LOSSLESS FORMATS (FLAC, ETC.)

MARGARET HOPKINS, MUMT 621

WHAT IS A LOSSLESS FORMAT?

- We compress audio to save memory
  → lossy formats like MP3 remove inaudible information – cannot be restored
- Lossless formats allow us to completely reconstruct the original signal
- Typically use more memory than lossy compression

FREE LOSSLESS AUDIO CODEC (FLAC)

- Open format, royalty free compression format
  → compresses to 50-70% of original size
  → all data can be completely recovered from the compressed version
- Fast encoding and decoding, extensive hardware support, and free reference implementation (Rivero & Mishra 2008)

free lossless audio codec

HOW DOES FLAC WORK?

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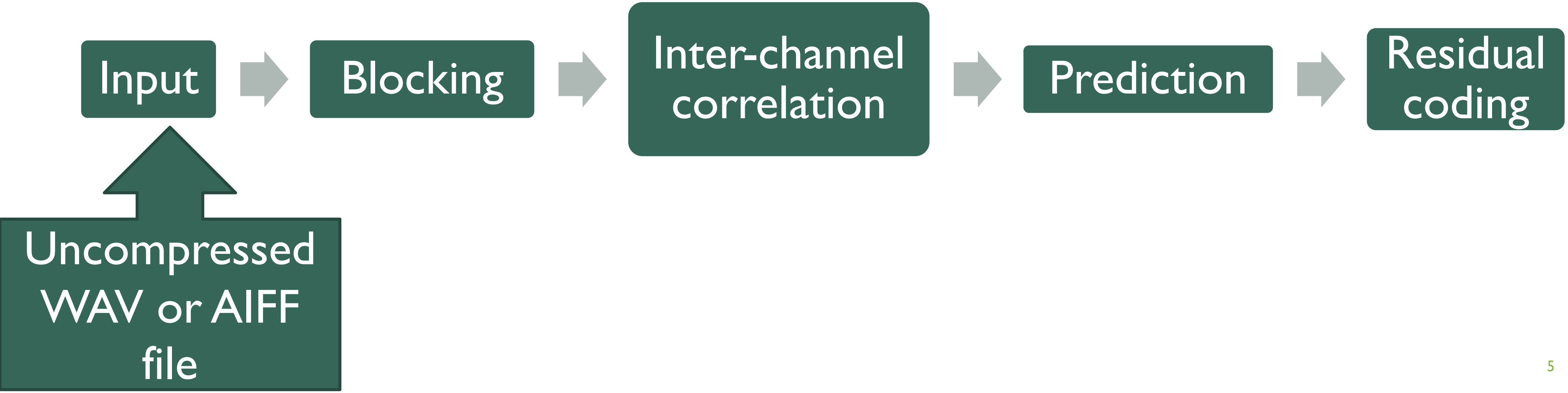

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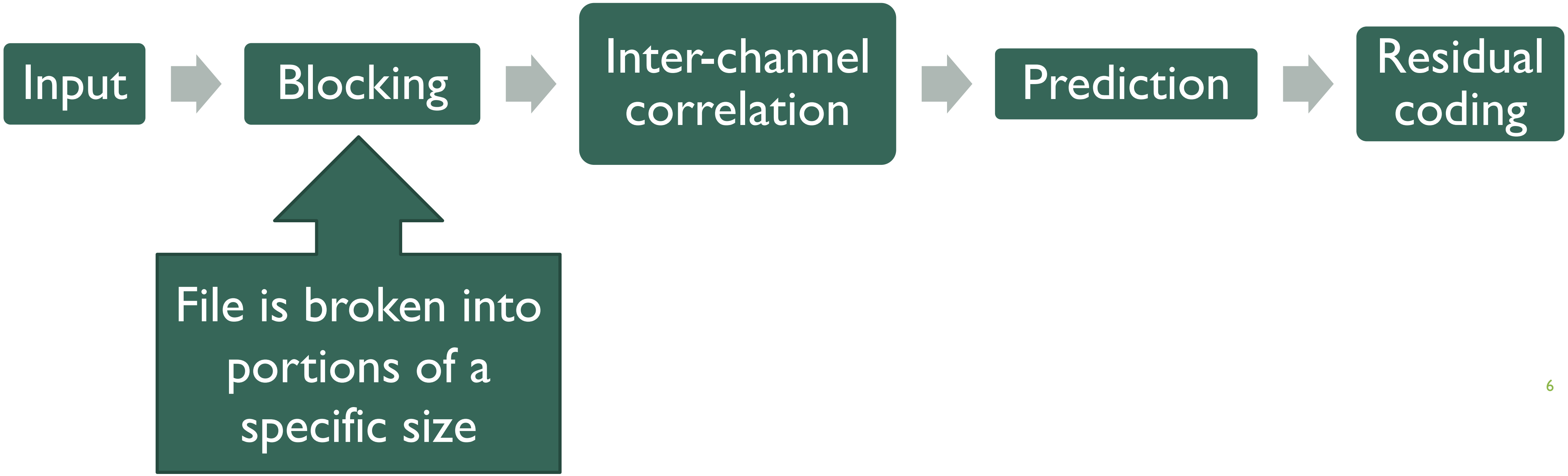

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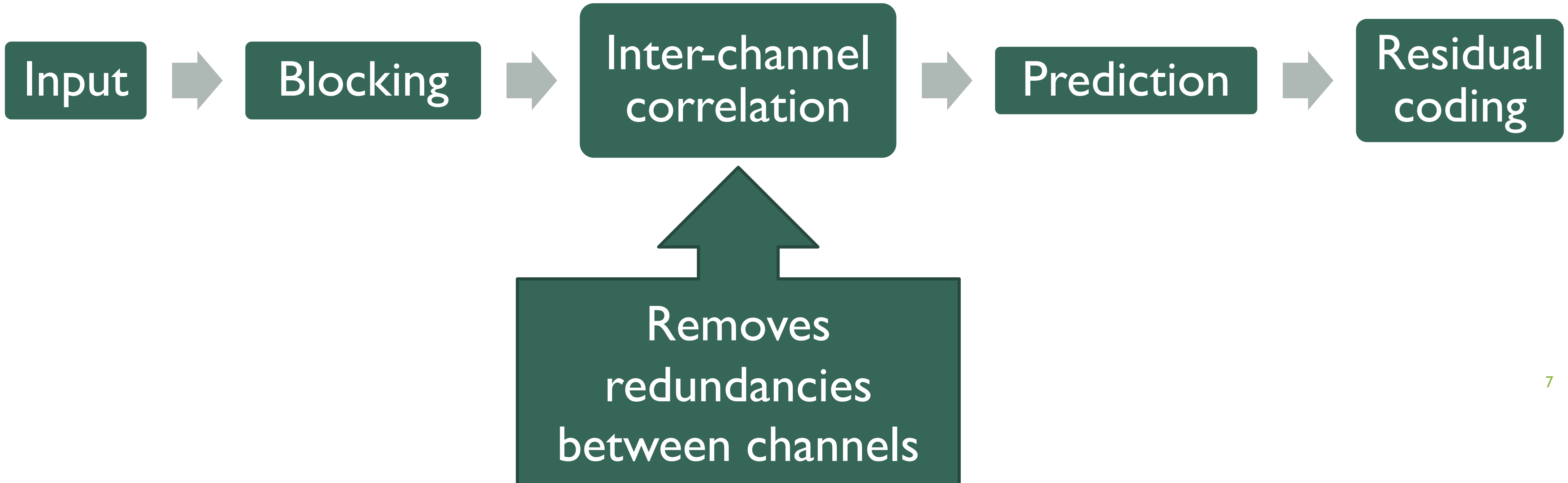

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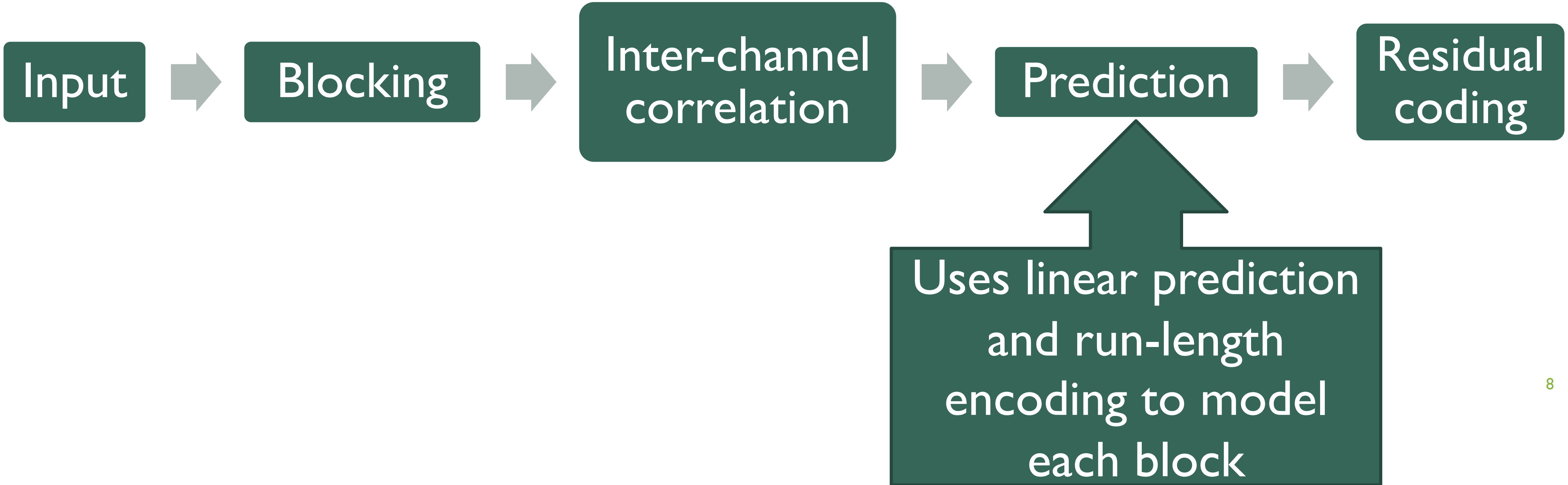

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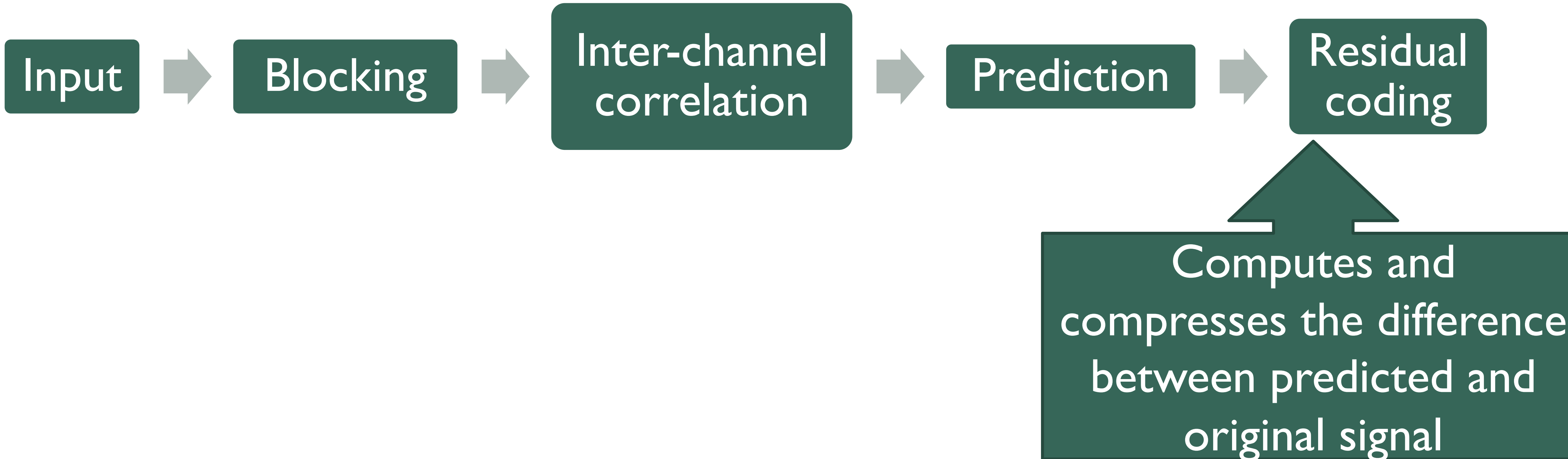
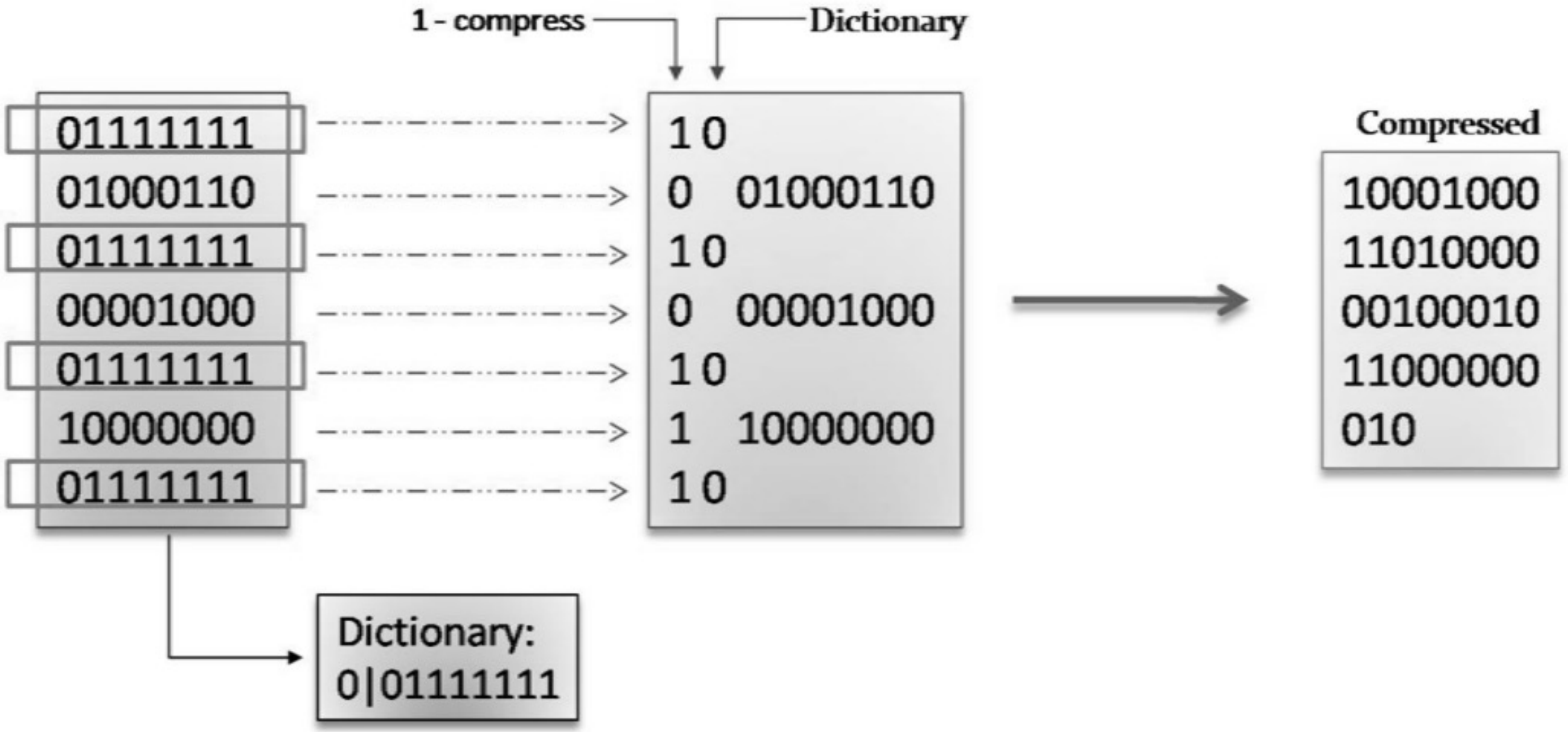


DICTIONARY-BASED COMPRESSION

- Uses a static or frequency-based dictionary → commonly used "words" are stored in dictionary and called by their index



Source: Rivero & Mishra (2008)

GRAMMAR-BASED COMPRESSION

- An algorithm creates a **context free grammar** for the string to be compressed
  → "grammars can capture repetitions occurring far apart in the data," – Cherniavsky & Ladner (2004)
- The grammar replaces substrings with their references in a combination that produces the smallest possible encoding (Humphries, Sidorov, Jones, & Marshall 2021)

GRAMMAR-BASED COMPRESSION

Source: Cherniavsky & Ladner (2004)

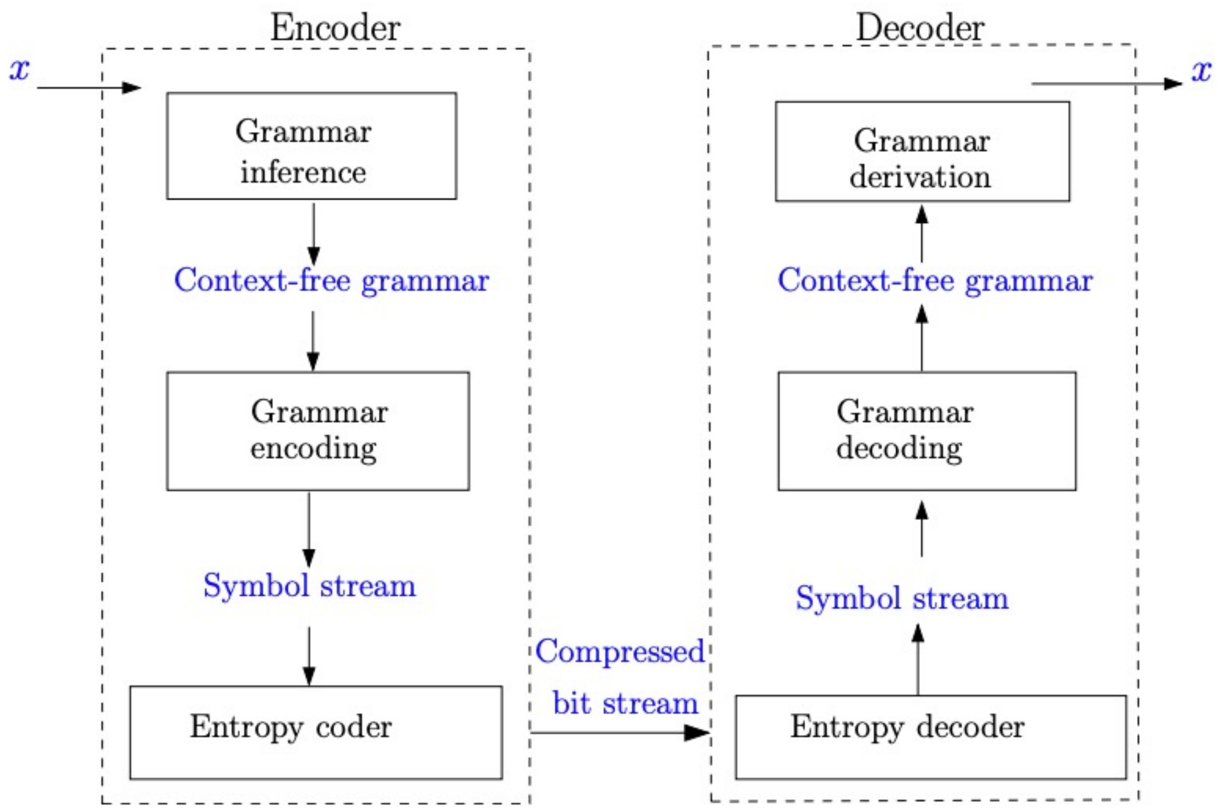


Figure 1: Overview of grammar compression

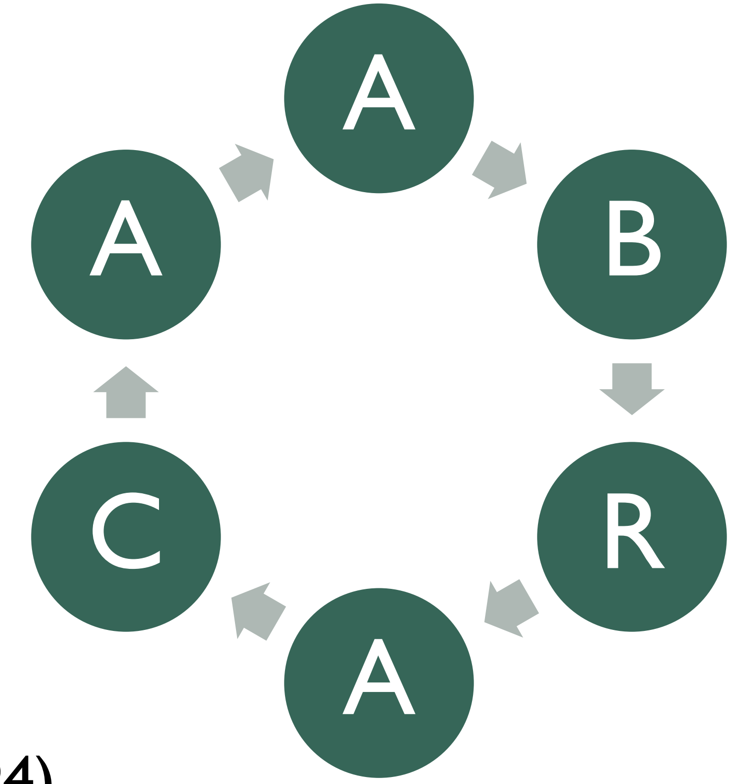
BURROWS-WHEELER TRANSFORM

- Proposed in 1994 as a method to prepare data for compression
- Reorders a string of characters so that there are more segments with repeated characters
  → makes the string more suitable for run-length and move-to-front encoding
- Can be reversed to restore the original string

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

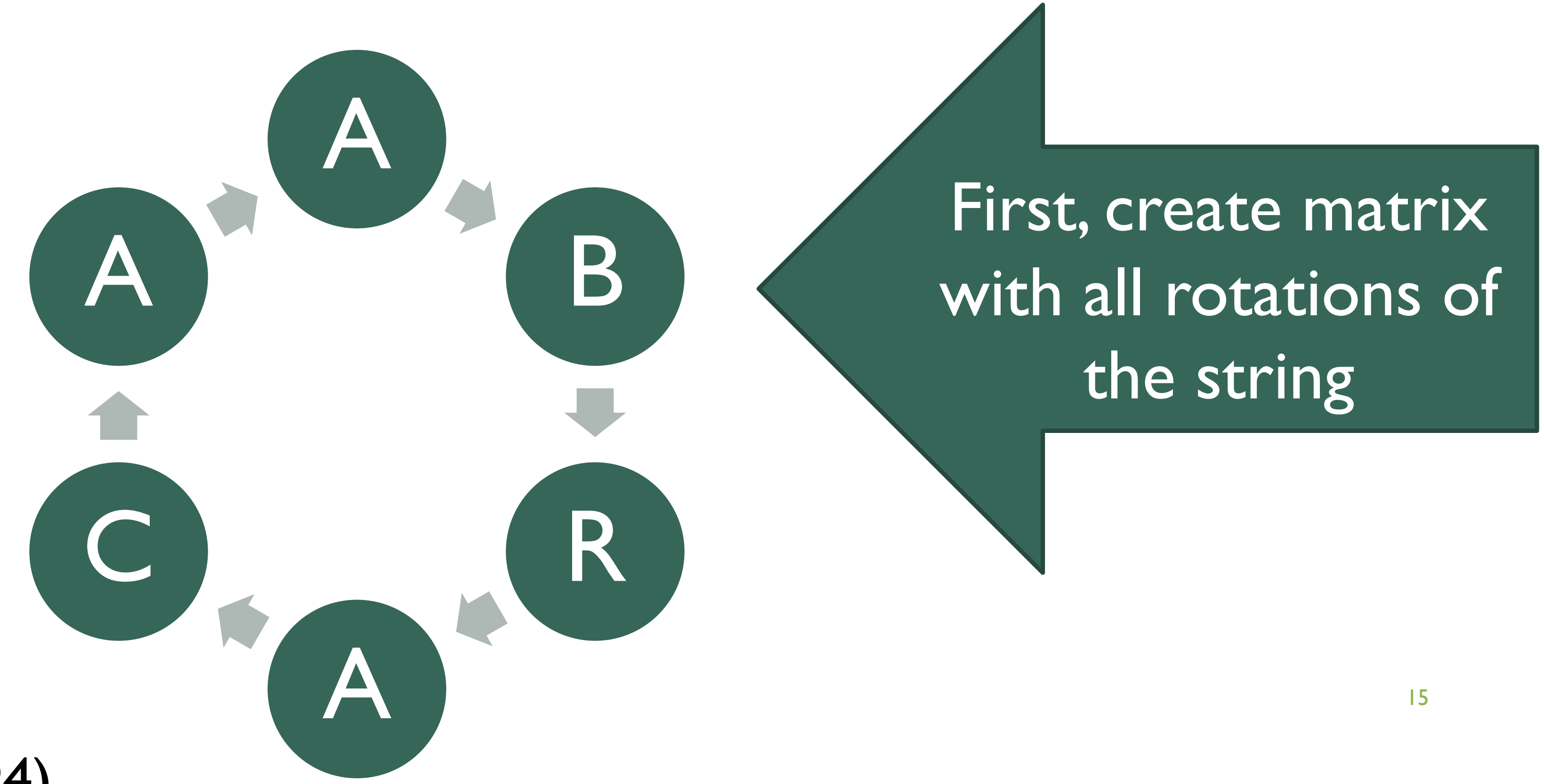
Consider the string "ABRACA":



Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

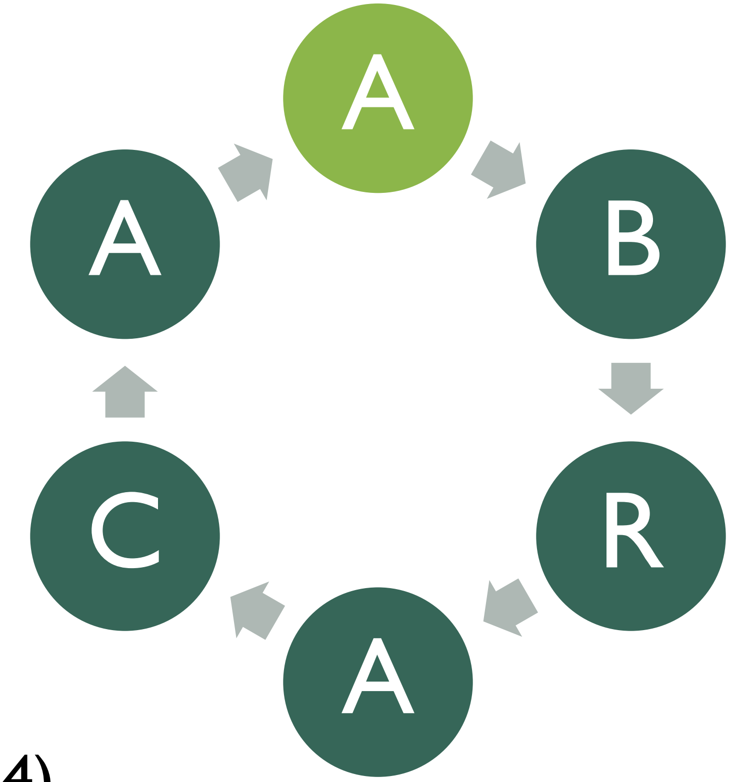
Consider the string “ABRACA”:



Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string "ABRACA":

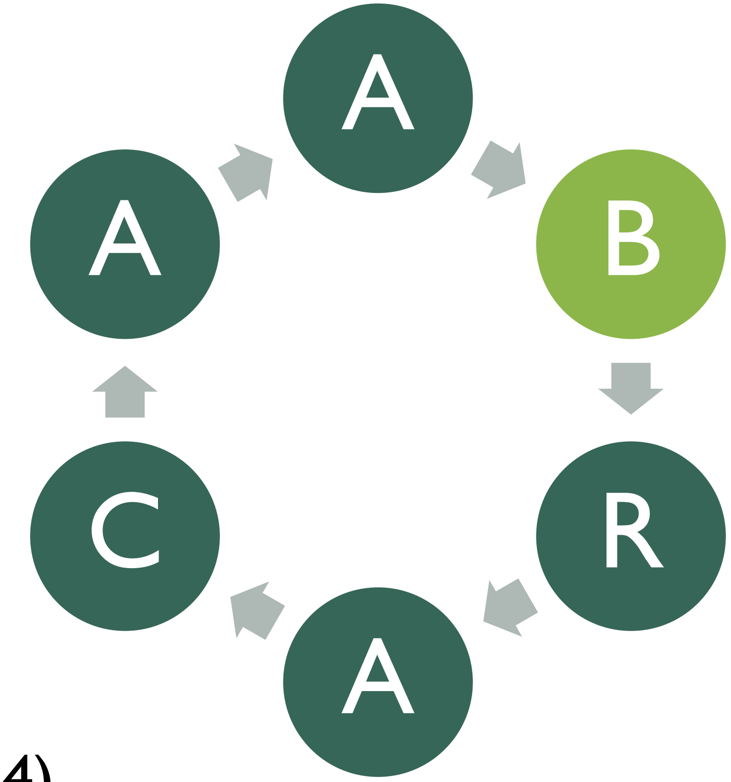


ABRACA

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string “ABRACA”:

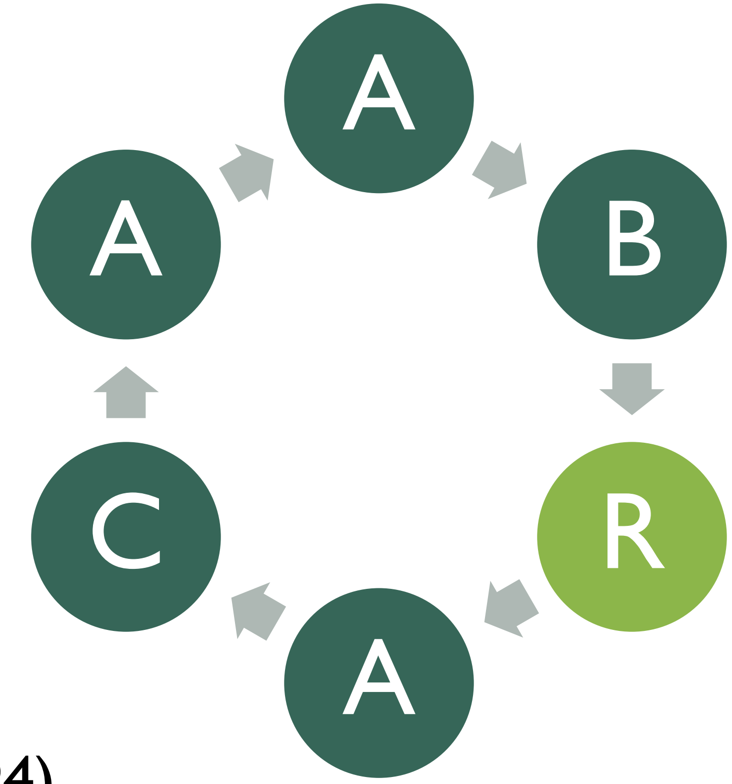


ABRACA
BRACAA

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string "ABRACA":

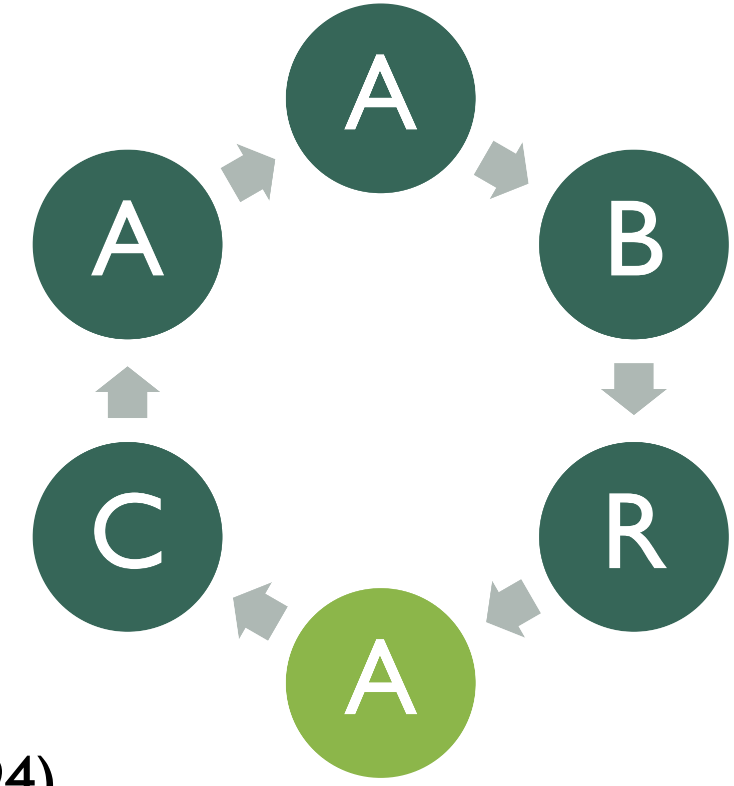


ABRACA
BRACAA
RACAAB

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string "ABRACA":

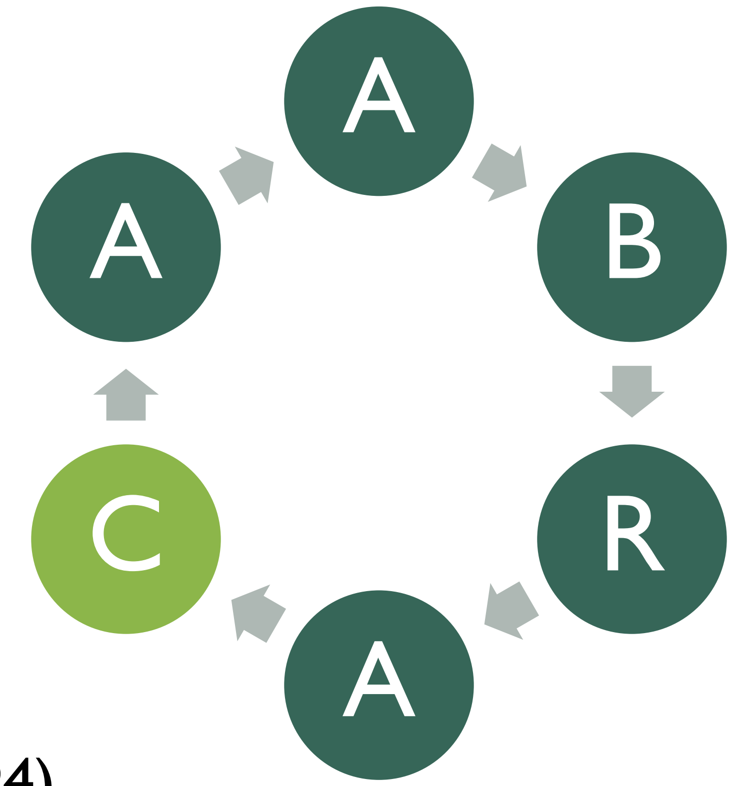


ABRACA
BRACAA
RACAAB
ACAABR

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string "ABRACA":

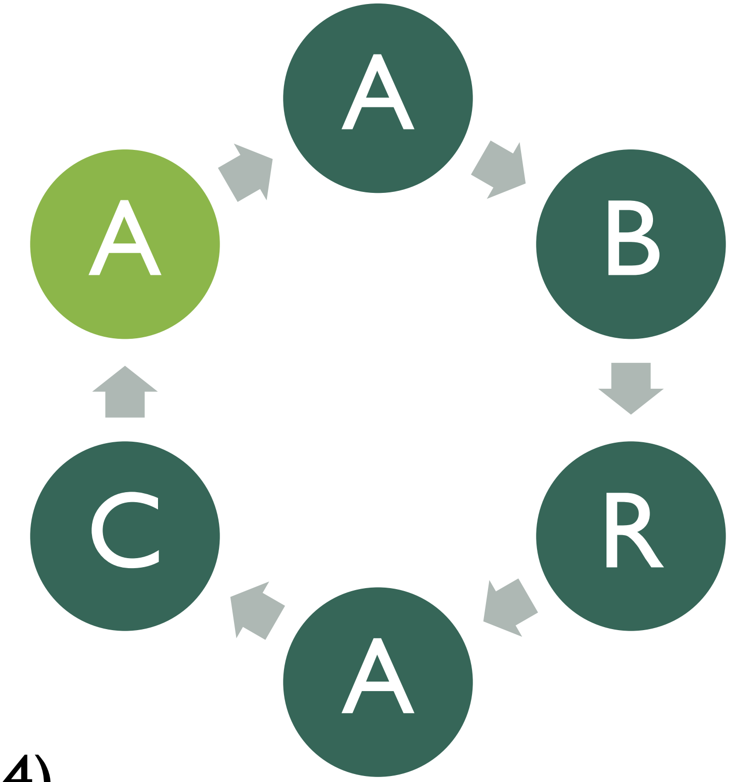


ABRACA
BRACAA
RACAAB
ACAABR
CAABRA

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Consider the string "ABRACA":



ABRACA
BRACAA
RACAAB
ACAABR
CAABRA
AABRAC

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

Next, we reorder the matrix lexographically, noting the index of the row with the original string

ABRACA	→	AABRAC
BRACAA		ABRACA
RACAAB		ACAABR
ACAABR		BRACAA
CAABRA		CAABRA
AABRAC		RACAAB

Index = 2

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM - EXAMPLE

The Burrows-Wheeler transform of of the string is the last column of the new matrix

ABRACA	→	AABRAC
BRACAA		ABRACA
RACAAB		ACAABR
ACAABR		BRACAA
CAABRA		CAABRA
AABRAC		RACAAB

Index = 2

Source: Burrows & Wheeler (1994)

BURROWS-WHEELER TRANSFORM

ABRACA → CARAAB

The resulting string has more runs of repeated characters, especially if there were repeated words in the input

LOSSLESS IMAGE/VIDEO COMPRESSION

- Other types of media can also be compressed into lossless formats:
  → photos: PNG, GIF, TIFF
  → videos: H.264 Lossless, H. 265 Lossless, Motion JPEG Lossless, Apple Animation Quicktime RLE

APPLICATIONS TO MIR

ARCHIVAL PURPOSES

- Cooper (2020)
  → archiving a large collection donated to the University of Leeds by Trevor Jones
  → digitized recordings and stored using FLAC in order to retain all information while saving memory
- Lai, Li, & Fujinaga (2005)
  → digitizing album covers from David Edelberg's record collection
  → tested two lossless image compression formats: TIFF and PNG
  → chose PNG for significant file size reduction, open format, and good metadata

HUMPHREYS, SIDOROV, JONES, & MARSHALL (2021)

- Used grammar-based compression to perform musicological tasks
  → detecting transcription errors
  → classifying pieces by melodic characteristics
  → segmenting pieces for musical analysis
  Dataset: 7928 scores from Acadia Early Music Archive, CPDL and Musopen
- Used string processing techniques designed for compression and pattern matching within text
- Algorithms used: Lempel-Ziv Welch, Burrows-Wheeler with run-length encoding, and GZIP

HUMPHREYS, SIDOROV, JONES, & MARSHALL (2021)

- Error detection: compared size of compressed original data and altered data
  → if the size was different, there was an alteration
  → all algorithms could detect a single error
  → logarithmic response to increasing number of errors
- Classification: used compression distance between two scores to rate their similarity
  → used the Meertens Tune Collections
  → compressing scores with common components produces a smaller model
  → success rates: 0.92 for ZZ and 0.83 for IIR-MC

HUMPHREYS, SIDOROV, JONES, & MARSHALL (2021)

- Segmentation: hypothesized that using a grammar-based compressor would divide the data in a musicologically significant way
  → ZZ performed well on pieces containing exact matches, like Bach's Fugue no. 20 from the Well-Tempered Clavier
  → strong correlation between rules from the grammar-based compressors and analysis by Bruhn (1993)

CONCLUSIONS

- Lossless compression allows us to store audio and visual data with reduced memory use without losing any information
- Compression algorithms can also be used for pattern recognition that can be applied to structural music analysis, classification, and error detection

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