# Generalized Elias-Fano code for the compressed indexing of arbitrary integer sequences

Supplementary Material: Detailed Experimental Results

Michelangelo Pucci
ETH Zürich
Zürich, Switzerland
mpucci@ethz.ch

Paolo Ferragina
Sant'Anna School of Advanced Studies
and University of Pisa
Pisa, Italy
paolo.ferragina@santannapisa.it

**Table 1: Compression Ratio (%) Bold: Best, Underlined: Second, *Italics*: Third.**

| | General-purpose compressors | | | | | Special-purpose compressors | | | | | | | | | | GEF variants | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | Brotli | Lz4 | Snappy | Xz | Zstd | ALP | Camel | Chimp | Chimp128 | DAC | ELF | Falcon | Gorilla | LeCo | NeaTS | TSXor | RLE-GEF | U-ĜEF | U-GEF* | B-ĜEF | B-GEF* | B*-ĜEF | B*-GEF* |
| IT | 0.14 | 0.41 | 0.37 | 0.13 | 0.23 | 0.17 | 0.20 | 0.72 | 0.30 | 0.24 | 0.38 | *0.11* | 0.79 | 0.16 | 0.12 | 0.31 | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 | **0.10** | **0.10** |
| US | 0.09 | 0.27 | 0.21 | 0.09 | 0.13 | 0.11 | 0.20 | 0.55 | 0.19 | 0.25 | 0.27 | *0.07* | 0.57 | 0.10 | 0.08 | 0.19 | 0.08 | 0.09 | 0.08 | 0.07 | 0.08 | **0.06** | **0.06** |
| ECG | 0.12 | 0.34 | 0.26 | 0.12 | 0.17 | 0.16 | 0.22 | 0.69 | 0.27 | 0.25 | 0.32 | *0.12* | 0.73 | 0.16 | 0.14 | 0.24 | 0.13 | 0.13 | 0.13 | 0.12 | 0.12 | **0.11** | **0.11** |
| WD | 0.28 | 0.53 | 0.54 | 0.24 | 0.34 | 0.25 | 0.40 | 0.84 | 0.44 | 0.26 | 0.54 | 0.23 | 0.91 | 0.25 | 0.25 | 0.47 | **0.23** | 0.23 | 0.23 | 0.23 | 0.23 | *0.23* | *0.23* |
| AP | 0.13 | 0.26 | 0.25 | **0.12** | 0.18 | 0.25 | 0.44 | 0.36 | 0.30 | 0.41 | 0.37 | 0.16 | 0.38 | 0.24 | 0.20 | 0.35 | *0.14* | 0.19 | 0.16 | 0.18 | 0.16 | 0.17 | 0.17 |
| UK | 0.09 | 0.27 | 0.21 | 0.09 | 0.13 | 0.12 | 0.15 | 0.47 | 0.23 | 0.26 | 0.36 | *0.08* | 0.54 | 0.11 | 0.09 | 0.16 | 0.09 | 0.11 | 0.10 | 0.09 | 0.09 | **0.07** | **0.07** |
| GE | 0.11 | 0.30 | 0.24 | 0.11 | 0.15 | 0.14 | 0.23 | 0.67 | 0.21 | 0.29 | 0.36 | *0.11* | 0.71 | 0.14 | 0.12 | 0.21 | 0.12 | 0.14 | 0.13 | 0.12 | 0.12 | **0.10** | **0.10** |
| LON | 0.19 | 0.50 | 0.49 | *0.17* | 0.33 | 0.26 | 0.37 | 0.62 | 0.55 | 0.47 | 0.64 | **0.15** | 0.63 | 0.25 | 0.18 | 0.66 | 0.19 | 0.19 | 0.18 | 0.19 | 0.17 | 0.19 | 0.19 |
| LAT | 0.24 | 0.52 | 0.51 | *0.21* | 0.41 | 0.25 | 0.26 | 0.61 | 0.44 | 0.47 | 0.63 | **0.19** | 0.64 | 0.30 | 0.22 | 0.51 | 0.24 | 0.24 | 0.23 | 0.24 | 0.21 | 0.23 | 0.23 |
| DP | 0.17 | 0.49 | 0.48 | 0.16 | 0.29 | 0.21 | 0.26 | 0.77 | 0.50 | 0.27 | 0.42 | *0.15* | 0.83 | 0.21 | 0.16 | 0.61 | 0.16 | 0.17 | 0.16 | 0.15 | 0.15 | **0.13** | **0.13** |
| CT | 0.16 | 0.43 | 0.38 | 0.16 | 0.25 | 0.15 | 0.23 | 0.74 | 0.36 | 0.19 | 0.66 | 0.14 | 0.87 | 0.15 | 0.14 | 0.31 | *0.14* | 0.14 | 0.14 | 0.14 | 0.14 | **0.13** | **0.13** |
| DU | **0.08** | 0.23 | 0.19 | *0.08* | 0.11 | 0.13 | 0.18 | 0.40 | 0.22 | 0.12 | 0.21 | 0.08 | 0.44 | 0.13 | 0.09 | 0.18 | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 |
| BT | 0.46 | 0.67 | 0.69 | **0.46** | 0.58 | *0.47* | 0.53 | 0.84 | 0.48 | 0.57 | 0.82 | 0.52 | 0.93 | 0.55 | 0.65 | 0.56 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.51 | 0.51 |
| BW | 0.41 | 0.59 | 0.59 | **0.36** | 0.50 | 0.48 | 0.54 | 0.88 | 0.71 | 0.46 | 0.80 | 0.44 | 1.00 | 0.49 | 0.45 | 0.82 | 0.46 | 0.47 | 0.46 | 0.47 | *0.44* | 0.47 | 0.47 |
| BM | 0.21 | 0.44 | 0.39 | **0.20** | 0.29 | 0.33 | 0.41 | 0.65 | 0.41 | 0.37 | 0.65 | 0.22 | 0.73 | 0.31 | 0.24 | 0.48 | 0.24 | 0.24 | 0.24 | 0.25 | *0.22* | 0.24 | 0.24 |
| BP | 0.40 | 0.69 | 0.71 | 0.37 | 0.66 | 0.37 | 0.63 | 0.77 | 0.72 | 0.46 | 0.68 | *0.36* | 0.83 | 0.40 | 0.40 | 0.88 | 0.36 | 0.37 | 0.37 | 0.36 | 0.36 | **0.34** | **0.34** |

With $\hat{C}$ and $C^*$, we denote the GEF variant $C$ that uses either its approximated or optimal split point, respectively.

**Table 2: Compression Throughput (MB/s) Bold: Best, Underlined: Second, *Italics*: Third.**

| | General-purpose compressors | | | | | Special-purpose compressors | | | | | | | | | | GEF variants | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | Brotli | Lz4 | Snappy | Xz | Zstd | ALP | Camel | Chimp | Chimp128 | DAC | ELF | Falcon | Gorilla | LeCo | NeaTS | TSXor | RLE-GEF | U-ĜEF | U-GEF* | B-ĜEF | B-GEF* | B*-ĜEF | B*-GEF* |
| IT | 0.61 | 442.35 | 501.31 | 2.38 | 184.03 | **1150.28** | 152.99 | 352.88 | 94.01 | 270.83 | 185.40 | 132.70 | *656.62* | 676.70 | 0.93 | 25.79 | 595.60 | 312.58 | 240.28 | 305.28 | 230.45 | 305.55 | 288.16 |
| US | 0.47 | 592.79 | 605.66 | 1.91 | 263.73 | **1166.41** | 160.56 | 380.98 | 103.65 | 255.93 | 204.54 | 169.91 | *659.78* | 690.99 | 0.85 | 88.67 | 606.75 | 317.88 | 281.37 | 322.83 | 273.05 | 115.42 | 305.65 |
| ECG | 0.49 | 541.03 | 505.57 | 1.93 | 213.85 | **1224.58** | 166.22 | 351.66 | 98.23 | 263.07 | 192.74 | 126.51 | 509.76 | 668.91 | 0.97 | 62.13 | *543.82* | 277.47 | 252.39 | 263.93 | 230.98 | 305.53 | 269.00 |
| WD | 0.69 | 444.31 | 471.34 | 3.07 | 176.50 | **1144.40** | 114.37 | 348.78 | 100.61 | 242.56 | 164.79 | 100.97 | 696.08 | *602.99* | 1.21 | 16.28 | 519.86 | 294.93 | 191.65 | 294.48 | 186.73 | 313.38 | 283.93 |
| AP | 0.34 | 441.54 | 430.91 | 3.09 | 191.74 | **1178.13** | 126.03 | 421.52 | 100.00 | 175.94 | 185.42 | 116.38 | 758.33 | *655.06* | 0.86 | 50.73 | 593.83 | 322.83 | 202.86 | 333.74 | 201.83 | 348.38 | 300.21 |
| UK | 0.47 | 596.55 | 665.63 | 1.99 | 260.94 | **1207.73** | 182.03 | 372.88 | 198.32 | 242.99 | 184.54 | 161.15 | 719.00 | *688.38* | 0.79 | 89.32 | 627.52 | 318.40 | 270.75 | 321.79 | 264.61 | 147.30 | 284.17 |
| GE | 0.51 | 554.42 | 628.86 | 1.90 | 236.69 | **1190.77** | 145.32 | 358.71 | 153.74 | 259.14 | 184.56 | 148.98 | 692.19 | *667.01* | 0.81 | 71.50 | 612.28 | 296.10 | 241.46 | 298.83 | 232.76 | 303.48 | 281.54 |
| LON | 0.74 | 410.05 | 440.85 | 3.19 | 158.00 | **1224.46** | 130.99 | 511.80 | 271.65 | 212.62 | 183.34 | 124.01 | *682.23* | 664.94 | 0.84 | 19.73 | 755.51 | 399.76 | 191.12 | 401.54 | 192.42 | 426.22 | 374.51 |
| LAT | 0.72 | 406.75 | 446.68 | 3.22 | 155.01 | **1200.09** | 142.22 | 506.26 | 251.82 | 213.78 | 193.54 | 113.21 | *676.35* | 654.05 | 0.89 | 19.46 | 748.54 | 398.03 | 175.73 | 398.20 | 177.25 | 422.64 | 375.70 |
| DP | 0.67 | 397.49 | 395.39 | 2.62 | 172.53 | **1174.17** | 141.55 | 355.31 | 115.74 | 244.25 | 187.55 | 126.10 | 510.45 | *558.47* | 0.70 | 18.08 | 595.14 | 280.02 | 184.64 | 262.17 | 209.48 | 284.10 | 282.48 |
| CT | 0.61 | 385.29 | 464.48 | 2.18 | 173.27 | **1157.93** | 131.21 | 340.30 | 106.46 | 254.39 | 166.60 | 127.89 | 680.35 | *622.12* | 0.77 | 22.67 | 508.65 | 271.39 | 251.08 | 267.36 | 249.24 | 303.04 | 265.01 |
| DU | 0.41 | 667.27 | *697.29* | 2.21 | 297.39 | **1187.17** | 179.78 | 412.29 | 325.89 | 221.18 | 225.26 | 134.19 | 777.18 | 656.01 | 0.57 | 101.97 | 562.94 | 322.94 | 245.30 | 361.11 | 260.32 | 350.99 | 340.35 |
| BT | 0.58 | 392.03 | 358.25 | 2.84 | 144.51 | **1098.87** | 105.51 | 358.01 | 233.56 | 155.59 | 137.09 | 69.84 | 665.07 | 481.23 | 1.26 | 17.59 | *567.58* | 323.01 | 113.68 | 306.08 | 126.17 | 304.18 | 294.56 |
| BW | 0.55 | 364.43 | 382.55 | 2.89 | 149.80 | 367.32 | 100.44 | 337.59 | 232.14 | 157.03 | 123.73 | 72.65 | **711.52** | *576.47* | 1.11 | 18.06 | 673.24 | 310.63 | 128.14 | 348.15 | 114.65 | 325.03 | 273.04 |
| BM | 0.52 | 392.18 | 405.10 | 2.16 | 152.74 | **760.28** | 118.49 | 360.90 | 224.46 | 95.80 | 143.31 | 95.49 | 667.98 | 594.68 | 0.62 | 32.38 | *656.96* | 317.44 | 184.03 | 335.79 | 180.75 | 364.45 | 323.45 |
| BP | 0.54 | 336.05 | 311.96 | 2.23 | 117.38 | 450.78 | 99.88 | 343.65 | 237.94 | 146.31 | 154.83 | 82.51 | **689.55** | *486.39* | 1.17 | 16.32 | 608.94 | 275.50 | 160.01 | 265.43 | 152.98 | 290.93 | 265.02 |

With $\hat{C}$ and $C^*$, we denote the GEF variant $C$ that uses either its approximated or optimal split point, respectively.

**Table 3: Decompression Throughput (GB/s) Bold: Best, Underlined: Second, *Italics*: Third.**

| | General-purpose compressors | | | | | Special-purpose compressors | | | | | | | | | | GEF variants | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | Brotli | Lz4 | Snappy | Xz | Zstd | ALP | Camel | Chimp | Chimp128 | DAC | ELF | Falcon | Gorilla | LeCo | NeaTS | TSXor | RLE-GEF | U-GEF | B-GEF | B*-GEF |
| IT | 0.30 | 0.79 | 0.49 | 0.08 | 0.33 | **3.94** | 0.24 | 0.49 | 0.50 | 1.40 | 0.28 | 0.43 | 0.58 | *2.81* | 3.20 | 0.58 | 0.99 | 1.09 | 0.83 | 1.17 |
| US | 0.41 | 1.03 | 0.78 | 0.12 | 0.47 | 4.09 | 0.28 | 0.54 | 0.69 | 1.18 | 0.33 | 0.55 | 0.60 | *2.93* | **4.43** | 0.88 | 1.12 | 1.20 | 1.12 | 1.36 |
| ECG | 0.27 | 0.96 | 0.59 | 0.09 | 0.43 | **5.53** | 0.29 | 0.49 | 0.52 | 1.45 | 0.25 | 0.39 | 0.48 | *2.71* | 3.92 | 0.69 | 0.90 | 0.96 | 0.80 | 1.17 |
| WD | 0.22 | 1.06 | 0.42 | 0.05 | 0.34 | **5.88** | 0.16 | 0.47 | 0.47 | 1.14 | 0.25 | 0.30 | 0.61 | *2.67* | 4.08 | 0.56 | 0.73 | 0.80 | 0.72 | 1.13 |
| AP | 0.30 | 0.83 | 0.69 | 0.08 | 0.45 | **5.71** | 0.16 | 0.68 | 0.53 | 0.64 | 0.38 | 0.31 | 0.74 | *2.59* | 3.78 | 0.72 | 0.88 | 1.20 | 0.96 | 1.11 |
| UK | 0.41 | 1.04 | 0.81 | 0.12 | 0.48 | **4.90** | 0.33 | 0.53 | 0.56 | 1.03 | 0.34 | 0.53 | 0.64 | *2.93* | 4.45 | 0.86 | 1.13 | 1.19 | 1.01 | 1.31 |
| GE | 0.36 | 0.99 | 0.76 | 0.10 | 0.45 | **6.17** | 0.25 | 0.51 | 0.63 | 1.27 | 0.29 | 0.46 | 0.61 | *2.85* | 4.57 | 0.80 | 1.06 | 1.09 | 0.87 | 1.19 |
| LON | 0.29 | 0.92 | 0.44 | 0.06 | 0.31 | **4.36** | 0.17 | 0.80 | 0.50 | 1.40 | 0.31 | 0.33 | 0.60 | *2.63* | 4.00 | 0.55 | 1.38 | 1.22 | 0.96 | 1.59 |
| LAT | 0.23 | 0.96 | 0.44 | 0.05 | 0.30 | **4.35** | 0.20 | 0.77 | 0.43 | 1.36 | 0.31 | 0.29 | 0.59 | *2.52* | 4.31 | 0.52 | 1.36 | 1.12 | 0.95 | 1.54 |
| DP | 0.28 | 0.86 | 0.43 | 0.06 | 0.29 | **6.40** | 0.20 | 0.50 | 0.40 | 1.46 | 0.27 | 0.43 | 0.58 | 2.64 | *2.25* | 0.47 | 0.95 | 0.99 | 0.82 | 1.14 |
| CT | 0.27 | 0.73 | 0.50 | 0.07 | 0.31 | **5.02** | 0.24 | 0.45 | 0.47 | 1.30 | 0.28 | 0.45 | 0.58 | 2.75 | *2.15* | 0.58 | 0.74 | 0.89 | 0.74 | 1.13 |
| DU | 0.44 | 1.16 | 0.87 | 0.14 | 0.53 | **7.94** | 0.34 | 0.66 | 0.59 | 0.79 | 0.36 | 0.42 | 0.75 | *2.84* | 3.54 | 0.90 | 1.07 | 1.24 | 1.13 | 1.45 |
| BT | 0.16 | 0.88 | 0.42 | 0.03 | 0.31 | **8.50** | 0.09 | 0.50 | 0.45 | 1.17 | 0.25 | 0.18 | 0.60 | 2.17 | *1.56* | 0.50 | 0.82 | 0.84 | 0.81 | 1.07 |
| BW | 0.15 | 0.83 | 0.44 | 0.04 | 0.29 | 3.43 | 0.10 | 0.48 | 0.37 | 1.28 | 0.22 | 0.19 | 0.63 | *2.20* | **4.75** | 0.46 | 1.36 | 1.18 | 0.89 | 1.41 |
| BM | 0.22 | 0.84 | 0.49 | 0.06 | 0.36 | **9.58** | 0.16 | 0.50 | 0.51 | 0.84 | 0.27 | 0.25 | 0.61 | *2.53* | 2.73 | 0.58 | 1.59 | 1.06 | 0.84 | 1.50 |
| BP | 0.17 | 1.12 | 0.41 | 0.02 | 0.25 | **6.15** | 0.12 | 0.51 | 0.40 | 1.35 | 0.26 | 0.22 | 0.60 | *2.38* | 4.40 | 0.46 | 0.88 | 0.90 | 0.84 | 1.19 |

**Table 4: Random Access Throughput (MB/s) Bold: Best, Underlined: Second, *Italics*: Third.**

| | General-purpose compressors | | | | | Special-purpose compressors | | | | | | | | | | GEF variants | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | Brotli | Lz4 | Snappy | Xz | Zstd | ALP | Camel | Chimp | Chimp128 | DAC | ELF | Falcon | Gorilla | LeCo | NeaTS | TSXor | RLE-GEF | U-GEF | B-GEF | B*-GEF |
| IT | 0.33 | 0.98 | 0.55 | 0.08 | 0.35 | 7.22 | 0.48 | 0.87 | 0.89 | **140.37** | 0.53 | 0.50 | 0.97 | 121.42 | 44.58 | 1.02 | *64.78* | 18.94 | 9.32 | 22.71 |
| US | 0.44 | 1.32 | 0.93 | 0.12 | 0.52 | 8.02 | 0.56 | 0.95 | 1.40 | 76.99 | 0.61 | 0.63 | 1.07 | **134.66** | 53.60 | 1.58 | *68.01* | 21.84 | 11.22 | 28.35 |
| ECG | 0.32 | 1.21 | 0.77 | 0.09 | 0.47 | 5.83 | 0.56 | 0.83 | 1.01 | **139.14** | 0.49 | 0.46 | 0.81 | 121.78 | 48.52 | 1.33 | *60.28* | 10.52 | 10.33 | 24.98 |
| WD | 0.23 | 1.37 | 0.48 | 0.05 | 0.37 | 7.36 | 0.31 | 0.82 | 0.90 | 133.38 | 0.48 | 0.33 | 1.00 | **142.19** | 11.47 | 1.02 | *71.40* | 26.14 | 14.64 | 30.24 |
| AP | 0.35 | 1.21 | 0.78 | 0.09 | 0.51 | 5.72 | 0.31 | 1.10 | 1.10 | *66.26* | 0.69 | 0.35 | 1.29 | **135.02** | 23.69 | 1.25 | 75.79 | 26.05 | 15.93 | 26.60 |
| UK | 0.45 | 1.35 | 0.99 | 0.12 | 0.53 | 6.03 | 0.67 | 0.95 | 1.13 | 129.98 | 0.63 | 0.60 | 1.13 | **193.98** | 69.66 | 1.57 | *113.17* | 31.08 | 15.92 | 36.17 |
| GE | 0.39 | 1.28 | 0.91 | 0.11 | 0.50 | 6.25 | 0.48 | 0.92 | 1.28 | 179.22 | 0.53 | 0.53 | 1.06 | **202.92** | 66.50 | 1.47 | *119.35* | 35.01 | 16.77 | 40.35 |
| LON | 0.31 | 1.16 | 0.49 | 0.06 | 0.35 | 10.50 | 0.33 | 1.42 | 1.01 | 204.02 | 0.58 | 0.36 | 1.07 | **212.05** | 76.67 | 0.99 | *136.65* | 35.69 | 19.68 | 46.74 |
| LAT | 0.25 | 1.20 | 0.49 | 0.05 | 0.33 | 10.39 | 0.39 | 1.37 | 0.87 | 203.26 | 0.58 | 0.31 | 1.06 | **207.58** | 72.32 | 0.94 | *130.67* | 34.98 | 19.55 | 46.35 |
| DP | 0.31 | 1.05 | 0.48 | 0.06 | 0.32 | 14.26 | 0.39 | 0.92 | 0.80 | 319.40 | 0.57 | 0.47 | 1.02 | **419.93** | 99.87 | 0.89 | *212.01* | 51.21 | 27.95 | 69.74 |
| CT | 0.28 | 0.89 | 0.57 | 0.07 | 0.35 | 17.28 | 0.47 | 0.83 | 1.06 | 460.05 | 0.55 | 0.50 | 1.07 | **561.48** | 116.44 | 1.12 | *240.90* | 68.91 | 34.23 | 82.39 |
| DU | 0.51 | 1.57 | 1.10 | 0.14 | 0.62 | 27.53 | 0.67 | 1.23 | 1.34 | 393.38 | 0.71 | 0.47 | 1.33 | **953.09** | 132.78 | 1.61 | *320.34* | 70.73 | 42.21 | 96.88 |
| BT | 0.18 | 1.13 | 0.47 | 0.03 | 0.34 | 21.83 | 0.19 | 0.94 | 0.94 | 654.43 | 0.46 | 0.19 | 1.07 | **999.03** | 122.00 | 0.97 | *292.19* | 67.32 | 38.91 | 94.63 |
| BW | 0.16 | 1.04 | 0.50 | 0.04 | 0.32 | 9.71 | 0.19 | 0.86 | 0.80 | 764.17 | 0.44 | 0.21 | 1.13 | **984.79** | 132.25 | 0.88 | *297.95* | 75.99 | 40.97 | 91.14 |
| BM | 0.26 | 1.11 | 0.59 | 0.06 | 0.43 | 26.32 | 0.32 | 1.02 | 1.12 | 502.65 | 0.53 | 0.28 | 1.17 | **1083.34** | 136.37 | 1.13 | *344.71* | 89.25 | 52.11 | 119.83 |
| BP | 0.21 | 1.62 | 0.48 | 0.03 | 0.32 | 28.46 | 0.25 | 1.06 | 0.94 | 866.33 | 0.55 | 0.26 | 1.24 | **1159.38** | 128.05 | 1.00 | *317.75* | 105.95 | 57.97 | 118.63 |