Sequence analysis

GABAC: an arithmetic coding solution for genomic data

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Abstract

Motivation: In an effort to provide a response to the ever-expanding generation of genomic data, the International Organization for Standardization (ISO) is designing a new solution for the representation, compression and management of genomic sequencing data: the Moving Picture Experts Group (MPEG)-G standard. This paper discusses the first implementation of an MPEG-G compliant entropy codec: GABAC. GABAC combines proven coding technologies, such as context-adaptive binary arithmetic coding, binarization schemes and transformations, into a straightforward solution for the compression of sequencing data.

Results: We demonstrate that GABAC outperforms well-established (entropy) codecs in a significant set of cases and thus can serve as an extension for existing genomic compression solutions, such as CRAM.

Availability and implementation: The GABAC library is written in C++. We also provide a command line application which exercises all features provided by the library. GABAC can be downloaded from https://github.com/mitogen/gabac.

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Supplementary information: Supplementary data are available at Bioinformatics online.

1 Introduction

The Moving Picture Experts Group (MPEG or ISO/IEC JTC1/SC29/WG11) is designing a new solution for the representation, compression and management of genomic sequencing data: the MPEG-G standard. The standard in itself consists of a set of decoding specifications and does not provide, per se, actual encoding implementations.

This paper discusses the first implementation of an MPEG-G compliant entropy codec: GABAC. GABAC combines proven coding technologies, such as context-adaptive binary arithmetic coding (CABAC) (Marpe et al., 2003), binarization schemes and transformations, into a straightforward solution for the compression of sequencing data. Although GABAC has been designed following the MPEG-G specifications, in what follows we will show that integrating GABAC into other genomic compression solutions, such as CRAM (Bonfield, 2014; Fritz et al., 2011) or DecZ (Hach et al., 2014) can lead to significant improvements.
transformation, i.e. pass-through): (i) run-length coding, where a repeated symbol is replaced by the symbol itself and its run-length; (ii) match coding, an LZ77-style transformation and (iii) equality coding, where a symbol is replaced by a flag indicating equality with its predecessor and a correction symbol, if required. In the second transformation step, for each sub-stream separately, a look-up table transformation can be applied. Finally, in the third transformation step, one can choose to apply differential coding. For each transformed sub-stream, a binarization algorithm (used for conversion of each symbol into a bit string) is picked together with a context selection algorithm. In the last step, each bit of the binarization is combined with a context and both are processed using CABAC. For more detailed explanations on the GABAC working principles, we refer the reader to the Supplementary Data.

3 Results and discussion

To analyze the performance of the GABAC encoder, we modified the compression tools CRAM and DeeZ to output their internal data representations, such as mapping positions and read pairing information, to separate descriptor stream files. We encode every descriptor stream with the (entropy) codecs used in CRAM (i.e. bzip2, gzip, rANS order-0, rANS order-1 or xz), plus GABAC. This way we can compare the performance of GABAC to the currently used (entropy) codecs.

Table 1. Compressed sizes (in bytes) for different codec sets applied to the CRAM and DeeZ descriptor streams

|                | CRAM streams | DeeZ streams |
|----------------|--------------|--------------|
| CRAM           | 1 2 3 4 5    | 1 2 3 4 5    |
| CRAM + GABAC   | 6 7 8 9 10   | 11 12 13 14 15 |
| CRAM + GABAC + gzip + rANS-0 | 16 17 18 19 20 |

Note: Best results in bold.

To further analyze to which extent existing solutions can benefit from the incorporation of GABAC, Table 1 shows the compressed sizes for different codec sets (where for each stream the codec with the highest compression ratio is selected): the set of codecs used in CRAM, the set of codecs used in CRAM plus GABAC and the set of codecs that rank last (34% and 2 MiB/s, respectively) and the set of codecs that rank last (34% and 2 MiB/s, respectively). As it can be observed in Fig. 1, GABAC obtains the best compression ratios on average. GABAC is also faster than gzip and xz provided that its optimal configuration [i.e. the optimal combination of transformation(s), binarization(s) etc.] is known (see Supplementary Data).

To further analyze to which extent existing solutions can benefit from the incorporation of GABAC, Table 1 shows the compressed sizes for different codec sets (where for each stream the codec with the highest compression ratio is selected): the set of codecs used in CRAM, the set of codecs used in CRAM plus GABAC and the set of codecs used in CRAM plus GABAC with gzip and rANS order-0 removed. This table shows that adding GABAC to the set of CRAM codecs further improves compression effectiveness. Removing gzip does not affect the compression [Fig. 1 (left) shows that gzip is never ranked first] and removing rANS order-0 has only a minor effect (<0.005%).

Hence, we can conclude that adding GABAC as entropy codec to both CRAM and DeeZ is beneficial both in terms of compression ratio and speed. Additionally, it has been shown that the (entropy) codec set can be limited to bzip2, rANS order-1, GABAC and xz, with no performance degradation. Finally, we can conclude that it would be valuable for implementations of the MPEG-G standard to be able to employ other (entropy) codecs in addition to GABAC.

4 Conclusion

GABAC, the first implementation of an entropy codec as specified in the MPEG-G standard, already outperforms well-established (entropy) codecs, improving in several cases both the compression ratio and the compression speed. In addition, the proposed implementation forms a valid extension to the set of (entropy) codecs used in CRAM. We hope that it will serve as a baseline for future implementations, within and outside of MPEG-G, as the performance of new implementations is expected to improve over time.
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Conflict of Interest: none declared.

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