STYROFOAM

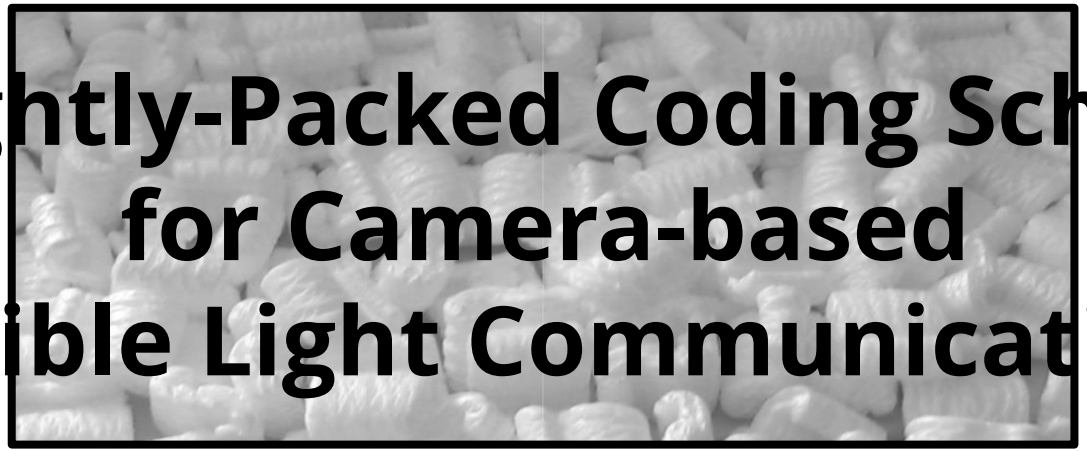
Robert LiKamWa, David Ramirez, Jason Holloway

Advisors: Lin Zhong, Behnaam Aazhang, Ashok Veeraraghavan

Rice University

STYROFOAM

A Tightly-Packed Coding Scheme for Camera-based Visible Light Communication



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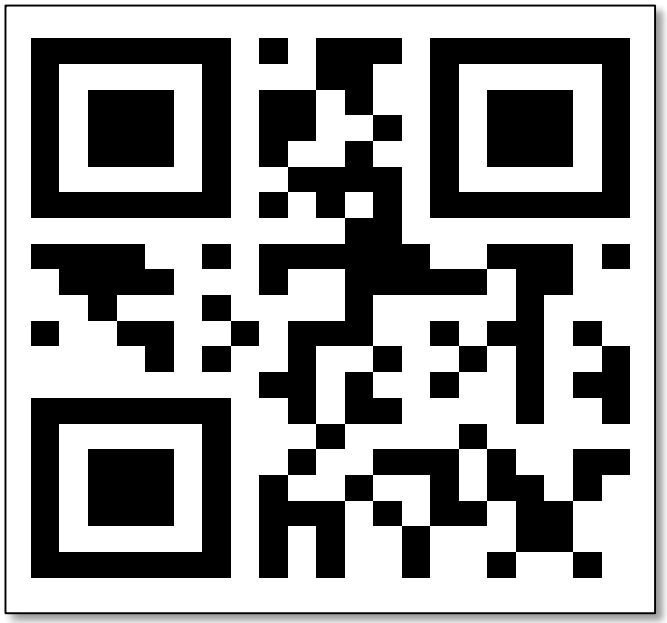
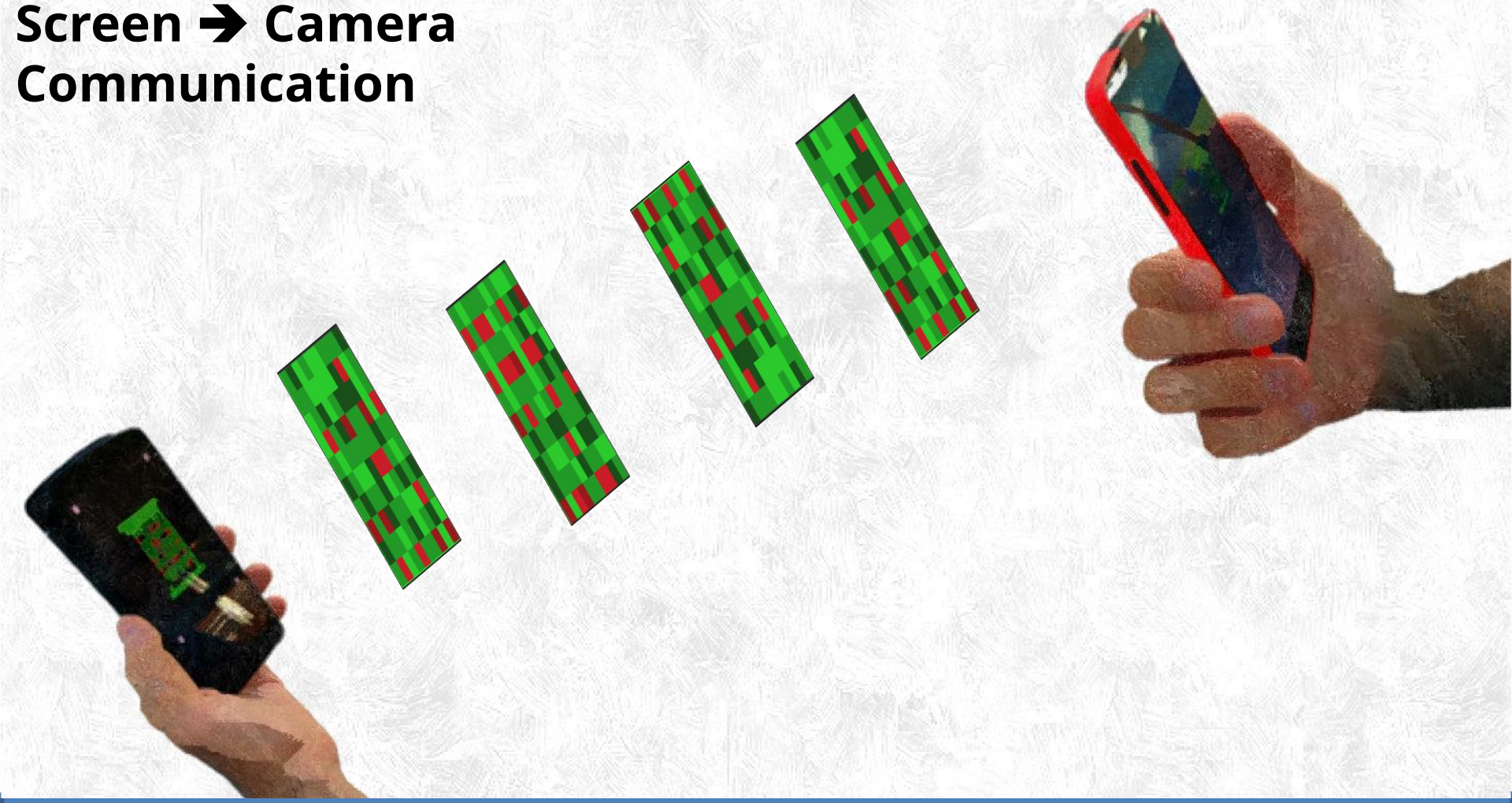
Screen → Camera Communication

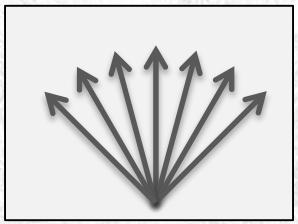


Screen ➔ Camera Communication

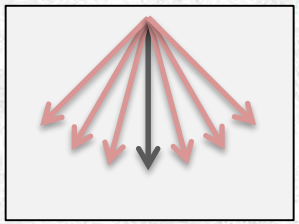


Benefits

Pairless infrastructure



Multi-cast transmission



Targeted interaction

Device-Specific Broadcast

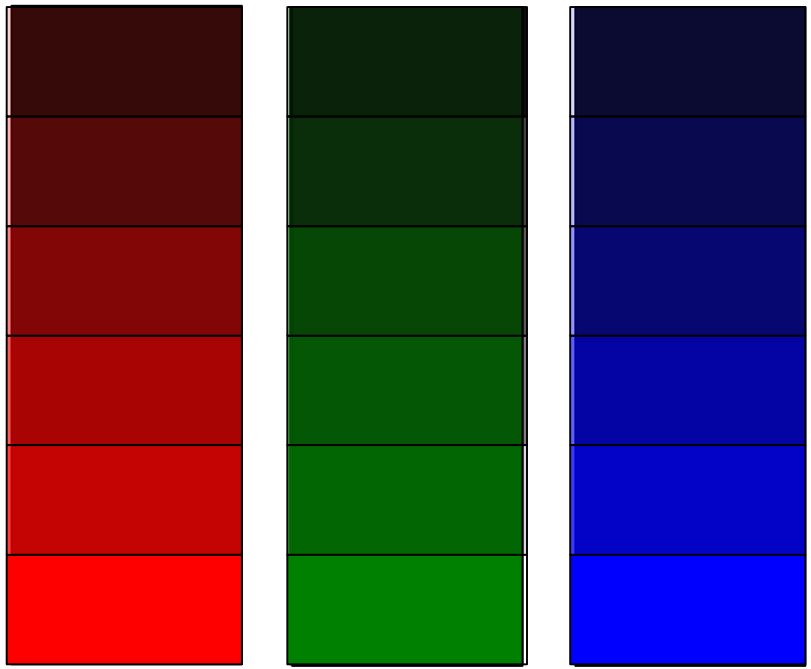
Easy Access Media

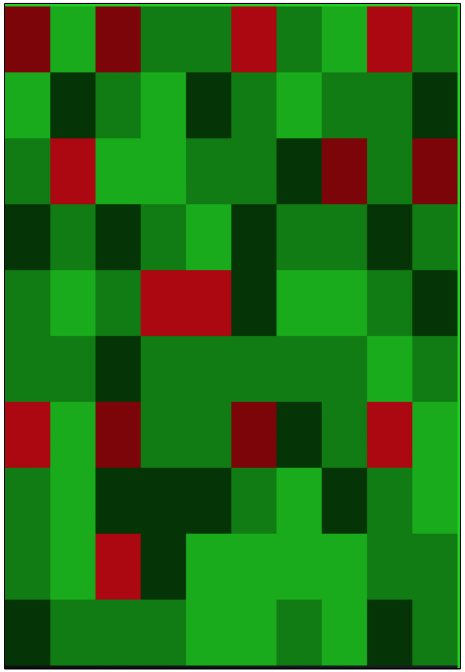
Wearable Transmissions

Use Cases

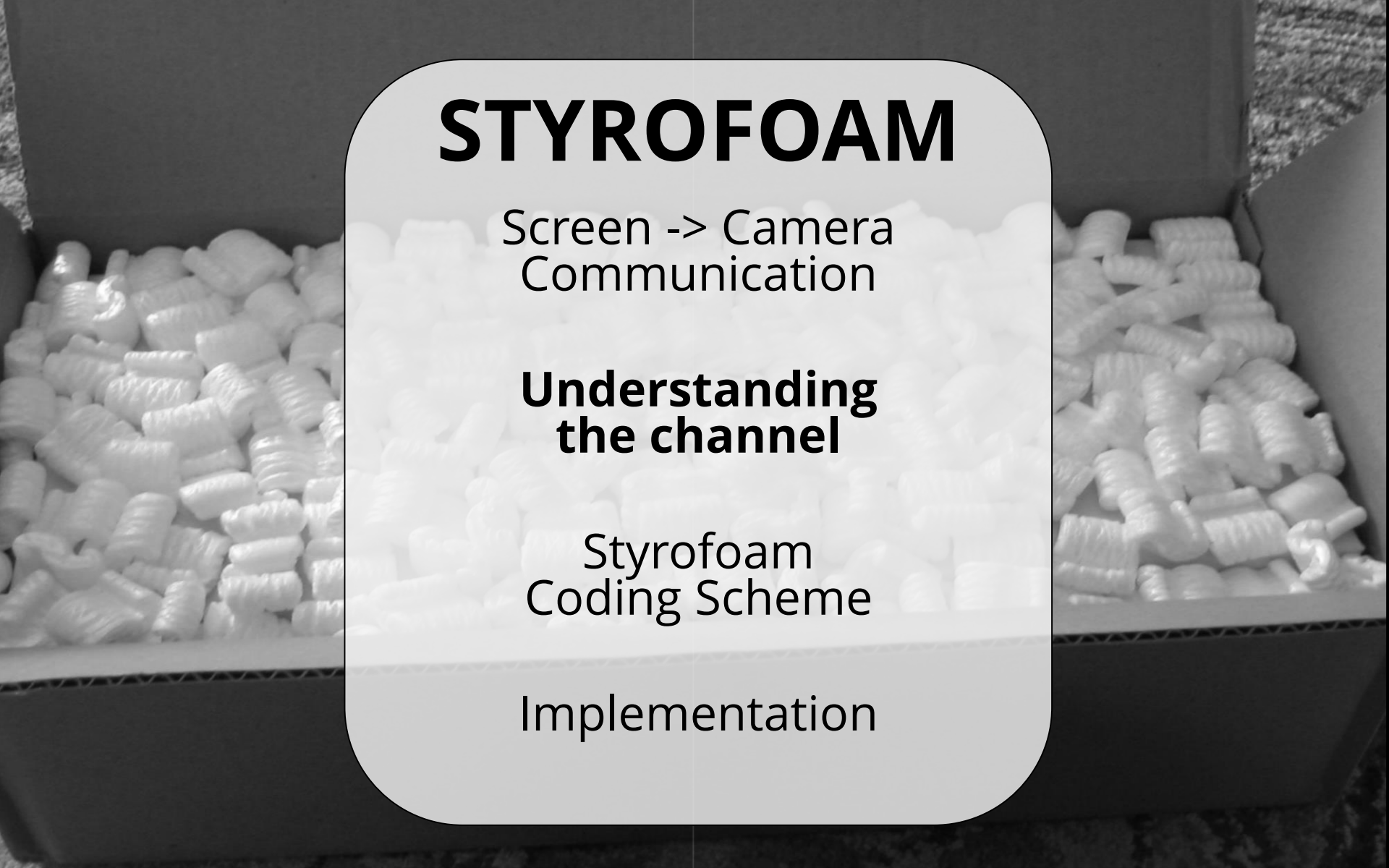
Camera-based VLC Research Challenges

- Efficient Marker Tracking (COBRA)
- Blur-aware Ordering (COBRA)
- Unsync'ed Camera/Screen rates (LightSync)
- Increasing block bit-depth (Styrofoam)





- Increasing block bit-depth (Styrofoam)



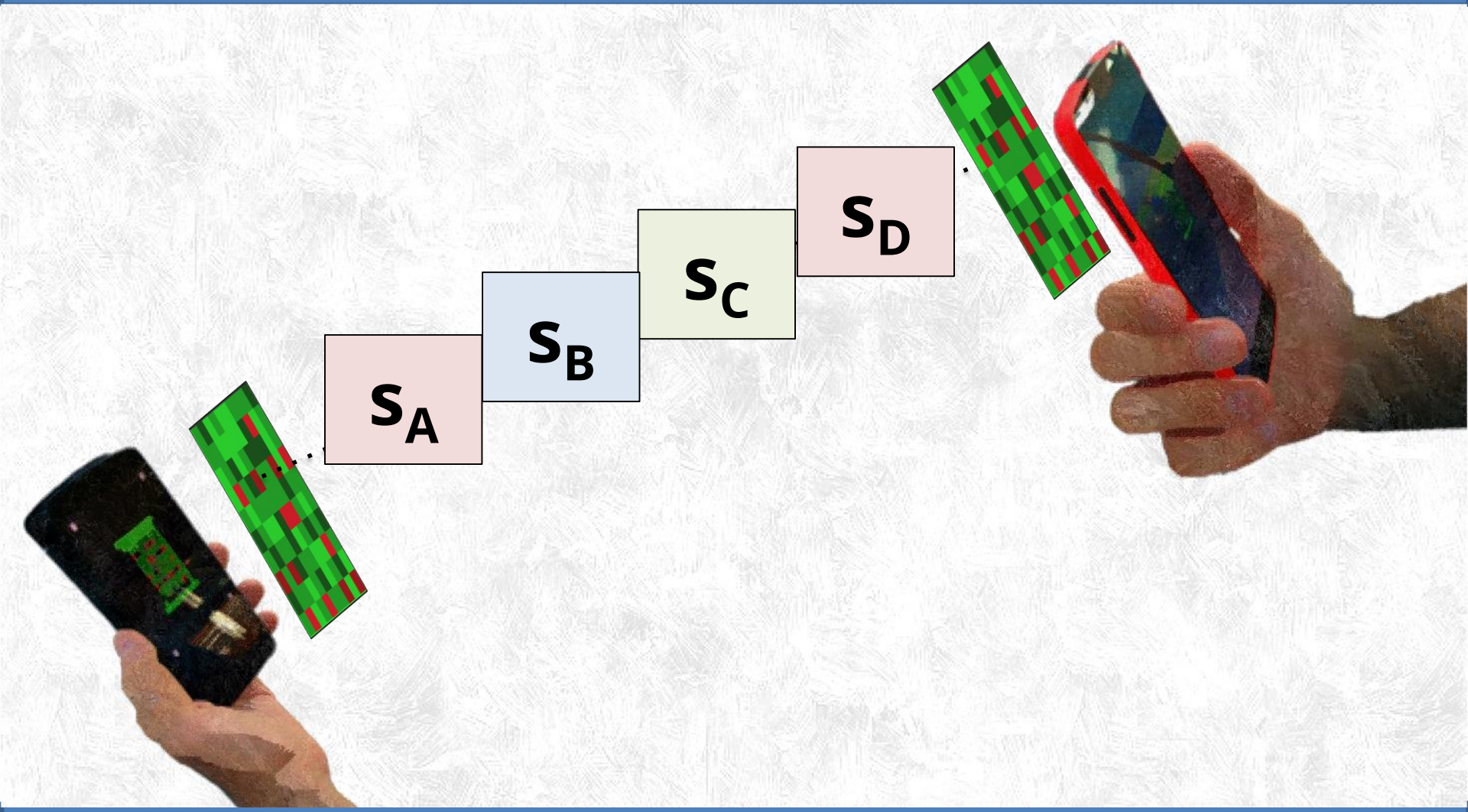
STYROFOAM

Screen -> Camera
Communication

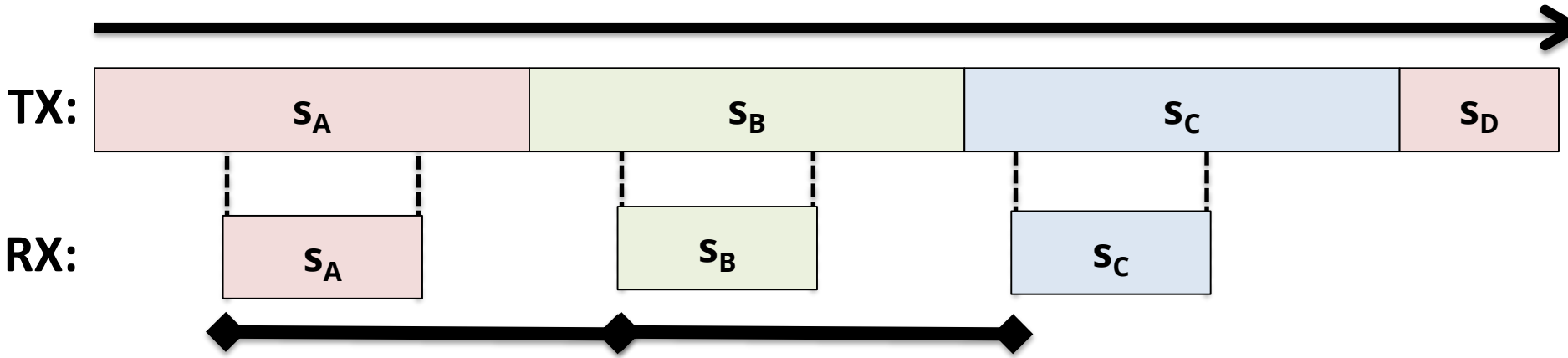
Understanding the channel

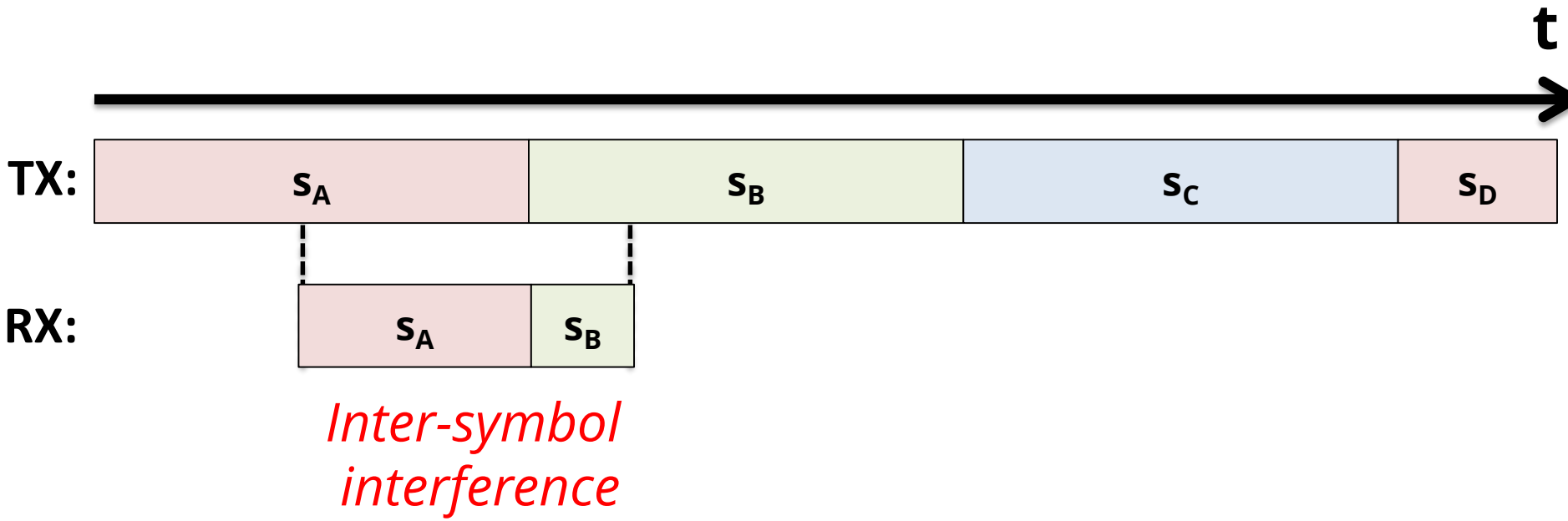
Styrofoam
Coding Scheme

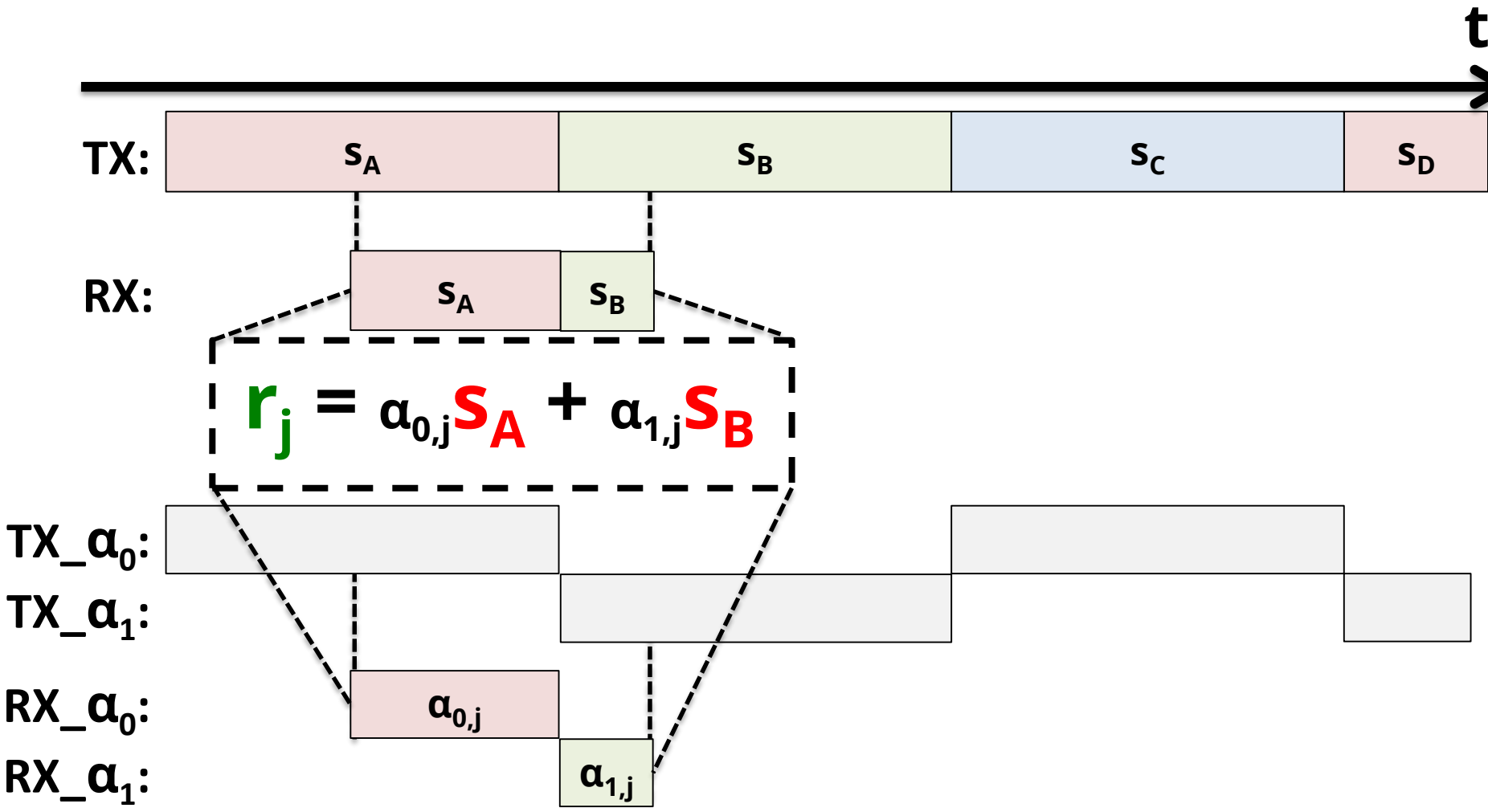
Implementation

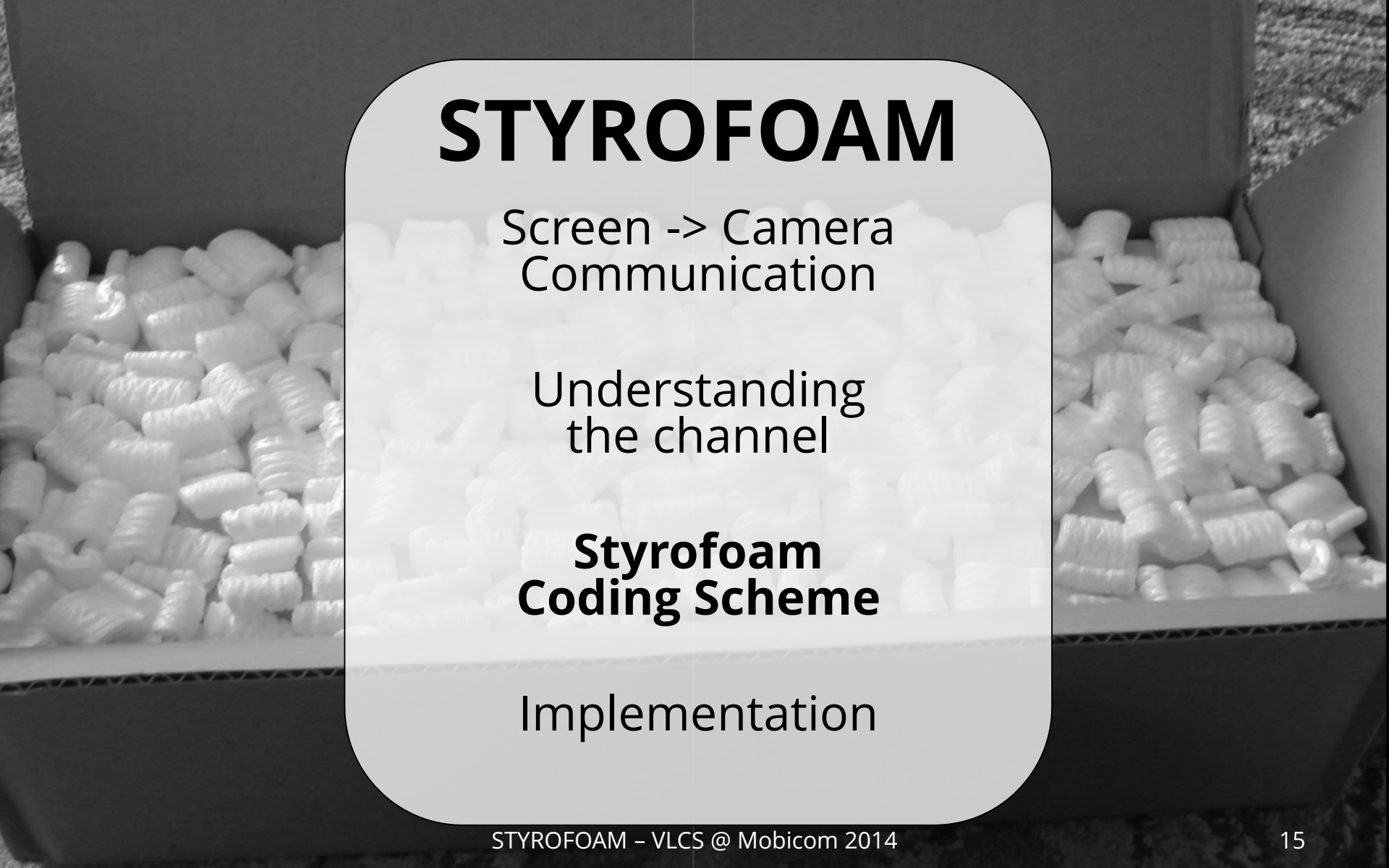

s_A
s_B
s_C
s_D

TX:


TX:
s_A
s_B
s_C
s_D
RX:
s_A
s_B
s_C


t
TX:
s_A
s_B
s_C
s_D
RX:
s_A
s_B
Inter-symbol interference


t
TX:
s_A
s_B
s_C
s_D
RX:
s_A
s_B
$r_j = \alpha_{0,j} s_A + \alpha_{1,j} s_B$
TX_α_0:
TX_α_1:
RX_α_0:
$\alpha_{0,j}$
RX_α_1:
$\alpha_{1,j}$



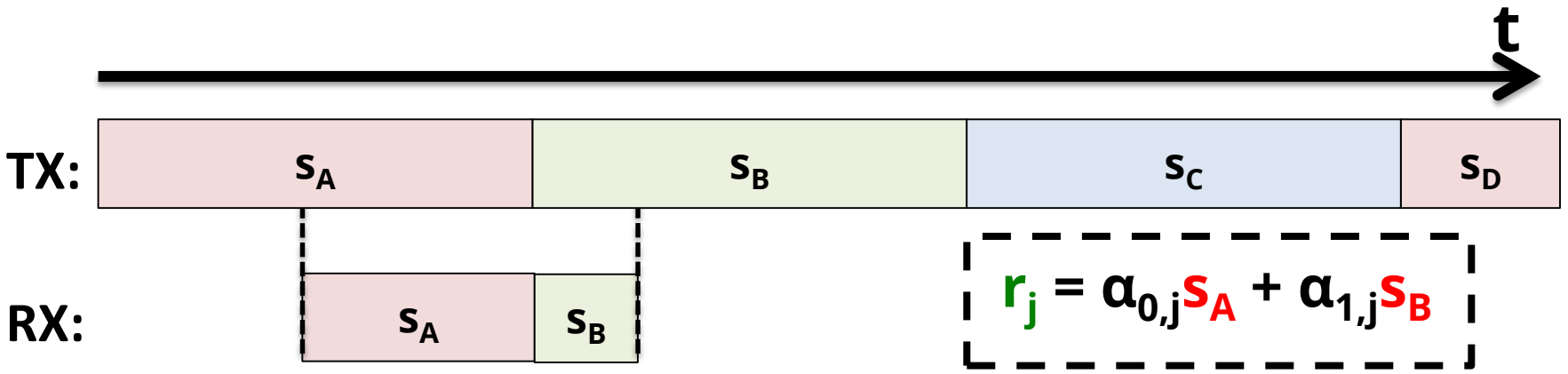
STYROFOAM

Screen -> Camera Communication

Understanding the channel

Styrofoam Coding Scheme

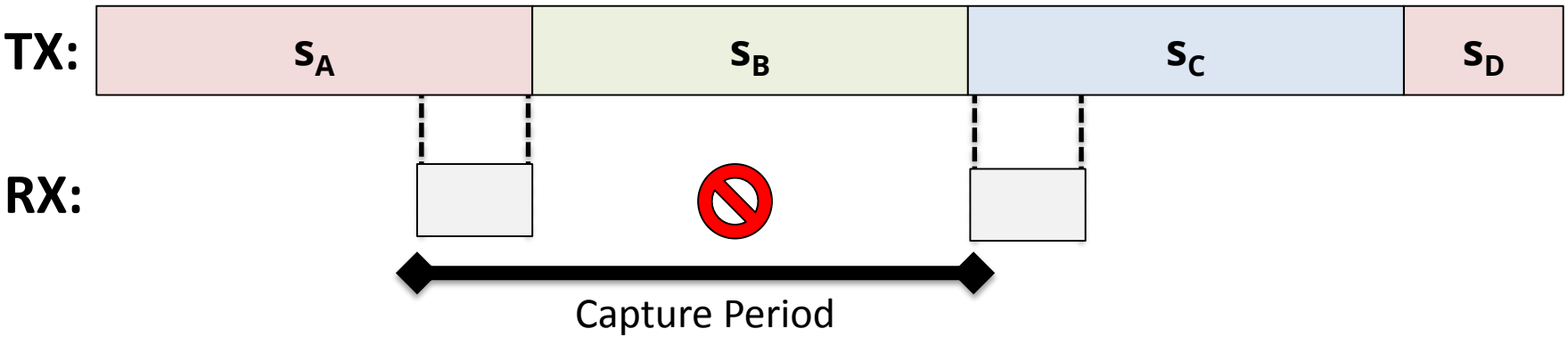
Implementation



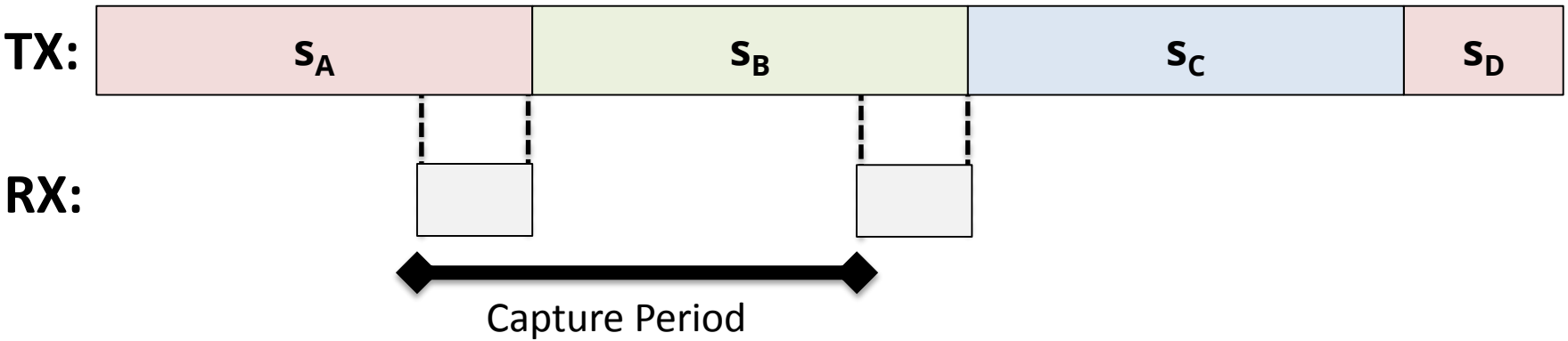
Styrofoam Coding Scheme

Guaranteeing resolvability

Constraint #1
Symbol Visibility

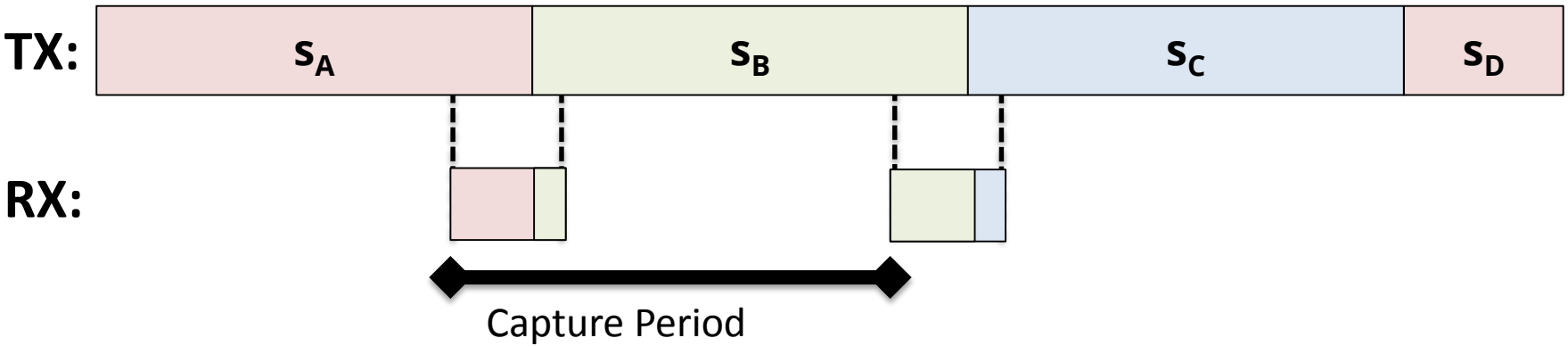


Constraint #1
Symbol Visibility



Capture Period < Symbol Period

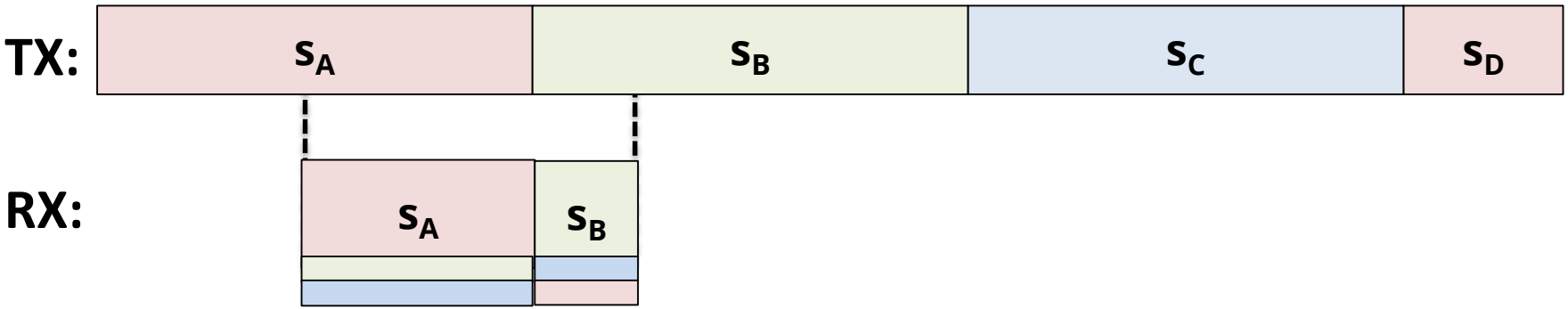
Constraint #1
Symbol Visibility



Capture Period < Symbol Period

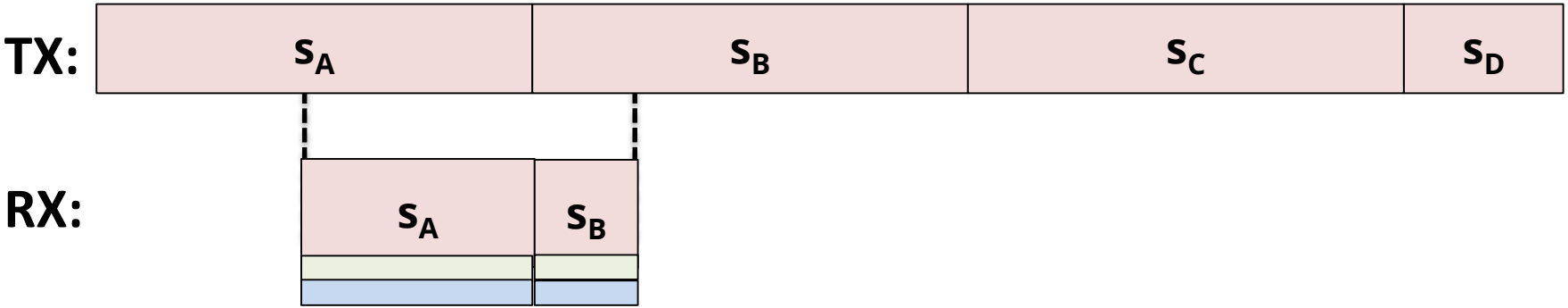
This guarantees each symbol is RXed with $\alpha > 0.5$

Constraint #2
Symbol Color Fidelity



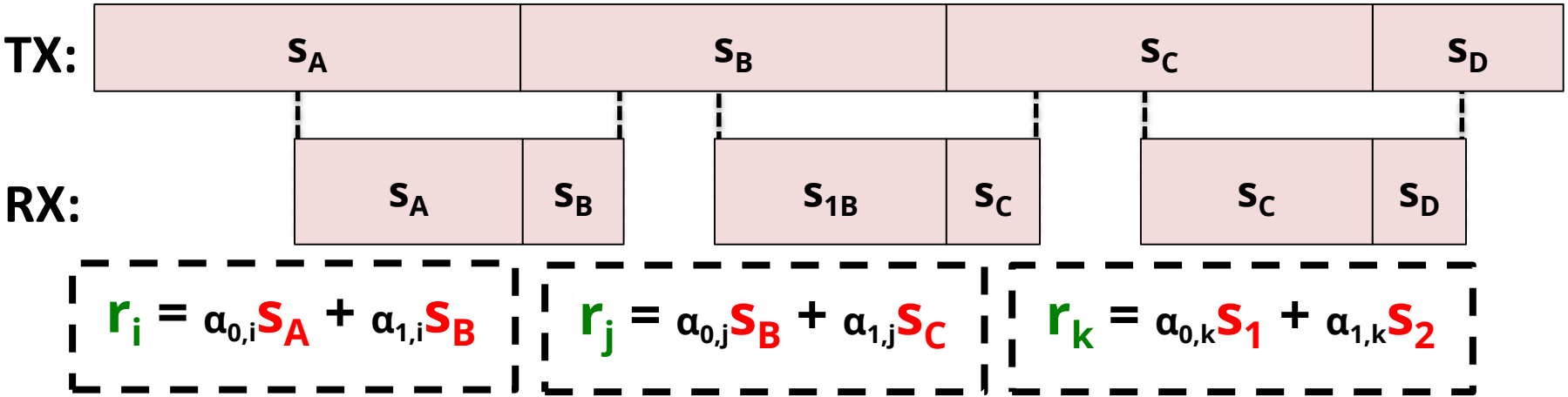
Adjacent symbols must match color channels.

Constraint #2
Symbol Color Fidelity



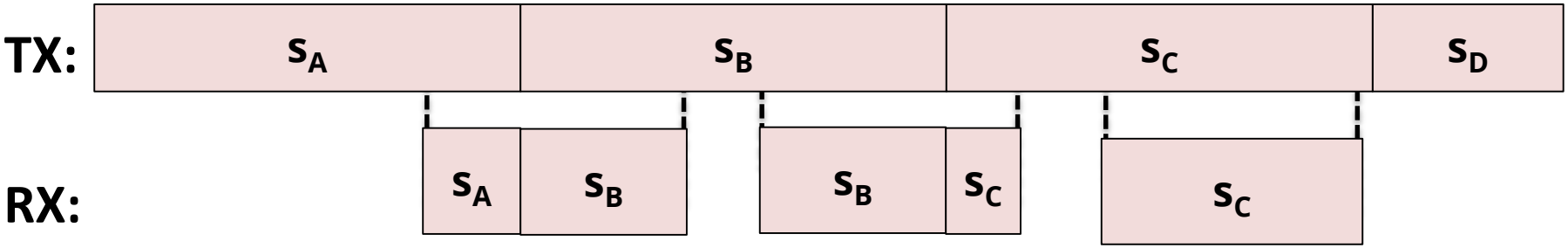
Adjacent symbols must match color channels.

Constraint #3
Symbol Resolvability



Mixed Capture: **1 eqn**, **2 var**

Constraint #3
Symbol Resolvability



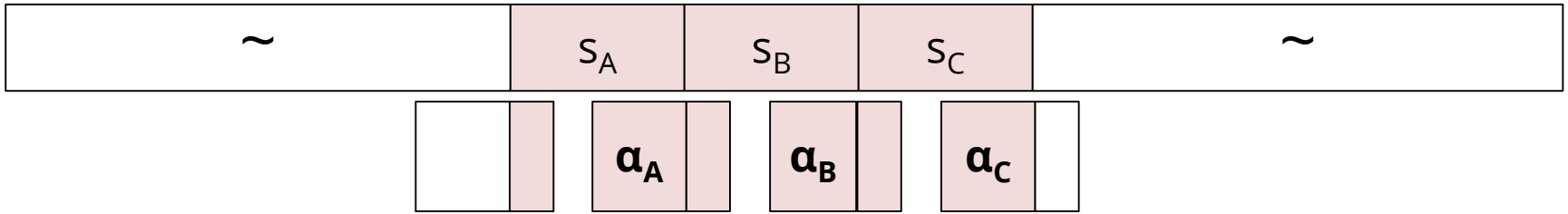
$r_i = \alpha_{0,i} s_A + \alpha_{1,i} s_B$ $r_j = \alpha_{0,j} s_B + \alpha_{1,j} s_C$ $r_k = \alpha_{1,k} s_C$

Mixed Capture: **1 eqn**, **2 var**

Pure Capture: **1 eqn**, **1 var**

Ensure pure captures with Styrofoam Blocks

Constraint #3
Symbol Resolvability



Constraint #1: Visibility Spacing

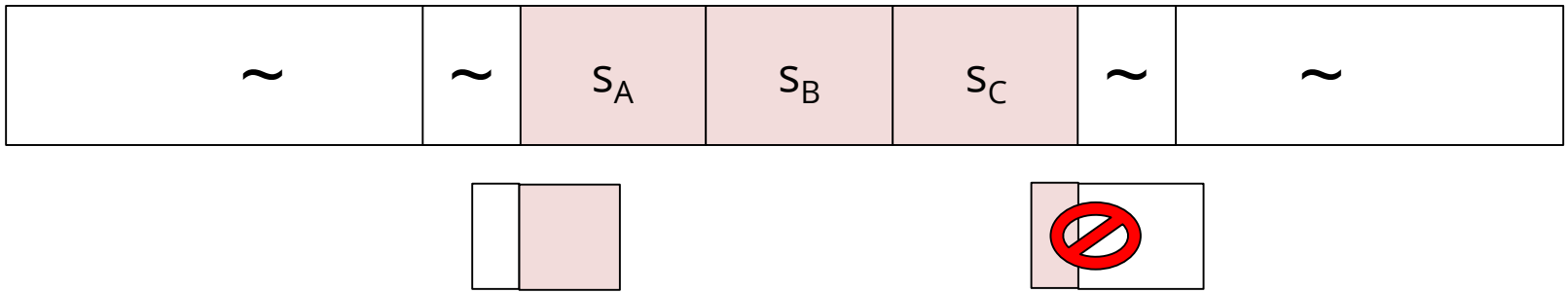
Spacing => Every symbol appears with **$\alpha > 0.5$**

A mixed capture target is always followed by the mixed symbol's capture.

Spacing => **$\alpha_A < \alpha_B < \alpha_C$**

Ensure pure captures with Styrofoam Blocks

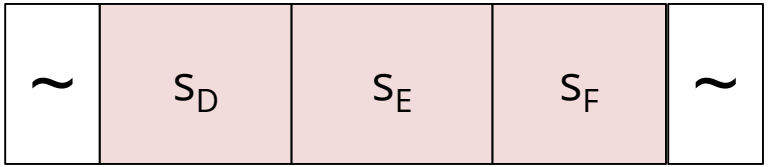
Styrofoam Block Size

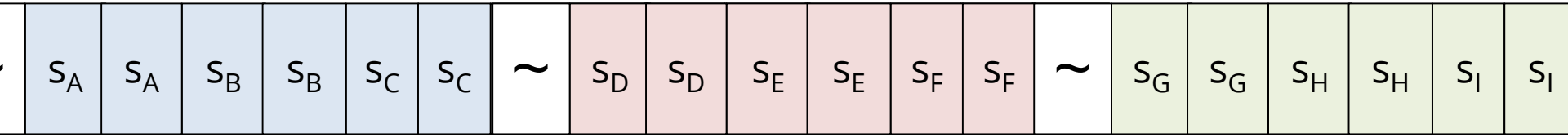


Styrofoam blocks are only useful when symbol $\alpha > 0.5$
Remainder of block is < 0.5.

Styrofoam blocks need only be half as wide as symbol blocks

Styrofoam Frame Timing

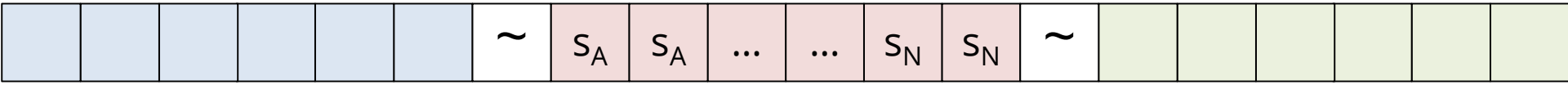




Display each symbol for two frames,
Styrofoam Block for one frame

Display Frame Rate < 2 x Camera Frame Rate
e.g. (Display : 30 FPS, Camera : 15 FPS)`

Styrofoam Coding



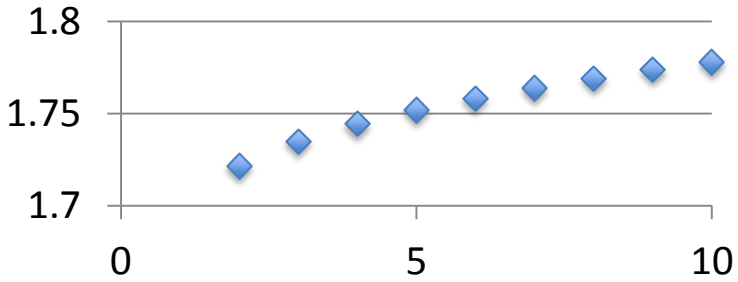
Data Rate

$$\frac{log_2(L_R^N + L_G^N + L_B^N)}{2N+1}$$

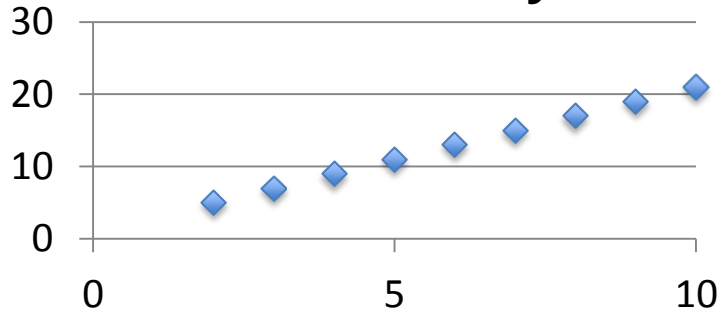
Decode Latency

$$2N+1$$

Bit depth/Block/Display Frame

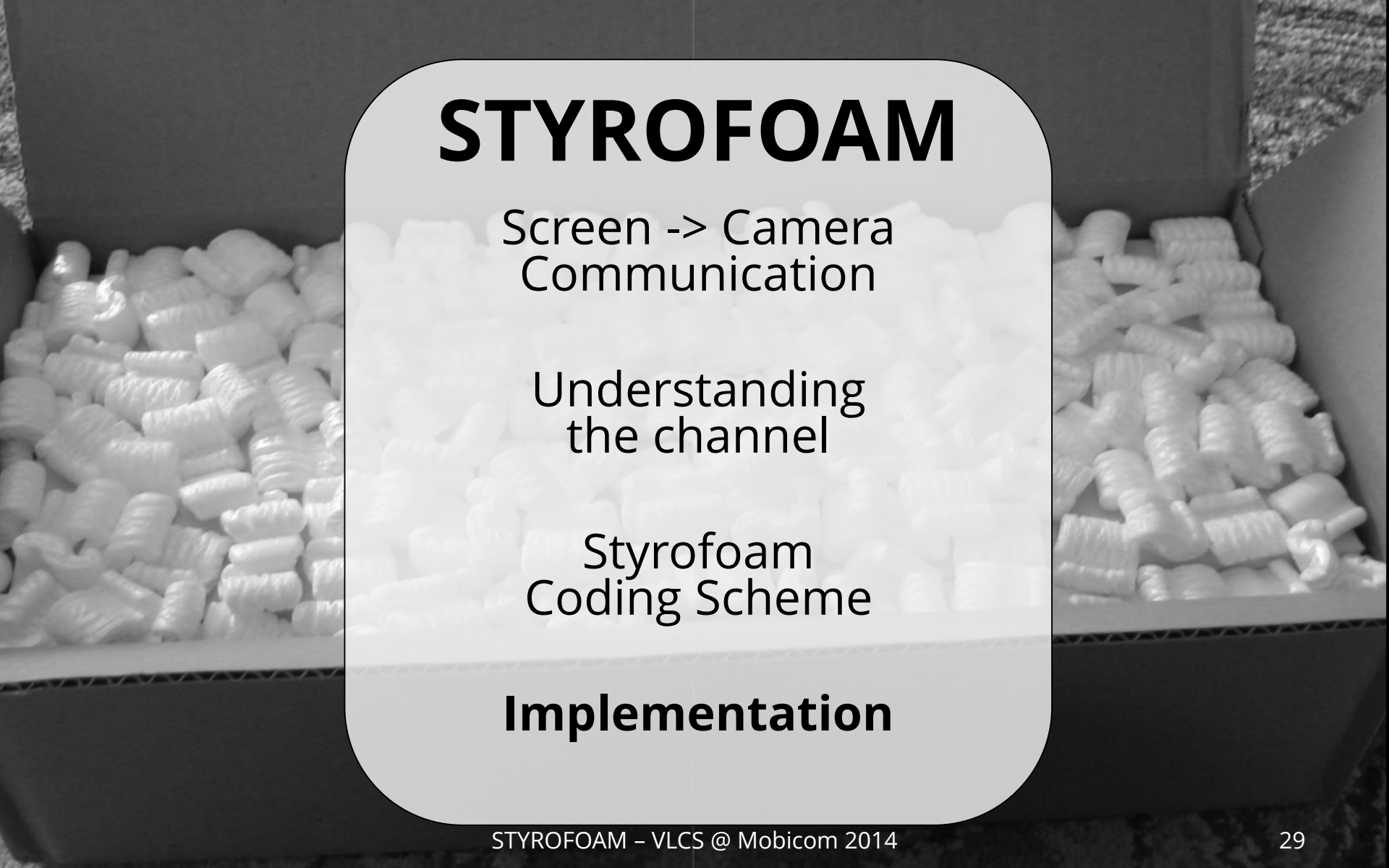


Frame Latency



Per-block, Per-Display Frame Rate Datarate Comparisons

- Traditional (1-bit, blank alternate frames): **0.5 bits**
- COBRA (5-values, half-frame rate): **1.16 bit**
- LightSync ("Synchronization" interference blocks): **1 bit**
- Styrofoam: **1.7 bits**
  - **1.7 bits * 720 blocks * 60 fps = 73.4 kbps**



STYROFOAM

Screen -> Camera Communication

Understanding the channel

Styrofoam Coding Scheme

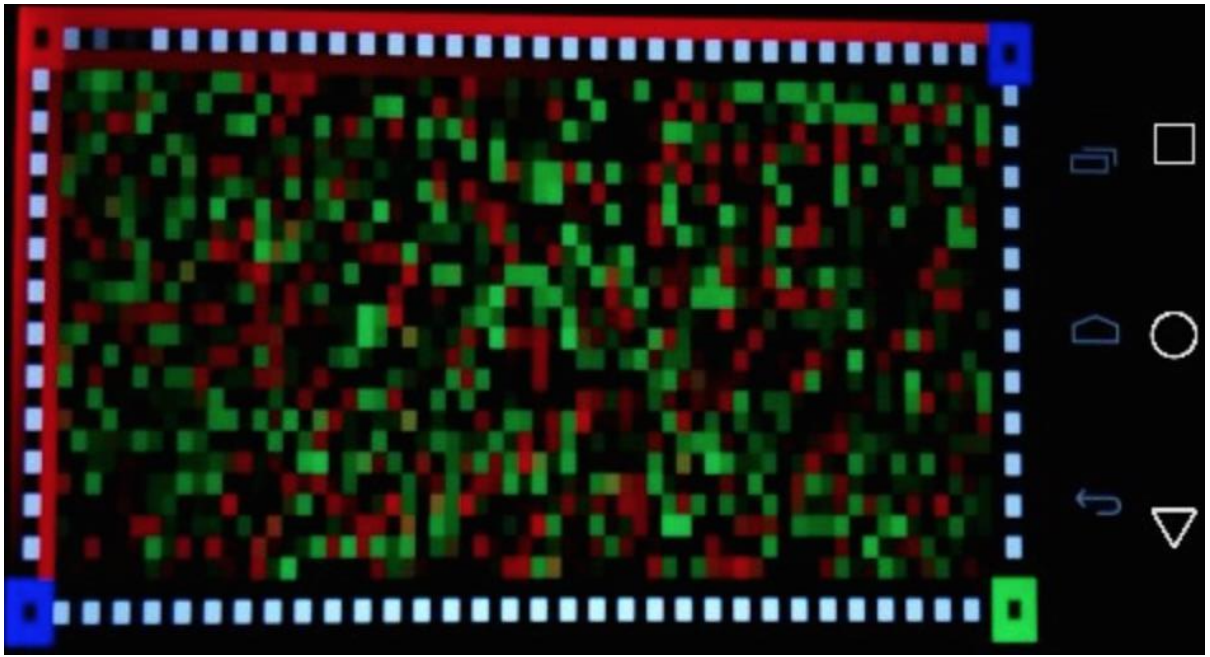
Implementation

Implementation

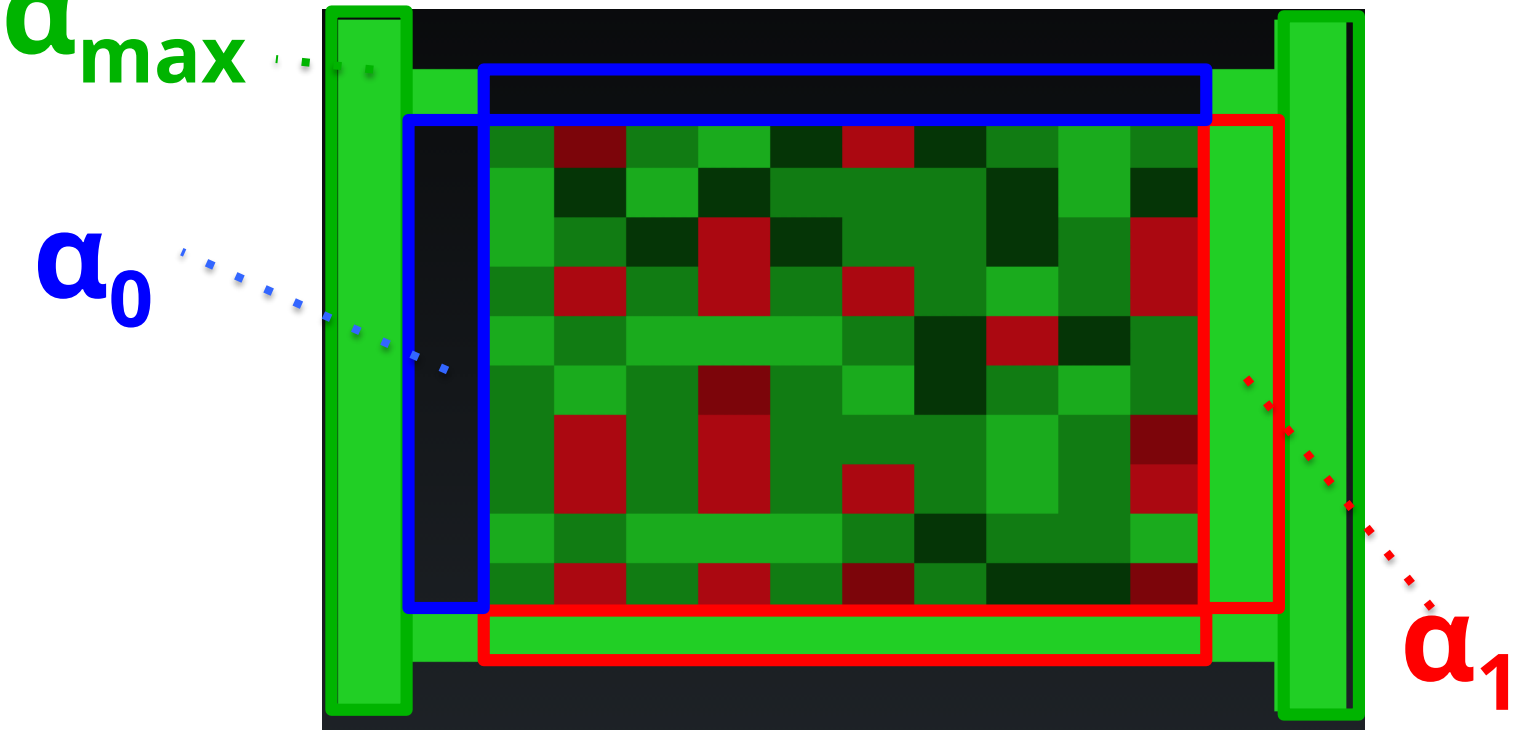
- In paper:
  - Transmitter: Blackberry Z30, 60 FPS
  - Receiver: Nokia Lumia, 30 FPS
    - Hardware ISO & Exposure control
  - Decoded offline w/ MATLAB

- Demo:
  - Nexus 5 + Nexus 5
    - Android L hardware controls

Styrofoam Barcode (Nexus 5)

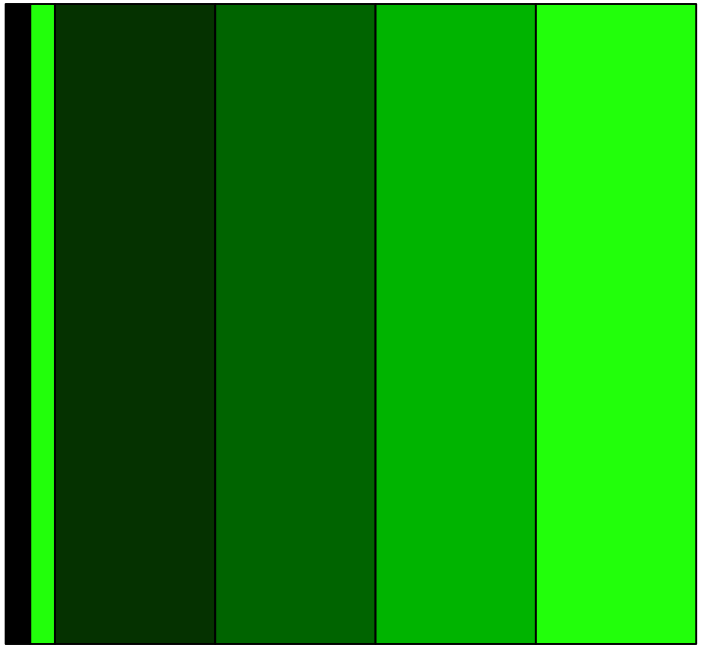


Styrofoam Barcode (Simplified Version)

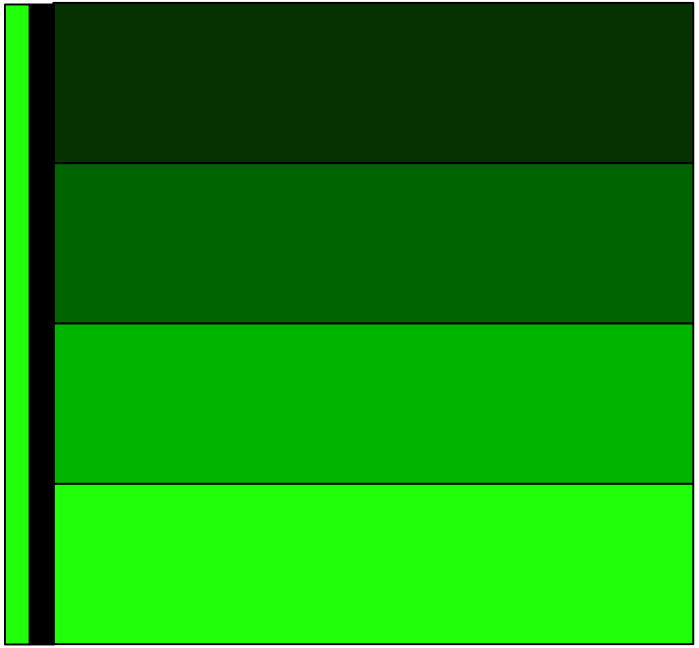


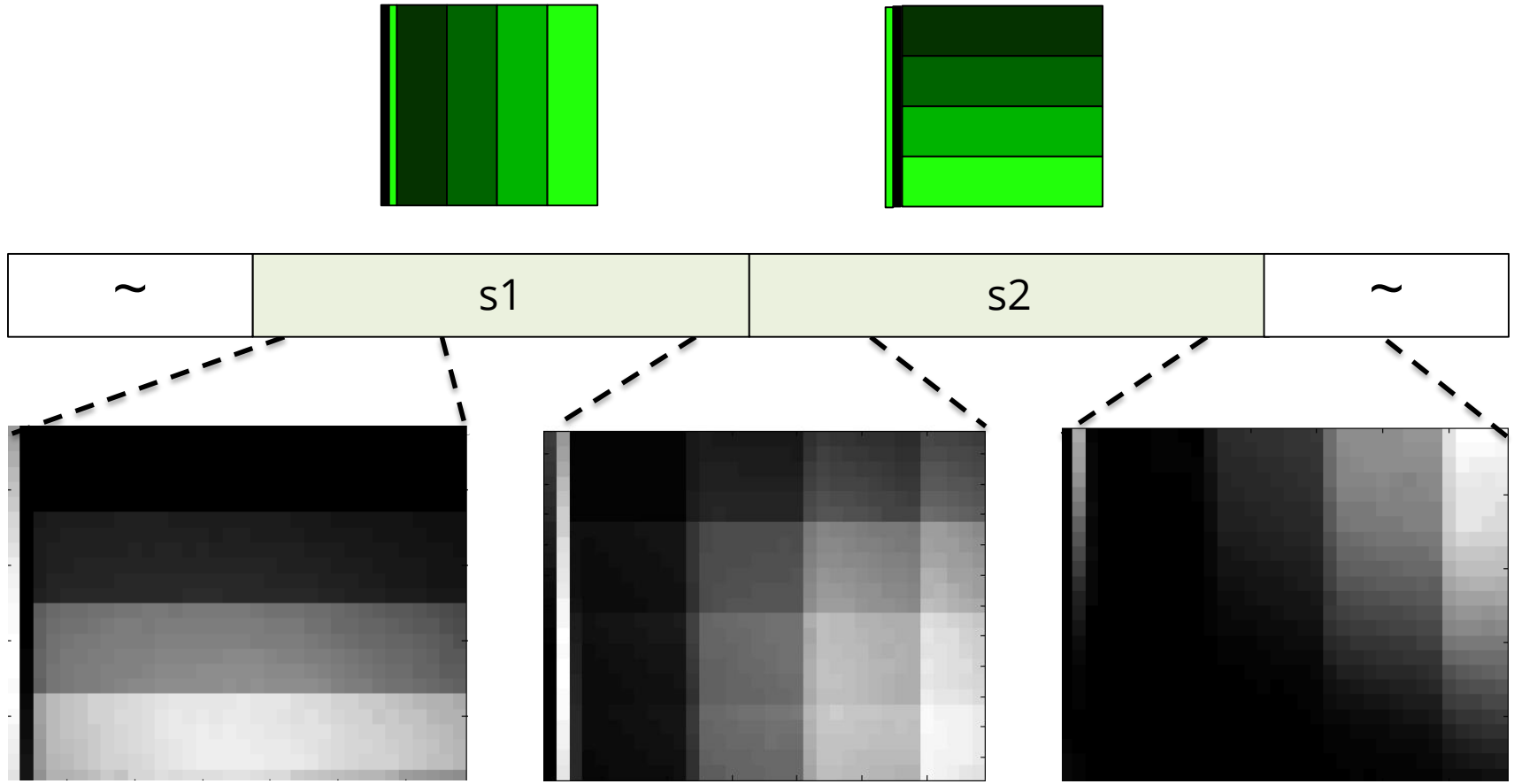
Sample TX

Even

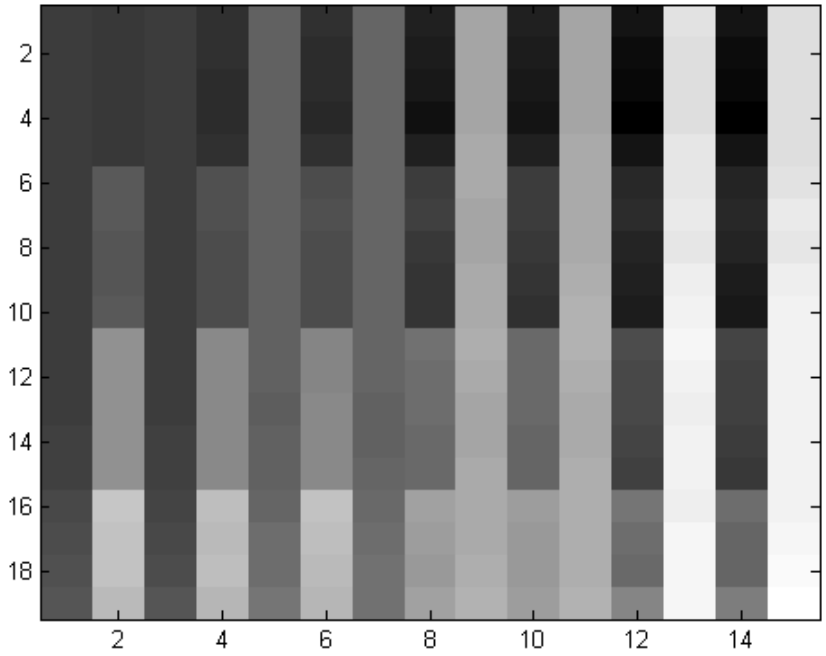


Odd




~
s1
s2
~

Decoded Pairs

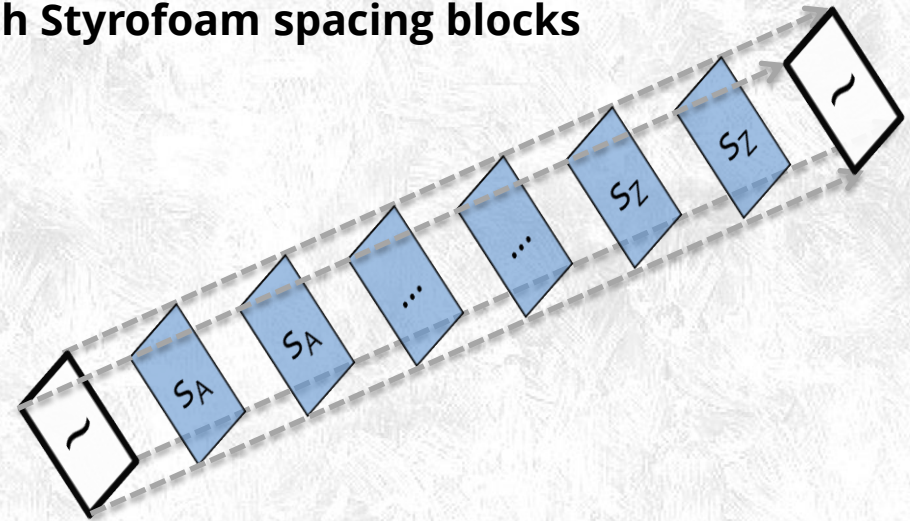


Additional Styrofoam Research Challenges

- Steganography
  - Can we hide the Styrofoam blocks?
- Power Efficiency
  - Of the display? Of the receiver?
- Leveraging YUV color channels
  - Mixing colors safely?
- Geometric problems
  - Screen -> Camera angles?

STYROFOAM

Characterize and constrain inter-symbol interference with Styrofoam spacing blocks



RICE
Unconventional Wisdom

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Constraints

- Display Frame > Symbol Frame
  - Symbol Visibility for at least half capture
- Styrofoam block spacing
  - To guarantee pure captures
  - Block at least half width of symbol
- Color Matching
  - To deter color filter issues