

Halftone QR Codes



Hung-Kuo Chu



Chia-Sheng Chang



Ruen-Rone Lee



Niloy J. Mitra



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National Tsing Hua University, Taiwan



University College London



What is QR code® ?

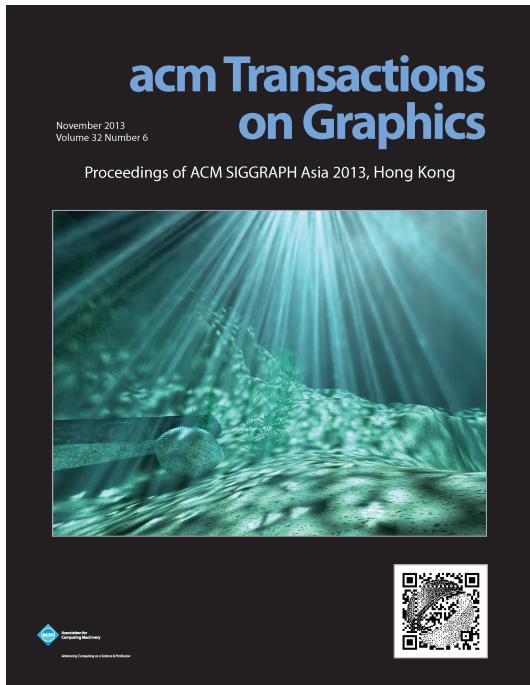
Quick Response Code



- Denso Wave, 1994
 - Automotive industry
- 2D matrix barcode
 - Black/white squares (modules)
- Massive storage capacity
 - 1,817(Kanji) ~ 7,089 (Numeric)
- Error correction capability
- Fast readability



Marketing and Advertisements



Motivations



- Black/white squares are clutter and boring
- Users are blind to the encoded content
- Require additional visual/text contents



Visual QR Codes



- Incorporate high-level visual features
 - Add color, smooth corners
 - Embed logo, figure...etc



Image courtesy : [flickr OR code Art](#)

Challenges

- **Visual quality**
 - High fidelity to integrated image
 - High visual acuity at various viewing distances
- **Machine readability**
 - Stability: Lighting conditions, camera specifications, etc.
 - Patented and ill-documented barcode readers
 - Reading QR code is not redundant

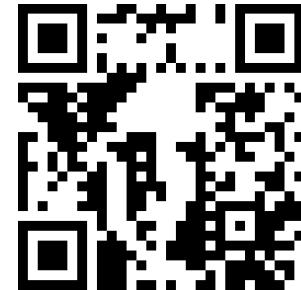
Related Works

Encoding-based Approach

- Inbuilt error correcting capability
- Modify encoding algorithm
- Visual quality
 - Dependent on the QR code setting
 - Little or no user control
- Machine readability
 - Trial-and-error style validation



[Unitag]



[QArt Codes]



[Lin et al., PG'13]



[Lin et al., IEEE TMM'13]

Appearance-based Approach

- Blend image with QR code modules
- Visual quality
 - Sensitive to the appearance of QR code
 - Corruption in the salient image features
 - Little or no user control
- Machine readability
 - Trial-and-error style validation



[[Visualead](#)]

Halftone QR Codes



- A new representation that
 - minimally binds to modules; and
 - is flexible to adapt to halftone image
 - encodes module's appearance using a set of *binary patterns*
- Machine readability
 - Pattern reliability
 - Controllable level of readability
- Allow user intervention



High Fidelity and Acuity

[[Halftone QR code](#)]



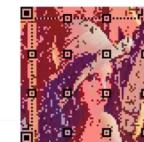
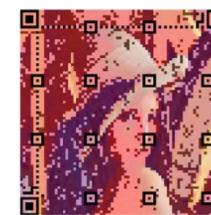
[[Visualead](#)]



[[Unitag](#)]



[[Lin et al., IEEE TMM'13](#)]



Stable Visual Quality

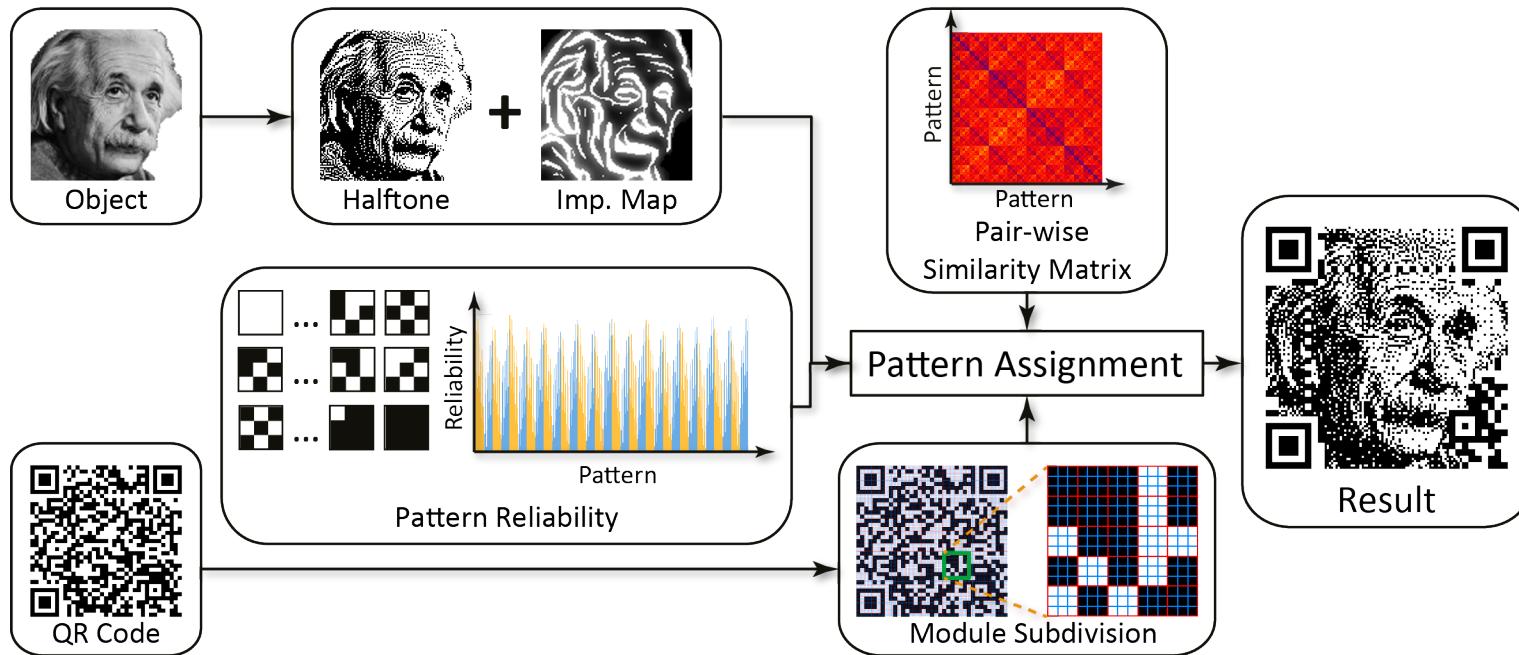


[[Halftone QR code](#)]

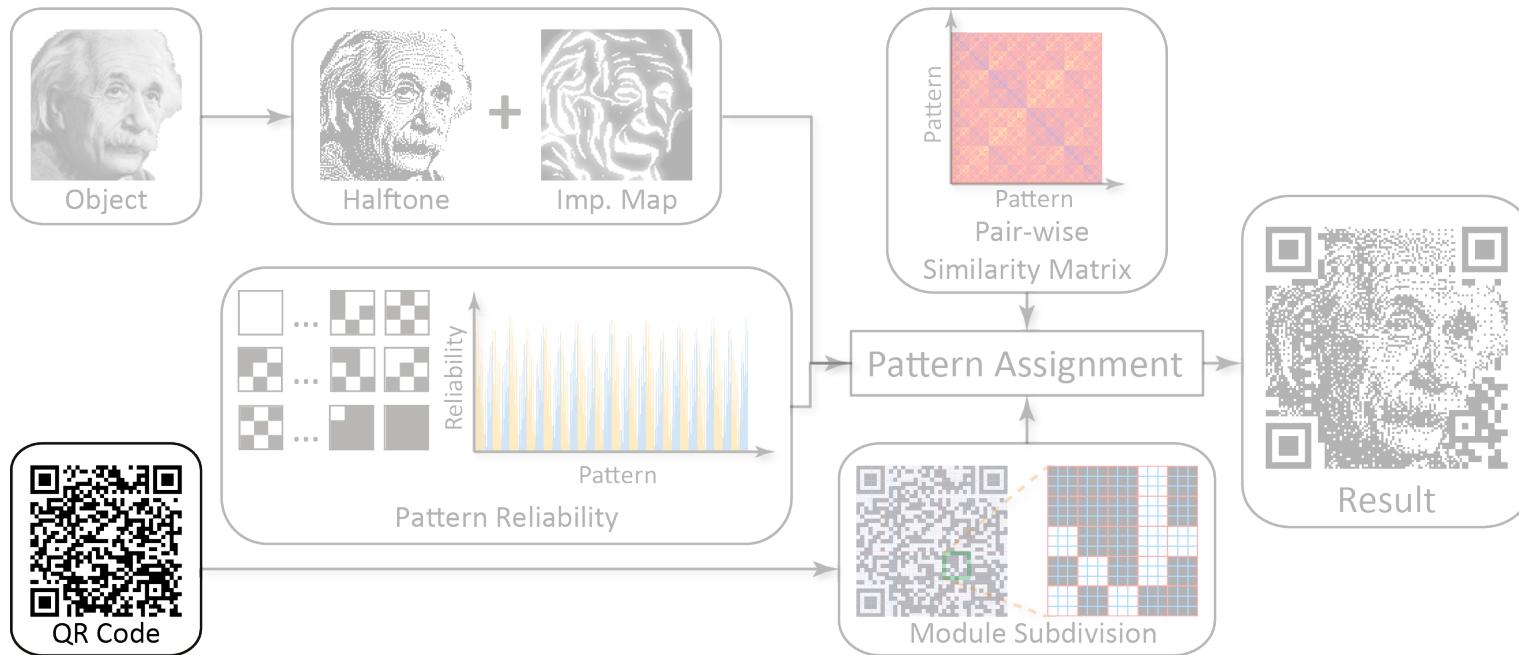


[[Visualead](#)]

System Overview



QR Code® Specification



Modules and Appearance

- Black/white modules
- Different encoded data

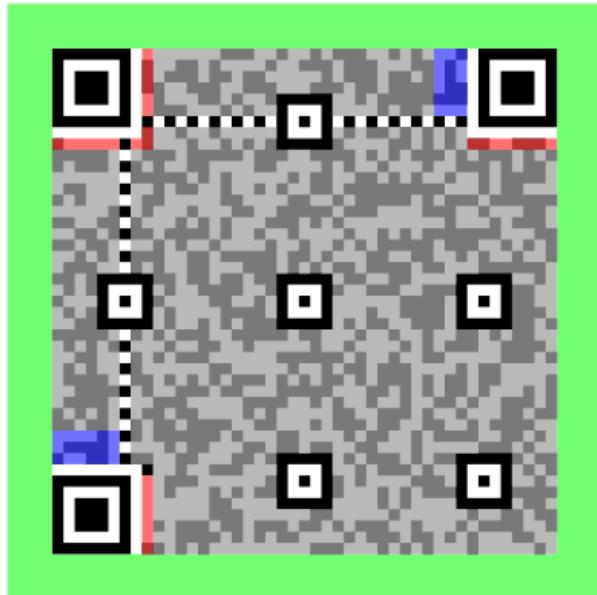


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Structure



- 1. Version information
- 2. Format information
- 3. Data and error correction keys
- 4. Required patterns
 - 4.1. Position
 - 4.2. Alignment
 - 4.3. Timing
- 5. Quiet zone

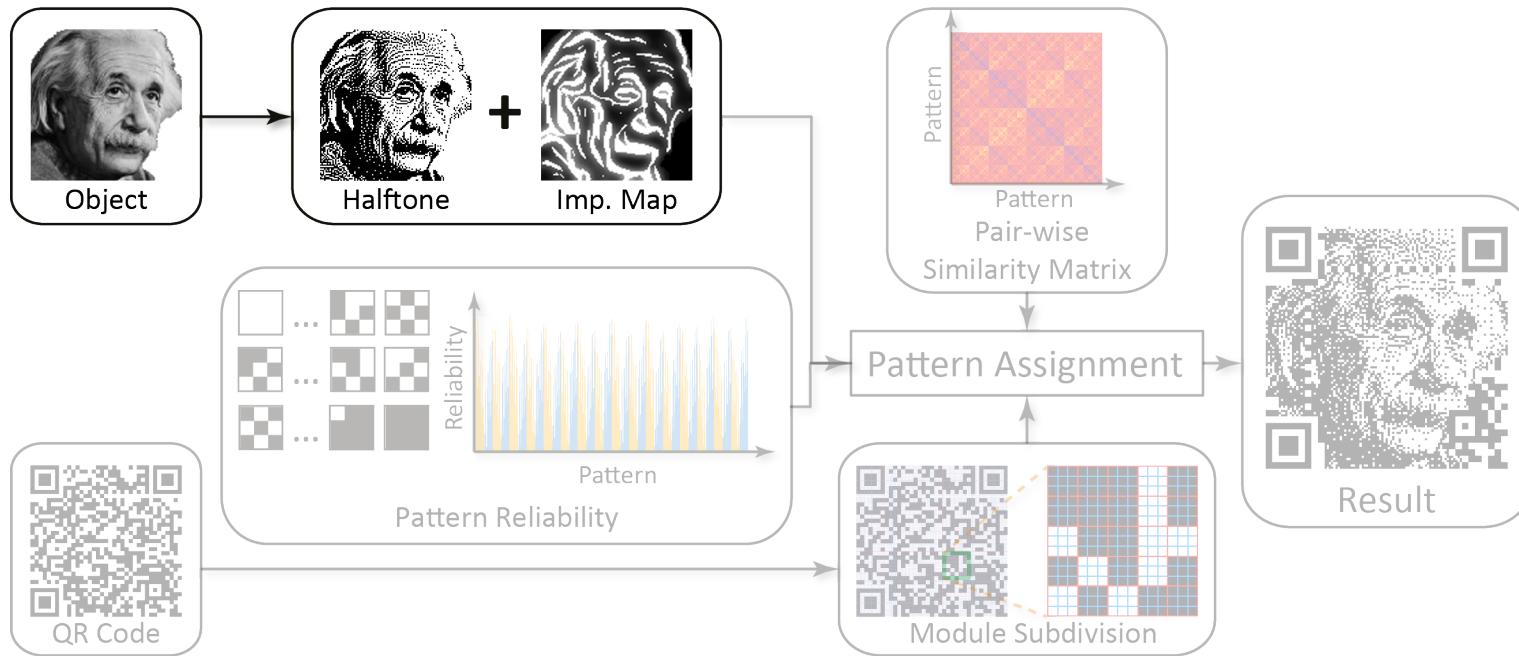
Version and Size



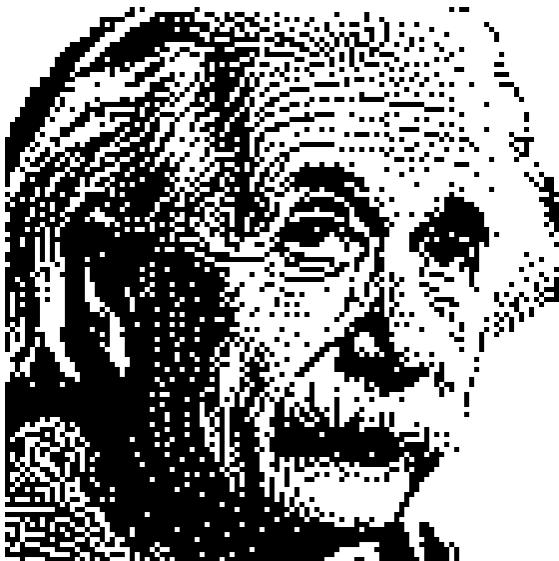
...



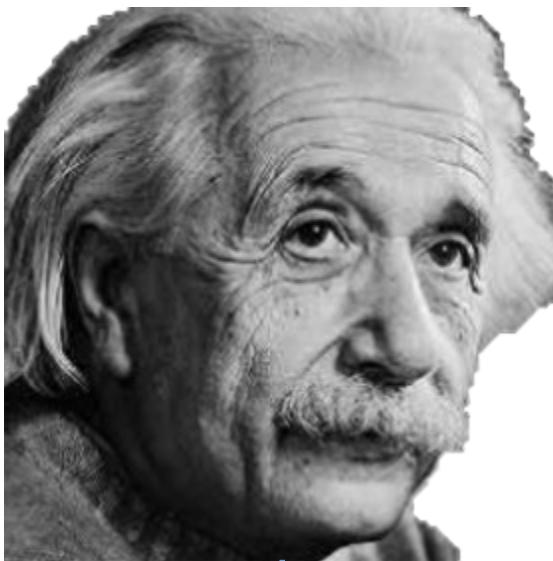
Input Image



Halftone and Importance Map



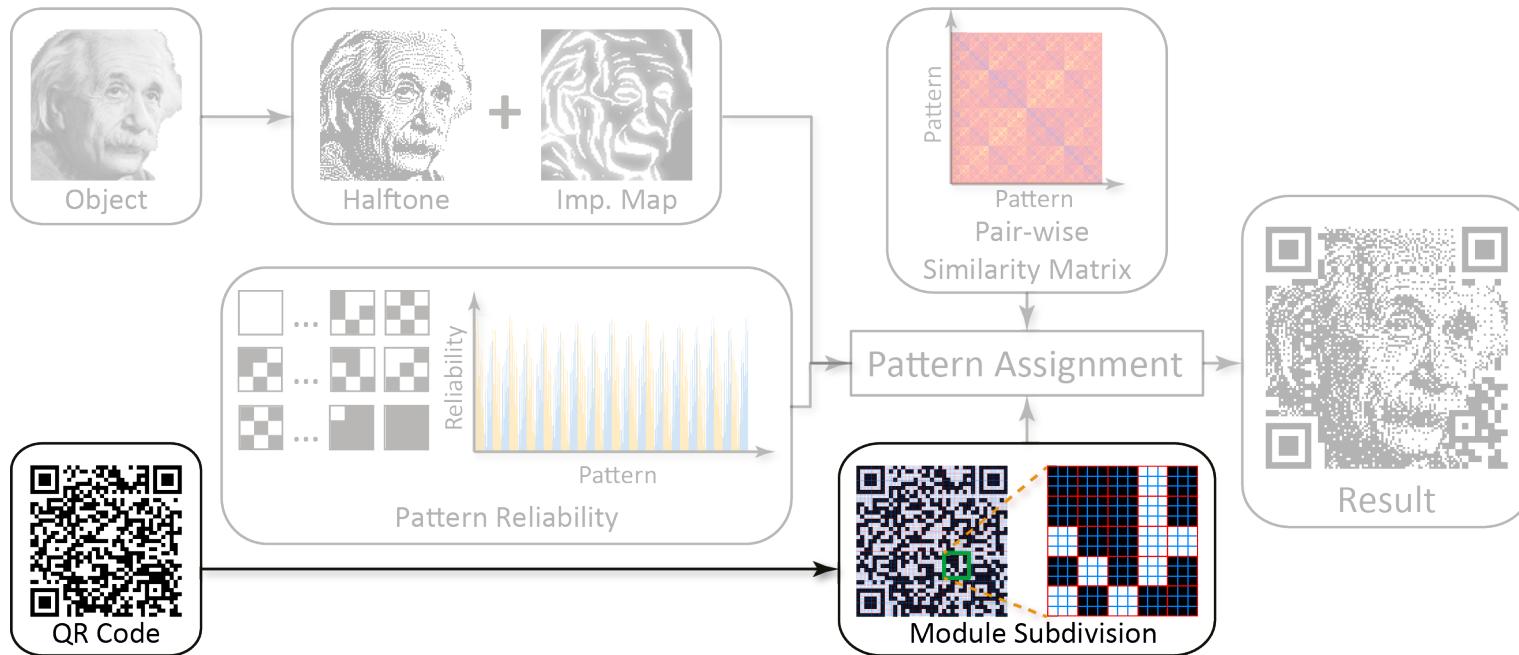
“Structure-aware error diffusion”
[Chang et al. 2009]



“Image abstraction by
structure adaptive filtering.”
[Kyprianidis and Döllner 2008]

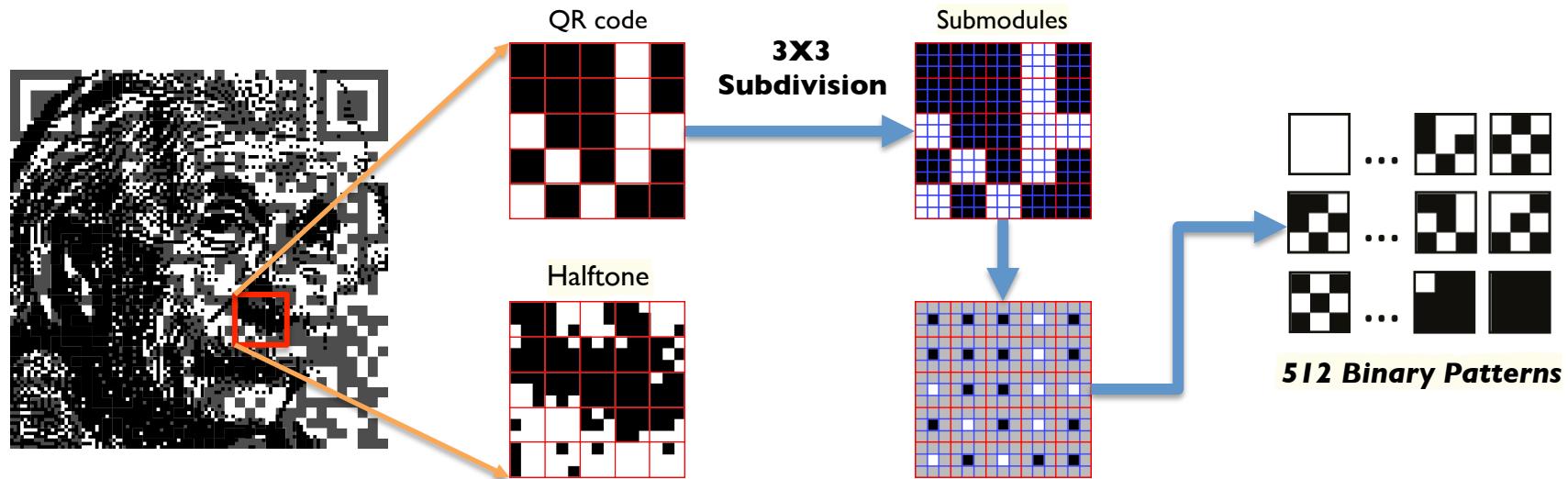


Module Subdivision

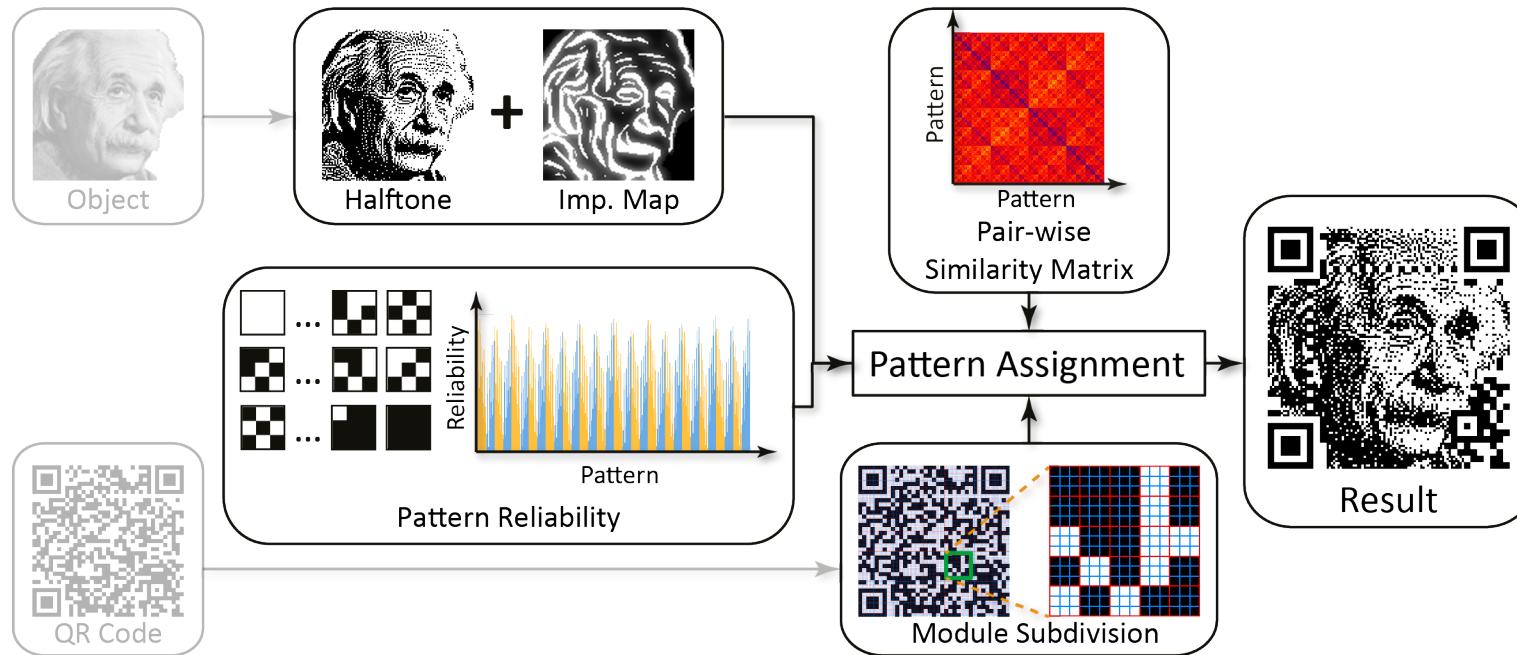


New Representation Model

- Minimally bind to the original module
- Flexible to adopt to underlying halftone patterns



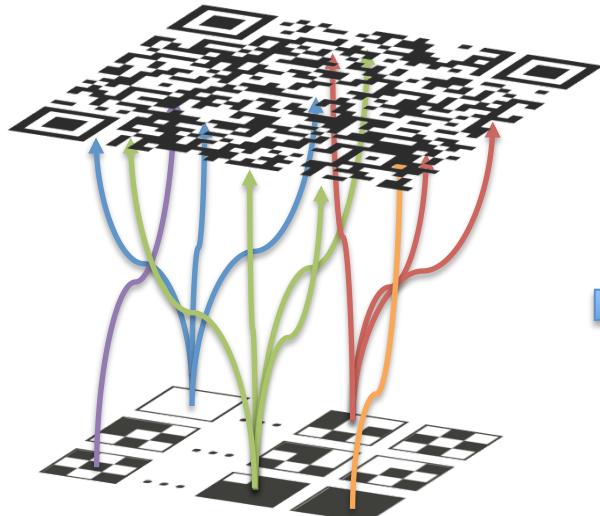
Synthesis



Pattern Assignment

Reliability

Maximize readability



512 Binary Patterns

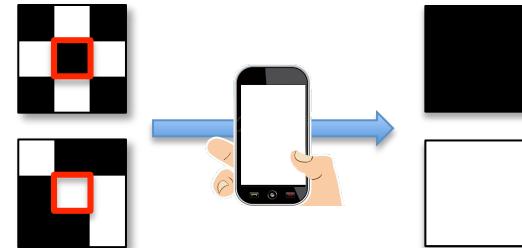
Regularization

Similarity to halftone image



Reliability Energy

- Pattern reliability r_i ([0, 1.0])
 - How likely a pattern is decoded to what it supposes to be ?
- Prefer the assignment of patterns with higher reliability



$$E_R(P') = \sum_{m_i \in M} \exp(-w_i) (1.0 - R(m_i, p'_i))$$

importance weight

The assigned pattern

$$R(m_i, p'_i) = \begin{cases} r_{f(i)} & \text{if } c_{f(i)}^p = c_i^m \\ 0 & \text{otherwise.} \end{cases}$$

Binding check

Regularization Energy



- Module-wise image difference between the synthesized QR code and target halftone
- Distance metric: $D(\cdot, \cdot)$
 - Structural Similarity Index Measure (SSIM) [Wang et al. 2004]
- Pre-computation of pattern similarity

$$E_G(P') = \sum_{m_i \in V} D(I_i^m, I_{f(i)}^p) + w_s \sum_{e_{ij} \in E} \exp(-D(I_i^m, I_j^m)) D(I_{f(i)}^p, I_{f(j)}^p)$$

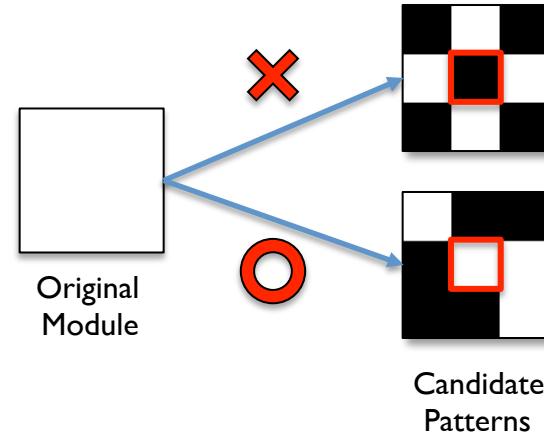
Data term Favoring the smoothness between 4-connected neighboring modules

Binding Constraint

- Ensure the data of original modules are retained
- Penalize the assignment of patterns with wrong color

$$E_C(P') = \sum_{m_i \in M} \beta \delta_{m_i, p'_i}$$

$$\delta_{m_i, p'_i} = \begin{cases} 1 & \text{if } c_{f(i)}^p \neq c_i^m \\ 0 & \text{otherwise.} \end{cases}$$



Optimization



- Total energy

$$E_{total}(P') = \lambda E_R(P') + E_G(P') + E_C(P')$$

- λ is used to control the level of readability according to the performance of different barcode readers
 - See Experiment II
- Multi-label graph cut algorithm [Boykov et al.2001]

Pattern Reliability Evaluation



- Ideally, the binding constraint ensures the 100% readability
- In reality, the readability of QR code easily gets affected by various factors:
 - Poor lighting condition, poor camera resolution, spatial perturbation...etc.
- **Pattern reliability**
 - Probability of retaining the module's readability by the pattern substitution

Synthetic QR Code Database

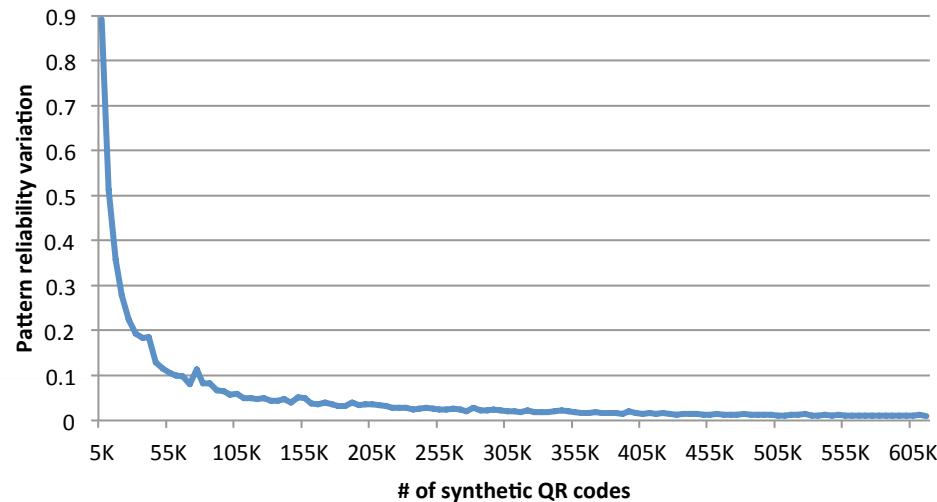
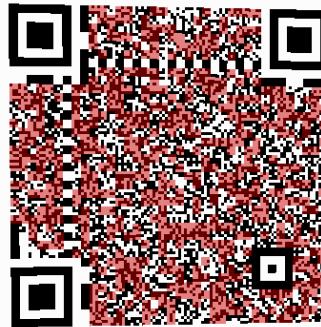


- Generate massive QR codes
 - Using random data strings
 - Replace modules with random binary patterns that adhere binding constraint
- Apply random perturbations
 - Mimic scenarios of scanning a code in reality
 - Scanning at non-frontal orientations
 - Scanning at different distances



Probability Evaluation

- Batch decode synthetic QR codes in database
 - Using an open source barcode reader, ZBar [Brown 2007]
- Calculate pattern reliability as a ratio of number of successful decodes among all samples in database



Enhancement

- Utilize the error correction capability
- User draws strokes on critical regions
- Iteratively remove binding constraint from modules



Results













Demo

Validation

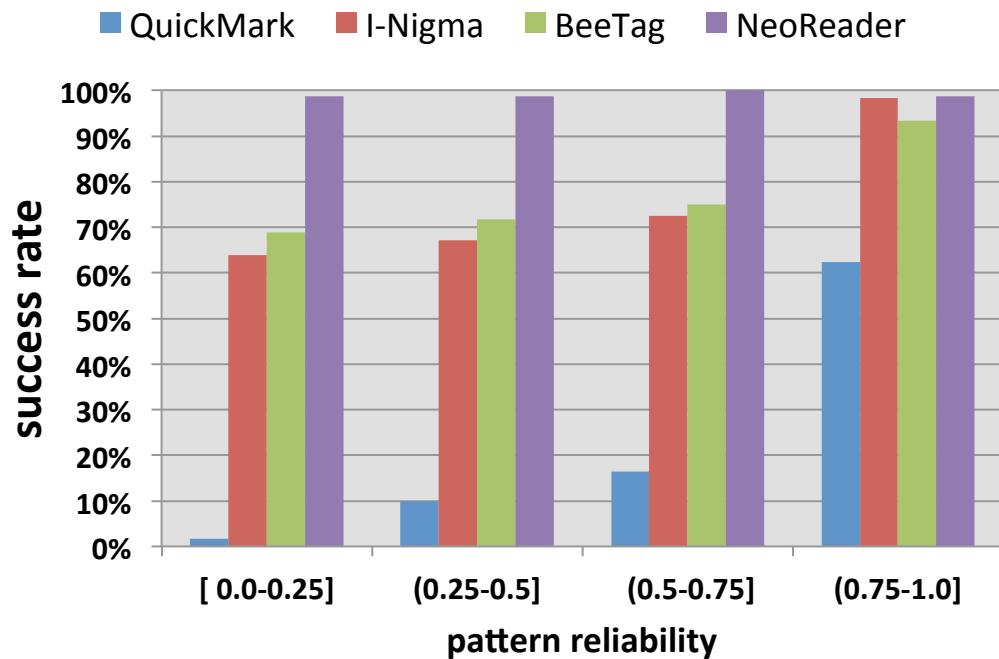
Manual Scan Setting



- A smart phone device
 - 8-megapixels camera
 - 4 barcode readers
- One QR code per trial
 - User scans the code using the smart phone;
 - puts down the device before starting the next trial
- Successful scan
 - The reader responses within 3 seconds.

Exp. I: Pattern Reliability

- 4 intervals of reliability
- 4 groups of patterns
- 60 synthetic QR codes for each group
- Each code is scanned by three users



Exp. II: Level of Readability

- Generate 100 results using $\lambda = 0$, and run the manual scan
- For the results which failed in one or more barcode readers:
 - Regenerate results using another two values, $\lambda=0.3$ and $\lambda=0.6$



$\lambda=0.0$

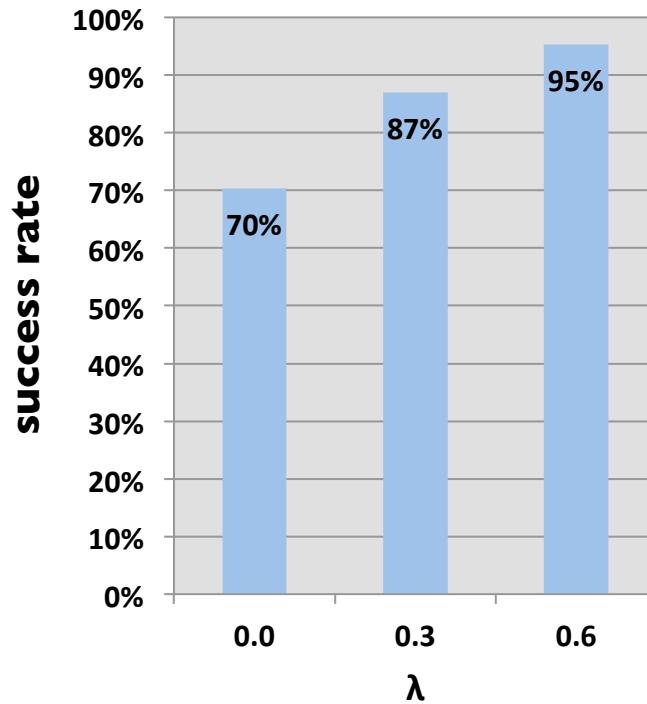


$\lambda=0.3$



$\lambda=0.6$

Exp. II: Statistics



Exp. III: Sensitivity of Readability



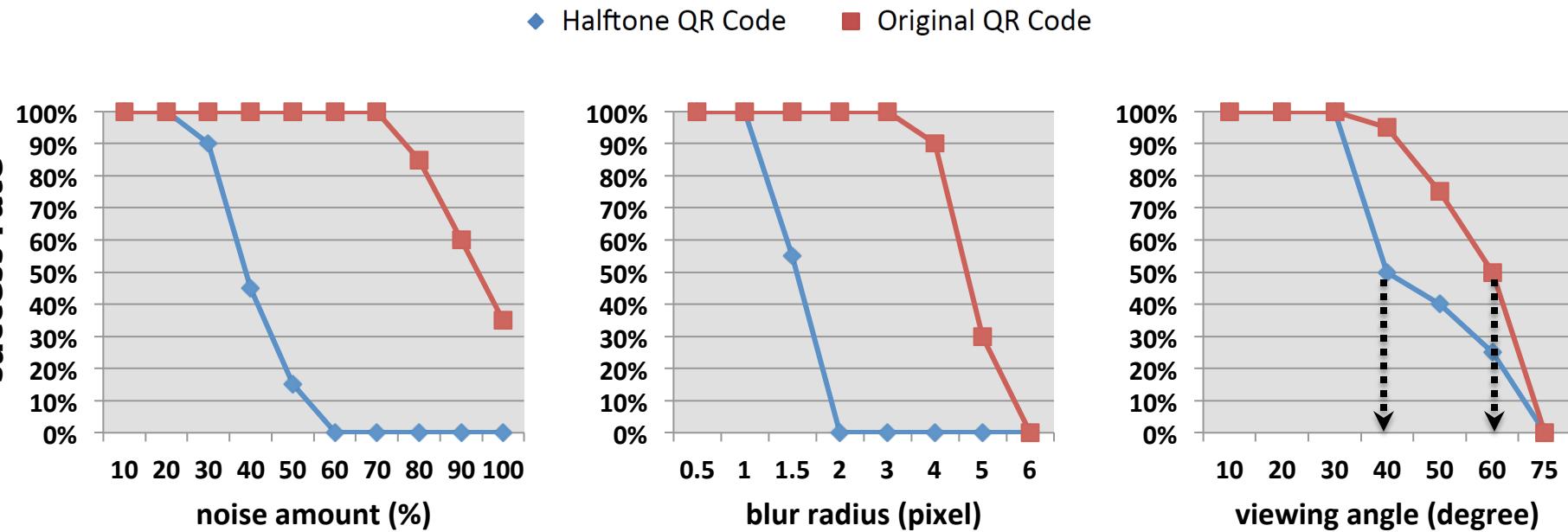
- 5 random results and original QR codes
- Apply various image distortions
 - Gaussian noise
 - Gaussian blur
 - Scanning at tilted angle



Exp. III: Statistics



success rate



Extension: Animated Halftone QR Codes

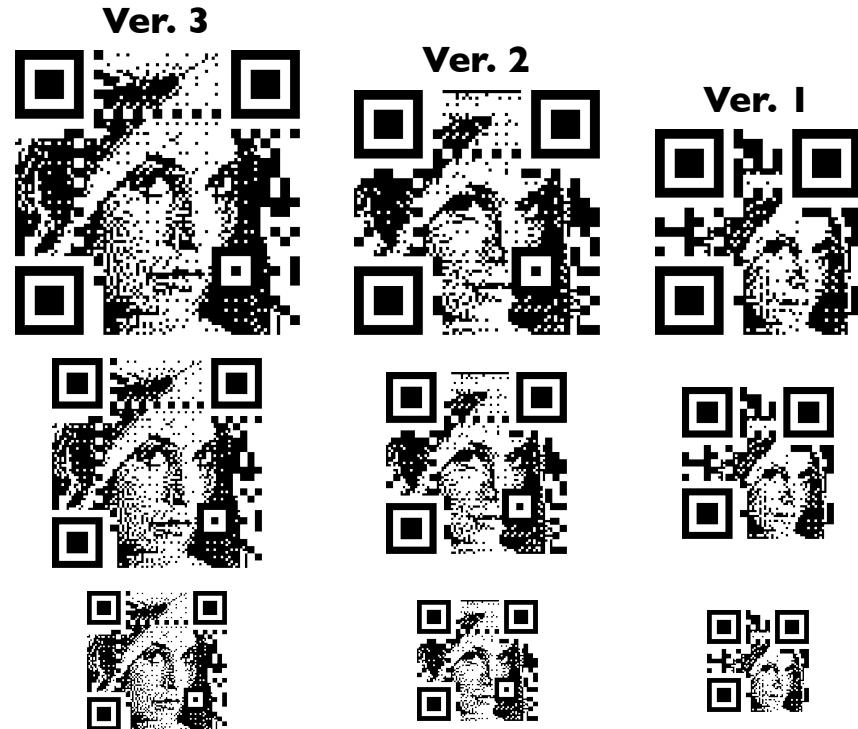


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Limitations

- The quality is restricted by image resolution
 - Resolution of input image
 - Size of QR code
- Readability is sensitive to image blurring
 - Damage to the center submodule



Conclusion and Future Work

- A new type of visual QR code
 - Halftone QR code
 - High visual quality and fidelity
- An automatic algorithm
 - Synthesize halftone QR code
 - Readability level control
- Future works
 - Color halftone
 - Gray scale image
 - Color image



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- Gerardo Figueroa for video/FastForward narration
- Luis Sousa for the panda photo

Supplemental Materials



- [Project webpage](#)
- More results and paper video
- User study images
- Stand alone generator (Windows)
- Online generator
- Coming soon...
 - Source codes (non-commercial usage)
 - Generator for mobile (Android, iOS)

Thanks for your attention!

