Automatic Summarization

Berlin Chen
Department of Computer Science & Information Engineering
National Taiwan Normal University

Outline

- Introduction
- Spectrum of Summarization Research
- Extractive Summarization Methods
- Evaluation Metrics
- Applications
- Conclusions

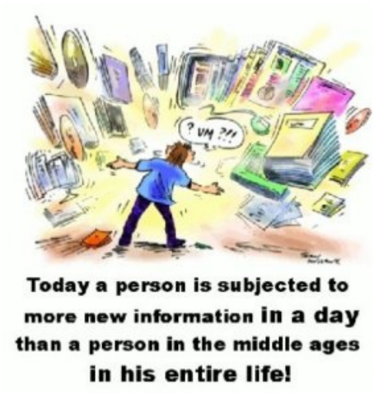
This talk gives only a partial picture of automatic summarization research, biased and subject to the presenter's expertise.
For more detailed reviews on the developments of automatic summarization, please also refer to, among others,

1 Nenkova and McKeown , "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011
2. Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

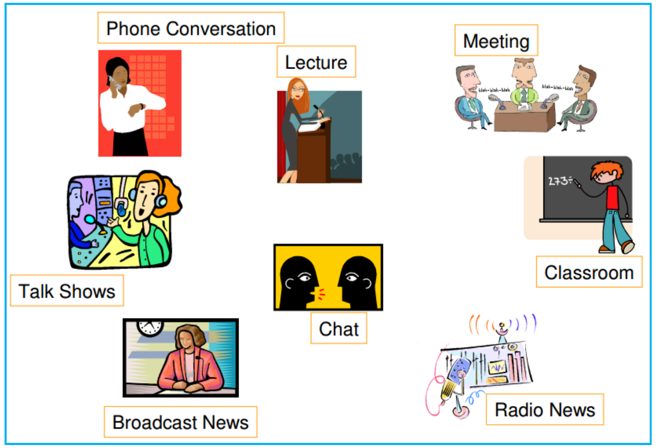
Introduction: Information Overload

- Content Creation vs. Content Management
  - *Too much information kills information!*

Text



Speech & Multimedia

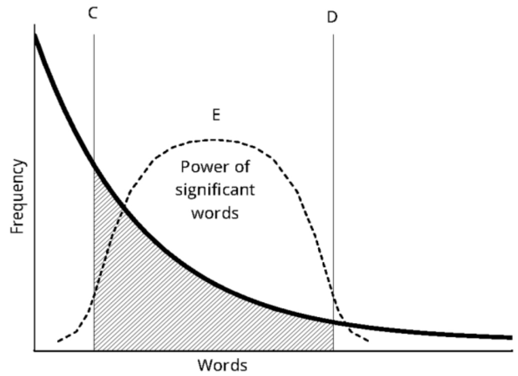


- Automatic summarization figures prominently in dealing with the information overload problem
  - Facilitate people to browse multimedia documents and distill their themes both efficiently and effectively

Introduction: Seminal Work (1/2)

- Developments in automatic summarization date back to the late 1950s (Luhn, 1958) and have continued to be the focus of much research

  - *Luhn put forward a simple idea that shaped much of later research*
  - *Namely, some words in a document are descriptive of its content, and the sentences that convey the most important information in the document are the ones that contain many such descriptive words close to each other*



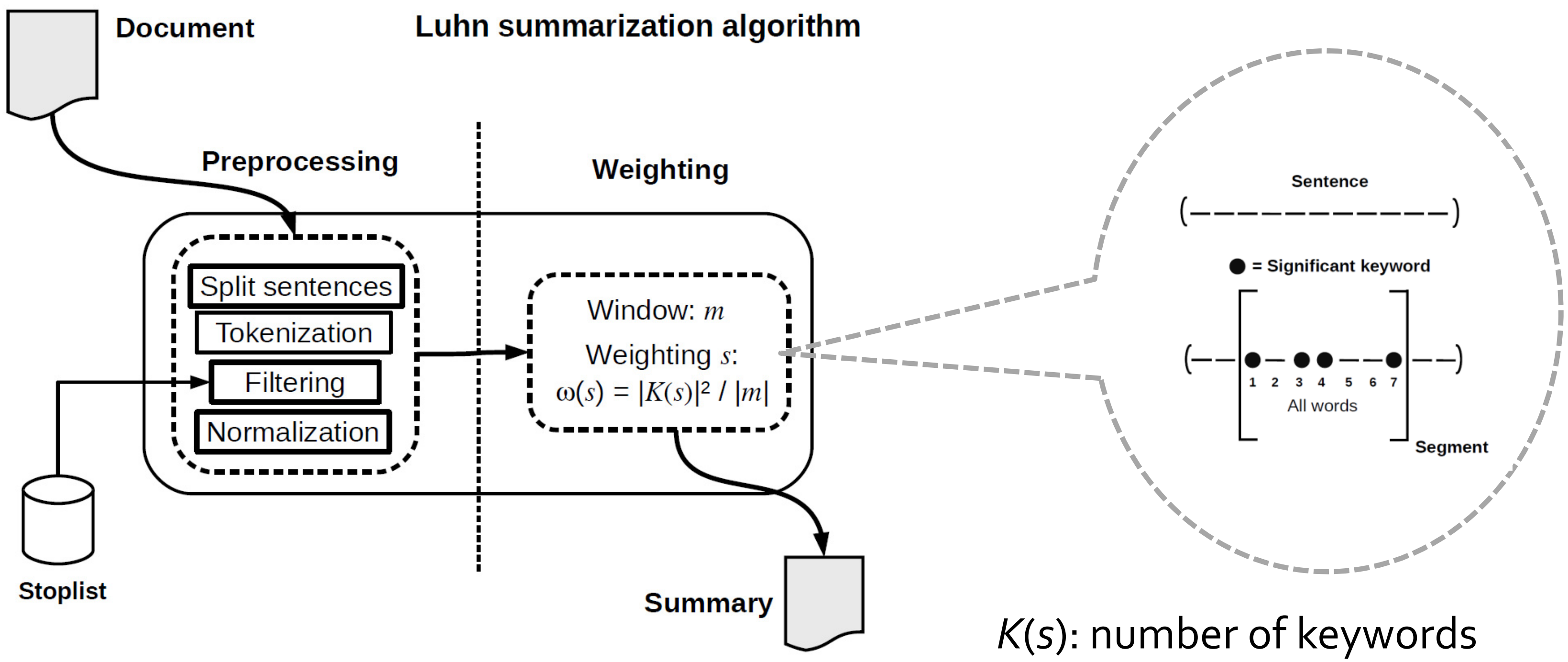
  (Mean what? **frequency**, **proximity** and **burstiness/structure** of different levels of lexical/semantic/syntactic units?)

- Nowadays, this research realm is extended to cover a wider range of tasks, including multi-document, multilingual and multimedia (e.g., speech) summarization

1., H. E Luhn , " The automatic creation of literature abstracts," IBM Journal of Research and Development, 1958
2. Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

Introduction: Seminal Work (2/2)

- Schematic Description of Luhn's Method



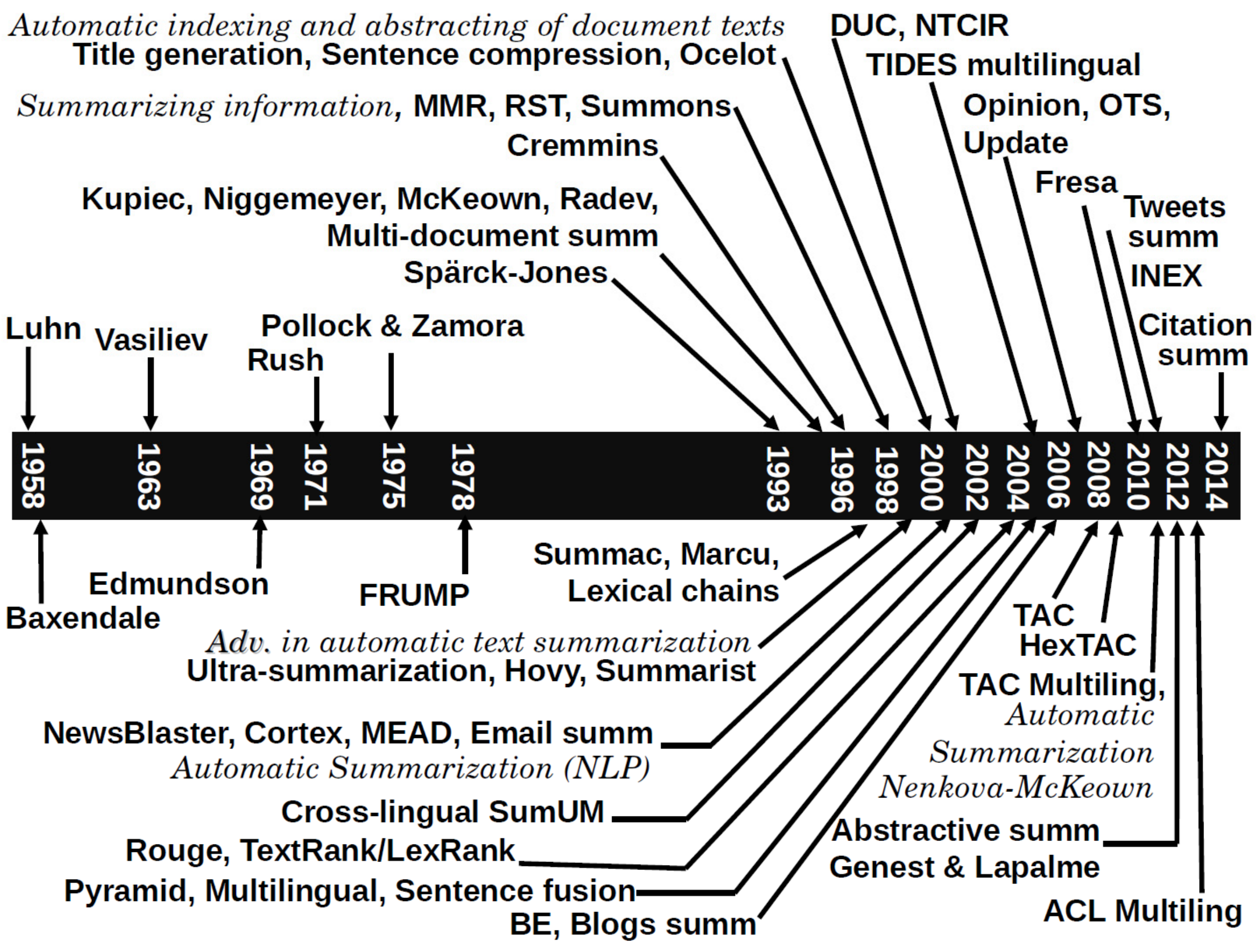
$K(s)$: number of keywords

  - A window of the size *m* words is defined as the longest segment in a sentence between two keywords

This figure is adopted from Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

Historical Evolution

- Timeline of Summarization Research



This figure is adopted from Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

Spectrum of Summarization Research

Types

- Abstractive
- Extractive

Sources

- Single-document
- Multi-document

Evaluation Metrics

- Extrinsic
- Intrinsic

Contexts

- Generic
- Query-focused
- Update

Functions

- Informative
- Indicative
- Critical
- Contrastive

S.-H. Lin, "Speech Summarization - Features, Models and Applications," Ph.D. Dissertation, 2011

1. Sources

- A summary can be produced from ***a single document*** (single- document summarization) or ***multiple documents*** (multi-document summarization)
- For the latter case, ***information redundancy*** and ***event causality*** (or ordering) are the two main issues concerned, since the information is gathered from several documents

2. Functions (1/2)

- An ***informative*** summary is a condensed presentation which reflects the overall content (ideas/facts) of the original document(s)
  - It usually acts as a surrogate for (can be read in replace of) the original document(s)

- An ***indicative*** summary may provide characteristics such as topics, lengths and writing styles of the original document(s) but does not convey the detailed information of the original document(s)

2. Functions (2/2)

- A ***critical*** summary provides judgement (either positive and negative) on the input document(s)
  - E.g., *Article review is a critical summarization of another article. Review is basically a productive analysis of an article by summarizing the main points discussed in the topic and by classifying, comparing and assessing the original article critically*

- A ***contrastive*** summary is formed by automatically extracting and summarizing the multiple contrastive viewpoints implicitly expressed in the opinionated document(s), allowing for digestion and comparison of different viewpoints

1. http://bigtopmagazine.com/how-to-write-a-unique-article-review-from-scratch.asp
2. M. J. Paul et al., "Summarizing contrastive viewpoints in opinionated text," EMNLP 2010

2. Functions:
Contrastive Summarization- An Example (1/2)

- 2010 U.S. Healthcare Legislation
  - 948 verbatim responses from Gallup opinion phone survey
  - 45% for, 48% against (March 2010)

For: "because a lot of people **can't afford it** [insurance]; 45,000 people **die** each year because of lack of healthcare."

Against: "everybody should have their own healthcare, and if you **can't afford it**, you should just **die**."

Different viewpoints

Same issue

M. J. Paul et al., "Summarizing contrastive viewpoints in opinionated text," EMNLP 2010

2. Functions:

Contrastive Summarization- An Example (2/2)

- Make the viewpoint summaries more comparable

For the healthcare bill	Against the healthcare bill
• i favor healthcare for who needs it, mostly old **people** who don't have healthcare. the **government** should **help** the **people** when they are old. they should have that kind of healthcare. • i just think something has to be done, the **price** of health is going up. • [i] pay for private insurance. • bring down **cost**.	• i think we can't be responsible for other **people's** healthcare. • doesn't address things that **need** to be done, addresses things that don't **need** to be done. • it's going to increase the **cost** to those insured. • i believe we can't afford it. • way too **expensive**, too intrusive, too much **government** control.

M. J. Paul et al., "Summarizing contrastive viewpoints in opinionated text," EMNLP 2010

3. Contexts

- A summary can be either ***generic***, ***query-oriented, or updated***
  - In ***generic summarization***, each summary provides a general point of view of the original document(s) without regarding to any specific information need
  - ***Query-oriented summarization***, by contrast, is primarily concerned with producing a concise summary that is related to some specific topic (or information need)
  - ***Update summaries*** *only show important new information and avoid repeating information when users are familiar with a particular topic (it is presumed that they have already read documents and their summaries relating to this topic)*

Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

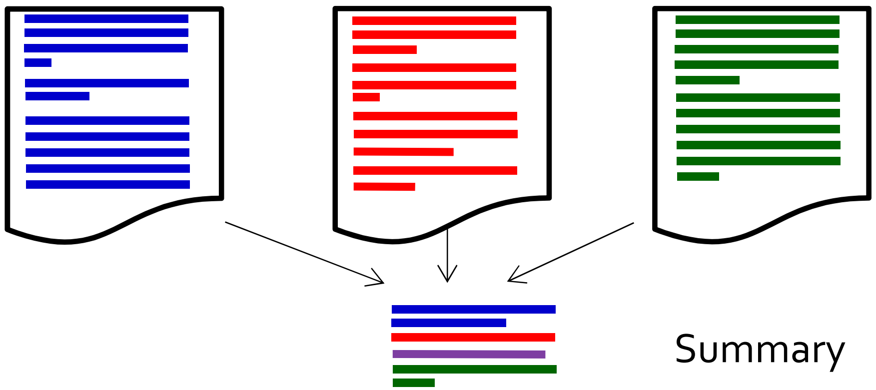
4. Types (1/2)

- Abstractive Summarization
  - Generate a fluent and concise abstract (rewrite a short series of sentences), reflecting the most important information of an original document or a set of documents
  - Require highly sophisticated ***natural language processing*** (**NLP**) techniques, including semantic representation and inference, as well as natural language generation
  - *Writing a concise and fluent summary requires the capability to reorganize, modify and merge information expressed in different sentences in the input. Full interpretation of documents and generation of abstracts is often difficult for people, and is certainly beyond the state of the art for automatic summarization*

Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

4. Types (2/2)

- Extractive Summarization
  - Select a set of salient sentences from an original document or a set of documents (according to a predetermined target summarization ratio), and concatenate them to form a summary
  - Typical operations includes **sentence selection** (ranking) [mandatory], **sentence ordering** [mandatory], **sentence fusion** [optional] , **sentence revision** [optional] and **sentence compression** [optional], etc.



5. Methodology for Evaluation (1/2)

- Research on automatic summarization has frequently been criticized for lacking ideal (unanimous) “**gold-standard**” summaries when evaluating the performance of given automatically generated summaries
- However, current evaluation approaches can generally be classified as either ***extrinsic*** or ***intrinsic***

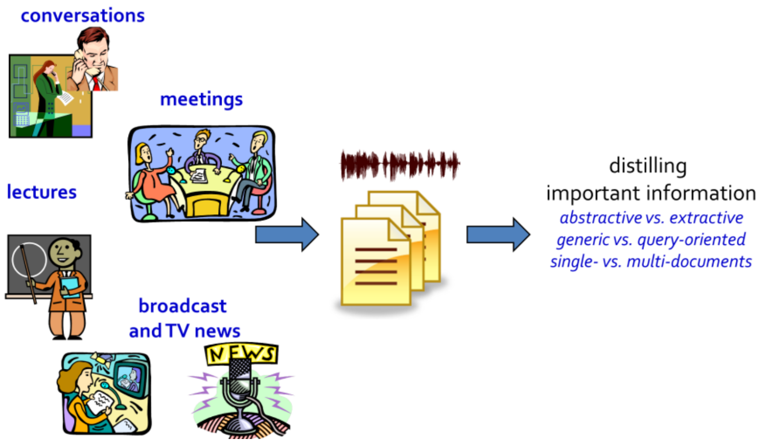
5. Methodology for Evaluation (2/2)

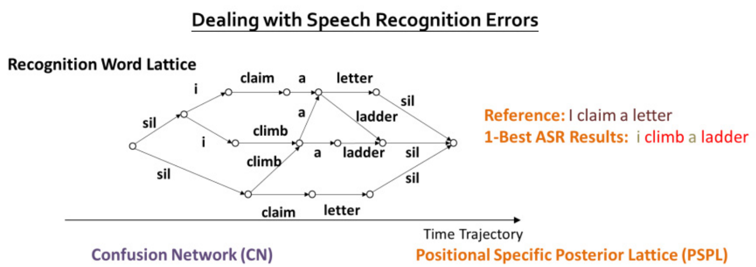
- ***Extrinsic evaluation*** measures the impact of the summary on the performance of downstream applications (tasks)
  - Such as information retrieval, document classification, essay scoring, among others
  - *Could be time-consuming, expensive and require a considerable amount of careful planning*
- ***Intrinsic evaluation*** examines how well a summarizer performs in relation to human experts
  - Usually, it can be done by comparing the automatic summaries output from the summarizer to those provided by human experts (in terms of ***objective*** and ***subjective*** quality)

Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

Speech Summarization

- Speech Summarization vs. Text Summarization
  - Speech summarization inevitably suffers from the problems of ***recognition errors*** and ***incorrect sentence boundaries*** when using ASR techniques to transcribe the spoken documents into text forms
  - On the other hand, speech summarization also presents information cues that are peculiar to it and do not exist for text summarization, such as information cues about ***prosodies/acoustics*** and ***emotions/ speakers***, which can potentially help in determining the important parts or implicit structures of spoken documents





Confusion Network (CN)

Cluster 1	Cluster 2	Cluster 3	Cluster 4
- 0.3 i 0.7	claim 0.1 climb 0.9	- 0.01 a 0.99	letter 0.5 ladder 0.5

Positional Specific Posterior Lattice (PSPL)

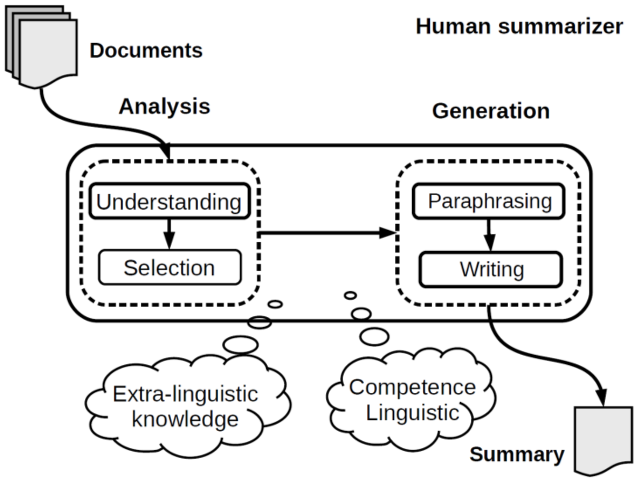
Cluster 1	Cluster 2	Cluster 3	Cluster 4
claim 0.1 climb 0.1 i 0.8	a 0.2 claim 0.3 climb 0.4	a 0.9 ladder 0.08 letter 0.02	letter 0.5 ladder 0.5

1. Liu and Hakkani-Tur, “Speech summarization,” in Spoken Language Understanding: Systems for Extracting Semantic Information from Speech, 2011
2. Lin et al., "Leveraging Kullback-Leibler divergence measures and information-rich cues for speech summarization," IEEE Transactions on Audio, Speech and Language Processing, 2011

How Humans Produce Summaries?

- The human production of summaries may involve two phases:
  - First, understand and interpret the source text
  - Then, write a concise and shortened version of it

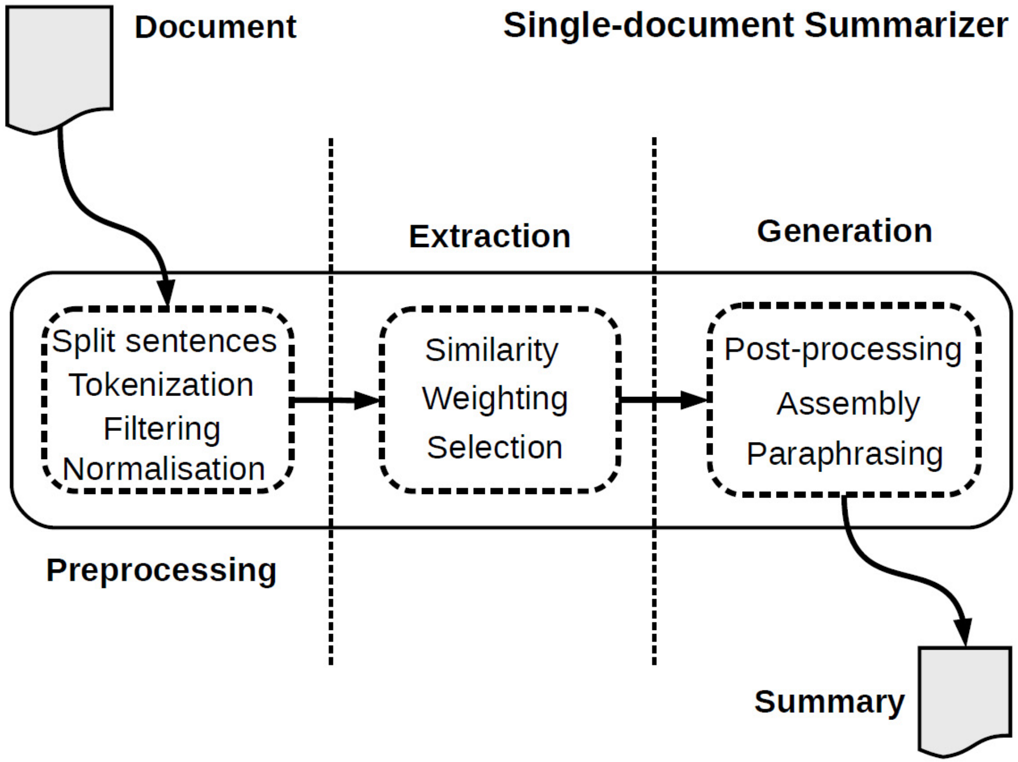
  Both require ***linguistic and extra-linguistic skills*** *and* ***(world) knowledge*** *on the part of the summarizer*



- *Is it worth modeling and trying to replicate the abstracting process of humans?*

This figure and associated text is adopted from Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

More on Extractive Summarization



This figure is adopted from Torres-Moreno , "Automatic Text Summarization," Wiley-ISTE, 2014.

Considerations when Conducting Extractive Summarization

- A sentence to be selected as part of a summary may be considered from the following three factors

  1) ***Salience***—the importance of the sentence itself, which is usually evident by its structure, location or word-usage information, and many more

  2) ***Relevance***—the more relevant a sentence to the input document(s) or the other sentences in the document(s), the more likely it should be included in the summary

  3) ***Redundancy***—the information carried by the sentence and that of the already selected summary sentences should cover different topics or concepts of the document(s)

1. Lin and Chen, "A risk minimization framework for extractive speech summarization," ACL 2010
2. Chen and Lin, "A risk-aware modeling framework for speech summarization," IEEE Transactions on Audio, Speech and Language Processing, 2012

Categorization of Extractive Summarization Methods

- The wide array of ***extractive summarization*** methods may roughly fall into three main categories:
  - Approaches simply based on ***sentence structure or position information, word-level statistics***
    - LEAD
  - Approaches based on ***unsupervised machine-learning***
    - Vector-based methods
      - VSM, LSA, MMR
    - Graph-based methods
      - TextRank, LexRank, MRW
    - Combinatorial optimization-based methods
      - ILP, Submodular
    - Language modeling methods, word/sentence embeddings
  - Approaches based on ***supervised machine-learning***
    - GMM, BC, SVM, CRF, DNN/RNN/LSTM

SMIL

LEAD

- The ***LEAD*** method condenses an input document using only the first portion of document (the lead; e.g., the first several sentences) until the target length of the summary is reached
- ***LEAD*** was known to be effective than other methods (at the time of its day) for document summarization of newspapers in lower summarization ratio

1. Brandow et al., "Automatic condensation of electronic publications by sentence selection," Information Processing and Management, 1995
2. Wasson, "Using leading text for news summaries: evaluation results and implications for commercial summarization applications, ACL 1998

Method Using Simple Word-level Statistics

- Word Probability (SumBASIC)
  - Calculate the word probability for ***content words*** in a document to be summarized

$$P(w) = \frac{c(w)}{N}$$

  - Determine the importance of a sentence based on the average probabilities of ***content words*** involved in the sentence

$$\text{Weight}(S) = \frac{\sum_{w \in S} P(w)}{|\{w \mid w \in S\}|}$$

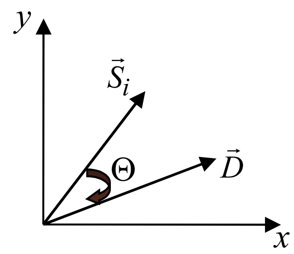
    - After the best sentence is selected, the probability of each word that appears in the chosen sentence is adjusted, set to a smaller value (?)
    - Then select another best-scoring sentences from the rest until the desired summary length is achieved

Vanderwende et al. , "Beyond Sum-Basic: Task-focused summarization with sentence simplification and lexical expansion," Information Processing and Management, 2007

Vector Space Model (VSM)

- Represent sentences and the document to be summarized as vectors using statistical weighting such as the product of ***Term Frequency*** (TF) and the ***Inverse Document Frequency***
- Sentences are ranked based on their similarity to the document

$$\mathrm{SIM}(S,D)=\frac{\vec{S}\cdot\vec{D}}{|\vec{S}||\vec{D}|}$$

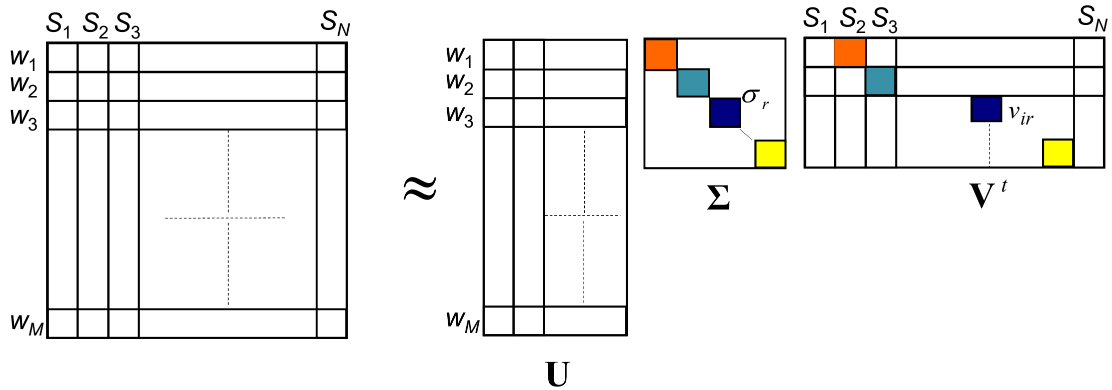


- To summarize more important and different concepts in a document
  - The terms occurring in the sentence with the highest relevance score SIM(*S*, *D*) are removed from the document
  - The document vector is then reconstructed and the ranking of the rest of the sentences is performed accordingly

Gong and Liu, "Generic text summarization using relevance measure and latent semantic analysis," SIGIR 2001

Latent Semantic Analysis (LSA)

- Construct a "term-sentence" matrix for a given document
- Perform SVD on the "term-sentence" matrix
  - The **right singular vectors** with larger singular values represent the dimensions of the more important latent semantic concepts in the document
  - Represent each sentence of a document as a vector in the latent semantic space
- Sentences with the largest index (element) values in each of the top *L* right singular vectors are included in the summary



Gong and Liu, "Generic text summarization using relevance measure and latent semantic analysis," SIGIR 2001

Maximum Marginal Relevance (MMR)

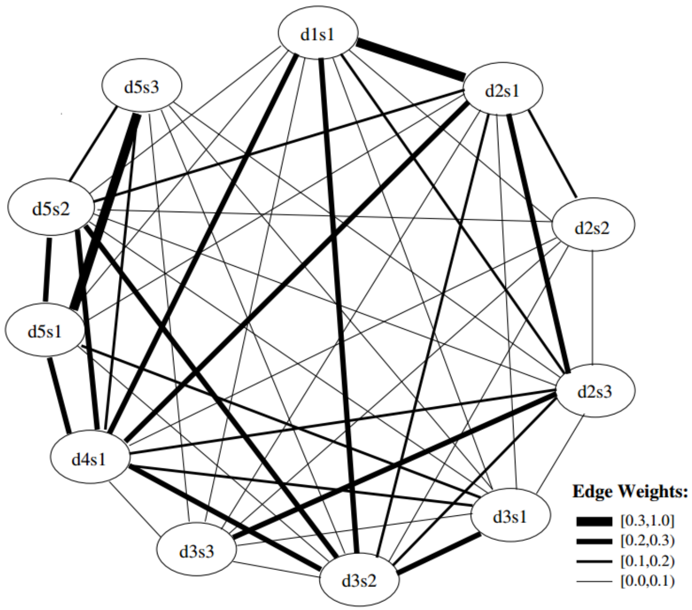
- Perform sentence selection iteratively with the criteria of topic relevance and coverage
- A summary sentence is selected according to
  - Whether it is more similar to the whole document than the other sentences (***Relevance***)
  - Whether it is less similar to the set of sentences selected so far than the other sentences (***Redundancy***)

$$S_{MMR} = \arg\max_{S_i}\left[\beta \cdot Sim(S_i, D) - (1-\beta) \cdot \max_{S' \in \mathbf{Summ}} Sim(S_i, S')\right]$$

Carbonell and Goldstein, "The use of MMR, diversity-based reranking for reordering documents and producing summaries," SIGIR 1998

Graph-based Methods (1/2)

- Graph-based methods, such as ***TextRank*** and ***LexRank***, conceptualize the document to be summarized as a network of sentences
  - Where each node represents a sentence and the associated weight of each link represents the lexical or topical similarity relationship between a pair of nodes



TextRank

1. Mihalcea et al., "TextRank: Bringing order into texts," EMNLP 2004
2. Günes et al., "LexRank: graph-based lexical centrality as salience in text summarization." Journal of Artificial Intelligence Research, 2004

Graph-based Methods (2/2)

- After constructing the conceptualized network, a graph-based centrality algorithm is then applied to obtain an importance score for each sentence
- The network actually can be viewed as a Markov chain in which the states are the sentences and the corresponding state transition distribution is given by a similarity matrix **W**
- Then, the importance of each sentence can be derived by the following equation

$$\mathrm{WS}(v_i) = (1-\alpha) + \alpha \times \sum_{v_j \in In(v_i)} \frac{w_{ji}}{\sum_{v_k \in Out(v_j)} w_{jk}} \cdot \mathrm{WS}(v_j)$$

Prestige Score

$$w_{ij} = w_{ji} = \mathrm{SIM}(S_i, S_j) = \frac{\sum_{w \in S_i, S_j} c(w, S_i) + c(w, S_j)}{\log(|s_i|) + \log(|s_j|)}$$

TextRank

Integer Linear Programming (ILP) (1/2)

- The ILP-based summarization methods have gained considerable attention since they, to some extent, solve the sub-optimal (greedy) summary sentences selection problem
  - Summary Selection vs. Sentence Selection
- ILP is developed for the constrained optimization problem, where both the cost function and constraint are linear in a set of integer variables

McDonald, "A study of global inference algorithms in multi-document summarization," ECIR 2007

Integer Linear Programming (ILP) (2/2)

- The extractive summarization task is formulated as a maximum convergence problem which is subjected to a set of defined objective functions and summary-length constraint

$$\begin{aligned} &maximize && \sum_i \alpha_i Relevance(i) - \sum_{i<j} \beta_{ij} Redundancy(i,j) \\ &subject\ to && (1)\ \alpha_i, \beta_{ij} \in 0,1 \\ & && (2)\ \sum_i \alpha_i l(i) \le K \\ & && (3)\ \beta_{ij} - \alpha_i \le 0 \\ & && (4)\ \beta_{ij} - \alpha_j \le 0 \\ & && (5)\ \alpha_i + \alpha_j - \beta_{ij} \le 1 \end{aligned}$$

length constraint

$\alpha_i = 1$ means that sentence i is included in the summary

$\beta_{i,J} = 1$ means that sentences i and j are simultaneously included in the summary

  - Relevance(i) is the relevance degree of sentence S_i to the entire document
  - Redundancy(i, j) refers to the similarity between sentence pairs S_i and S_j

Language Modeling (LM) Methods (1/3)

- Document-Likelihood Measure (DLM)
  - Each sentence S of a document D is treated as a probabilistic generative model for generating the document
  - The higher the probability $P(D|S)$, the more representative S is likely to be for D

$$P(S \mid D) = \frac{P(D|S)P(S)}{P(D)} \approx P(D \mid S)$$

Sentence Modeling $$P(D \mid S) \approx \prod_{w \in D} \underbrace{P(w \mid S)}_{\frac{c(w,S)}{|S|}}{}^{c(w,D)}$$

Maximum Likelihood Estimation (MLE)

- Kullback-Leibler Divergence Measure (KLM)
  - Rank a sentence according its ***model distance*** to the document

$$KL(D \,\|\, S) = \sum_{w \in V} P(w \mid D) \log \frac{P(w \mid D)}{P(w \mid S)}$$

  - KLM is reduced to DLM when $P(w|D)$ is computed with MLE

1. Chen et al., "A probabilistic generative framework for extractive broadcast news speech summarization," IEEE Transactions on Audio, Speech and Language Processing, 2009
2. Lin et al., "Leveraging Kullback-Leibler divergence measures and information-rich cues for speech summarization," IEEE Transactions on Audio, Speech and Language Processing, 2011

Language Modeling (LM) Methods (2/3)

- Extension 1: ***Sentence Clarity Measure***
  - Quantify the thematic specificity of each candidate summary sentence

$$Clarity(S) \overset{def}{=} CE(B \| S) - H(S)$$

  - Where

$$CE(B \| S) = -\sum_{w \in V} P(w|B) \log P(w|S)$$

    - $CE(B\|S)$ is the cross entropy between the background unigram model $P(w|B)$ and the sentence model $P(w|S)$
    - It is hypothesized that the higher the cross entropy (or the farther the sentence model away from the background model), the more thematic information the sentence S is to convey

$$-H(S) = \sum_{w \in V} P(w|S) \log P(w|S)$$

    - The higher the negative entropy $-H(S)$, the more concentrative the word usage of the sentence S is, revealing that S concentrates more on some important aspect of the document
  - Sentence Ranking

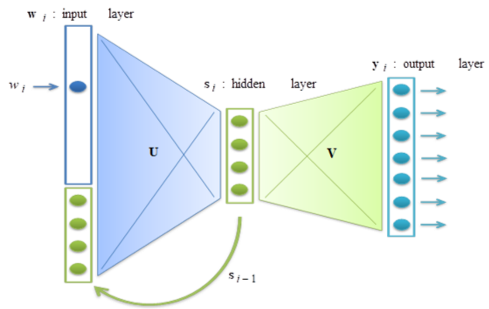
$$-KL(D \| S) + Clarity(S)$$

Liu et al., "Combining relevance language modeling and clarity measure for extractive speech summarization," IEEE/ACM Transactions on Audio, Speech, and Language Processing, 2015

Language Modeling (LM) Methods (3/3)

- Extension 2: ***Recurrent Neural Networks (RNN)***
  - Leverage RNN for sentence modeling

$$P_{\text{RNNLM}}(D \mid S) = \prod_{i=1}^{L} P_{\text{RNNLM}}(w_i \mid w_1, \ldots, w_{i-1}, S)$$



Train the document RNN model

Adapt the document RNN model to a sentence RNN model

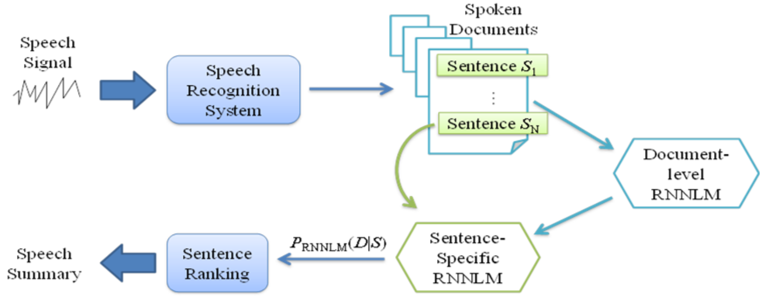
Calculate the document likelihood given a sentence RNN model

Input:
H: Number of Hidden Layer Neurons
$\mathbf{D} = \{D_1, \cdots, D_m, \cdots, D_M\}$
$D_m = \{S_1^{D_m}, \cdots, S_j^{D_m}, \cdots, S_{|D_m|}^{D_m}\}$

Model Training & Important Sentence Ranking:
for D_1 to D_M do
  document-level RNNLM model training
  $\mathcal{L}(\mathbf{U}_m, \mathbf{V}_m) = \sum_{i=1}^{|D_m|} \log(y_i)$
  for $S_1^{D_m}$ to $S_{|D_m|}^{D_m}$ do
    sentence-level RNNLM model training
    $\mathcal{L}\left(\mathbf{U}_{S_j^{D_m}}, \mathbf{V}_{S_j^{D_m}} \middle| \mathbf{U}_m, \mathbf{V}_m\right) = \sum_{i=1}^{|S_j^{D_m}|} \log(y_i)$
  end for
  for $S_1^{D_m}$ to $S_{|D_m|}^{D_m}$ do
    calculate document likelihood
    $P(D_m \mid S_j^{D_m}) = \prod_{i=1}^{|S_j^{D_m}|} P(w_i \mid w_1, \ldots, w_{i-1}, S_j^{D_m})$
    $= \prod_{i=1}^{|S_j^{D_m}|} P\left(w_i \middle| \mathbf{U}_{S_j^{D_m}}, \mathbf{V}_{S_j^{D_m}}, S_j^{D_m}\right)$
  end for
  Sentence selection according to $P(D_m \mid S_j^{D_m})$
end for

- Schematic Depiction

  E.g., speech summarization



The design of learning curriculum for RNN is of paramount importance here

Chen et al., "Extractive broadcast news summarization leveraging recurrent neural network language modeling techniques," IEEE/ACM Transactions on Audio, Speech, and Language Processing, 2015

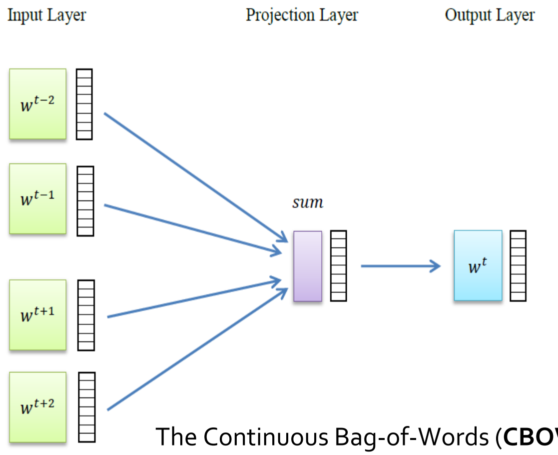
Representation Learning for Summarization (1/4)

- Word (Sentence) Embeddings (**WE/SE**)
  - Instead of a one-hotspot vector, a word is represented by a real-valued vector with a much smaller size (normally by several hundreds)
  - The syntactic and semantic regularities of words can be encoded in the distributed vector space: the Euclidean distance between two words in the lower-dimensional vector space represents the syntactic or semantic similarity between them
    - E.g., vector("***king***")-vector("***man***")+vector("***woman***") results in a vector that is closest to vector("***queen***")
  - A common thread of leveraging word embeddings to NLP-related tasks is to represent the document (or query and sentence) by averaging the word embeddings corresponding to the words occurring in the document (or query and sentence)

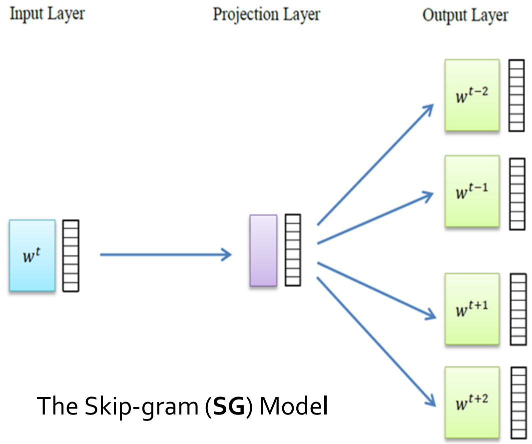
1. Bengio et al., "Representation Learning-A Review and New Perspectives ," IEEE Transactions on Pattern Analysis and Machine Intelligence, 2013
2. Mikolov et al., "Distributed representations of words and phrases and their compositionality," NIPS 2013

Representation Learning for Summarization (2/3)

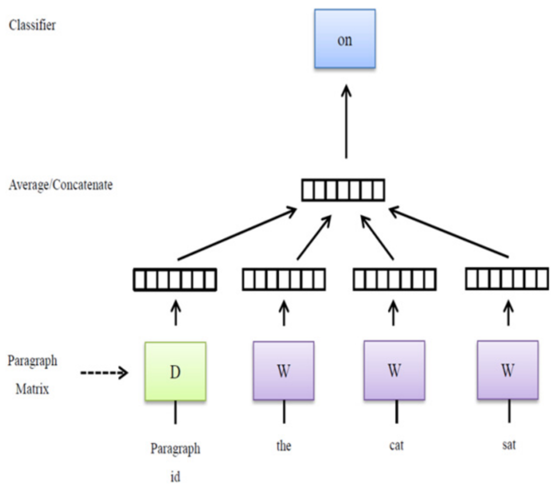
- Some Typical Learning Architectures



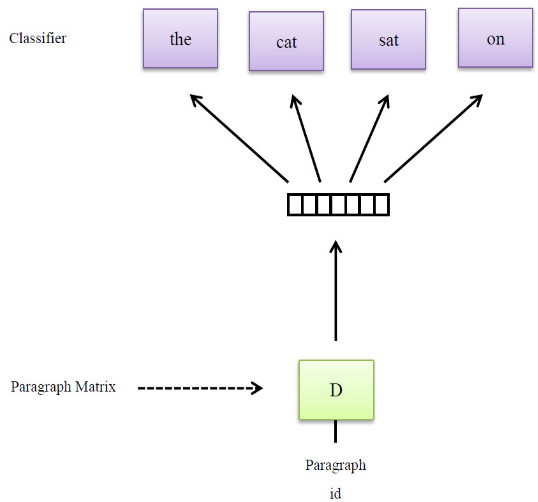
The Continuous Bag-of-Words (**CBOW**) Model



The Skip-gram (**SG**) Model

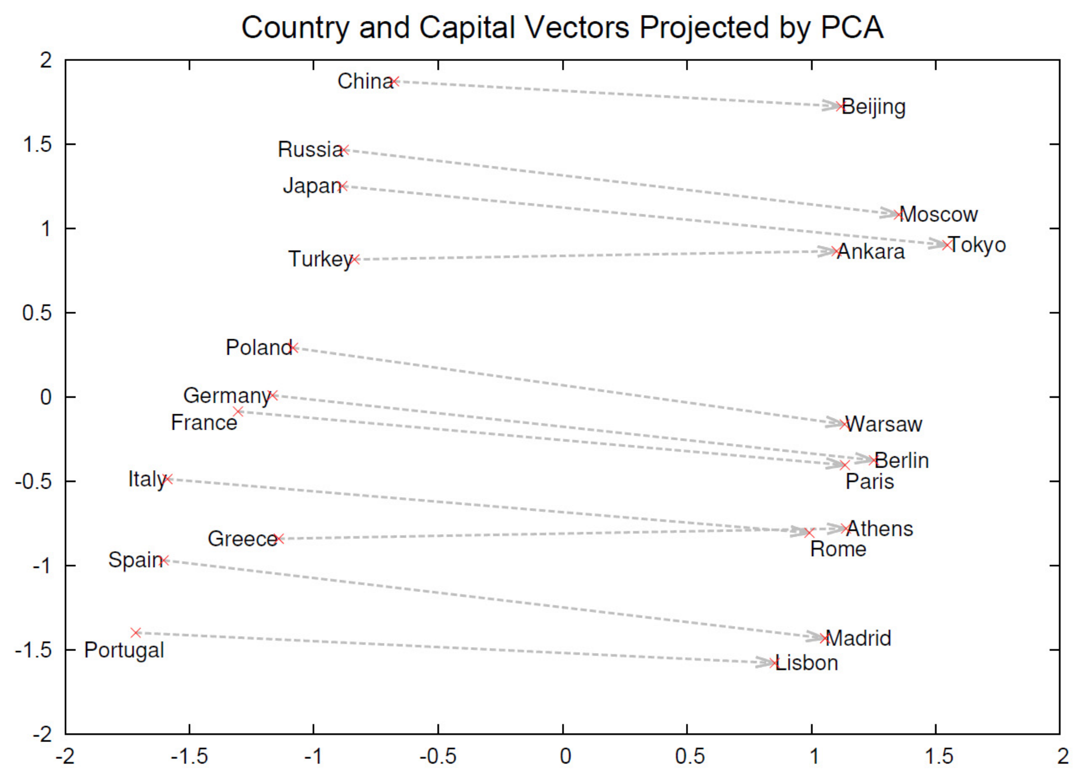


The Distributed Memory of Paragraph Vector(**PV-DM**) Model



The Distributed Bag-of-Words of Paragraph Vector (**PV-DBOW**) Model

Representation Learning for Summarization (3/4)



Two-dimensional PCA projection of the 1,000-dimensional Skip-gram vectors of countries and their capital cities. The figure illustrates ability of the model to automatically organize concepts and learn implicitly the relationships between them, as no any supervised information about what a capital city means was provided during the training .

This figure is adopted from Mikolov et al., "Distributed representations of words and phrases and their compositionality," NIPS 2013

Representation Learning for Summarization (4/4)

- Incorporate Word/Sentence/Document Emebddings into Extractive Summarization (sentence ranking)
  - **Vector Space Model** (Cosine Similarity Measure)

$$\mathrm{SIM}(S,D) = \frac{v_S \cdot v_D}{\|v_S\| \cdot \|v_D\|} \qquad \text{where} \quad v_D = \frac{\sum_{w \in D} v_w}{|D|}$$

  - **Graph-based Model** (Centrality Measure)

$$\mathrm{WS}(v_i) = (1-\alpha) + \alpha \times \sum_{v_j \in In(v_i)} \frac{w_{ji}}{\sum_{v_k \in Out(v_j)} w_{jk}} \cdot WS(v_j) \qquad \text{where} \quad w_{ij} = wji = \frac{v_i \cdot vj}{|v_i||vj|}$$

  - **Language Model** (Document Likelihood Measure)

$$\mathrm{P}(D|S) = \prod_{w_j \in D} \left[\lambda \cdot \sum_{w_i \in S} P_{\mathrm{MLE}}(w_i|S) \cdot P_{\mathrm{WE}}(w_j|w_i) + (1-\lambda) \cdot P_{\mathrm{MLE}}(w_j|C) \right]^{c(w_j,D)}$$

where $P_{\mathrm{WE}}(w_j|w_i) = \frac{exp(v_i \cdot v_j)}{\sum_{w_k \in V} exp(v_i \cdot v_k)}$

Chen et al., "Leveraging word embeddings for spoken document summarization," Interspeech 2015

Supervised Summarization Methods

- A number of classification-based methods using various kinds of representative (heterogeneous) features also have been investigated
  - In these methods, important sentence selection is usually formulated as a ***binary classification*** problem
  - A sentence can either be included in a summary or not
- These classification-based methods need a set of training documents along with their corresponding ***handcrafted summaries*** (or ***labeled data***) for training the classifiers (or summarizers)

1. Lin et al., "A comparative study of probabilistic ranking models for Chinese spoken document summarization," ACM Transactions on Asian Language Information Processing, 2009
2. Chen et al., "Extractive speech summarization using evaluation metric-related training criteria," Information Processing & Management, 2013

Support Vector Machines (SVM)

- **SVM** attempts to find an optimal hyper-plane by utilizing a decision function that can correctly separate the ***summary*** and ***non-summary*** sentences
  - Specifically, SVM to construct a binary summarizer to output the decision score $g(S_i)$ of a sentence S_i
  - The posterior probability of a sentence S_i being included in the summary class **S** can be approximated by

$$P(S_i \in \mathbf{S} \mid \mathbf{X}_i) \approx \frac{1}{1+\exp(\alpha \cdot g(S_i)+\beta)}$$

- In contrast to SVM, **Ranking SVM** seeks to create a more rank- or preference-sensitive ranking function

$$l(S_i) \succ l(S_j) \Leftrightarrow f(S_i) \succ f(S_j)$$

  - $l(S_i)$ denotes the preference label of a sentence S_i ; $f(S_i)$ denotes the decision value

Liu et al., "A margin-based discriminative modeling approach for extractive speech summarization," APSIPA ASC 2014

Perception

- The decision score of sentence S_i produced by ***Perception*** is

$$f(S_i) = \boldsymbol{\alpha} \cdot \mathbf{X}_i$$

  - That is, the inner product of feature vector of sentence S_i and model parameter $\boldsymbol{\alpha}$
- The model parameter vector of Perceptron can be estimated by maximizing the accumulated ***squared score distances*** of all the training spoken documents defined as follows

$$F_{Perceptron}(\boldsymbol{\alpha}) = \frac{1}{2} \cdot \sum_{n=1}^{N} \sum_{S_R \in \mathbf{Summ}_n} \left(f(S_R) - f(S_n^*) \right)^2$$

  - N is total training documents; $\mathbf{Summ}_n$ is the reference summary of the n-th training document D_n; S_R is a summary sentence in $\mathbf{Summ}_n$; S_n^* is the non-summary sentence of D_n that has the highest decision score

Global Conditional Log-linear Model (GCLM)

- The model parameter vector $\boldsymbol{\alpha}$ of GCLM is estimated by maximizing the following objective function

$$F_{\mathbf{GCLM}}(\boldsymbol{\alpha}) = \sum_{n=1}^{N} \sum_{S_R \in \mathbf{Summ}_n} \mathbf{log} \frac{\mathbf{exp}(\boldsymbol{\alpha} \cdot \mathbf{X}_R)}{\sum_{S_j \in D_n} \mathbf{exp}(\boldsymbol{\alpha} \cdot \mathbf{X}_j)}$$

- By doing so, the GCLM method will maximize the posterior of the summary sentences of each given training spoken document

Lo et al., "Constructing effective ranking models for speech summarization," ICASSP 2012

More NLP-Intensive Methods

- Yet another school of thought *either relies on existing **manually constructed semantic resources** (lexical chains, concepts), on **coreference tools**, or on **knowledge about lexical items induced from large collections of unannotated text***

- Most of methods developed along this line of research might tend to be **fragile**, or **difficult** to replicate or extend from constrained domains to more general domains

The review on the NLP-intensive methods is largely based on Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

Lexical Chains (1/2)

- *The lexical chains approach exploits the intuition that topics are expressed using not a single word but instead different related words*
  - *E.g., words "**car**", "**wheel**", "**seat**" and "**passenger**" indicate a clear topic, even if each of the words is not by itself very frequent*
  - *The methods heavily rely on external hand-crafted resources, such as **WordNet** which lists the different sense of each word, as well as word relationships such as synonymy, antonymy, part-whole (**fingers** vs. **hands**) and general-specific (**drink** vs. **coffee**)*
  - *In addition, the lexical chains approach requires some degree of **linguistic preprocessing**, including **part of speech tagging** and **division into topically related segments** of the input to the summarizer*

The review on the NLP-intensive methods is largely based on Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

Lexical Chains (2/2)

- *As an illustration, summarization is conducted by segmenting an input document, identifying lexical chains first within segments and then across segments, identifying and scoring lexical chains, and finally selects one sentence for each of the most highly scored chains*
  - *The strength (score) of a lexical chain, for example, can be computed by its length, defined as the number of words found to be members of the same chain*

- *The core of the problem is how to* ***construct good lexical chains*** *, with emphasis on* ***word sense disambiguation*** *of words with multiple meaning*
  - *E.g., the word "bank" can mean a financial institution or the land near a river or lake*

The review on the NLP-intensive methods is largely based on Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

SMIL

Coreference Information

- *Another way of tracking lexically different references to the same semantic entity is the use of coreference resolution*

- ***Coreference resolution** is the process of finding all references to the same entity in a document, regardless of the syntactic form of the reference: full noun phrase or pronoun*

- *However, some initial uses of **coreference information** exclusively to determine sentence importance for summarization did not lead to substantial improvements in content selection compared to shallower methods*

The review on the NLP-intensive methods is largely based on Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

Rhetorical Structure Theory (1/2)

- *Other research uses analysis of the discourse structure of the input document to produce single document summaries.* ***Rhetorical Structure Theory*** *(**RST**)*
  - *It requires the overall structure of a text to be represented by a tree, being one such approach that has been applied to summarization*
- *In RST, the smallest units of text analysis are **elementary discourse units** (**EDUs**)*
  - *They are in most cases sub-sentential clauses*
  - *Adjacent EDUs are combined through rhetorical relations into larger spans*
    - *The larger units recursively participate in relations, yielding a hierarchical tree structure covering the entire text*
    - *The discourse units participating in a relation are assigned **nucleus** or **satellite** status*

The review on the NLP-intensive methods is largely based on Nenkova and McKeown, "Automatic Summarization," Foundations and Trends in Information Retrieval, 2011

SMIL

Rhetorical Structure Theory (2/2)

- *Properties of the RST tree used in summarization include the nucleus–satellite distinction, notions of salience and the level of an EDU in the tree*

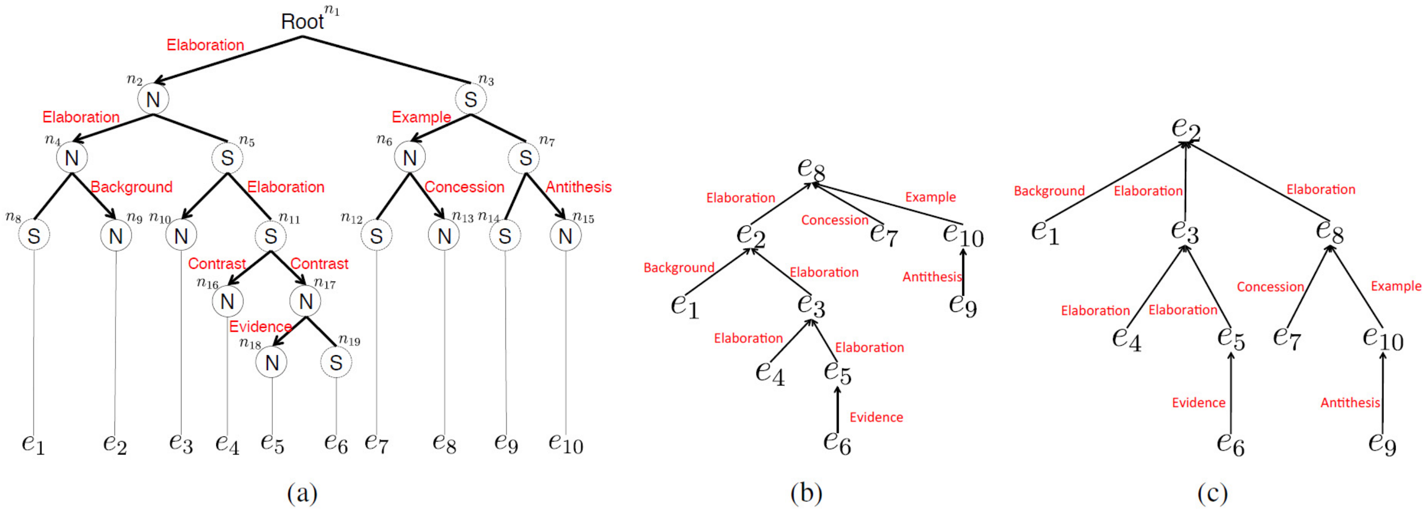
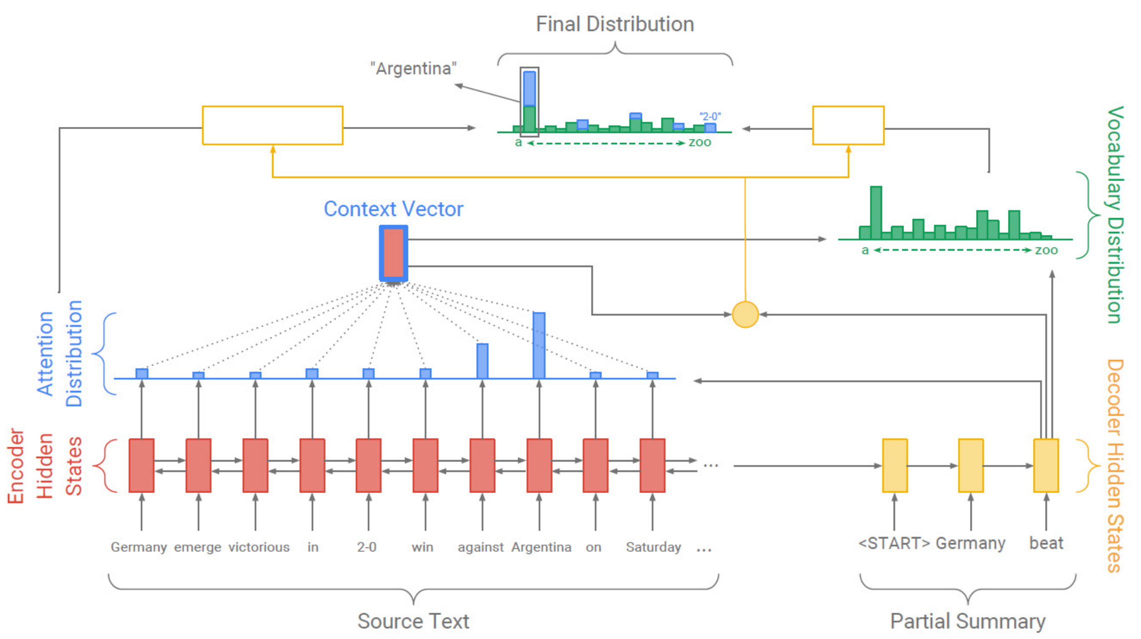


Figure 1: Examples of RST-DT and DEP-DT. $e_1, \cdots, e_{10}$ are EDUs. (a) Example of an RST-DT from (Marcu, 1998). $n_1, \cdots, n_{19}$ are the non-terminal nodes. (b) Example of the DEP-DT obtained from the incorrect RST-DT that is made by swapping the Nucleus-Satellite relationship of the node n_2 and the node n_3. (c) The correct DEP-DT obtained from the RST-DT in (a).

Yoshida et al., "Dependency-based discourse parser for single-document summarization," Foundations and Trends in Information Retrieval, EMNLP 2014

Abstractive Summarization with Neural Networks (1/2)

- The recent success of sequence-to-sequence models, in which recurrent neural networks (RNNs) both read and freely generate text, has made abstractive summarization viable



A. See et al., "Get to the point: summarization with pointer-generator networks," ACL 2017

Abstractive Summarization with Neural Networks (2/2)

- Some shortcomings remains to be solved
  - Inaccurately reproducing factual details
  - An inability to deal with out-of-vocabulary (OOV) words
  - Often repeating themselves

Original Text (truncated): lagos, nigeria (cnn) a day after winning nigeria's presidency, ***muhammadu buhari*** told cnn's christiane amanpour that **he plans to aggressively fight corruption that has long plagued nigeria** and go after the root of the nation's unrest. *buhari* said he'll "rapidly give attention" to curbing violence in the northeast part of nigeria, where the terrorist group boko haram operates. by cooperating with neighboring nations chad, cameroon and niger, **he said his administration is confident it will be able to thwart criminals** and others contributing to nigeria's instability. for the first time in nigeria's history, the opposition defeated the ruling party in democratic elections. *buhari* defeated incumbent goodluck jonathan by about 2 million votes, according to nigeria's independent national electoral commission. **the win comes after a long history of military rule, coups and botched attempts at democracy in africa's most populous nation.**

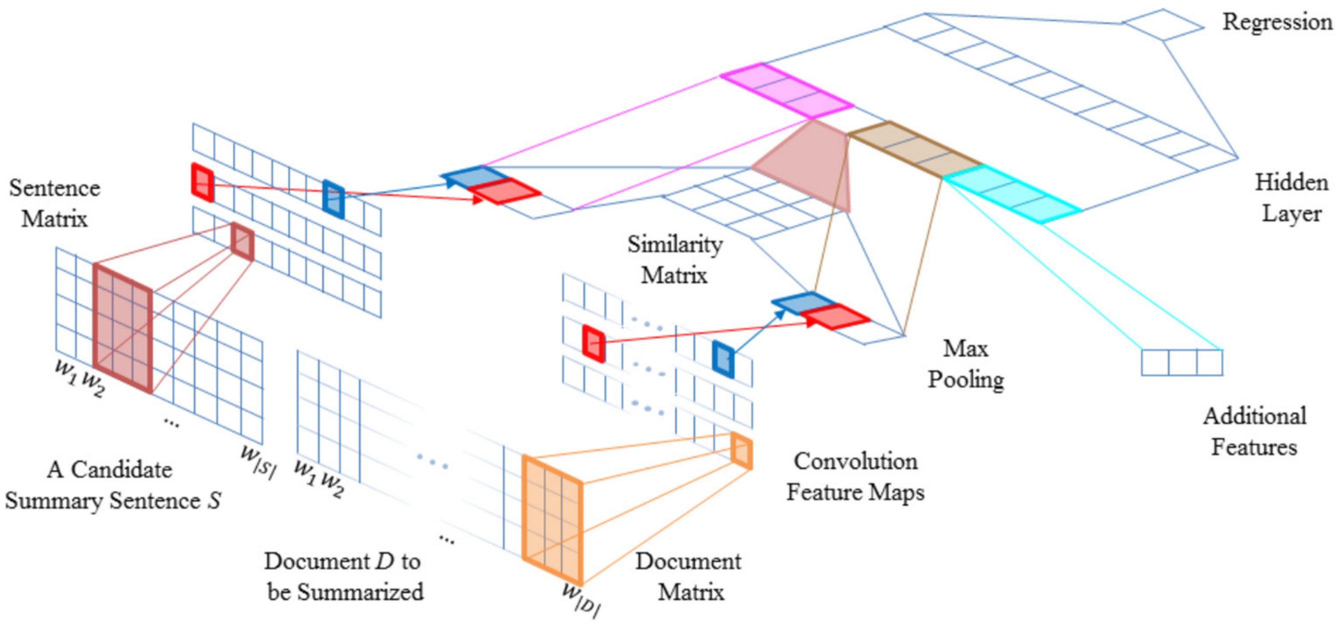
Baseline Seq2Seq + Attention: UNK UNK says his administration is confident it will be able to **destabilize nigeria's economy**. UNK says his administration is confident it will be able to thwart criminals and other **nigerians**. **he says the country has long nigeria and nigeria's economy.**

Pointer-Gen: *muhammadu buhari* says he plans to aggressively fight corruption **in the northeast part of nigeria**. he says he'll "rapidly give attention" to curbing violence **in the northeast part of nigeria**. he says his administration is confident it will be able to thwart criminals.

Pointer-Gen + Coverage: *muhammadu buhari* says he plans to aggressively fight corruption that has long plagued nigeria. he says his administration is confident it will be able to thwart criminals. the win comes after a long history of military rule, coups and botched attempts at democracy in africa's most populous nation.

A. See et al., "Get to the point: summarization with pointer-generator networks," ACL 2017

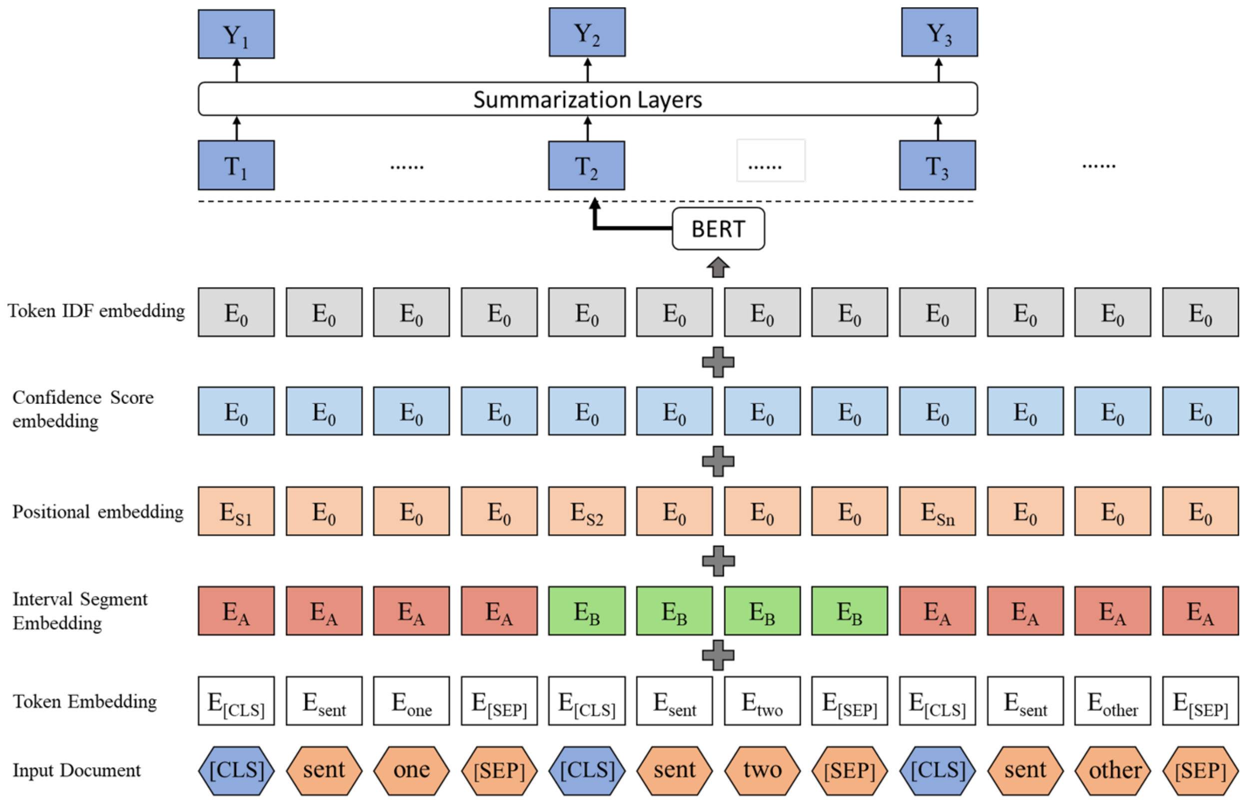
Extractive Summarization with Neural Networks



- The CNN components can be replaced with BERTs

C.-I. Tsai et al., "Extractive speech summarization leveraging convolutional neural network techniques," SLT 2016
M. Zhong et al., "Extractive summarization as text matching," ACL 2020

BERT-based Summarization method



More on Evaluation Metrics

Intrinsic Evaluations

- Intrinsic evaluations on automatic summaries could be ***objective*** and ***subjective***
- Objective evaluations:
  - Compare the automatic summaries with human-authored (reference) summaries that serve as the gold-standards
  - Less human involvement is usually preferred
- Subjective evaluations:
  - Solicit human judgements on the goodness and utility of automatically generated summaries

Objective Evaluations: Recall and Precision

- **Recall**
  - The fraction of the reference (human chosen) summary sentences that are included in the automatic summary

$$\text{Recall} = \frac{|\text{overlap between refernce and automatic summary sentences}|}{|\text{refernce summary sentences}|}$$

- **Precision**
  - The fraction of the reference (human chosen) summary sentences that are included in the automatic summary

$$\text{Precision} = \frac{|\text{overlap between refernce and automatic summary sentences}|}{|\text{automatic summary sentences}|}$$

- **F-measure** is the harmonic mean of precision and recall

To avoid susceptibility to bias produced by personal opinions, the above evaluations usually involve multiple reference summaries.

SMIL

Objective Evaluations: ROUGE (1/2)

- Recall-Oriented Understudy for Gisting Evaluation (**ROUGE**) evaluates the quality of the summarization by counting the number of overlapping units
  - Such as *N*-grams, longest common subsequences or skip-bigrams, between the automatic summary and a set of reference summaries
  - The ROUGE-*N* is an *N*-gram recall measure defined as follows

$$\text{ROUGE}-N = \frac{\sum_{\mathcal{M}\in\mathcal{S}_{Ref}} \sum_{\text{gram}_N \in \mathcal{M}} Count_{\text{match}}(\text{gram}_N)}{\sum_{\mathcal{M}\in\mathcal{S}_{Ref}} \sum_{\text{gram}_N \in \mathcal{M}} Count(\text{gram}_N)},$$

Where *N* denotes the length of the *N*-gram; *M* is an individual reference (or manual) summary; S_{Ref} is a set of reference summaries; $Count_{\text{match}}(\text{gram}_N)$ is the maximum number of *N*-grams co-occurring in the automatic summary and the reference summary; and $Count(\text{gram}_N)$ is the number of *N*-grams in the reference summary

C. Y. Lin, "ROUGE: Recall-oriented understudy for gisting evaluation," 2003: Available: http://haydn.isi.edu/ROUGE/.

Objective Evaluations: ROUGE (2/2)

- The ROUGE-1 measure evaluates the **informativeness** of automatic summaries
- The ROUGE-2 measure estimates the **fluency** of automatic summaries
- ROUGE-*L* does not reward for fixed-length *N*-grams but instead for a combination of the maximal substrings of words, which works well in general for evaluating both **content** and **grammaticality**

The variants of the ROUGE measure are evaluated by computing the correlation coefficient between ROUGE scores and human judgement scores, while ROUGE-2 performs the best among the ROUGE-*N* variants.

Feifan and Liu, "Correlation between ROUGE and Human Evaluation of Extractive Meeting Summaries," ACL 2008

Objective Evaluations: An Example (1/2)

- Broadcast News Summarization
  - Results achieved with **unsupervised methods**

	Text Documents (TD)			Spoken Documents (SD)		
	ROUGE-1	ROUGE-2	ROUGE-L	ROUGE-1	ROUGE-2	ROUGE-L
KLM	0.411	0.298	0.371	0.364	0.210	0.307
LEAD	0.310	0.194	0.276	0.255	0.117	0.221
VSM	0.347	0.228	0.290	0.342	0.189	0.287
LSA	0.362	0.233	0.316	0.345	0.201	0.301
MMR	0.368	0.248	0.322	0.366	0.215	0.315
MRW	0.412	0.282	0.358	0.332	0.191	0.291
LexRank	0.413	0.309	0.363	0.305	0.146	0.254
Submodularity	0.414	0.286	0.363	0.332	0.204	0.303
ILP	0.442	0.337	0.401	0.348	0.209	0.306

	Text Documents (TD)			Spoken Documents (SD)		
	ROUGE-1	ROUGE-2	ROUGE-L	ROUGE-1	ROUGE-2	ROUGE-L
KLM+Clarity	0.447	0.335	0.393	0.403	0.261	0.354
KLM+RM+Clarity	0.477	0.373	0.426	0.400	0.266	0.354
KLM+WRM+Clarity	0.476	0.367	0.424	0.403	0.263	0.355
KLM+TRM+Clarity	0.474	0.376	0.424	0.388	0.250	0.341

  - As a side note, the agreement among the subjects (for TD)

Kappa	ROUGE-1	ROUGE-2	ROUGE-L
0.544	0.600	0.532	0.527

Liu et al., "Combining relevance language modeling and clarity measure for extractive speech summarization," IEEE/ACM Transactions on Audio, Speech, and Language Processing, 2015

Objective Evaluations: An Example (2/2)

- Results achieved with **supervised methods**

	Text Documents (TD)			Spoken Documents (SD)		
	ROUGE-1	ROUGE-2	ROUGE-L	ROUGE-1	ROUGE-2	ROUGE-L
SVM	0.470	0.364	0.426	0.383	0.245	0.342
Ranking SVM	0.490	0.391	0.447	0.388	0.254	0.344
Perceptron	0.487	0.394	0.439	0.393	0.259	0.352
GCLM	0.482	0.386	0.433	0.380	0.250	0.342
DNN	0.506	0.411	0.466	0.411	0.267	0.370
CNN	0.501	0.404	0.459	0.413	0.271	0.370
CNN+RNN	0.530	0.425	0.485	0.413	0.280	0.372

- **DNN**: Deep Neural Networks
- **CNN**: Convolutional Neural Networks
- **CNN+RNN**: Integration of Convolutional Neural Networks and Recurrent Neural Networks

Subjective Evaluations

- Conduct manual evaluation with respect to factors such as content coverage and linguistic quality
  - Factors that affect linguistic quality could be ***focus***, ***readability***, ***fluency/coherence***, ***referential clarity***, ***ease of understanding***, ***appropriateness***, to name just a few
  - For each factor we may adopt five-level grades: 1-very bad; 2-bad; 3-normal; 4-good; 5-very good to score an automatic summary

Again, to avoid susceptibility to bias produced by personal opinions, the evaluation usually involves several assessors or multiple reference summaries.

Conclusions

- Although various ingenious and sophisticated summarization methods have been developed, most of them are far to be prefect with lots of open questions remained to be solved (still in their infancy? there are still a great number of questions to be solved)
  - E.g., content and linguistic quality of automatic summaries
  - (Leverage or ignore?) the cognitive processes and the knowledge of human beings that go into document understanding
- Automatic summarization has many possible downstream applications of its own, such as information retrieval, document classification and organization, among others
- One promising research direction is to harness the power of a wide range of machine learning techniques, such as deep neural networks (DNN) and their variants, word/sentence /document embeddings and curriculum learning, to name just a few