Cross-platform ECG Compression Library for Mobile HealthCare Services

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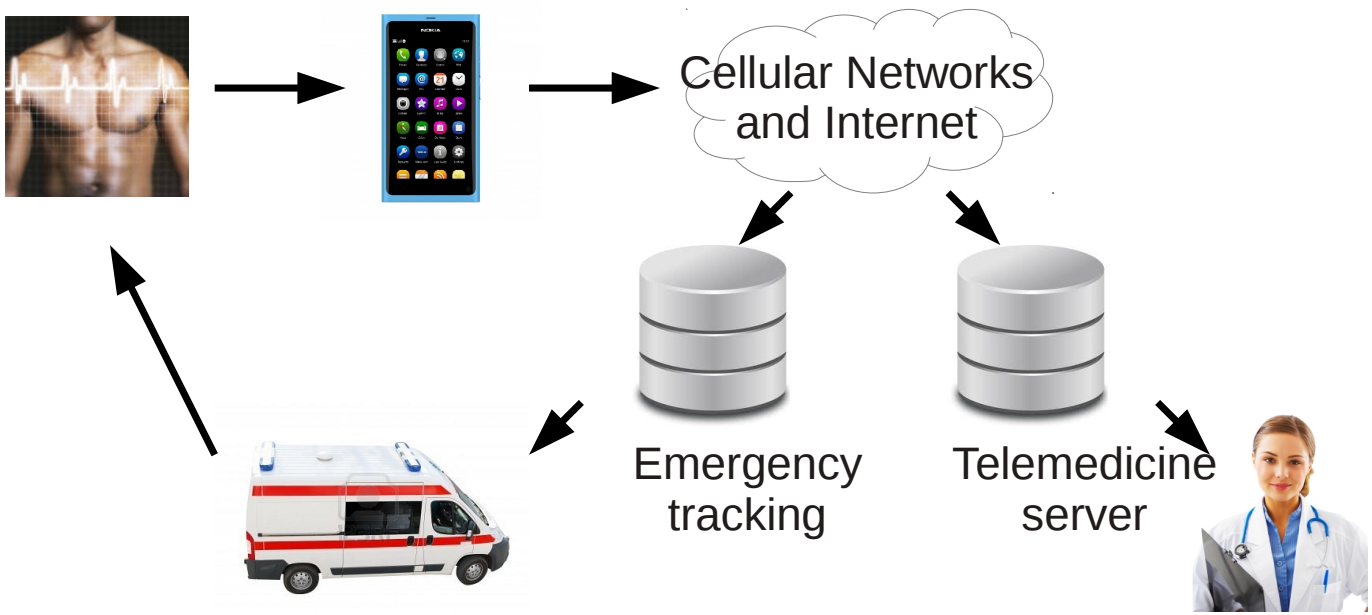
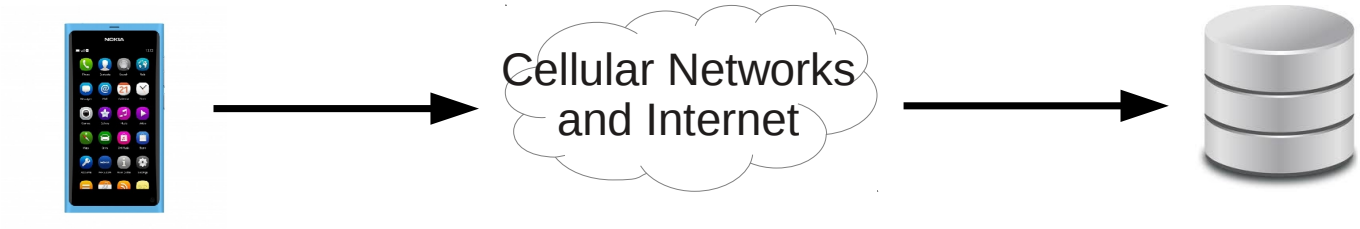
Mobile Healtcare vs. Cardiovascular Deseases

- Heart Attack — the leading cause of sudden death in developed countries and Russia
- Long-term continous monitoring — is the way to alarm a doctor timely
- Impossible in hospital circumstances and with standard 12-lead ECG monitors
- We need simple personal-use devices

Common Mobile HealthCare System Architecture

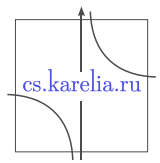


Why compression?



The CardioZip library

- Lossless and lossy ECG data compression based on wavelet transform
- The pilot project aimed at growing the competences in Mobile HealthCare area in PetrSU

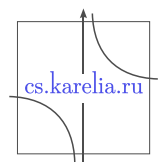


The Team

	07	08	09	10	11	12	01	02	03	04
Alexander Borodin	+	+	+	+	+	+	+	+	+	+
Yulia Zavyalova			+	+	+	+	+	+	+	+
Maxim Obryadin				+	+	+				
Anna Sapankevich				+	+	+				

Limitations of mobile platforms

- An efficient implementation of the algorithm should be provided since huge and time-consuming computations can quickly discharge the battery.
- Real arithmetics should be avoided if possible due to the lack of floating point unit on some devices.



Preprocessing ECG data with wavelet transform

- Good reputation in 1D and 2D signal compression
  - JPEG 2000
  - Dirac video codec
- Distribution of values for the wavelet coefficients centered close to zero with very few large coefficients
- Effective computation algorithm (lifting schemes)
- Integer-to-integer can be computed with no FPU

Lifting scheme of DWT computation

- Splitting step: the original signal $x = \{x_i\}$ is splitted into two (odd and even) subsequences.

$$\begin{aligned} s^{(0)} &= \{x_{2i}\} \\ d^{(0)} &= \{x_{2i+1}\} \end{aligned} \tag{1}$$

- Several repeats of lifting step: the odd and even subsequences are filtered by the prediction and update filters, $P_n(x)$ and $U_n(x)$.

$$\begin{aligned} d^{(j)} &= d^{(j-1)} - P_j\{s^{(j-1)}\} \\ s^{(j)} &= s^{(j-1)} + U_j\{d^{(j)}\} \end{aligned} \tag{2}$$

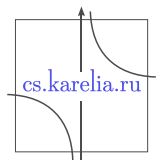
Lifting scheme of DWT computation

- Denote the length of a vector as k. Then the filter have the following general form:

$$F_n\{x\} = \sum_{i=1}^{k} f_n(k) x_i \tag{3}$$

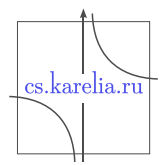
- Normalization step: at last the coefficients are normalized. Denote the number of lifting steps as N. Then the normalization step can be expressed in the following form, where M_0 and M_1 are constant values:

$$\begin{aligned} d^{(N)} &= M_0 d^{(N)} \\ s^{(N)} &= M_1 s^{(N)} \end{aligned} \tag{4}$$



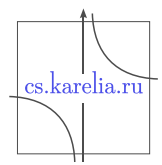
Lifting scheme for Le Gall 5/3 DWT

$$
\begin{aligned}
s_i &= d_i^{(1)} &&= d_i^{(0)} - \tfrac{1}{2}(s_i^{0} + s_{i+1}^{(0)}) \\
d_i &= s_i^{(1)} &&= s_i^{(0)} + \tfrac{1}{4}(d_i^{1)} + d_{i-1}^{(1)}) \\
&&&= -\tfrac{1}{8}s_{i-1}^{(0)} + \tfrac{1}{4}d_{i-1}^{0)} + \tfrac{3}{4}s_i^{(0)} + \tfrac{1}{4}d_i^{(0)} - \tfrac{1}{8}s_{i+1}^{(0)}
\end{aligned}
\tag{5}
$$



Lifting scheme for Daubechies 9/7 DWT

$$
\begin{aligned}
d_i^{(1)} &= d_i^{(0)} + \alpha(s_i^{0)} + s_{i+1}^{(0)}) \\
s_i^{(1)} &= s_i^{(0)} + \beta(d_i^{1)} + d_{i-1}^{(1)}) \\
d_i^{(2)} &= d_i^{(1)} + \gamma(s_i^{1)} + s_{i+1}^{(1)}) \\
s_i^{(2)} &= s_i^{(1)} + \delta(d_i^{2)} + d_{i-1}^{(2)}) \\
s_i &= \zeta s_i^{(2)} \\
d_i &= \zeta^{-1} d_i^{(2)}
\end{aligned}
\tag{6}
$$

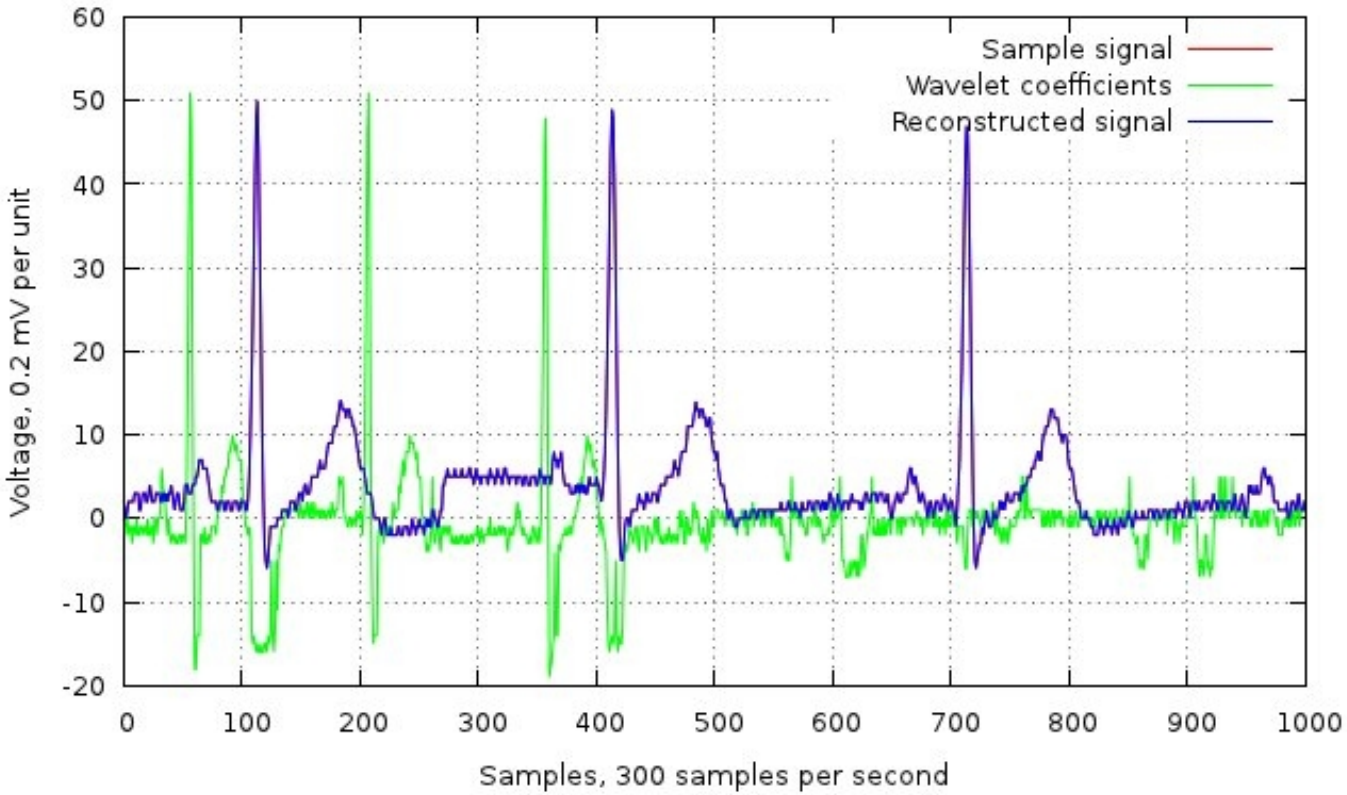


Quantized values of Daubechies 9/7 DWT

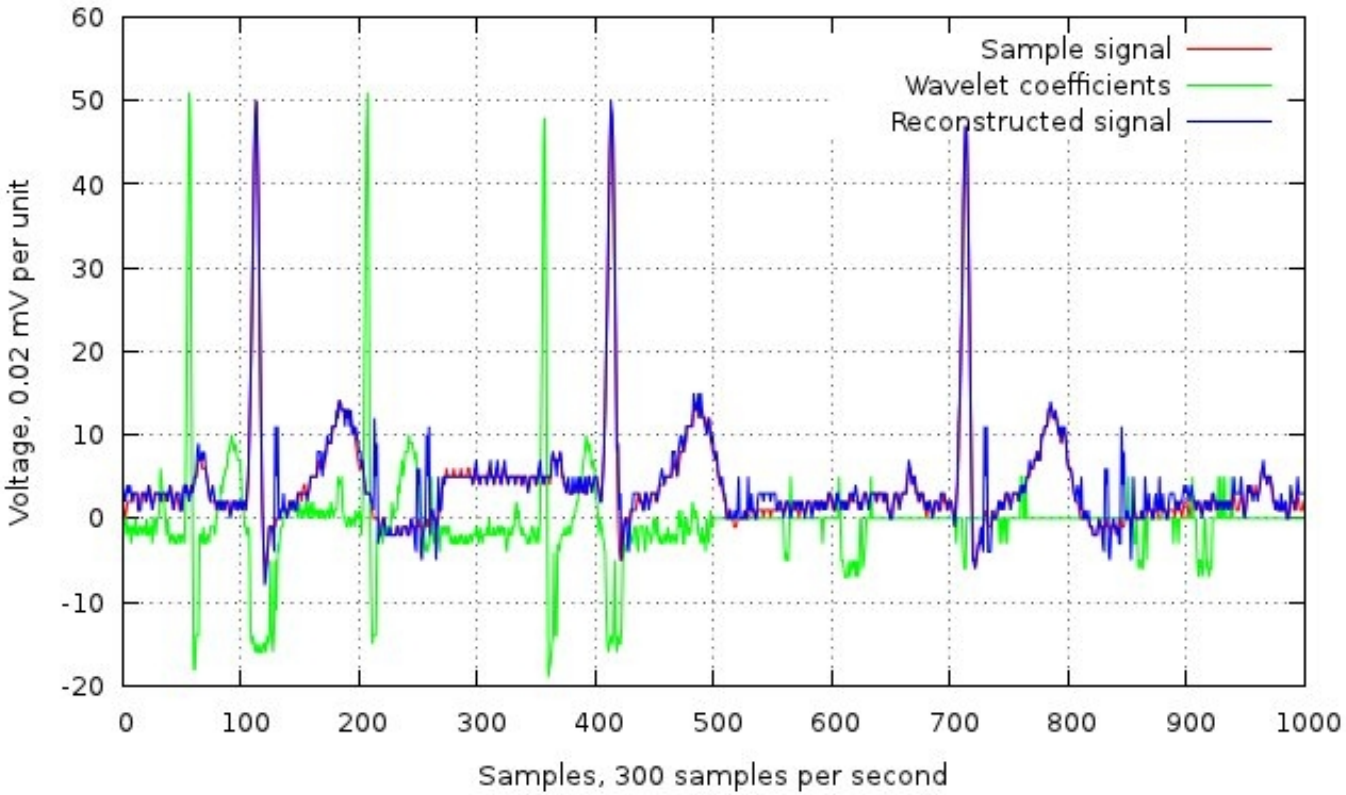
Таблица : Quantized values of Daubechies 9/7 DWT

Coefficient	Irrational	Quantized rational
α	$-1.58613434\ldots$	-1.5
β	$-0.0529801185\ldots$	-0.0625
γ	$0.882911076\ldots$	0.46875
δ	$0.443506852\ldots$	0.7998046875
ζ	$1.14960439\ldots$	-1.25

Wavelet transform with no thresholding

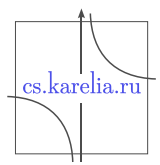


Wavelet transform with thresholding



Compressing the coefficients of wavelet transform

- Dynamic Markov Compression
  - Moderate speed
  - Good for DWT coefficients
  - There are scalability problems
- Range Arithmetic Coding
  - Fast
  - Good compression ratio



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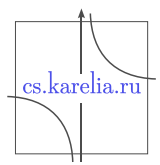
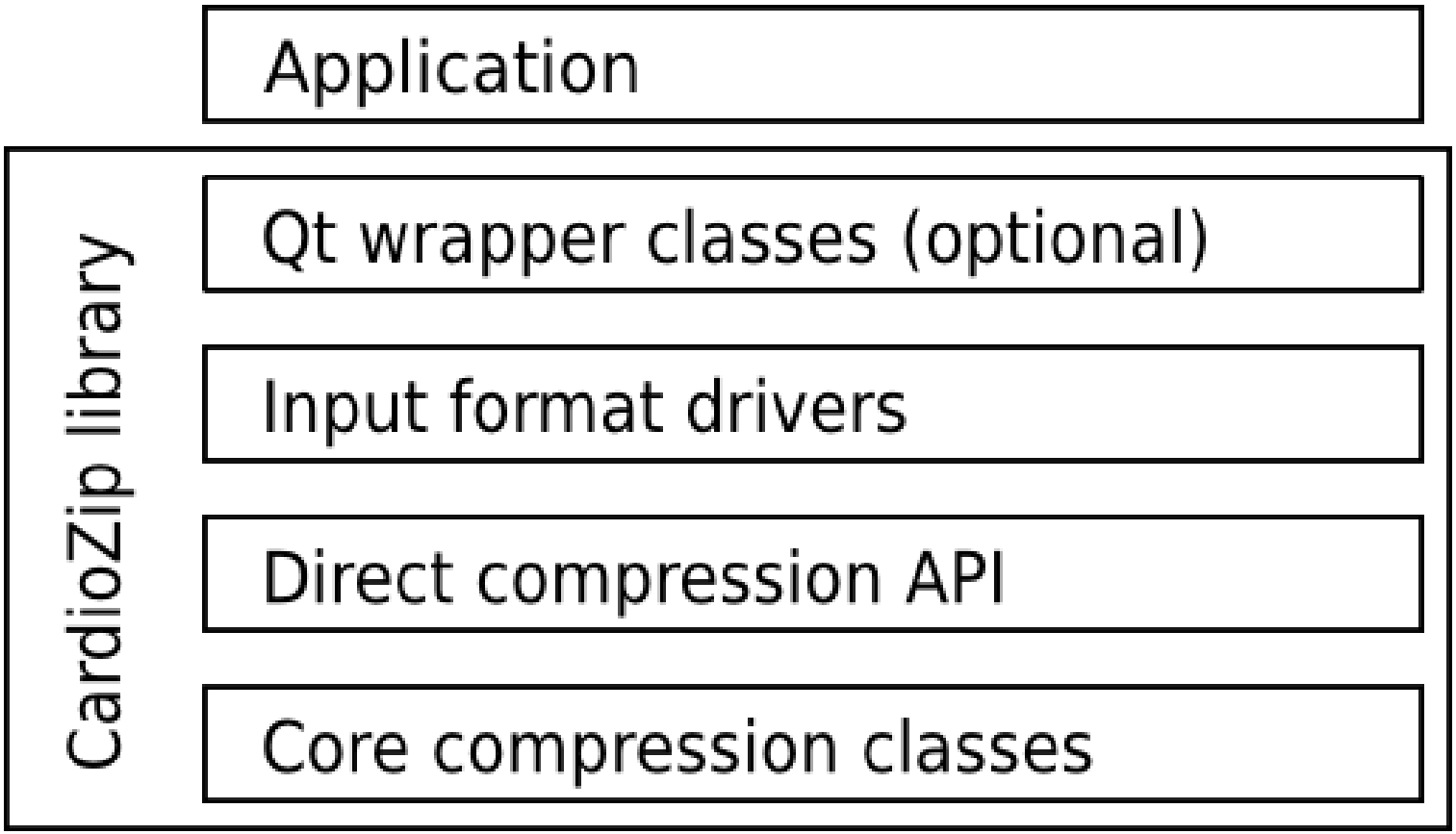


Lossless compression results

Input packet size, bytes	Average output size, bytes	Average CR
300	201	1.49
1000	562	1.78
10000	3534	2.83
25000	8211	3,04
50000	16120	3.10

Library architecture and overview



Compressed file format

- Zero Header (4 bytes)
  - CZF in ASCII (3 bytes)
  - Size of memory block in bytes (1 byte)
- File Header
- Integrity Header
- Security Header
- Patient Header
- Algorithms Header
- Compressed ECG Recordings