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# Demonstration of Rapid Frequency Selective Reconstruction for Image Resolution Enhancement

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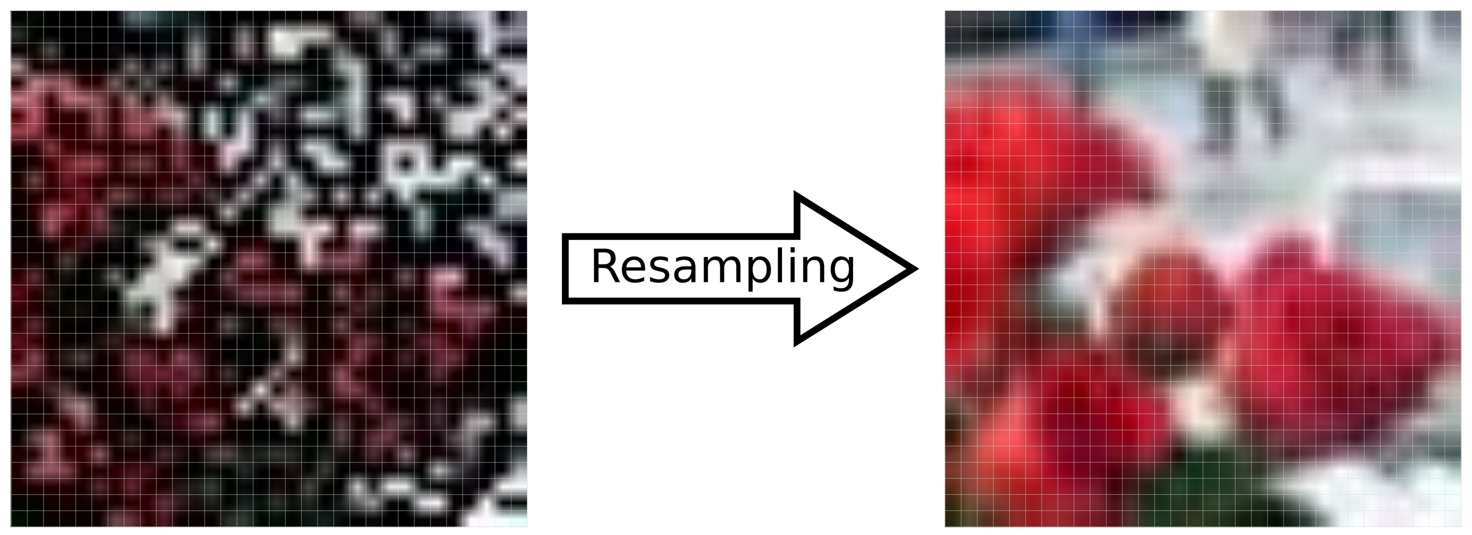
LMS

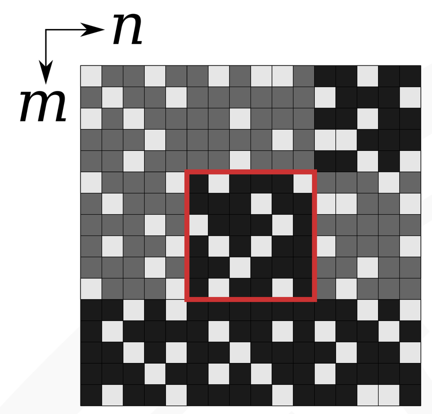
## 1. Motivation

- Many scenarios, where amplitude information of an image is not available on a regular, rectangular grid
  - Optical Cluster Eye
  - Micro-Optical Artificial Compound Eyes
  - Reducing visible influence of aliasing
  - Super-Resolution techniques [1]
- For further processing or displaying, a resampling to the full regular grid is required




## 2. Frequency Selective Reconstruction (FSR) [2]

- Iterative sparse model generation by superimposing weighted Fourier basis functions: $g[m,n] = \sum_{k \in \mathcal{K}} \hat{c}_k \varphi_k[m,n]$




- Spatial weighting function

$$w[m,n] = \begin{cases} \hat{\rho}^{\sqrt{\left(m-\frac{M-1}{2}\right)^2+\left(n-\frac{N-1}{2}\right)^2}} & , (m,n) \in \mathcal{A} \\ \delta\hat{\rho}^{\sqrt{\left(m-\frac{M-1}{2}\right)^2+\left(n-\frac{N-1}{2}\right)^2}} & , (m,n) \in \mathcal{R} \\ 0 & , (m,n) \in \mathcal{B}_i \cup \mathcal{B}_o \end{cases}$$

support area
reconstructed area
loss area

- Fixed frequency prior to favor low frequencies

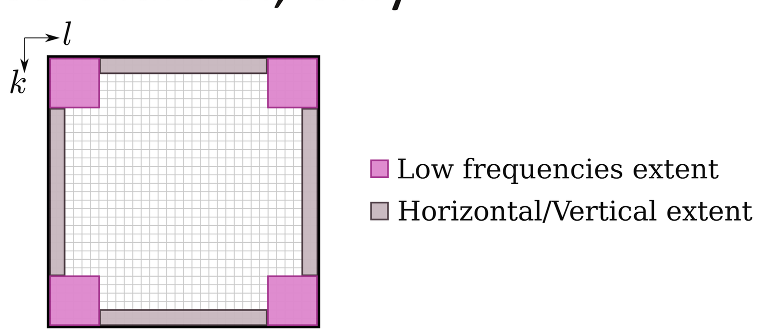
$$w_f[k,l] = \left(1 - \sqrt{2}\sqrt{\frac{\tilde{k}^2}{M^2} + \frac{\tilde{l}^2}{N^2}}\right)^2$$

→ Approximation of the Optical Transfer Function
→ Improved reconstruction quality

## 3. Demonstration

### Algorithmic Enhancements

- YUV color space dependent reconstruction [3]
  - Linear interpolation for chroma channels
  - FSR for luminance channel, only
- Restrict number and set of basis functions [4], [5]




- Real-valued, spectrally constrained model [6]
- Texture dependent block partitioning and parameter estimation [7]

### Software Optimizations

- C++ implementation using FFTW3 library
- Parallelization using OpenMP pragmas to make use of all processor cores
- Vectorization
  - Manual preparation of loops
    → Avoid control flows
  - GCC's autovectorization features and OpenMP's SIMD pragmas

### Test Systems

| **Notebook** | |
|---|---|
| CPU | i7-6700HQ |
| Speed | 2.60 GHz |
| Cores | 4 |
| RAM | 8 GB |
| **Xeon** | |
| CPU | 2 × Xeon E5-2630v4 |
| Speed | 2.20 GHz |
| Cores | 2 × 10 |
| RAM | 32 GB |

## 4. Conclusion

Reconstruction quality in dB PSNR for different subsampling densities (TECNICK)

| | 5% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FSR | **27.03** | **29.69** | **32.83** | **34.94** | **36.66** | **38.23** | **39.79** | **41.50** | **43.59** | **46.75** | **49.55** |
| SKR | 16.69 | 28.11 | 31.81 | 33.23 | 34.29 | 35.30 | 36.41 | 37.75 | 39.55 | 42.55 | 45.42 |
| CLS | 24.82 | 26.94 | 29.85 | 32.06 | 34.03 | 35.92 | 37.87 | 40.01 | 42.58 | 46.28 | 49.37 |
| SI | 24.30 | 27.17 | 30.87 | 33.31 | 35.33 | 37.16 | 38.98 | 40.93 | 43.23 | 46.60 | 49.46 |

SKR: Steering Kernel Regression, CLS: Constrained Split Augmented Lagrangian Shrinkage Algorithm, SI: Sparse Wavelet Inpainting

- FSR well suited for image reconstruction problems
- Visually noticeable gains of several dB PSNR compared to other state-of-the-art algorithms
- Acceleration of the reconstruction process by
  → Reducing the number of basis functions
  → Lowering the required set of basis functions
  → Texture dependent block partitioning
  → Partitioning based parameter estimation
  → Setting up a real-valued, spectrally constrained model
  → Software optimizations

Accelerated reconstruction process:
→ 15 fps using test system Notebook
→ 25 fps for test system Xeon

Reference implementation:

## References

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[2] J. Seiler, M. Jonscher, M. Schöberl, and A. Kaup, "Resampling images to a regular grid from a non-regular subset of pixel positions using frequency selective reconstruction," *IEEE Transactions on Image Processing*, vol. 24, no. 11, pp. 4540–4555, Nov. 2015.

[3] M. Bätz, A. Eichenseer, M. Jonscher, J. Seiler, and A. Kaup, "Accelerated hybrid image reconstruction for non-regular sampling color sensors," in *Proc. IEEE International Conference on Visual Communications and Image Processing*, Dec. 2014, pp. 217–220.

[4] N. Genser, J. Seiler, and A. Kaup, "Local statistics estimation for rapid frequency selective extrapolation," in *Proc. 2017 International Conference on Systems, Signals and Image Processing*, May 2017, pp. 1–5.

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[6] N. Genser, J. Seiler, F. Schilling, and A. Kaup, "Signal and loss geometry aware frequency selective extrapolation for error concealment," in *Proc. Picture Coding Symposium*, 2018.

[7] N. Genser, J. Seiler, and A. Kaup, "Spectral constrained frequency selective extrapolation for rapid image error concealment," in *Proc. 25th International Conference on Systems, Signals and Image Processing*, 2018.