QUALITY ASSESSMENT FOR SAR RAW DATA COMPRESSION METHODS*

Johanna Bolle
Institut für Theoretische Nachrichtentechnik und Informationsverarbeitung
Appelstr. 9A, D-30167 Hannover, Germany
Phone: +49-511-762-5305, Fax: +49-511-762-5333, E-Mail: bolle@tnt.uni-hannover.de

ABSTRACT

The raw data rate of a Synthetic Aperture Radar is in the order of hundreds Mbit/s. To reduce this data rate coding is applied usually directly to the I and Q components of the raw data. In a recently presented method the coding is applied to preprocessed raw data. The preprocessing consists of a reversible transform of the raw data. The coding techniques under consideration here, are the DCT with subsequent Huffman coding, and the LBG vector quantisation.
Since these coding techniques perform lossy, objective criteria have to be developed for comparisons. Most of these criteria have to be derived from the SAR image, which has been processed from original raw data.
After coding and decoding at different rates by the above mentioned techniques, SAR images are generated. The assessment criteria are then applied to the images.
Additionally, as a subjective comparison, the influence of coding on the processed image and on an image segmentation algorithm will be discussed. The segmentation result of the original SAR image is compared to the results achieved on images with coded/decoded raw data.

1.0 INTRODUCTION

Due to the very poor correlation and high entropy of SAR raw data it is not useful to apply redundancy reduction techniques directly. With lossless coding compression ratios only in the order of 1.15-1.2 are possible. Higher compression can be provided with lossy coding. Compression ratios in the order of 4 have been achieved (Cöster, 1997). This corresponds to a data rate of 2 bit/sample relative to a quantisation with 8 bit/sample for the original raw data.

In a recently published conference paper a new coding technique has been presented which is based upon a reversible transform of the raw data (Bolle, 1997). This technique allows the application of redundancy reduction techniques, also. Data rates in the order of 2 bit/sample have been achieved by means of a Discrete Cosine Transform with subsequent Huffman Coding of the DCT coefficients (T-DCT). In addition, the lossy coding techniques can be applied in a more efficient way. By means of the Linde-Buzo-Gray vector quantisation applied to transformed raw data (T-LBG-VQ) data rates up to 0.5 bit/sample have been reported in (Bolle, 1998). To evaluate the developed coding techniques on the one hand the $SNR(RawData)$ of the decoded raw data and on the other hand the $SNR(ImageData)$ of the processed images have been calulated. Then, the corresponding SNR values have been plotted versus the

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achieved coded data rate. The SNR was the only criterion to assess the quality of the reconstructed raw data and of the processsed images, respectively. But, only by means of the SNR a *true* evaluation can't be done. For a more precise assessment the need of more objective quality metrics is obvious.

After a short description of the statistical properties of the investigated raw data and of the transformed raw data, respectively, the developed encoder will be explained. The encoding is performed at different data rates. In the next section the applied quality assessment criteria will be defined. The assessment is performed in the raw data domain as well as in the image data domain. The evaluation results are presentend in a separate section. The paper will finish with some conclusions.

2.0 STATISTICS OF SAR RAW DATA

The correlation of SAR raw data is very poor. Due to the contained so-called *speckle noise*, which is a typical phenomenon in systems working at very high frequencies, the phase of the demodulated signal is uniformly and the signal magnitude is Rayleigh distributed. As a consequence the I and Q components can be assumed to be Gaussian, (Papoulis, 1991). The quantisation of the investigated raw data is 8 bit/sample for the I and Q component, respectively. The raw data were acquired by the German airborne SAR sensor DOSAR. The entropy of the raw data ranges between 6 and 7 bit/sample for the I and Q component, respectively.

3.0 STATISTICS OF TRANSFORMED SAR RAW DATA

A detailed description of the reversible transform T is given in (Bolle, 1997). T works like a conventional SAR processor, but all steps of T can be lossless reversed. After performing T we get complex transformed data which have some properties of the processed complex image data. In particular, the redundancy and correlation of the transformed data are increased. Contrary to the SAR raw data the transformed data can be efficiently coded by redundancy reduction coding techniques. The I and Q components are still Gaussian, the phase uniform and the magnitude Rayleigh distributed. The calculated zero-order entropy (memoryless source) indicates that coding of I and Q gives a better compression than coding of magnitude and phase due to the uniformly distributed phase.

4.0 CODING OF SAR RAW DATA

The investigated coding techniques are here

- 1D-DCT with Huffman coding of the DCT coefficients (T-DCT),
- Linde-Buzo-Gray vector quantisation (T-LBG-VQ).

Both methods were applied to the transfomed SAR raw data, which is marked by the capital letter T. The length of the DCT was $N_{DCT} = 32$. The degree of compression is a function of the quantisation step. The codebook size in case of the T-LBG-VQ was $N_{VQ} = 256$. Vectors of 4×1, 8×1 and 16×1, respectively, have been generated.

An additional aim of this work is a comparison of the above mentioned coding schemes with direct compression of the SAR raw data. Due to the lack of correlation only the LBG-VQ is applied in case of direct SAR raw data coding (RAW-LBG-VQ). The parameters of the RAW-LBG-VQ coder were chosen as in case of transformed data. The whole developed encoder scheme for assessment experiments is shown in Fig. 1.

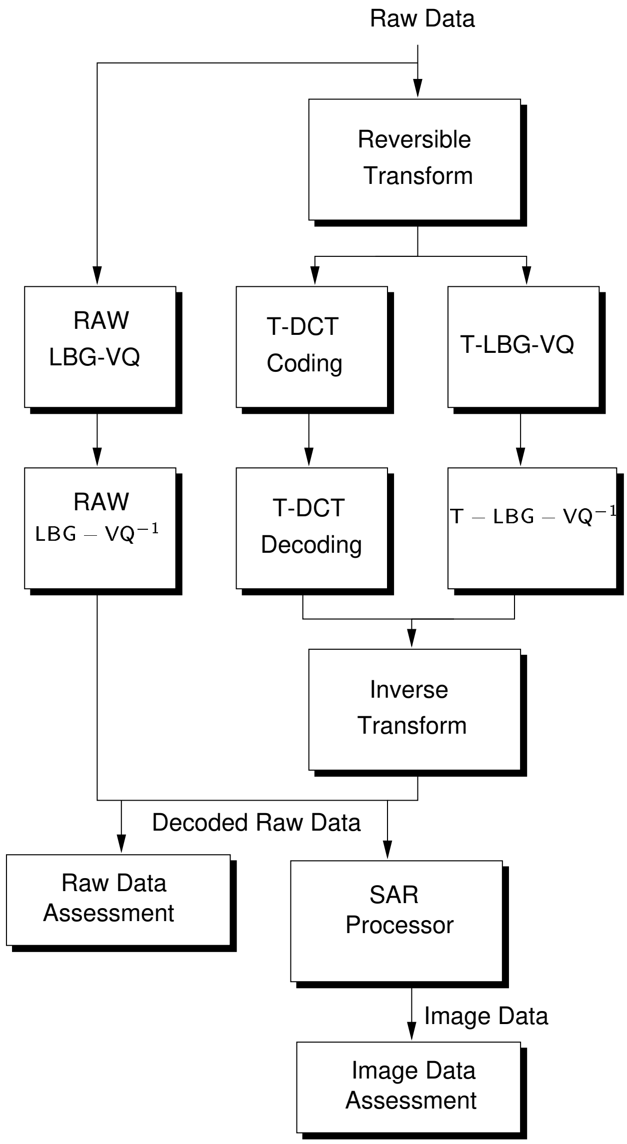

Figure 1: Encoder Scheme.

5.0 DEFINITION OF ASSESSMENT CRITERIA

Due to the different statistics of SAR raw data and SAR image data it is necessary to consider the both data domains separately.

5.1 RAW DATA DOMAIN

In the raw data domain the following objective criteria have been considered:

- NMSE - the normalised mean square error

$$NMSE = \frac{\sum_{n=1}^{N}(|X_n - Y_n|)^2}{\sum_{n=1}^{N}|X_n|^2},$$

  where X are the original SAR raw data (reference) and Y are the reconstructed raw data (reconstruction).

- SNR - the signal to noise ratio is the most common criterion to compare different compression algorithms

$$SNR = 10\log_{10}\frac{1}{NMSE} \text{ in } dB.$$

  Unfortunately, the $NMSE$ and SNR are only global quality metrics and they don't take into account the local behaviour of the data.

- phase error, because of the importance of the phase in interferometric and polarimetric applications

$$\Delta\overline{\phi} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\phi_{xn} - \phi_{yn})^2} \text{ in degree.}$$

- Entropy of the data

$$H = -\sum_{n=1}^{N} P(a_n)\log_2 P(a_n),$$

  where $P(a_n)$ is the probability of occurence for the symbol a_n.

5.2 IMAGE DATA DOMAIN

The SAR image data are represented with 16 bit/sample. In image data domain we applied the following objective criteria

- $NMSE$,
- SNR,
  which are defined in a similar way. Now, the reference X is a SAR image which is processed directly from the original SAR raw data and the reconstruction Y is processed from the coded/decoded raw data.
- $PSNR$, which is the peak signal to noise ratio.
- Entropy of the image data processed from the coded/decoded raw data.

Moreover, two subjective criteria are available

- the quality of processed images,
- the efficiency of an image segmentation algorithm.

Both can be evaluate visually.

6.0 EVALUATION RESULTS

The entropy of the investigated reference raw data was $H_{RAW} = 5.9$ bit/sample (I/Q) and the entropy of the reference image was $H_{IMAGE} = 13.2$ bit/sample (magnitude). In the following Tab. 1, 2 and 3, respectively, the measured quality criteria are listed for all kinds of coding, which have been considered here (see Fig. 1). In Fig. 2 the operational Rate-Distortion-Functions are plotted. The distortion is the SNR of the reconstructed raw data and processed image, respectively. In the last case, the distortion is the $PSNR$ of the processed image. In Fig. 3 the reconstruction of point targets is shown.

Rate	T-DCT $N_{DCT} = 32$						
	Raw Data			Image Data			
	SNR	Phase Error	H	SNR	$PSNR$	$NMSE$	H
$\frac{bit}{sample}$	dB	degree	$\frac{bit}{sample}$	dB	dB		$\frac{bit}{sample}$
1.9	15.6	10.7	5.9	25.2	44.6	0.003	13.2
1.4	10.8	14.2	5.9	19.2	38.7	0.012	13.2
1.1	6.50	18.9	5.9	13.9	33.4	0.041	13.3

Table 1: Assessment of the T-DCT Coding.

Rate	T-LBG-VQ Codebook Size $N_{VQ} = 256$						
	Raw Data			Image Data			
	SNR	Phase Error	H	SNR	$PSNR$	$NMSE$	H
$\frac{bit}{sample}$	dB	degree	$\frac{bit}{sample}$	dB	dB		$\frac{bit}{sample}$
2	13.5	10.2	5.9	24.4	43.9	0.004	13.2
1	8.60	13.6	5.8	17.6	37.1	0.020	13.2
0.5	5.30	16.9	5.6	12.8	32.2	0.050	13.1

Table 2: Assessment of the T-LBG-VQ Coding.

Rate	RAW-LBG-VQ $N_{VQ} = 256$						
	Raw Data			Image Data			
	SNR	Phase Error	H	SNR	$PSNR$	$NMSE$	H
$\frac{bit}{sample}$	dB	degree	$\frac{bit}{sample}$	dB	dB		$\frac{bit}{sample}$
2	12.8	10.5	5.8	20.2	39.7	0.01	13.1
1	7.70	13.8	5.7	12.9	32.3	0.05	13.1
0.5	4.60	22.6	5.6	8.70	28.1	0.10	13.0

Table 3: Assessment of the RAW-LBG-VQ Coding.

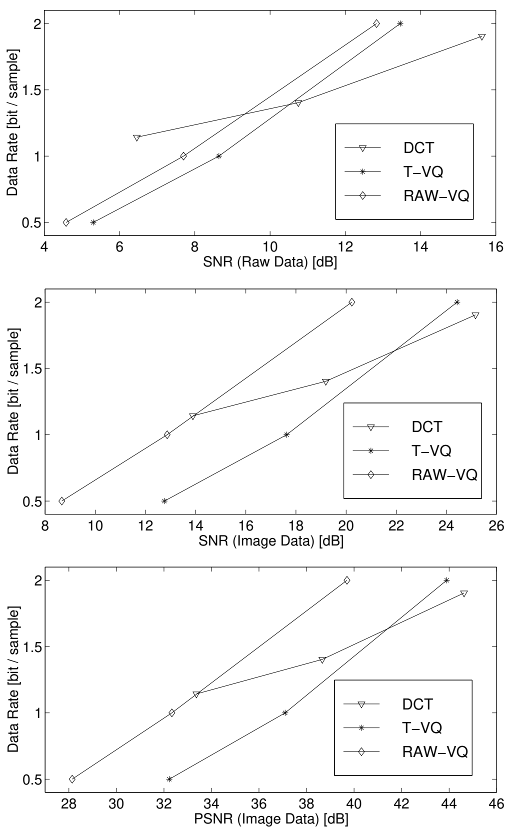

Figure 2: Operational Rate-Distortion-Functions

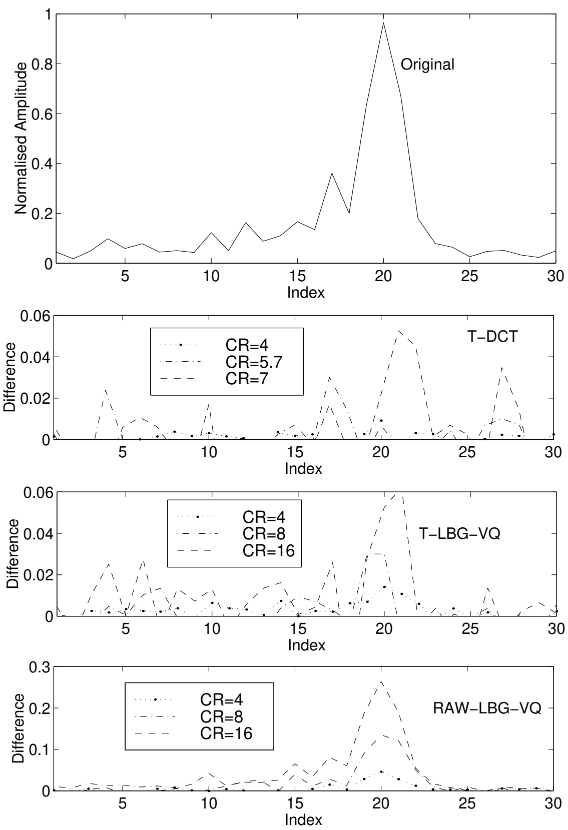

Figure 3: Peak Reconstruction

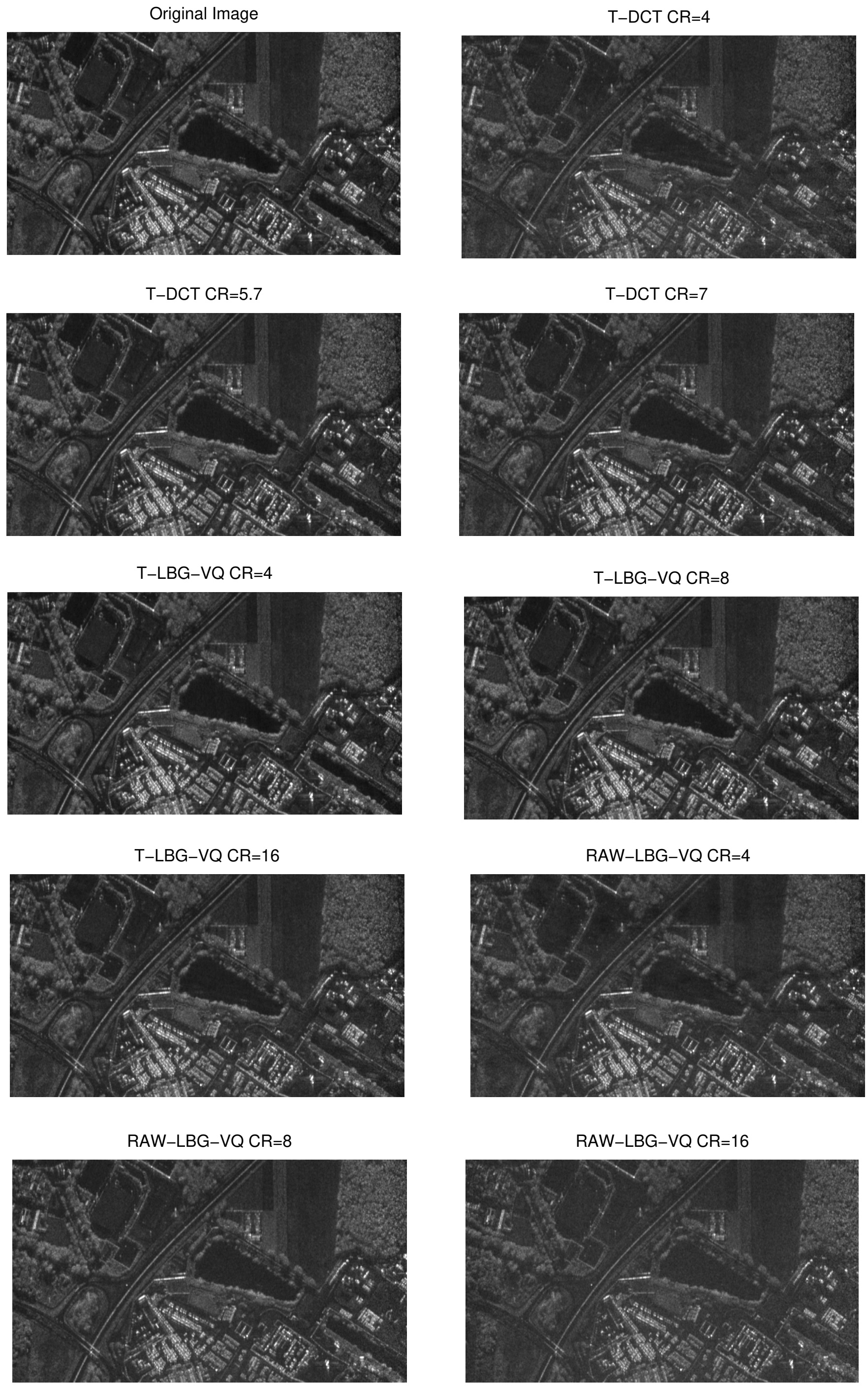

Figure 4: Processed SAR Images

Finally, in Fig.4 a subjective comparison of the processed images is done. CR=8/DR is the calulated compression ratio, where DR is the achieved data rate as listed in Tab. 1, 2 and 3, respectively. Additionally, the impact of coding losses on an image segmentation algorithm is visualised in Fig.5. The applied segmentation algoritm is based on Gibbs-Markov random fields and has been adapted to the statistics of SAR image data (Gimel'farb, 1991).

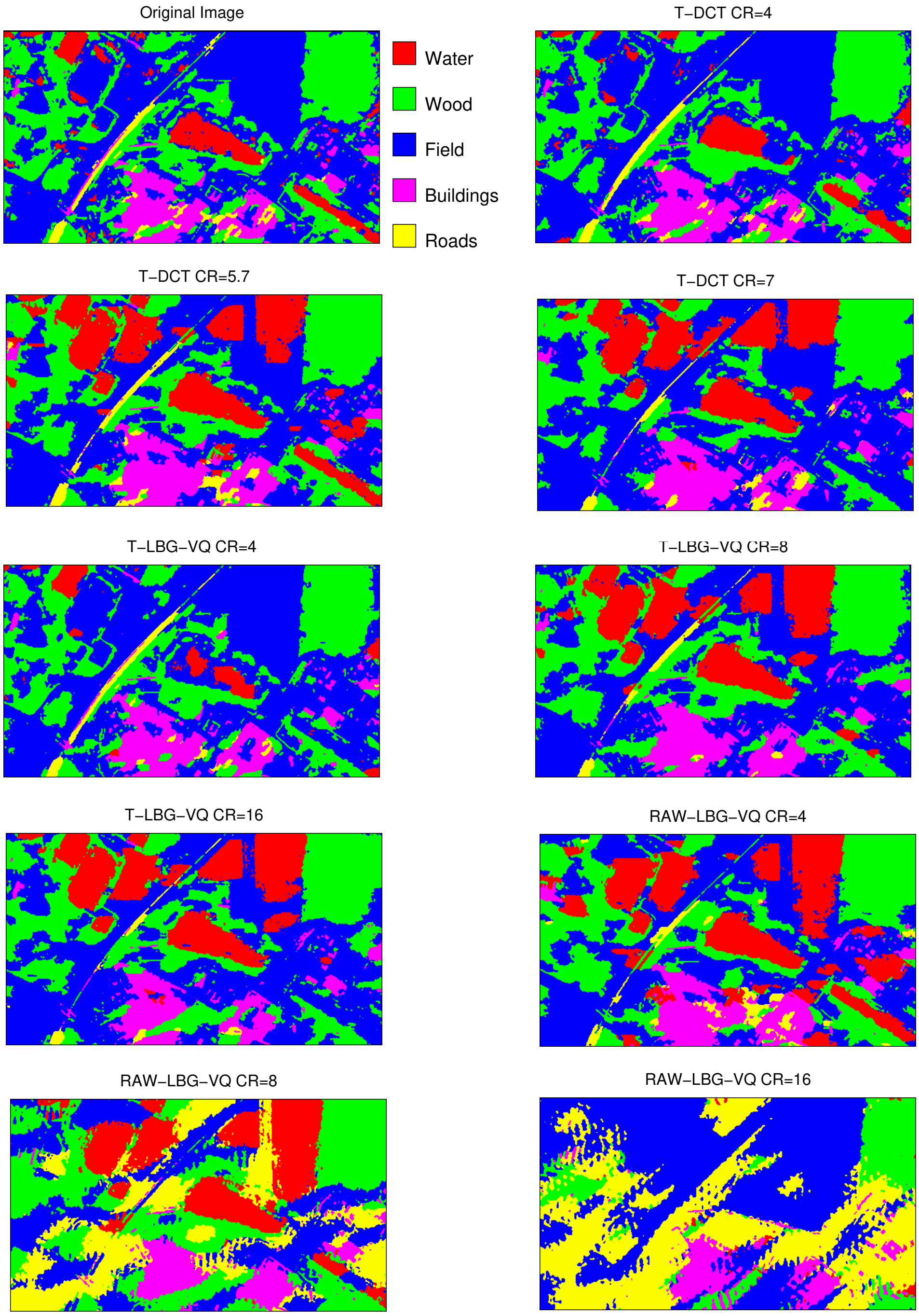

Figure 5: Segmentation Results Corresponding to Fig. 4

7.0 CONCLUSIONS

The aim of this paper was the assessment of a recently developed coding technique for SAR raw data. In this technique coding is applied to suitable transformed SAR raw data. The transform perform lossless. Both, lossless and lossy coding techniques have been applied to the transformed raw data. To assess the reconstructed SAR raw data the following objective criteria have been defined and calculated NMSE, SNR, PSNR, phase error $\Delta\overline{\phi}$, and entropy.

Data reduction has been achieved in two ways. In a first approach, the DCT with subsequent Huffman coding of the DCT coefficients, and in a second approach, the LBG vector quantisation have been applied to the transformed raw data. To evaluate the effciency of the transform T, the LBG-VQ has been applied directly to the SAR raw data, also.

An important result is, that the T-DCT and T-LBG-VQ, respectively, perform better up to a data rate of about 1.2 bit/sample than the RAW-LBG-VQ, if the quality of the processed images is considered. At lower data rates, the T-LBG-VQ always gets better results than the RAW-LBG-VQ. Subjective comparisons of the generated SAR images support the achieved assessment results. Moreover, the application of the segmentation algorithm gives much better results, if applied to the transformed data.

The direct compression of the SAR raw data provides an acceptable quality of the reconstruction (raw data and image data, respectively) only up to a data rate of 2 bit/sample. Higher compression is achievable only in case of transformed raw data as provided by T. T-LBG-VQ coding with 0.5 bit/sample results in a good image quality.

8.0 ACKNOWLEDGEMENTS

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