Implementing BOLA-BASIC on Puffer: Lessons for the use of SSIM in ABR logic

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Abstract

One ABR algorithm implemented on Puffer is BOLA-BASIC, the simplest variant of BOLA. BOLA finds wide use in industry, notably in the MPEG-DASH reference player used as the basis for video players at Akamai, BBC, Orange, and CBS [1]. The overall goal of BOLA is to maximize each encoded chunk’s video quality while minimizing rebuffering. To measure video quality, Puffer uses the structural similarity metric SSIM, whereas BOLA and other ABR algorithms like BBA, MPC, and Pensieve are more commonly implemented using bitrate (or a variant of bitrate).

While bitrate is frequently used, BOLA allows the video provider to define its own proxy of video quality as the algorithm’s “utility” function. However, using SSIM as utility proved surprisingly complex for BOLA-BASIC, despite the algorithm’s simplicity. Given the rising popularity of SSIM and related quality metrics, we anticipate that a growing number of Puffer-like systems will face similar challenges. We hope developers of such systems find our experiences informative as they implement algorithms designed with bitrate-based utility in mind.

1 Background: SSIM and video quality

ABR algorithms like BOLA decide the bitrate at which to download each chunk of video into the client’s buffer. As the throughput of the network varies, the goal is to minimize stalls caused by an empty buffer while choosing high-quality encodings (see the Puffer paper [2] for more background on ABR). Much recent work has focused on objective metrics for an encoding’s subjective quality. Measuring perceived video quality is difficult, and no metric is perfect. Recently, Netflix’s VMAF has attempted to combine the strengths of several metrics by using them as input to a machine-learning model [3].

In the BOLA paper and DASH player, the “utility” metric that measures video quality is the normalized logarithm of encoded chunk size. Using size as utility is effectively equivalent to using bitrate and is a common choice. Bitrate is also easily computed, and is already made available to the ABR logic in DASH and other streaming protocols [4]. However, video quality does not correlate directly with bitrate [4]. When the content of a video changes over time, like the live TV streamed on Puffer, some chunks are easier to encode than others. For instance, a stream may have a black screen for several seconds, followed by a fast-moving scene. The all-black chunks can be encoded more efficiently than the scene, so they are likely to both look better and be smaller than more complex chunks.

SSIM [5] is one of many metrics that attempt to capture this variation. Unlike bitrate, SSIM is a compute-intensive metric, and Puffer is unusual in providing it at runtime. In fact, 18 of Puffer’s cores are solely devoted to SSIM. Many systems use metrics like SSIM, or the older PSNR, to evaluate chunks after they are chosen by the ABR algorithm. However, to our knowledge Puffer is the first study to use SSIM or PSNR as a factor in the ABR decision.

2 BOLA-BASIC on Puffer

Unlike many other ABR algorithms, BOLA-BASIC is very simple in implementation. The objective is a function of each encoded chunk’s utility and size, along with the buffer level and two control parameters. If the buffer is not too full, the algorithm chooses the encoded chunk with the highest objective. Otherwise, BOLA elects not to download any chunk before the next decision opportunity [1].

The first implementation of BOLA-BASIC on Puffer was a direct representation of the algorithm as presented in the paper [1], using SSIM in decibels...
(SSIMdB) as the utility function. Puffer also uses SSIMdB to measure video quality in the other ABR algorithms implemented on the platform, as well as to measure their performance (in conjunction with stall ratio).

3 A less basic BOLA-BASIC

The BOLA authors shared their expertise to help optimize the initial implementation of BOLA-BASIC. This resulted in three changes.

The first two changes related to BOLA’s decision thresholds, i.e. the buffer levels at which BOLA changes its bitrate decision. At the first threshold, BOLA switches from choosing the smallest to the second-smallest encoding. At the last threshold, BOLA switches from the largest chunk to no chunk at all.

The decision thresholds in the average case are shown in Figure 1. BOLA’s control parameters $V$ and $\gamma$ are calculated statically, using long-term averages for the utility and size of each of the ten encoded formats. So, Figure 1 shows the decisions BOLA would make if the ten options produced by the encoder at some time slot exactly matched the averages used to calculate the parameters. Puffer uses 3 and 15 seconds for minimum and maximum buffer size, which correspond to the first and last thresholds in the average case.

Since BOLA elects not to send a chunk at buffer levels above the maximum, BOLA will never exercise any of the thresholds beyond 15 seconds. To mitigate the appearance of such thresholds, the authors suggested two modifications to the utility function.

The first change in BOLA-BASIC “v2” is to use the raw value of SSIM, without converting to decibels. Although the data correlating SSIMdB with perceived quality is noisy, there is some evidence that the decibel transformation creates an approximately linear relationship with human preference [6]. However, the transformation to decibels expands the values in the upper SSIM range, as shown in Figure 3.

As a result, the utility of higher-quality encodings is inflated using SSIMdB relative to SSIM, pushing the thresholds to the right. So, the BOLA authors expected the algorithm to behave better with raw SSIM.

As a second adjustment to the utility function, the authors suggested using the maximum possible utility (i.e. 1.0 for raw SSIM) in the parameter calculations, rather than the maximum average utility. On average, the highest-quality encoding available is 0.983, so using 1.0 instead is a significant change.

As shown in Figure 4, most of the decision thresholds...
Conversion of SSIM to decibels is asymptotic in the upper range.

Separately, the authors suggested a third change, relating to the case where the objective is negative for all available encodings. In this situation, the DASH reference implementation pauses until the buffer has drained enough so that some objective is non-negative. Puffer implements ABR on the server, so this pause was simulated to avoid introducing BOLA-specific logic in the server. Specifically, the authors suggested that if all objectives are negative, BOLA-BASIC “v2” should choose the chunk with highest utility rather than highest objective. This simulates the client’s pause, since the point at which the objective becomes positive is a factor only of utility, not the size in the denominator (see Figure 7).

4 BOLA-BASIC and SSIM

The changes in the second implementation of BOLA-BASIC on Puffer do not address a fundamental issue with the use of SSIM (whether decibels or raw) in BOLA. The BOLA parameters are calculated statically, but SSIM varies dynamically with bitrate. According to the paper, BOLA can use any utility function as long as the utility of the available encodings for each chunk is nondecreasing with respect to their size. In fact, the paper identifies the ability to define utility in “very general” ways as a unique strength of BOLA. SSIM satisfies BOLA’s requirement of monotonicity with respect to size within the encodings for each chunk (120 frames on Puffer). However, as discussed above, utility can vary independently of size, and therefore bitrate, across chunks.

Unlike direct functions of bitrate, SSIM captures this variation. However, this causes BOLA to behave very differently when choosing between a set of format options with low utility than when choosing between higher-quality chunks. Due to the way utility is used in BOLA’s objective (Figure 5), when utility is near $-\gamma p$, a small gain in utility can outweigh a large bitrate increase, particularly if the buffer is near empty. For instance, BOLA could prefer a format twice as large offering only a 0.4dB SSIM increase. While downloading this much larger chunk, the near-empty buffer may drain completely. In contrast, when choosing between chunks whose utility is larger in magnitude relative to $-\gamma p$, the same utility gain has less impact relative to the bitrate difference.

$$\frac{V(v_m + \gamma p) - Q(t_k)}{S_m}$$

It seems that the static parameter calculation inherent to BOLA is fundamentally incompatible with a utility function involving variables beyond bitrate. It’s interesting that the variation of SSIM with bitrate is a strength of SSIM as a utility metric, but makes SSIM less amenable to algorithms based on more approximate utility metrics.

5 Results

Figure 6 shows the performance of the initial “v1” implementation of BOLA-BASIC, as well as the “v2” im-
plementation with the three changes discussed above. Also shown are BBA and two ML-based ABR algorithms developed on Puffer. Each of the five algorithms has over 3.5 cumulative stream-years of data.

![Figure 6: Performance of both versions of BOLA-BASIC on Puffer (95% confidence intervals), for all stream speeds (top plot) and slow streams only (bottom plot). Both plots show data from 2020-07-26 to 2020-11-07 (see Puffer [2] for latest data). All speeds comprises 685,022 streams (17.7 stream-years); slow speeds comprises 96,646 streams (1.5 stream-years).](https://puffer.stanford.edu/results)

The two versions of BOLA-BASIC are broadly similar at this timescale, with “v2” showing slight improvement in SSIMdB and stall ratio. Relative to BBA, both versions improve SSIMdB while increasing stall time.

6 Conclusions

It should be noted that BOLA-BASIC is considerably simpler than production implementations of BOLA, e.g. BOLA-E and BOLA-O in the DASH reference player. Also, Puffer has several architectural differences from DASH and other client-side players (see the Puffer paper [2] for detail). For these reasons, we don’t intend to present these results as a comment on the general performance of BOLA relative to the other algorithms. Instead, we see these results as an indication of the surprising complexity possible when using SSIM in even the simplest ABR algorithms.

Newer video quality metrics like SSIM more accurately reflect human perception. However, existing ABR algorithms may not always be designed to take full advantage of these metrics. If measurements like SSIM are the future of ABR, Puffer will not be alone in facing these challenges.

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