A Survey on Semantic Steganography Systems

João Figueira

Abstract

Steganography is the practice of concealing a message within some other carrier or cover message. It is used to allow the sending of hidden information through communication channels where third parties would only be aware of the explicit information in the carrier message. With the growth of internet surveillance and the increased need for secret communication, steganography systems continue to find new applications. In semantic steganography, the redundancies in the semantics of a language are used to send a text steganographic message. In this article we go over the concepts behind semantic steganography and propose a hierarchy for classifying systems within the context of text steganography and steganography in general. After laying this groundwork we list systems for semantic steganography that have been published in the past and review their properties. Finally, we comment on and briefly compare the described systems.

Keywords

Steganography, Linguistic, Semantics, Survey, Markov, Encryption

Introduction and Background

Steganography systems describe methods for taking an “innocuous” message, called covertext and embed it with some plaintext message that is desired to remain hidden, outputting a stegotext. This stegotext is a slightly altered version of the covertext that is still “innocuous” and from which the plaintext is extractable. Effectively, steganography is the process of encrypting a message and having the output appear to be a non-encrypted message.

In certain contexts, a communication channel provider might refuse to relay messages that it can see are encrypted and does not know are trustworthy. More recently, some governments have been planning to outlaw or to regulate the usage of some encryption systems and others have already begun to do so. Steganography finds applications in these situations and will continue to do so with the growing threat of mass surveillance.

Semantic steganography is the branch of text steganography that uses redundancies in the vocabulary of natural languages as the space for the plaintext message (1).

The Steganographic Process

As described by Kingslin in (1), a steganography system can be divided into two components:

- An embedding or injection method, where a covertext is modified to receive the plaintext, outputting the stegotext. These functions make use of the redundancies in the covertext and exploit them as the space in which the plaintext will be inserted. This is performed by the message sender.

- An extraction method, where the plaintext is extracted from the stegotext (in some systems, the original covertext can also be obtained here). This is done by the message receiver.

Figure 1. Diagram showing a generic setting for steganography. The sender embeds the plaintext message $m$ into the covertext $c$, producing the stegotext $s$. This stegotext is sent to the receiver who uses the extraction function to recover the original plaintext. A third party might see the stegotext but it should be innocuous enough that no suspicion would be raised to the fact that it is carrying a message.

A diagram explaining the usage of these two functions to hide and send messages can be seen in Figure 1.

Definition 0.1. A steganography system (or scheme) can be defined as a quadruple $< C, M, E, D >$, where $C$ is the set of possible covertexts (messages that are innocuous and would not raise suspicion to a third party), $M$ is the set of possible plaintexts (the set of all messages over the plaintext alphabet $\Sigma, \Sigma^*$), with $|C| \geq |M|$, $E : C \times M \rightarrow C$ is the embedding or insertion function, $D : C \rightarrow M$ is the extraction function. The property $D(E(m)) = m$ is verified for all $m \in M$. The embedding and extraction functions might take additional parameters, depending on the system.

A Hierarchy for Text Steganography Systems

Most Steganography methods can embed a hidden message of any nature into a cover message of a specific nature, i.e.

---

1 Instituto Superior Técnico, Portugal

Email: joaoperfig@gmail.com
Steganography
Format-Based Text Steganography
Text steganography classification of text steganography systems. A diagram of
In this section we provide and describe a hierarchy for the
approaches, these differ mostly in what elements of the
research that has seen the development of some very different
information in comparison to the other digital media formats.
is because a text file lacks a large scale redundancy of
steganography is still seen as the most difficult
kind of steganography. As Sharma describes it in (6), this
this, text steganography is seen as the most difficult
millimetres, or even adding extra spaces between words (7;
for example, hide information in the frequencies of certain
words or letters.
Linguistic Text Steganography Text steganography systems that deal with the linguistic properties of the covertext are
called linguistic steganographic systems (3; 1; 4). These
systems perform alterations on the text itself and exploit the
ambiguities or redundancies of natural languages.
As described by Kingslin (1) and Singh (4), the family
of linguistic steganography systems can be further divided
according to which linguistic properties of the text are being
used to embed the plaintext. As such, the following two sub-
families of linguistic steganography can be formalized:

• **Syntactic Text Steganography** Linguistic steganography systems that deal with the syntax of text are
called syntactic text steganography systems. Such systems
might change the grammatical structures of sentences to embed a hidden message. Simpler systems in this
family might simply add or remove commas from text in places where their necessity is arguable (such as the Oxford comma).

• **Semantic Text Steganography** Semantic text stenography is the branch of text steganography that uses the
redundancy of words as the space for the hidden message. Steganographic systems in this family replace words in a cover message with their synonyms. Trivial implementations of such systems label words and their synonyms with a binary value. The message sender identifies the words that can be replaced in the covertext, and, depending on the desired bit from the plaintext, will choose to keep the original word or replace it with its synonym. The message receiver will do the same process and identify the message sender’s choices to determine the hidden message bits.

**Classifications for Embedding Functions**
The embedding and extraction functions are the defining
element of a steganographic system. As inverse functions, these two methods are co-dependant and need to be jointly defined. For their relevance, steganographic systems can be classified according to the working principles of these functions. The following classifications were proposed by Kaufmann in (2):

• **Steganography by Cover Modification** Steganography systems in which the embedding function alters an existing covertext are called steganography by cover
On The Security of Semantic Steganography Systems

The primary objective of any steganography system is to provide a hidden channel for communication, such that third parties can intercept the cover messages and not be suspicious that these messages are carrying a hidden embedded message. Some third parties, might, however, be aware of the possibility of usage of steganography in a certain communication channel. In this situation, they might use the extraction functions of some steganography systems to "screen" messages for possible hidden embedded messages. Because of this, it is always ideal to first encrypt the hidden message using, for example, some simple symmetric-key encryption algorithm. If the extraction function can be used on any cover message and have some output, the natural randomness of some covertext should be indistinguishable from the ciphertext produced by some cryptosystem (10). This means that not only is the message encrypted, but there is also no evidence that any steganography system was used, as any message would give a seemingly random output from the extraction function.

Semantic Steganography Systems

The following is our survey of existing systems for semantic steganography that have been published in the past.

Synonym Table Steganography Systems

Semantic steganography systems use the redundancy in the words of natural languages as the space for a hidden message. The most trivial implementation of such a system would be one that replaces words in the covertext with their synonyms. In our survey, the majority of such systems make usage of a synonym table (exemplified in Table 1) that is shared between the message sender and receiver. These tables, of usually two columns, pair words with their synonyms.

In these systems, the hidden message is encoded into the choice of synonyms that was used in the covertext. This way, each word in the covertext (that can be replaced by a synonym) will encode a character of the plaintext, corresponding to which column of the synonym table it is in.

Embedding Method In all of these systems (7; 12; 11; 13), the embedding method functions as follows, for a given covertext and plaintext:

1. The plaintext is converted into an alphabet $\Sigma$ such that $|\Sigma| = c$, where $c$ is the number of columns in the synonym table.
2. The covertext is scanned and occurrences of words in the synonym table are identified.
3. The $n^{th}$ identified word of the covertext is replaced with a synonym from the table’s column corresponding to the $n^{th}$ character of the plaintext.

This embedding method is further clarified in Figure 3.

Extraction Method The stegotext generated by the message sender using the aforementioned embedding method is sent to the message receiver which will apply the corresponding extraction method. The extraction method for these systems can be described as follows:

1. The stegotext is scanned and occurrences of words in the synonym table are identified.
2. The $n^{th}$ character of the plaintext will correspond to the column of the $n^{th}$ identified word of the stegotext.

This extraction method is further clarified in Figure 4.

Table 1. Example of a short synonym table, used by Bender in (7).

| big      | large |
|----------|-------|
| small    | little|
| chilly   | cool  |
| smart    | clever|
| spaced   | stretched |
Acronyms and their unabbreviated counterparts can also be seen as synonyms. In (12), the authors explored the application of the abbreviations and acronyms commonly used in SMS messages for such a system. Their approach would ideally be applied to SMS messaging where the usage of the aforementioned acronyms would be most innocuous (such as using "NP" instead of "No problem"). An obvious disadvantage of this, however, is that SMS messaging is not an ideal channel for steganography, due to the character limit of text messages. In the described system, only about three hundreds of messages would be needed to send a single bit of information could be sent per message. As such, hundreds of messages would be needed to send a single paragraph of plaintext, which would not be very innocuous.

The work of Shirali-Shahreza (12) was extended by Rafat’s research (11). In this article, the author explored the expansion of the security of the system by using a stego-key to shuffle elements of the synonym table between the left and right columns. For his implementation, the author used a process of XoR-Encryption supported by a Linear Feedback shift register to perform the shuffling. This system is more secure in that a third party that might know the system would still be unable to extract the hidden information without the stego-key.

Rafat’s approach does, however, have some vulnerabilities. Shuffling the synonym table for security means that expressions in the table will always correspond to the same character of the hidden alphabet. For example, a third party that knows the system but does not know the stego-key would not know which bit is encoded in an instance of the acronym “np” in the covertext. However, this third party will know that all instances of “np” encode the same bit value which consequentially is different from the bit value of all instances of “no problem”. This means the system might be vulnerable to some statistical analysis methods. A simpler and safer approach to security would be the one described in section .

**Variable Synonym Cardinality Steganography Systems**

In the examples described in previous section, the synonym table has a set number of columns and, as such, all words in such a synonym table are restricted to having that set number of possible replacements (usually just one, for the embedding of a binary string). This is rather restrictive since some words (usually the most common ones) can have a large number of synonyms. These words have a potential to encode more information that is not being exploited by the described system.

The most trivial solution for this problem is the one described by Weinstein (14) in his description for a "naive algorithm". The described approach groups words into sets of mutually interchangeable synonyms. The system embeds a binary message into the covertext, each word can embed as many bits as the base two logarithm of the number of words in its synonym set. As such, the number of elements in these sets of synonyms is restricted to being some power of 2. This approach is exemplified in Figure 5. A similar approach is also used in (15) and (16).

**Winston's Ideal Coding**

In (14), Weinstein improves on the aforementioned "naive algorithm" by proposing a related system in which the synonym sets can have any number of words (as opposed to only powers of 2). His proposal consists on converting the hidden message into a multi-base number (each digit may have a different base), where each digit corresponds to a word in the synonym table, and the base of each digit is the
The Hidden Message

A proposed by Huffman (19). Commonly used for lossless data compression, it was first Huffman compression functions. A Huffman function (or mimic function) is described as the function that alters the statistical properties of a text file A to be the same as some other file B. Formally, if \( p(t, A) \) is the probability of a substring \( t \) occurring in \( A \), then the mimic function \( f \) encodes \( A \) so that \( p(t, f(A)) \) approximates \( p(t, B) \).

Wayner introduces mimic functions as the inverse of Huffman compression functions. A Huffman function (or Huffman code) is a type of optimal prefix code that is commonly used for lossless data compression, it was first proposed by Huffman (19).

The proposed approach is to construct the Huffman compression functions for the files A and B, \( f_A \) and \( f_B \). The inverse of \( f_B, g_B \) is then computed. The composite function \( g_B(f_A(A)) \) is the first order mimic function that converts A to have the statistical properties of B. Larger order mimic functions can be computed by joining sequences of \( n \) characters together (for an \( n^{th} \) order mimic function) and interpreting them as being a single character.

This system can be seen as a cover synthesis steganographic system (the cover message is generated for the specific plaintext) in which, for a hidden message A, and a cover message B, the mimic function \( g_B(f_A(A)) \) will generate a stegotext message that has the statistical properties of the covertext B. The stegotext outputted by this system will be text that contains word or even short expressions found in the covertext but that lacks any grammatical structure or sense. For a human third party, this stegotext will obviously raise suspicion. Wayner improved on his system by joining it with context-free grammars to ensure the sentences maintain grammatical consistency. This improved the iniquity of the stegotext, but it still remained mostly devoid of meaning.

Mimic Functions

A well known approach for semantic steganography is the one proposed by Wayner in his articles (17) and (18). Here Wayner described the construction of mimic functions and their applications for text steganography.

A mimic function \( f \) is described as the function that alters the statistical properties of a text file A to be the same as some other file B. Formally, if \( p(t, A) \) is the probability of a substring \( t \) occurring in \( A \), then the mimic function \( f \) encodes \( A \) so that \( p(t, f(A)) \) approximates \( p(t, B) \).

Wayner introduces mimic functions as the inverse of Huffman compression functions. A Huffman function (or Huffman code) is a type of optimal prefix code that is commonly used for lossless data compression, it was first proposed by Huffman (19).

The proposed approach is to construct the Huffman compression functions for the files A and B, \( f_A \) and \( f_B \). The inverse of \( f_B, g_B \) is then computed. The composite function \( g_B(f_A(A)) \) is the first order mimic function that converts A to have the statistical properties of B. Larger order mimic functions can be computed by joining sequences of \( n \) characters together (for an \( n^{th} \) order mimic function) and interpreting them as being a single character.

This system can be seen as a cover synthesis steganographic system (the cover message is generated for the specific plaintext) in which, for a hidden message A, and a cover message B, the mimic function \( g_B(f_A(A)) \) will generate a stegotext message that has the statistical properties of the covertext B. The stegotext outputted by this system will be text that contains word or even short expressions found in the covertext but that lacks any grammatical structure or sense. For a human third party, this stegotext will obviously raise suspicion. Wayner improved on his system by joining it with context-free grammars to ensure the sentences maintain grammatical consistency. This improved the iniquity of the stegotext, but it still remained mostly devoid of meaning.

Markov Chain Based Text Steganography

In (20), Dai introduced the usage of Markov chains for text steganography, this research was continued in (21). Dai’s proposal involves constructing a Markov model for the desired covertext.

A Markov model constructed from some text corpus would maintain the probabilities of any two consecutive words appearing in the corpus \( p(w_i | w_{i-1}) = \frac{\text{count}(w_{i-1}, w_i)}{\text{count}(w_{i-1})} \). The model could be used to construct new text samples that mimicked the statistical properties of the corpus (much like the mimic functions described in Section ). Higher order Markov models can be used, these models take in account more words to provide a more accurate probability of the next. An \( n^{th} \) order Markov model would compute and use the probabilities \( p(w_{i-n} | w_{i-1}, w_{i-2}, ..., w_{i-n}) \).

In Dai’s approach, the transitions of the Markov model are labelled with parts of the hidden message. To synthesise the stegotext, it is only necessary to use the plaintext to determine the sequence of state transitions that is done on the model. This process is exemplified Figure 7.

Moraldo’s Fixed Size Steganography

In (22), Moraldo described how Dai’s Markov systems produce “unnatural” looking text by not taking into account the probability of transitions. With the way that transitions are labelled, any outgoing transition from any given state has the same probability of occurring in a stegotext.

Moraldo’s solution involves grouping multiple consecutive transitions together and labeling these groups with parts of the hidden message. More probable state transitions will occur in more of these labelled groups. This way, the resulting stegotext will have more natural word sequences that occur with the frequency that is expected of a real text. This system is exemplified in Figure 8.

Markov Chain and Huffman Coding Based Text Steganography

In (23), the authors also explore the problem of ensuring a natural probability distribution of transitions on a Markov
based steganographic system. For their approach, the authors make use of Huffman coding to construct a tree for the transitions at each step of the Markov model. More frequent transitions are labelled with shorter labels and are thus more likely to appear in the hidden message. This is exemplified in Figure 9. This system shares a lot of similarities with the mimic functions described by Wayner (17) and with Moraldo’s approach (22).

Conclusion

Text steganography systems continue to be tools with very niche and circumstantial applications but that are sure to see increased usage with the growing trend of online surveillance and censorship. We found that the literature on the topic was sparse and and not coherent across publications and hope that our survey helps standardize approaches to semantic steganography.

In regards to the listed approaches, all have very similar applicability and differ mostly on whether the hidden message is embedded into an existing cover message or if the cover message is synthesized for it. Among the systems that use an existing cover message, Winston’s ideal coding (14), described in section would have the best rate of hidden information given that it is the only system that can use all possible synonyms of words. Among systems for cover synthesis, the usage of Markov chains to generate the cover, using Huffman coding to ensure the text is statistically “natural” (23), described in section , is effectively the state of the art of semantic steganography and produces the most natural results with the highest rate of hidden information.

References

[1] Sumathy Kingslin and N. Kavitha. Evaluative approach towards text steganographic techniques. Indian Journal of Science and Technology, 8, 11 2015. doi: 10.17485/ijst/2015/v8i11/84415.
[2] Ingemar Cox, Matthew Miller, Jeffrey Bloom, Jessica Fridrich, and Ton Kalker. Digital Watermarking and Steganography. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2 edition, 2007. ISBN 9780080555805.
[3] Monika Agarwal. Text steganographic approaches: A comparison. International Journal of Network Security and Its Applications, 5, 02 2013. doi: 10.5121/ijnssa.2013.5107.
[4] Harjit Singh. Analysis of different types of steganography. International journal of scientific research in science, engineering and technology, 2:578–582, 2016.
[5] Masoud Nosrati, Ronak Karimi, and Mehdi Hariri. An introduction to steganography methods. World Applied Programming, 1:191–195, 08 2011.
[6] S. Sharma, A. Gupta, M. C. Trivedi, and V. K. Yadav. Analysis of different text steganography techniques: A survey. In 2016 Second International Conference on Computational Intelligence Communication Technology (CICT), pages 130–133, 2016.
[7] W. Bender, D. Gruhl, N. Morimoto, and A. Lu. Techniques for data hiding. IBM Systems Journal, 35(3.4):313–336, 1996.
[8] Sangita Roy and Manini Manasmita. A novel approach to format based text steganography. pages 511–516, 01 2011. doi: 10.1145/1947940.1948046.
[9] Baharudin Osman, A. Yasin, and Mazni Omar. An analysis of alphabet-based techniques in text steganography. 8:109–115, 01 2016.
[10] Stefan Katzenbeisser and Fabien A. Petitcolas. Information Hiding Techniques for Steganography and Digital Watermarking. Artech House, Inc., USA, 1st edition, 2000. ISBN 1580530354.
[11] K. F. Rafat. Enhanced text steganography in sms. In 2009 2nd International Conference on Computer, Control and Communication, pages 1–6, 2009.
[12] M. Shirali-Shahreza and M. H. Shirali-Shahreza. Text steganography in sms. In 2007 International Conference on Convergence Information Technology (ICCIT 2007), pages 2260–2265, 2007.
[13] M. H. Shirali-Shahreza and M. Shirali-Shahreza. A new synonym text steganography. In 2008 International Conference on Intelligent Information Hiding and Multimedia Signal Processing, pages 1524–1526, 2008.
[14] Keith Weinstein. Lexical steganography through adaptive modulation of the word choice hash. 1998.
[15] Mark Chapman, George I. Davida, and Marc Rennhard. A practical and effective approach to large-scale automated linguistic steganography. In George I. Davida and Yair Frankel, editors, Information Security, pages 156–165, Berlin, Heidelberg, 2001. Springer Berlin Heidelberg.
[16] H. Huanhuan, Z. Xin, Z. Weiming, and Y. Nenghai. Adaptive text steganography by exploring statistical and linguistic distortion. In 2017 IEEE Second International Conference on Data Science in Cyberspace (DSC), pages 145–150, 2017.
[17] Peter Wayner. Mimic functions. Cryptologia, 16(3):193–214, 1992. doi: 10.1080/0161-119291866883.
[18] Peter Wayner. Strong theoretical steganography. *Cryptologia*, 19(3):285–299, 1995. doi: 10.1080/0161-119591883962.

[19] D. A. Huffman. A method for the construction of minimum-redundancy codes. *Proceedings of the IRE*, 40(9):1098–1101, 1952.

[20] Weihui Dai, Yue Yu, and Bin Deng. Bintext steganography based on markov state transferring probability. pages 1306–1311, 11 2009. doi: 10.1145/1655925.1656165.

[21] Weihui Dai, Yue Yu, Yonghui Dai, and Bin Deng. Text steganography system using markov chain source model and des algorithm. *JSW*, 5:785–792, 07 2010. doi: 10.4304/jsw.5.7.785-792.

[22] Horacio Moraldo. An approach for text steganography based on markov chains. 09 2014.

[23] Zhongliang Yang, Shuyu Jin, Yongfeng Huang, Yujin Zhang, and Hui Li. Automatically generate steganographic text based on markov model and huffman coding, 2018.