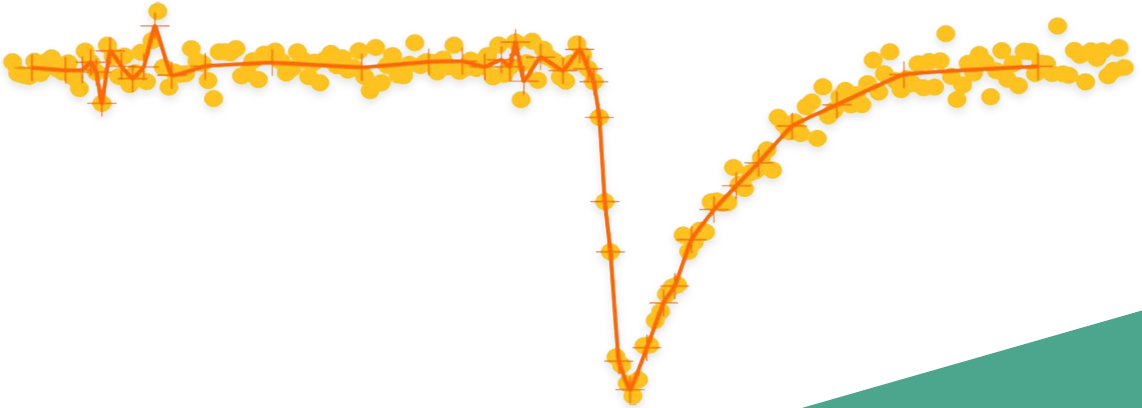
Adaptive downsampling of traces with FPGAs



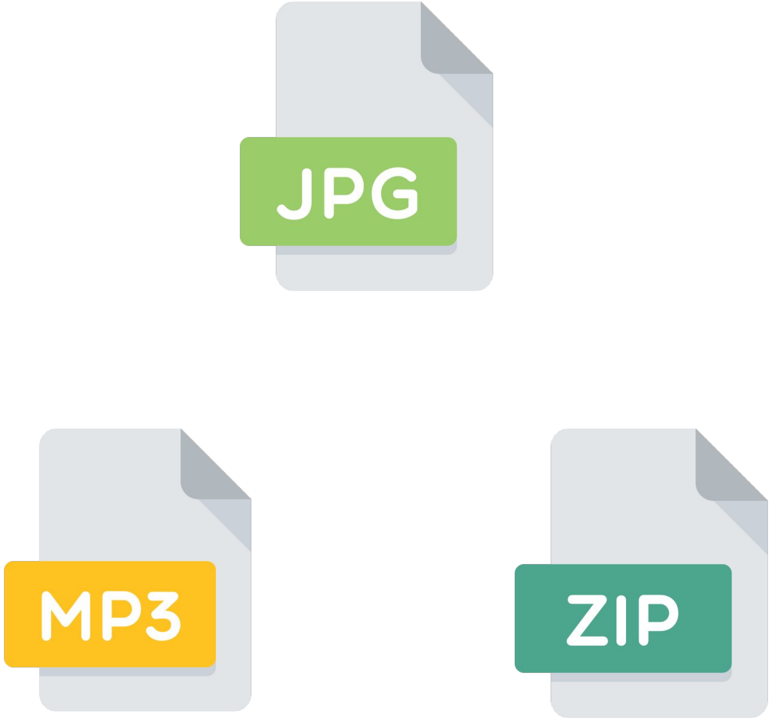
ANTON FREDRIKSSON
LUKAS RAHMN

2020-06-27

CHALMERS
UNIVERSITY OF TECHNOLOGY

The context

- **Why Compression?**
- Large scale physics experiment
- Field-Programmable Gate Array (FPGA)
- Signal traces



Icons by https://www.flaticon.com/authors/dimitry-miroliubov

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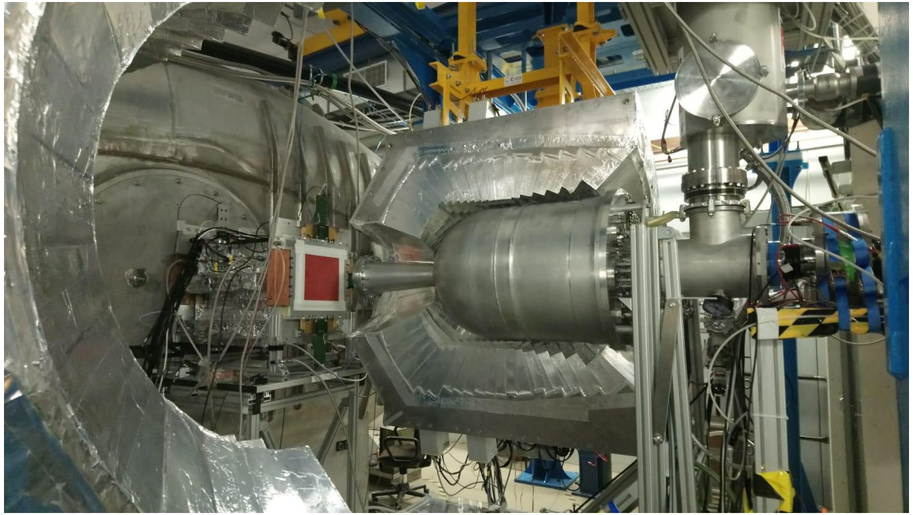

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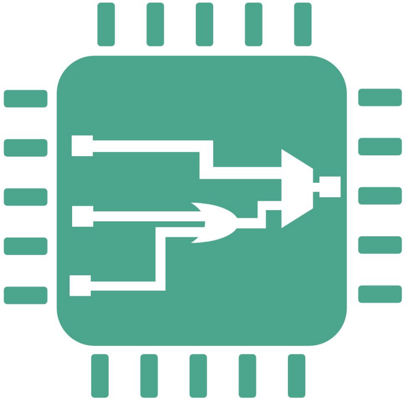
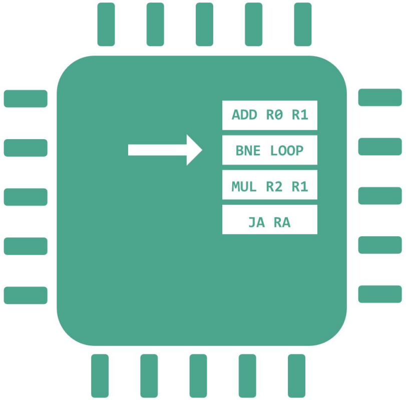
- Large scale physics experiment
- **Field-Programmable Gate Array (FPGA)**
- Signal traces

FPGA



Processor



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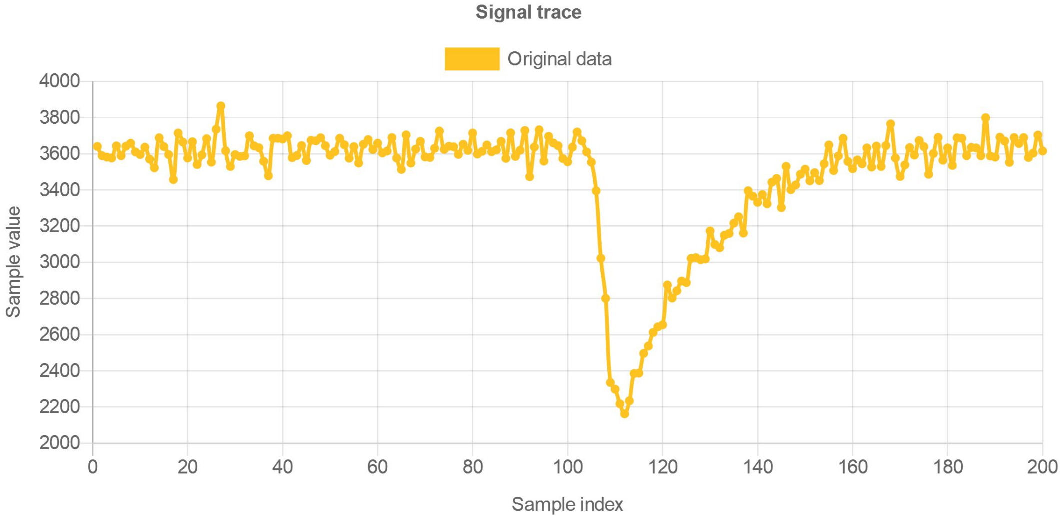
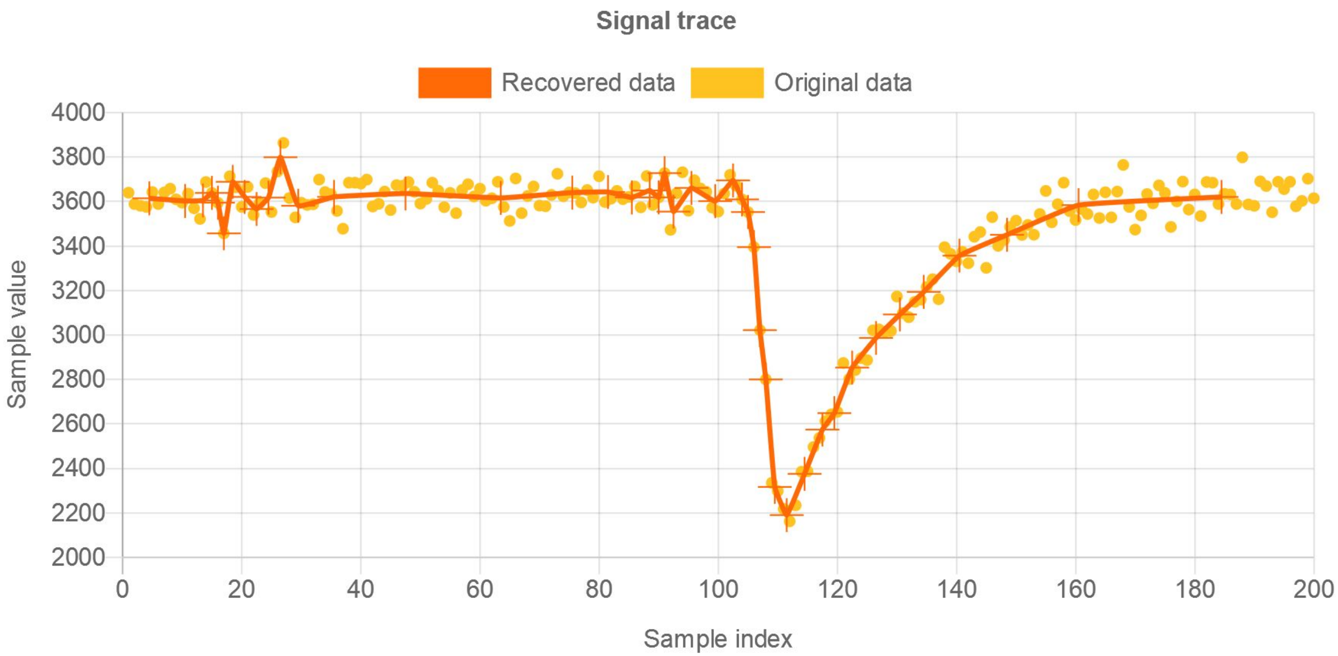
- **Signal traces**

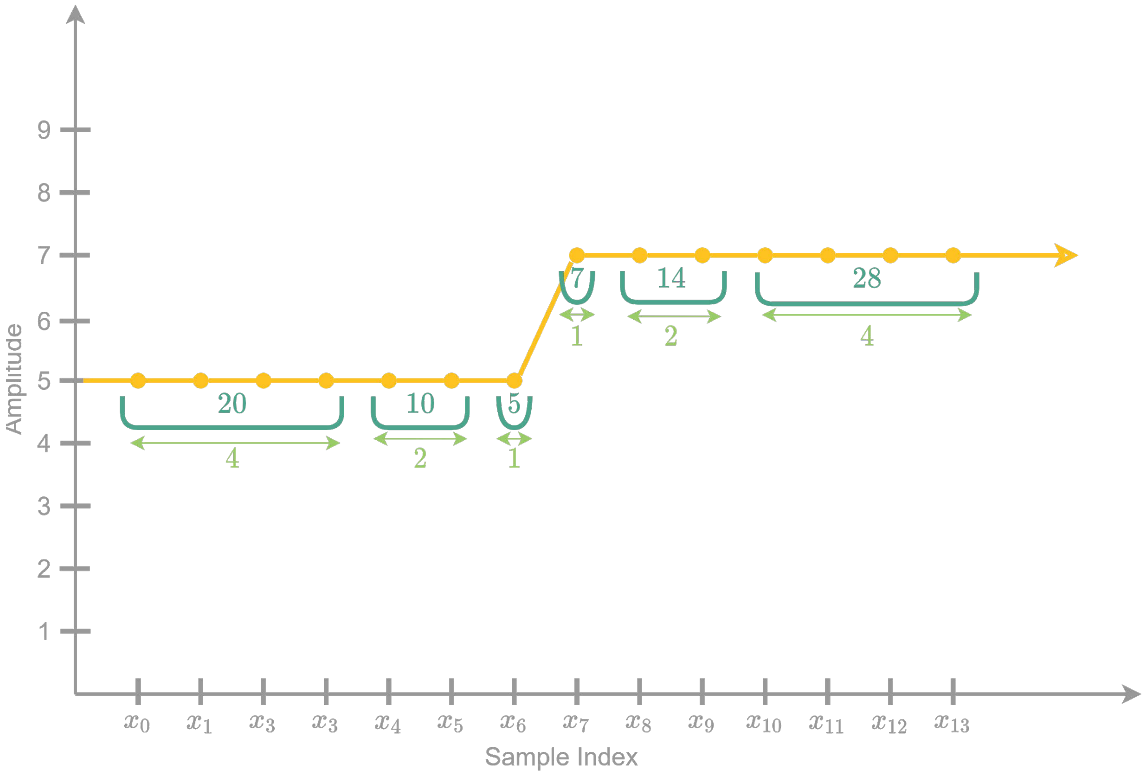


Our work

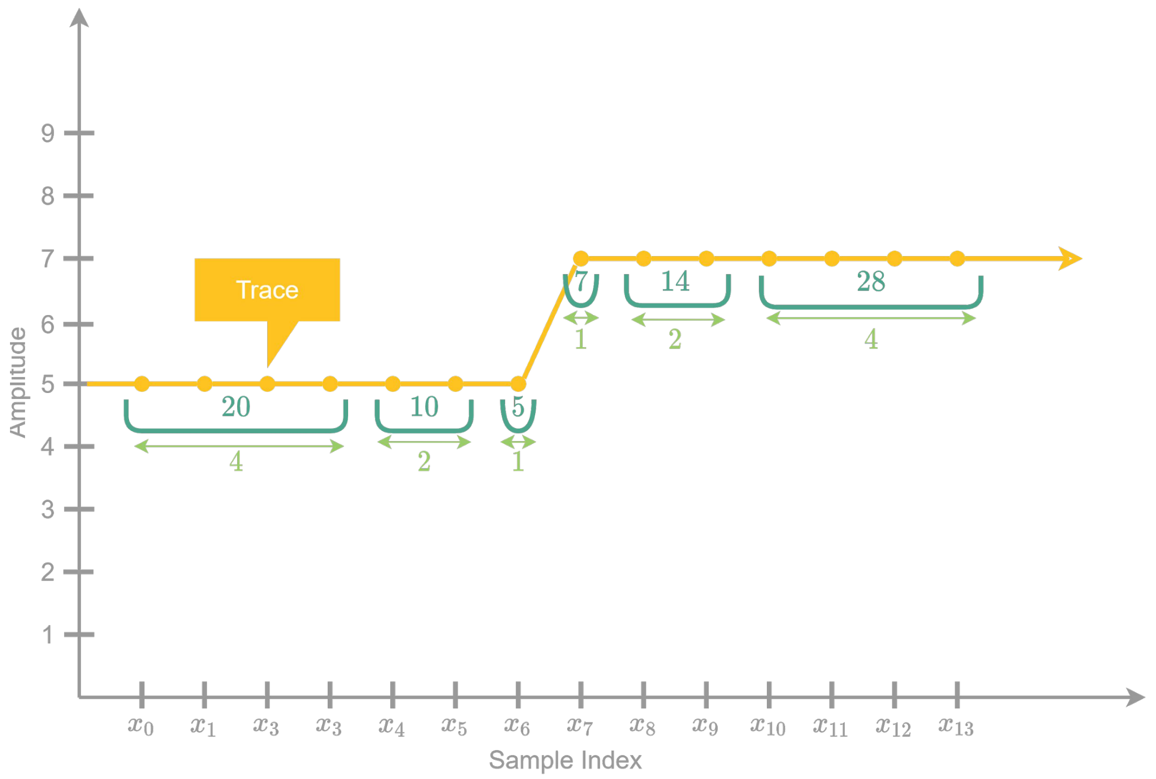
- A novel lossy trace compression algorithm.
- Compression/Decompression software
- FPGA firmware implementing the compression.



Compressed trace signal



Adaptive downsampling



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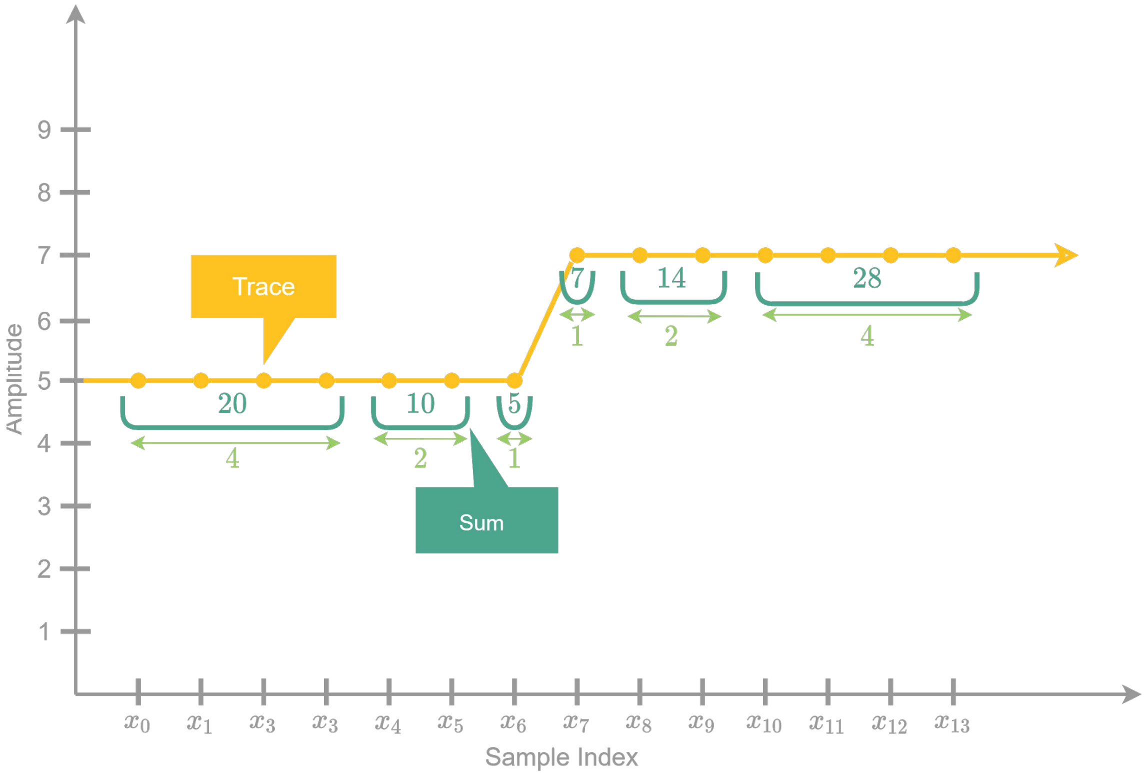
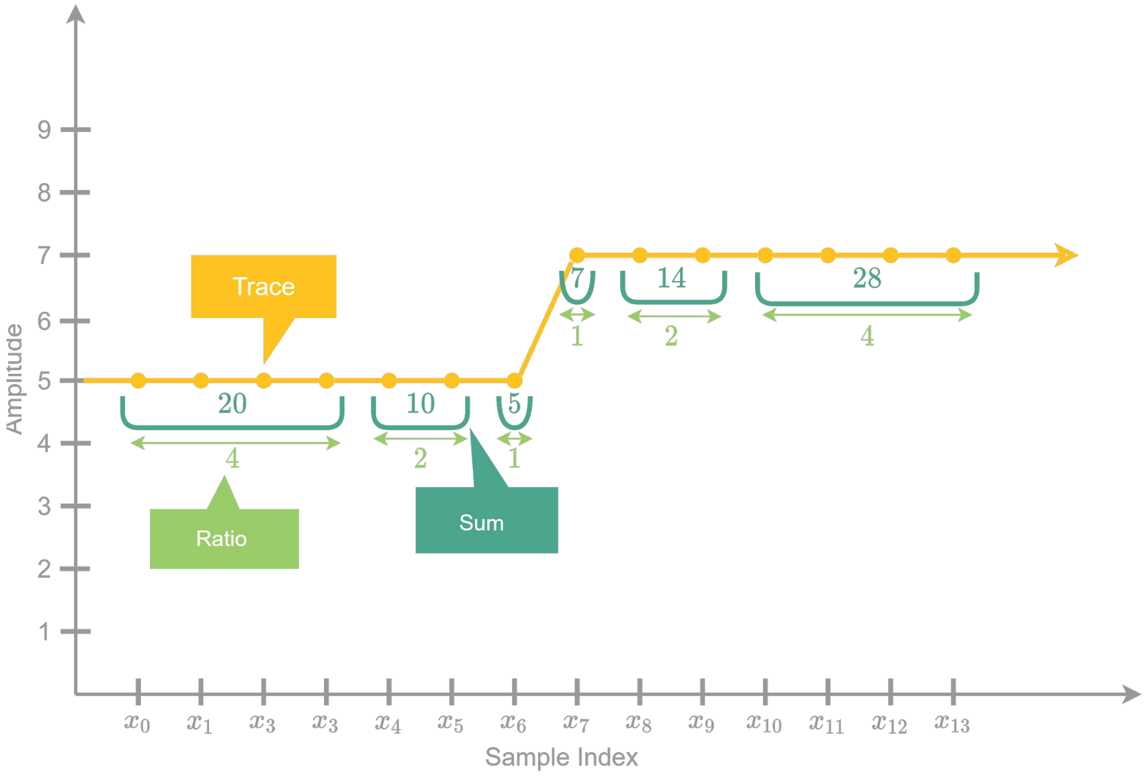
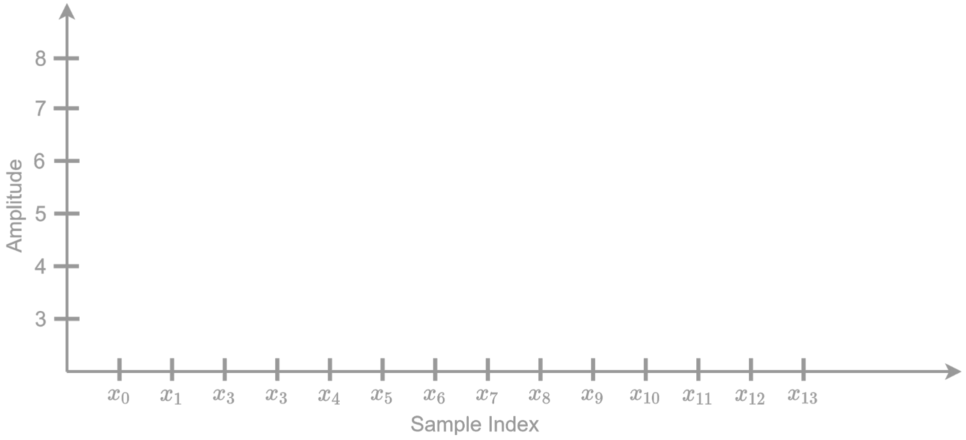
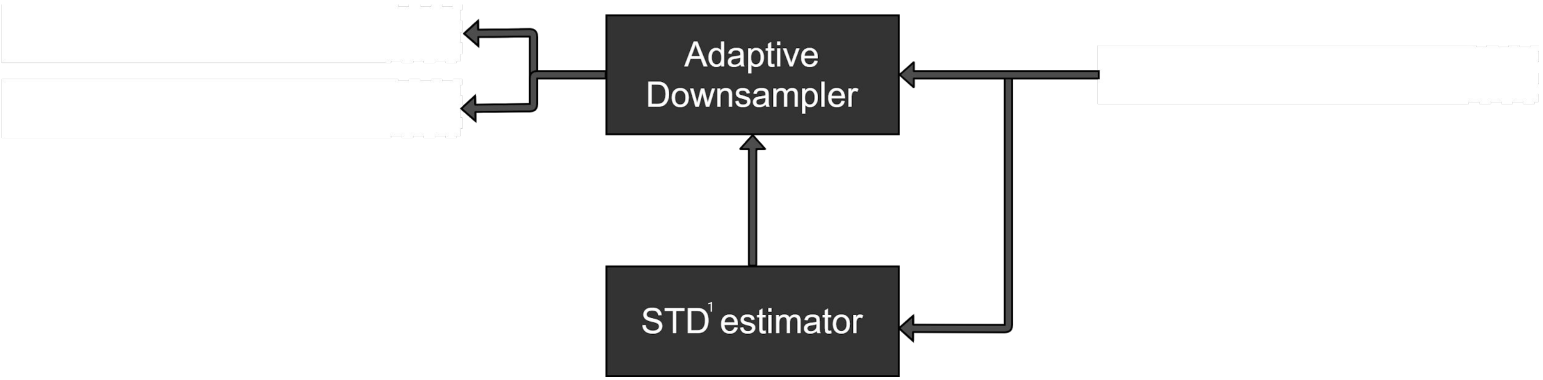


Adaptive downsampling



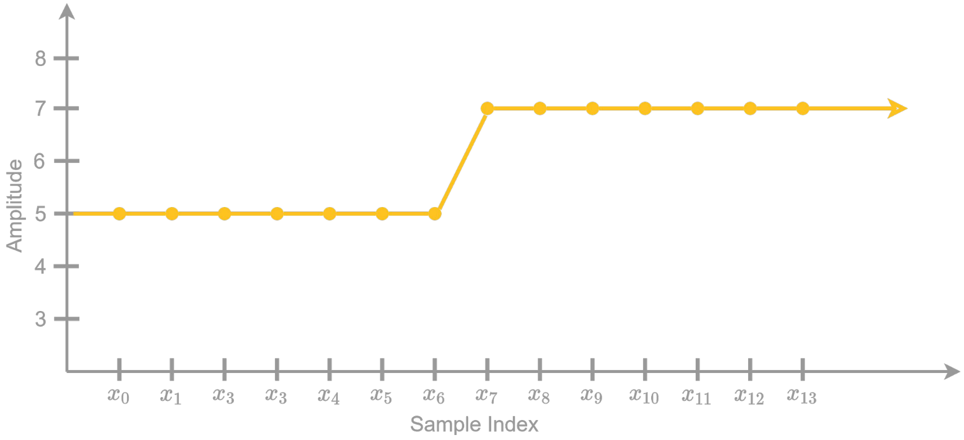
Adaptive downsampling

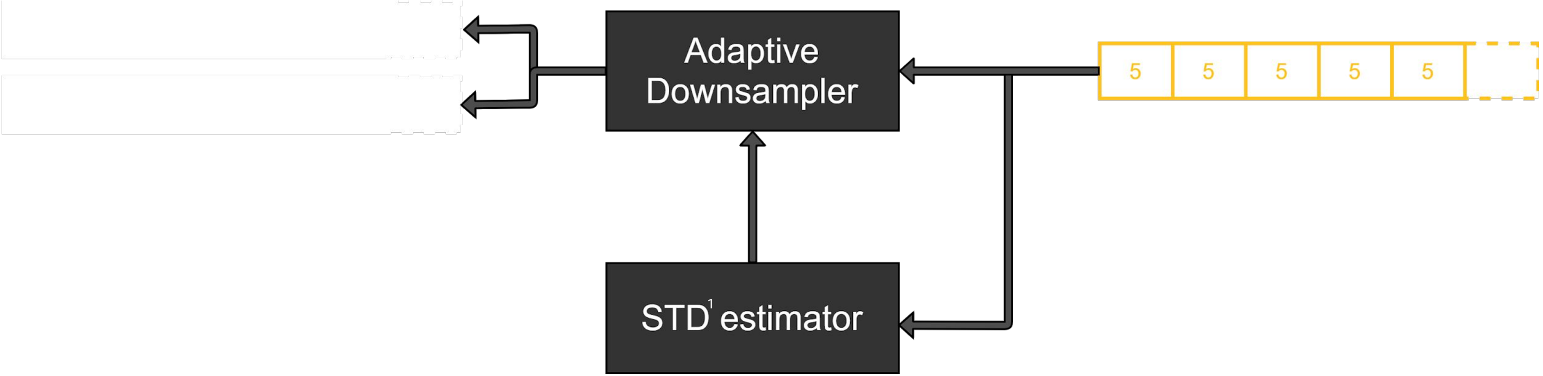




The system

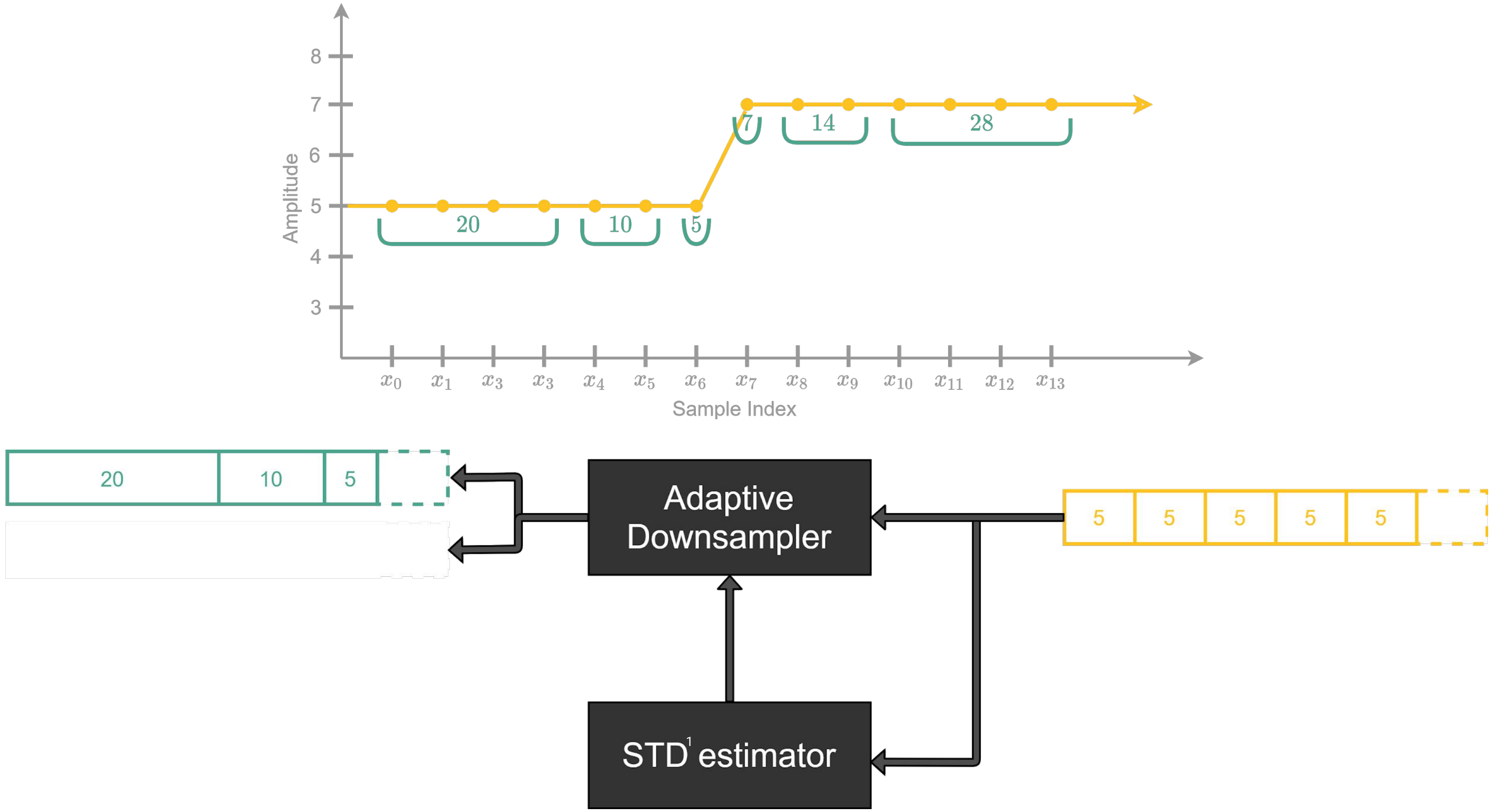
[1]*Standard deviation* (σ)





The system

[1]Standard deviation (σ)



The system

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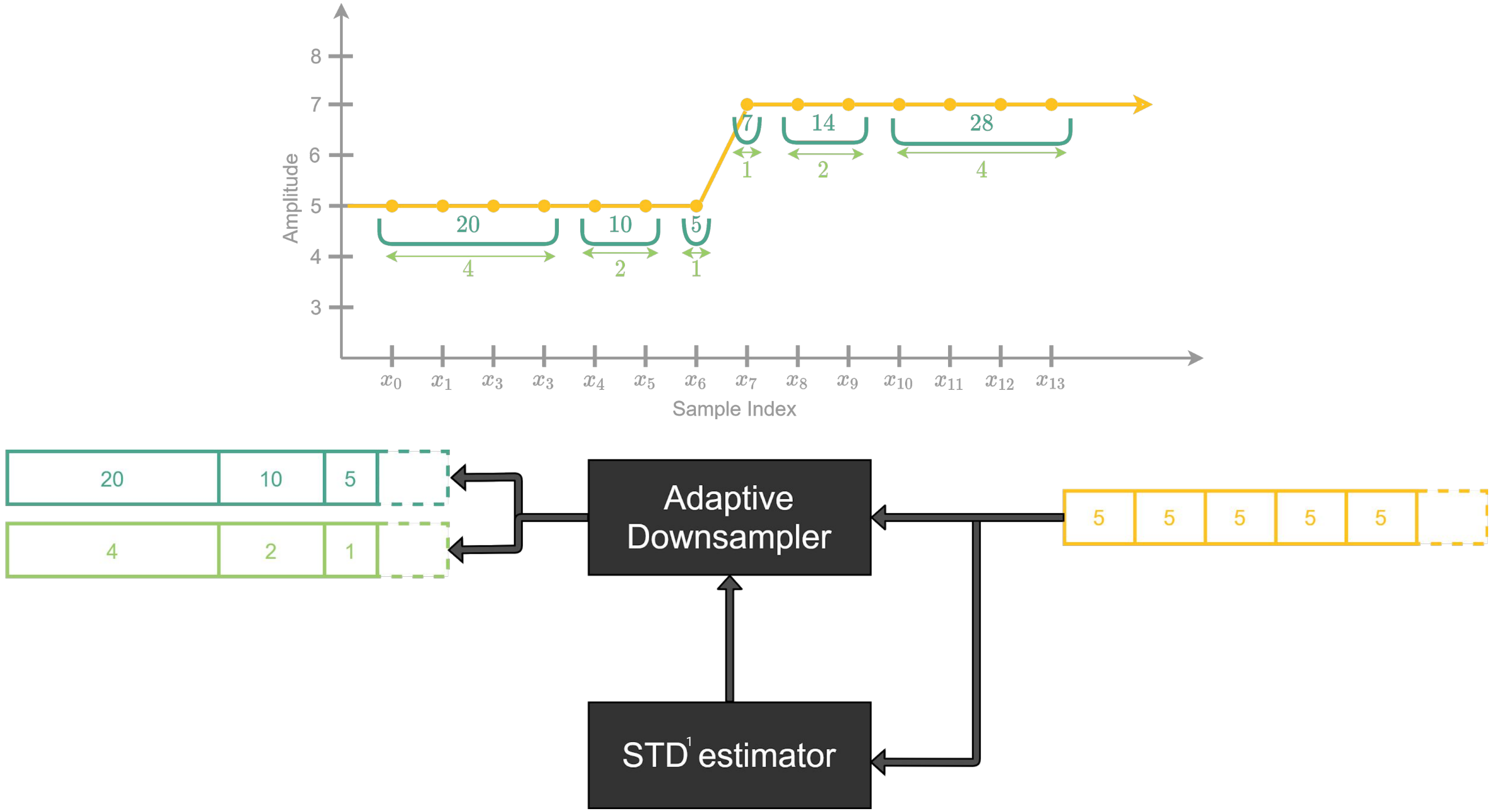


The system

[1]*Standard deviation (σ)*

Our website

- A webutility to demonstrate compression.
- Runs the same code as PC software.

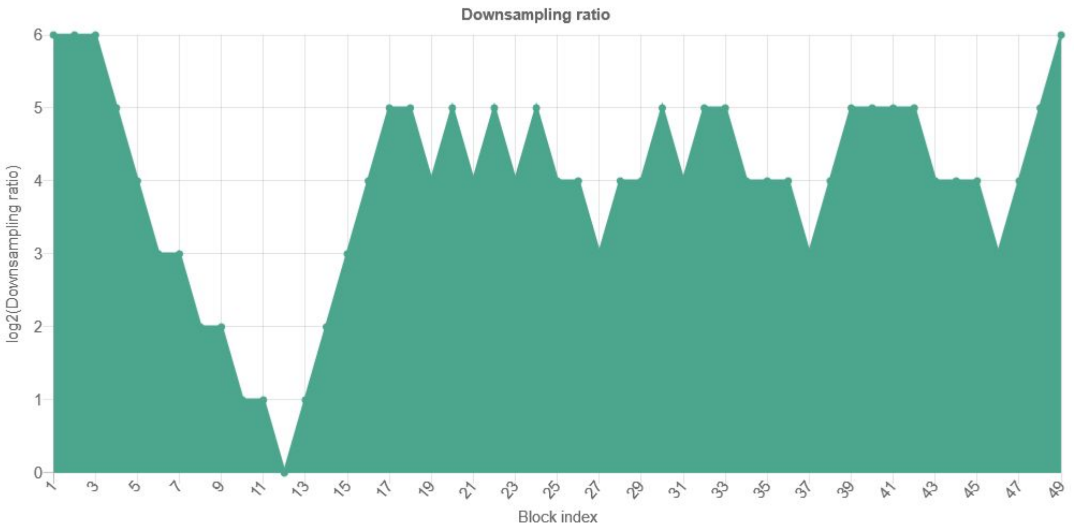
http://fy.chalmers.se/subatom/ads/compressor/

Ratio selection?

The downsampling ratio is always a power of two.

Only three ratio changes are allowed

- Increase by doubling
- Keep constant
- Decrease by halving



Significance testing

- Local decision
- Compare the difference of averages to this standard deviation.
- Checked for all possible ratios
- Length of average depend on ratio

$$|\bar{x} - \bar{g}| \leq \frac{2K\sigma}{\sqrt{R}}$$

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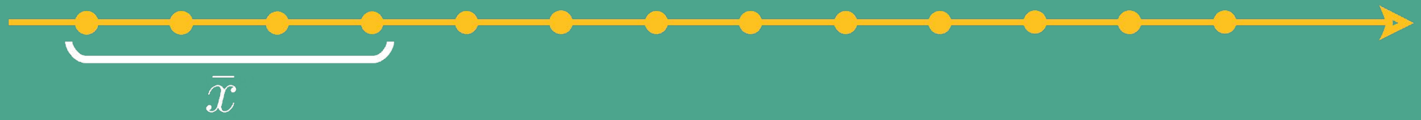

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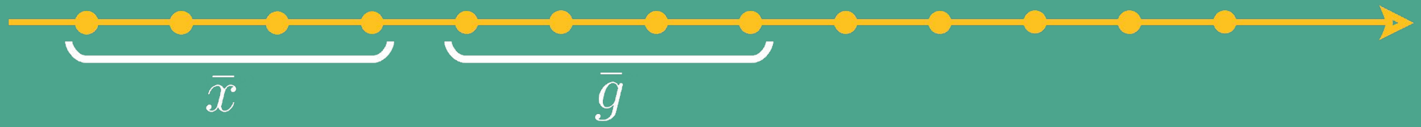

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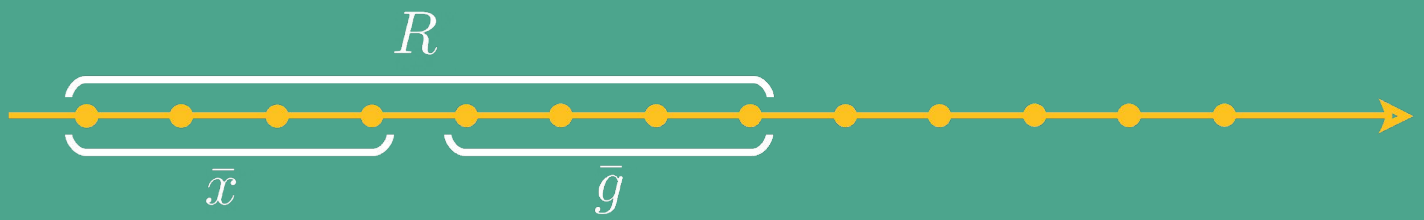

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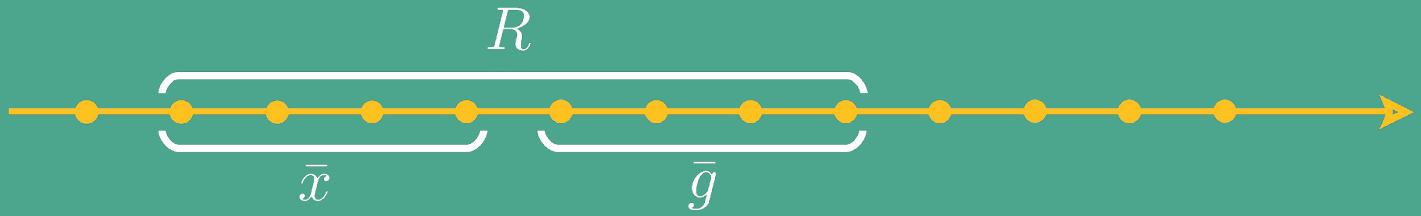
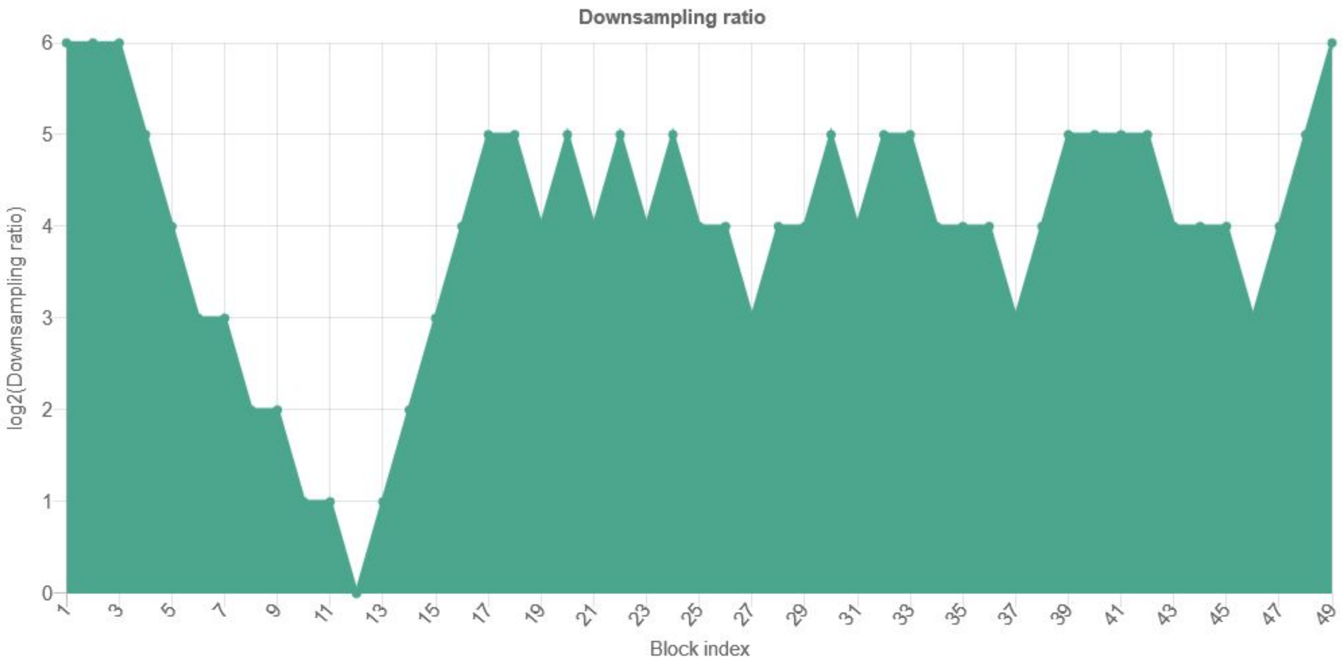


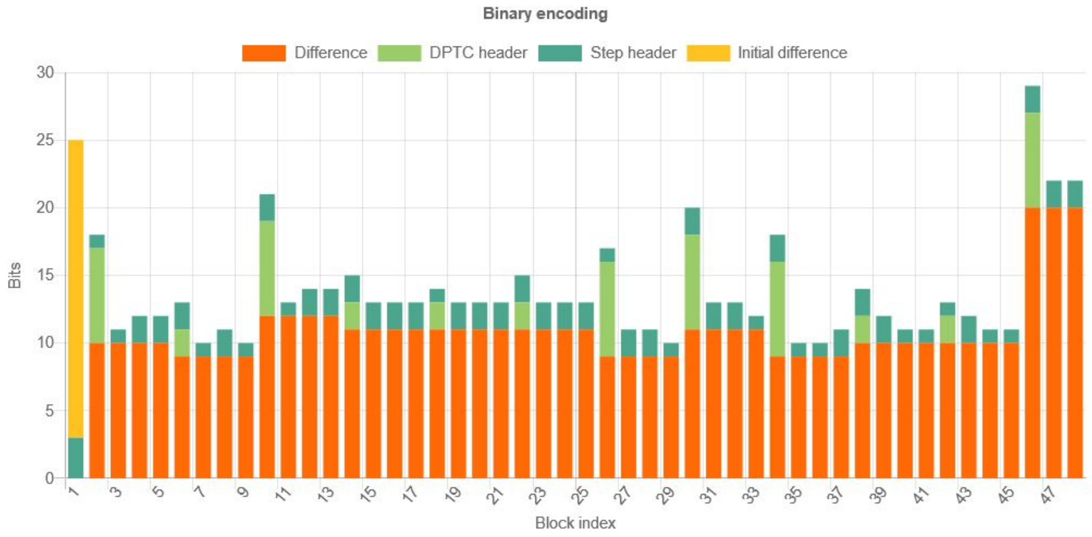


Global decisions

Encoding

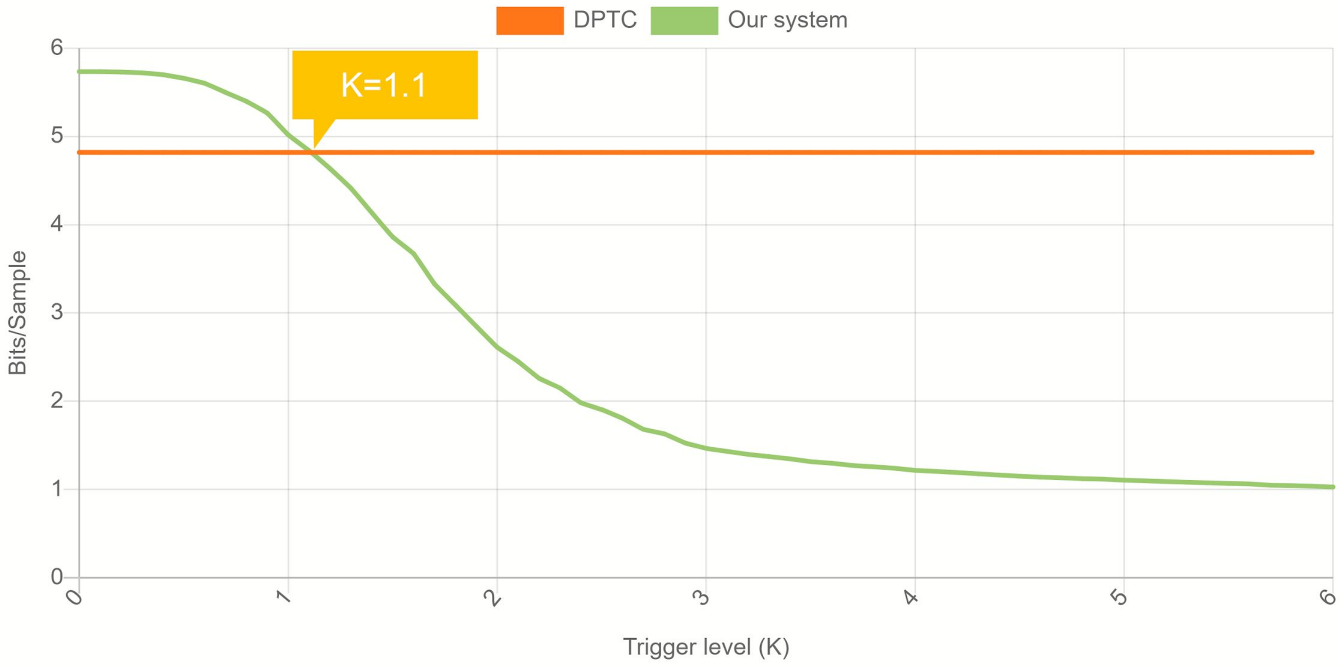
To encode the sum and ratio a pre-existing lossless compression scheme is used called DPTC [1].

Difference predicted trace compression (DPTC)



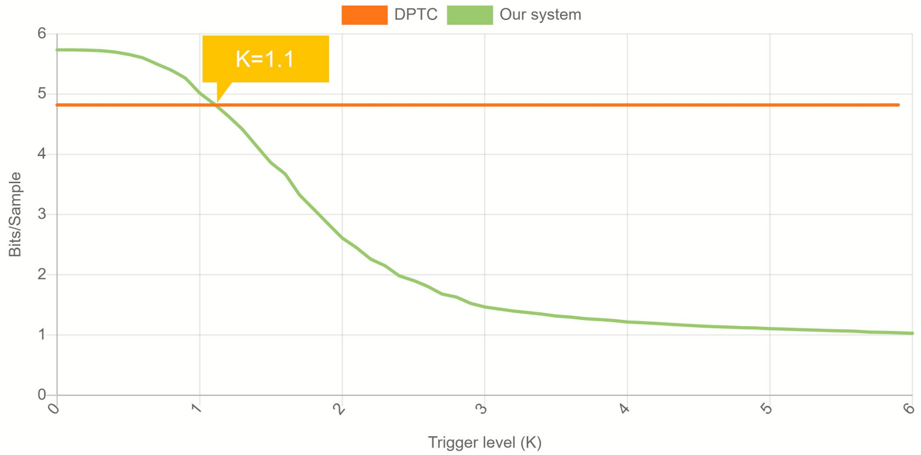
[1] DOI: 10.1109/TCSI.2019.2945179

Compression



Recap

- Compression is important
- Significance testing
- Try the website with your own traces
- All source code will be made available at http://fy.chalmers.se/subatom/ads



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Recap

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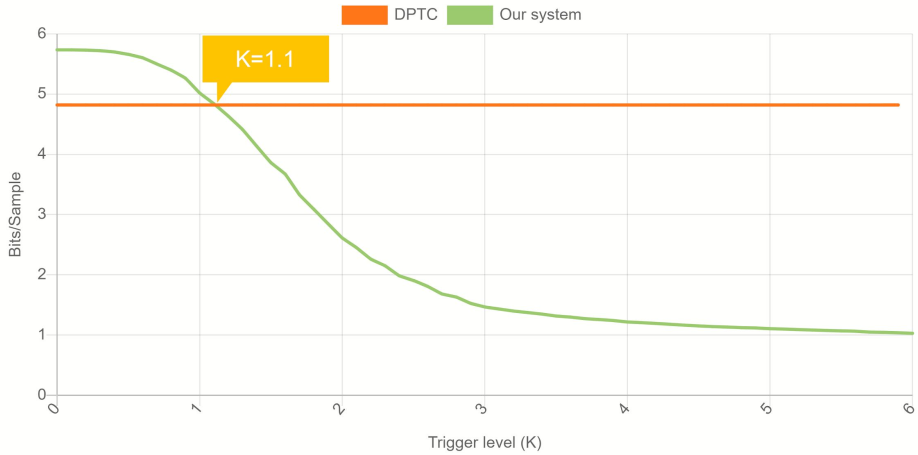
Thank you for listening!



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Trace compression

This website serves to demonstrate a novel lossy trace compression algorithm developed for data acquisition systems employed in physics experiments. Compression is achived by adaptivly downsampling the trace where regions of interest are kept at an high resolution whilst regions dominated by noise is downsampled. Regions of interest are defined as sections of the trace where signal deviations are signficant compared to the estimated standard deviation of the noise. For a more detailed principle of operation please consulte our Master's thesis.

To get started either select one of the test traces or upload your own trace file. This file should contain a list of integers representing the samples of the trace. The system is quite linient so formats that approximates JSON or CSV should be acceptable.

Realworld example

UPLOAD TRACE FILE

NEXT

Trace compression

General settings

Sample bits

16

Max ratio

64

Standard deviation estimation

Estimate whilst compressing

☐

Estimate before compression

☐

Initial STD guess

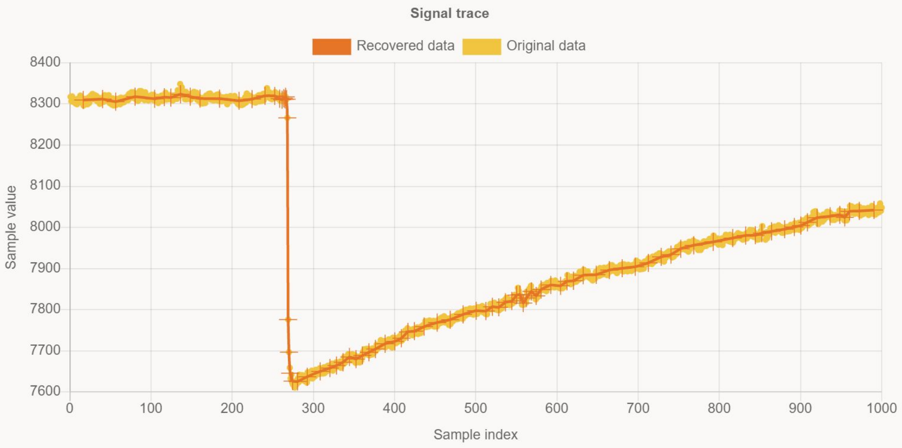
8.0

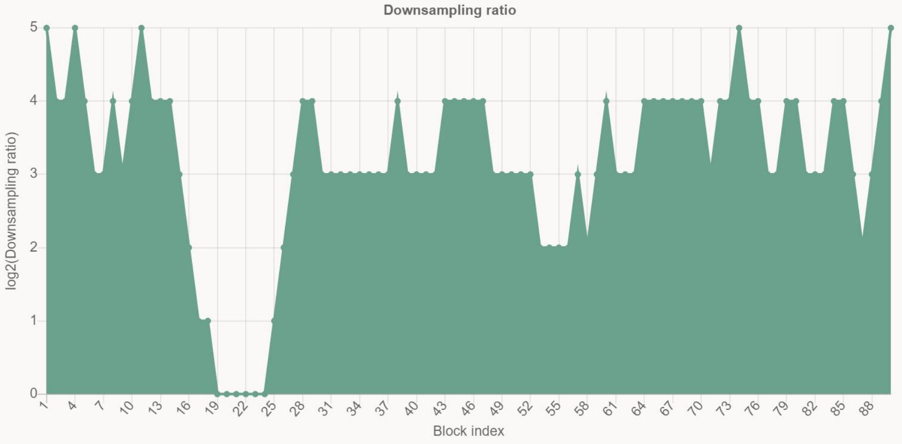
Trigger level

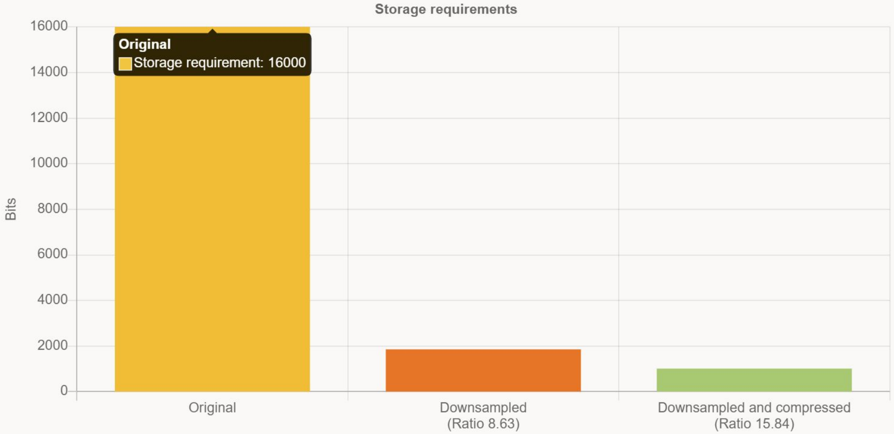
3

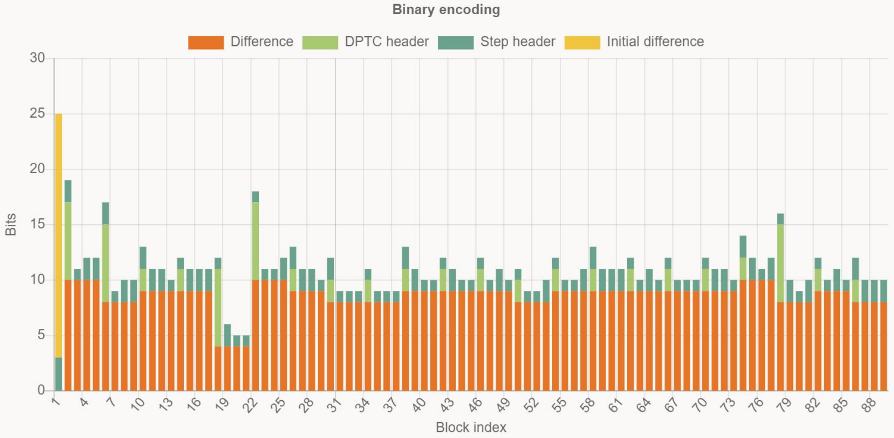
PREVIOUS

NEXT


Signal trace
Recovered data
Original data
Sample value
Sample index

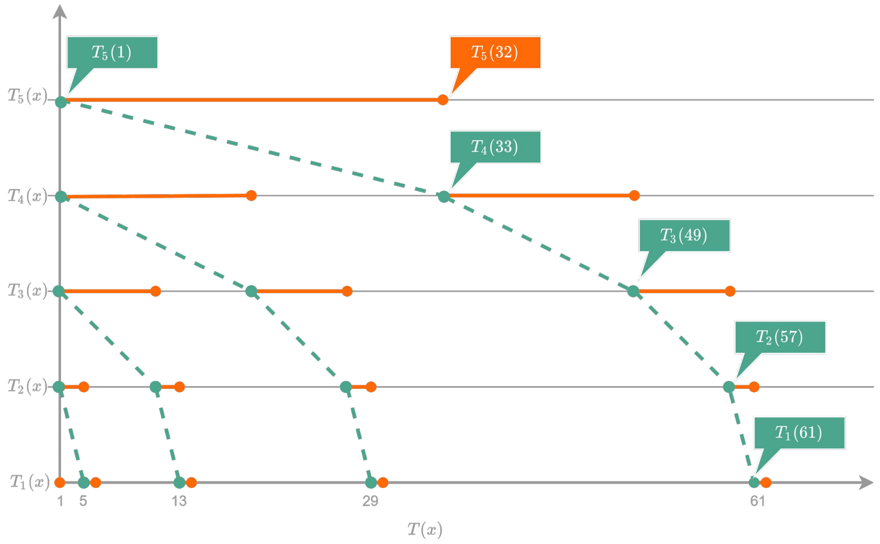

Downsampling ratio
log2(Downsampling ratio)
Block index


Storage requirements
Original
Storage requirement: 16000
Bits
16000
14000
12000
10000
8000
6000
4000
2000
0
Original
Downsampled
(Ratio 8.63)
Downsampled and compressed
(Ratio 15.84)


Binary encoding
Difference
DPTC header
Step header
Initial difference
Bits
30
25
20
15
10
5
0
Block index

Look-ahead

- Ratio selection rules implies look-ahead, i.e future samples must be inspected to decide ratio.
- System always increases ratio if possible
- Local decision by significance testing.



The result

K=3

Label	Category	Details	Traces #	Samples #	σ	DPTC	ADS	ADS + DPTC
						— — — Bits/Sample	— — —	
a		core signal	40	5000	2.16	3.89	1.70	0.79
b	γ in segmented BEGe	segment 1	40	5000	2.16	3.86	1.81	0.85
c		segment 5	40	5000	2.21	3.91	1.81	0.85
d		Ionisation chamber	200	200	71.2	9.16	1.84	1.53
e	n/γ discrimination	n-det, anode	200	200	4.88	5.36	2.67	1.72
f		n-det, cathode	200	200	6.20	5.71	2.48	1.59
g	position-sensitive	α-particles	50	1000	29.7	7.81	1.13	0.81
h	Si pin-diode	^{40}Ar	50	1000	6.36	5.58	2.28	1.35
i		no signal split	100	200	5.30	5.55	3.88	2.51
j	γ from ^{137}Cs	signal split 1:2	100	200	3.90	5.08	3.46	2.15
k	in $LaBr_3$	signal split 1:4	100	200	3.23	4.81	3.20	1.95
l		signal split 1:8	100	200	3.05	4.65	2.78	1.69
m		350V	100	600	0.25	1.67	1.90	0.62
n	cosmic μ in $LaBr_3$,	400V	100	600	0.25	1.67	2.22	0.74
o	varying HV of PMT	450V	100	200	4.28	5.55	4.55	3.01
p	cosmic μ in $LaCl_3$,	CAEN DT5730	100	400	3.88	5.00	2.50	1.49
q	different digitizers	CAEN DT5751	100	400	0.86	2.72	2.95	1.28
r		all values 0	1	1000	0	1.51	0.34	0.06
s	Flat traces	all values 10	1	1000	0	1.51	0.34	0.09
t		all values 100	1	1000	0	1.51	0.34	0.10

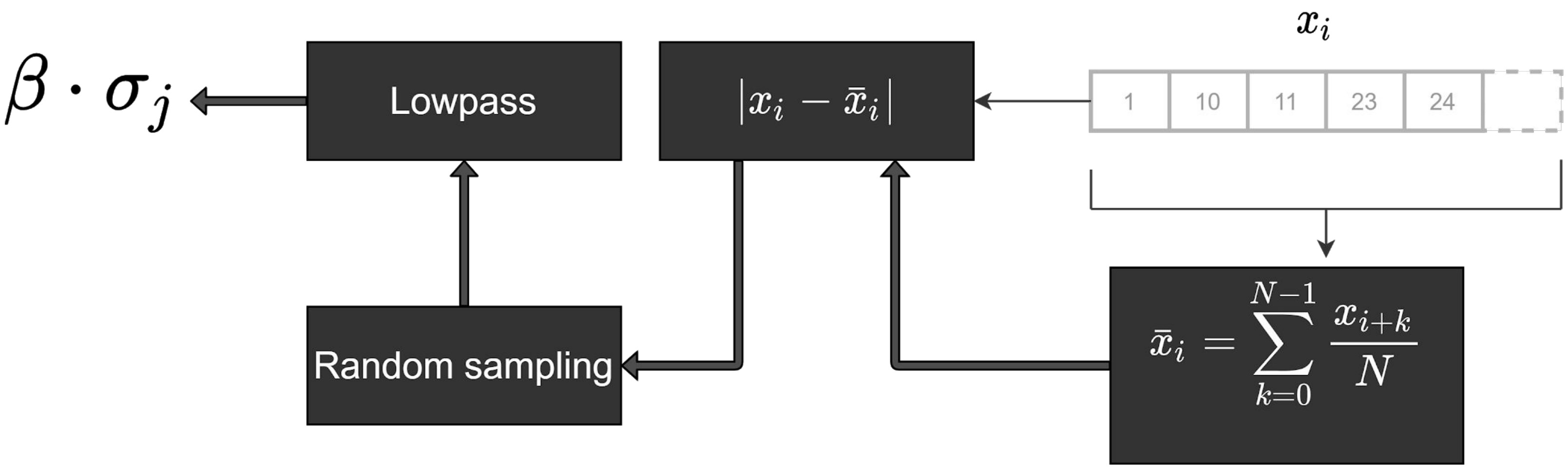
The result

K=2

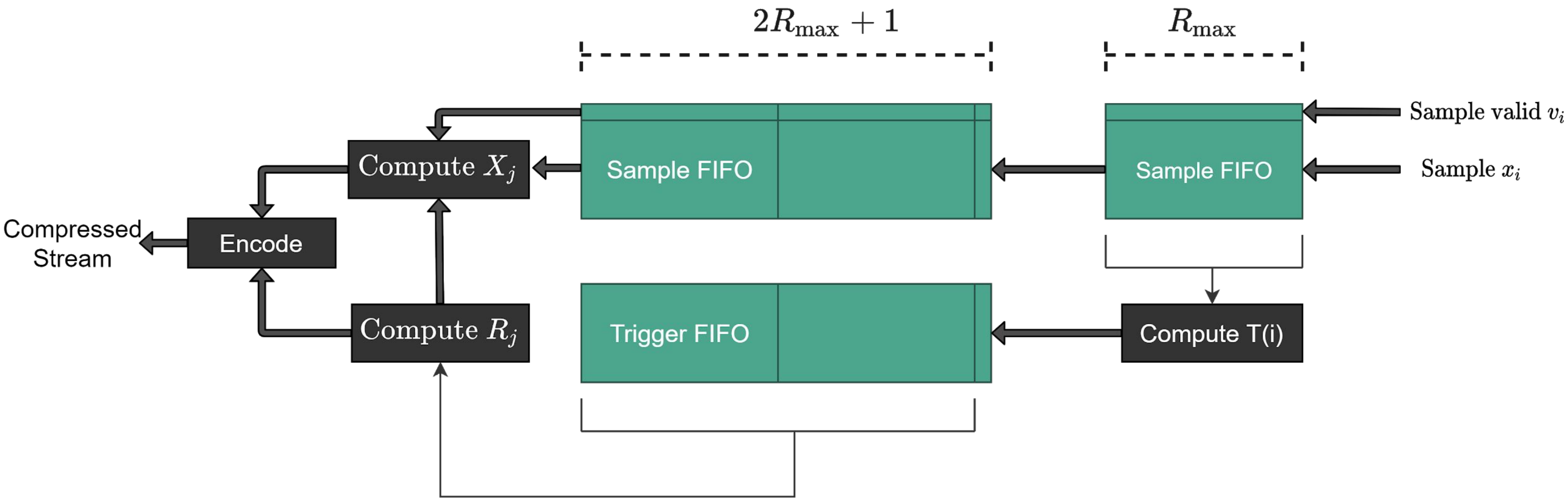
Label	Category	Details	Traces #	Samples #	σ	DPTC	ADS	ADS + DPTC
						— — — Bits/Sample — — —		
a		core signal	40	5000	2.16	3.89	4.83	2.08
b	γ in segmented BEGe	segment 1	40	5000	2.16	3.86	4.76	2.07
c		segment 5	40	5000	2.21	3.91	5.06	2.20
d		Ionisation chamber	200	200	71.2	9.16	5.41	4.08
e	n/γ discrimination	n-det, anode	200	200	4.88	5.36	5.48	3.06
f		n-det, cathode	200	200	6.20	5.71	5.42	3.06
g	position-sensitive	α-particles	50	1000	29.7	7.81	2.93	1.93
h	Si pin-diode	^{40}Ar	50	1000	6.36	5.58	4.77	2.60
i		no signal split	100	200	5.30	5.55	5.61	3.34
j	γ from ^{137}Cs	signal split 1:2	100	200	3.90	5.08	5.76	3.17
k	in $LaBr_3$	signal split 1:4	100	200	3.23	4.81	5.75	3.03
l		signal split 1:8	100	200	3.05	4.65	5.83	2.99
m		350V	100	600	0.25	1.67	3.74	0.95
n	cosmic μ in $LaBr_3$,	400V	100	600	0.25	1.67	4.41	1.13
o	varying HV of PMT	450V	100	200	4.28	5.55	5.80	3.58
p	cosmic μ in $LaCl_3$,	CAEN DT5730	100	400	3.88	5.00	5.86	3.00
q	different digitizers	CAEN DT5751	100	400	0.86	2.72	5.67	2.14
r		all values 0	1	1000	0	1.51	0.34	0.06
s	Flat traces	all values 10	1	1000	0	1.51	0.34	0.09
t		all values 100	1	1000	0	1.51	0.34	0.10

FPGA Family	Part number	Max frequency	LUT usage	FF usage
Zynq-7000	xc7z020-1	182 MHz	1560	1246
Spartan-7	xc7s75-1	182 MHz	1559	1246
Spartan-6	xc6slx9-2	154 MHz	1508	1172
Virtex-4	xc4vlx15-12	158 MHz	1980	1183

- 14 bit wide ADC
- Max ratio of 64



Standard deviation estimator



Compressor details