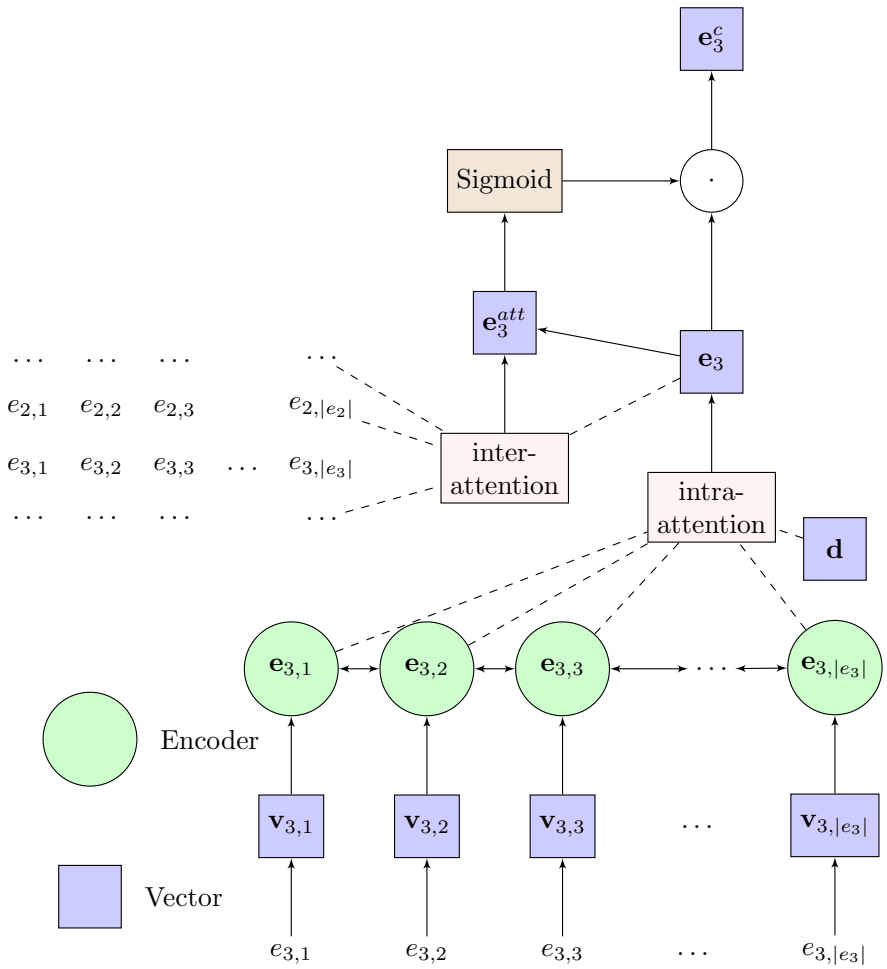

Figure 5.6: Paragraph plan representation and contextualization for macro planning. $e_{3,1}, e_{3,2}, \ldots e_{3,|e_3|}$ are the tokens of the paragraph plan e_3. $\mathbf{d}$ is a query vector randomly initialized and learnt along with the rest of the parameters. Computation of $\mathbf{e}_3$ is detailed in Equations (5.1), (5.2), $\mathbf{e}_3^{att}$ in Equation (5.3), and $\mathbf{e}_3^c$ in Equation (5.4). $\mathbf{e}_3^c$ represents the contextualized representation of e_3.

5.4 Model Description

The input to our model is a set of paragraph plans each of which is a sequence of tokens. We first compute paragraph plan representations $\in \mathbb{R}^n$, and then apply a contextualization and content planning mechanism similar to the planning modules introduced in Chapter 3, and in Chen and Bansal (2018). Predicted macro plans serve as input to our text generation model which adopts an encoder-decoder architecture (Bahdanau et al., 2015; Luong et al., 2015a).

5.4.1 Macro Planning

Paragraph Plan Representation We encode tokens in a verbalized paragraph plan e_i as $\{\mathbf{e}_{i,j}\}_{j=1}^{|e_i|}$ with a BiLSTM (Figure 5.6 bottom part). To reflect the fact that some records will be more important than others, we compute an attention weighted sum of $\{\mathbf{e}_{i,j}\}_{j=1}^{|e_i|}$ following Yang et al. (2016b). Let $\mathbf{d} \in \mathbb{R}^n$ denote a randomly initialized query vector learnt jointly with the rest of parameters. We compute attention values $\alpha_{i,j}$ over $\mathbf{d}$ and paragraph plan token representation $\mathbf{e}_{i,j}$:

$$\alpha_{i,j} \propto \exp(\mathbf{d}^\intercal \mathbf{e}_{i,j}) \tag{5.1}$$

Paragraph plan vector $\mathbf{e}_i$ is the attention weighted sum of $\mathbf{e}_{i,j}$ (with $\sum_j \alpha_{i,j} = 1$):

$$\mathbf{e}_i = \sum_j \alpha_{i,j} \mathbf{e}_{i,j} \tag{5.2}$$

Next, we contextualize each paragraph plan representation vis-a-vis other paragraph plans (Figure 5.6 top left part). First, we compute attention scores $\beta_{i,k}$ over paragraph plan representations to obtain an attentional vector $\mathbf{e}_i^{att}$ for each:

$$\begin{aligned} \beta_{i,k} &\propto \exp(\mathbf{e}_i^\intercal \mathbf{W}_a \mathbf{e}_k) \\ \mathbf{c}_i &= \sum_{k \neq i} \beta_{i,k} \mathbf{e}_k \\ \mathbf{e}_i^{att} &= \mathbf{W}_g [\mathbf{e}_i; \mathbf{c}_i] \end{aligned} \tag{5.3}$$

where $\mathbf{W}_a \in \mathbb{R}^{n \times n}, \mathbf{W}_g \in \mathbb{R}^{n \times 2n}$ are parameter matrices, and $\sum_{k \neq i} \beta_{i,k} = 1$. Then, we compute a content selection gate, and apply this gate to $\mathbf{e}_i$ to obtain new paragraph plan representation $\mathbf{e}_i^c$:

$$\begin{aligned} \mathbf{g}_i &= \text{sigmoid}\left(\mathbf{e}_i^{att}\right) \\ \mathbf{e}_i^c &= \mathbf{g}_i \odot \mathbf{e}_i \end{aligned} \tag{5.4}$$

where $\odot$ denotes element-wise multiplication. Thus, each element in $\mathbf{e}_i$ is weighted by corresponding element of $\mathbf{g}_i \in [0,1]^n$ to obtain a contextualized paragraph plan representation $\mathbf{e}_i^c$.

Content Planning Our model learns to predict macro plans, after having been trained on pairs of sets of paragraph plans and corresponding macro plans (Sections 5.3.2 and 5.3.3 explain how we obtain these for data-to-text datasets like ROTOWIRE and MLB). More formally, we model macro plan $z = z_1 \ldots z_{|z|}$ as a sequence of pointers,

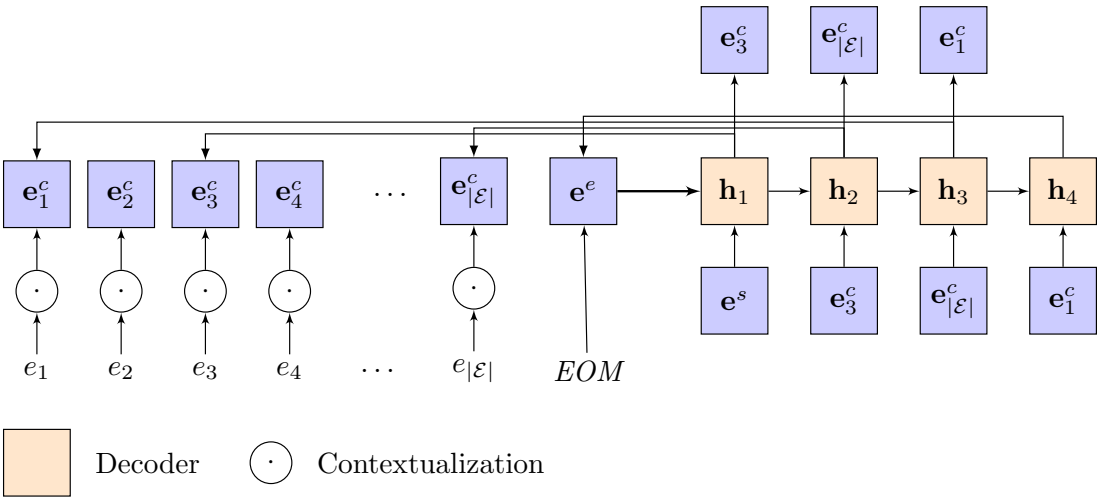

Figure 5.7: Macro planning model; paragraph plan representation and contextualization mechanism are detailed in Figure 5.6. The output points to e_3, $e_{|\mathcal{E}|}$, and e_1 (see Equations (5.5) and (5.6)). *EOM* is end of macro plan token.

with each z_k pointing to an input paragraph plan, i.e., $z_k \in \{e_i\}_{i=1}^{|\mathcal{E}|}$. We decompose $p(z|\mathcal{E})$, the probability of macro plan z given paragraph plans $\mathcal{E}$, as:

$$p(z|\mathcal{E}) = \prod_{k=1}^{|z|} p(z_k|z_{<k}, \mathcal{E}) \tag{5.5}$$

where $z_{<k} = z_1 \ldots z_{k-1}$.

We use Pointer Networks (Vinyals et al., 2015) to model $p(z_k|z_{<k}, \mathcal{E})$ as:

$$p(z_k = e_i|z_{<k}, \mathcal{E}) \propto \exp(\mathbf{h}_k^\intercal \mathbf{W}_b \mathbf{e}_i^c) \tag{5.6}$$

where $p(z_k|z_{<k}, \mathcal{E})$ is normalized to 1 and $\mathbf{W}_b \in \mathbb{R}^{n \times n}$. Rather than computing a weighted representation, Pointer Networks make use of attention to point to specific elements in the input (see Figure 5.7). We use a decoder LSTM to compute hidden representation $\mathbf{h}_k$ at time step k. We initialize $\mathbf{h}_0$ with the mean paragraph plan representation, $\text{avg}(\{\mathbf{e}_i^c\}_{i=1}^{|\mathcal{E}|})$. Once the output points to e_i, its representation $\mathbf{e}_i^c$ is used as input to the next step of the LSTM decoder. The process stops when the model points to *EOM*, a token indicating end of the macro plan.

5.4.2 Text Generation

Recall that z is a sequence of pointers with each entry z_k pointing to a paragraph plan i.e., $z_k \in \{e_i\}_{i=1}^{|\mathcal{E}|}$. We can deterministically obtain macro plan x from z by retrieving the

paragraph plans being pointed to, adding <P> separators in between. The conditional output probability $p(y|x)$ is modeled as:

$$p(y|x) = \prod_{t=1}^{|y|} p(y_t|y_{<t}, x)$$

where $y_{<t} = y_1 \ldots y_{t-1}$.

To compute $p(y|x)$, we use an encoder-decoder architecture enhanced with an attention mechanism (Bahdanau et al., 2015; Luong et al., 2015a). We encode macro plan x with a bidirectional LSTM (Hochreiter and Schmidhuber, 1997). At time step t, we lookup the embedding of the previously predicted word y_{t-1} and feed it as input to the decoder which is another LSTM unit. The decoder attends over hidden states of the macro plan to predict y_t. We further incorporate a copy mechanism (Gulcehre et al., 2016b) in the decoder to enable copying values directly from the macro plan.

We expect the text generation model to learn to generate summary tokens while focusing on the corresponding macro plan and that the output summary will indeed follow the plan in terms of the entities and events being described and their order. At the same time, we believe that text generation is relatively easier as the encoder-decoder model is relieved from the tasks of document structuring and information selection.

5.4.3 Training and Inference

We train two independent models for macro planning and text generation. Our training objective for macro planning aims to maximize the log likelihood of the macro plan given the paragraph plans:

$$\max_{\theta} \sum_{(\mathcal{E},z)\in\mathcal{D}} \log p\left(z|\mathcal{E};\theta\right)$$

where $\mathcal{D}$ is the training set consisting of pairs of (sets of) paragraph plans and macro plans, and θ are model parameters.

Our training objective for text generation aims to maximize the log likelihood of the output text given the macro plan:

$$\max_{\phi} \sum_{(x,y)\in\mathcal{F}} \log p\left(y|x;\phi\right)$$

where $\mathcal{F}$ is the training set consisting of pairs of macro plans and game summaries, and ϕ are model parameters.

	ROTOWIRE	MLB
Vocab Size	11.3K	38.9K
# Tokens	1.5M	14.3M
# Instances	4.9K	26.3K
# Record Types	39	53
Avg Records	628	565
Avg Paragraph Plans	10.7	15.1
Avg Length	337.1	542.05

Table 5.2: Dataset statistics for ROTOWIRE and MLB. Vocabulary size, number of tokens, number of instances (i.e., table-summary pairs), number of record types, average number of records, average number of paragraph plans, and average summary length.

During inference, we employ beam search to find the most likely macro plan $\hat{z}$ among candidate macro plans z' given paragraph plans as input.

$$\hat{z} = \arg\max_{z'} p(z'|\mathcal{E};\theta)$$

We deterministically obtain $\hat{x}$ from $\hat{z}$, and output summary $\hat{y}$ among candidate outputs y' given macro plan $\hat{x}$ as input:

$$\hat{y} = \arg\max_{y'} p(y'|\hat{x};\phi)$$

5.5 Experimental Setup

Data We performed experiments on the ROTOWIRE (Wiseman et al., 2017) and MLB benchmarks. The details of these two datasets are given in Table 5.2. The average length of a macro plan for ROTOWIRE is 10.7 in terms of the count of paragraph plans, whereas the average length of a macro plan for MLB is 15.1. We make use of a tokenization script[1] to detokenize and retokenize the summaries in both ROTOWIRE and MLB.

We used a version of the MLB dataset, which included game summaries with paragraph delimiters (recall no paragraph delimiters were used in Chapter 4). Specifically, we downloaded the same summaries from the ESPN website[2] and added the <P> de-

[1] https://github.com/neulab/DGT

[2] http://www.espn.com/mlb/recap?gameId={gameid}

limiter to paragraphs in the summaries.[3] The ROTOWIRE dataset does not come with paragraph delimiters in game summaries. We reverse engineered these as follows: (1) we split summaries into sentences using the NLTK (Bird et al., 2009) sentence tokenizer; (2) initialized each paragraph with a separate sentence; (3) merged two paragraphs into one if the entities in the former were a superset of entities in the latter; (4) repeated Step 3 until no merges were possible.

Training Configuration We tuned the model hyperparameters on the development set. For training the macro planning and the text generation stages, we used the AdaGrad (Duchi et al., 2011) optimizer. Furthermore, the text generation stage made use of truncated BPTT (Williams and Peng, 1990) with truncation length 100. We learn subword vocabulary (Sennrich et al., 2016) for paragraph plans in the macro planning stage. We used 2.5K merge operations for ROTOWIRE and 8K merge operations for MLB. In text generation, we learn a joint subword vocabulary for the macro plan and game summaries. We used 6K merge operations for ROTOWIRE and 16K merge operations for MLB. All models were implemented on OpenNMT-py (Klein et al., 2017b). We add to set $\mathcal{E}$ the paragraph plans corresponding to the output summary paragraphs, to ensure full coverage during training of the macro planner. During inference, while predicting macro plans, we employ length normalization (Bahdanau et al., 2015) to avoid penalizing longer outputs; specifically, we divide the scores of beam search by the length of the output. In addition, we adopt bigram blocking (Paulus et al., 2018). For MLB, we further block beams containing more than two repetitions of a unigram. This helps improve the diversity of the predicted macro plans.

System Comparisons We compared our model with the following systems: (1) the **Templ**ate-based generator from Wiseman et al. (2017) for ROTOWIRE and Chapter 4 for MLB. Both systems apply the same principle, they emit a sentence about the teams playing in the game, followed by player-specific sentences, and a closing sentence. MLB additionally contains a description of play-by-play; (2) **ED+CC**, the best performing system in Wiseman et al. (2017), is a vanilla encoder-decoder model equipped with an attention and copy mechanism; (3) **NCP+CC**, the micro planning model of Chapter 3; (4) **ENT**, the entity-based model of Chapter 4.

[3] Although our model is trained on game summaries with paragraph delimiters, and also predicts these at generation time, for evaluation we strip <P> from model output.

5.6 Results

Automatic Evaluation For automatic evaluation, following earlier work (Wiseman et al. 2017 and Chapters 3 and 4, inter alia) we report BLEU (Papineni et al., 2002) with the gold summary as reference but also make use of the Information Extraction (IE) metrics from Wiseman et al. (2017) which are defined over the output of an IE system.We reused the IE model from Chapter 3 for ROTOWIRE but retrained it for MLB to improve its precision and recall.

Specifically, we improved the precision of the IE system for MLB by making use of event detection. The earlier system matches entities (e.g., *Mullins* from Figure 5.1) to record types (e.g., *double batter*) no matter which play they occur in, thus resulting in too many false positives. Instead, we extract inning information from model output summaries following the steps in Section 5.3.2, and narrow down the valid candidates for record types to those present in the plays of a specific inning. For example, we verify if *double* by *Mullins* indeed occurred in the *sixth* inning. We thus increase the recall of play-by-play by including more record types such as *ground out, triple, sacrifice fly*, etc.

Furthermore, the implementation of Wiseman et al. (2017) computes RG, CS, and CO excluding duplicate relations. This artificially inflates the performance of models whose outputs contain repetition. We include duplicates in the computation of the IE metrics (and recreate them for all comparison systems).

Table 5.3 (top) presents our results on the ROTOWIRE test set. In addition to Templ, NCP+CC, ENT, and ED+CC we include the best performing model of Wiseman et al. (2017) (WS-2017; note that ED+CC is an improved re-implementation of their model), and the model of Rebuffel et al. (2020) (RBF-2020) which represents the state of the art on ROTOWIRE. This model has a Transformer encoder (Vaswani et al., 2017) with a hierarchical attention mechanism over entities and records within entities. The models of Saleh et al. (2019), Iso et al. (2019), and Gong et al. (2019) make use of additional information not present in the input (e.g., previous/next games, summary writer) and are not directly comparable to the systems in Table 5.3. Results for the MLB test set are in the bottom portion of Table 5.3.

Templ has the highest RG precision and count on both datasets. This is not surprising, by design Templ is always faithful to the input. However, notice that it achieves the lowest BLEU amongst comparison systems indicating that it mostly regurgitates facts with low fluency. Macro achieves the highest RG precision amongst all neural

ROTOWIRE	RG		CS			CO	BLEU
	#	P%	P%	R%	F%	DLD%	
Templ	**54.3**	**99.9**	27.1	57.7	36.9	13.1	8.46
WS-2017	34.1	75.1	20.3	36.3	26.1	12.4	14.19
ED+CC	35.9	82.6	19.8	33.8	24.9	12.0	14.99
NCP+CC	40.8	87.6	28.0	51.1	36.2	15.8	16.50
ENT	32.7	91.7	**34.7**	48.5	40.5	16.6	16.12
RBF-2020	44.9	89.5	23.9	47.0	31.7	14.3	**17.16**
Macro	42.1	97.6	34.1	**57.8**	**42.9**	**17.7**	15.46
−Plan(4)	36.2	81.3	22.1	38.6	28.1	12.1	14.00

MLB	RG		CS			CO	BLEU
	#	P%	P%	R%	F%	DLD%	
Templ	**62.3**	**99.9**	21.6	**55.2**	31.0	11.0	4.12
ED+CC	32.5	91.3	27.8	40.6	33.0	17.1	9.68
NCP+CC	19.6	81.3	**44.5**	44.1	44.3	**21.9**	9.68
ENT	23.8	81.1	40.9	49.5	44.8	20.7	11.50
Macro	30.8	94.4	40.8	54.9	**46.8**	21.8	**12.62**
−Plan(SP,4)	25.1	92.7	40.0	44.6	42.2	**21.9**	11.09

Table 5.3: Evaluation on ROTOWIRE and MLB test sets; relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%), recall (R%) and F-measure (F%), content ordering (CO) in complement of normalized Damerau-Levenshtein distance (DLD%), and BLEU.

models for ROTOWIRE and MLB. We obtain an absolute improvement of 5.9% over ENT for ROTOWIRE and 13.3% for MLB. In addition, Macro achieves the highest CS F-measure for both datasets. On ROTOWIRE, Macro achieves the highest CO score, and the highest BLEU on MLB. On ROTOWIRE, in terms of BLEU, Macro is worse than comparison models (e.g., NCP+CC or ENT). Inspection of the output showed that the opening paragraph, which mostly describes how the two teams fared, is generally shorter in Macro, leading to shorter summaries and thus lower BLEU. There is high variance in the length of the opening paragraph in the training data[4] and Macro verbalizes the corresponding plan conservatively. Ideas such as length normalisation (Wu

[4]The length of the opening paragraph ranges from 6 tokens to 258 tokens in ROTOWIRE.

Macro	CS-P	CS-R	CS-F	CO
ROTOWIRE	81.3	73.2	77.0	45.8
MLB	80.6	63.3	70.9	31.4

Table 5.4: Evaluation of macro planning stage; content selection precision (CS-P), recall (CS-R), F-measure (CS-F) and content ordering (CO) between the inferred plans and gold plans in terms of entities and events for ROTOWIRE (RW) and MLB test sets.

et al., 2016) or length control (Kikuchi et al., 2016; Takeno et al., 2017; Fan et al., 2018) could help alleviate this; however, we do not pursue them further for fair comparison with the other models.

The Contribution of Macro Planning To study the effect of macro planning in more detail, we further compared Macro against text generation models (see Section 5.4.2) which are trained on verbalizations of the tabular data (and gold summaries) but do not make use of document plans or a document planning mechanism. On ROTOWIRE, the model was trained on verbalizations of players and teams, with the input arranged such that the verbalization of the home team was followed by the visiting team, the home team players and the visiting team players. Mention of players was limited to the four best ones, following Saleh et al. (2019) (see −Plan(4) in Table 5.3). For MLB, we additionally include verbalizations of innings focusing on scoring plays which are likely to be discussed in game summaries (see −Plan(SP,4) in Table 5.3). Note that by preprocessing the input in such a way some simple form of content selection takes place simply by removing extraneous information which the model does not need to consider.

Across both datasets, −Plan variants appear competitive. On ROTOWIRE −Plan(4) is better than ED+CC in terms of content selection but worse compared to ENT. On MLB, −Plan(SP,4) is again superior to ED+CC in terms of content selection but not ENT whose performance lags behind when considering RG precision. Taken together, these results confirm that verbalizing entities and events into a text sequence is effective. At the same time, we see that −Plan variants are worse than Macro across most metrics which underlines the importance of an explicit planning component.

Table 5.4 presents intrinsic evaluation of the macro planning stage. Here, we compare the inferred macro plan with the gold macro plans. We use the CS and CO metrics but compute them over entities and events instead of relations. We see that our macro

<V(Rays)> <P> <V(8-B)> <P> <V(Rays)> <P> <V(Rays)> <V(Red Sox)> <P> <V(8-B)> <P> <V(8-T)> <P> <V(9-T)> <P> <V(Clay Buchholz)> <P> <V(5-T)> <P> <V(Edwin Jackson)> <P> <V(5-T)> <P> <V(8-T)>

ST. PETERSBURG, Fla. (AP) – The **Tampa Bay Rays** are making the most of it. <P> Akinori Iwamura hit a two-run homer in the **eighth** inning and the Rays beat the Boston Red Sox 2-1 on Sunday to complete a three-game sweep. <P> The **Rays**, who have the best record in the majors, have won six of their last seven games. <P> The **Rays** have won four of their last five series, including three in a row against the **Red Sox**, who have won six of their last seven overall. <P> Dioner Navarro singled with one out in the **eighth** off Clay Buchholz (1-2) and moved to third on Jason Bartlett's flyout to center. Iwamura then drove a 1-1 pitch into the left-field stands for his second homer of the season. <P> Scott Dohmann (2-0) got the win in relief , striking out Manny Ramirez with runners on first and third to end the **eighth**. <P> Troy Percival worked the **ninth** for his fifth save in five opportunities. <P> **Clay Buchholz** (1-2) gave up two runs and three hits in eight innings. He struck out nine and walked two. <P> The Red Sox loaded the bases with one out in the **fifth** on a single by Coco Crisp, a wild pitch and a walk to Jed Lowrie. Jacoby Ellsbury drove in Crisp with a two-out single to center. <P> **Jackson** struck out four and walked three. <P> The Red Sox loaded the bases with one out in the **fifth** on a single by Coco Crisp, a walk to Jed Lowrie and a one-out walk to Jed Lowrie. Jackson struck out Julio Lugo, but Jacoby Ellsbury singled to center to put the Red Sox up 1-0. <P> The Red Sox threatened in the **eighth** when J. D. Drew drew a two-out walk against Trever Miller, but Ramirez struck out to end the inning.

Table 5.5: Predicted macro plan (top) with corresponding model output (bottom). Entities and events in summary corresponding to those in the macro plan are bold faced.

planning model (Macro) achieves high CS and CO scores for both ROTOWIRE and MLB. We further used the CS and CO metrics to check how well the generated summary follows the (predicted) plan. We followed the steps in Section 5.3.2 and reverse engineered macro plans from the model summaries and compared these extracted plans with the original macro plans with regard to entities and events. We found that Macro creates summaries which follow the plan closely: for ROTOWIRE, the CS F-score and CO are greater than 98%; for MLB, the CS F-score is greater than 94% and CO is greater than 89%.

We show an output summary for Macro in Table 5.5 together with the predicted document plan. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the output summary. Table 5.6 shows the corre-

<V(Clay Buchholz)> <V(Akinori Iwamura)> <V(Rays)><P> <V(8-B)> <P> <V(8-B)> <P> <V(Akinori Iwamura)> <P> <V(8-B)> <P> <V(Clay Buchholz)> <P> <V(Red Sox)> <P> <V(8-T)> <P> <V(9-T)> <P> <V(5-T)> <P> <V(Edwin Jackson)> <P> <V(Red Sox)> <V(David Ortiz)> <P> <V(7-B)> <P> <V(1-B)> <P> <V(Red Sox)> <V(Dustin Pedroia)> <V(Rays)> <Carl Crawford>

Table 5.6: Oracle macro plan for the example in Table 5.5.

sponding oracle macro plan, and Table 5.7 contains the human written summary. We can see that the model summary in Table 5.5 captures the important facts present in the human written summary.

Human-Based Evaluation We also asked participants to assess model output in terms of relation generation, grammaticality, coherence, and conciseness (Wiseman et al. 2017, and Chapters 3 and 4), For ROTOWIRE, we compared Macro against RBF-2020[5], ED+CC, Gold, and Templ. For MLB, we compared Macro against ENT, ED+CC, Gold, and Templ.

In our first study, we presented crowdworkers with sentences randomly selected from summaries along with their corresponding box score (and play-by-play in case of MLB) and asked them to count supported and contradicting facts. We evaluated 40 summaries from the test set (20 per dataset), 4 sentences from each summary and elicited 3 responses per summary. Altogether 131 crowdworkers participated in this study.

As shown in Table 5.8, Macro yields the smallest number of contradicting facts among neural models on both datasets. On ROTOWIRE the number of *contradicting* facts for Macro is comparable to Gold and Templ (the difference is not statistically significant) and significantly smaller compared to RBF-2020 and ED+CC. The count of *supported* facts for Macro is comparable to Gold, and ED+CC, and significantly lower than Templ and RBF-2020. On MLB, Macro has significantly fewer *contradicting* facts than ENT and ED+CC and is comparable to Templ, and Gold (the difference is not statistically significant). The count of *supported* facts for Macro is comparable to Gold, ENT, ED+CC and Templ. For both datasets, Templ has the lowest number of contradicting facts. This is expected as Templ essentially parrots facts (aka records) from the table.

[5]We are grateful to Clément Rebuffel for providing us with the output of their system.

<P> ST. PETERSBURG , Fla. (AP) – **Clay Buchholz** made one mistake and **Akinori Iwamura** turned it into another **Tampa Bay** victory . <P> Iwamura homered in the **eighth** inning and Tampa Bay beat the Boston Red Sox 2 - 1 on Saturday night for the Rays ' first five - game winning streak in more than two years . <P> Iwamura 's two - out , two - run homer , his first since Sept. 3 , came on a 1 - 1 pitch from Buchholz (1 - 2) , who took a one - hit shutout into the inning . <P> **Iwamura** said he looking for a curveball . <P> Dioner Navarro got the Rays ' second hit , a pinch-hit single with one out in the **eighth** . After Jason Bartlett flew out , Iwamura 's shot helped Tampa Bay win its fifth straight for the first time since Aug. 16 - 21 , 2005 . <P> **Buchholz** allowed two runs and three hits over eight innings in his first complete game of the season . He matched his career-high by striking out nine , and walked two . <P> **Boston** has lost four in a row . <P> Scott Dohmann (2 - 0) struck out Manny Ramirez , the only batter he faced in the **eighth** , to win for the second straight day . He got the victory Friday when he got David Ortiz to hit into an inning-ending double play in the 11th inning . <P> Troy Percival pitched the **ninth** for his fifth save in five chances . <P> Coco Crisp opened the **fifth** with a single , advanced two bases to third on Edwin Jackson 's wild pitch and scored on Jacoby Ellsbury 's infield hit that put Boston up 1 - 0 . <P> **Jackson** gave up one run and five hits in seven innings . He had four strikeouts and three walks . <P> **Boston** 's **Ortiz** was scratched from the starting lineup due to a bruised right knee . He was hurt diving into first base attempting to beat out a double-play grounder in the final inning of Boston 's 5 - 4 , 11-inning loss to the Rays on Friday night . <P> Kevin Youkilis of the Red Sox established a new major league record for first basemen when he fielded his 1,701 consecutive chance without an error in the **seventh** , recording the out on Eric Hinske 's grounder to second . The old mark of 1,700 was set by Stuffy McInnis from May 31 , 1921 to June 2 , 1922 . Youkilis ' last error at first came on July 4 , 2006 , a span of a major league-best 205 games . <P> Red Sox DH J. D. Drew had an unique two - out infield single in the **first** . He broke his bat , with the barrel forcing first baseman Carlos Pena to take several steps toward second to avoid it . By the time Pena reached first , Drew was able to beat second baseman Iwamura 's throw to the base . <P> **Boston** second baseman **Dustin Pedroia** went 0 - for - 4 , snapping his hitting streak at 14 games . **Rays** ' left-fielder **Carl Crawford** had a 12-game hitting streak end after going hitless in four at-bats .

Table 5.7: Human written summary for the example in Table 5.5.

We also conducted a second study to evaluate the quality of the generated summaries. We presented crowdworkers with a pair of summaries and asked them to choose the better one in terms of *Grammaticality* (is the summary written in well-formed English?), *Coherence* (is the summary well structured and well organized and

ROTOWIRE	#Supp	#Contra	Gram	Coher	Concis
Gold	3.63	0.07	38.33	46.25*	30.83
Templ	7.57*	0.08	−61.67*	−52.92*	−36.67*
ED+CC	3.92	0.91*	5.0	−8.33	−4.58
RBF-2020	5.08*	0.67*	13.33	4.58	3.75
Macro	4.00	0.27	5.0	10.42	6.67

MLB	#Supp	#Contra	Gram	Coher	Concis
Gold	3.59	0.14	21.67	30.0	26.67
Templ	4.21	0.04	−51.25*	−43.75*	7.5
ED+CC	3.42	0.72*	−22.5*	−12.08*	−39.17*
ENT	3.71	0.73*	5.83*	−0.83*	−22.08*
Macro	3.76	0.25	46.25	26.67	27.08

Table 5.8: Average number of supported (#Supp) and contradicting (#Contra) facts in game summaries and *best-worst scaling* evaluation (higher is better). Systems significantly different from Macro are marked with an asterisk * (using a one-way ANOVA with posthoc Tukey HSD tests; $p \leq 0.05$).

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does it have a natural ordering of the facts?) and *Conciseness* (does the summary avoid unnecessary repetition including whole sentences, facts or phrases?). We divided the five competing systems into ten pairs of summaries and elicited ratings for 40 summaries (20 per dataset). Each summary pair was rated by 3 raters. 206 crowdworkers participated in this task.

As shown in Table 5.8, on ROTOWIRE, Macro is comparable to Gold, RBF-2020, and ED+CC in terms of *Grammaticality* but significantly better than Templ. In terms of *Coherence*, Macro is comparable to RBF-2020 and ED+CC but significantly better than Templ and significantly worse than Gold. With regard to *Conciseness*, Macro is comparable to Gold, RBF-2020, and ED+CC, and significantly better than Templ. On MLB, Macro is comparable to Gold in terms of *Grammaticality* and significantly better than ED+CC, ENT and Templ. Macro is comparable to Gold in terms of *Coherence* and significantly better than ED+CC, ENT and Templ. In terms of *Conciseness*, raters found Macro comparable to Gold and Templ and significantly better than ED+CC, and ENT. Taken together, our results show that macro planning leads to improvement in

<V(Rockets)> <V(Nuggets)> <P> <V(Dwight Howard)> <P> <V(Donatas Motiejunas)> <P> <V(James Harden)> <P> <V(Trevor Ariza)> <P> <V(Rockets)> <P> <V(Nuggets)> <P> <V(Darrell Arthur)> <P> <V(Ty Lawson)> <P> <V(J.J. Hickson)> <P> <V(Arron Afflalo)> <P> <V(Nuggets)>
The Houston **Rockets** defeated the Denver **Nuggets** , 108 - 96 , at Toyota Center on Saturday . The Rockets (18 - 5) came into this game as one of the worst defenses in the NBA , but they were able to prevail with a huge road win . The Nuggets (10 - 13) have now lost three of their last four games , as they continue to slide down the stretch . <P> **Dwight Howard** led the way with a game - high 26 points on 9 - of - 11 shooting , to go along with 13 rebounds , three blocks , two assists and one steal , in 30 minutes . <P> **Donatas Motiejunas** was solid with 25 points on 11 - of - 19 shooting , along with five rebounds , one assist and one steal , in 32 minutes . <P> **James Harden** finished with 24 points , 10 rebounds , 10 assists , two blocks and one steal , in 38 minutes . <P> **Trevor Ariza** chipped in 13 points , eight rebounds , two assists and two steals , in 42 minutes . <P> The **Rockets** shot 44 percent from the field and 29 percent from three - point range . <P> **Denver** shot just 38 percent from the field and 25 percent from three - point range . <P> **Darrell Arthur** led the way off the bench with 20 points , six rebounds and one assist . <P> **Ty Lawson** followed up with 19 points , 12 assists and four rebounds , in 39 minutes . <P> **J. J. Hickson** added 14 points , 10 rebounds , two assists and two blocks , in 22 minutes . <P> **Arron Afflalo** chipped in 12 points , four rebounds , three steals and two assists , in 37 minutes . <P> Next up , the **Nuggets** play the second game of a back - to - back as they host the Timberwolves on Sunday .

Table 5.9: Predicted macro plan (top) with corresponding model output (bottom) for ROTOWIRE. Entities in summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the model output. In addition, the model output exhibits coherent ordering of facts.

data-to-text generation in comparison to other systems for both ROTOWIRE and MLB datasets.

5.7 Discussion

Our results show that macro planning is more advantageous for generation tasks expected to produce longer texts with multiple discourse units, and could be easily extended to other sports domains such as cricket (Kelly et al., 2009) or American foot-

<V(Pacers)> <V(Knicks)> <P> <V(Rodney Stuckey)> <P> <V(David West)> <P> <V(Roy Hibbert)> <P> <V(Pacers)> <P> <V(Knicks)> <P> <V(Carmelo Anthony)> <P> <V(Lou Amundson)> <P> <V(Knicks)>
<P> The Indiana **Pacers** (17 - 31) defeated the New York **Knicks** (9 - 38) 103 - 82 on Saturday . Indiana came into this game as a sizable favorite and they did n't disappoint . In fact , they held the Knicks to just 42 percent shooting from the field and 31 percent from three - point range . Rebounding was a huge factor as well , with the Pacers winning that battle , 49 - 33 . The Knicks (9 - 38) have now lost five of their last six games , as they continue to slide down the standings . <P> **Rodney Stuckey** led the team in scoring , as he tallied 22 points , five rebounds and three assists . <P> **David West** was second on the team , finishing with 10 points , six rebounds and six assists . <P> **Roy Hibbert** recorded a double - double , totaling 18 points and 10 rebounds . <P> On deck for the **Pacers** is a road matchup against the Milwaukee Bucks on Saturday . <P> The **Knicks** (9 - 38) have now lost three - straight games , as they continue to slide down the standings . <P> **Carmelo Anthony** was the player of the game , as he tallied 18 points , one rebound , one assist and one block . <P> **Lou Amundson** was the only other starter in double figures , as he totaled 17 points and three rebounds . <P> The **Knicks** will look to bounce back on Friday in a road matchup against the Orlando Magic .

Table 5.10: Predicted macro plan (top) with corresponding model output (bottom) for ROTOWIRE. Entities in summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the model output. In addition, the model output exhibits coherent ordering of facts.

ball (Barzilay and Lapata, 2005). While other approaches focusing on micro planning (Chapter 3 and Moryossef et al. 2019) might be better tailored for generating shorter texts. There has been a surge of datasets recently focusing on single-paragraph outputs and the task of content selection such as E2E (Novikova et al., 2017b), WebNLG (Gardent et al., 2017), WikiBio (Lebret et al., 2016; Perez-Beltrachini and Lapata, 2018) and ToTTo(Parikh et al., 2020). We note that in our model content selection takes place during macro planning *and* text generation. The results in Table 5.3 show that Macro achieves the highest CS F-measure on both datasets indicating that the document as a whole and individual sentences discuss appropriate content.

We provide two examples each of predicted macro plan and model output for ROTOWIRE (Wiseman et al., 2017) and MLB in Tables 5.9 – 5.12. The macro plan is at the top, and model output is at the bottom. The paragraph plans in the macro plan, and

<V(Jose Guillen)><P> <V(6-B)> <P> <V(Jose Guillen)><P> <V(Luke Hochevar)> <P> <V(9-T)> <P> <V(Shaun Marcum)> <P> <V(4-B)> <P> <V(5-T)> <P> <V(6-B)> <P> <V(8-T)> <P> <V(8-T)>
KANSAS CITY , Mo . (AP) – **Jose Guillen** is going to have to wait at least one more day . <P> Guillen homered for the first time in more than a month , and the Kansas City Royals beat the Toronto Blue Jays 2 - 1 on Wednesday night . <P> Guillen , who had been 0 - for - 7 in the first two games of the series , led off the bottom of the **sixth** with his first home run of the season , a shot to left that gave the Royals a 2 - 1 lead . <P> It was **Guillen** 's first home run since Sept. 22 , 2007 , at Detroit . <P> **Hochevar** (1 - 1) gave up one run and six hits in six innings , walking two and striking out three . <P> Joakim Soria worked the **ninth** for his sixth save in six opportunities . <P> **Shaun Marcum** (2 - 2) gave up two runs and four hits in seven innings . He walked three and struck out four . <P> The Royals scored their first run in the **fourth** when Teahen led off with a double and scored on Ross Gload 's single . <P> The Blue Jays tied it in the **fifth** when Gregg Zaun led off with a double , took third on David Eckstein 's single and scored when Alex Rios hit a grounder to shortstop Tony Pena Jr. , who threw wildly to the plate for an error . <P> Guillen led off the **sixth** with his first home run of the season . <P> The Blue Jays loaded the bases with one out in the **eighth** on a walk to Alex Rios and a one - out single by Matt Stairs . Ramon Ramirez came in and got Adam Lind to ground out to end the inning . <P> The Blue Jays loaded the bases with one out in the **eighth** against Juan Carlos Oviedo , who struck out Scott Rolen and got Adam Lind to ground out .

Table 5.11: Predicted macro plan (top) with corresponding model output (bottom) for MLB. Entities and events in summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the model output. In addition, the model output exhibits coherent ordering of facts.

the paragraphs in the model output are delimited by <P> tags. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the model output. In addition, the model output exhibits coherent ordering of facts.

Throughout our experiments we observed that template-based systems score poorly in terms of CS (but also CO and BLEU). This is primarily due to the inflexibility of the template approach which is limited to the discussion of a fixed number of (high-scoring) players. Yet, human writers (and neural models to a certain extent), synthesize summaries taking into account the particulars of a specific game (where some players might be more important than others even if they scored less) and are able to override

<V(Felipe Lopez)><P> <V(Felipe Lopez) V(Nationals) V(Mets)><P>
<V(6-B)> <P> <V(Felipe Lopez)><P> <V(6-B)> <P> <V(7-B)> <P> <V(9-T)>
<P> <V(Oliver Perez)><P> <V(3-T)> <P> <V(4-T)> <P> <V(5-T)> <P>
<V(5-B)>

WASHINGTON (AP) – **Felipe Lopez** was n't sure what to expect when he came to the plate with the bases loaded and two outs . <P> **Lopez** hit a grand slam and drove in six runs , leading the Washington **Nationals** to a 10 - 5 victory over the New York **Mets** on Friday night . <P> Lopez 's second career grand slam came in the **sixth** inning , and the Nationals ' second grand slam of the season . <P> **Lopez** had been 0 - for - 12 in his first three games with the bases loaded this season . <P> The Nationals loaded the bases with two outs in the **sixth** on a single by Wily Mo Pena , a single by Aaron Boone and a walk to Lastings Milledge . Aaron Heilman came on to face Lopez , who hit a 3 - 2 pitch into the Nationals ' bullpen in left field for his first career grand slam . <P> Johnny Estrada added an RBI single in the **seventh** off Jorge Sosa . <P> Marlon Anderson and Carlos Beltran homered for the Mets , who have lost four of five . <P> **Oliver Perez** (2 - 1) gave up five runs and six hits in 5 2/3 innings . He walked four and struck out three . <P> The Mets took a 1 - 0 lead in the **third** when Raul Casanova singled , took second on a sacrifice bunt by Jose Reyes and scored on a single by Castillo . <P> The Mets made it 2 - 0 in the **fourth** . Ryan Church led off with a walk , stole second and scored on a single by Perez . <P> The Mets made it 3 - 0 in the **fifth** . Luis Castillo led off with a single , moved to second on a wild pitch and scored on Ryan Church 's two - out single . <P> The Nationals tied it in the bottom of the **fifth** on a two - run single by Felipe Lopez and a run-scoring groundout by Zimmerman .

Table 5.12: Predicted macro plan (top) with corresponding model output (bottom) for MLB. Entities and events in summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between the paragraph plans in macro plan, and the paragraphs in the model output. In addition, the model output exhibits coherent ordering of facts.

global defaults. Template sentences are fluent on their own, but since it is not possible to perform aggregation (Reiter, 1995), the whole summary appears stilted, it lacks coherence and variability, contributing to low BLEU scores. The template baseline is worse for MLB than ROTOWIRE which reflects the greater difficulty to manually create a good template for MLB. Overall, we observe that neural models are more fluent and coherent, being able to learn a better ordering of facts which is in turn reflected in better CO scores.

Despite promising results, there is ample room to improve macro planning, espe-

cially in terms of the precision of RG (see Table 5.3, P% column of RG). We should not underestimate that Macro must handle relatively long inputs (the average input length in the MLB development set is ~3,100 tokens) which are challenging for the attention mechanism. Consider the following output of our model on the MLB dataset: *Ramirez's two-run double off Joe Blanton tied it in the sixth, and Brandon Moss added a two-out RBI single off Alan Embree to give Boston a 3-2 lead.* Here, the name of the pitcher should have been *Joe Blanton* instead of *Alan Embree*. In fact, *Alan Embree* is the pitcher for the following play in the half inning. In this case, attention diffuses over the relatively long MLB macro plan, leading to inaccurate content selection. We could alleviate this problem by adopting a noisy channel decomposition (Yee et al., 2019; Yu et al., 2020), i.e., by learning two different distributions: a conditional model which provides the probability of *translating* a paragraph plan to text and a language model which provides an unconditional estimate of the output (i.e., the whole game summary).

For ROTOWIRE, the main source of errors is the model's inability to understand numbers. For example, Macro generates the following output *The Lakers were the superior shooters in this game, going 48 percent from the field and 30 percent from the three-point line, while the Jazz went 47 percent from the floor and 30 percent from beyond the arc.*. Here, *30 percent* should have been *24 percent* for the Lakers but the language model expects a higher score for the *three-point line*, and since *24* is low (especially compared to 30 scored by the Jazz), it simply copies *30* scored by the Jazz instead. A mechanism for learning better representations for numbers (Wallace et al., 2019) or executing operations such as argmax or minus (Nie et al., 2018) should help alleviate this problem.

Finally, although our focus so far has been on learning document plans from data, the decoupling of planning from generation allows to flexibly generate output according to specification. For example, we could feed the model with manually constructed macro plans, consequently controlling the information content and structure of the output summary (e.g., for generating short or long texts, or focusing on specific aspects of the game). In the example in Table 5.13, we show a macro plan with a different ordering of entities and events as compared to that in Table 5.5. We see that the model output closely follows the plan.

<V(Akinori Iwamura)> <P> <V(8-B)> <P> <V(Akinori Iwamura)> <P> <V(8-B)> <P> <V(Clay Buchholz)> <P> <V(Red Sox)> <P> <V(8-T)> <P> <V(9-T)> <P> <V(5-T)> <P> <V(Edwin Jackson)> <P> <V(David Ortiz)> <P> <V(7-B)> <P> <V(1-B)>
ST. PETERSBURG , Fla. (AP) – **Akinori Iwamura** was n't sure what to expect when he came to the plate . <P> Iwamura hit a tiebreaking two - run homer in the **eighth** inning and the Tampa Bay Rays beat the Boston Red Sox 2 - 1 on Sunday to complete a three - game sweep . <P> **Iwamura** , who had a two - run homer in the opener of a three - game series Friday night , is hitting .221 with three homers and seven RBIs in his last seven games . <P> Dioner Navarro singled with one out in the **eighth** off Clay Buchholz (1 - 2) and took second on a flyout by pinch-hitter Dioner Navarro . Iwamura then drove a 1 - 1 pitch over the wall in left for his second homer of the season . <P> **Buchholz** (1 - 2) gave up two runs and three hits in eight innings . He struck out nine and walked two . <P> The Red Sox have lost four of five . <P> Scott Dohmann (2 - 0) recorded the final out of the **eighth** for the win . <P> Troy Percival worked the **ninth** for his fifth save in five opportunities . <P> Jacoby Ellsbury put the Red Sox up 1 - 0 on a two - out RBI single in the **fifth** . <P> **Jackson** gave up one run and five hits in seven innings . He struck out four and walked three . <P> **David Ortiz** , who was scratched from the Tampa Bay lineup because of a sore left wrist , was scratched from the lineup after being hit in the helmet by a pitch in the ninth inning of Tampa Bay 's 4 - 3 loss to the New York Yankees on Friday night . <P> Buchholz retired the first 11 batters he faced before Carlos Pena drew a two - out walk in the **seventh** . <P> Buchholz walked two and struck out nine , including the side in the **first** inning .

Table 5.13: A macro plan with a different ordering of entities and events as compared to the example in Table 5.5. We see that the model output closely follows the plan.

5.8 Summary

In this chapter we presented a plan-and-generate approach for data-to-text generation which consists of a macro planning stage representing high-level document organization in terms of structure and content, followed by a text generation stage. Extensive automatic and human evaluation shows that our approach achieves better results than existing state-of-the-art models and generates summaries which are factual, coherent, and concise.

As identified in the earlier discussion, macro plans tend to be long and thus challenging for the attention mechanism during text generation. In the next chapter, we explore a sequential latent variable approach to planning which alleviates this problem.

We generate game summaries using a sequence of interleaved planning and generation steps. At each step, we select a paragraph plan from the set of paragraph plans, conditioned on the previously selected paragraph plans and previously generated paragraphs. We then generate the corresponding output paragraph conditioned primarily on the current paragraph plan, previous paragraph plans, and previously generated paragraphs.

Chapter 6

Variational Sequential Planning

In the previous chapter, we introduced macro planning in neural generation. We reconceptualized the input in terms of paragraph plans arguing that generation from this input rather than tabular data facilitates document-level planning. We advocated the use of *macro plans* for improving the organization of document content and structure. A macro plan is a *sequence* of paragraph plans, and each paragraph plan corresponds to a document paragraph. The intermediate macro plan renders generation more interpretable (differences in the output can be explained by differences in macro planning). It also makes modeling easier, the input is no longer a complicated table but a sequence of paragraph plans which in turn allows us to treat data-to-text generation as a sequence-to-sequence learning problem. Nevertheless, decoding to a long document remains challenging for at least two reasons. Firstly, the macro plan may be encoded as a sequence but a very long one (more than 3,000 tokens) which the decoder has to attend to at each time step in order to generate a summary token-by-token. Secondly, the prediction of the macro plan is conditioned solely on the input and does not make use of information present in the summary.

In this chapter, we address these shortcomings by introducing variational sequential planning. We infer *latent* (document) plans sequentially with a structured variational model, while interleaving the steps of planning and generation. Text is now generated by conditioning on previous variational decisions *and* previously generated text.

6.1 Introduction

In Figure 5.1, we saw a example from the MLB dataset which pairs human written summaries (Table C) with major league baseball game statistics. Game summaries

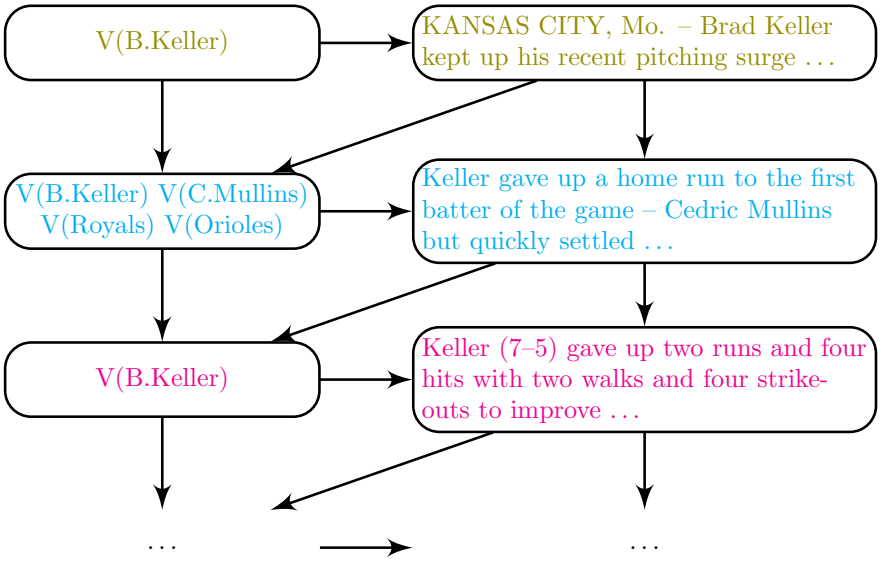


Figure 6.1: Conceptual sketch of interleaving planning with generation. The paragraph plan and its corresponding paragraph have the same color.

in MLB are relatively long (540 tokens on average) with multiple paragraphs (15 on average).

We hypothesize that planning would be more accurate were it to consider information available in the table (and corresponding paragraph plans) *and* the generated summary, more so because the plans are coarse-grained and there is a one-to-many relationship between a paragraph plan and its realization. For example, we can see that the plan for <V(B.Keller)> results in two very different realizations in the summary in Figure 5.1 (see first and third paragraph).

In this chapter, we present a model which interleaves macro planning with text generation (see Figure 6.1 for a sketch of the approach). We begin by selecting a plan from a pool of paragraph plans (see Table D in Figure 5.1), and generate the first paragraph by conditioning on it. We select the next paragraph plan by conditioning on the previous plan *and* the previously generated paragraph. We generate the next paragraph by conditioning on the currently selected plan, the previously predicted plan, and generated paragraph. We repeat this process until the final paragraph plan is predicted. We model the selection of paragraph plans as a *sequential latent variable process* which we argue is intuitive since content planing is inherently latent. Contrary to the approach in Chapter 5, we do not a priori decide on a *global* macro plan. Rather our planning process is *incremental* and as a result less rigid. Planning is informed by generation and vice versa, which we argue should be mutually beneficial (they are conditioned on each other).

During training, the sequential latent model can better leverage the summary to render paragraph plan selection more accurate and take previous decisions into account. We hypothesize that the interdependence between planning and generation allows the model to cope with diversity. In general, there can be many ways in which the input table can be described in the output summary, i.e., different plans give rise to equally valid game summaries. The summary in Figure 5.1 (Table C) focuses on the performance of *Brad Keller* who is a high scoring pitcher (first three paragraphs). An equally plausible summary might have discussed a high scoring batter first (e.g., *Ryan O'Hearn*). Also notice that the summary describes innings in chronological order. However, another ordering might have been equally plausible, for example, describing innings where the highest runs are scored first or innings which are important in flipping the outcome of the match. In the face of such diversity, there may never be enough data to learn an accurate global plan. It is easier to select a paragraph plan from the pool once some of the summary is known, and different plans can be predicted for the same input. The proposed model is end-to-end differentiable and gradients for summary prediction also inform plan prediction.

Our contributions can be summarized as follows: (1) we decompose data-to-text generation into sequential plan selection and paragraph generation. The two processes are interleaved and generation proceeds incrementally; (2) in contrast to previous models (Chapters 3 and 5) where content plans are monolithic and determined in advance, our approach is more flexible, it simplifies modeling (we do not need to learn alignments between paragraph plans and summary paragraphs), and leads to sample efficiency and robustness in low resource scenarios; (3) our approach scales better for tasks involving generation of long multi-paragraph texts, as we do not need to specify the document plan in advance and is closer to how humans generate text incrementally: look at what has been already generated, make a plan on what to discuss next, realize the plan, and repeat (Levelt, 1993; Guhe, 2020); (4) experimental results on English and German ROTOWIRE (Wiseman et al., 2017; Hayashi et al., 2019), and MLB show that our model is well-suited to long-form generation and produces more factual, coherent, and less repetitive output compared to strong baselines.

6.2 Related Work

Recent work has recognized that planning can be beneficial for various generation tasks ranging from summarization (Narayan et al., 2021) to dialogue modeling (Kim et al.,

Input Table: Match date: Saturday, 22nd October 2018							
Team	Name	City	At Home?	W	L	Pts	Reb
Chicago Bulls	Bulls	Chicago	Home	3	1	100	21
LA Lakers	Lakers	Los Angeles	Away	2	5	80	25
Player	Name	Surname	Team	Pts	Reb	Ast	...
Michael Jordan	Michael	Jordan	Chicago Bulls	25	10	10	...
Shaquille O' Neal	Shaquille	O' Neal	LA Lakers	30	15	11	...
...	...	...	...	...	...	...	...
Content Plan							
S1: Chicago_Bulls city, Chicago_Bulls name, LA_Lakers city, LA_Lakers name, Chicago_Bulls points, LA_Lakers points, Match date, EOS.							
S2: LA_Lakers name, LA_Lakers wins, LA_Lakers losses, Shaquille_ONeal surname, Shaquille_ONeal points, EOS.							
S3: Chicago_Bulls city, Chicago_Bulls name, Chicago_Bulls wins, Chicago_Bulls losses, Michael_Jordan name, Michael_Jordan surname, Michael_Jordan points, Michael_Jordan rebounds, EOS.							
Realization							
S1: The Chicago Bulls won against the Los Angeles Lakers 100 - 80 on Saturday.							
S2: It was a poor showing for the Lakers (2 - 5) in spite of O'Neal's 30 point contribution.							
S3: The Chicago Bulls' (3 - 1) best player was, predictably, Michael Jordan with 25 points and 10 rebounds.							

Table 6.1: Example from Narayan et al. (2020). They predict each record of the micro plan conditioned on the table and previously predicted records. They add a special token identifying the end of sentence plan. This model first extracts sentence plans and then verbalizes them one-by-one by conditioning on previously generated sentences.

2020). Narayan et al. (2020) treat content selection as task similar to extractive summarization (example in Table 6.1). Specifically, they post-process micro plans from Chapter 3 with special tokens identifying the end of a sentence. They predict each record of the micro plan conditioned on the table and previously predicted records. Their model first extracts sentence plans and then verbalizes them one-by-one by conditioning on previously generated sentences.

Our approach builds on Chapter 5 where *macro planning* is proposed as a way of

organizing high-level document content. We follow the same formulation of content planning as paragraph plan prediction. Our model thus operates over larger content units compared to related work (Chapter 3 and Narayan et al., 2020) and performs the tasks of micro- and macro-planning in one go. In contrast to Chapter 5, we predict paragraph plans and their corresponding paragraphs *jointly* in an incremental fashion. Our approach is reminiscent of psycholinguistic models of speech production (Levelt, 1993; Taylor and Taylor, 1990; Guhe, 2020) which postulate that different levels of processing (or modules) are responsible for language generation; these modules work in an incremental fashion, each producing output as soon as the information it needs is available and the output is processed immediately by the next module.

We assume plans form a sequence of paragraphs which we treat as a latent variable and learn with a structured variational model. Sequential latent variables (Chung et al., 2015; Fraccaro et al., 2016; Goyal et al., 2017) have previously found application in modeling attention in sequence-to-sequence networks (Shankar and Sarawagi, 2019), document summarization (Li et al., 2017), controllable generation (Li and Rush, 2020; Fu et al., 2020), and knowledge-grounded dialogue (Kim et al., 2020). Ye et al. (2020) use latent variables to disentangle the content from the structure (operationalized as templates) of the output text. Their approach generates diverse output output by sampling from the template-specific sample space. They apply their model to single-sentence generation tasks (Lebret et al., 2016; Reed et al., 2018) (example in Table 6.2).

6.3 Model

Following Chapter 5, we assume that at training time our model has access to a pool of paragraph plans $\mathcal{E}$ (see Table D in Figure 5.1) which represent a clustering of records. Given $\mathcal{E}$, we aim to generate a sequence of paragraphs $y = [y^1, ..., y^T]$ that describe the data following a sequence of chosen plans $z = [z^1, ..., z^T]$. Let y^t denote a paragraph, which can consist of multiple sentences, and T the count of paragraphs in a summary. With a slight abuse of notation, superscripts denote indices rather than exponentiation. So, y^t_i refers to the i-th word in the t-th paragraph. A plan $z = [z^1, ..., z^T]$ is a list of discrete variables where $z^t = j$ means that we choose the j-th item from pool $\mathcal{E}$ of candidate plans to guide the generation of paragraph y^t.

Table	name[nameVariable], eatType[pub], food[Japanese], priceRange[average], customerRating[low], area[riverside]
Template1	[name] is a [food] restaurant, it is a [eatType] and it has an [priceRange] cost and [customerRating] rating. it is in [area].
Sentence1	nameVariable is a Japanese restaurant, it is a pub and it has an average cost and low rating. it is in riverside.
Template2	[name] has an [priceRange] price range with a [customerRating] rating, and [name] is an [food] [eatType] in [area].
Sentence2	nameVariable has an average price range with a low rating, and nameVariable is an Japanese pub in riverside.
Template3	[name] is a [eatType] with a [customerRating] rating and [priceRange] cost, it is a [food] restaurant and[name] is in [area].
Sentence3	nameVariable is a pub with a low rating and average cost, it is a Japanese restaurant and nameVariable is in riverside.

Table 6.2: Example from Ye et al. (2020). They propose an approach to disentangle content from the structure (which they operationalize as templates) of text. They create a dataset of pairs of table and corresponding sentence and replace all sentence tokens which match with the record values in the table with a keyword indicating the record type. With this, they aim to remove content information from the sentence and only retain the structure information. The processed sentences resemble Template1, Template2, and Template3 in the example above. They learn a model to produce templates by training on this dataset. During inference, they can generate diverse output by sampling from different templates.

Generation with Latent Plans The core technique of our model is learning the *sequence* of latent plans that guides long document generation. We consider a conditional generation setting where the input $\mathcal{E}$ is a set of paragraph plans and the output $y_{1:T}$ are textual paragraphs following selected sequence $z = z_{1:T}$. Our goal is to induce variables z that indicate which paragraphs are being talked about and in which order. Similar to previous work (Li and Rush, 2020; Fu et al., 2020), we model this process as a conditional generative model that produces both y and z and factorizes as:

$$p_\theta(y,z|\mathcal{E}) = \prod_t p_\theta(z^t|y^{<t},z^{<t},\mathcal{E})p_\theta(y^t|y^{<t},z^{1:t},\mathcal{E}) \tag{6.1}$$

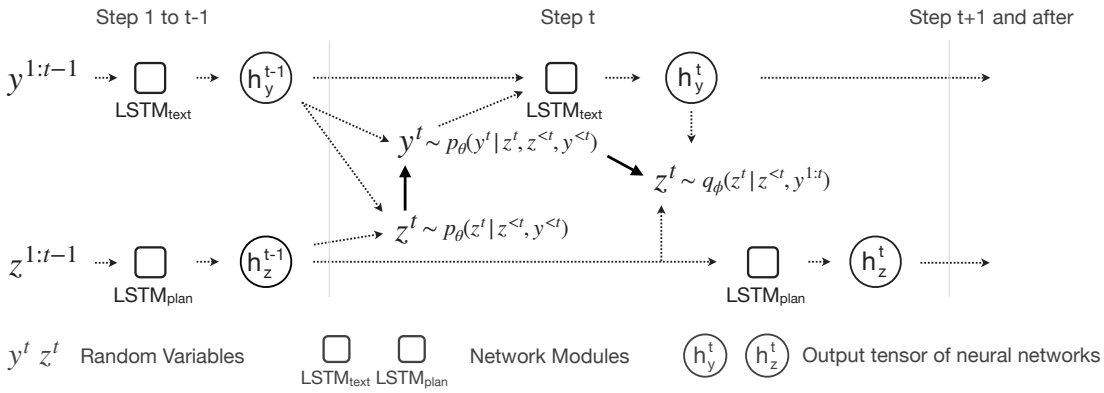


Figure 6.2: Model workflow. Solid arrows show dependencies between random variables. Dashed arrows show the computation graph whose backbone consists of an $\text{LSTM}_{\text{text}}$ and an $\text{LSTM}_{\text{plan}}$. Note that the variational model and the generative model are tied closely with the shared LSTM. To generate long documents, the model observes what has been already generated, decides a on plan about what to discuss next, uses this plan to guide next stage generation, and repeats until the end.

where θ denotes model parameters and $< t$ all indices smaller than t. We believe this formulation is intuitive and mimics how humans might write a document, by inspecting $y^{<t}$ (what has been already said), then making a plan z^t about what to say next, realize this plan by generating a new paragraph y^t, and so on.

Inference Model We are interested in the posterior distribution $p_\theta(z|y,\mathcal{E})$, i.e., the probability over plan sequences z for a known text y and input $\mathcal{E}$. This distribution is intractable to compute in general as the summation of all possible plan sequences z is exponentially complex:

$$p_\theta(z|y,\mathcal{E}) = \frac{p_\theta(y,z|\mathcal{E})}{\sum_z p_\theta(y,z|\mathcal{E})} \tag{6.2}$$

We use variational inference (Kingma and Welling, 2014; Rezende et al., 2014) to approximate the posterior with a parametrized distribution $q_\phi(z|y,\mathcal{E})$ from which we sample values of z that are likely to produce y (see Doersch (2016) for a tutorial on this topic). Specifically, we employ an autoregressive inference model factorized as:

$$q_\phi(z|y,\mathcal{E}) = \prod_t q_\phi(z^t|y^{1:t}, z^{<t}, \mathcal{E}) \tag{6.3}$$

Note that a major difference between q above and p in Equation (6.1) is that p generates y_t under the guidance of z_t (conceptually $z^t \rightarrow y^t$) while q infers z_t given *observed* y_t (conceptually $y^t \rightarrow z^t$).

Neural Parametrization At step t, we start with the encoding of previous paragraphs $y^{<t}$ and plans $z^{<t}$ (see Figure 6.2 left). We use a Bi-directional LSTM with a self-attention layer to encode paragraph y^t as a vector r_y^t at step t:

$$r_y^t = \text{Attn}(q_{\text{text}}, \text{BiLSTM}(y^t)) \tag{6.4}$$

where q_{text} is a trainable query vector. Next, we encode $r_y^{<t}$ with $\text{LSTM}_{\text{text}}$:

$$h_y^{<t} = \text{LSTM}_{\text{text}}(r_y^{<t}) \tag{6.5}$$

We encode candidate plans in pool $\mathcal{E} = [e_1, .., e_N]$ with a BiLSTM, similar to the paragraph encoding shown in Equation (6.4), and select one of them at each step. Let r_z^t denote plan embedding at step t. We encode $r_z^{<t}$ using $\text{LSTM}_{\text{plan}}$:

$$h_z^{<t} = \text{LSTM}_{\text{plan}}(r_z^{<t}) \tag{6.6}$$

The currently selected plan is parametrized as:

$$h^{t-1} = \text{FF}([h_z^{t-1}; h_y^{t-1}]) \tag{6.7}$$

$$p_\theta(z^t | y^{<t}, z^{<t}, \mathcal{E}) = \text{Attn}(h^{t-1}, \mathcal{E}) \tag{6.8}$$

where h^{t-1} summarizes information in $y^{<t}$ and $z^{<t}$, $\text{FF}(\cdot)$ denotes a feed-forward layer, and $\text{Attn}(\cdot)$ returns the attention probability for choosing a plan from $\mathcal{E}$ with current state h^{t-1}, and serves essentially as a copy mechanism. Then, a plan z^t is sampled from p (we use greedy decoding in our experiments), and its representation r_z^t is used to update the $\text{LSTM}_{\text{plan}}$ (see Figure 6.2 right):

$$h_z^t = \text{LSTM}_{\text{plan}}(r_z^t, h_z^{t-1}) \tag{6.9}$$

We guide the generation of y^t with current plan z^t and decode each word y_i^t sequentially with an LSTM_{gen} decoder. Let s_i denote the i-th decoder state (initialized with the plan encoding). We update it as:

$$s_i = \text{LSTM}_{\text{gen}}(y_{i-1}^t, s_{i-1}, h_y^{t-1}) \tag{6.10}$$

Note that we feed h_y^{t-1}, representing the context of previous paragraphs, as additional input similar to Serban et al. (2017). Let $r_{z,1}^t, ..., r_{z,l}^t$ denote the encoding of tokens of the current plan where $r_{z,k}^t$ is the output of the plan encoding BiLSTM and l the length of the chosen plan. We generate the next word as:

$$c_i = \text{Attn}(s_i, [r_{z,1}^t, ..., r_{z,l}^t]) \tag{6.11}$$

$$p_\theta(y_i^t | z^t, y_{1:i-1}^t, y^{<t}, z^{<t}, \mathcal{E}) = \text{softmax}(\text{FF}([s_i; c_i])) \tag{6.12}$$

where c denotes the context vector. In addition, we equip the decoder with copy attention (Gulcehre et al., 2016b) to enable copying tokens from z^t. Once paragraph y^t has been generated, we obtain its encoding r_y^t with Equation (6.4), and update $\text{LSTM}_{\text{text}}$ (see Figure 6.2 middle):

$$h_y^t = \text{LSTM}_{\text{text}}(r_y^t, h_y^{t-1}) \tag{6.13}$$

We parametrize the variational model so that it shares the LSTMs for encoding y and $\mathcal{E}$ with the generative model:

$$\tilde{h}^t = \text{FF}([h_z^{t-1}; h_y^t]) \tag{6.14}$$

$$q_\phi(z^t | y^{1:t}, z^{<t}, \mathcal{E}) = \text{Attn}(\tilde{h}^t, \mathcal{E}) \tag{6.15}$$

Note that Equation (6.14) differs from Equation (6.7) in that it uses the updated h_y^t instead of the previous h_y^{t-1} because now y^t is observed. The variational distribution is again parametrized by the attention probability. Essentially, p and q are strongly tied to each other with the shared LSTM encoders.

Although we primarily focus on the inference, and how the latent plan can improve the generation of long documents, we note that the model sketched above could be parametrized differently, e.g., by replacing the encoder and decoder with pretrained language models like BART (Lewis et al., 2020). However, we leave this to future work.

Training We optimize the standard evidence lower bound (ELBO) loss:

$$\begin{aligned}\mathcal{L}_0 &= \log p_\theta(y|\mathcal{E}) - D(q_\phi(z|y,\mathcal{E}) \parallel p_\theta(z|y,\mathcal{E})) \\ &= \mathbb{E}_{q_\phi(z|y,\mathcal{E})}[\log p_\theta(y,z|\mathcal{E}) - \log q_\phi(z|y,\mathcal{E})]\end{aligned}$$

where $\log p_\theta(y|\mathcal{E})$ is the log-evidence from the data, and $D(q_\phi(z|y,\mathcal{E}) \parallel p_\theta(z|y,\mathcal{E}))$ the Kullback-Leibler divergence between q_ϕ and the true posterior.

Advantageously, we can exploit oracle plans (see Table E in Figure 5.1 and the description in Section 6.4 for how these were created) to obtain weak labels z^* which we use as distant supervision to the inference model:

$$\mathcal{L}_1 = \mathbb{E}_{z^*}[\log q_\phi(z^*|y,\mathcal{E})] \tag{6.16}$$

$$\mathcal{L} = \mathcal{L}_0 + \lambda \mathcal{L}_1 \tag{6.17}$$

Such distant supervision is essential for stabilizing training (it would be extremely challenging to optimize the model in a fully unsupervised way) and for mitigating

	RW	MLB	DE-RW
Vocab Size	11.3K	38.9K	9.5K
# Tokens	1.5M	14.3M	234K
# Instances	4.9K	26.3K	723
# Paragraphs	399K	47.7K	7K
# Record Types	39	53	39
Avg Records	628	565	628
Avg Length	337.1	542.1	323.6
Avg Plan length	10.6	15.1	9.5

Table 6.3: Dataset statistics for ROTOWIRE (RW), MLB and German ROTOWIRE (DE-RW). Vocabulary size, number of tokens, number of instances (i.e., table-summary pairs), number of paragraphs, number of record types, average number of records, average summary length, average macro plan length measured in terms of number of paragraphs.

posterior collapse. We use Gumbel-Softmax (Maddison et al., 2017; Jang et al., 2017) for differentiable sampling (reparameterization) from q. The model is trained with scheduled sampling (Bengio et al., 2015), and follows the curriculum learning strategy using linear decay scheduling. During earlier stages of training, predicted plans are less accurate, and we thus sample from oracle plans at a rate which decays linearly with training:

$$\varepsilon_k = \max(0, 1 - c * k) \tag{6.18}$$

where c is the slope of the decay at training step k.

6.4 Experimental Setup

Data We performed experiments on the ROTOWIRE (Wiseman et al., 2017) and MLB datasets and the German ROTOWIRE provided as part of the WNGT 2020 DGT shared task on "Document-Level Generation and Translation" (Hayashi et al., 2019). Statistics on these datasets are shown in Table 6.3. We used the official train/dev/test splits of 3,398/727/728 for ROTOWIRE, 22,821/1,739/1,744 for MLB, and 242/240/241 for German ROTOWIRE. The latter dataset is considerably smaller than its English counterpart and MLB, and serves to illustrate our model's robustness to limited training data.

All three datasets were preprocessed following the method of Chapter 5. A paragraph plan for an entity was constructed by verbalizing its records in a fixed sequence of record type followed by its value. For example, pitcher *B.Keller* from Figure 5.1 would be verbalized as <PLAYER>B.Keller <H/V>V <W>7 <L>5 <IP>8 <PH>4 .... We denote this using the shorthand <V(B.Keller)>. The paragraph plan for an event is the verbalization of the players in the event followed by the verbalization of play-by-plays. Candidate paragraph plans $\mathcal{E}$ are obtained by enumerating entities and events and their combinations (see Table D in Figure 5.1). Oracle macro plans are obtained by matching the mentions of entities and events in the gold summary with the input table. We make use of these oracle macro plans during training. The versions of MLB and ROTOWIRE created in Chapter 5 contain paragraph delimiters for gold summaries; we preprocessed the German ROTOWIRE in a similar fashion.

Table 6.3 also shows the average length of the macro plan in terms of the number of paragraph plans it contains. This is 10.6 for ROTOWIRE, 15.1 for MLB, and 9.5 for German RotoWire.

Training Configuration We train our model with the AdaGrad optimizer (Duchi et al., 2011) and tune parameters on the development set. We learn a joint subword vocabulary (Sennrich et al., 2016) for paragraph plans and summaries with 6K merge operations for ROTOWIRE, 16K merge operations for MLB, and 2K merge operations for German ROTOWIRE. The model is implemented on a fork of OpenNMT-py (Klein et al., 2017b). For efficiency, we batch using summaries instead of individual paragraphs. Batch sizes for MLB, ROTOWIRE, and German-ROTOWIRE are 8, 5, and 1 respectively. We set λ to 2 in Equation (6.17). In Equation (6.18), c is 1/100,000 for MLB, 1/50,000 for ROTOWIRE, and 1/30,000 for German-ROTOWIRE.

During inference in MLB, similar to Chapter 5, we block the repetition of paragraph plan bigrams (i.e., we disallow the repetition of (z^t, z^{t+1})) and select the paragraph plan with the next higher probability in Equation (6.8). In addition, we block consecutive repetitions, and more than two repetitions of a unigram. During training we observed high variance in the length of paragraphs y^t since the same plan can result in a shorter or longer paragraph. For example, <V(B.Keller)> corresponds to two paragraphs (first and third paragraph) with different lengths in Figure 5.1. We found that this encourages the model to be conservative and generate relatively short output. We control the paragraph length (Fan et al., 2018) by creating discrete bins, each containing approximately an equal number of paragraphs. During training, we prepend

the embedding of the bin to the current plan r_z^t (see Equation (6.11)). For inference, bins are tuned on the validation set.

We ran inference for 15 steps on ROTOWIRE and German ROTOWIRE, and for 20 steps on MLB; we stop when the model predicts token *EOP* as the end of paragraph plan. Unlike previous work (Wiseman et al., 2017 and Chapters 3 and 4, *inter alia*), we do not make use of truncated Back Propagation Through Time (BPTT; Williams and Peng, 1990), as we incrementally generate paragraphs instead of long documents.

System Comparisons We compared our model with: (1) a **Templ**ate-based generator which creates a document consisting of template sentences. We used Wiseman et al.'s (2017) system on ROTOWIRE and the system we developed in Chapter 4 on MLB. They are both similar in that they describe team scores followed by player specific statistics and a concluding statement. In MLB, the template additionally describes play-by-play details. (2) **ED+CC**, the best performing model of Wiseman et al. (2017). It consists of an encoder-decoder model equipped with attention and copy mechanisms. (3) **NCP+CC**, the micro planning model from Chapter 3. It first creates a content plan by pointing to input records through the use of Pointer Networks (Vinyals et al., 2015). The content plan is then encoded with a Bidirectional LSTM and decoded using another LSTM with an attention and copy mechanism. (4) **ENT**, the latent entity planning model of Chapter 4. It creates entity-specific representations which are updated dynamically. At each time step during decoding, the model makes use of hierarchical attention by attending over entity representations and the records corresponding to these. (5) **MACRO**, the two-stage planning model of Chapter 5, which first makes use of Pointer Networks (Vinyals et al., 2015) to predict a macro plan from a set of candidate paragraph plans. The second stage takes the predicted plan as input and generates the game summary with a sequence-to-sequence model enhanced with attention and copy mechanisms. In addition, we compare with a variant of Macro enhanced with length control (+Bin).

6.5 Results

Our experiments were designed to explore how the proposed model compares to related approaches which are either not enhanced with planning modules or non-incremental. We also investigated the sample efficiency of these models and the quality of the predicted plans when these are available. The majority of our results focus on

automatic evaluation metrics. We also follow previous work (Wiseman et al. 2017 and Chapters 3, 4 and 5) in eliciting judgments to evaluate system output.

6.5.1 Automatic Evaluation

We evaluate model output using BLEU (Papineni et al., 2002) with the gold summary as a reference. We also report model performance against the Information Extraction (IE) metrics of Wiseman et al. (2017) which are defined based on the output of an IE model which extracts entity (team and player names) and value (numbers) pairs from the summary and predicts the type of relation between them. We reuse the IE model from Chapter 3 for ROTOWIRE, Chapter 5 for MLB, and Hayashi et al. (2019) for German ROTOWIRE. Computation of IE metrics includes duplicate records following Section 5.6 in Chapter 5.

In addition to IE-based metrics, we report the number of errors made by systems according to Number (incorrect number in digits, number spelled in words, etc.), Name (incorrect names of teams, players, days of week, etc.), and Word (errors in usage of words) following the classification of Thomson and Reiter (2020). We detect such errors automatically using the system of Kasner et al. (2021) which scored best against gold standard human annotations of the same type (Thomson and Reiter, 2021). We only report these metrics for English ROTOWIRE, since error annotations (for automatic metric learning) are not available for other datasets. Moreover, with regard to Word errors, we only report errors for incorrect usage of the word *double-double*.[1] We found such errors to by detected reliably in contrast to Word errors as a whole for which the precision of the system of Kasner et al. (2021) is ~50%.

MLB Dataset Table 6.4 summarizes our results on MLB. Our sequential planning model (SeqPlan) has the highest RG P% among neural models and performs best in terms of CS F%, CO and BLEU. The variant of Macro with length control (+Bin) performs comparably or worse than Macro.

To examine the importance of latent sequential planning, we also present a variant of our model which uniformly samples a plan from the pool $\mathcal{E}$ instead of Equation (6.8) (see row w(ith) Uniform in Table 6.4). This version obtains lower values compared to SeqPlan across all metrics underscoring the importance of sequential planning. We also present two variants of SeqPlan (a) one which makes use of oracle (instead of

[1] a double-double occurs when a player scores 10 points or more in exactly two record types: points, rebounds, assists, steals or blocks.

MLB	RG		CS			CO	BLEU
	#	P%	P%	R%	F%	DLD%	
Templ	62.3	99.9	21.6	55.2	31.0	11.0	4.12
ED+CC	32.5	91.3	27.8	40.6	33.0	17.1	9.68
NCP+CC	19.6	81.3	44.5	44.1	44.3	21.9	9.68
ENT	23.8	81.1	40.9	49.5	44.8	20.7	11.50
Macro	30.8	94.4	40.8	54.9	46.8	21.8	12.62
+Bin	31.2	93.7	38.3	52.4	44.2	21.6	12.32
SeqPlan	28.9	95.9	43.3	53.5	47.8	22.7	14.29
w Uniform	18.5	90.9	36.5	30.6	33.3	14.5	10.30
w Oracle	27.6	95.9	42.5	50.4	46.1	22.0	13.13
2-Stage	28.6	95.9	41.4	50.8	45.6	21.3	13.96

Table 6.4: MLB results (test set); relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%), recall (R%) and F-measure (F%), content ordering (CO) in complement of normalized Damerau-Levenshtein distance (DLD%), and BLEU.

predicted) plans during training to generate y^t; essentially, it replaces z^t with z^* in Equation 6.12 (row w(ith) Oracle in Table 6.4) and (b) a two stage model which trains the planner (Equation 6.15) and generator (Equation 6.12) separately (row as 2-stage in Table 6.4); in this case, we use greedy decoding to sample z^t from Equation (6.15) instead of using Gumbel-Softmax and replace z^t with z^* in Equation (6.12). Both variants are comparable to SeqPlan in terms of RG P% but worse in terms of CS F%, CO, and BLEU.

Furthermore, we evaluated the accuracy of the inferred plans by comparing them against oracle plans, using the CS and CO metrics (computed over the entities and events in the plan). Table 6.6 shows that SeqPlan achieves higher CS-F and CO scores than Macro. Again, this indicates planning is beneficial, particularly when taking the table and the generated summary into account.

English and German ROTOWIRE Results on ROTOWIRE are presented in Table 6.5 (top). In addition to Templ, ED+CC, NCP+CC, and ENT, we compare with the models of Wiseman et al. (2017) (WS-2017) and Rebuffel et al. (2020) (RBF-2020).

RW	RG		CS			CO	BLEU
	#	P%	P%	R%	F%	DLD%	
Templ	54.3	99.9	27.1	57.7	36.9	13.1	8.46
WS-2017	34.1	75.1	20.3	36.3	26.1	12.4	14.19
ED+CC	35.9	82.6	19.8	33.8	24.9	12.0	14.99
NCP+CC	40.8	87.6	28.0	51.1	36.2	15.8	16.50
ENT	32.7	91.7	34.7	48.5	40.5	16.6	16.12
RBF-2020	44.9	89.5	23.9	47.0	31.7	14.3	17.16
Macro	42.1	97.6	34.1	57.8	42.9	17.7	15.46
+Bin	61.0	97.2	26.8	66.1	38.2	15.8	16.48
SeqPlan	46.7	97.6	30.6	57.4	39.9	16.7	16.26
w Uniform	22.0	80.2	18.2	19.6	18.9	6.0	8.61
w Oracle	50.4	97.2	29.0	59.1	38.9	16.8	16.32
2-stage	53.4	97.5	28.5	61.3	38.9	16.1	16.61

DE-RW	RG		CS			CO	BLEU
	#	P%	P%	R%	F%	DLD%	
NCP+CC	17.7	52.5	11.3	25.7	15.7	9.6	7.29
Macro	30.2	49.7	5.1	21.0	8.3	6.1	5.15
SeqPlan	13.8	91.8	38.0	38.4	38.2	21.2	8.65

Table 6.5: Evaluation on ROTOWIRE (RW) and German ROTOWIRE (DE-RW) test sets; relation generation (RG) count (#) and precision (P%), content selection (CS) precision (P%), recall (R%) and F-measure (F%), content ordering (CO) in complement of normalized Damerau-Levenshtein distance (DLD%), and BLEU.

WS-2017 is the best performing model of Wiseman et al. (2017). Note that ED+CC is an improved re-implementation of WS-2017 (see Section 2.4 in Chapter 2). RBF-2020 represents the current state-of-the-art on ROTOWIRE, and comprises of a Transformer encoder-decoder architecture (Vaswani et al., 2017) with hierarchical attention on entities and their records. The models of Saleh et al. (2019), Iso et al. (2019), and Gong et al. (2019) are not comparable as they make use of information additional to the table such as previous/next games or the author of the game summary. The model of Narayan et al. (2020) is also not comparable as it relies on a pretrained language model

		CS			CO
Datasets		P%	R%	F%	DLD%
MLB	Macro	73.6	45.9	56.5	27.0
	SeqPlan	74.4	51.1	60.6	27.1
RW	Macro	81.5	62.7	70.9	36.3
	SeqPlan	79.1	61.6	69.3	35.5
DE-RW	Macro	86.8	34.2	49.0	30.1
	SeqPlan	73.1	60.8	66.4	31.0

Table 6.6: Evaluation of macro planning stage (test set); content selection (CS) precision (P%), recall (R%) and F-measure (F%), content ordering (CO) in complement of normalized Damerau-Levenshtein distance (DLD%).

(Rothe et al., 2020) to generate the summary sentences. Table 6.5 (bottom) shows our results on German ROTOWIRE. We compare against NCP+CC's entry in the WNGT 2019 shared task (Hayashi et al., 2019), and our implementation of Macro. Saleh et al. (2019) are not comparable as they pretrain on 32M parallel English-German, 420M English and 534M German monolingual data.

On ROTOWIRE, we find that SeqPlan achieves highest RG P% amongst neural models, and performs on par with Macro (it obtains higher BLEU but lower CS F% and CO scores). The +Bin variant of Macro performs better on BLEU but worse on other metrics. As in Table 6.4, w Uniform struggles across metrics corroborating our hypothesis that latent sequential planning improves generation performance. The other two variants (w Oracle and 2-Stage) are worse than SeqPlan in RG P% and CS F%, comparable in CO, and slightly higher in terms of BLEU.

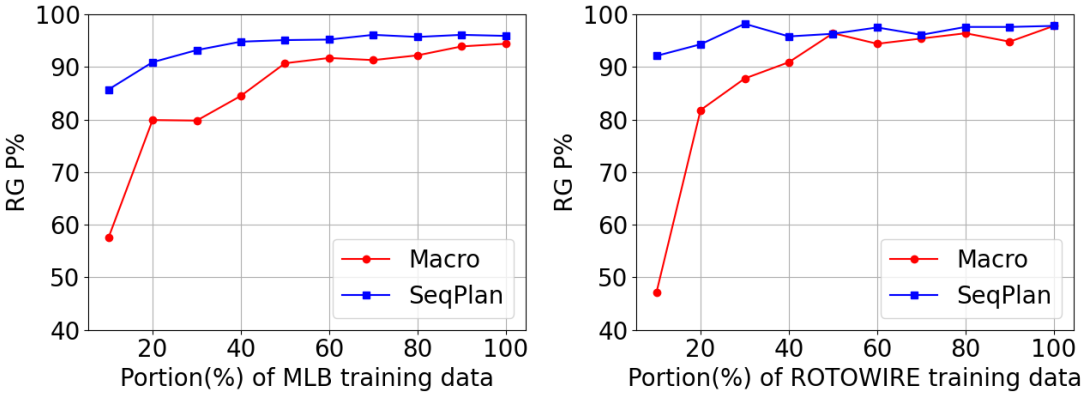
On German, our model is best across metrics achieving an RG P% of 91.8% which is higher by 42% (absolute) compared to of Macro. In fact, the RG P% of SeqPlan is superior to Saleh et al. (2019) whose model is pretrained with additional data and is considered state of the art (Hayashi et al., 2019). RG# is lower mainly because of a bug in the German IE which excludes number records. RG# for NCP+CC and Macro is too high because the summaries contain a lot of repetition. The same record will repeat at least once with NCP+CC and three times with Macro, whereas only 7% of the records are repeated with SeqPlan.

	Number	Name	double-double
Templ	0.08*	3.05*	0.00*
WS-2017	13.01*	9.66*	0.36*
ED+CC	8.11*	8.29*	0.31*
NCP+CC	7.89*	7.76*	0.14
ENT	5.89*	7.24*	0.15
RBF-2020	6.20*	8.39*	0.41*
Macro	2.57	4.60*	0.18
SeqPlan	2.70	6.56	0.20

Table 6.7: Number, Name, and double-double (Word) errors per example. Systems significantly different from SeqPlan are marked with an asterisk * (using a one-way ANOVA with posthoc Tukey HSD tests; $p \leq 0.05$).

Table 6.6 evaluates the quality of the plans inferred by our model on the ROTOWIRE dataset. As can be seen, SeqPlan is slightly worse than Macro in terms of CS-F% and CO%. We believe this is because summaries in ROTOWIRE are somewhat formulaic, with a plan similar to Templ: an opening statement is followed by a description of the top scoring players, and a conclusion describing the next match. Such plans can be learnt well by Macro without access to the summary. MLB texts show a lot more diversity in terms of length, and the sequencing of entities and events. The learning problem is also more challenging, supported by the fact that the template system does not do very well in this domain (i.e., it is worse in BLEU, CS F%, and CO% compared to ROTOWIRE). In German ROTOWIRE, SeqPlan plans achieve higher CS F% and CO% than Macro.

Table 6.7 reports complementary automatic metrics on English ROTOWIRE aiming to assess the factuality of generated output. We find that Templ has the least Number, Name, and double-double errors. This is expected as it simply reproduces facts from the table. SeqPlan and Macro have similar Number errors, and both are significantly better than other neural models. SeqPlan has significantly more Name errors than Macro, and significantly fewer than other neural models. Inspection of Name errors revealed that these are mostly due to incorrect information about next games. Such information is not part of the input and models are prone to hallucinate. SeqPlan fares worse as it attempts to discuss next games for both teams while Macro focuses on one team only. In terms of double-double errors, SeqPlan is comparable to Macro, ENT



(a) (b)

Figure 6.3: Sample efficiency for (a) MLB and (b) ROTOWIRE datasets. SeqPlan and Macro are trained on different portions (%) of the training dataset and performance is measured with RG P%.

and NCP+CC, and significantly better than WS-2017, ED+CC, and RBF-2020.

6.5.2 Sample Efficiency

We also evaluated whether SeqPlan is more sample efficient in comparison to Macro, by examining how RG P% varies with (training) data size. As shown in Figure 6.3, the difference between SeqPlan and Macro is more pronounced when relatively little data is available. For example, with 10% of training data, RG P% for SeqPlan on MLB is 85.7% and 92.1% on ROTOWIRE. In contrast, Macro obtains 63.3% on MLB and 47.1% on ROTOWIRE. As more training data becomes available, the difference in RG P% decreases. The slope of increase in RG P% for Macro is higher for ROTOWIRE than MLB. We hypothesize this is because MLB has longer summaries with more paragraphs, and is thus more difficult for Macro to learn alignments between paragraph plans and text paragraphs in the game summary.

6.5.3 Evaluation of Paragraph Plan Prediction Accuracy

We evaluated the accuracy of the predicted paragraph plan depending on whether the paragraph is observed or not. Essentially we compared the accuracy of q_ϕ in Equation (15) and p_θ in Equation (8), respectively. Table 6.8 presents the results. We see that plan prediction accuracy is higher when the paragraph is observed. This validates our modeling decision of making use of q_ϕ to predict the paragraph plan during training.

Dataset	Model	y^t is observed	y^t is not observed
MLB	SeqPlan	80.3	24.9
	Random	1.3	1.3
ROTOWIRE	SeqPlan	81.8	48.8
	Random	1.8	1.8

Table 6.8: Accuracy of paragraph plan prediction for SeqPlan and Random with observed paragraph y^t and without.

6.5.4 Human Evaluation

We used the Amazon Mechanical Turk (AMT) crowdsourcing platform for our judgment elicitation study as detailed in Chapter 2. We compared SeqPlan with Gold, Templ, ED+CC, and Macro; we did not compare against ENT as Chapter 5 has shown that it performs poorly against Macro. For ROTOWIRE, we additionally compared against RBF-2020.

We conducted two elicitation studies. The first one provided raters with boxscores (and play-by-plays in the case of MLB), along with sentences randomly extracted from game summaries. We asked them to count supported and contradicting facts (ignoring hallucinations). This evaluation was conducted on 40 summaries (20 for each dataset), with four sentences per summary, each rated by three participants. Altogether, we had 177 participants.

Table 6.9 (columns #Supp and #Contra) presents our results. On MLB, all systems display a comparable count of *supported* facts (differences are not statistically significant), with the exception of Templ which contains significantly more. In terms of *contradicting* facts, SeqPlan performs on par with Macro, Gold and Templ, and is significantly better than ED+CC. On ROTOWIRE, in terms of *supported* facts, SeqPlan performs on par with the other neural models, is significantly higher than Gold, and significantly lower than Templ. In terms of *contradicting* facts, SeqPlan performs on par with Macro, Gold and Templ, and significantly better than ED+CC and RBF-2020. Templ achieves the lowest count of *contradicting* facts and the highest count of *supported* facts for both the datasets. This is no surprise as it essentially regurgitates facts (i.e., records) from the table.

In our second study, raters were asked to choose the better summary from a pair of summaries based on *Coherence*, *Conciseness*, and *Grammaticality*. We assessed 40 summaries from the test set (20 for each dataset). Each summary pair was rated by

MLB	#Supp	#Contra	Gram	Coher	Concis
Gold	3.59	0.14	21.67	29.17	14.17
Templ	4.21*	0.04	−58.33*	−48.33*	9.17
ED+CC	3.42	0.72*	−32.50*	−18.33*	−48.33*
Macro	3.76	0.25	37.50	15.00	22.50
SeqPlan	3.68	0.19	31.67	22.50	2.50

ROTOWIRE	#Supp	#Contra	Gram	Coher	Concis
Gold	3.63*	0.07	42.67*	40.67	28.00
Templ	7.57*	0.08	−57.33*	−55.33*	−34.67*
ED+CC	3.92	0.91*	4.00	−14.67*	−13.33
RBF-2020	5.08	0.67*	6.00	1.33	−0.67
Macro	4.00	0.27	0.67	7.33	10.00
SeqPlan	4.84	0.17	4.00	20.67	10.67

Table 6.9: Average number of supported (#Supp) and contradicting (#Contra) facts in game summaries and *best-worst scaling* evaluation for Coherence (Coher), Conciseness (Concis), and Grammaticality (Gram); higher is better. Systems significantly different from SeqPlan are marked with an asterisk * (using a one-way ANOVA with posthoc Tukey HSD tests; $p \leq 0.05$).

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three participants. Altogether, 377 raters participated in this task.

On MLB, SeqPlan is significantly more *coherent* than ED+CC and Templ, and is comparable with Gold and Macro. A similar picture emerges with grammaticality. SeqPlan is as *concise* as Gold, Macro and Templ, and significantly better than ED+CC. On ROTOWIRE, SeqPlan is significantly more coherent than Templ and ED+CC, but on par with Macro, RBF-2020 and Gold. In terms of conciseness, SeqPlan is comparable with Gold, Macro, RBF-2020, and ED+CC, and significantly better than Templ. In terms of grammaticality, SeqPlan is comparable with Macro, RBF-2020, and ED+CC, significantly better than Templ, and significantly worse than Gold.

<V(Cardinals)> → <V(9-T)> → <V(Cardinals)> → <V(Cardinals)> <V(Brewers)>→ <V(9-T)> → <V(8-B)> → <V(8-T)> → <V(8-B)> → <V(9-B)> → <V(Brewers)>→ <V(Adam Wainwright)>→ <V(Brewers)>→ <V(3-T)> → <V(3-B)> → <V(Carlos Villanueva)>
ST. LOUIS – The **St. Louis Cardinals** have been waiting for their starting rotation. <P> Skip Schumaker drove in the go-ahead run with a double in the **ninth** inning, and the Cardinals beat the Milwaukee Brewers 4-3 on Wednesday night to avoid a three-game sweep. <P> The **Cardinals** have won four of five, and have won four in a row. <P> The **Cardinals** have won four of five, including a three-game sweep by the **Brewers**. <P> Brian Barton led off the **ninth** with a pinch-hit double off Derrick Turnbow (0-1) and moved to third on Cesar Izturis' sacrifice bunt. Schumaker drove in Barton with a double down the left-field line. <P> Ryan Braun, who had two hits, led off the **eighth** with a double off Ryan Franklin (1-1). Braun went to third on a wild pitch and scored on Corey Hart's triple into the right-field corner. <P> Albert Pujols was intentionally walked to load the bases with one out in the **eighth**, and Guillermo Ankiel flied out. Troy Glaus walked to load the bases for Kennedy, who hit a sacrifice fly off Guillermo Mota. <P> Ryan Franklin (1-1) got the win despite giving up a run in the **eighth**. Ryan Braun led off with a double and scored on Corey Hart's one-out triple. <P> Jason Isringhausen pitched a perfect **ninth** for his seventh save in nine chances. He has converted his last six save opportunities and has n't allowed a run in his last three appearances. <P> The **Brewers** lost for the seventh time in eight games. <P> **Wainwright** allowed two runs and four hits in seven innings. He walked four and struck out six. <P> **Brewers** manager Ron Roenicke was ejected by home plate umpire Bill Miller for arguing a called third strike. <P> The Cardinals took a 2-0 lead in the **third**. Albert Pujols walked with two outs and Rick Ankiel walked. Glaus then lined a two-run double into the left-field corner. <P> The Brewers tied it in the **third**. Jason Kendall led off with a double and scored on Rickie Weeks' double. Ryan Braun's RBI single tied it at 2. <P> **Villanueva** allowed two runs and three hits in seven innings. He walked four and struck out one.

Table 6.10: Predicted macro plan (top) and generated output from our model. Transitions between paragraph plans are shown using →. Paragraphs are separated with <P> delimiters. Entities and events in the summary corresponding to the macro plan are boldfaced.

6.6 Discussion

Table 6.10 gives an example of SeqPlan output. We see that the game summary follows the macro plan closely. In addition, the paragraph plans and the paragraphs exhibit coherent ordering. Table 6.11 shows the oracle macro plan for the example in Table 6.10,

<V(Derrick Turnbow)> <V(Brewers)> <V(Cardinals)> → <V(9-T)> → <V(Skip Schumaker)> → <V(9-T)> → <V(Derrick Turnbow)> → <V(8-B)> <V(9-B)> → <V(Brewers)> <V(Ryan Franklin)> → <V(8-T)> → <V(Corey Hart)> → <V(8-B)> → <V(8-T)> → <V(Corey Hart)> → <V(8-T)> → <V(8-T)>

Table 6.11: Oracle macro plan for the example in Table 6.10

and Table 6.12 contains the corresponding human written summary. We see that the SeqPlan summary captures the important facts from the human written summary. As SeqPlan does not have to learn alignments between the macro plan and the output text, it is better suited for long-form generation. Potential applications include summarizing books (Kryściński et al., 2021) where the output can be longer than 1,000 tokens or generating financial reports (Kogan et al., 2009; Händschke et al., 2018) where the output exceeds 9,000 tokens.

Manual inspection of SeqPlan's summaries reveals that a major source of errors in MLB relate to attention diffusing over long paragraph plans. As an example, consider the following paragraph produced by SeqPlan "*Casey Kotchman had three hits and three RBIs , including a two - run double in the second inning that put the Angels up 2 - 0. Torii Hunter had three hits and drove in a run .*" In reality, *Torii Hunter* had two hits but the model incorrectly generates hits for *Casey Kotchman*. The corresponding paragraph plan is 360 tokens long and attention fails to discern important tokens. A more sophisticated encoder, e.g., based on Transformers (Vaswani et al., 2017), could make attention more focused. In ROTOWIRE, the majority of errors involve numbers (e.g., team attributes) and numerical comparisons. Consider an example from model output for ROTOWIRE dataset: *The Jazz got off to a quick start in this one , out - scoring the Cavaliers 29 - 25 in the first quarter* . In this case, the model generates the correct first quarter points for Jazz as *29*. However, the model realises that the first quarter points for Cavaliers too is *29* which is not less than Jazz's first quarter points. So it copies the second quarter points of Jazz. Incorporating pre-executed operations such as min, max (Nie et al., 2018) could help alleviate these errors.

6.7 Qualitative Examples

We provide two examples each of predicted macro plan and model output for ROTOWIRE (Wiseman et al., 2017), German ROTOWIRE Hayashi et al. (2019) and MLB

MILWAUKEE (AP) – **Derrick Turnbow** is finally throwing strikes now. Unfortunately for the **Brewers**, the **Cardinals** are well aware of that. <P> Skip Schumaker doubled in the go-ahead run in the **ninth** and St. Louis put Turnbow 's first three pitches in play to overcome a fielding blunder in the eighth in a 4-3 win over Milwaukee on Monday night. <P> **Schumaker** had been 0-for-4 before his hit. <P> Brian Barton, who pinch hit for reliever Ryan Franklin, doubled off a 95 mph fastball from Turnbow (0-1) to start the inning. After Cesar Izturis sacrificed Barton to second by bunting a 96 mph fastball, Schumaker came up and took another 95 mph fastball to the wall for an RBI double. <P> **Turnbow**, who has been frustrated since he 's no longer the primary set-up man, has failed to inspire any confidence for the Brewers since his precipitous decline starting July 2006. After converting 62 of his first 70 save chances with a 2.60 ERA, he 's only converted two of nine with a 6.75 ERA in his last 109 games. <P> After seven strong innings from Cardinals starter Adam Wainwright, Franklin (1-1) got the win despite giving up an unearned run by limiting the damage in the **eighth**, and Jason Isringhausen earned his seventh save in eight chances with a perfect **ninth** on six pitches. <P> It appeared the **Brewers** had all the momentum before **Franklin** stopped them cold. <P> With St. Louis leading 3-2, Ryan Braun doubled to start the **eighth** inning and right fielder Ryan Ludwick charged hard on a fly ball from Corey Hart, but slipped and lost the ball in the lights. <P> It nearly hit him in the head, but instead bounced harmlessly behind him for a triple that left **Hart** shaking his head in disbelief at his RBI that tied it at 3 after he made an errant play himself in the top half of the inning. <P> But Franklin didn't allow Milwaukee to take the lead as Hart was caught in a rundown when he tried to score on contact off a chopper by Bill Hall and J.J. Hardy grounded out to end the inning. <P> In the top half of the **eighth**, St. Louis went ahead 3-2 as a result of Hart's gaffe in right field on Ludwick's fly ball that hit the webbing of Hart's glove to put Ludwick on third with no outs. <P> **Hart** said he lost the ball in the lights, too. <P> Reliever Brian Shouse, who came in to start the **eighth** after Carlos Villanueva retired 13 of his last 14 batters, walked Albert Pujols – he had three of St. Louis' seven in the game and has reached base safely every game this season – and got Rick Ankiel to pop out. <P> But reliever Guillermo Mota could n't keep the Cardinals off the board after walking Troy Glaus despite having him down 0-2. With the bases loaded, Adam Kennedy 's sacrifice fly gave St. Louis a 3-2 lead.

Table 6.12: Human written summary for the example in Table 6.10

in Tables 6.13 – 6.18. The macro plan is at the top and the game summary is below. We see that there is strong alignment between the macro plan and the game summary. In addition, the game summary exhibits coherent ordering of facts.

<V(Thunder)> <V(Nets)> → <V(Russell Westbrook)> → <V(Victor Oladipo)> → <V(James Harden)> → <V(Steven Adams)> → <V(Enes Kanter)> → <V(Nets)> → <V(Brook Lopez)> → <V(Rondae Hollis-Jefferson)> → <V(Trevor Booker)> → <V(Justin Hamilton)> → <V(Nets)>

The Oklahoma City **Thunder** (8-5) defeated the Brooklyn **Nets** (4-8) 124-105 on Friday. Oklahoma City is on a two-game win streak, but they were able to prevail with a big road win. <P> **Russell Westbrook** continued his dominant season, as he finished with 30 points, 13 assists and 10 rebounds in 34 minutes. <P> **Victor Oladipo** added 26 points and six assists in 36 minutes. <P> **Steven Adams** scored 15 points and grabbed seven rebounds in 32 minutes. <P> **Enes Kanter** played 13 minutes off the bench and scored 13 points on 3-of-4 shooting. <P> The **Nets** have lost four of their last five games as they continue to struggle. <P> **Brook Lopez** led the way, scoring 22 points on 8-of-16 shooting in 28 minutes. <P> **Rondae Hollis-Jefferson** was the only other starter in double figures, as he posted 13 points and five rebounds. <P> **Trevor Booker** was the only other starter in double figures, as he scored four points to go along with four rebounds. <P> **Justin Hamilton** played 20 minutes off the bench and scored 10 points on 4-of-6 shooting. <P> Up next for the **Nets** is a road matchup against the Oklahoma City Thunder on Sunday.

Table 6.13: Predicted macro plan (top) with corresponding model output (bottom) for ROTOWIRE. Entities in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the summary mentions the result of the game followed by the description of the winning players, losing players and a statement about the next game.

6.8 Conclusion

In this chapter, we proposed a novel sequential latent variable model for joint macro planning and generation. Key in our approach is the creation of a latent plan in a sequential manner, while interleaving the prediction of plans and the generation of corresponding paragraphs. We proposed to deconstruct monolithic long document generation into smaller units (paragraphs in our case) which affords flexibility and better communication between planning and generation. Taken together, the results of automatic and human evaluation suggest that SeqPlan performs best in terms of factuality and coherence, it generates diverse, and overall fluent summaries and is less data-hungry compared to strong systems like Macro and NCP+CC.

<V(Pacers)> <V(Knicks)> → <V(Rodney Stuckey)> → <V(Roy Hibbert)> → <V(David West)> → <V(Knicks)> <V(Carmelo Anthony)> → <V(Lou Amundson)> → <V(Knicks)> <V(Tim Hardaway Jr.)>→ <V(Pacers)> <V(Knicks)>
The Indiana **Pacers** (17-31) defeated the New York **Knicks** (9-38) 103-82 on Monday at Bankers Life Fieldhouse in Indianapolis. The Pacers got off to a quick start in this one, outscoring the Knicks 35-12 in the first quarter alone. The Pacers were the superior shooters in this one, going 53 percent from the field and 33 percent from the three-point line, while the Knicks went just 42 percent from the floor and 31 percent from beyond the arc. <P> **Rodney Stuckey** led all scorers, going 8-for-13 from the field and 1-for-2 from the three-point line to finish with a team-high of 22 points. <P> **Roy Hibbert** recorded a double-double of his own, scoring 18 points (9-11 FG) and grabbing 10 rebounds. It was his second double-double of the year. <P> Notching a double-double of his own, **David West** finished with 10 points (3-8 FG, 4-4 FT), six rebounds and six assists. <P> The **Knicks** were led by **Carmelo Anthony**, who finished with 18 points (7-16 FG, 2-4 3Pt, 2-2 FT) in 25 minutes. <P> **Lou Amundson** had 17 points (8-10 FG, 1-3 FT) and three rebounds. <P> Considering he 's averaging only 7 points per game on the season, it was a nice surprise for the **Knicks**. <P> **Tim Hardaway Jr.** came off the bench to score 11 points (3-9 FG, 2-4 3Pt, 3-4 FT) and grabbed five rebounds in 20 minutes. <P> The **Pacers** ' next game will be at home against the Philadelphia 76ers on Friday, while the **Knicks** will be at home against the Brooklyn Nets on Friday.

Table 6.14: Predicted macro plan (top) with corresponding model output (bottom) for ROTOWIRE. Entities in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the summary mentions the result of the game followed by the description of the winning players, losing players and a statement about the next game.

<V(Wizards)> <V(Lakers)> → <V(John Wall)> → <V(Bradley Beal)> → <V(David West)> → <V(Otto Porter Jr .)> → <V(Lakers)> → <V(D'Angelo Russell)> → <V(Jordan Clarkson)> → <V(Tarik Black)> → <V(Lakers)> → <V(Wizards)>
Die Washington **Wizards** besiegten die Los Angeles **Lakers** am Freitag im Verizon Center mit 119-108 durchsetzen. <P> Sie wurden wieder einmal von ihrem Backcourt-Duo **John Wall** und John Green angeführt. <P> **Bradley Beal** wurde Zweiter im Team und erzielte 16 Punkte und 10 Rebounds. <P> **Otto Porter Jr.** kam auf 16 Punkte und vier Rebounds. <P> Für die **Lakers** steht ein Heimspiel gegen Utah Jazz am Samstag auf dem Programm. <P> **D'Angelo Russell** führte mit 28 Punkten, neun Rebounds und neun Assists an. <P> **Jordan Clarkson** kam auf 22 Punkte, acht Rebounds und drei Assists. <P> T. J. Tario kam von der Bank aus zu elf Punkten in 23 Minuten. <P> Für die **Lakers** steht ein Heimspiel am Samstag gegen die New Orleans Pelicans. <P> Die **Wizards** haben am Montag ein Heimspiel gegen die New Orleans Pelicans.

Table 6.15: Predicted macro plan (top) with corresponding model output (bottom) for German ROTOWIRE. Entities in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the summary mentions the result of the game followed by the description of the players of the two teams and a statement about the next game.

<V(Celtics)> <V(Pacers)> → <V(Isaiah Thomas)> → <V(Myles Turner)> → <V(Amir Johnson)> → <V(Monta Ellis)> → <V(Thaddeus Young)> → <V(Pacers)> → <V(Jeff Teague)> → <V(Al Jefferson)> → <V(Pacers)>
Die Boston **Celtics** (5-4) besiegten die Indiana **Pacers** (4-6) am Mittwoch mit 112:99 in der Verlängerung im Staples Center. Die Celtics (5-4) befinden sich weiter auf ihrem unglaublichen Pfad der Durchschnittlichkeit und haben in ihren letzten 15 Spielen abwechselnd gewonnen. <P> **Isaiah Thomas** tat sein Bestes, um mit 23 Punkten, elf Rebounds und fünf Assists fortsetzte. <P> **Myles Turner** erreichte ein Double-Double mit 17 Punkten und acht Rebounds. <P> **Amir Johnson** war der einzige andere Starter mit zweistelliger Punkteanzahl und kam auf 14 Punkte, neun Rebounds, drei Assists und einen Steal. <P> **Monta Ellis** steuerte 15 Punkte, vier Rebounds und vier Assists. <P> **Thaddeus Young** führte mit 10 Punkten die Bank an. <P> Für die **Pacers** folgt am Freitag ein weiteres Heimspiel gegen die Denver Nuggets. <P> **Jeff Teague** kam auf 20 Punkte und vier Assists. <P> **Al Jefferson** war in 17 Minuten von der Bank sehr gut, mit 10 Punkten, drei Rebounds und zwei Assists. <P> Für die **Pacers** steht ein Heimspiel am Samstag gegen die New Orleans Pelicans.

Table 6.16: Predicted macro plan (top) with corresponding model output (bottom) for German ROTOWIRE. Entities in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the summary mentions the result of the game followed by the description of the players of the two teams and a statement about the next game.

<V(Roy Halladay)> → <V(Roy Halladay)> <V(Blue Jays)> <V(Red Sox)> → <V(Roy Halladay)> → <V(Josh Beckett)> → <V(Red Sox)> → <V(Josh Beckett)> → <V(5-B)> → <V(9-B)> → <V(3-T)> → <V(4-B)> → <V(5-B)> → <V(6-B)> → <V(7-T)> → <V(8-T)> → <V(9-T)>
ST. PETERSBURG, Fla. – **Roy Halladay** is making the most of his opportunity. <P> **Halladay** pitched eight strong innings and the Toronto **Blue Jays** beat the Boston **Red Sox** 7-of-4 on Friday night. <P> **Halladay** (1-of-1) allowed four runs and eight hits, walked one and struck out six. <P> **Josh Beckett** (0-of-1) gave up five runs and three hits in 4 2/3 innings. <P> The **Red Sox** lost for the fourth time in five games. <P> **Beckett** said he felt fine with his control, but said he felt fine. <P> Vernon Wells hit a two-of-run homer and Aaron Hill and Aaron Hill each had two hits and an RBI for the Blue Jays, who have won four of five. Boston has lost four in a row. <P> Jeremy Accardo pitched the **ninth** for his third save in as many chances. The Blue Jays put runners on the corners with one out, but Jacoby Ellsbury struck out and Julio Lugo flied out. <P> Jacoby Ellsbury led off the **third** with a drive to left, his third homer of the season, but the Red Sox could n't hold on. The Red Sox had runners on first and second with two outs but David Ortiz grounded out to end the inning. <P> The Blue Jays took the lead with a two-of-run **fourth**. Alex Rios walked to begin the inning and Wells followed with a drive into the second deck in left, his fourth. <P> The Blue Jays chased Beckett with a four-of-run **fifth**. Aaron Hill singled and stole second, Alex Rios walked and Vernon Wells walked to load the bases. Thomas then hit the first pitch he saw from Manny Delcarmen into the second deck in left, his fourth homer of the season. <P> Aaron Hill hit an RBI double off David Aardsma in the **sixth** to make it 7-of-2, but Rios popped out to end the inning with runners at second and third. <P> Drew made it 7-of-3 in the **seventh** with a leadoff homer to left, his seventh. It was the first time this season the Red Sox have hit back-to-back homers, and the first time Halladay has gone more than six innings. <P> Youkilis hit a one-of-out triple in the **eighth** and scored on Ortiz 's single to left. Halladay got Manny Ramirez to ground into a double play to end the inning. <P> Boston put runners on the corners with one out in the **ninth**, but Accardo struck out Jacoby Ellsbury and got Julio Lugo to fly out to end the game.

Table 6.17: Predicted macro plan (top) with corresponding model output (bottom) for MLB. Entities and events in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the game summary describes the prominent entities in the game, followed by the description of the events in a coherent sequence.

<V(Edinson Volquez)> → <V(Edinson Volquez)> <V(Reds)> <V(Dodgers)> → <V(Edinson Volquez)> → <V(Reds)> → <V(4-B)> → <V(5-B)> → <V(Dodgers)> → <V(4-B)> → <V(3-T)> → <V(5-B)> → <V(8-B)> → <V(9-T)>
CINCINNATI – **Edinson Volquez** is making the most of his opportunity. <P> **Volquez** allowed one run in seven innings, and the Cincinnati **Reds** beat the Los Angeles **Dodgers** 8-1 on Friday night. <P> **Volquez** (3-0) struck out seven and walked four. <P> The **Reds** have won four of five, including a three-game sweep at Cincinnati. <P> Jerry Hairston Jr. had four hits, including a two-out, two-run single in the **fourth** inning that gave the Reds a 5-1 lead. Hairston had four hits and three RBIs. <P> Brandon Phillips and Brandon Phillips homered for the Reds, who have lost four of five. Joey Votto had three hits, including a run-scoring double in the **fifth** inning, and Joey Votto had three hits. <P> The **Dodgers**, who have lost four of five, were held to five hits. <P> Volquez (3-0) allowed one run and three hits in seven innings, struck out seven and walked four. The right-hander, who was called up from Triple-A Albuquerque earlier in the day, replaced Hong-Chih Kuo (0-1). <P> The Dodgers took a 1-0 lead in the **third** on a one-out double by Kuo and an RBI double by Rafael Furcal, who was called up from Triple-A Louisville earlier in the day. <P> Phillips hit a solo homer off Esteban Loaiza in the **fifth**, and Joey Votto added an RBI double later in the inning to make it 7-1. <P> The Reds added a run in the **eighth** on Corey Patterson 's one-out triple and scored on Jerry Hairston 's single. Patterson hit a one-out triple and scored on Jerry Hairston 's single. <P> The Dodgers had a chance to add to their lead in the **ninth** when Andre Ethier walked and Kemp grounded into a double play. Loney followed with a single, but Juan Pierre flied out to end the inning.

Table 6.18: Predicted macro plan (top) with corresponding model output (bottom) for MLB. Entities and events in the summary corresponding to those in the macro plan are bold faced. We see that there is strong alignment between paragraph plans in the macro plan, and paragraphs in the model output. In addition, the generated summary exhibits coherent ordering of facts. In this case, the game summary describes the prominent entity in the game, followed by the description of the events in a coherent sequence.

Chapter 7

Conclusions

In this thesis, we have focused on data-to-text generation, which aims to produce textual output from non-linguistic input. Most recent work on data-to-text generation makes use of neural networks to address this task focusing almost exclusively on the encoder-decoder architecture. Such models are often trained in an end-to-end manner without specific modules for document or micro planning. The expectation is that these models will learn to perform planning on their own without the addition of any special-purpose mechanisms or changes to the encoder-decoder architecture. Despite producing overall fluent text, neural systems have difficulty capturing long-term structure and generating documents more than a few sentences long. Wiseman et al. (2017) showed that neural text generation techniques perform poorly at content selection, struggle to maintain inter-sentential coherence, and more generally a reasonable ordering of the selected facts in the output text. Additional challenges include avoiding redundancy and being faithful to the input. More recently, Maynez et al. (2020) conducted a large-scale human evaluation exercise to study the faithfulness of model output for the task of abstractive summarization. In this study, they asked human raters to annotate spans in summaries that are not faithful to the input document. They compared different variants of neural models, including pretrained models and found that the latter are faithful only 26.9% of the time to the input document.

In this thesis, we have argued that the introduction of planning can address some of these challenges in neural data-to-text generation. We have hypothesized that content planning can serve as an intermediate stage between the (data) input and (textual) output. The content plan provides information about what should be communicated and in what structure in the output document, which in turn enables the decoder to focus on the less challenging task of predicting tokens conformant to the plan.

Micro planning generally involves deciding on specific words to describe concepts and relations, generating referring expressions, and aggregating content into sentences (Reiter and Dale, 2000). We introduced neural micro planning in Chapter 3. We proposed modifications to contemporary neural encoder-decoder models, which inject planning in the generation process. Specifically, we developed a model which learns a micro plan from the input and conditions on it to generate the output document. We operationalized micro plans as a sequence of records from the input table. For training the micro planner, we extracted oracle micro plans from game summaries following an information extraction (IE) approach. Specifically, we adopted the IE model introduced in Wiseman et al. (2017), which identifies candidate entity (i.e., player, team,and city) and value (i.e., number or string) pairs that appear in the text, and then predicts the type (aka relation) of each candidate pair. Given the output of an IE system, a micro plan consists of (entity, value, record type) tuples in their order of appearance in a game summary.

Micro planning, however, requires fine-grained record level supervision for training. It assumes the availability of a highly precise and broad coverage IE tool. For MLB, the IE has lower precision and coverage, as it is difficult to detect entity-value pairs with simple pattern matching. Consequently, supervision for oracle micro plans is not easy to obtain and the reliance on IE as a preprocessing step makes the approach domain dependent and less scalable. In Chapter 4, we explored how to perform data-to-text generation by inducing latent plans which operate at a higher level than records, such as entities. Our model creates entity-specific representations which are dynamically updated. Text is generated by conditioning on the data input and entity memory representations using hierarchical attention at each time step.

Unfortunately, the approach of latent entity planning does not handle events, which are often present in data-to-text generation tasks, in particular those in the sports domain. For example, in the MLB dataset the play-by-play table documents the most important events in a game in chronological order. In Chapter 5, we introduced neural macro planning, which combines planning with the high level organization of entities *and* events. Macro planning reconceptualizes the input in terms of paragraph plans to facilitate *document-level* planning. In the sports domain, paragraphs typically mention entities (e.g, players important in the game), key events (e.g., scoring a run), and their interaction. And most of this information is encapsulated in the statistics accompanying game summaries. We thus define paragraph plans such that they contain verbalizations of entity and event records. Macro planning advocates the use of macro

plans for improving the organization of document content and structure. A macro plan is a sequence of paragraph plans, and each paragraph plan corresponds to a document paragraph. In the first stage of our model, the macro planner produces a macro plan from the input of a set of paragraph plans. In the second stage, the surface realisation module generates the text conditioned on the predicted macro plan.

With macro planning, the input to data-to-text generation is no longer a complicated table but a sequence of paragraph plans. Thus macro planning allows us to treat data-to-text generation as a sequence-to-sequence learning problem. Macro plans, however, tend to be long, and thus challenging for the attention mechanism during text generation. Moreover, the model introduced in Chapter 5 predicts a macro plan by conditioning on the input, without making use of information present in the summary. We remedy these problems by introducing variational sequential planning in Chapter 6. We infer latent plans sequentially with a structured variational model while interleaving the steps of planning and generation. Text is generated by conditioning on previous variational decisions and previously generated text.

The findings of this thesis include:

- We proposed different variants of content planning for data-to-text generation, including fine-grained planning (micro planning), latent entity planning, coarse-grained planning (macro planning), and variational sequential planning. In doing so, we have shown that planning remains an integral part of the generation process and can be integrated into modern neural network architectures.

- We showed that planning improves the factuality and coherence of the generated documents, and reduces redundancy in the output document. Although not the focus of this thesis, we have developed models which allow users to control the generation process, e.g., by explicitly changing the plan or merely inspecting it to rationalize model predictions.

- We created a new dataset for Major League Baseball (MLB). Compared to ROTOWIRE (Wiseman et al., 2017), MLB summaries are longer, and the input records are richer and more structured. Moreover, the MLB dataset is five times larger in size.

- The work presented in this thesis has influenced and is a part of a larger body of recent work integrating content planning in text generation (Moryossef et al.,

2019; Fu et al., 2019; Shao et al., 2019; Zhao et al., 2020; Shen et al., 2020; Narayan et al., 2020, 2021, inter alia).

7.1 Future Work

In this section we look into possible avenues for future work, and discuss extensions to the models presented in this thesis.

Combining Micro and Macro Planning In the future, we envisage creating a model which combines the merits of micro and macro planning. In this model, macro planning will be responsible for overall document coherence and selection of paragraph plans, while micro planning will assume the responsibility of generating an accurate, succinct, and fluent paragraph. Training a micro planner, however, requires fine-grained supervision. Such supervision in the form of relations extracted using IE suffers from low coverage and precision for some datasets such as MLB. We will need to investigate techniques to train micro planners using partial supervision. For example, we could use IE to extract relations that are high precision but possibly low recall. Unlike the approach in Chapter 3, where the micro plan contains all the relations in the game summary, the micro plan will now include a subset of high precision relations. The surface realiser will then describe these relations from the micro plan and may also describe other relations directly from the macro plan.

Discrete Reasoning In this thesis we have worked with two sports datasets, namely MLB and ROTOWIRE, both of which require discrete reasoning. Consider a sentence from a ROTOWIRE game summary "The host Toronto Raptors defeated the Philadelphia 76ers, 122 - 95, at Air Canada Center on Monday.". Generating such a sentence requires the model to know which team scored higher. For the statement "Sergio Rodriguez, Ersan Ilyasova, Nik Stauskas and Richaun Holmes all finished with 11 points apiece.", the model needs to compare scores of multiple players, reason that they are equal, and then generate the statement. Currently, the models presented in this thesis have a basic understanding of numbers acquired through word embeddings. It will be interesting to explore better numerical reasoning in the context of generation. Incorporating ideas from models used for QA datasets such as DROP (Dua et al., 2019)[1] requiring discrete reasoning seems a promising research direction. Recent work in data-to-

[1]DROP stands for Discrete Reasoning Over Paragraphs

text generation has incorporated pre-executed operations such as min, max (Nie et al., 2018). Wallace et al. (2019) show that character-level embeddings are better than word embeddings for encoding numbers when evaluated on DROP (Dua et al., 2019). Combining character embeddings with pre-executed operations (Nie et al., 2018) would be an interesting research direction to explore.

Pretrained Language Models Pretrained language models such as BART (Lewis et al., 2020) or T5 (Raffel et al., 2020) have recently found many applications in Natural Language Generation, including summarization (Rothe et al., 2021) and data-to-text generation of small outputs (Kale and Rastogi, 2020). These pretrained models can handle a maximum length of 512 tokens for the input and output, a restriction imposed by the Transformer (Vaswani et al., 2017) architecture. In Chapter 5, the input to text generation stage is a lengthy macro plan, and the output is the whole document. Longer inputs and outputs preclude the usage of pretrained language models. With the approach of variational sequential planning in Chapter 6, the input to text generation stage is a single paragraph plan, and the output is a paragraph of text. Thus, it is now feasible to initialize our variational sequential model with pretrained models and finetune on the RotoWire/MLB dataset. As pretrained models have been trained on large amounts of text, they will help improve the fluency of generated summaries.

Other Generation Tasks Finally, we hypothesize that micro and macro planning will be applicable to other generation tasks like summarization. Recent work by Narayan et al. (2021) produces content plans containing a list of entities while generating summaries. Their summaries are around four sentences long. Future work can involve enriching their micro plans with relations between entities. Such relations can be obtained using an Information Extraction approach (Angeli et al., 2015). Likewise, macro planning and variational sequential planning can be applicable to long-form summarization tasks such as summarizing books (Kryściński et al., 2021), where the output can be longer than 1,000 tokens.

Appendix A

Human Evaluation for Fact Verification

In this chapter and the next, we will go through the instructions provided to raters who conducted the human evaluation studies. We asked participants to assess model output in terms of relation generation, grammaticality, coherence, and conciseness for the two datasets: ROTOWIRE and MLB. We conducted our study on the Amazon Mechanical Turk (AMT) crowdsourcing platform. In this chapter, we will describe the instructions provided to the raters for the task of fact verification of model outputs for ROTOWIRE and MLB. In the next chapter, we will describe the instructions for evaluating the quality of model outputs in terms of grammaticality, coherence, and conciseness. Section A.1 describes the instructions to raters for fact verification of ROTOWIRE and Section A.2 describes the instructions to raters for fact verification of MLB. The annotation scripts for fact verification have been adapted from the scripts produced by Wiseman et al. (2017).

A.1 Fact Verification for ROTOWIRE Instructions

Table A.1 describes the title and description of the task, along with the qualifications required by the raters. The title and description is presented to the raters whereas the qualifications are used to automatically filter raters in the platform.

Instructions This questionnaire will ask you to determine whether an English sentence correctly reports the facts in an NBA basketball game's box- and line-score tables. You do not need to be familiar with basketball to answer these questions; we explain how to read the tables below!
This task contains validation instances (for which answers are known) that will be used

Title	Fact verification for NBA basketball game's box- and line-score tables
Description	Verify if an English sentence correctly reports the facts in an NBA basketball game's box- and line-score tables
Qualifications Required	HIT Approval Rate (%) for all Requesters' HITs greater than 98 Number of HITs Approved greater than 1000 Location is one of AU, CA, IE, NZ, GB, US

Table A.1: Title and description of human evaluation for fact verification for ROTOWIRE dataset

CITY	NAME	PTS QTR1	PTS QTR2	PTS QTR3	PTS QTR4	PTS	FG PCT	FG3 PCT	FT PCT	REB	AST	TOV	WIN	LOSS
Boston	Celtics	22	34	32	31	119	49	35	69	39	25	5	18	13
New York	Knicks	28	20	34	32	114	43	33	66	49	11	17	16	14

Table A.2: Example of line score for a single game in NBA between the Boston Celtics and the New York Knicks

for an automatic quality assessment of submissions. Therefore, please go through the task carefully .

How to Read Line- and Box-Scores Each NBA game has associated with it a box- and line-score table that summarizes the statistics from the game. We show an example line-score from a single game between the Boston Celtics and the New York Knicks in Table A.2.

The line-score (Table A.2) reports team-level statistics from the game. You can use the keys in Table A.3 to interpret the columns of the line-score.

So, for example, the line-score in Table A.2 indicates that Boston scored 32 points in the third quarter, that they had 5 turnovers overall, and that they have won 18 games this season, and lost 13.

Next is the same game's box-score, which contains statistics for each player (Table A.4). It should be interpreted in a similar way to the line-score, except that it reports statistics for each player, rather than for the team as a whole.

Some of the columns of the box-score are the same as in the line-score. We provide a key in Table A.5 explaining the remaining columns.

Line-Score Column Name(s)	Meaning
PTS QTR1	Points scored by team in game's first quarter. (PTS QTR2, PTS QTR3, PTS QTR4 are defined analogously).
PTS	Total team points.
FG PCT	Percentage of field goals made by team.
FG3 PCT	Percentage of 3 pointers made by team.
FT PCT	Percentage of free throws made by team.
REB	Total team rebounds.
AST	Total team assists.
TOV	Total team turnovers.
WINS	Number of games won by the team in the current season.
LOSSES	Number of games lost by the team in the current season.

Table A.3: Keys to interpret the columns of line score of NBA game

So, for example, the box-score in Table A.4 indicates that Lance Thomas played for 9 minutes, and scored 3 points by going 1-for-3 on his 2-point or 3-point shots. 1 of those shots was a 3-pointer, which he did not make, and the remaining shots were 2-pointers, which he made one of, giving 2 points. He also went 1-for-1 from the free-throw line, giving his third total point.

The Task You will be given a single pair of line- and box-score tables, as well as some English sentences that purport to report information in the tables. For each sentence, your task is to determine how many of the numbers (or number-words) in the sentence are actually supported by the tables, and how many are contradicted by the tables. For example, using the tables above, consider the following sentence:

Sentence: The Boston Celtics (18-13) defeated the New York Knicks (16-14) 119-115 on Wednesday night.

In the above example, there are 5 numbers that are supported by the table (Celtics WINS, Celtics LOSSES, Knicks WINS, Knicks LOSSES, Celtics PTS), and 1 that contradicts the table (Knicks PTS). Therefore, please select '5' from the "Correct numbers in sentence" dropdown, and '1' from the "Incorrect numbers in sentence" dropdown.

Here is another example:

Sentence: Carmelo Anthony finished with 38 points , seven rebounds , and two assists in 39 minutes improving over the 20 points he made last Thursday.

In this case there are three correct numbers (REB, AST, MIN), and one incorrect number (PTS), and so you should select '3' and '1' from the dropdowns, respectively.

PLAYER NAME	TEAM CITY	MIN	PTS	FGM	FGA	FG-3M	FG-3A	FTM	FTA	REB	AST	TOV	STL	BLK
Jae Crowder	Boston	34	16	5	9	3	6	3	4	6	1	0	0	0
Jaylen Brown	Boston	6	0	0	1	0	0	0	0	2	0	0	0	0
Marcus Smart	Boston	28	15	5	9	2	4	3	4	2	7	1	1	0
Jonas Jerebko	Boston	13	2	1	5	0	3	0	0	2	0	0	1	0
Isaiah Thomas	Boston	33	27	9	23	3	13	6	8	3	3	2	0	0
Avery Bradley	Boston	32	11	5	12	1	1	0	0	6	3	1	3	0
Kelly Olynyk	Boston	23	16	7	9	2	3	0	0	2	2	1	0	0
Al Horford	Boston	35	15	7	13	1	3	0	0	7	5	0	3	1
Gerald Green	Boston	12	8	3	6	2	3	0	0	3	1	0	1	1
Amir Johnson	Boston	24	9	3	6	0	0	3	4	6	3	0	1	0
Kyle O'Quinn	New York	13	6	3	4	0	0	0	0	4	0	4	0	0
Derrick Rose	New York	38	25	10	19	0	0	5	6	5	3	3	0	0
Brandon Jennings	New York	16	0	0	2	0	1	0	0	2	2	1	2	0
Willy Hernangomez	New York	3	0	0	0	0	0	0	0	0	0	0	0	0
Mindaugas Kuzminskas	New York	9	3	1	3	1	2	0	0	1	0	0	0	0
Courtney Lee	New York	34	11	4	9	2	6	1	2	3	0	0	0	2
Joakim Noah	New York	28	8	3	4	0	0	2	3	12	2	0	0	0
Kristaps Porzingis	New York	37	22	9	16	2	4	2	2	12	1	5	2	3
Carmelo Anthony	New York	39	29	9	24	2	7	9	9	7	2	2	1	1
Lance Thomas	New York	9	3	1	3	0	1	1	1	2	1	0	0	0
Justin Holiday	New York	14	7	1	3	1	2	4	4	1	0	2	0	0

Table A.4: Box score of a NBA game

While there is an additional number in the sentence (20 points last Thursday.), it is neither supported nor contradicted by any of the tables, and so it should not affect what you put in the dropdowns.

In order to get paid, please make sure that you answer all 4 questions.

Box-Score Column Name	Meaning
MIN	Minutes a player was in the game.
FGM	How many field-goals (2-point or 3-point shots) a player made.
FGA	How many field-goals (2-point or 3-point shots) a player attempted.
FG3M	How many 3-point shots a player made.
FG3A	How many 3-point shots a player attempted.
FTM	How many free-throws a player made.
FTA	How many free-throws a player attempted.
STL	Number of steals made by a player.
BLK	Number of blocks made by a player.

Table A.5: Keys to interpret the box score of NBA game

Consent Statement We invite you to participate in a research study related to the production of informative text. There are no risks or benefits associated with participating in this study, but you will be paid for your participation as indicated in the HIT. Your participation is of course voluntary, and you may withdraw at any time. If you have any questions, concerns, or complaints, please email r.puduppully [at] sms [dot] ed [dot] ac [dot] uk.

If your browser has JavaScript turned on, a counter will be displayed at the bottom of the page indicating how many questions have been answered. It is highly recommended that you turn on JavaScript and use this tool before submitting to ensure that all questions have been answered and you can receive payment.

Are you a native speaker of English? Yes/No (Your answer to this question does not affect the payment.)

Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

A.2 Fact Verification for MLB Instructions

Table A.6 describes the title and description of the task, along with the qualifications required by the raters. The title and description is presented to the raters whereas the qualifications are used to automatically filter raters in the platform.

Instructions This questionnaire will ask you to determine whether an English sentence correctly reports the facts in an MLB baseball game's box, line-score and play-by-play tables. You do not need to be familiar with baseball to answer these questions;

Title	Fact verification for MLB baseball game's box, line-score and play-by-play tables
Description	Verify if an English sentence correctly reports the facts in an MLB baseball game's box, line-score and play-by-play tables.
Qualifications Required	HIT Approval Rate (%) for all Requesters' HITs greater than 98 Number of HITs Approved greater than 1000 Location is one of AU, CA, IE, NZ, GB, US

Table A.6: Title and description of human evaluation for fact verification for MLB dataset

CITY	NAME	RUNS	HIT	ERR	RESULT	SIDE
San Francisco	Giants	6	17	1	loss	Home
Philadelphia	Phillies	7	8	1	win	Away

Table A.7: Example of line score from MLB game

we explain how to read the tables below!

This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please go through the task carefully .

How to Read Line, Box-Scores and Play-by-play Each MLB game has associated with it a box-, line-score and play-by-play table that summarizes the statistics from the game. In Table A.7 we show an example line-score from a single game between the San Francisco Giants and the Philadelphia Phillies.

The line-score in Table A.7 reports team-level statistics from the game. You can use the key in Table A.8 to interpret the columns of the line-score.

So, for example, the line-score in Table A.7 indicates that Phillies scored 7 runs, had 8 hits and won the game.

Next is the same game's box score including batting and pitching statistics. The batting statistics (Table A.9) report batting performance for each player. It should be interpreted in a similar way to the line-score, except that it reports batting statistics for each player, rather than for the team as a whole.

Some of the columns of the batting statistics are the same as in the line-score. In Table A.10 we provide a key explaining the remaining columns.

So, for example, the batting statistics in Table A.9 indicates that Nate Schierholtz

Line-Score Column Name(s)	Meaning
RUNS	Total team runs.
HIT	Total team hits.
ERR	Total team errors.
RESULT	Result of game
SIDE	Home or Away

Table A.8: Keys to interpret line score of MLB game

scored 3 runs and 1 RBI. Ryan Howard scored 2 runs out of which 1 was a home run.

Next is the same game's pitching statistics (Table A.11), which contains statistics for each pitcher. It should be interpreted in a similar way to the batting statistics, except that it reports statistics for each pitcher.

Some of the columns of the pitching statistics are the same as in the line-score/ batting statistics. In Table A.12 we provide a key explaining the remaining columns.

In the above pitching statistic, Ryan Madson has 1 wins and 0 losses, he pitched one inning and was the winning pitcher. Tim Lincecum (4 - 0) allowed 2 runs , 3 hits and 1 walks in 8 1/3 innings.

Next is the same game's play-by-play statistics (Table A.13), which contains details of events occurred in a game. It is in chronological order.

Some of the columns of the play-by-play statistics are the same as in the line-score/ batting/ pitching statistics. Below we provide a key explaining the remaining columns.

So, for example, the play-by-play above indicates that in the fifth inning, Ryan Howard hit 1 RBI homer for Phillies and Andres Torres hit 1 RBI double for Giants.

The Task You will be given a single pair of line-, box-score and play-by-play tables, as well as some English sentences that purport to report information in the tables. For each sentence, your task is to determine how many of the facts in the sentence are actually supported by the tables, and how many are contradicted by the tables. For example, using the tables above, consider the following sentence:

Here is one example:

Sentence: Tim Lincecum (4 - 4) was charged with 2 runs and 3 hits in 7 1/3 innings, striking out 11 and walking 1.

In the above example, there are 6 facts that are supported by the table (Lincecum 4 wins, 2 runs given, 3 hits allowed, 1/3 IP2, 11 strike outs, 1 walks), and 2 that contradicts the table (4 losses, 7 IP1). Therefore, please select '6' from the "Correct

PLAYER_NAME	TEAM	RUN	RBI	POS	AVG	WLK	ERR	HIT	HR	SIDE
Nate Schierholtz	Giants	3	1	RF	.378	1	0	5	0	Home
Bengie Molina	Giants	1	0	C	.350	2	0	3	0	Home
Eli Whiteside	Giants	1	0	PR	.353	0	0	0	0	Home
Matt Downs	Giants	1	0	2B	.308	0	0	1	0	Home
Andres Torres	Giants	0	3	CF	.275	1	0	2	0	Home
Edgar Renteria	Giants	0	2	SS	.320	1	0	2	0	Home
Travis Ishikawa	Giants	0	0	1B	.167	0	0	0	0	Home
Brian Wilson	Giants	0	0	P	.000	0	0	0	0	Home
Ryan Howard	Phillies	2	1	1B	.286	1	1	2	1	Away
Wilson Valdez	Phillies	1	1	SS	.231	0	0	1	0	Away
Raul Ibanez	Phillies	1	0	LF	.219	1	0	1	0	Away
Brian Schneider	Phillies	1	0	C	.143	0	0	0	0	Away
Chase Utley	Phillies	1	0	2B	.282	1	0	1	0	Away
Shane Victorino	Phillies	1	0	CF	.225	1	0	1	0	Away
Jayson Werth	Phillies	0	3	RF	.315	0	0	1	0	Away
Juan Castro	Phillies	0	0	SS	.283	0	0	0	0	Away
Placido Polanco	Phillies	0	0	3B	.313	0	0	1	0	Away
Nelson Figueroa	Phillies	0	0	P	.500	0	0	0	0	Away

Table A.9: Example of batting statistics in MLB

facts in sentence" dropdown, and '2' from the "Incorrect facts in sentence" dropdown.

Here is another example:

Sentence: Schierholtz went 5 - for - 5 with an RBI double in the 11th inning , and the Phillies beat the San Francisco Giants 6 - 6 on Tuesday night to snap a four - game losing streak .

In the above example, there are 4 facts that are supported by the tables (Schierholtz 1 RBI, Schierholtz Double, INNING 11, Giants 6) and one that contradicts the table (Phillies 6). Therefore, please select '4' from the "Correct facts in sentence" dropdown, and '1' from the "Incorrect facts in sentence" dropdown. While there are additional facts in the sentence (5 - for - 5, four - game losing streak), they are neither supported nor contradicted by any of the tables, and so it should not affect what you put in the dropdowns.

Here is one more example:

Sentence: Ryan Howard led off the fifth with a home run and Edgar Renteria added

Box-Score Column Name	Meaning
RUN	Runs scored by a player in the game.
RBI	Runs Batted In (RBI): action of a batter results in a run scored by other players in the team.
POS	Position of the player.
AVG	Batting Average. It is an indicator of the hits in the players' career.
WLK	A walk occurs when a pitcher throws four pitches out of the strike zone, none of which are swung at by the hitter.
HR	Batter hits the ball in the air over the outfield fence.

Table A.10: Keys to interpret batting statistics in MLB

a one - run single in the sixth to give the Giants a 4 - 1 lead .

In the above example, there are 6 facts that are supported by the table (Howard home run, Inning fifth, Renteria single, Inning sixth, Giants 4 runs, Phillies 1 run), and 1 that contradicts the table (Renterial one-run). Therefore, please select '6' from the "Correct facts in sentence" dropdown, and '1' from the "Incorrect facts in sentence" dropdown.

Another example:

Sentence: The Phillies defeated the Giants 7 - 6; Giants were shut out for the fifth time this season and have lost eight of their past ten games .

In the above example, there are two facts supported by the table (Phillies 7, Giants 6). While there are additional facts mentioned in the sentence (fifth time, lost eight of their past ten games), they are neither supported nor contradicted by the tables. So it should not affect what you put in the dropdowns. Therefore, please select '2' from the "Correct facts in sentence" dropdown, and '0' from the "Incorrect facts in sentence" dropdown.

In order to get paid, please make sure that you answer all 4 questions.

Consent Statement: We invite you to participate in a research study related to the production of informative text. There are no risks or benefits associated with participating in this study, but you will be paid for your participation as indicated in the HIT. Your participation is of course voluntary, and you may withdraw at any time. If you have any questions, concerns, or complaints, please email r.puduppully [at] sms [dot] ed [dot] ac [dot] uk.

If your browser has JavaScript turned on, a counter will be displayed at the bottom

PLAYER NAME	TEAM	RUN	WLK	HIT	HR	ER	ERA	NP	IP1	IP2	SO	WN	LS	W	L	SAV	SV	SIDE
Tim Lincecum	Giants	2	1	3	1	2	1.27	106	8	1/3	11	4	0	-	-	-	0	Home
Sergio Romo	Giants	2	0	2	0	1	1.64	22	1	1/3	2	0	2	-	Y	-	0	Home
Brian Wilson	Giants	2	2	2	0	2	2.25	25	0	2/3	0	0	0	-	-	-	4	Home
Jeremy Affeldt	Giants	1	1	1	0	1	3.12	15	0	2/3	1	2	2	-	-	-	1	Home
Cole Hamels	Phillies	4	4	9	0	4	5.28	113	6	-	10	2	2	-	-	-	0	Away
Nelson Figueroa	Phillies	1	0	3	0	1	3.38	28	1	-	0	1	1	-	-	Y	1	Away
Danys Baez	Phillies	0	0	1	0	0	5.63	15	1	-	0	0	1	-	-	-	0	Away
Ryan Madson	Phillies	1	1	2	0	1	7.00	27	1	-	0	1	0	Y	-	-	4	Away
Jose Contreras	Phillies	0	0	1	0	0	1.35	13	1	-	1	1	1	-	-	-	0	Away
David Herndon	Phillies	0	1	1	0	0	6.23	15	1	-	1	0	1	-	-	-	0	Away

Table A.11: Example of pitching statistics in MLB

of the page indicating how many questions have been answered. It is highly recommended that you turn on JavaScript and use this tool before submitting to ensure that all questions have been answered and you can receive payment.

Pitching Column Name	Meaning
RUN	Runs given by a player in the game.
WLK	Walks allowed by pitcher in a game.
HIT	Hits allowed by pitcher in a game.
HR	Home runs allowed by pitcher in a game.
ER	Earned Run (ER): An earned run is any run that scores against a pitcher.
ERA	Earned Run Average (ERA): Earned run average represents the number of earned runs a pitcher allows per nine innings.
NP	Number of Pitches: A pitcher's total number of pitches is determined by all the pitches he throws in game.
IP1	Innings Pitched (IP1): Innings pitched measures the number of innings a pitcher remains in a game. Because there are three outs in an inning, each out recorded represents one-third of an inning pitched.
IP2	Innings Pitched (IP2): Innings pitched measures the number of innings a pitcher remains in a game. Because there are three outs in an inning, each out recorded represents one-third of an inning pitched.
W	A pitcher receives a win when he is the pitcher of record when his team takes the lead for good.
L	A pitcher receives a loss when a run that is charged to him proves to be the go-ahead run in the game, giving the opposing team a lead it never gives up.
SO	A strikeout occurs when a pitcher throws any combination of three swinging or looking strikes to a hitter.
SAV	Save: A save is awarded to the relief pitcher who finishes a game for the winning team. A pitcher cannot receive a save and a win in the same game.
SV	Saves: The count of saves recorded by a pitcher in his career.

Table A.12: Key for pitching statistics in MLB

BATTER	PITCHER	BASE1	BASE2	BASE3	SCORER/S	EVENT	RUN	RBI	Runs (H)	Runs (A)	INN	SIDE
Ryan Howard	Tim Lincecum	-	-	-	-	Home Run	1	1	0	1	5	top
Andres Torres	Cole Hamels	-	Andres Torres	-	Nate Schierholtz	Double	1	1	1	1	5	bottom
Andres Torres	Cole Hamels	Andres Torres	Nate Schierholtz	Matt Downs	Bengie Molina	Walk	1	1	2	1	6	bottom
Edgar Renteria	Cole Hamels	Edgar Renteria	Nate Schierholtz	Andres Torres	Matt Downs, Nate Schierholtz	Single	2	2	4	1	6	bottom
Jayson Werth	Brian Wilson	-	Jayson Werth	-	Shane Victorino, Chase Utley, Ryan Howard	Double	3	3	4	4	9	top
Placido Polanco	Jeremy Affeldt	-	Shane Victorino	-	Brian Schneider	Wild Pitch	1	-	4	5	10	top
Andres Torres	Ryan Madson	Andres Torres	-	-	Nate Schierholtz	Single	1	1	5	5	10	bottom
Wilson Valdez	Sergio Romo	-	Wilson Valdez	-	Raul Ibanez	Double	1	1	5	6	11	top
Shane Victorino	Sergio Romo	-	Shane Victorino	-	Wilson Valdez	Field Error	1	-	5	7	11	top
Nate Schierholtz	Nelson Figueroa	-	Nate Schierholtz	Juan Uribe	Eli Whiteside	Double	1	1	6	7	11	bottom

Table A.13: Example of play-by-play statistics in MLB

Play-by-play Column Name	Meaning
BATTER	Batter in the play.
PITCHER	Pitcher in play.
BASE1	Player/s at first base position.
BASE2	Player/s at second base position.
BASE3	Player/s at third base position.
SCORER/S	Player/s scored in the play.
FIELDER_ERR	Player committed field error.
EVENT	Event of the play such as single, double, home run etc.
EVENT2	Second event of the play such as wild pitch, error etc.
INNING	Inning of the play.
Side	If home team is batting it is bottom and if away team is batting it is top.

Table A.14: Key for interpreting columns in play-by-play in MLB

Appendix B

Human Evaluation for Summary Quality

In the previous chapter, we went through the instructions provided to raters for the human evaluation study for fact verification. In this chapter, we go through the instructions provided to raters for the human evaluation study related to the quality of the summary including coherence, conciseness and grammaticality. Sections B.1- B.3 describe the instructions for the tasks for evaluation of coherence, conciseness and grammaticality respectively for ROTOWIRE dataset. Sections B.4- B.6 describe the instructions for evaluation of coherence, conciseness and grammaticality respectively for MLB dataset.

B.1 Evaluation of Coherence for ROTOWIRE

General Instructions Attempt HITs if you are a native speaker of English or a near-native speaker who can comfortably comprehend summary of NBA basketball games written in English. We are happy to receive feedback and improve this job accordingly. Feel free to send your comments to: r.puduppully [at] sms [dot] ed [dot] ac [dot] uk. Your responses are confidential. Any publications based on these will not include your specific responses, but rather aggregate information from many individuals. We will not ask any information that can be used to identify who you are.

Evaluate Sports Summaries of (NBA) basketball games Your task it to read two short texts which have been produced by different automatic systems. These systems typically take a large table as input which contains statistics of a basketball game and

produce a document which summarizes the table in natural langauge (e.g., talks about what happened in the game, who scored, who won and so on). Please read the two summaries carefully and judge how good each is according to the following criterion:

Coherence : How coherent is the summary? How natural is the ordering of the facts? The summary should be well structured and well organized and have a natural ordering of the facts.

This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully .

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Coherence.)

A: The Golden State Warriors (43 - 7) defeated the Los Angeles Clippers (31 - 19) 133 - 120 on Saturday . The Warriors came into this game as one of the best defenses in the NBA this season , but they were able to prevail with a huge road win . In fact , Golden State shot 53 percent from the field and 41 percent from three - point range . Golden State shot 53 percent from the field and 41 percent from three - point range . The Warriors also dominated the assist - to - turnover ratio , recording 38 assists to 11 turnovers , while the Clippers committed 15 turnovers to just 15 assists . The Warriors (31 - 19) had to play this game extremely shorthanded and they did n't disappoint . Stephen Curry carried the load , as he tallied 29 points , three rebounds and 11 assists on 11 - of - 23 shooting . Kevin Durant was the only other starter in double figures , as he dropped 26 points on 8 - of - 18 shooting . Klay Thompson finished with 21 points and seven rebounds . Draymond Green was the only other player in double figures , as he totaled 10 points , seven rebounds and two assists . The Clippers (31 - 19) were led by Blake Griffin , who tallied 31 points , eight rebounds and three steals in the defeat . Jamal Crawford also had a nice game off the bench , as he scored 21 points off the bench . On deck for Golden State is a road matchup against the Los Angeles Lakers on Thursday .

B: The Golden State Warriors defeated the Los Angeles Clippers , 133 - 120 , at Staples Center on Wednesday . The Warriors (43 - 7) came into this game as a sizable

favorite and they showed why in this clincher . Golden State (31 - 19) came into this game as a huge favorite and they showed some resiliency here with this win . Blake Griffin was the high - point man , as he tallied 31 points , eight rebounds , two assists , three steals and one block on 10 - of - 19 shooting . Klay Thompson finished with 21 points , seven rebounds and two assists . Austin Rivers was the only other starter in double figures , as he tallied 18 points , four rebounds and six assists on 7 - of - 15 shooting . Jamal Crawford was huge off the bench , providing 21 points (i) on 7 - of - 11 shooting off the bench . Blake Griffin led the team in scoring , dropping 31 points on 10 - of - 19 shooting . Kevin Durant finished with 26 points , eight rebounds and 10 assists . Jamal Crawford was huge off the bench , as he provided 21 points and four assists . DeAndre Jordan recorded a double - double , totaling 13 points and eight rebounds . Jamal Crawford was huge off the bench , dropping 21 points on 7 - of - 11 shooting , including 5 - of - 8 from three - point range . Austin Rivers led the Clippers in scoring with 18 points on 7 - of - 15 from the field . (ii)

Answers

Coherence

Best: A Worst: B

Analysis

Coherence. Summary A contains the details of better scoring players of the teams in the game in a coherent manner. The highlighted sentences in blue are one example of natural ordering of facts in the summary. In Summary B, in contrast, the facts are ordered in a less natural way such as sentences in (i) and (ii). Thus, Summary A is best.

Optional: Are you a native speaker of English? Yes/ No
(Your answer to this question will not affect acceptance of the HIT or your payment.)
Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

B.2 Evaluation of Conciseness for ROTOWIRE

General Instructions Attempt HITs if you are a native speaker of English or a near-native speaker who can comfortably comprehend summary of NBA basketball games written in English. We are happy to receive feedback and improve this job accordingly. Feel free to send your comments to: r.puduppully [at] sms [dot] ed [dot] ac [dot] uk. Your responses are confidential. Any publications based on these will not include your

specific responses, but rather aggregate information from many individuals. We will not ask any information that can be used to identify who you are.

Evaluate Sports Summaries of (NBA) basketball games Your task it to read two short texts which have been produced by different automatic systems. These systems typically take a large table as input which contains statistics of a basketball game and produce a document which summarizes the table in natural langauge (e.g., talks about what happened in the game, who scored, who won and so on). Please read the two summaries carefully and judge how good each is according to the following criterion:

Avoid repetition : Which summary is better at avoiding unnecessary repetition? Unnecessary repetition might take the form of whole sentences that are repeated, or repeated facts, or the repeated use of a phrase This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully .

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Avoiding repetition.)

A: The Golden State Warriors defeated the Los Angeles Clippers , 133 - 120 , at Staples Center on Wednesday . The Warriors (43 - 7) came into this game as a sizable favorite and they showed why in this clincher . Golden State (31 - 19) came into this game as a huge favorite and they showed some resiliency here with this win . Blake Griffin was the high - point man , as he tallied 31 points (i), eight rebounds , two assists , three steals and one block on 10 - of - 19 shooting . Klay Thompson finished with 21 points , seven rebounds and two assists . Austin Rivers was the only other starter in double figures , as he tallied 18 points , four rebounds and six assists on 7 - of - 15 shooting .(ii) Jamal Crawford was huge off the bench , providing 21 points (iii) on 7 - of - 11 shooting off the bench .Blake Griffin led the team in scoring , dropping 31 points on 10 - of - 19 shooting .(i) Kevin Durant finished with 26 points , eight rebounds and 10 assists .Jamal Crawford was huge off the bench , as he provided 21 points (iii) and four assists . DeAndre Jordan recorded a double - double , totaling 13 points and eight rebounds .Jamal Crawford was huge off the bench , dropping 21 points on 7 - of - 11 shooting (iii), including 5 - of - 8 from three - point range . Austin

Rivers led the Clippers in scoring with 18 points on 7 - of - 15 from the field . (ii)

B: The Golden State Warriors (43 - 7) defeated the Los Angeles Clippers (31 - 19) 133 - 120 on Saturday . The Warriors came into this game as one of the best defenses in the NBA this season , but they were able to prevail with a huge road win . In fact , Golden State shot 53 percent from the field and 41 percent from three - point range . The Warriors also dominated the assist - to - turnover ratio , recording 38 assists to 11 turnovers , while the Clippers committed 15 turnovers to just 15 assists . The Warriors (31 - 19) had to play this game extremely shorthanded and they did n't disappoint . Stephen Curry carried the load , as he tallied 29 points , three rebounds and 11 assists on 11 - of - 23 shooting . Kevin Durant was the only other starter in double figures , as he dropped 26 points on 8 - of - 18 shooting . Klay Thompson finished with 21 points and seven rebounds . Draymond Green was the only other player in double figures , as he totaled 10 points , seven rebounds and two assists . The Clippers (31 - 19) were led by Blake Griffin , who tallied 31 points , eight rebounds and three steals in the defeat . Jamal Crawford also had a nice game off the bench , as he scored 21 points off the bench . On deck for Golden State is a road matchup against the Los Angeles Lakers on Thursday .

Answers

Avoid Repetition

Best: B Worst: A

Analysis

Avoiding repetition. Summary B is the best as Summary A contains repetitive information such as phrases (i), (ii) and (iii).

Optional: Are you a native speaker of English? Yes/ No
(Your answer to this question will not affect acceptance of the HIT or your payment.)
Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

B.3 Evaluation of Grammaticality for ROTOWIRE

General Instructions Attempt HITs if you are a native speaker of English or a near-native speaker who can comfortably comprehend summary of NBA basketball games written in English. We are happy to receive feedback and improve this job accordingly.

Feel free to send your comments to: r.puduppully [at] sms [dot] ed [dot] ac [dot] uk. Your responses are confidential. Any publications based on these will not include your specific responses, but rather aggregate information from many individuals. We will not ask any information that can be used to identify who you are.

Evaluate Sports Summaries of (NBA) basketball games Your task it to read two short texts which have been produced by different automatic systems. These systems typically take a large table as input which contains statistics of a basketball game and produce a document which summarizes the table in natural langauge (e.g., talks about what happened in the game, who scored, who won and so on). Please read the two summaries carefully and judge how good each is according to the following criterion:

Grammaticality : Are the sentences grammatical and well-formed? The summary sentences should be grammatically correct. You should not rate the document as whole but rather whether the sentences could be written by a native speaker or by someone who is a learner and makes mistakes. Choose the more grammatical summary.

This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully .

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Grammaticality.)

A: The Milwaukee Bucks (18 - 17) defeated the New York Knicks (5 - 31) 95 - 82 on Sunday at Madison Square Garden in New York . The Bucks were able to have a great night defensively , giving themselves the scoring advantage in all four quarters . The Bucks showed superior shooting , going 46 percent from the field , while the Knicks went only 41 percent from the floor . The Bucks also out - rebounded the Knicks 48 - 36 , giving them in an even further advantage which helped them secure the 13 - point victory on the road . Brandon Knight led the Bucks again in this one . He went 6 - for - 14 from the field and 1 - for - 3 from beyond the arc to score 17 points , while also handing out five assists . He 's now averaging 21 points per game over his last three games , as he 's consistently been the offensive leader for this team . Zaza Pachulia also had a strong showing , finishing with 16 points (6 - 12 FG , 4 - 4

FT) and a team - high of 14 rebounds . It marked his second double - double in a row and fourth on the season , as the inexperienced centers on the Knicks ' roster were n't able to limit him . Notching a double - double of his own , Giannis Antetokounmpo recorded 16 points (6 - 9 FG , 1 - 1 3Pt , 3 - 6 FT) and 12 rebounds . The 12 rebounds matched a season - high , while it was his second double - double of the season . Coming off the bench for a big night was Kendall Marshall . He went 6 - for - 8 from the field and 3 - for - 3 from the free throw line to score 15 points in 20 minutes . The Knicks really struggled to score without Carmelo Anthony and Amare Stoudemire . Tim Hardaway Jr led the team as the starting shooting guard , going 6 - for - 13 from the field and 3 - for - 5 from the three - point line to score 17 points , while also adding four assists . He 's now scored 17 or more points in three out of his last four games , as he has put it on himself to pick up the slack with other key players sitting out . J. R. Smith also put together a solid outing as a starter . He finished with 15 points and seven rebounds in 37 minutes . Like Haradaway Jr , he 's also benefitted from other guys sitting out , and has now combined for 37 points over his last two games . While he did n't have his best night defensively , Cole Aldrich scored 12 points (6 - 10 FG) and grabbed seven rebounds in 19 minutes . The only other Knick to reach double figures in points was Jason Smith , who came off the bench for 10 points (3 - 11 FG , 4 - 4 FT) . The Bucks ' next game will be at home against the Phoenix Suns on Tuesday , while the Knicks will travel to Memphis to play the Grizzlies on Monday .

B: The Milwaukee Bucks (18-17) defeated the New York Knicks (5-31) 95-82 on Sunday at Madison Square Garden in New York. Giving himself the benefit of scoring in all four quarters, the Bucks got a good night for defensive defense. The Bucks went 46 percent off the field, while the Knicks went only 41 percent off the floor. The Bucks also knocked out - the Knicks rebuilt 48 - 36, giving them another advantage that helped them to a 13-point victory on the road. In it, Brandon Knight re-led the Bucks. He scored 17 - 6 - 14 - off the field and 1 - for - 3 off the arc, while also aiding five. He is now averaging 21 points per game in the last three games, as he is the team's consistently offensive leader. Zaza Pachulia also excelled with a high performance with 16 points (6 - 12 FG, 4 - 4 FT) and one team - 14 rebounds. This marked the second consecutive double and fourth double of the season because the inexperienced centers on the Knicks 'roster couldn't limit him. Giannis Antetokounmpo, in his own double-double position, reported 16 points (6 - 9 FG, 1 - 1 3 PT, 3 - 6 FT) and 12 rebounds. 12 rebounds matched the season - high, it was his second double of

the season . Getting off the bench on a big night was Kendall Marshall. He got 15 points in 20 minutes from 6 - for 8 - and 3 - for - 3 free throw lines from the field. The Knicks really struggled to score without Carmelo Anthony and Amare Stodmeier. Team Hardway Jr. led the team as an early shooting guard. 1 from and for out of the field. He scored 1 score and scored 3 points. He has now scored 17 or more points in three of his last four games, as he has tried to silence other key players. J. R. Smith put together a solid trip as a starter. He finished with 15 points and seven rebounds in 37 minutes. Like Hardway Jr., he also benefited from the other boys sitting out and now combined in the last two games with 37 points. Although he did not have the best night on the defensive side, Cole Aldrich scored 12 points (-10 FG) and made seven rebounds in 1 minute. Nick Jason Smith was the only one to reach double figures in points. He came on the bench for 10 points (3 - 11 FG, 4 - 4 FT). The Bucks' next game is at home against the Phoenix Sun on Tuesday, while the Knicks will travel to Memphis on Monday to play the Grizzlies.

Answers

Grammaticality

Best: A Worst: B

Analysis

Grammaticality. The sentences in Summary A are grammatical and fluent and appear to have been written by a native speaker of English. In contrast the sentences in Summary B have multiple issues including improper choice of words (eg: re-led, aiding, rebuilt), improper structure (eg: 12 rebounds matched the season - high, it was his second double of the season), wrong pronoun (eg: himself), etc. The sentences also appear to be less fluent (eg: This marked the second consecutive double ..., Like Hardway Jr, he also benefited..., etc.) . Thus Summary A is best.

Optional: Are you a native speaker of English? Yes/ No

(Your answer to this question will not affect acceptance of the HIT or your payment.)

Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

B.4 Evaluation of Coherence for MLB

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Coherence : How coherent is the summary? How natural is the ordering of the facts? The summary should be well structured and well organized and have a natural ordering of the facts. This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully.

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Coherence.)

A: HOUSTON – Alex Bregman hit a two - run homer , and Dallas Keuchel won for the first time in more than a month . Bregman homered and drove in three runs , Keuchel pitched seven strong innings and the Houston Astros beat the Tampa Bay Rays 6 - 2 on Tuesday night . The Astros won for the fifth time in six games and moved within a half-game of the first-place Los Angeles Angels in the AL West . Tampa Bay lost for the fifth time in six games . The Rays have lost four straight and eight of 10 . Bregman 's homer was his second in as many games . Keuchel (9 - 12) allowed nine hits and two runs with four strikeouts in seven innings . Blake Snell (4 - 7) allowed nine hits

and five runs – four earned – in three innings . Wilson 's homer was his second of the season . Yuli Gurriel added two hits and two RBI for the AL West leaders . Carlos Correa doubled to start the second inning and scored on a double by Gattis to put Houston up 1 - 0 . Yuli Gurriel followed with an RBI double to make it 2 - 0 . George Springer singled to start the third before Bregman drove a 1 - 2 pitch into the seats in right field to make it 4 - 0 . Marwin Gonzalez reached on an infield ingle with no outs in the fourth and scored on Bregman 's two - out single to make it 5 - 0 . Bobby Wilson hit a two - run homer in the fifth to cut the lead to 5 - 2 . The Astros added a run in the seventh when Jepsen walked Bregman and Altuve followed with a single . After Gattis walked , Gonzalez was intentionally walked to load the bases .

B:HOUSTON – The Houston Astros had a lot of opportunities against the Tampa Bay Rays . Alex Bregman hit a two - run homer , Dallas Keuchel pitched seven solid innings and the Astros beat the Tampa Bay Rays 6 - 2 on Tuesday night . The Astros have won six of their last eight games and have the worst record in the majors . The Astros have won 10 of their last 13 games and have the worst record in the majors . Keuchel (9 - 12) allowed nine hits and two runs with four strikeouts in seven innings to win for the first time in four starts . The right - hander has allowed two runs or fewer in each of his last five starts . The Astros have won five of their last six games and have the worst record in the majors . The Astros have lost five of their last six games and are 1 - 5 on their current road trip . Rays starter Blake Snell (4 - 7) allowed five runs and nine hits in three - plus innings . He struck out three and did n't walk a batter for the second time this season . The Astros have lost five of their last six games. Bobby Wilson hit a two - run homer in the fifth for Tampa Bay . Gurriel hit an RBI double in the seventh for the Astros for a 6 - 2 lead . Evan Gattis's RBI double in the second made it 1 - 0 (i). Gurriel 's RBI double in the seventh gave the Astros a 6 - 2 lead . Gurriel 's RBI double in the seventh inning gave the Astros a 6 - 2 lead . Gurriel 's RBI double in the seventh inning gave the Astros a 6 - 2 lead . It was the third time this season the Astros have hit back - to - back home runs . Alex Bregman hit a two - run homer in the third inning for Tampa Bay , which has lost four of five . The Rays scored in the second inning on a double by Evan Gattis and a sacrifice fly by Marwin Gonzalez .

Answers

Coherence

Best: A Worst: B

Analysis

Coherence. Summary A contains the details of the better scoring players and the important play-by-plays in the game in a coherent manner. The highlighted sentences in blue are one example of natural ordering of facts in the summary. In Summary B, in contrast, the facts are ordered in a less natural way such as sentences in (i). Thus, Summary A is best .

Optional: Are you a native speaker of English? Yes/ No
(Your answer to this question will not affect acceptance of the HIT or your payment.)
Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

B.5 Evaluation of Conciseness for MLB

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Avoid repetition : Which summary is better at avoiding unnecessary repetition? Unnecessary repetition might take the form of whole sentences that are repeated, or repeated facts, or the repeated use of a phrase This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully .

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Avoiding repetition.)

A: HOUSTON – The Houston Astros had a lot of opportunities against the Tampa Bay Rays . Alex Bregman hit a two - run homer , Dallas Keuchel pitched seven solid innings and the Astros beat the Tampa Bay Rays 6 - 2 on Tuesday night . The Astros have won six of their last eight games and have the worst record in the majors . The Astros have won 10 of their last 13 games and have the worst record in the majors (i). Keuchel (9 - 12) allowed nine hits and two runs with four strikeouts in seven innings to win for the first time in four starts . The right - hander has allowed two runs or fewer in each of his last five starts . The Astros have won five of their last six games and have the worst record in the majors . The Astros have lost five of their last six games (ii) and are 1 - 5 on their current road trip . Rays starter Blake Snell (4 - 7) allowed five runs and nine hits in three - plus innings . He struck out three and did n't walk a batter for the second time this season . The Astros have lost five of their last six games. (ii) Bobby Wilson hit a two - run homer in the fifth for Tampa Bay . Gurriel 's RBI double in the seventh made it 6 - 2 . Gurriel 's RBI double in the seventh gave the Astros a 6 - 2 lead . Gurriel 's RBI double in the seventh inning gave the Astros a 6 - 2 lead . Gurriel 's RBI double in the seventh inning gave the Astros a 6 - 2 lead .(iii) It was the third time this season the Astros have hit back - to - back home runs . Alex Bregman hit a two - run homer in the third inning for Tampa Bay , which has lost four of five . The Rays scored in the second inning on a double by Evan Gattis and a sacrifice fly by Marwin Gonzalez .

B: HOUSTON – Alex Bregman hit a two - run homer , and Dallas Keuchel won for the first time in more than a month . Bregman homered and drove in three runs , Keuchel pitched seven strong innings and the Houston Astros beat the Tampa Bay Rays 6 - 2 on Tuesday night . The Astros won for the fifth time in six games and moved within a half-game of the first-place Los Angeles Angels in the AL West . Tampa Bay lost for the fifth time in six games . The Rays have lost four straight and eight of 10 . Bregman 's homer was his second in as many games . Keuchel (9 - 12) allowed nine hits and two runs with four strikeouts in seven innings . Blake Snell (4 - 7) allowed nine hits and five runs – four earned – in three innings . Wilson 's homer was his second of the season . Yuli Gurriel added two hits and two RBI for the AL West leaders . Carlos Correa doubled to start the second inning and scored on a double by

Gattis to put Houston up 1 - 0 . Yuli Gurriel followed with an RBI double to make it 2 - 0 . George Springer singled to start the third before Bregman drove a 1 - 2 pitch into the seats in right field to make it 4 - 0 . Marwin Gonzalez reached on an infield ingle with no outs in the fourth and scored on Bregman 's two - out single to make it 5 - 0 . Bobby Wilson hit a two - run homer in the fifth to cut the lead to 5 - 2 . The Astros added a run in the seventh when Jepsen walked Bregman and Altuve followed with a single . After Gattis walked , Gonzalez was intentionally walked to load the bases .

Answers

Avoid Repetition

Best: B Worst: A

Analysis

Avoiding repetition. Summary B is the best as Summary A contains repetitive information such as phrases (i), (ii) and (iii).

Optional: Are you a native speaker of English? Yes/ No
(Your answer to this question will not affect acceptance of the HIT or your payment.)
Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

B.6 Evaluation of Grammaticality for MLB

General Instructions Attempt HITs if you are a native speaker of English or a near-native speaker who can comfortably comprehend summary of MLB baseball games written in English. We are happy to receive feedback and improve this job accordingly. Feel free to send your comments to: r.puduppully [at] sms [dot] ed [dot] ac [dot] uk. Your responses are confidential. Any publications based on these will not include your specific responses, but rather aggregate information from many individuals. We will not ask any information that can be used to identify who you are.

Evaluate Sports Summaries of (MLB) baseball games Your task it to read two short texts which have been produced by different automatic systems. These systems typically take a large table as input which contains statistics of a baseball game and produce a document which summarizes the table in natural langauge (e.g., talks about what happened in the game, who scored, who won and so on).

Please read the two summaries and judge how good each is according to the following criterion:

Grammaticality : Are the sentences grammatical and well-formed? The summary sentences should be grammatically correct. You should not rate the document as whole but rather whether the sentences could be written by a native speaker or by someone who is a learner and makes mistakes. Choose the more grammatical summary.

This task contains validation instances (for which answers are known) that will be used for an automatic quality assessment of submissions. Therefore, please read the summaries carefully.

Example

Summaries

(In this example, we show two summaries to give you an idea of how to judge them based on Grammaticality.)

A: CINCINNATI (AP) - Also it can be called Berkman's Ballpark. Lance Berkman hit his 18th homer at Great American Ball Park - the most by any incoming player. - and scored three on Thursday, including a 5–3 lead over the Cincinnati Reds with a fifth straight win to the Houston Astros done. Berkman had a two-run homer and a run-scoring double rookie Johnny Cuito (1 - 2), whose 96 mph fastball wasn't enough to slow Astro's growing offense or get the Reds out of their slump. They just can't stop Berkman. The Astros extended their best in less than a year, with Berkman playing her familiar role. Houston won five consecutive matches since April 16 last season. Astro scored 41 runs during a five-match lead. Even right-hander Jack Cassell (1 - 0) joined, adding a run-scoring single for his first career RBI. Cueto, a 22-year-old right-hander who first encountered Astro, learned that every other Cincinnati pitcher already knew: No one, like Berkman, has hurt the Reds. The first baseman has more career homers (42) and RBI (120) against the Reds than any other team. Rarely does a series against Cincinnati occur when he does not decide a game with a clutch hit or two. Now Cueto also knows. Berkman hit a homer twice in the first inning in the sixth of his season. Berkman's two-out, run-scoring double in the fifth made it 5 - 3. He later singled for his third hit of the game, extending his career from Great American to .360. One thing is sure: next time he will be more careful with Berkman.

B: CINCINNATI (AP) – Might as well call it Berkman's Ballpark. Lance Berk-

man hit his 18th homer at Great American Ball Park – the most by any visiting player – and drove in three runs Thursday, leading the Houston Astros to their fifth straight win, 5 - 3 over the Cincinnati Reds. Berkman had a two - run homer and a run-scoring double off rookie Johnny Cueto (1 - 2), whose 96 mph fastball wasn't enough to slow the Astros' surging offense or get the Reds out of their slump. They just can't stop Berkman from hitting homers in their own yard. With Berkman playing his familiar role, the Astros extended their best streak in a year. Houston hadn't won five in a row since April 16 - 20 last season. The Astros have piled up 41 runs during the five - game surge. Even right-hander Jack Cassel (1 - 0) got involved, adding a run-scoring single for his first career RBI. Cueto, a 22-year-old right-hander facing the Astros for the first time, learned what every other Cincinnati pitcher already knew : No one causes the Reds as much heartache as Berkman. The first baseman has more career homers (42) and RBIs (120) against the Reds than any other team. Hardly a series against Cincinnati goes by when he doesn't decide a game with a clutch hit or two. Now Cueto knows, too. Berkman hit a two - run homer in the first inning, his sixth of the season. Berkman's two - out, run-scoring double in the fifth made it 5 - 3. He later singled for his third hit of the game, raising his career batting average at Great American to .360. One thing's sure : Next time he'll be more careful with Berkman.

Answers

Grammaticality

Best: B Worst: A

Analysis

Grammaticality. The sentences in Summary B are grammatical and fluent and appear to have been written by a native speaker of English. In contrast the sentences in Summary A have multiple issues including improper choice of words (eg: incoming, growing offense, Jack Cassell (1 - 0) joined), improper punctuation (eg: No one, like Berkman, has hurt the Reds) wrong gender (eg: playing her familiar role) etc. The sentences also appear to be less fluent (eg: Also it can be called Berkman's Ballpark, learned that every other Cincinnati pitcher already knew, etc.) . Thus Summary B is best.

Optional: Are you a native speaker of English? Yes/ No
(Your answer to this question will not affect acceptance of the HIT or your payment.)
Optional: Please use this space to provide feedback on the task or ask any questions. This will not affect acceptance of the HIT or your payment.

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