Screen Gleaning

Receiving and Interpreting Pixels by Eavesdropping on Video Signals without a Line of Sight

February 25th, 2021

Dirk Lauret, Zhuoran Liu and Léo Weissbart

LASER 2021

Radboud Universiteit

Imagine…

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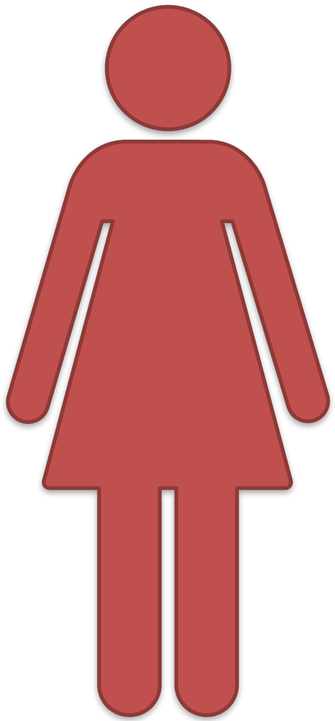

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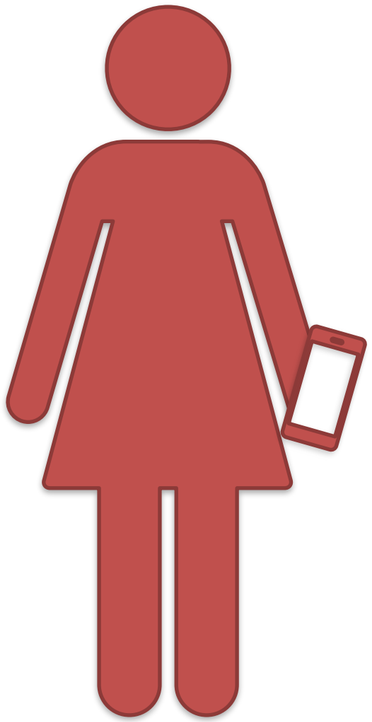

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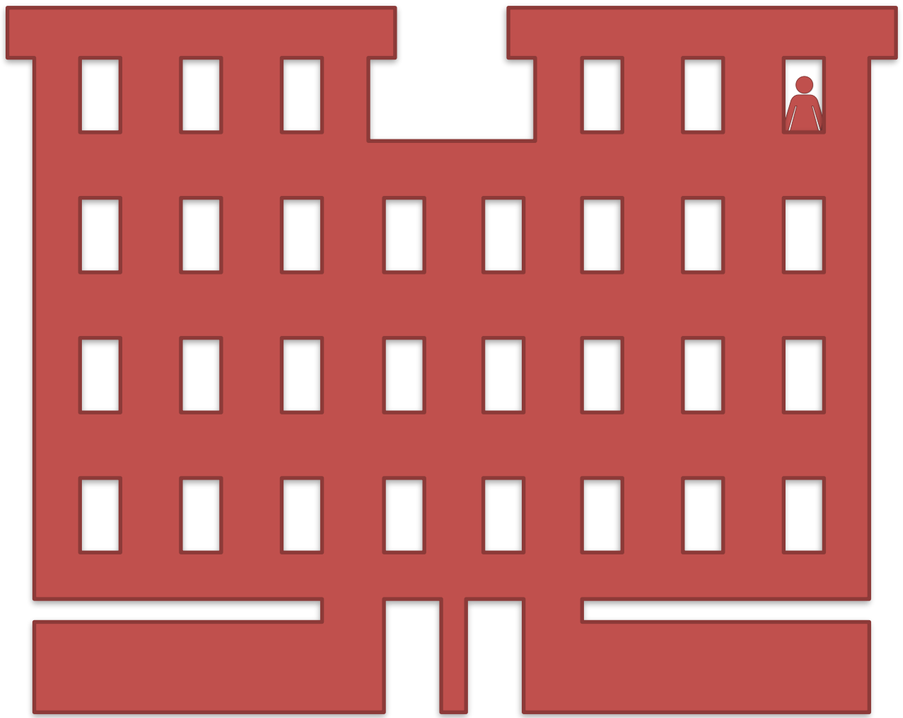

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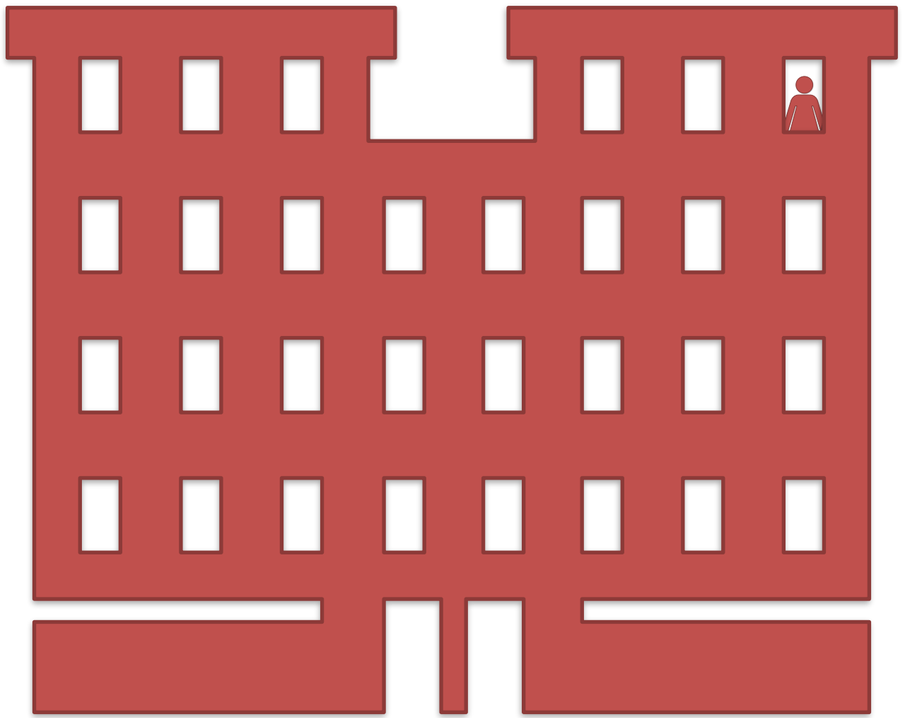

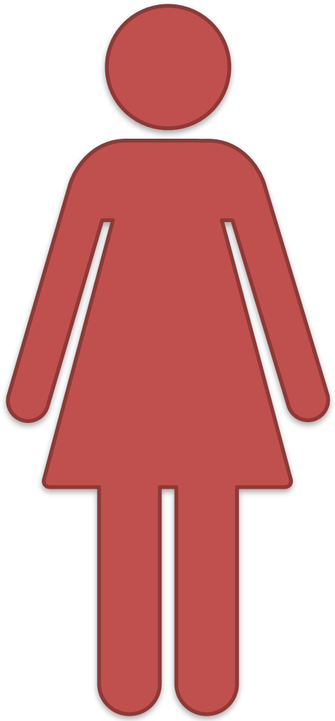

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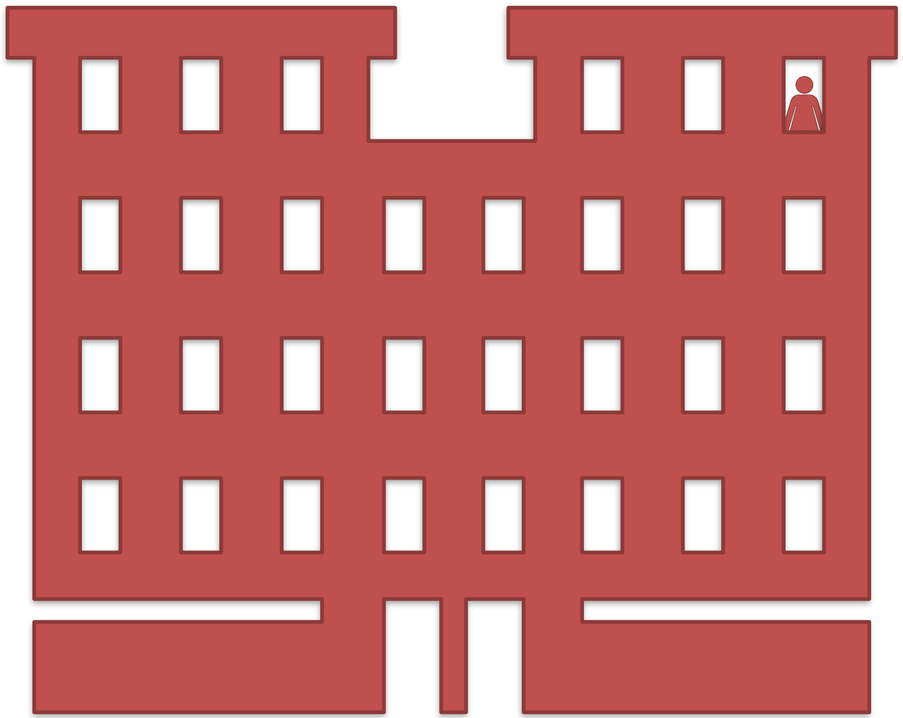

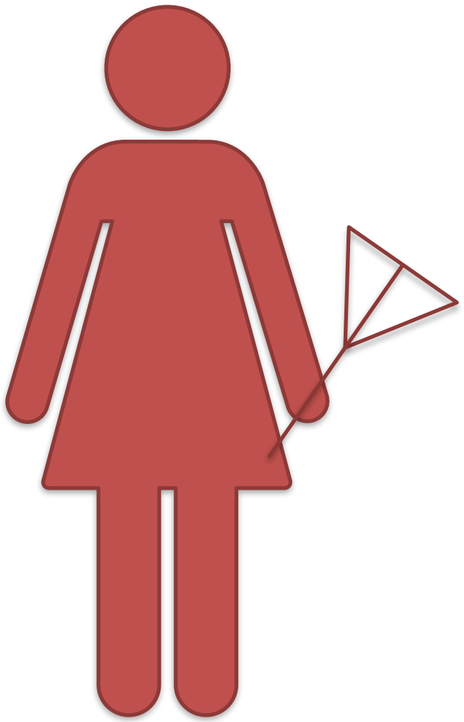

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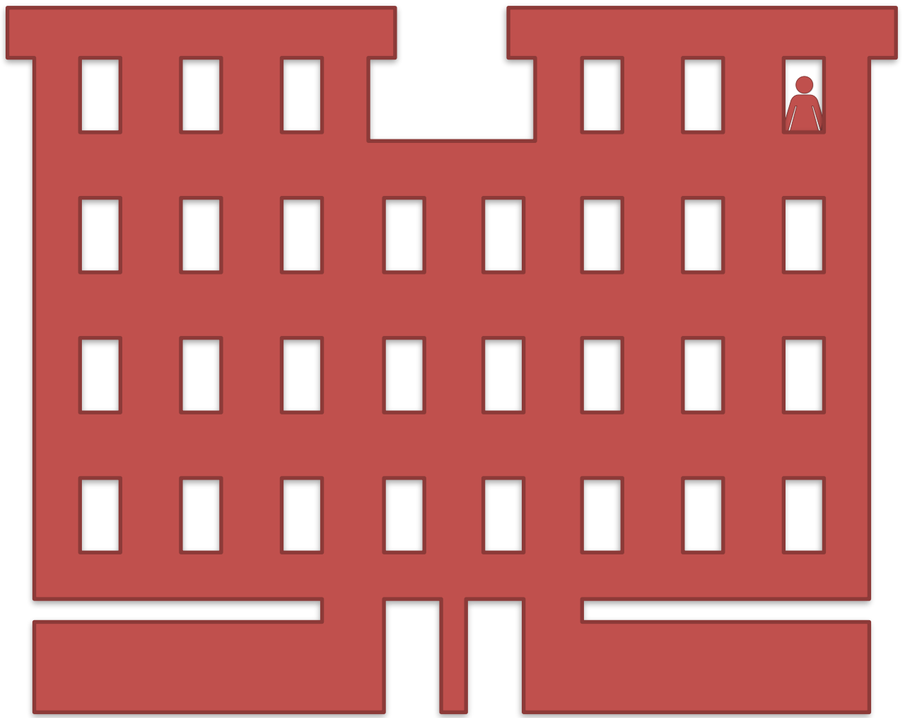

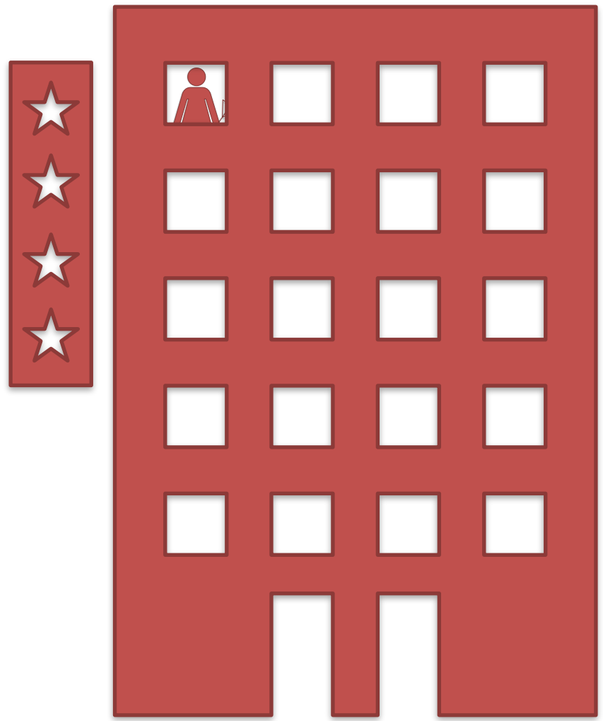

The Setup

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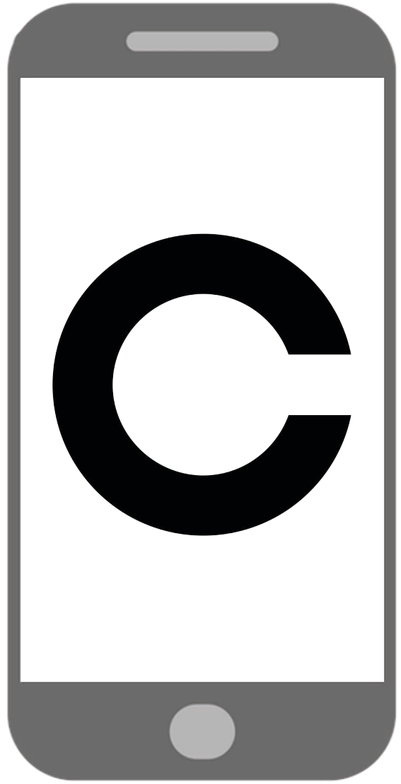

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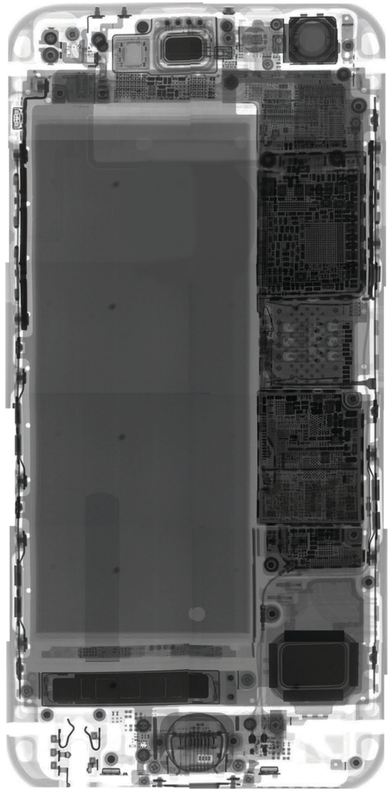

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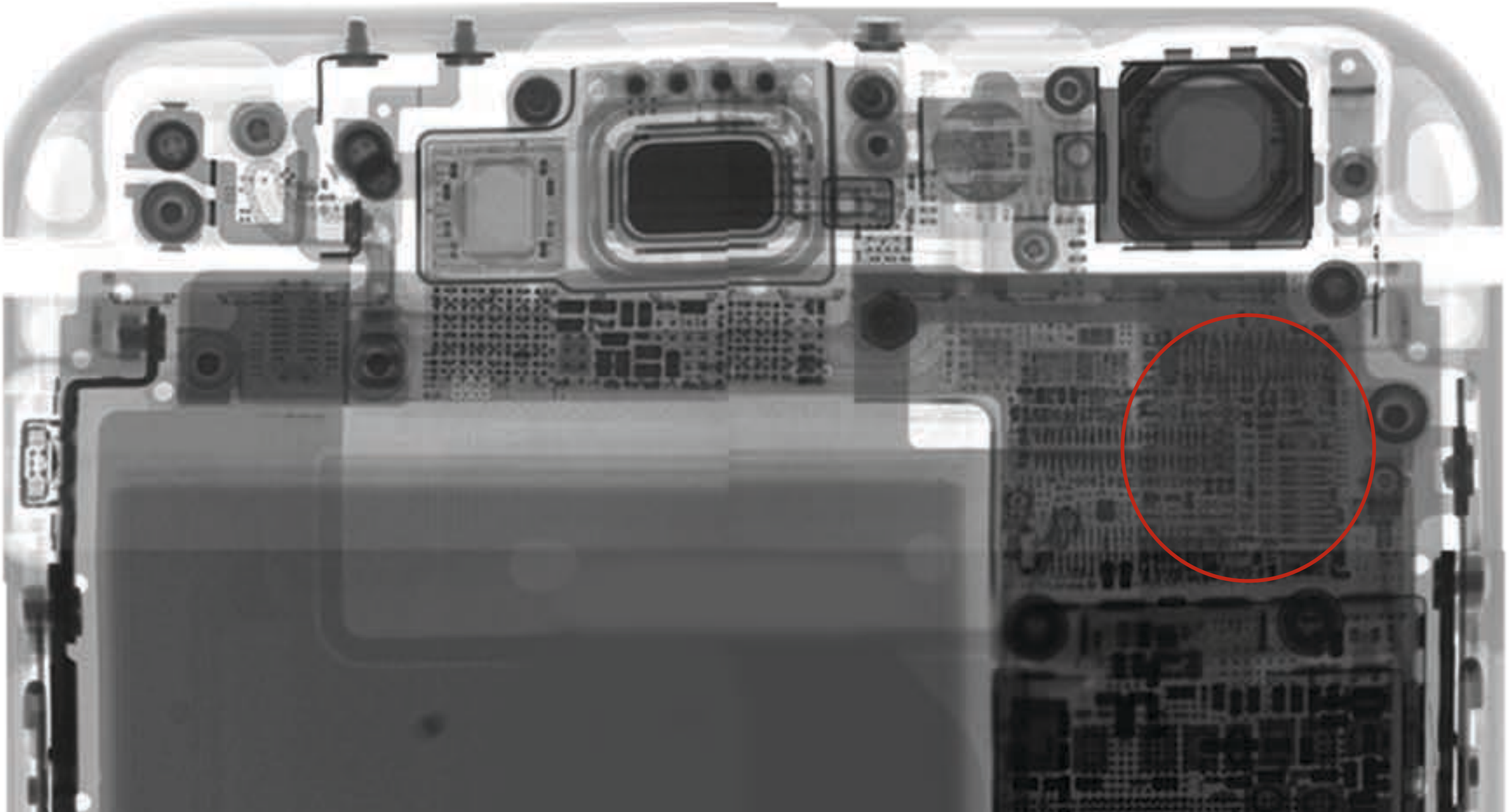

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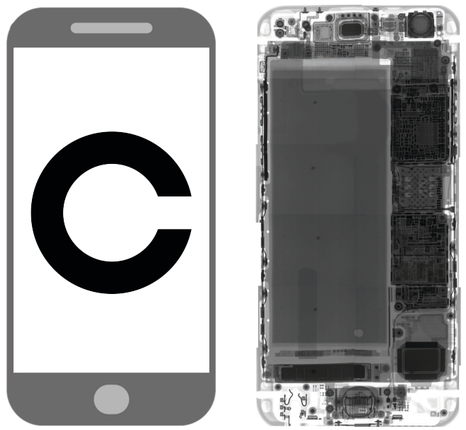

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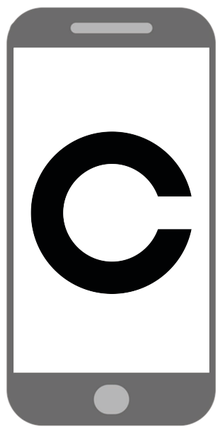

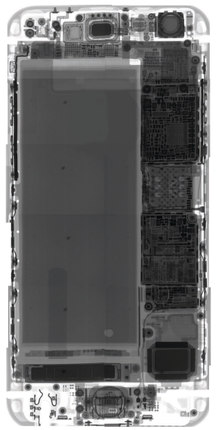

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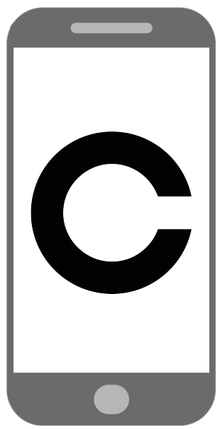

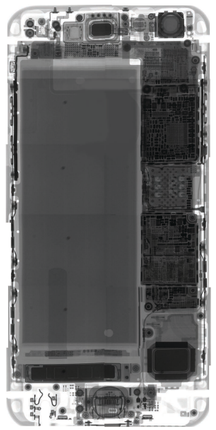

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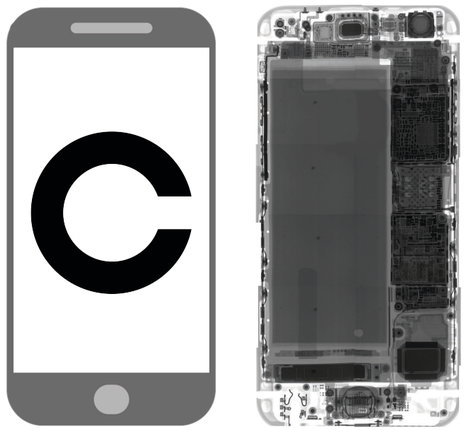

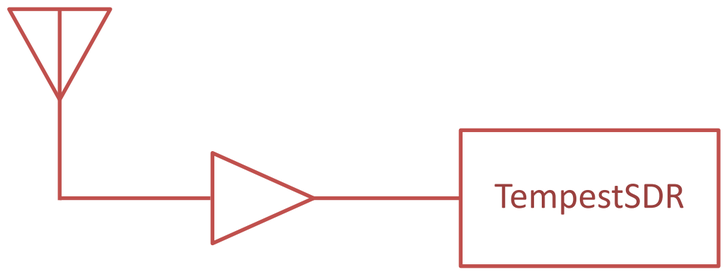

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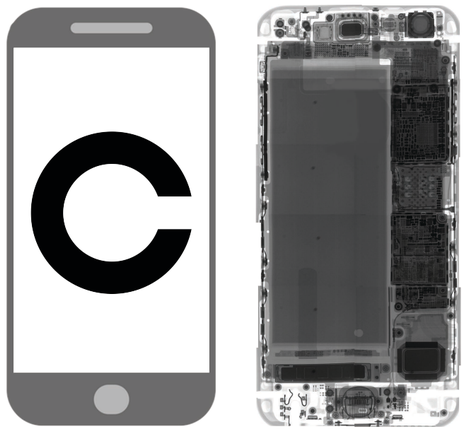

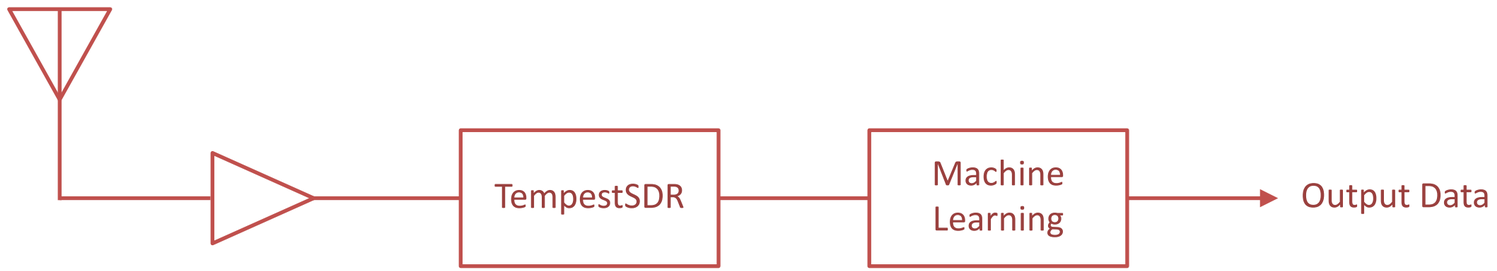

Used Setup

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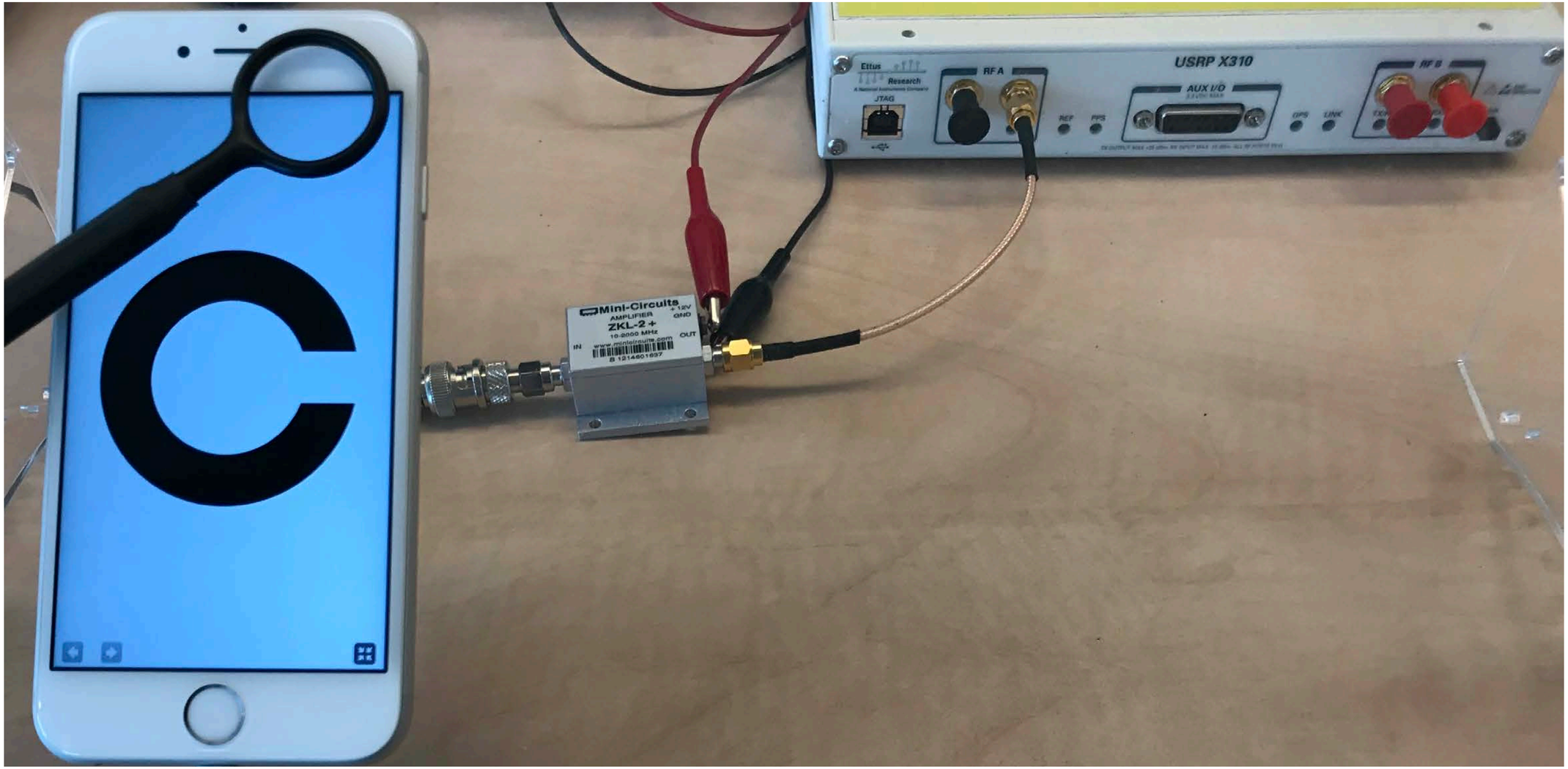
Ettus
Research
JTAG
RF A
USRP X310
AUX I/O
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REF
PPS
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LINK
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10-2000 MHz
+12V
GND
IN
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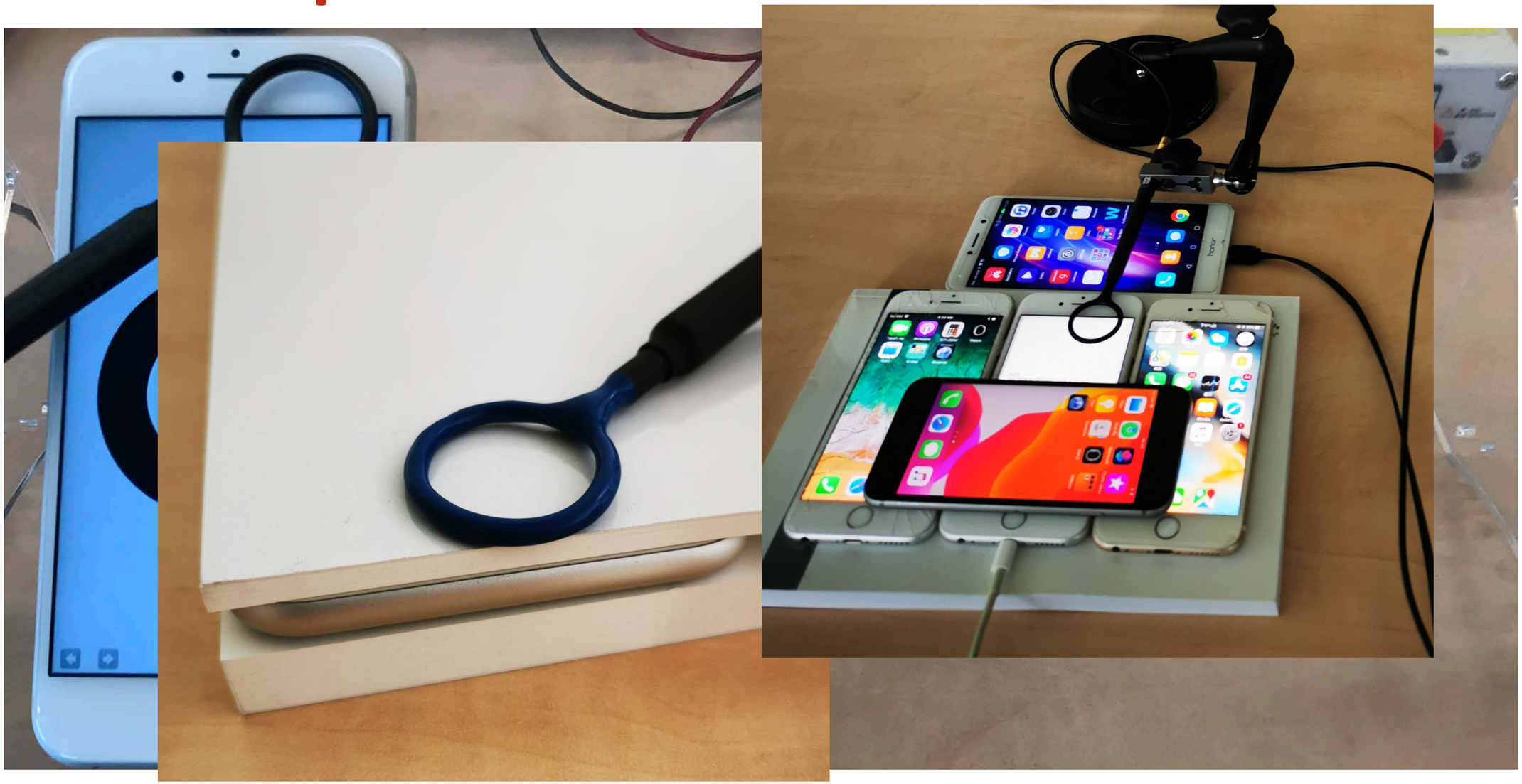

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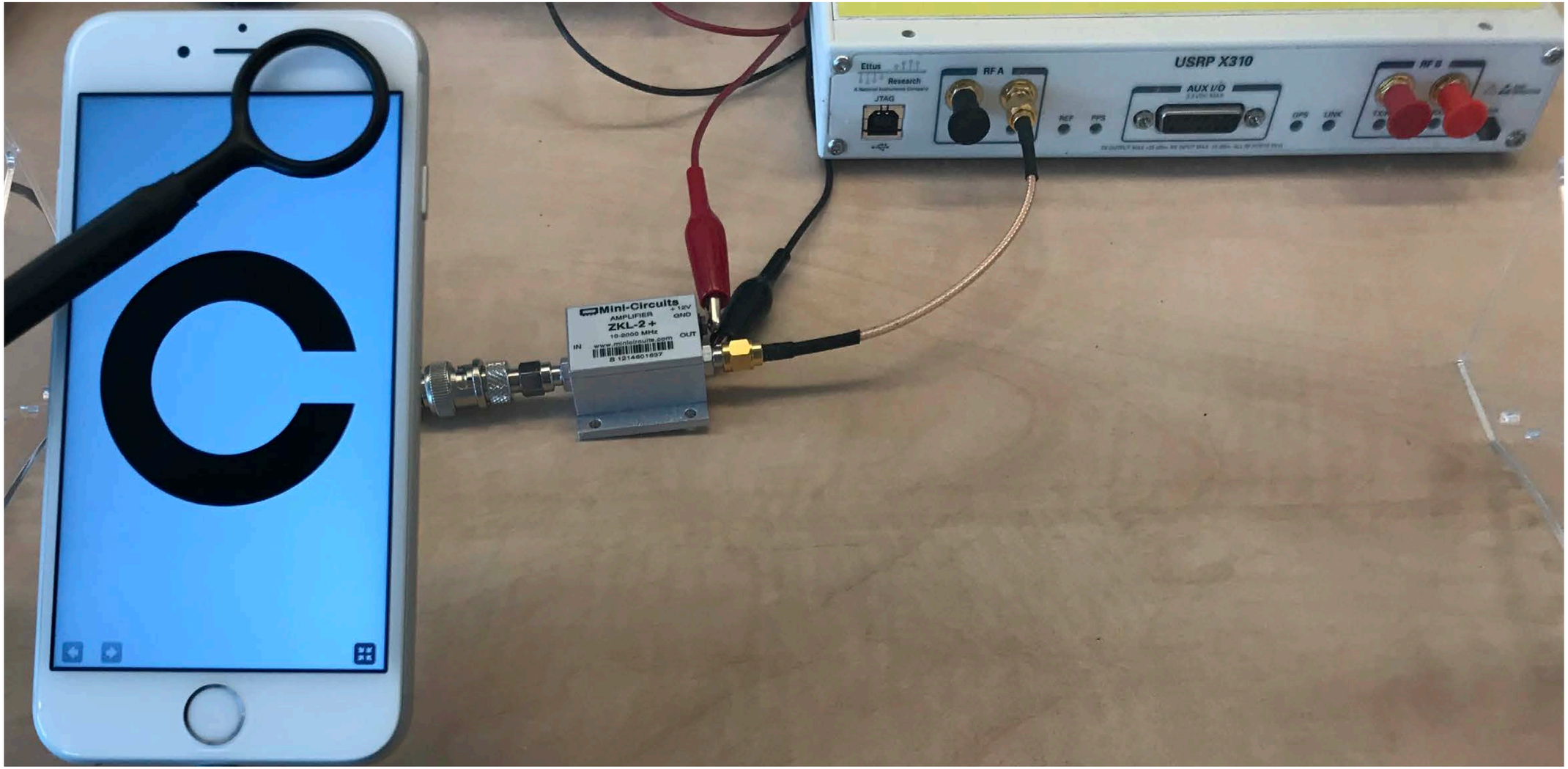
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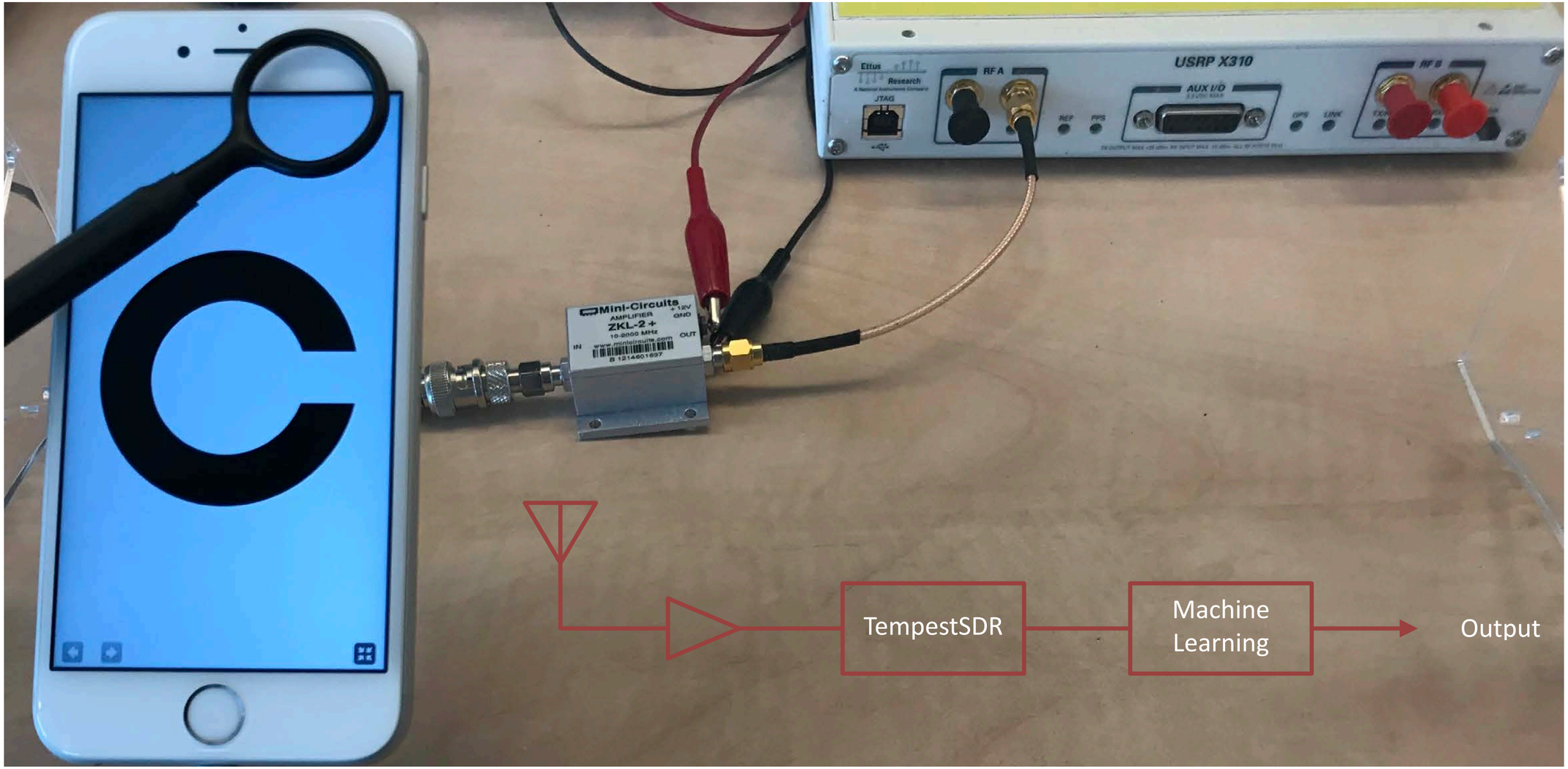
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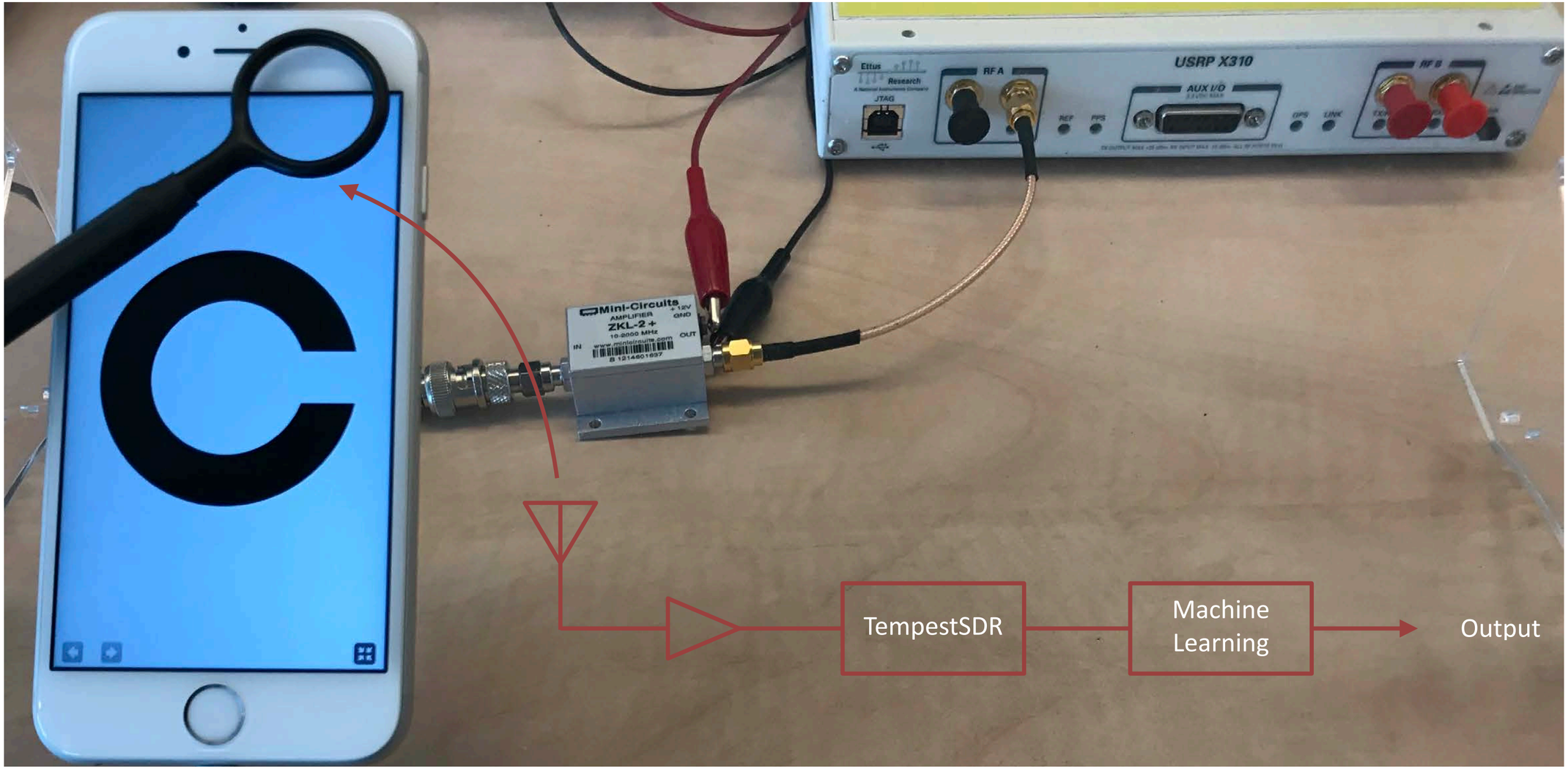
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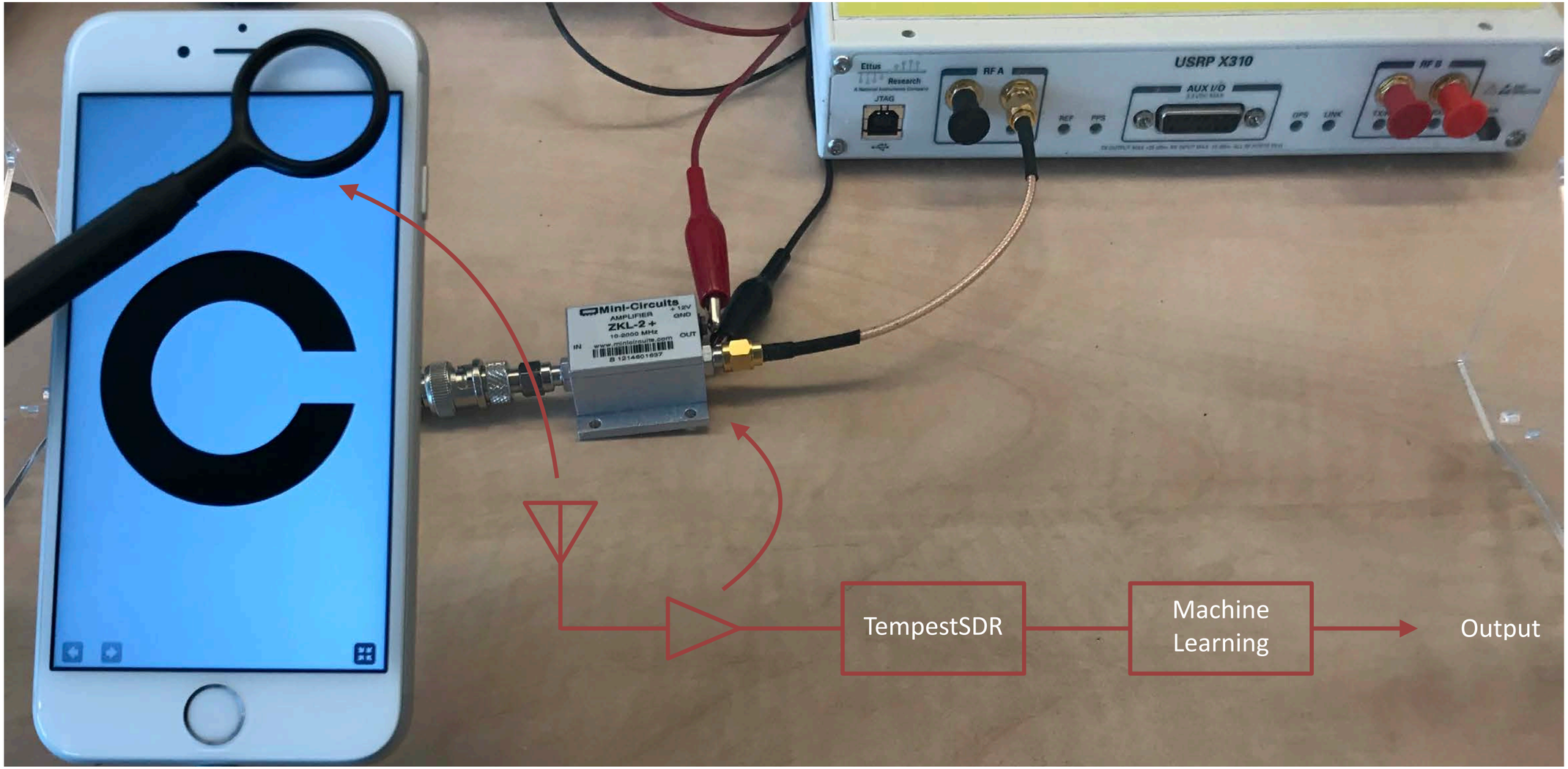
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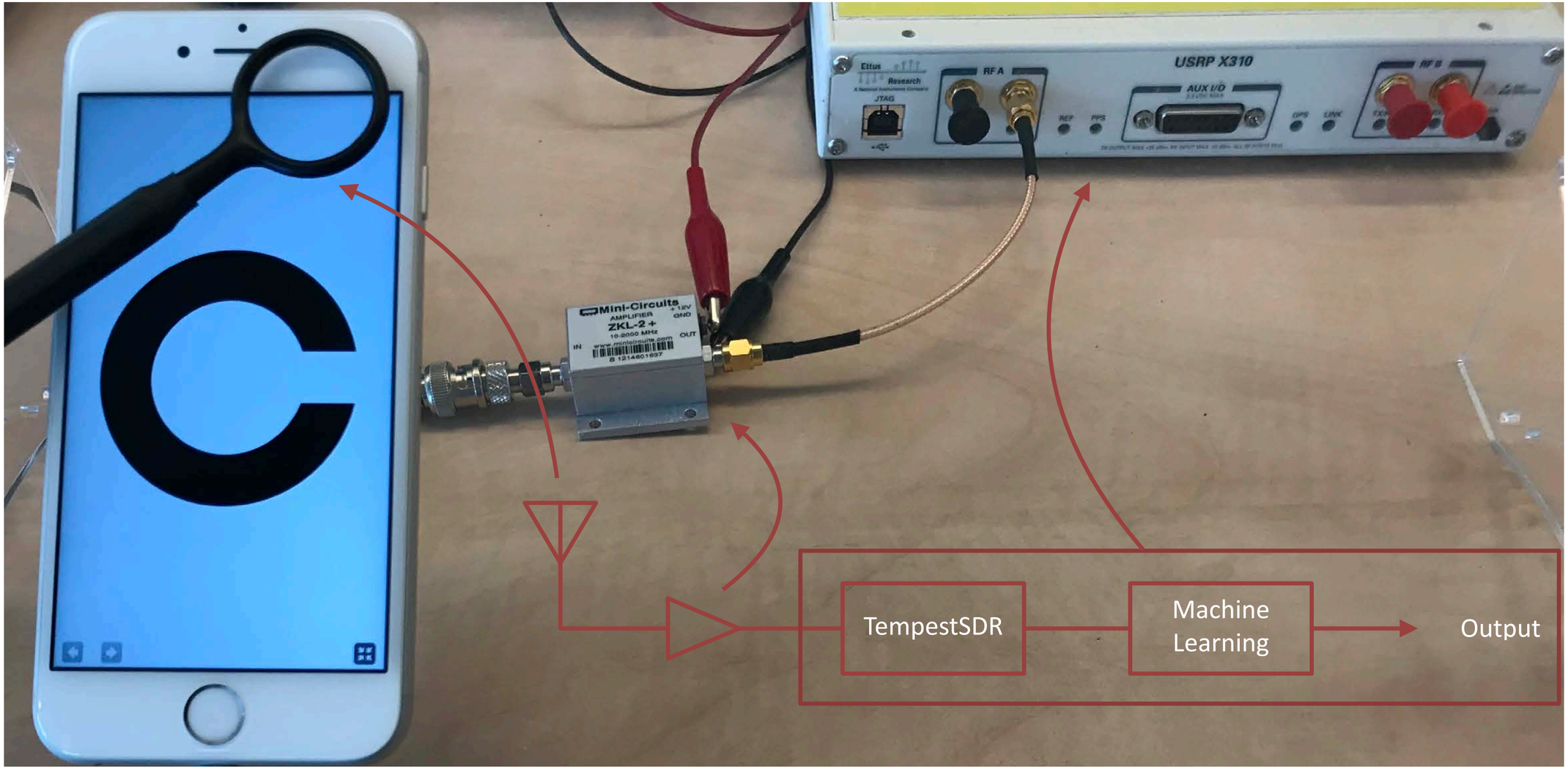
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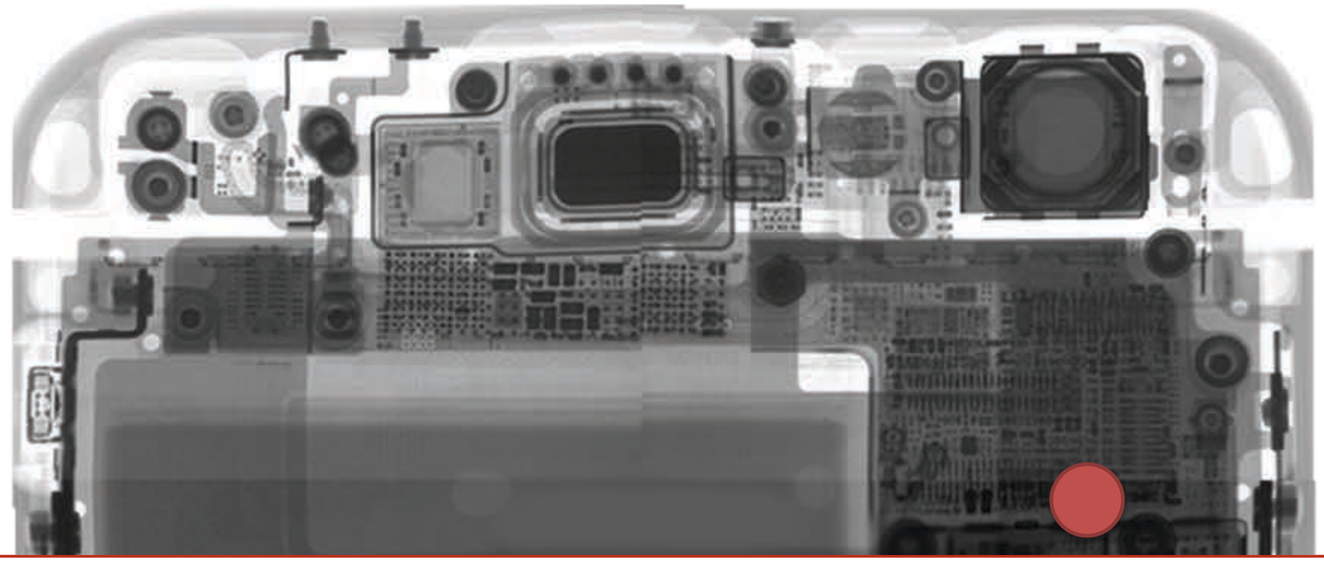

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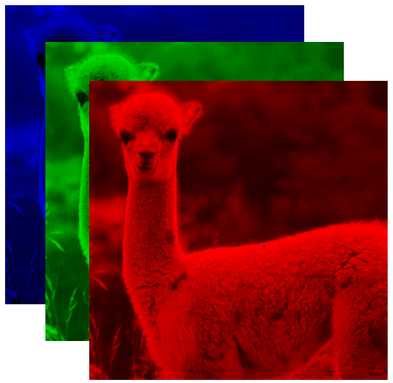

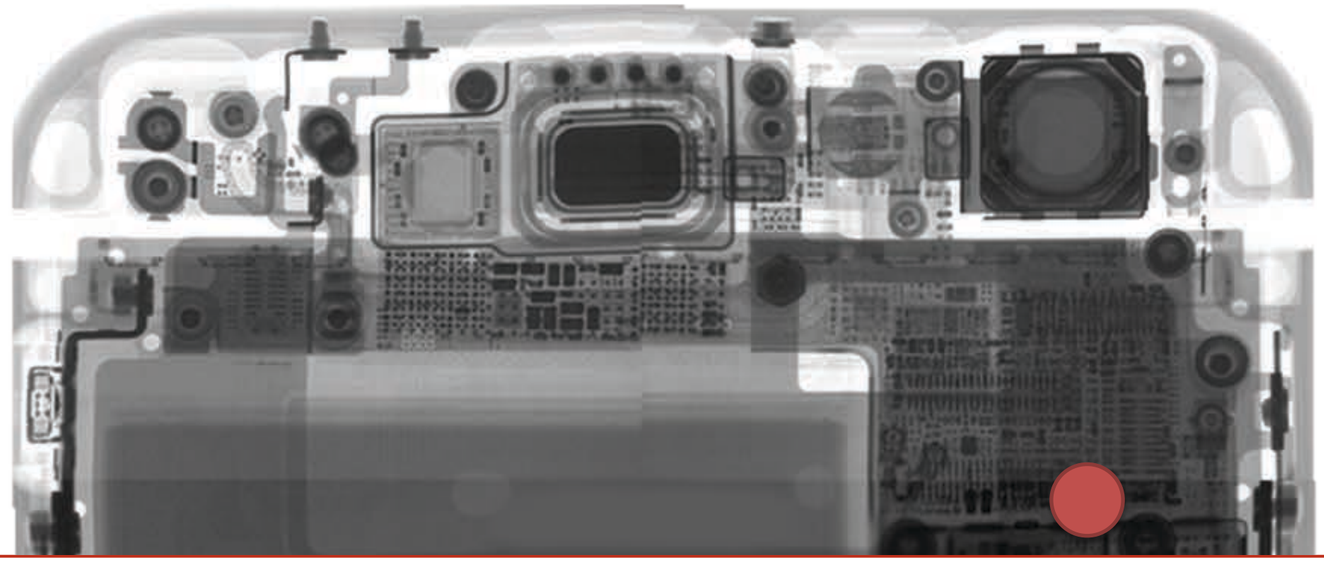

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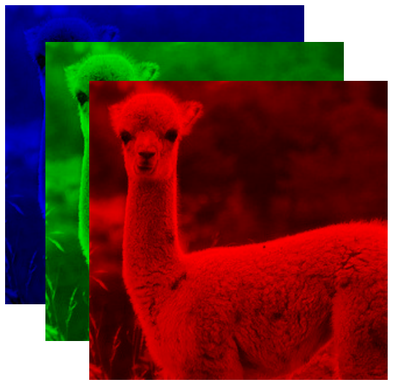

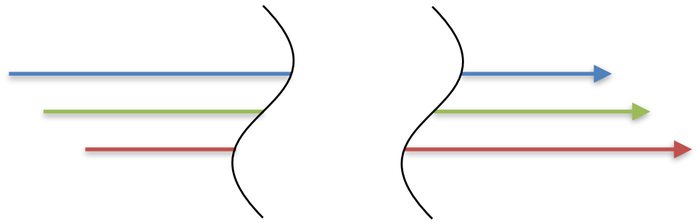

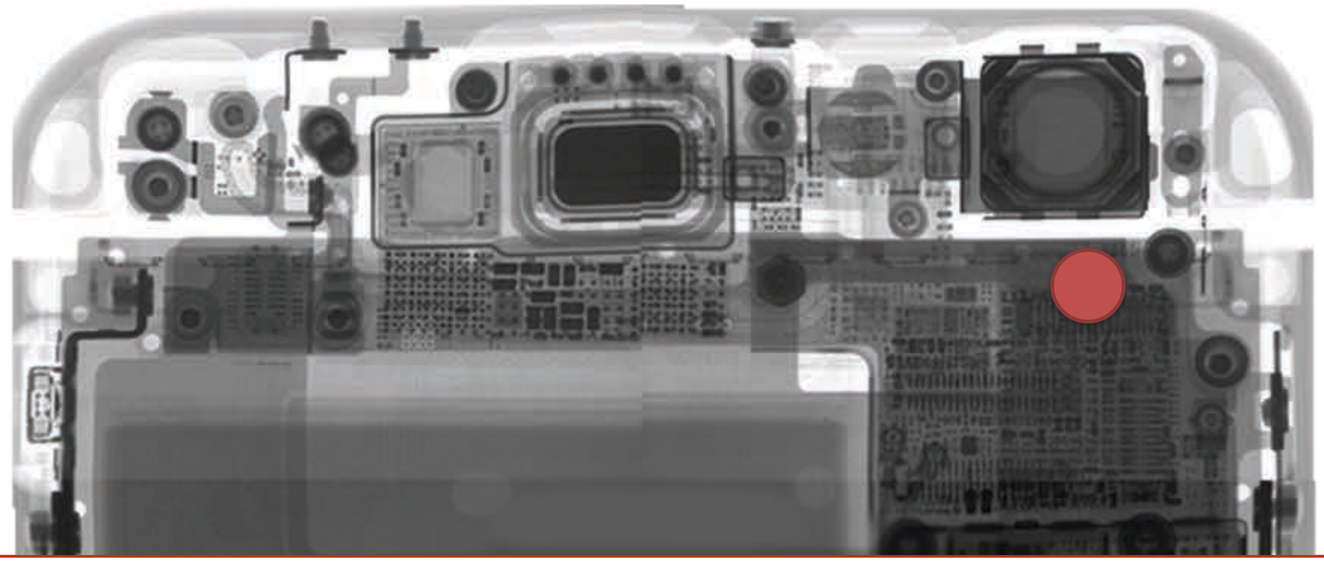

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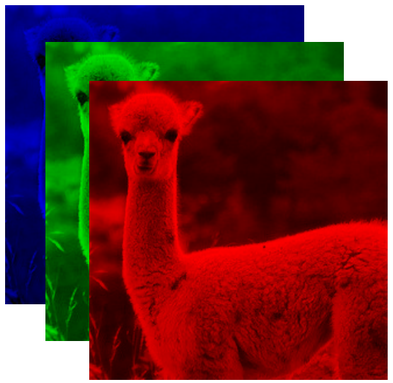

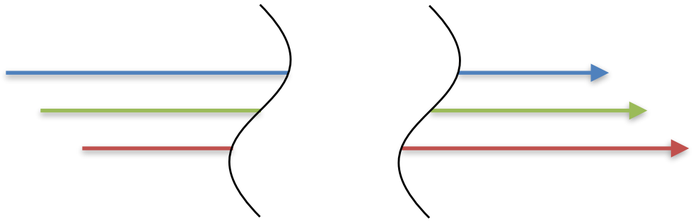

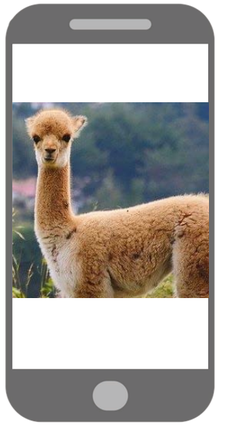

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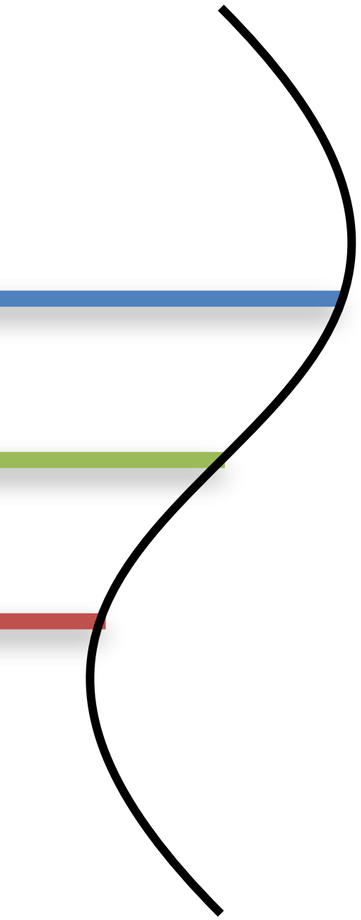

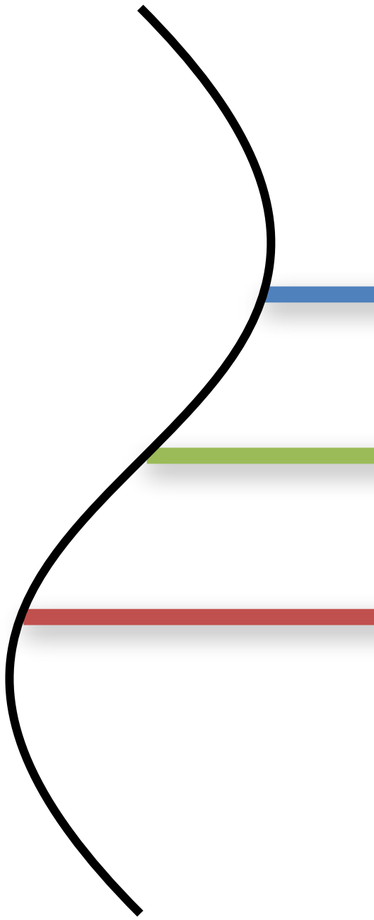

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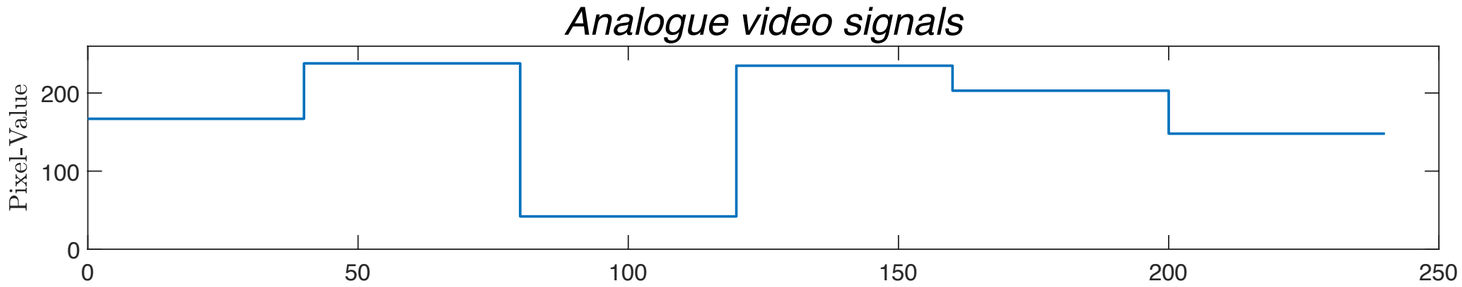

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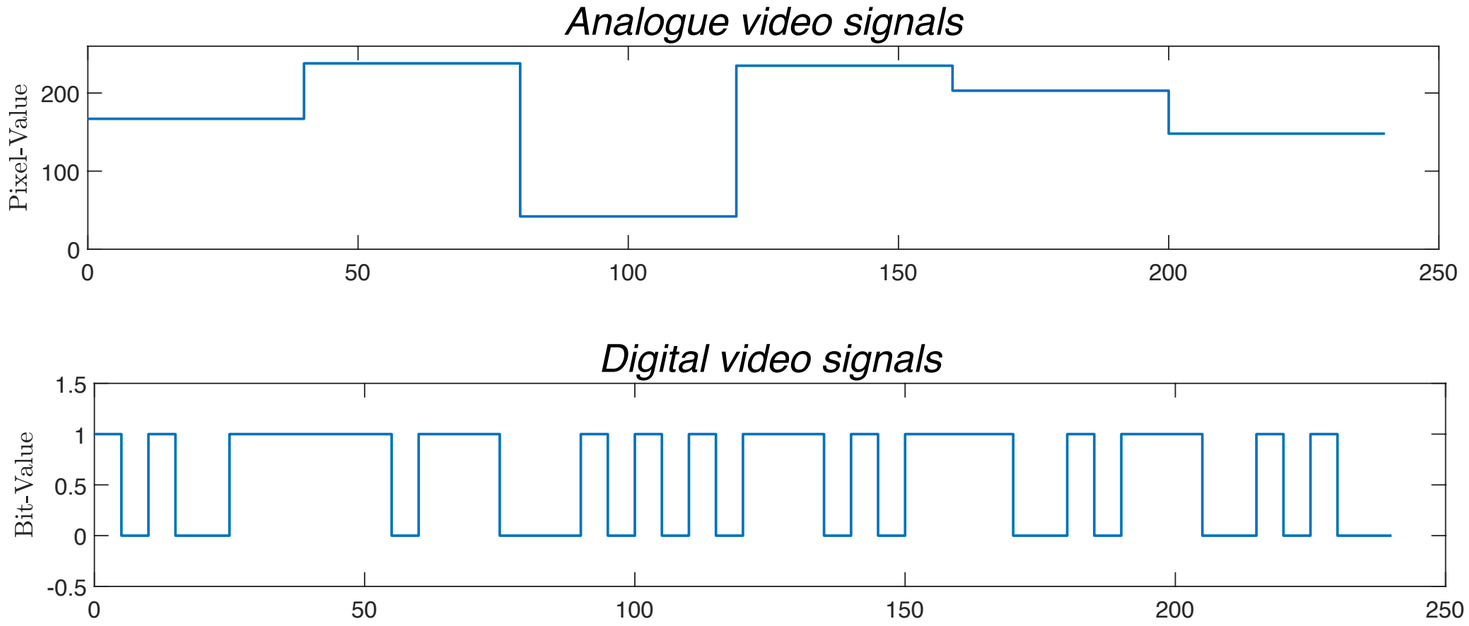

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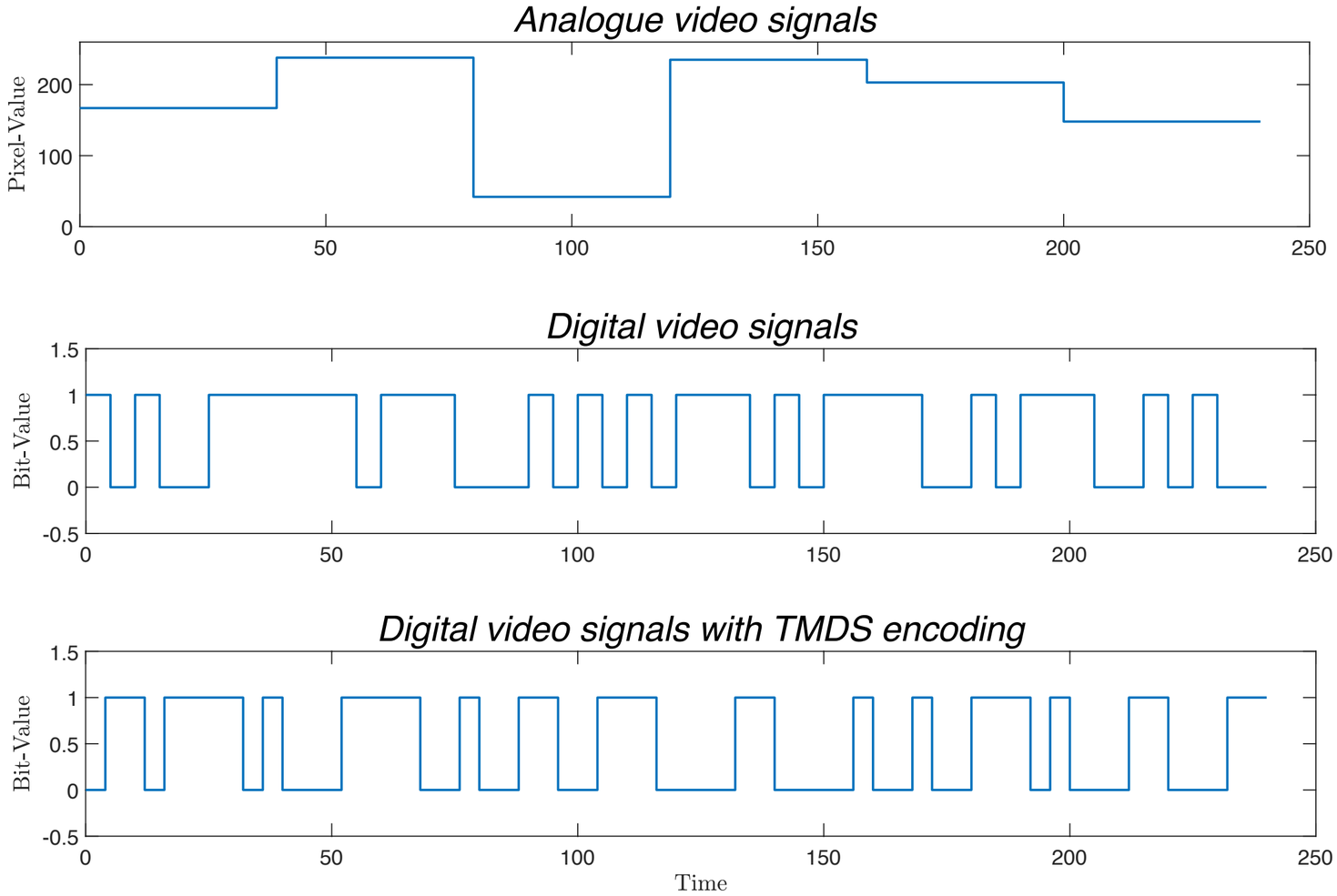

Electromagnetic Emanations

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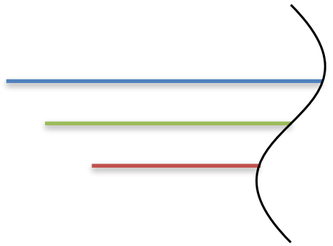

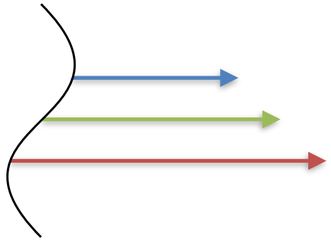

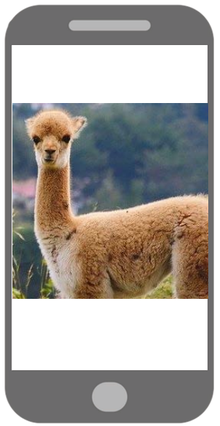

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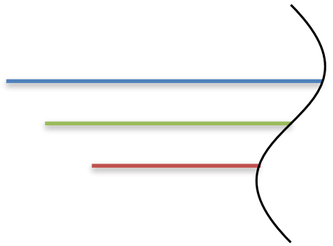
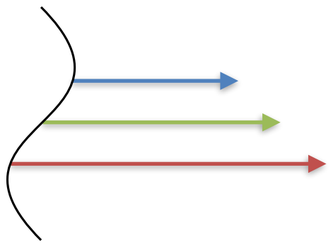
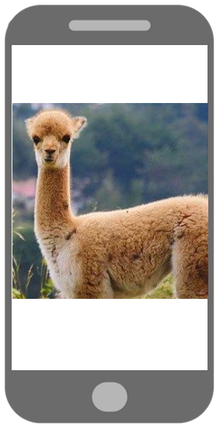
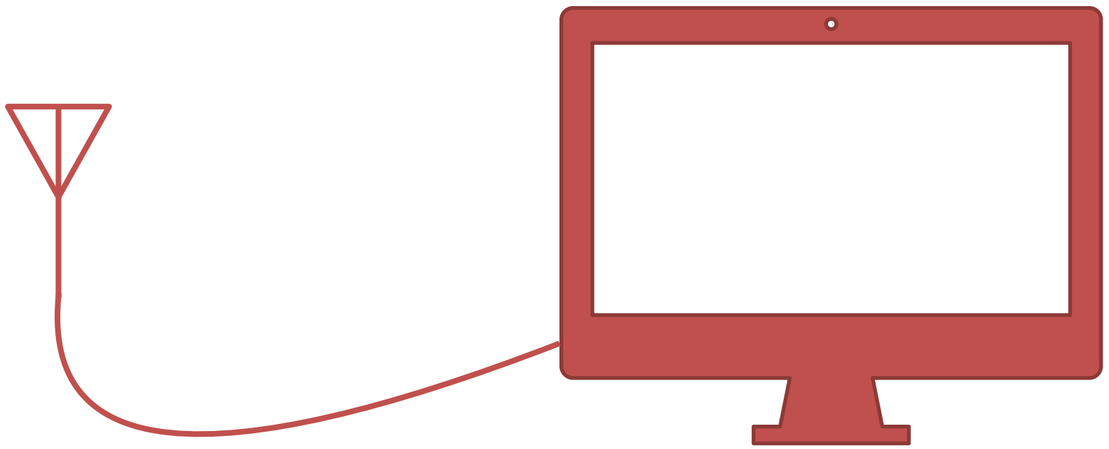


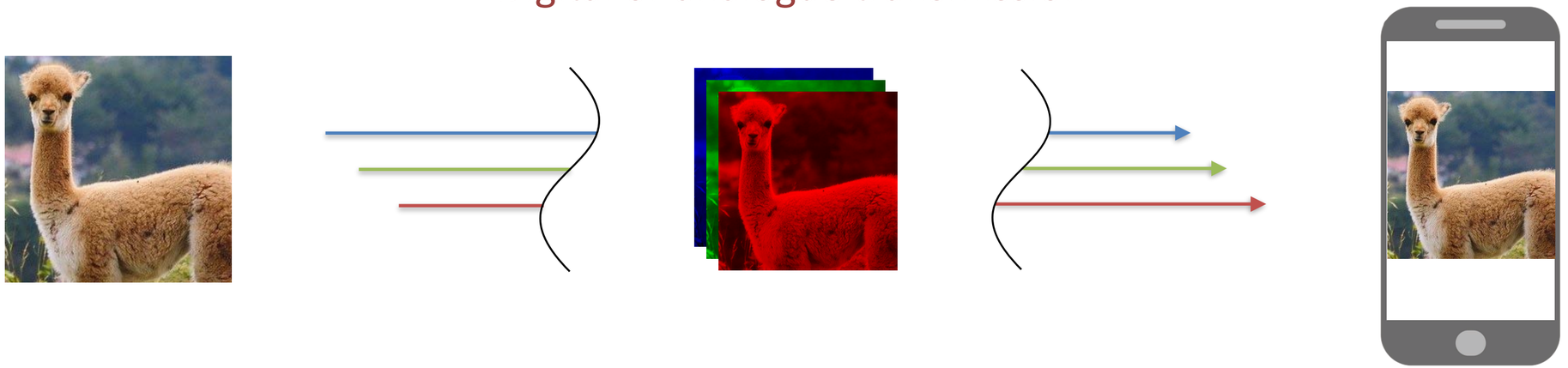


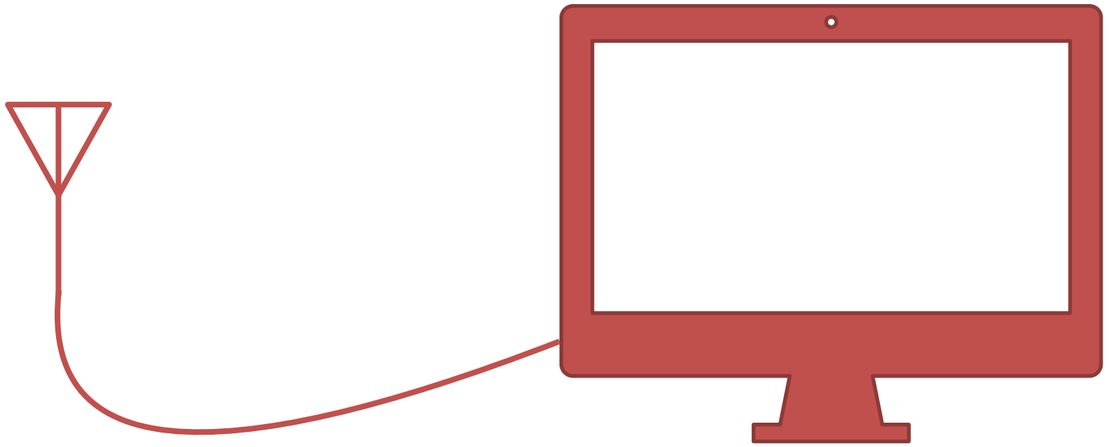




Electromagnetic Emanations

Digital or analogue transmission





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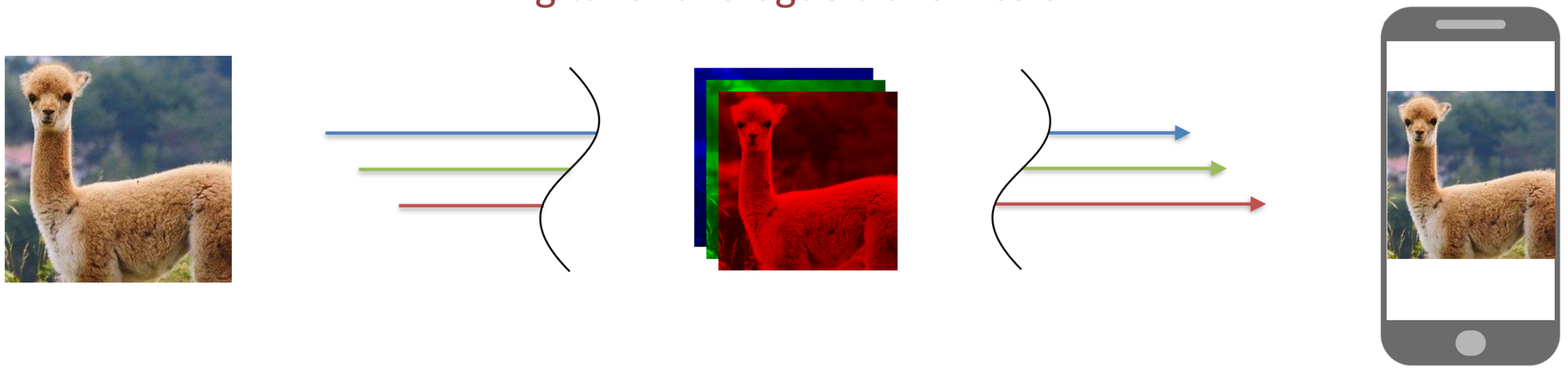

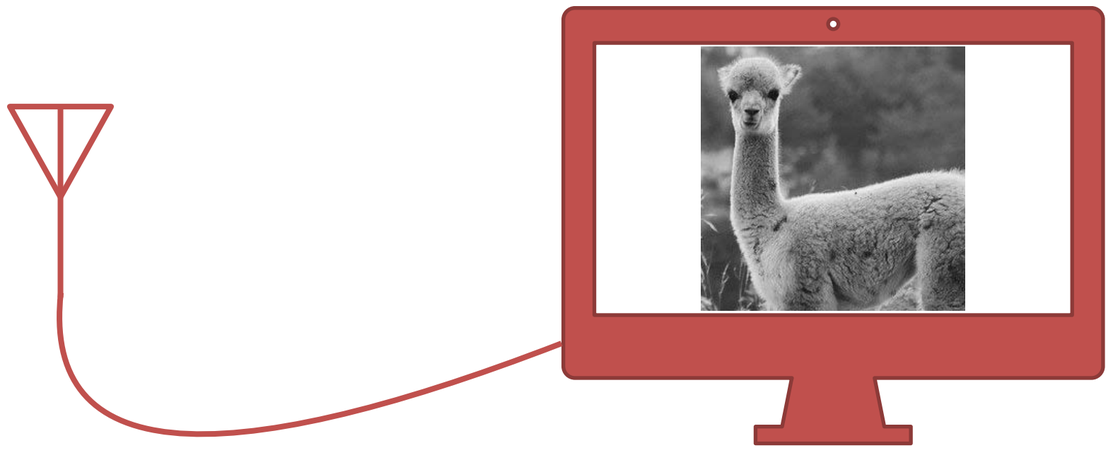

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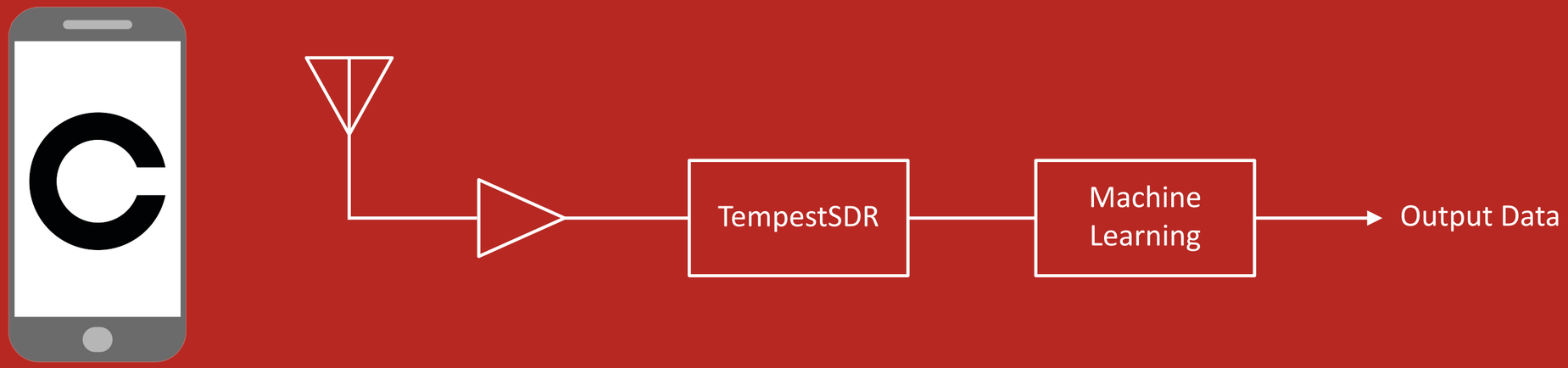

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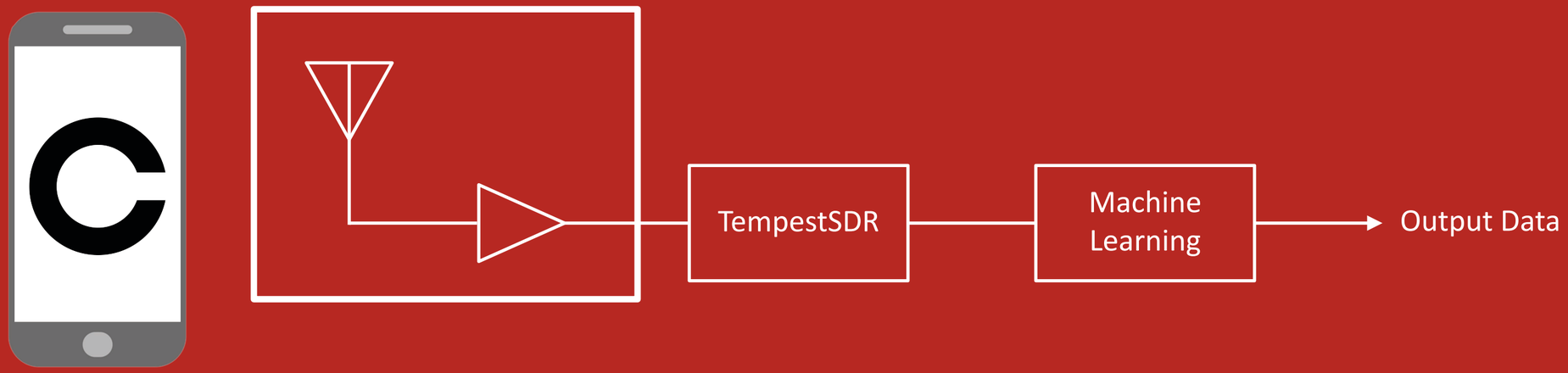

Antenna Positioning

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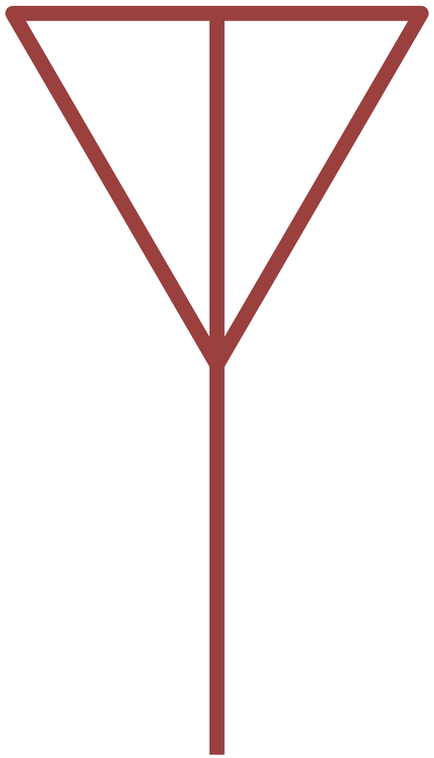
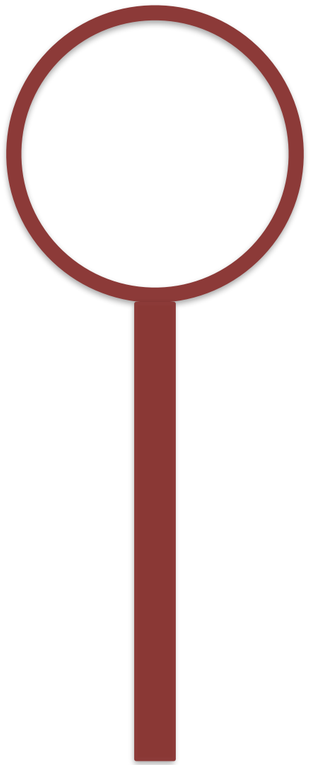


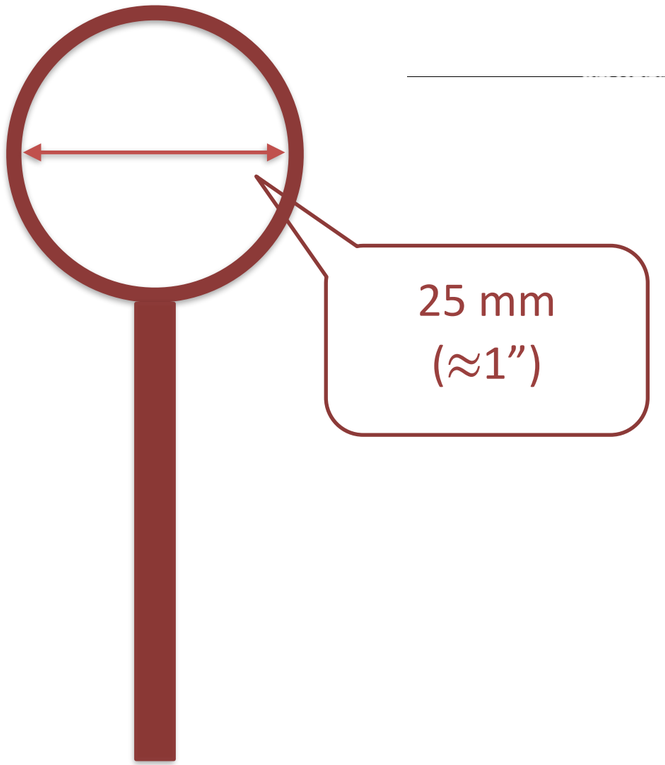
Antenna Positioning

Langer RF-R 400



Antenna Positioning

Langer RF-R 400



Antenna Positioning

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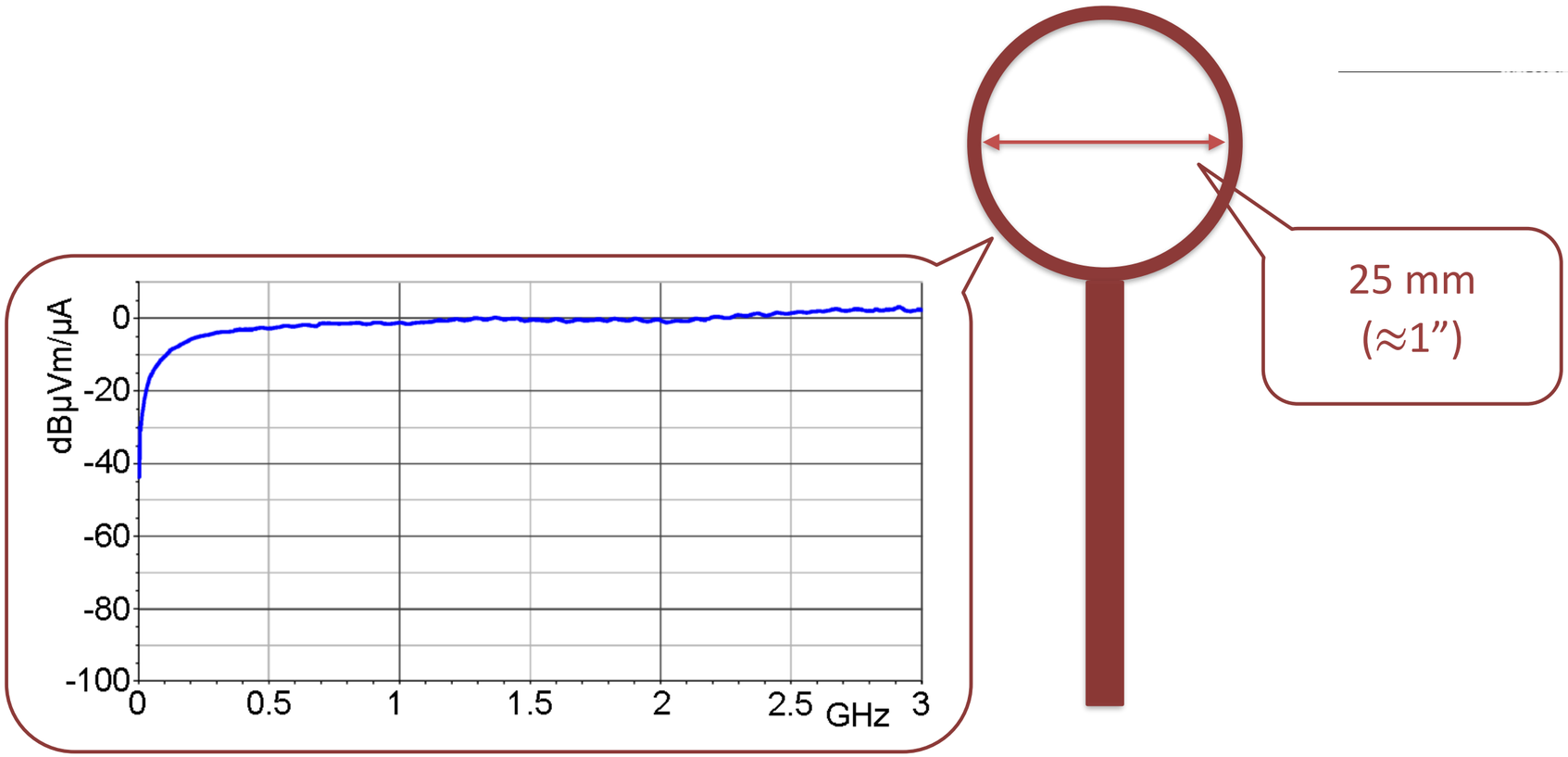
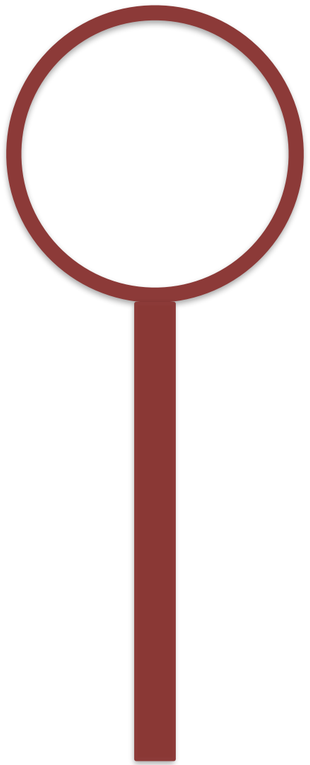
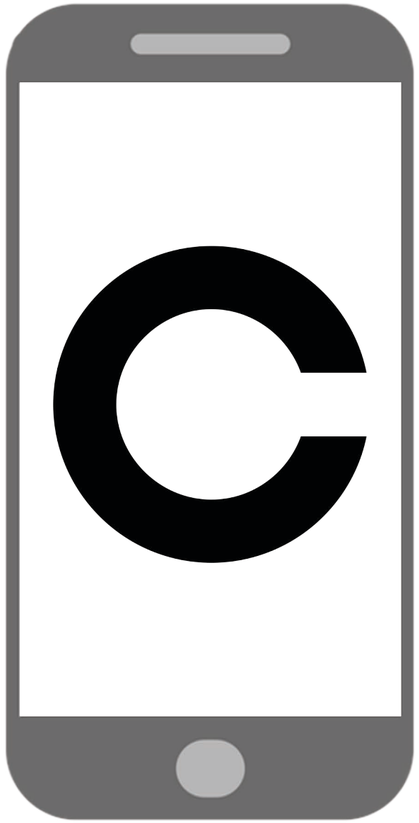


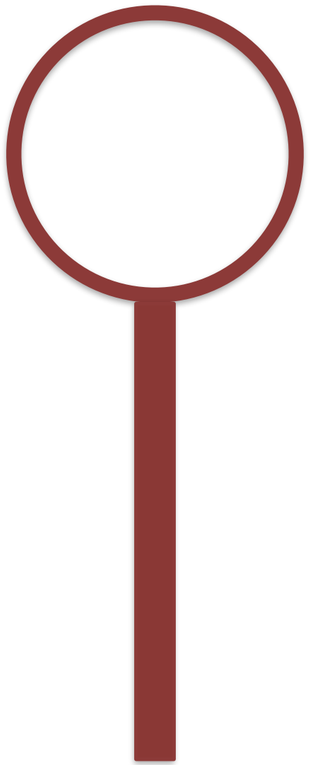
25 mm
(≈1”)

Antenna Positioning



Antenna Positioning





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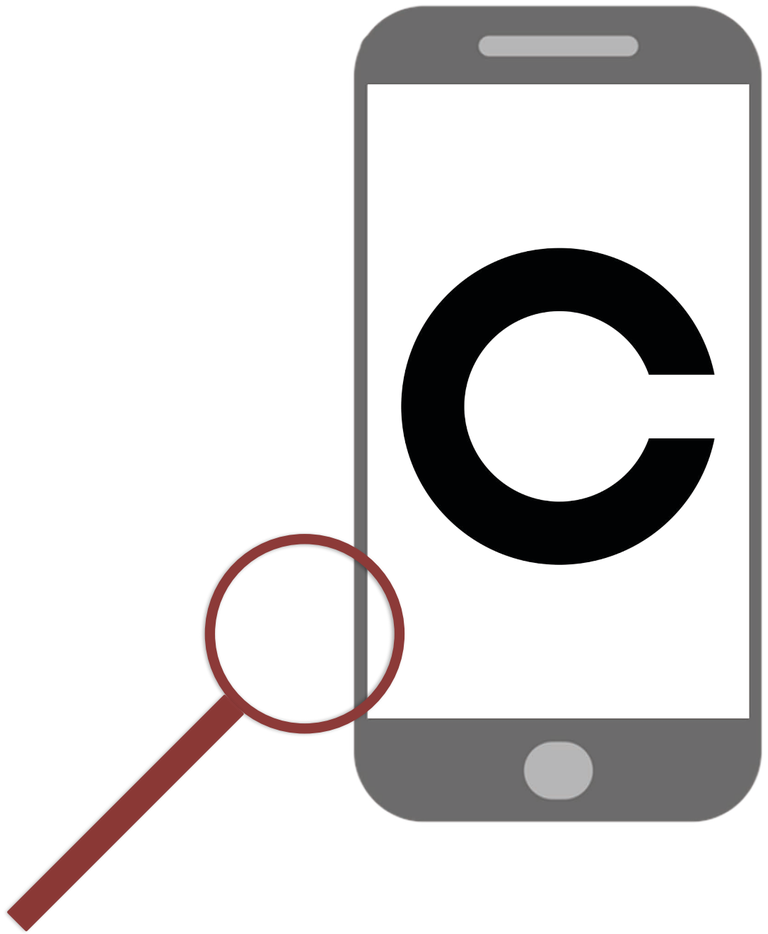

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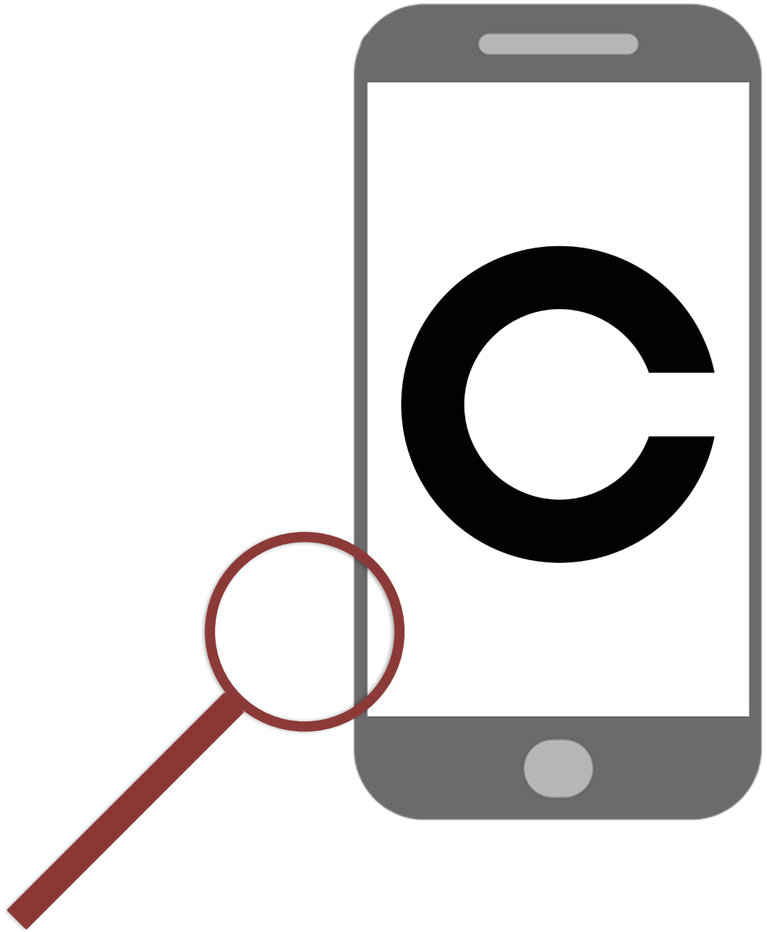
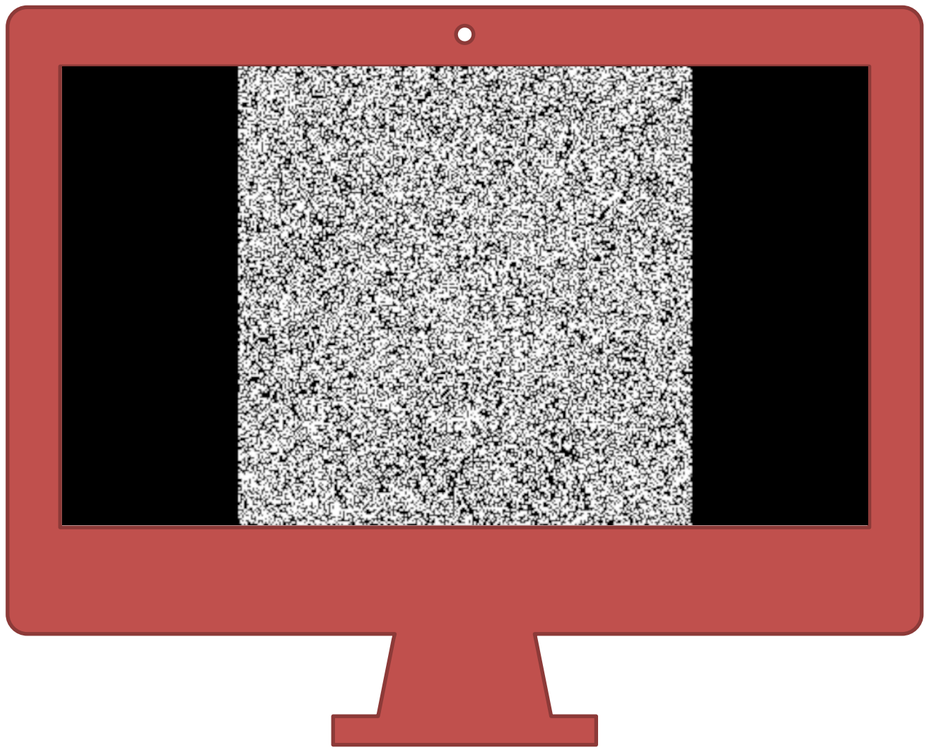
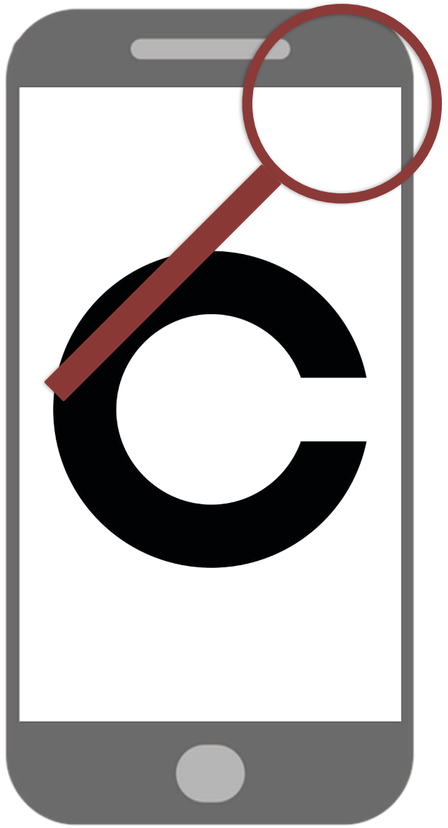
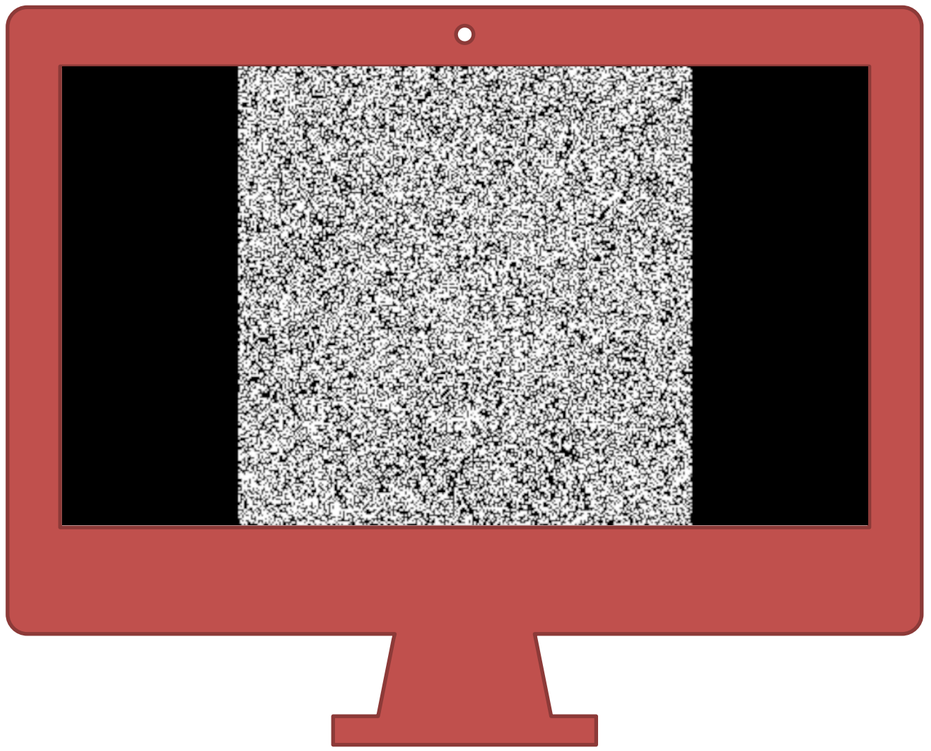




Antenna Positioning





Limitations

[1] Nathan Ida. Engineering electromagnetics. Springer, 2000.

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- Near-Field probes

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  - Only for showing proof of concept

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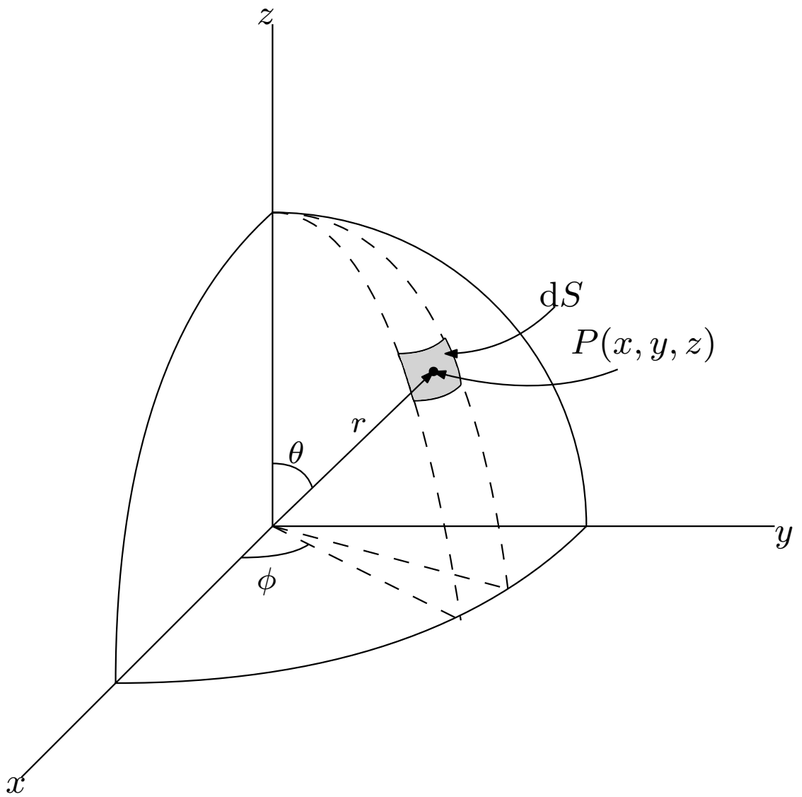

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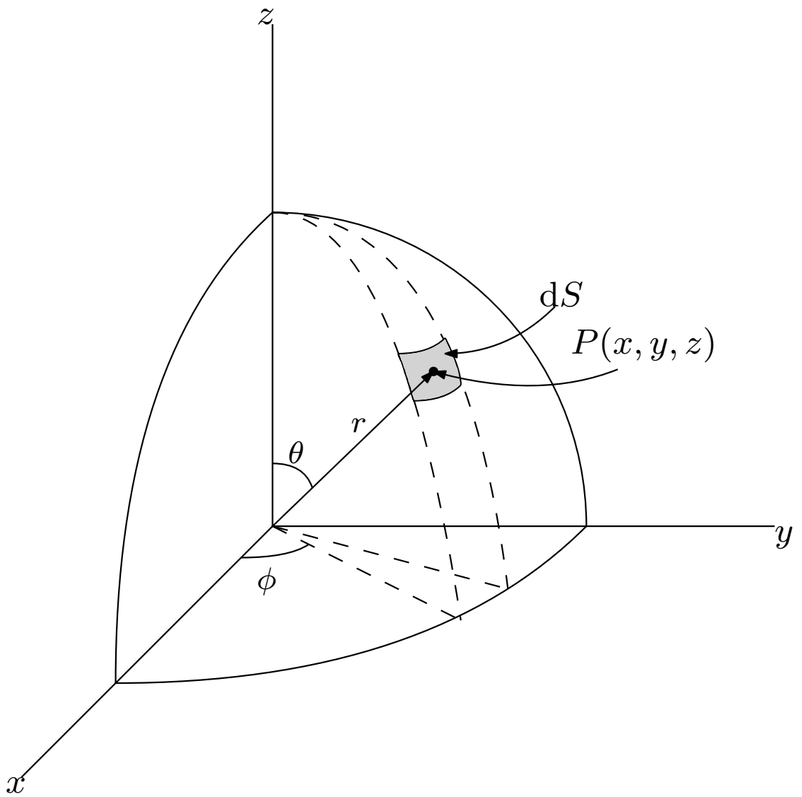

$$\mathscr{P}_{av} = \overrightarrow{e_r}\frac{j\omega\mu m^2}{16\pi r^5}\sin^2\theta - \overrightarrow{e_\theta}\frac{j\omega\mu m^2}{8\pi r^5}\sin\theta\cos\theta$$

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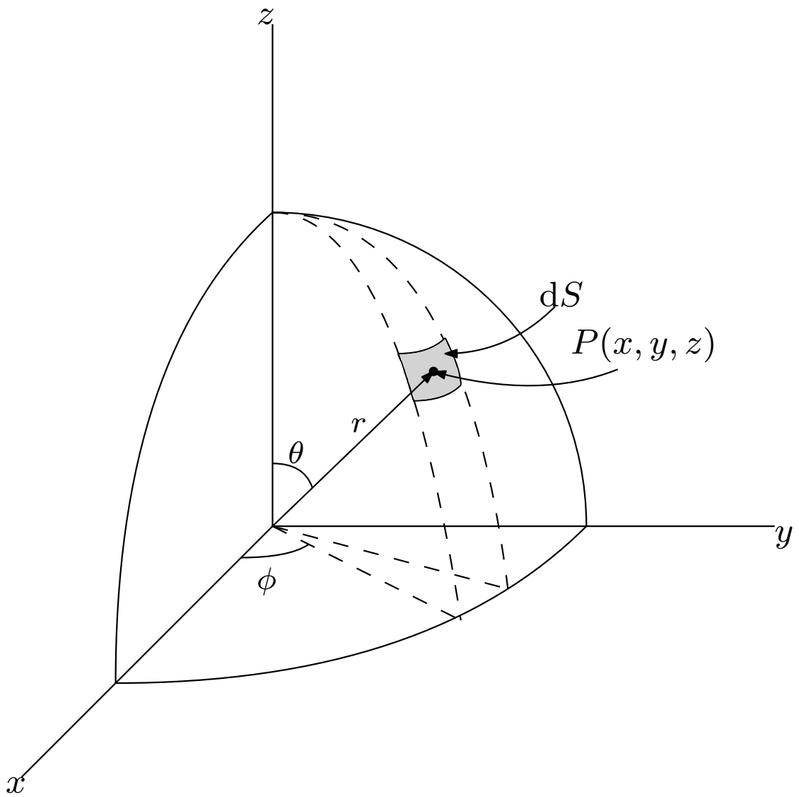

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$m :=$ magnetic moment of loop

$\mu :=$ magnetic permeability

$\omega :=$ angular frequency (i.e., $\omega = 2\pi f$)

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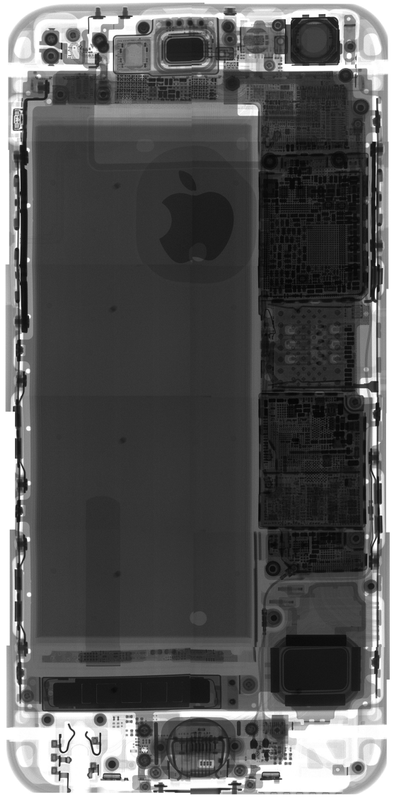
Signal Strength

Signal Strength

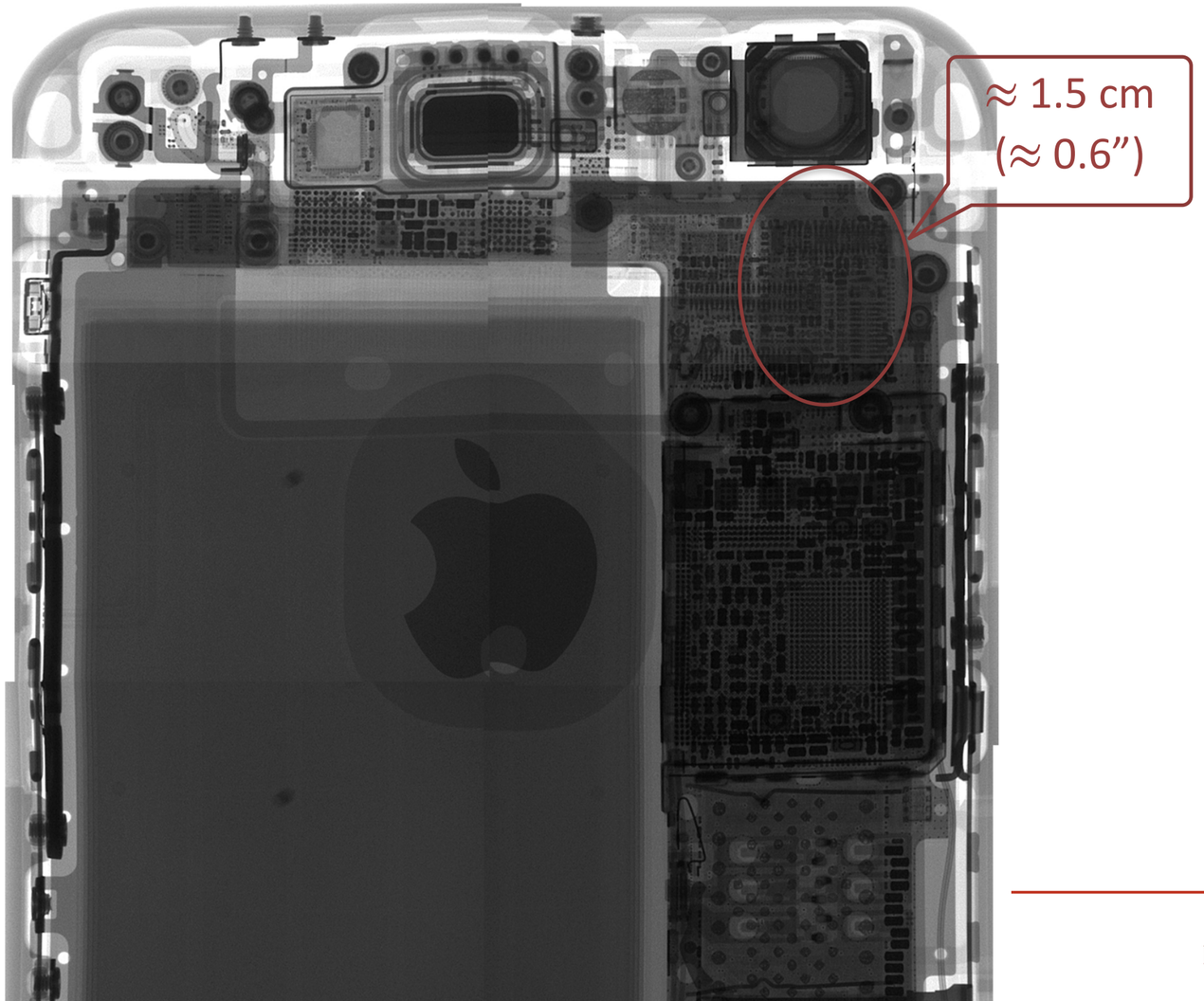


iPhone 6(s)

Signal Strength

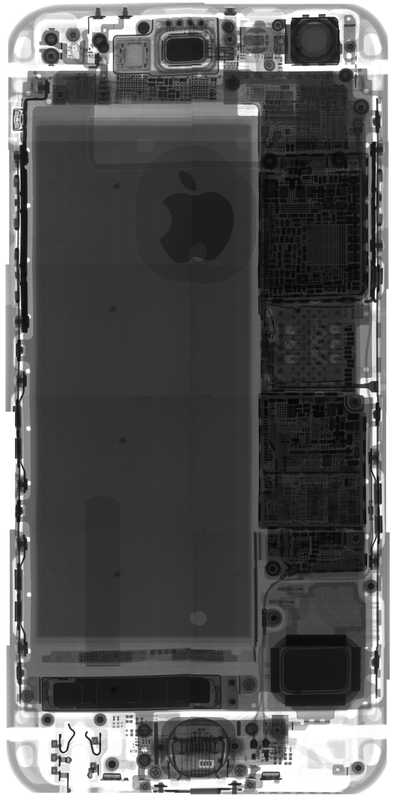
iPhone 6(s)

Signal Strength



iPhone 6(s)

Signal Strength



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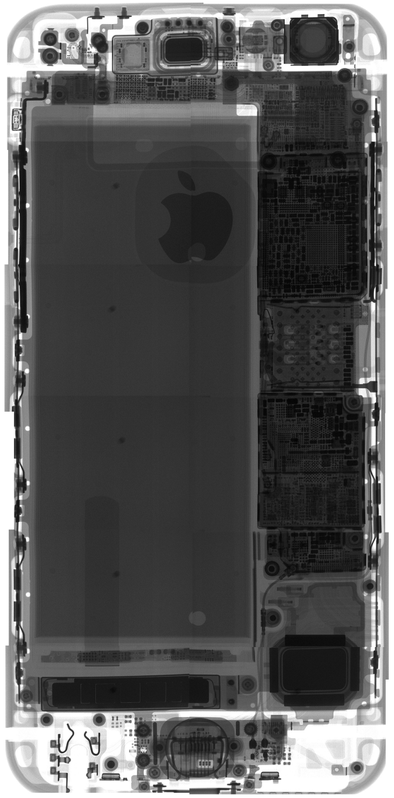
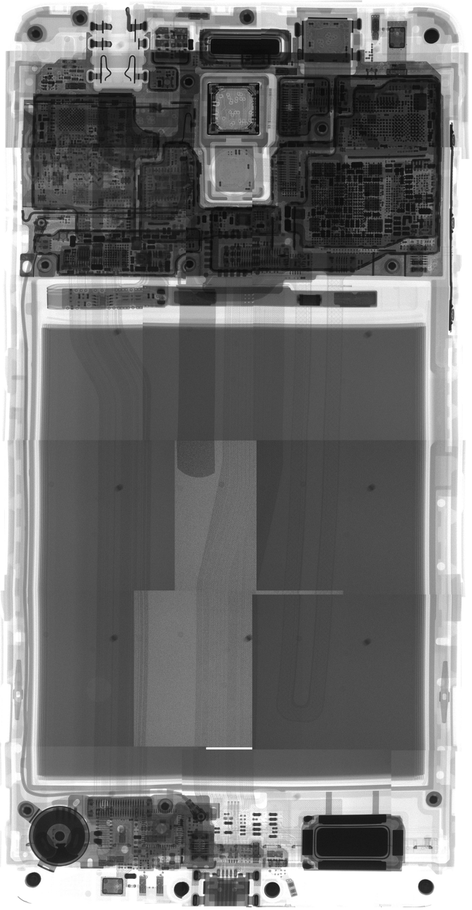
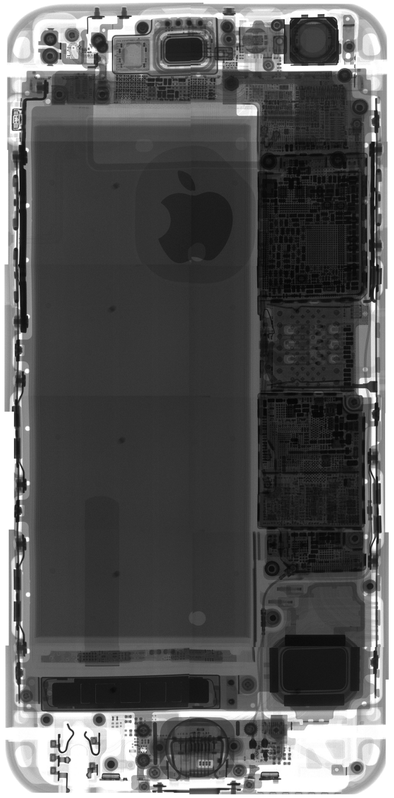


iPhone 6(s)



Honor 6X

Signal Streng



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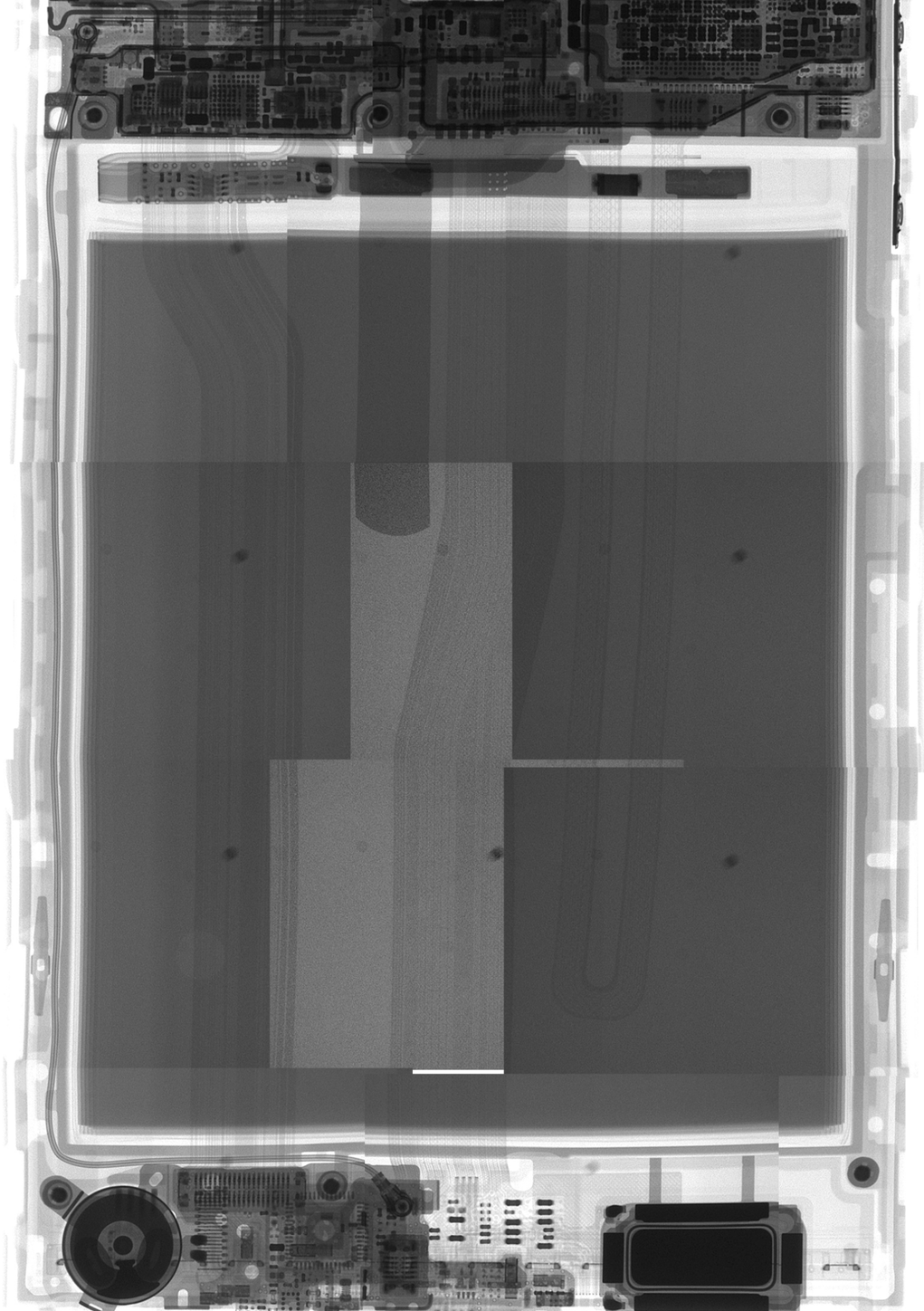
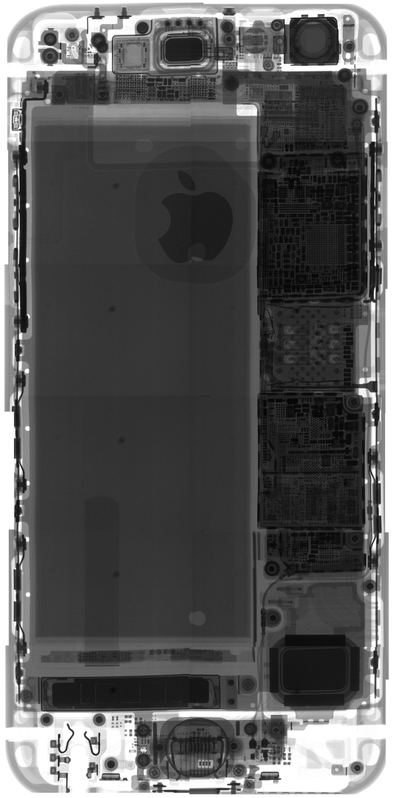


Signal Streng



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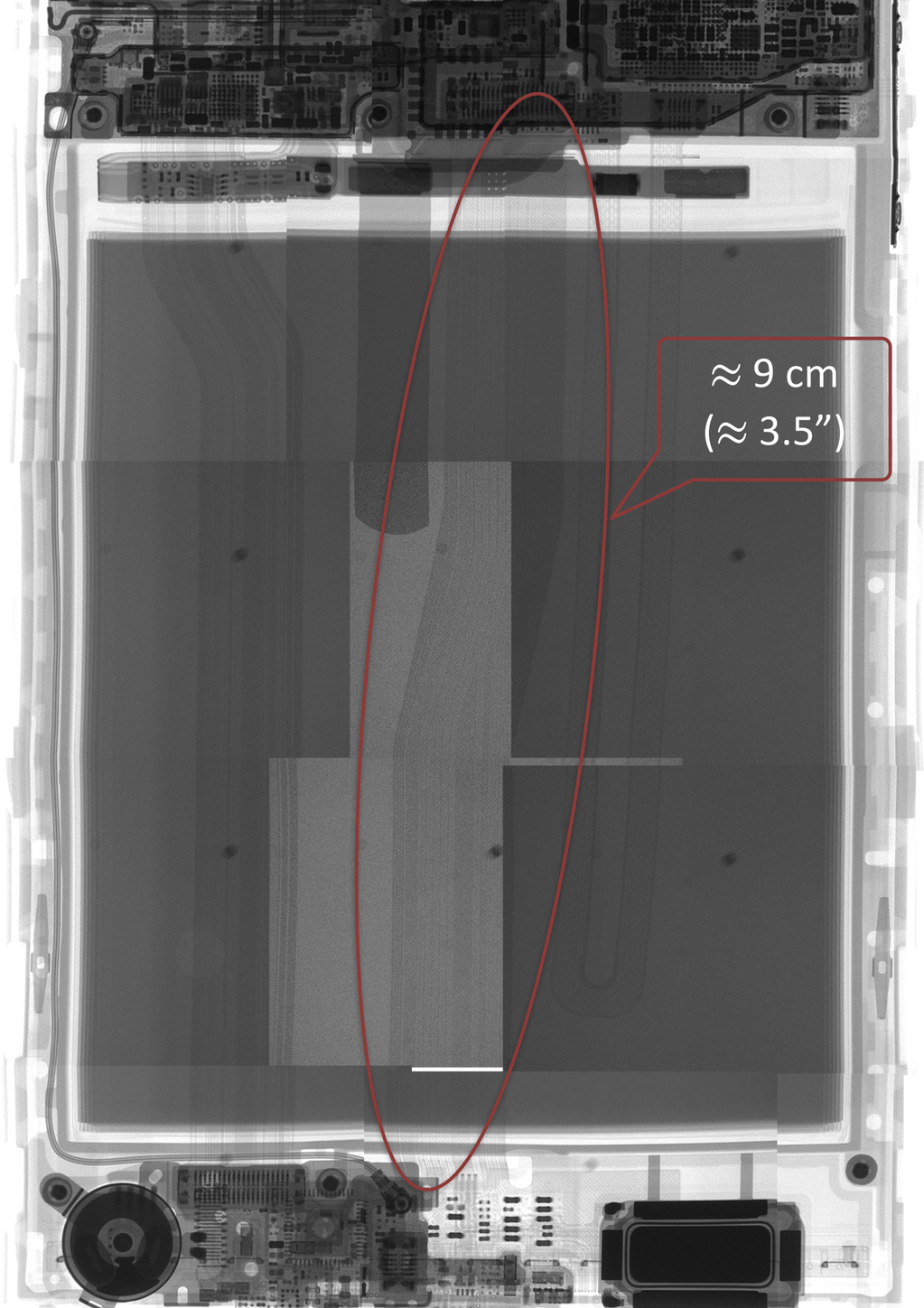
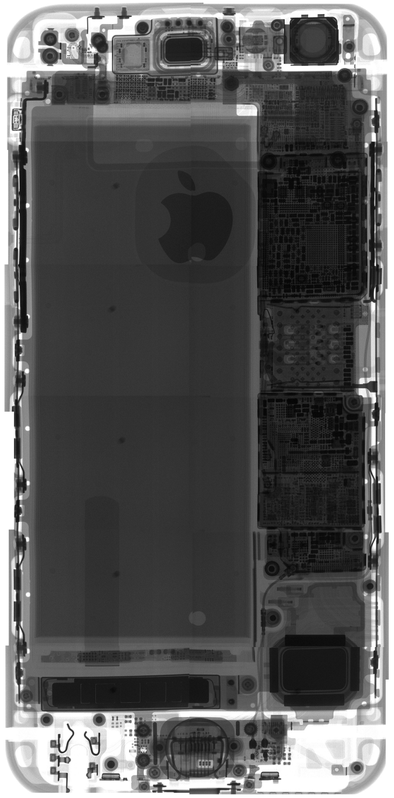


Signal Strength



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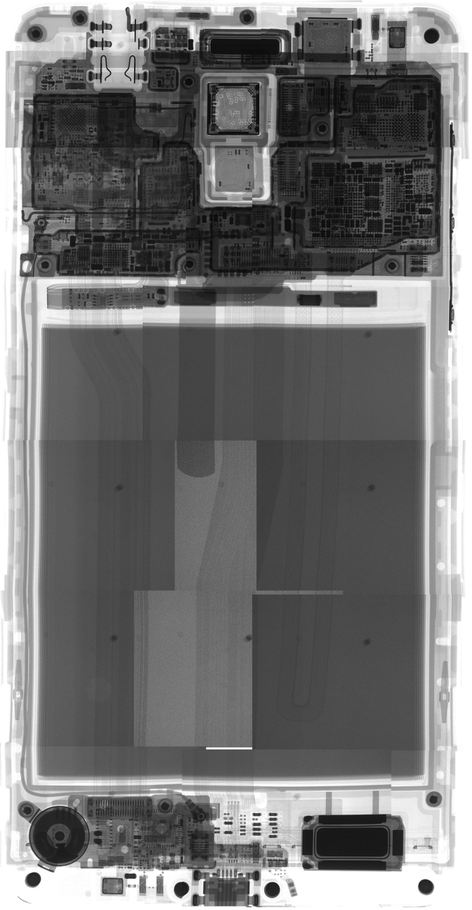

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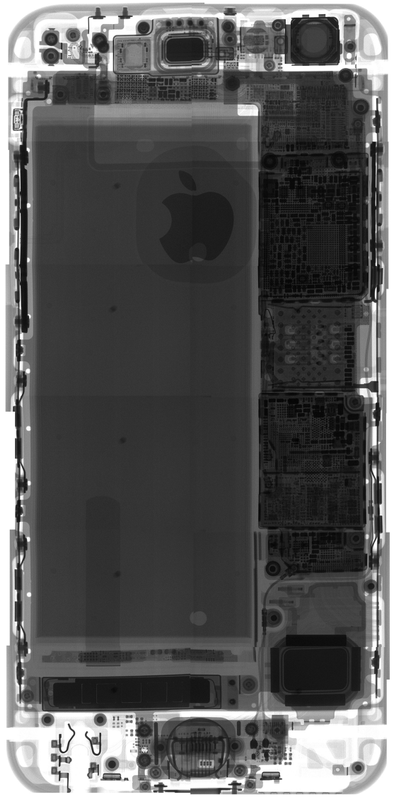
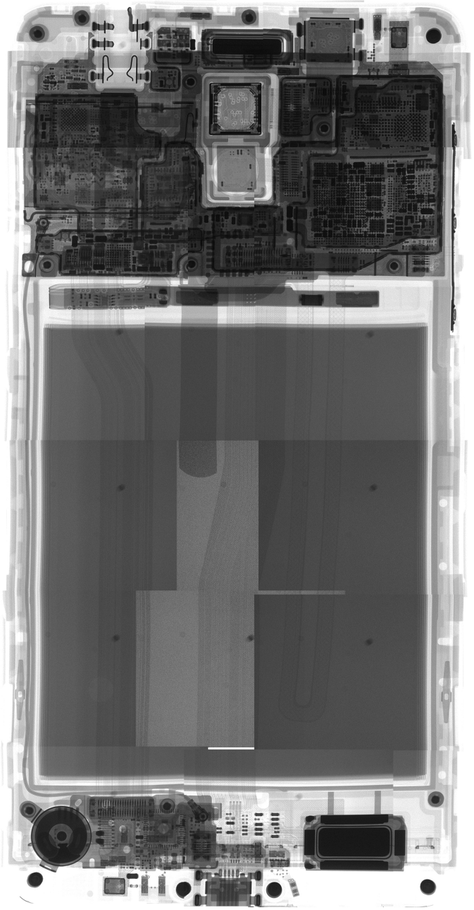


iPhone 6(s)



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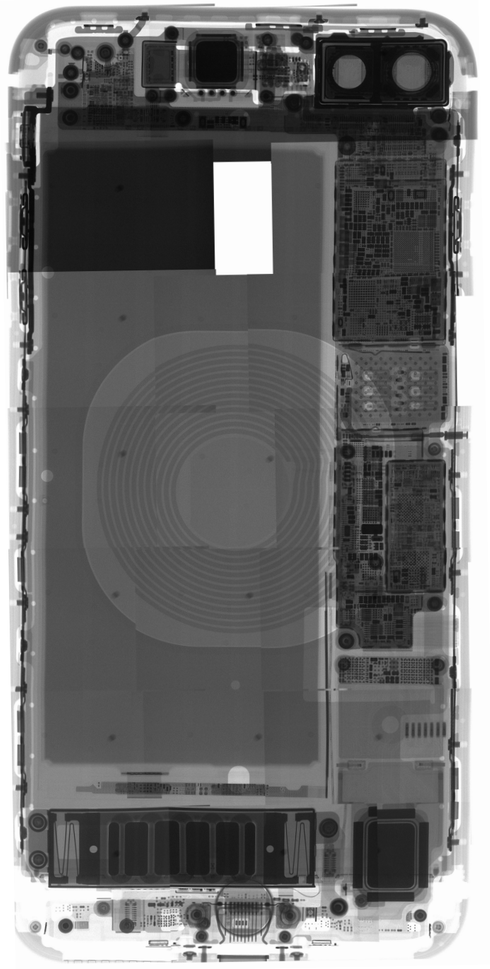
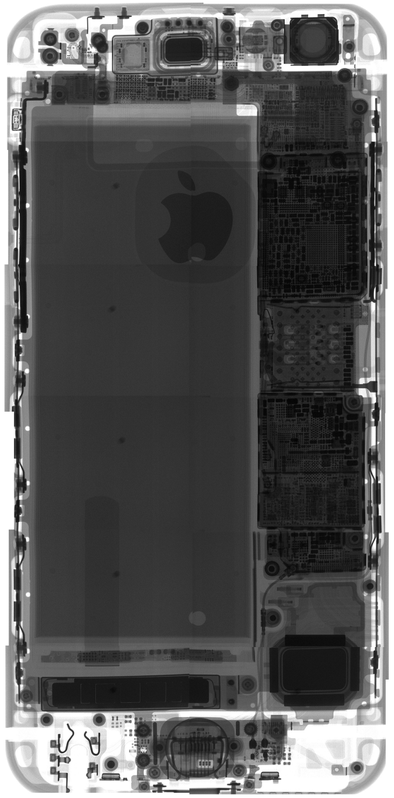


iPhone 8 Plus

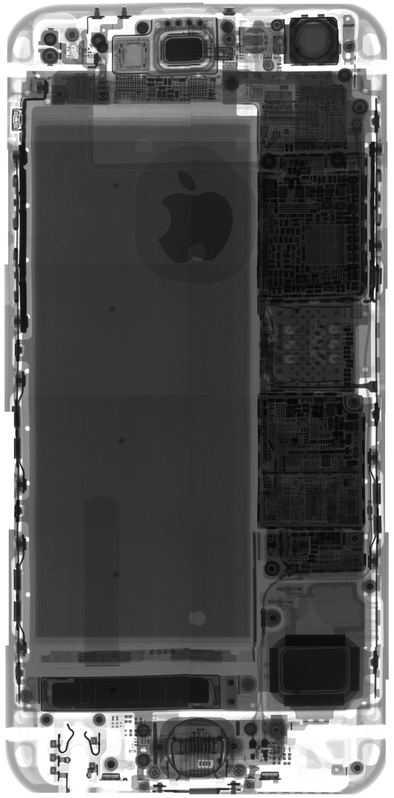
Signal Streng



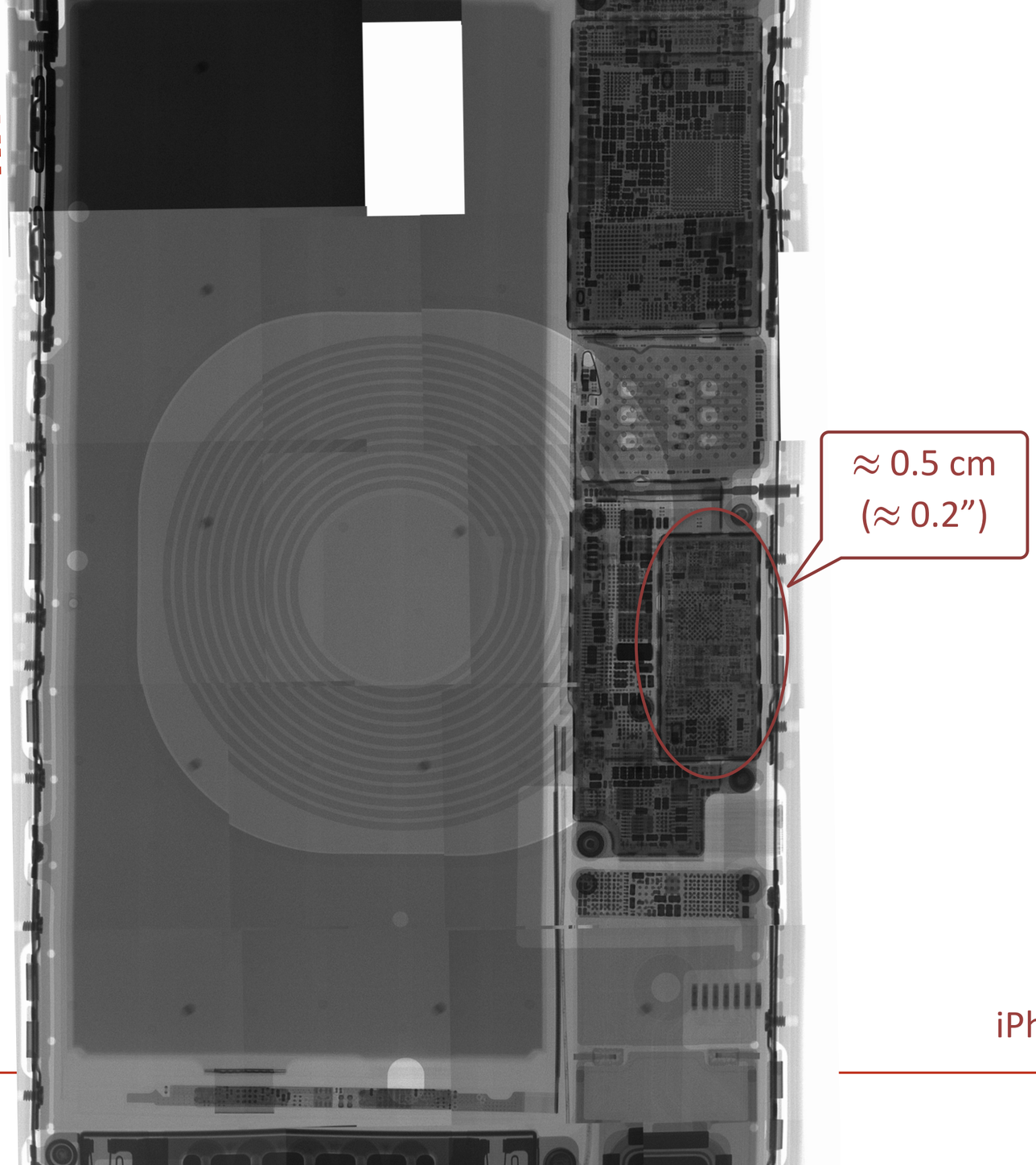
iPhone 6(s)

iPhone 8 Plus

Signal Streng



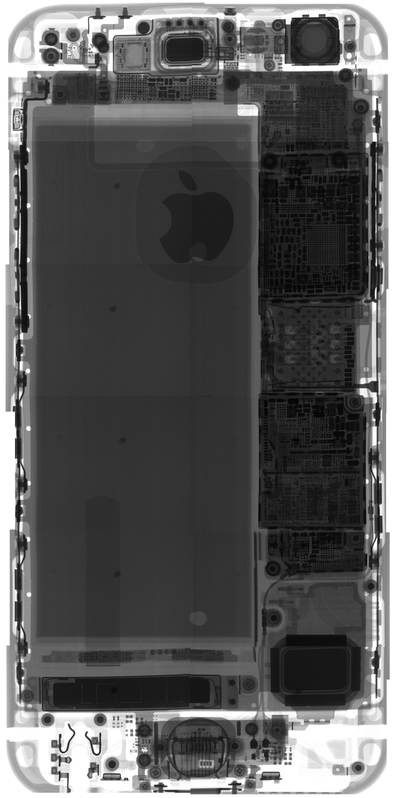
iPhone 6(s)



iPhone 8 Plus

Signal Streng

Better shielding
(More power to X-ray)

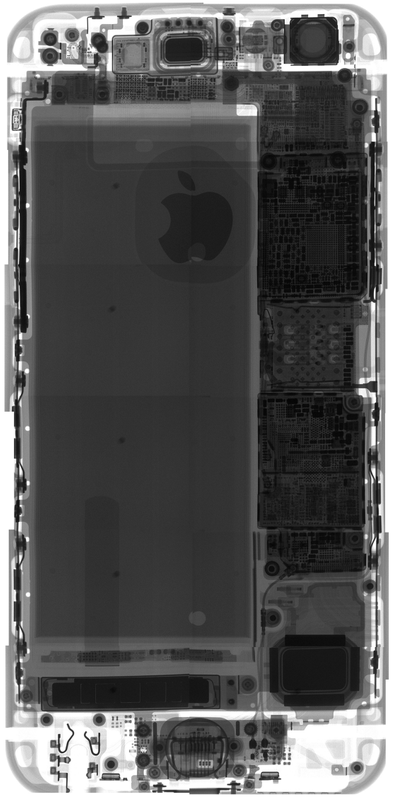


iPhone 6(s)

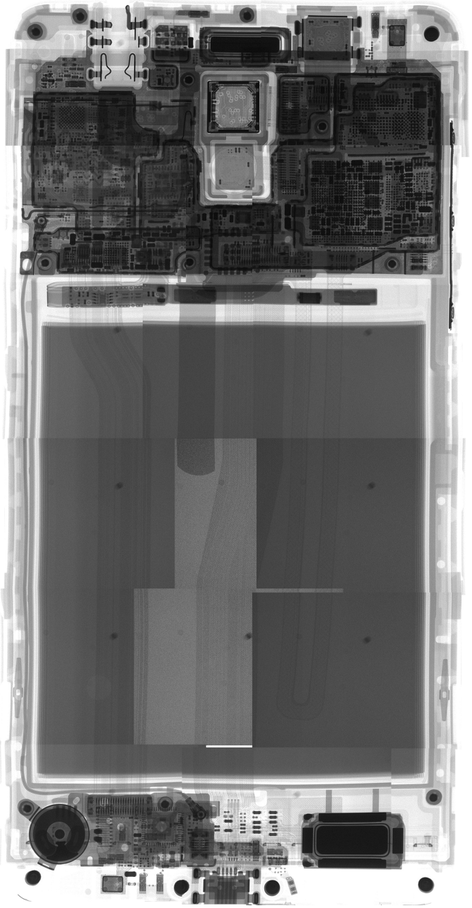
≈ 0.5 cm
(≈ 0.2”)

iPhone 8 Plus

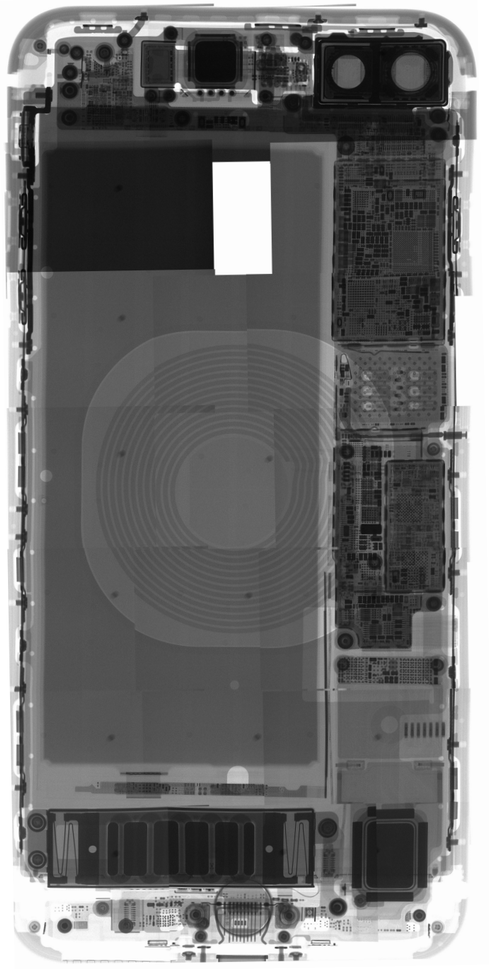
Signal Strength



iPhone 6(s)



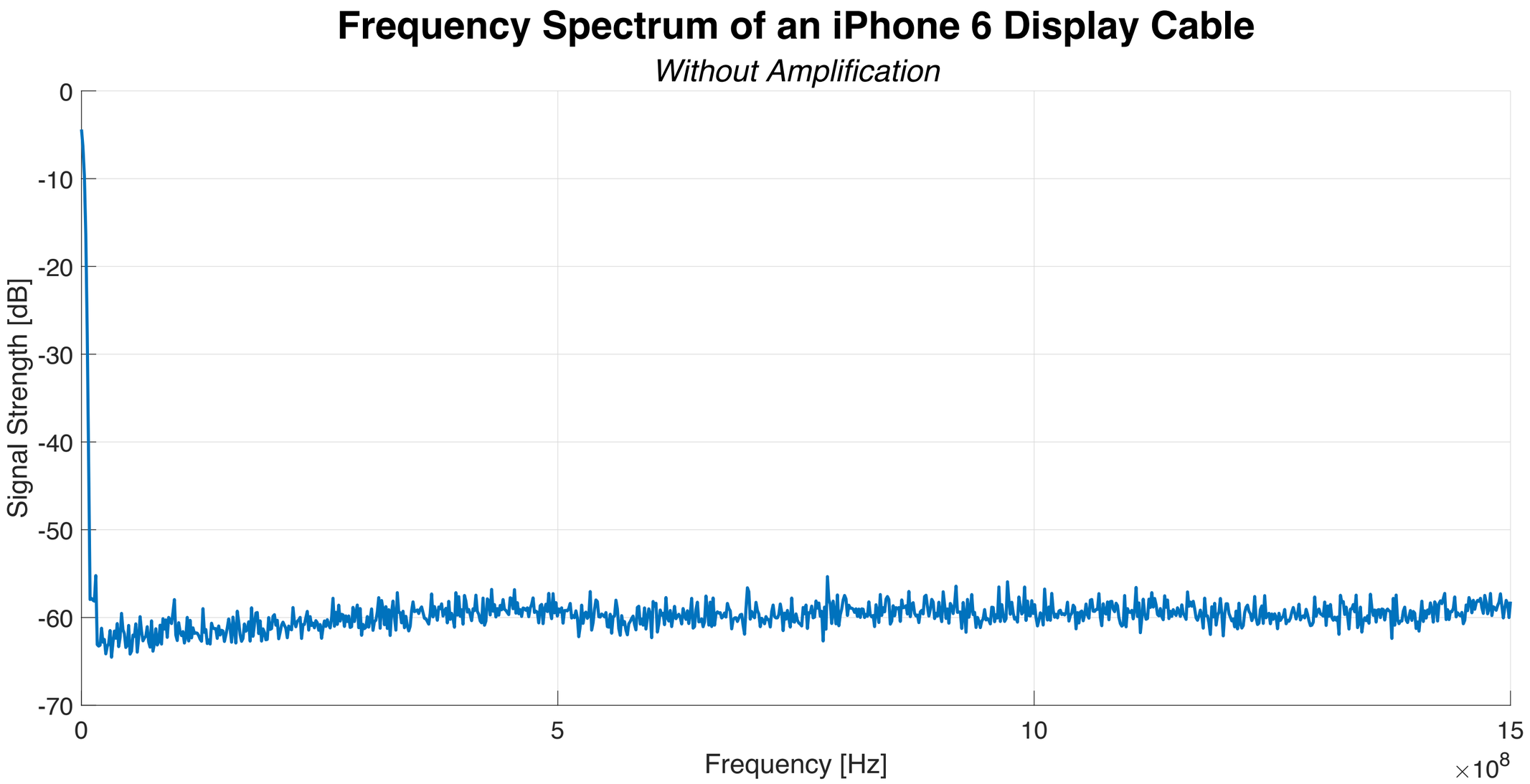
Honor 6X



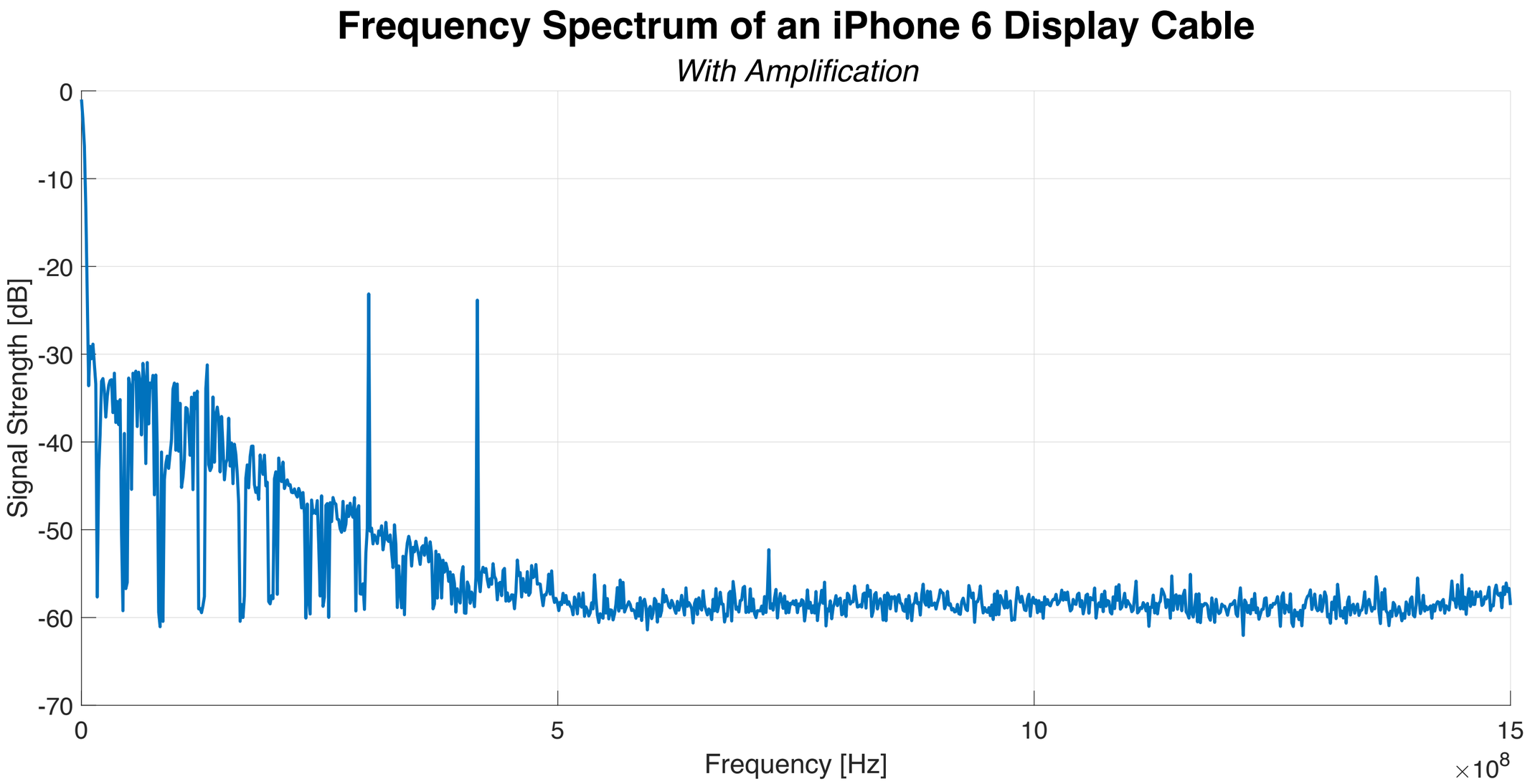
iPhone 8 Plus

Amplification

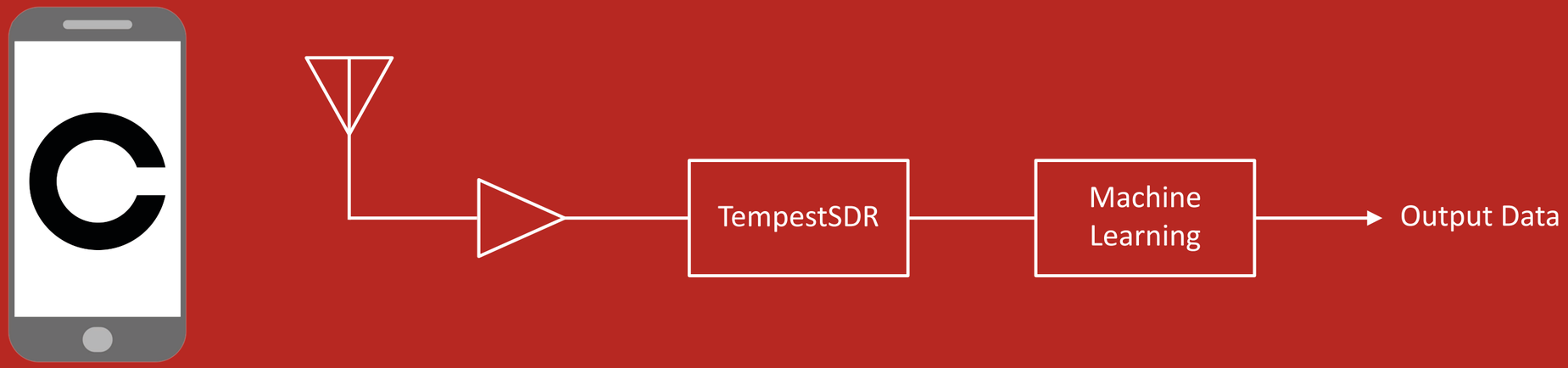
Amplification



Amplification



TempestSDR



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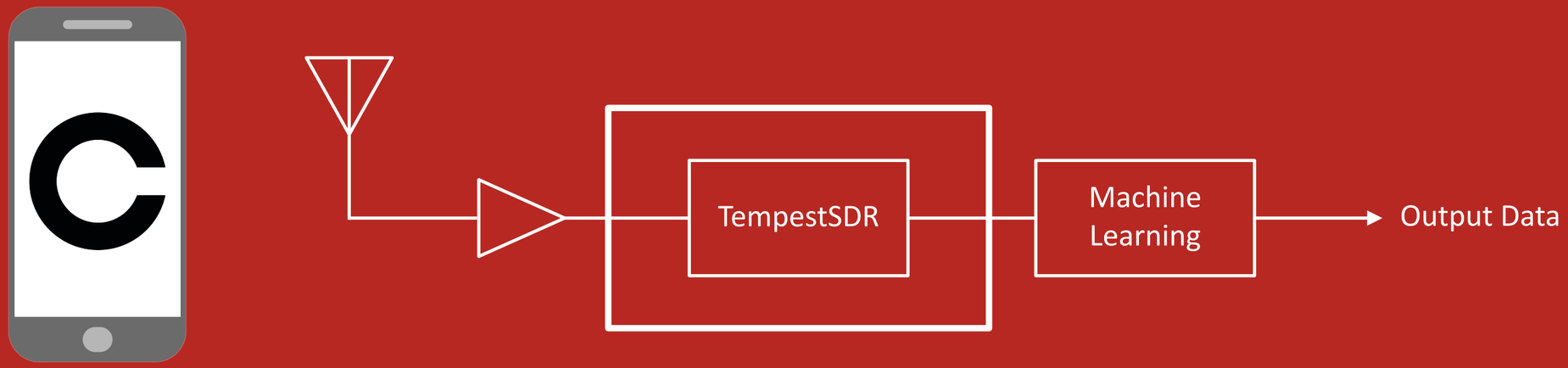
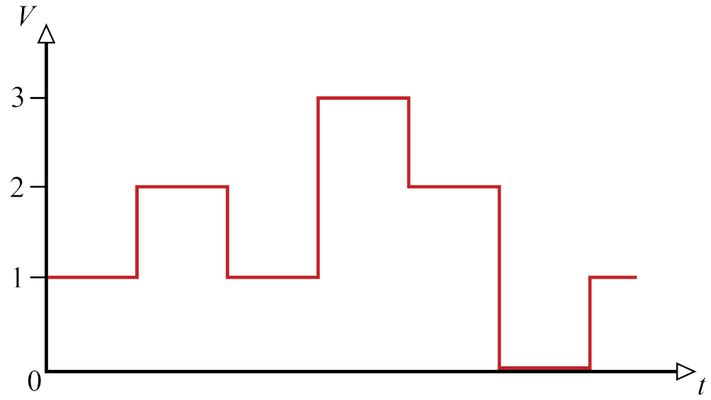


Schematic Design

Schematic Design



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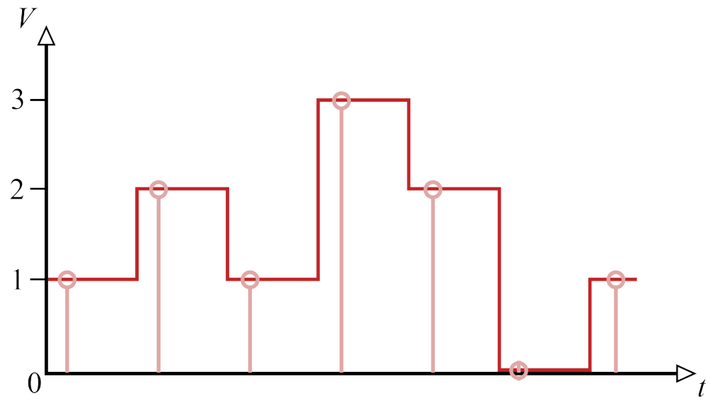

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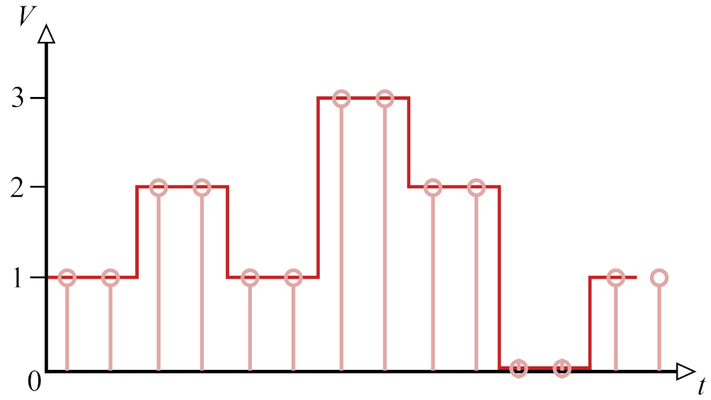
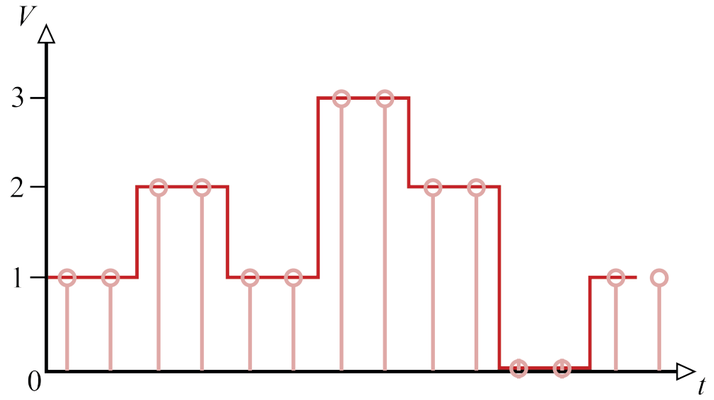


Schematic Design



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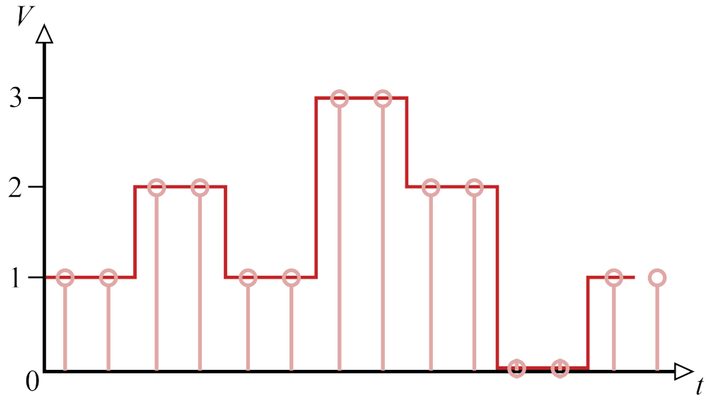

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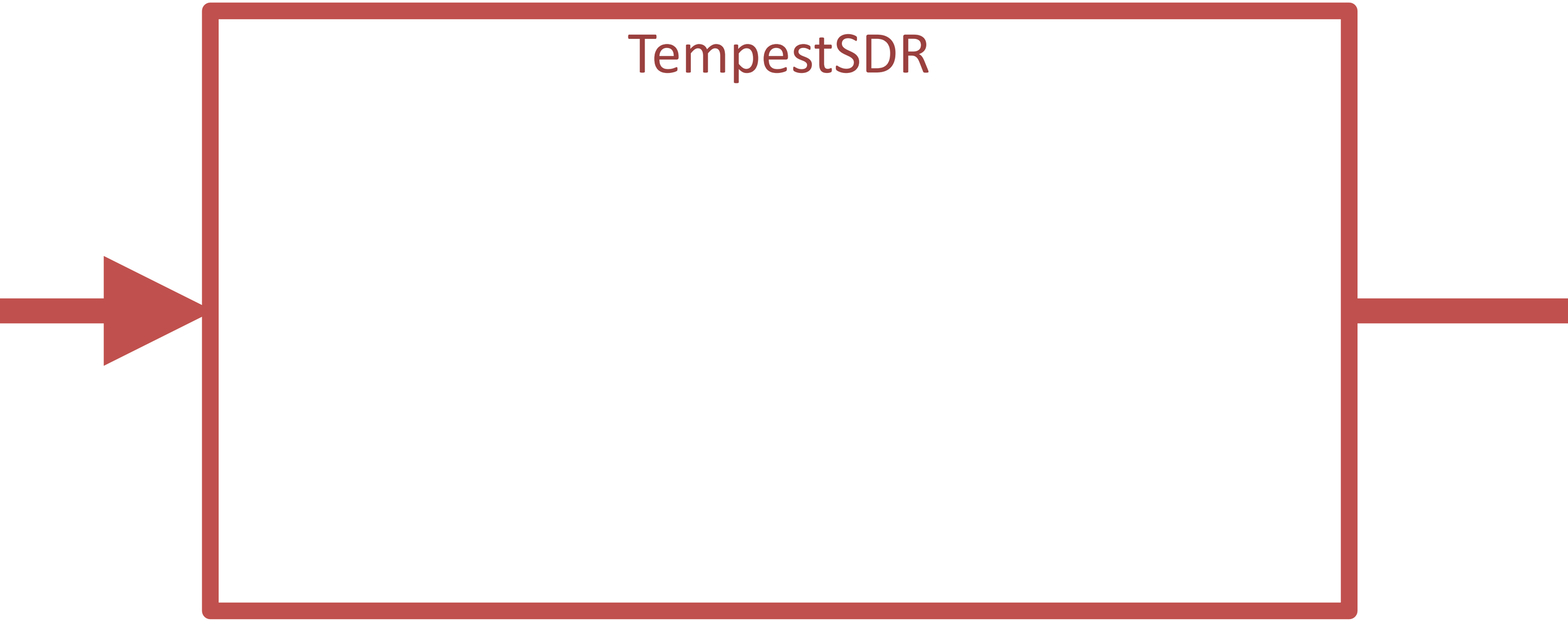
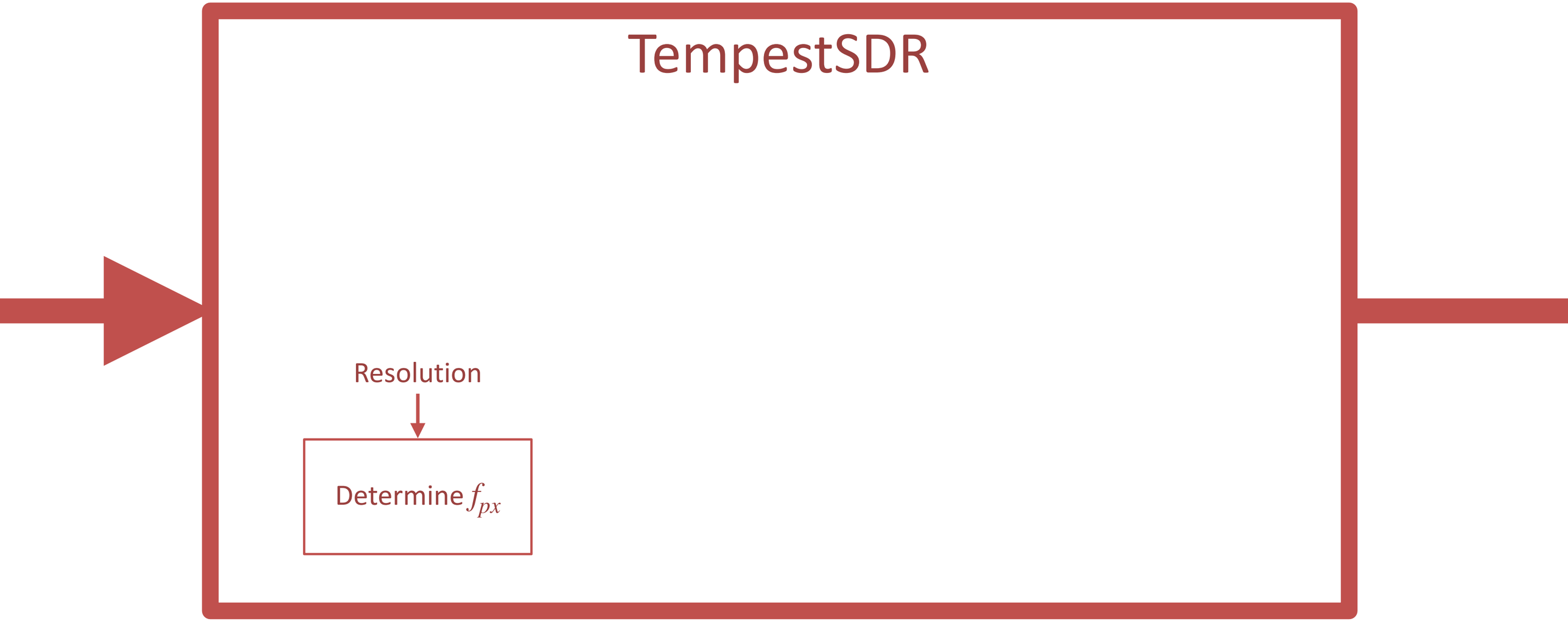
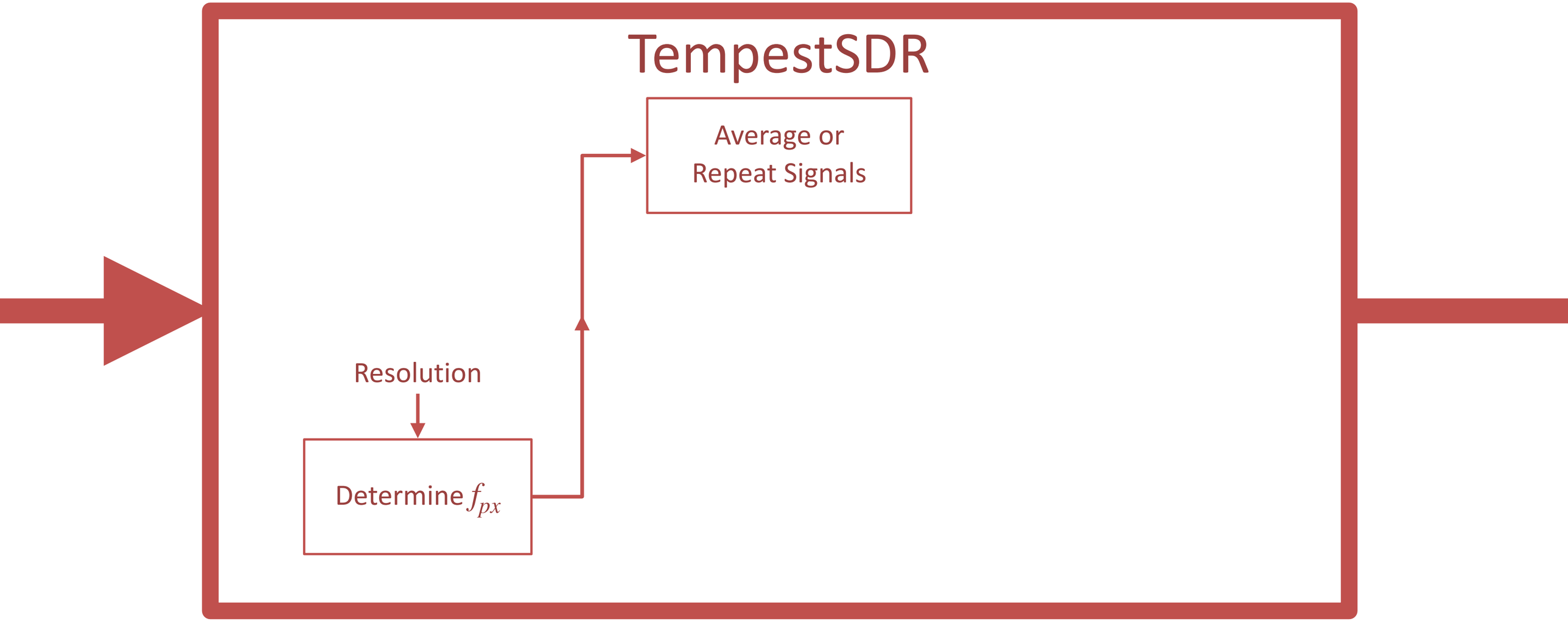


Schematic Design



Schematic Design



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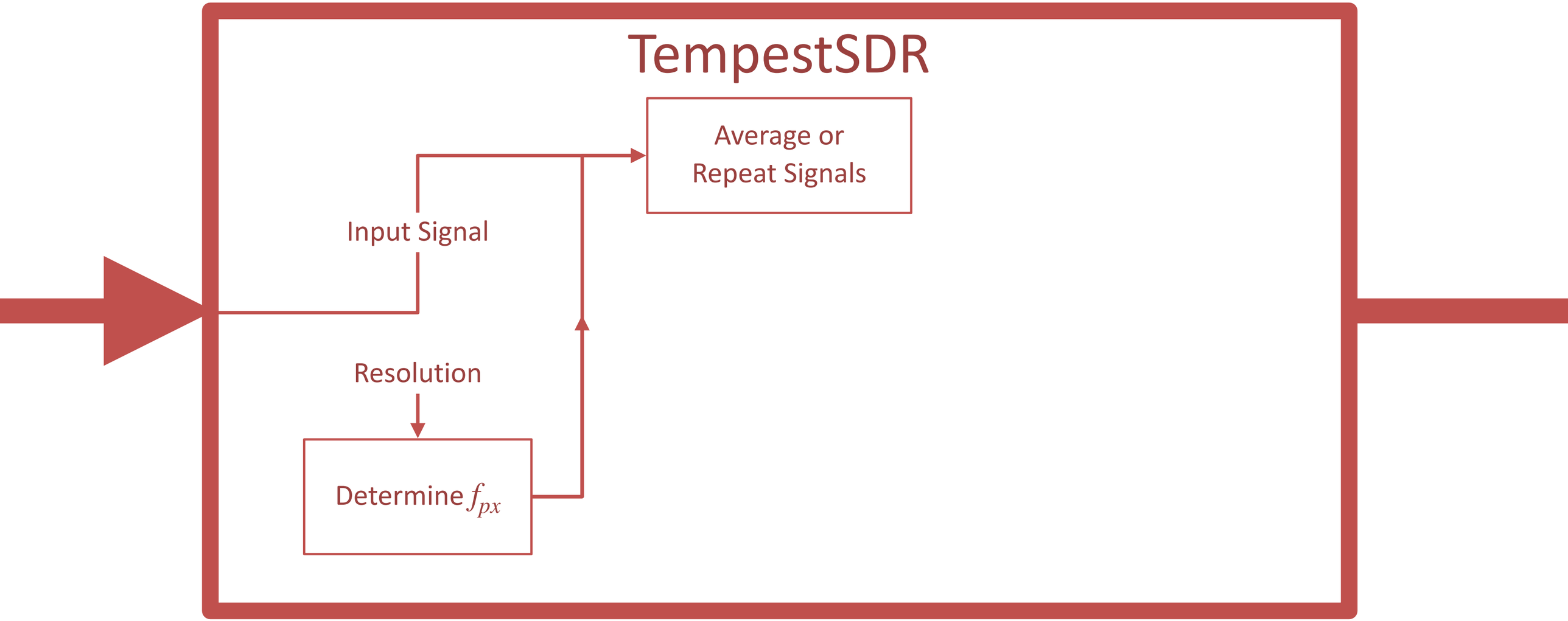

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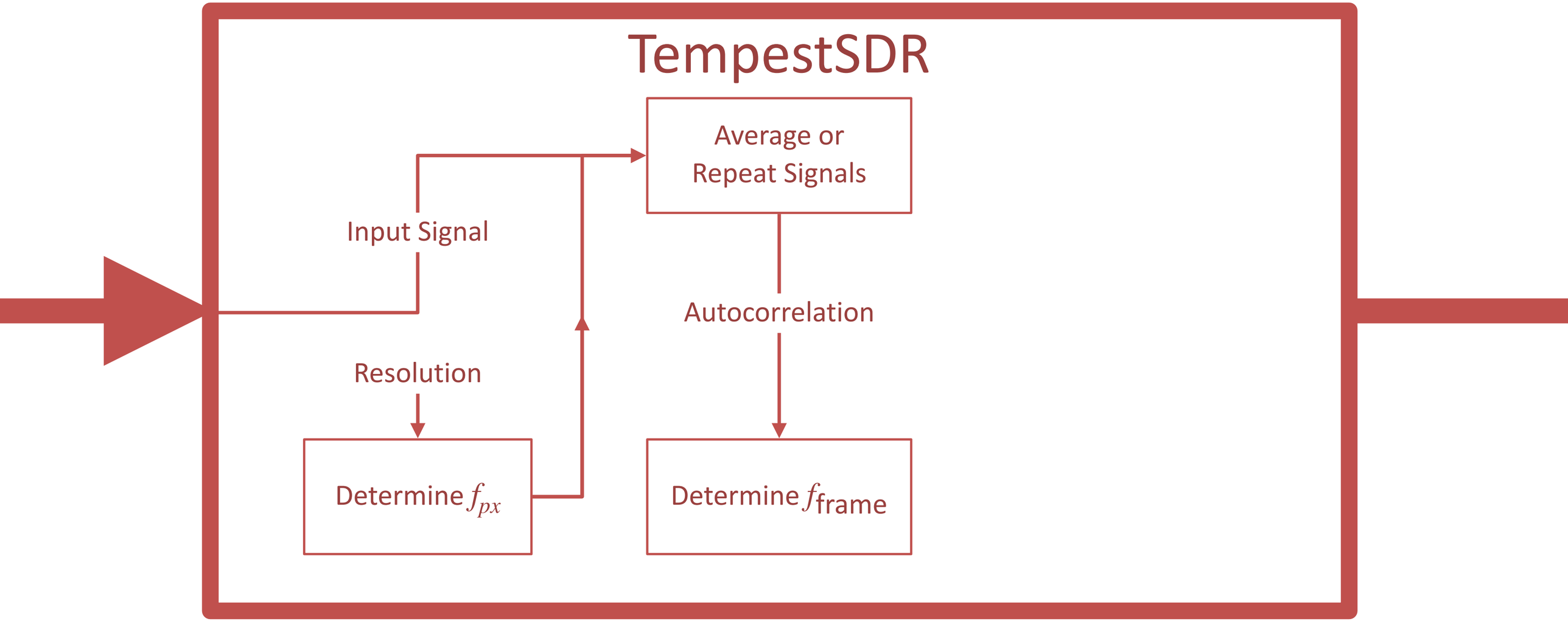

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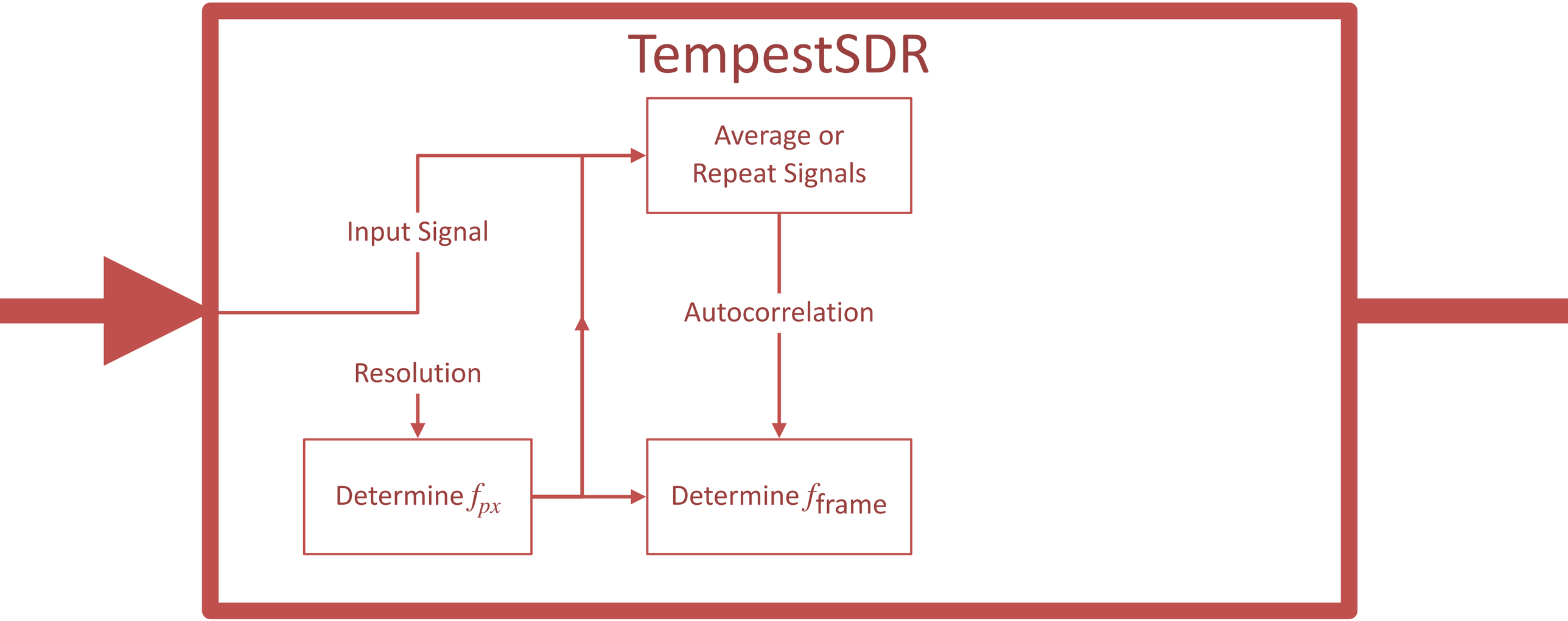

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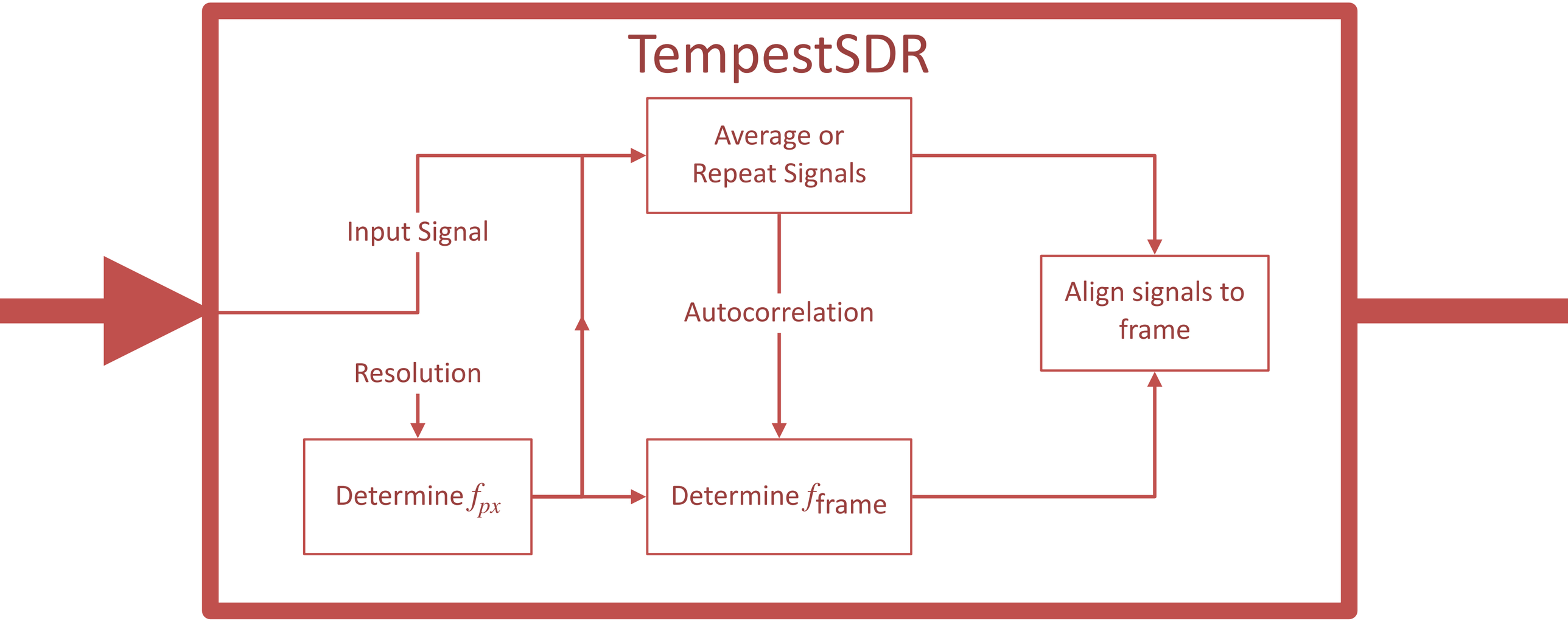
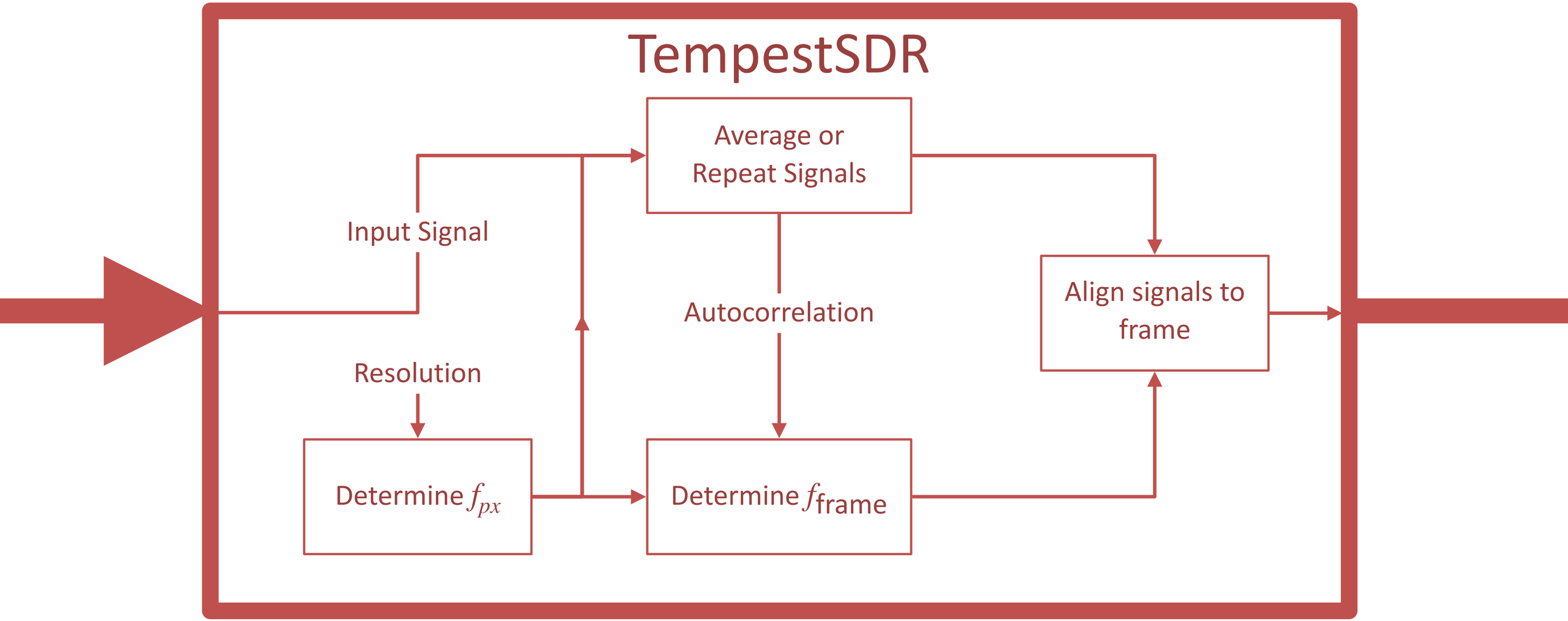
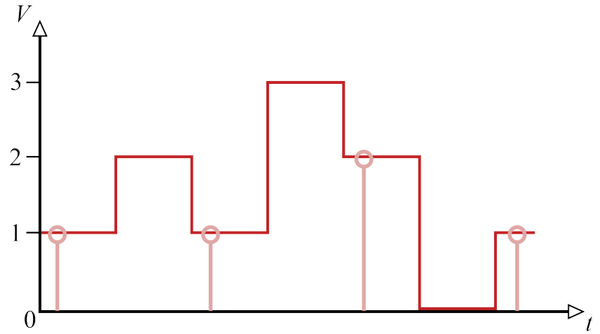


Schematic Design

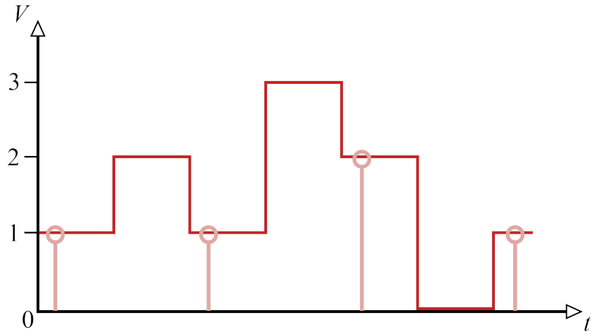


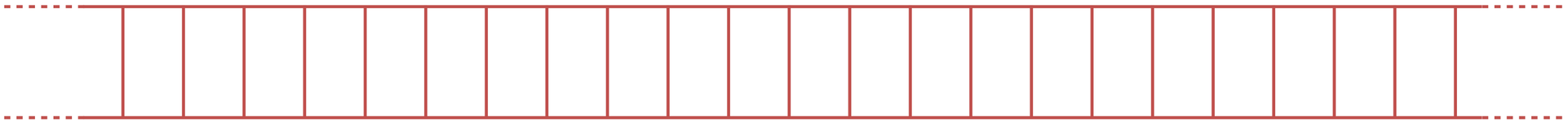
Distinguishing Pixels

Distinguishing Pixels

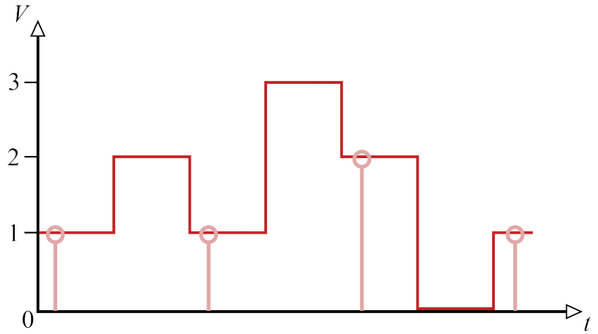


Distinguishing Pixels

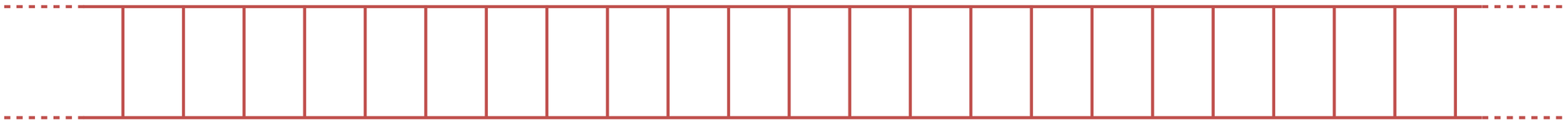




Distinguishing Pixels

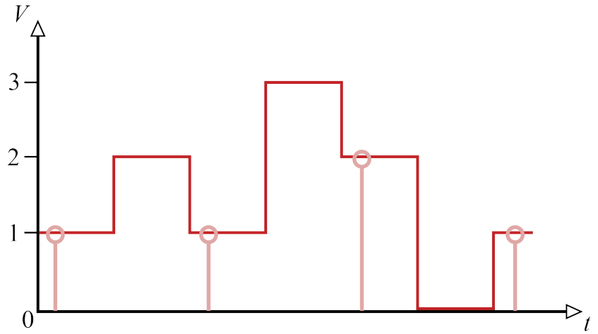


Input Signal

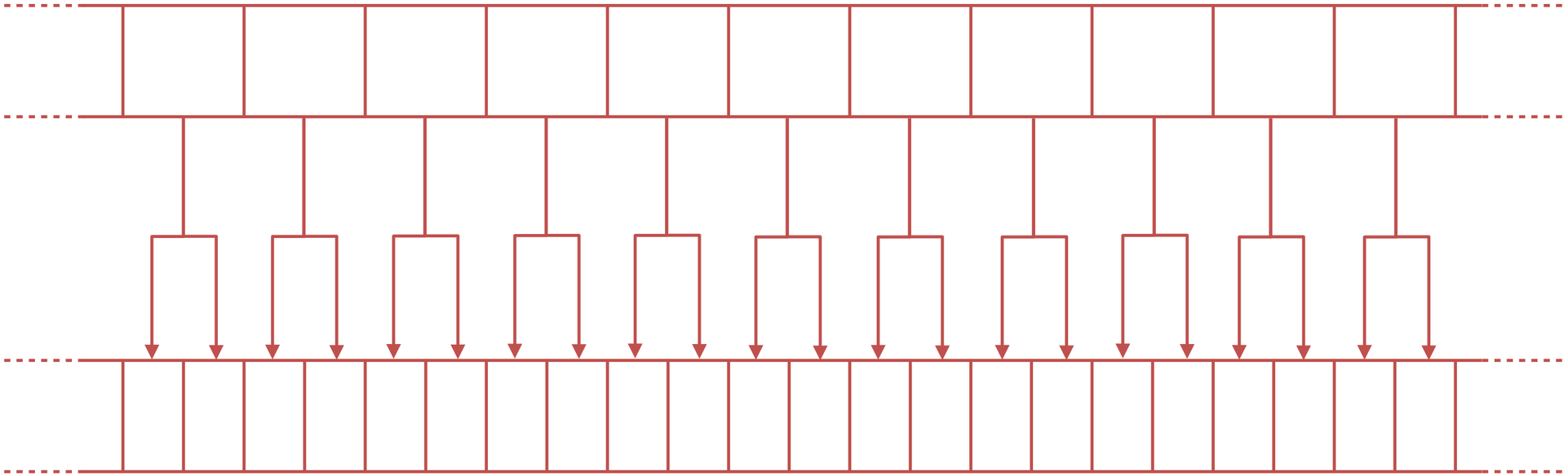


Pixel Component
(Bits or Steps)

Distinguishing Pixels

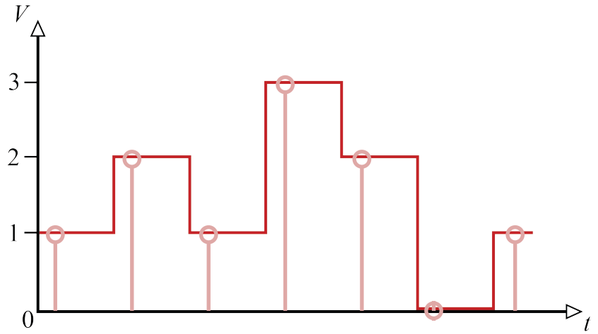


Input Signal



Pixel Component
(Bits or Steps)

Distinguishing Pixels



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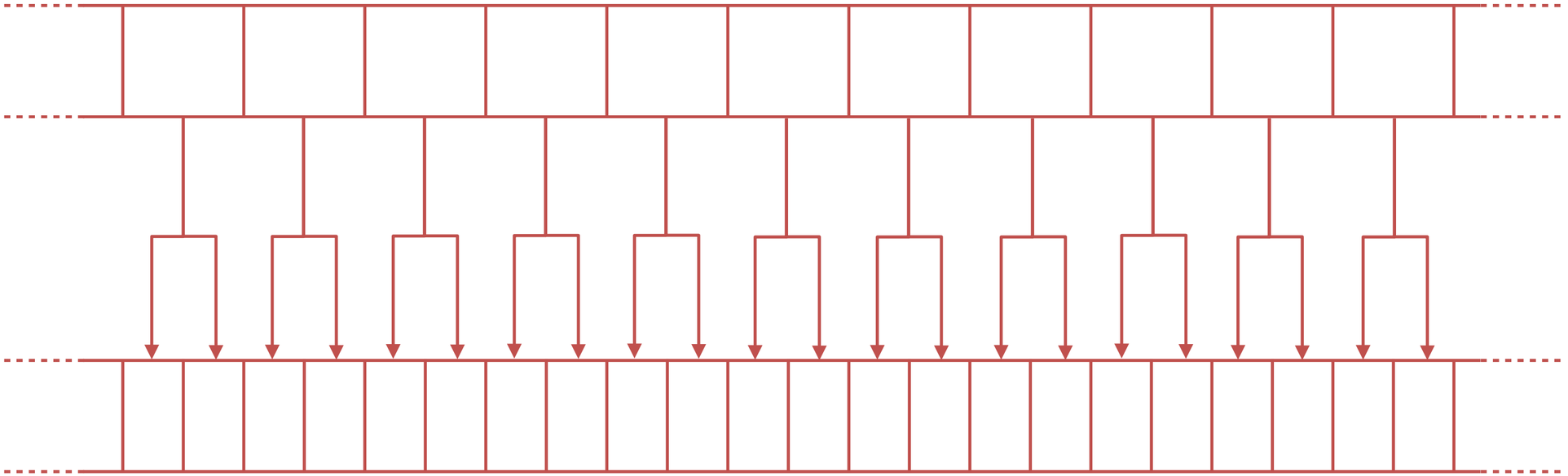
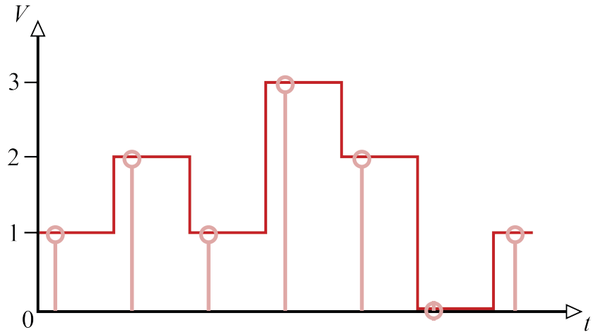


Pixel Component
(Bits or Steps)

Distinguishing Pixels



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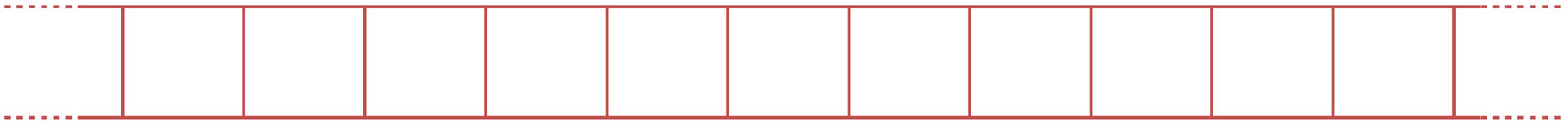
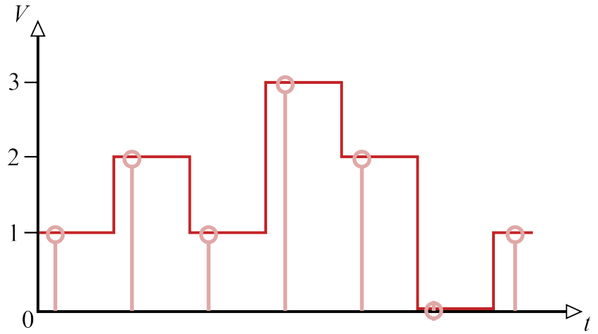


Pixel Component
(Bits or Steps)

Distinguishing Pixels



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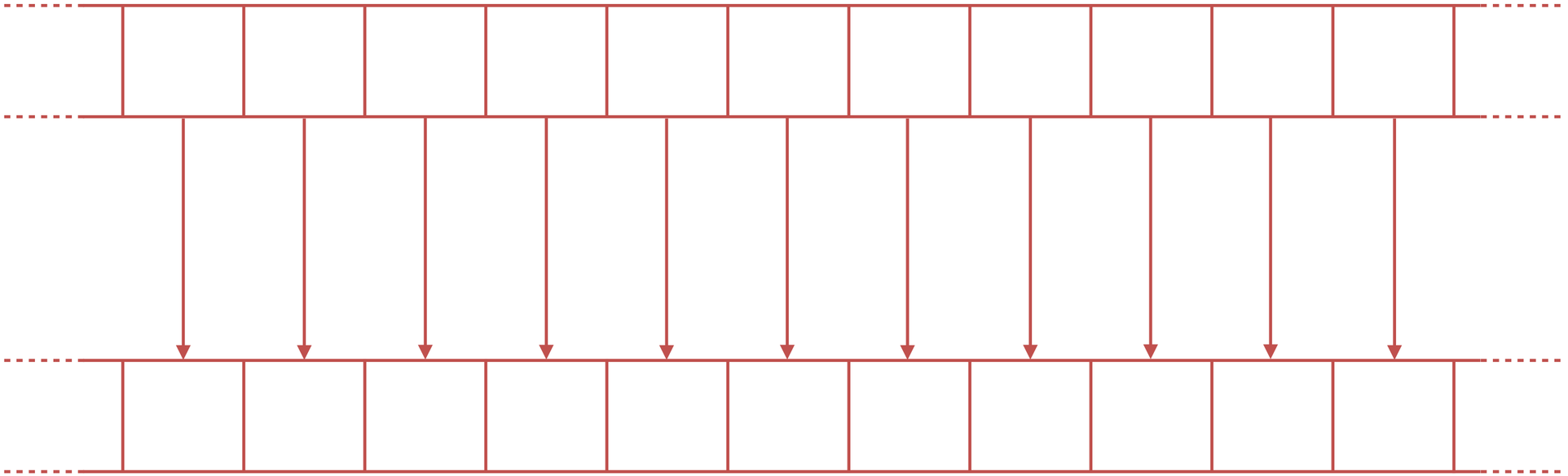
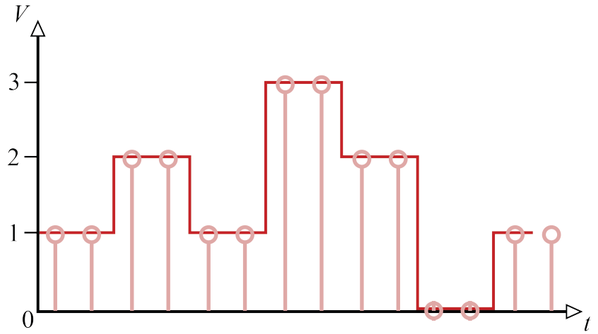


Pixel Component
(Bits or Steps)

Distinguishing Pixels



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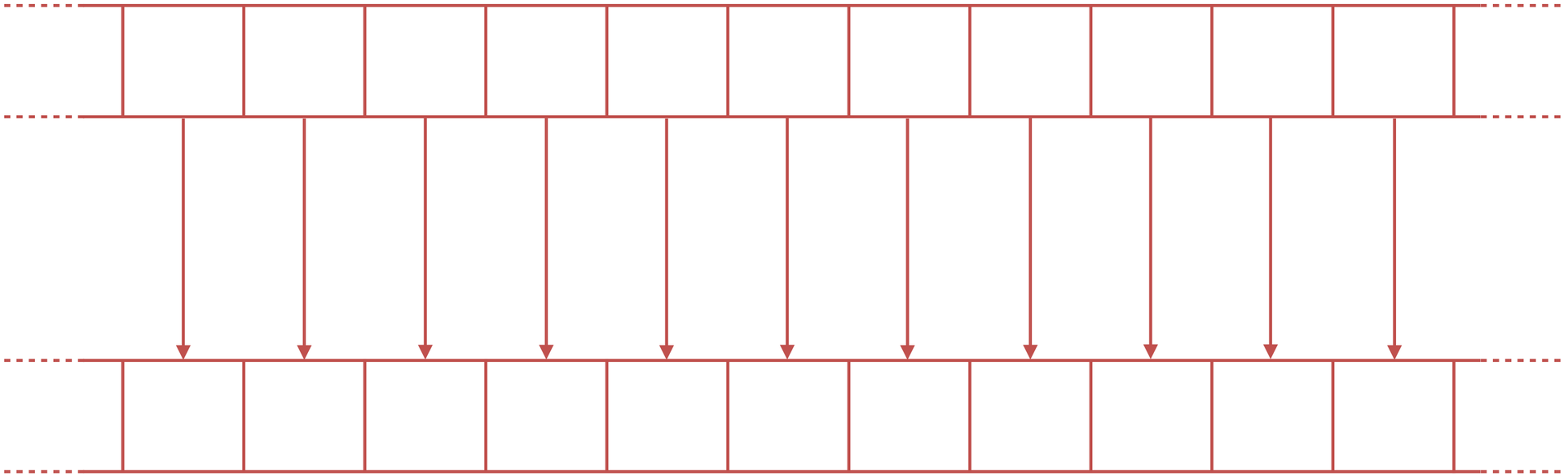

Pixel Component
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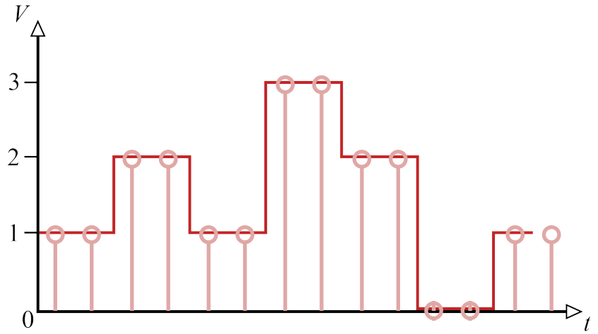
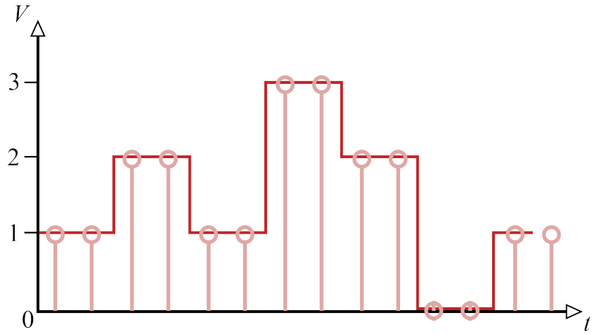
Distinguishing Pixels

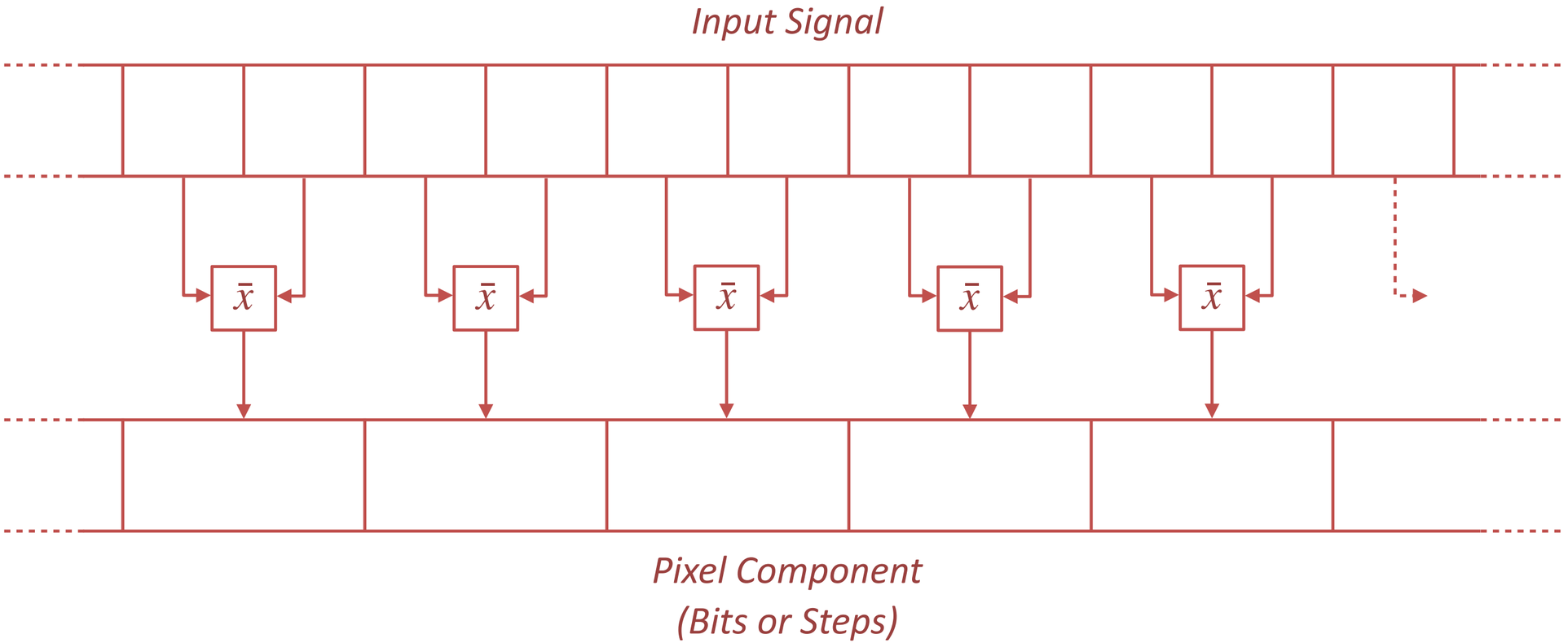


Input Signal

Pixel Component
(Bits or Steps)

Distinguishing Pixels

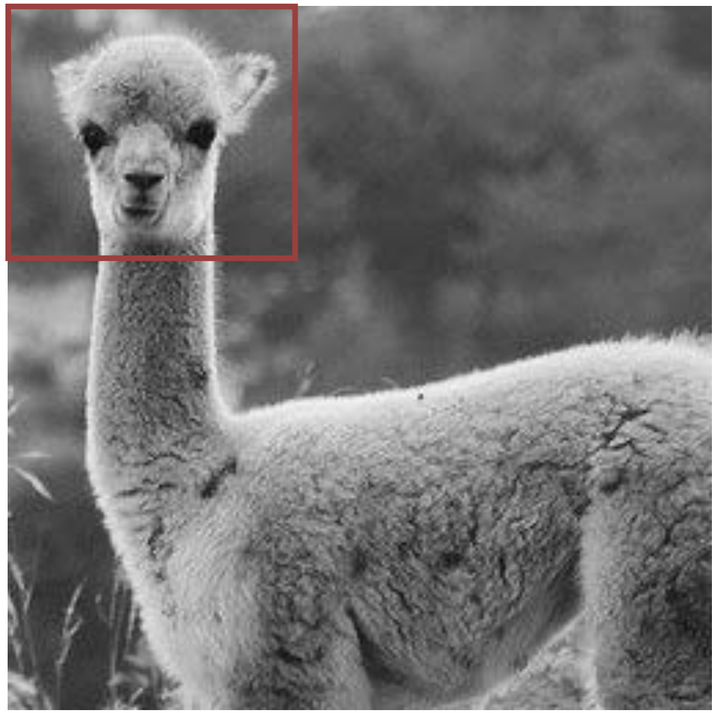




Distinguishing Frames

Distinguishing Frames

Distinguishing Frames



Distinguishing Frames

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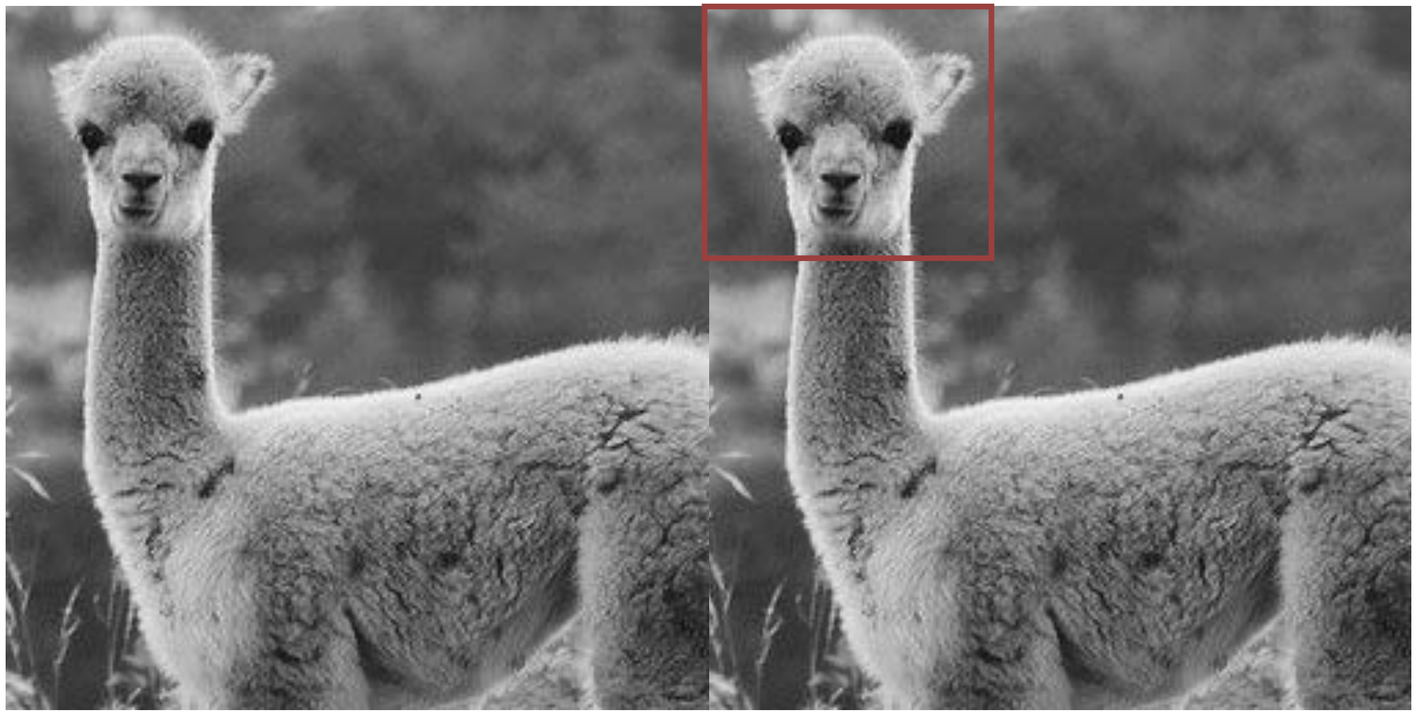
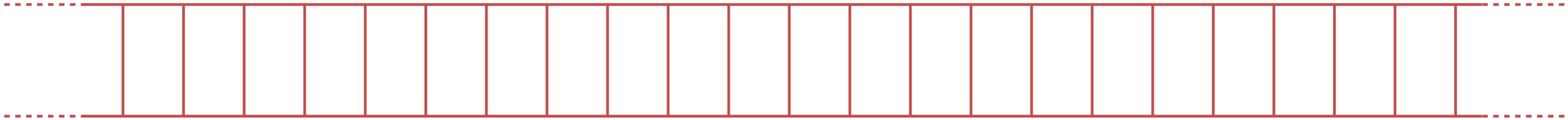


Alignment

Alignment



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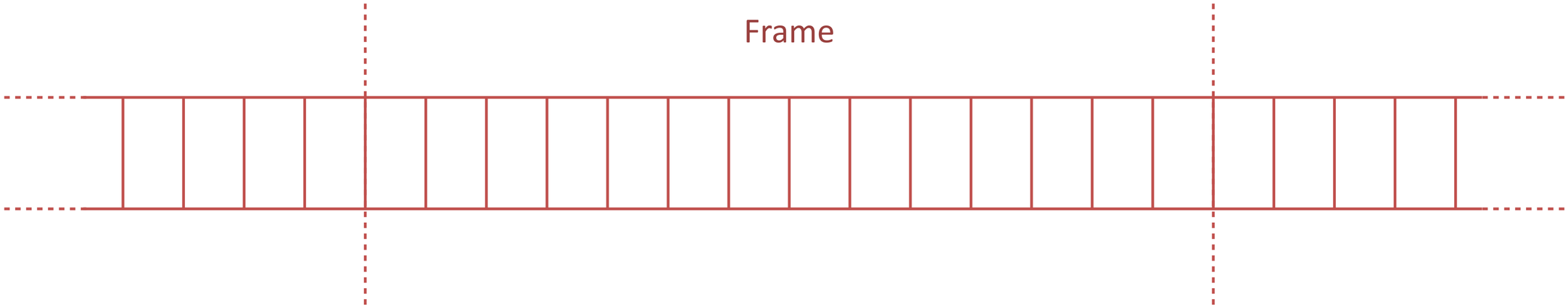

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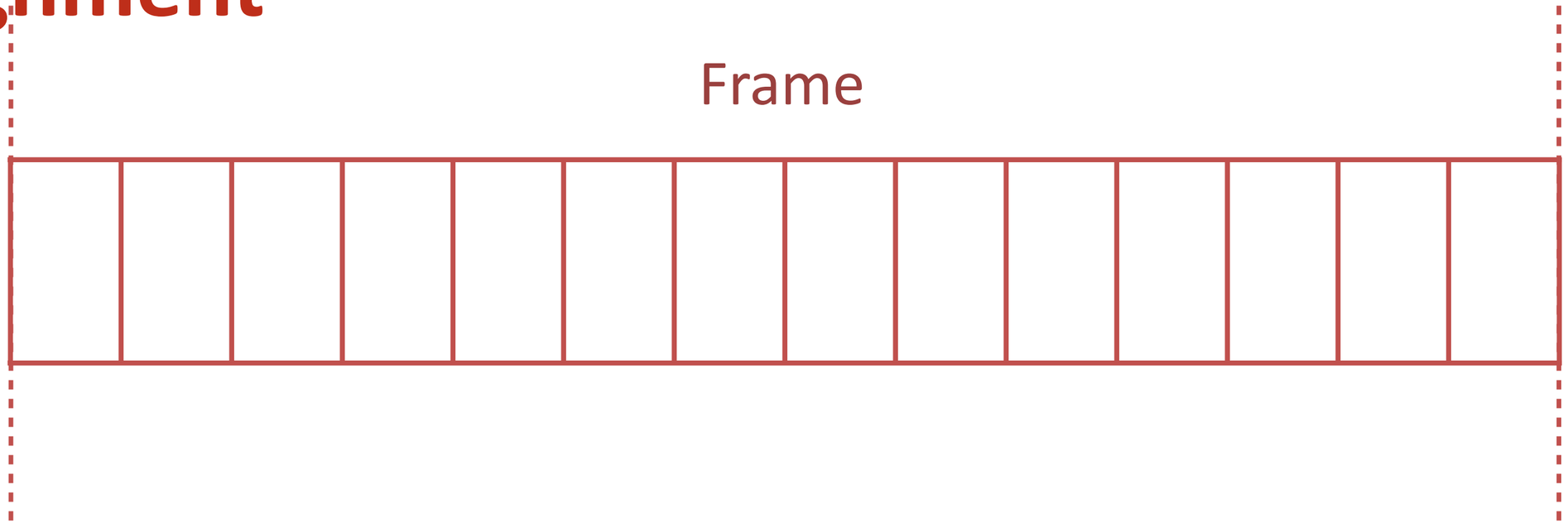

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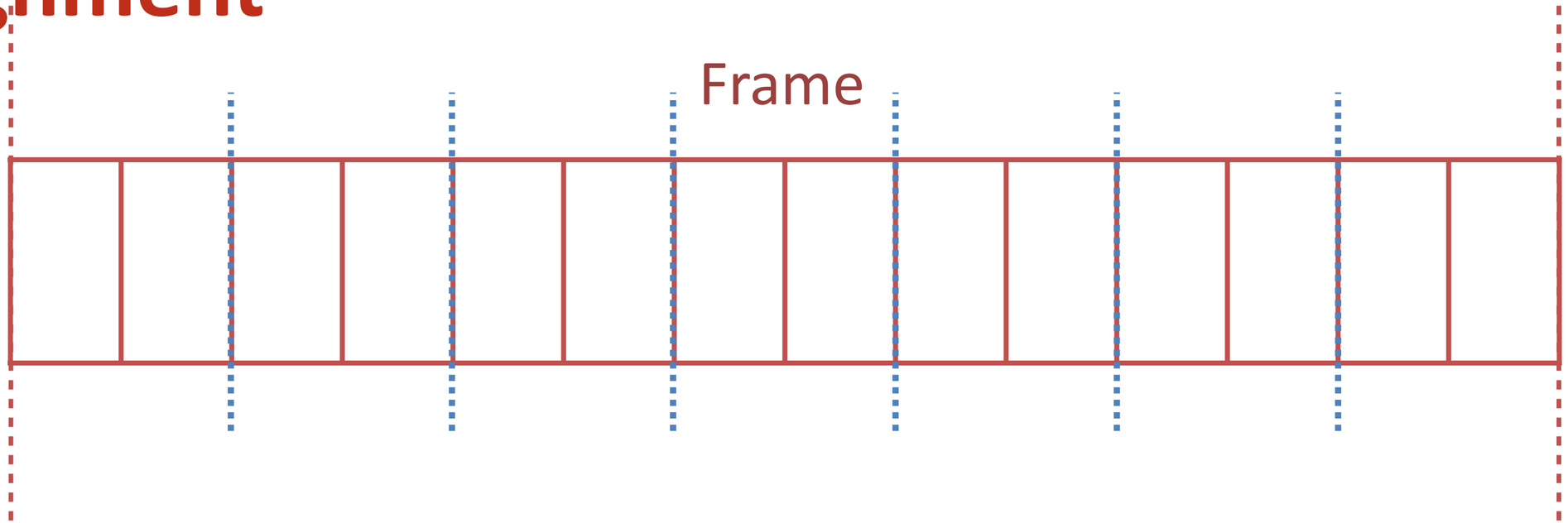

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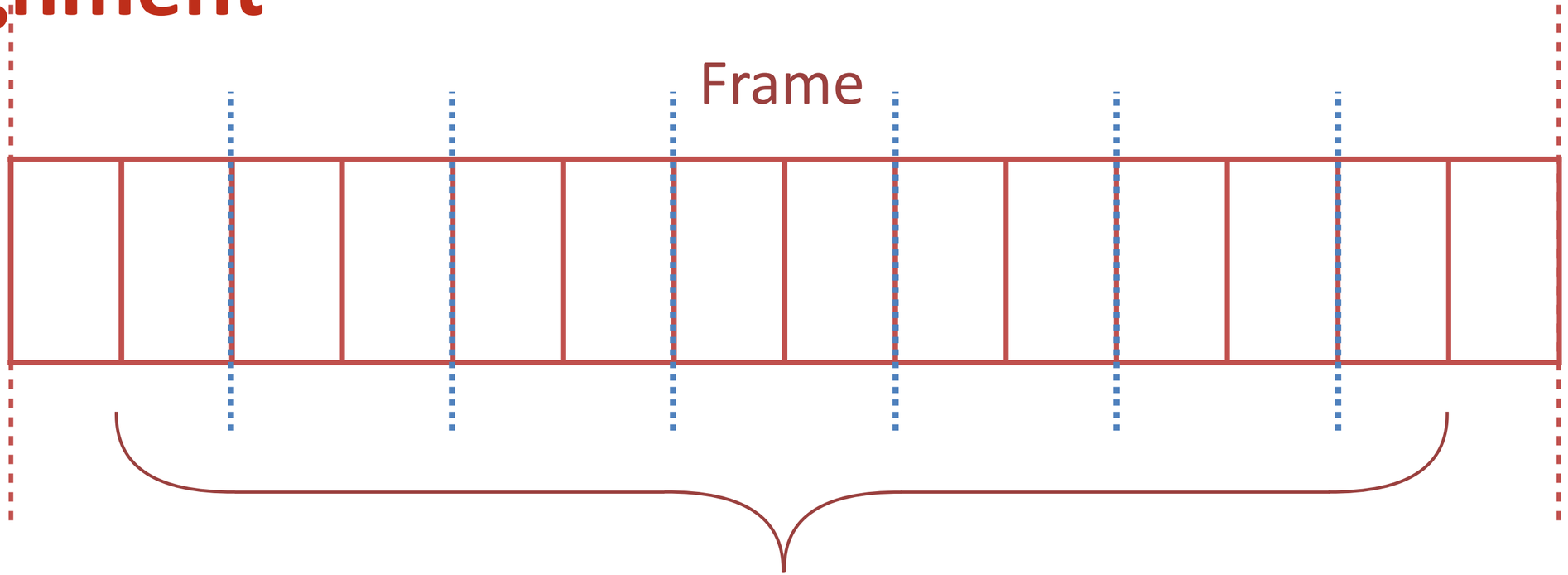

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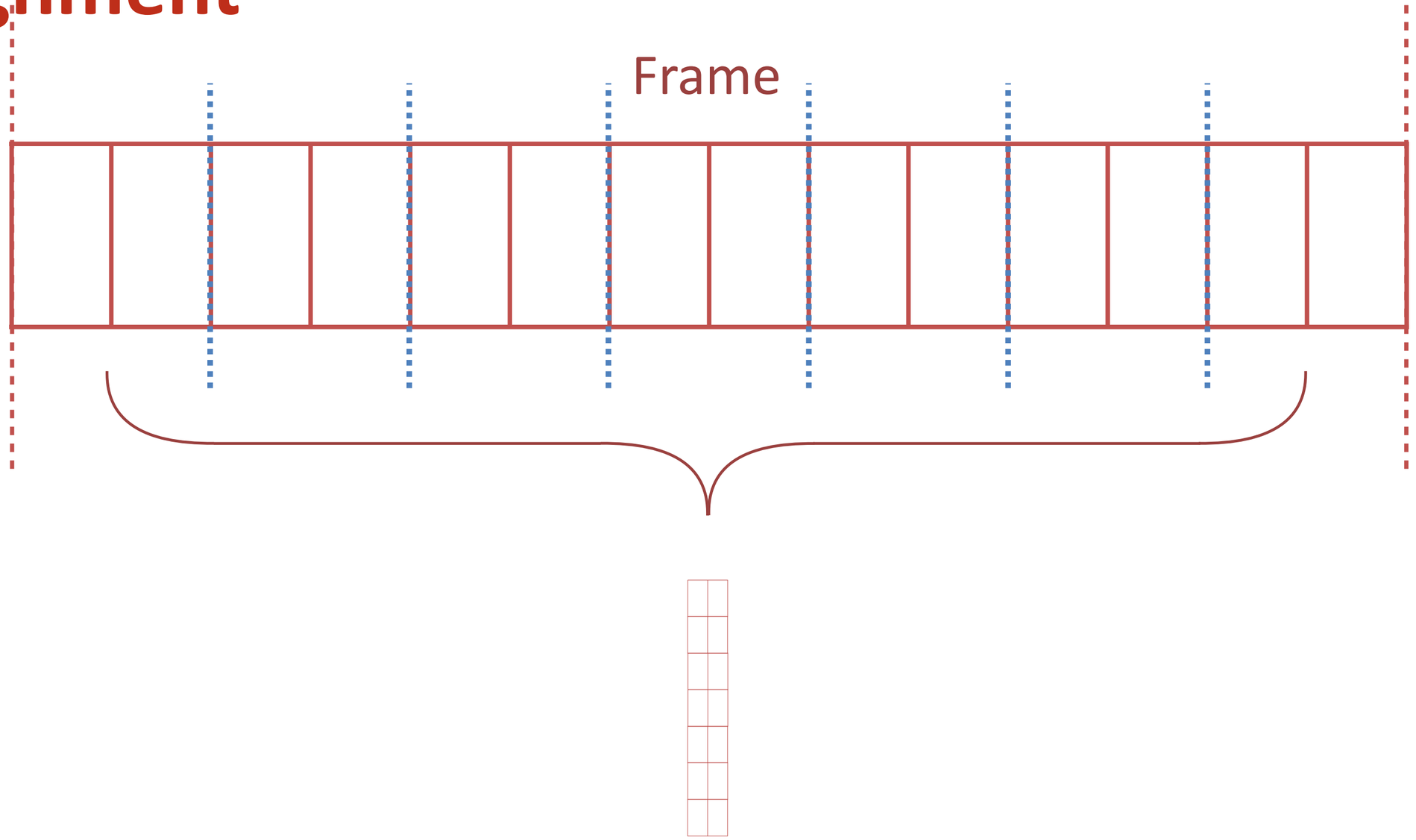

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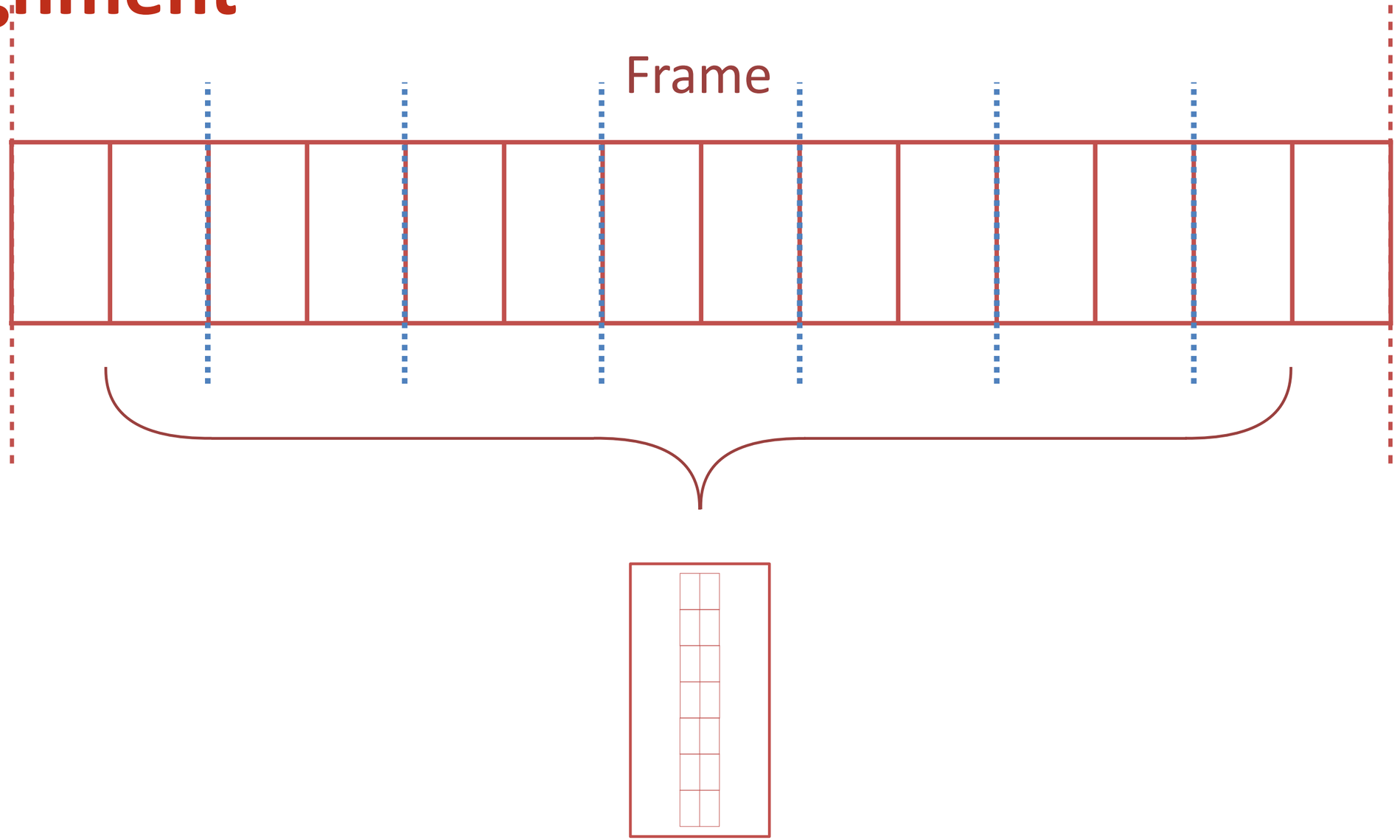

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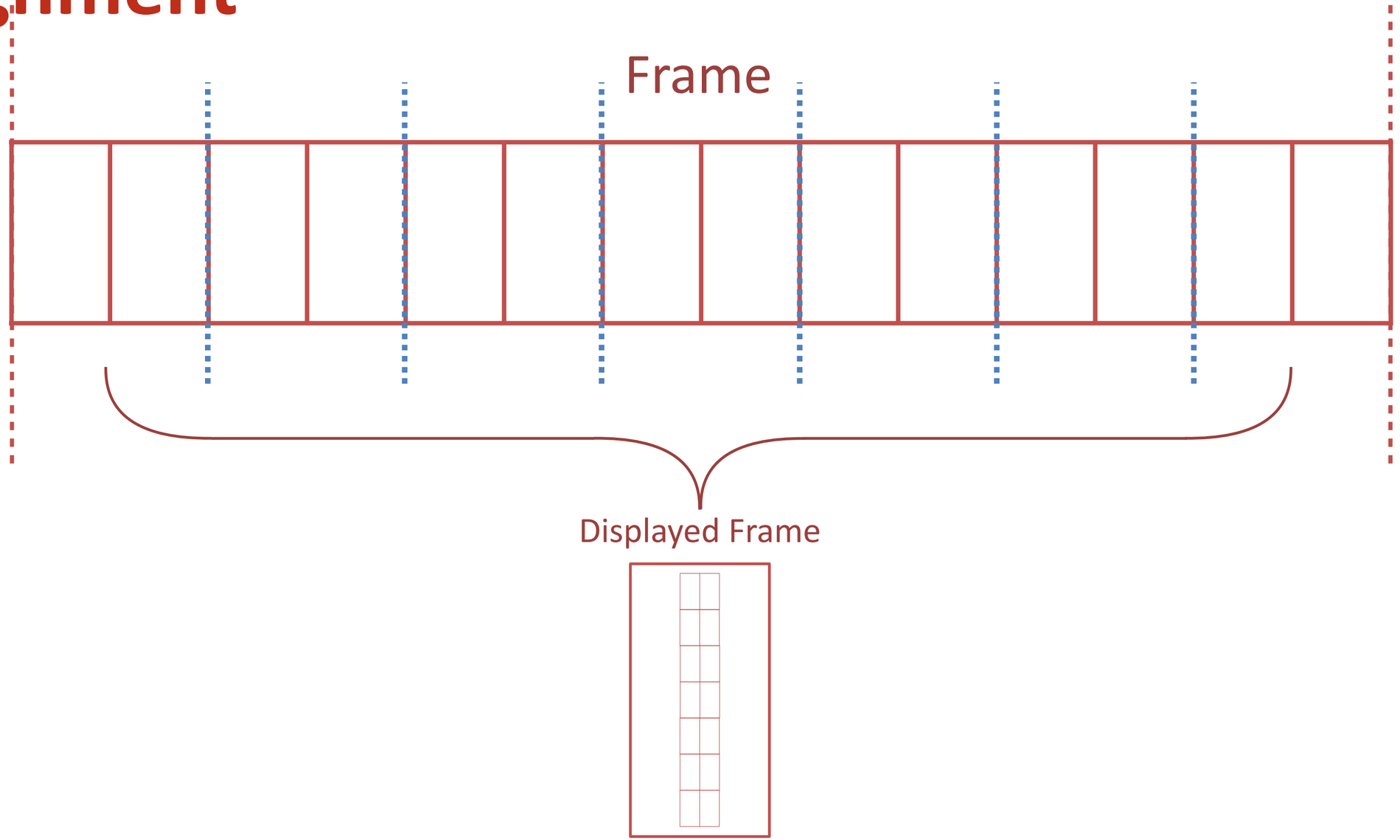
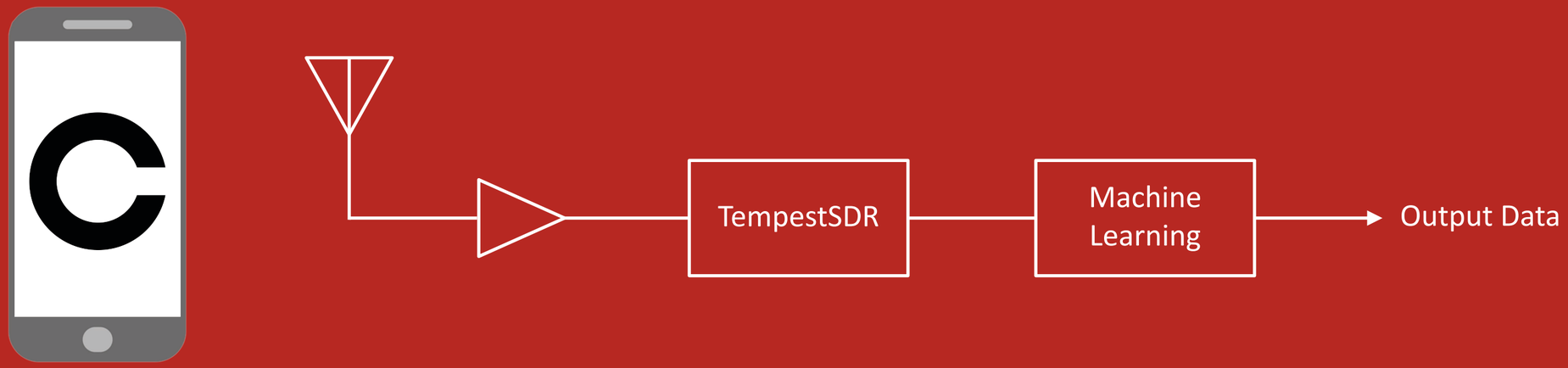
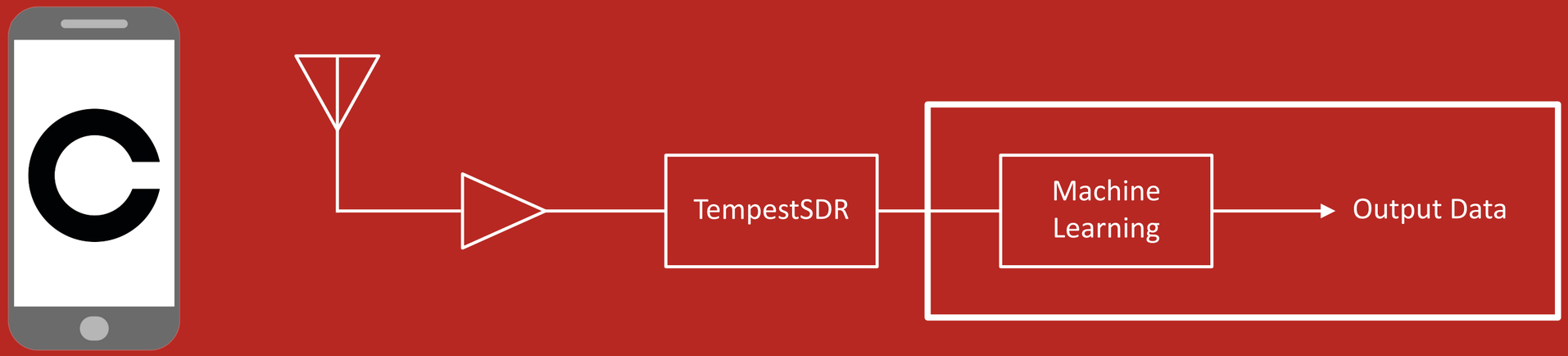


Machine Learning

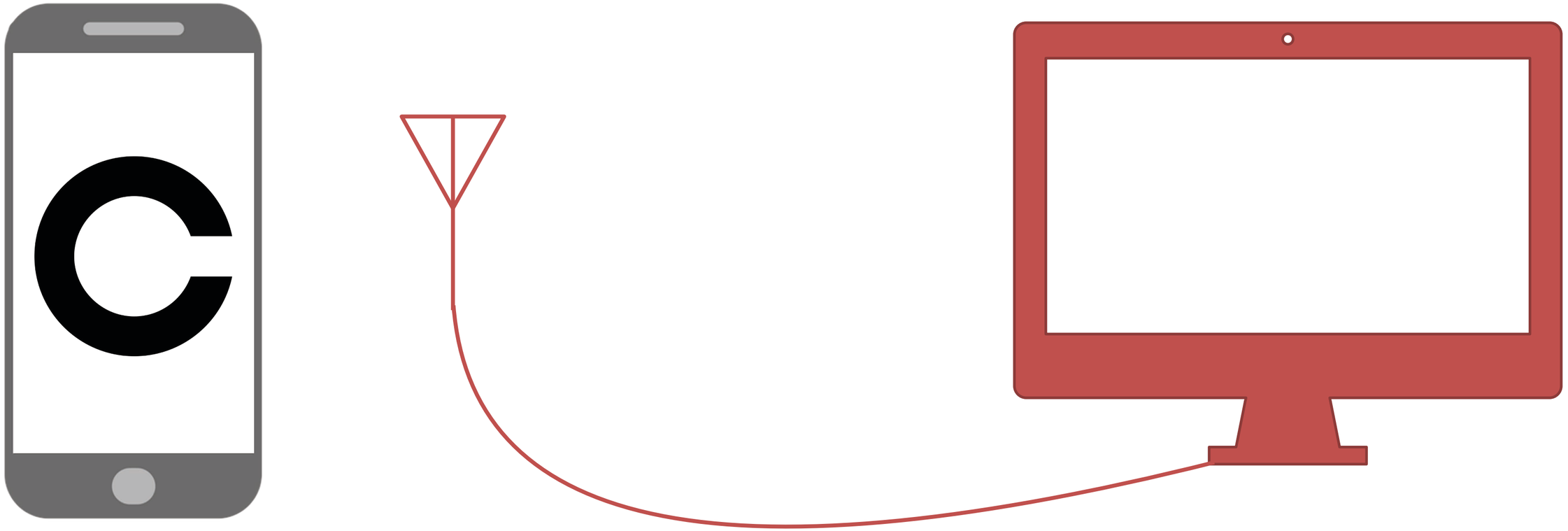


Machine Learning

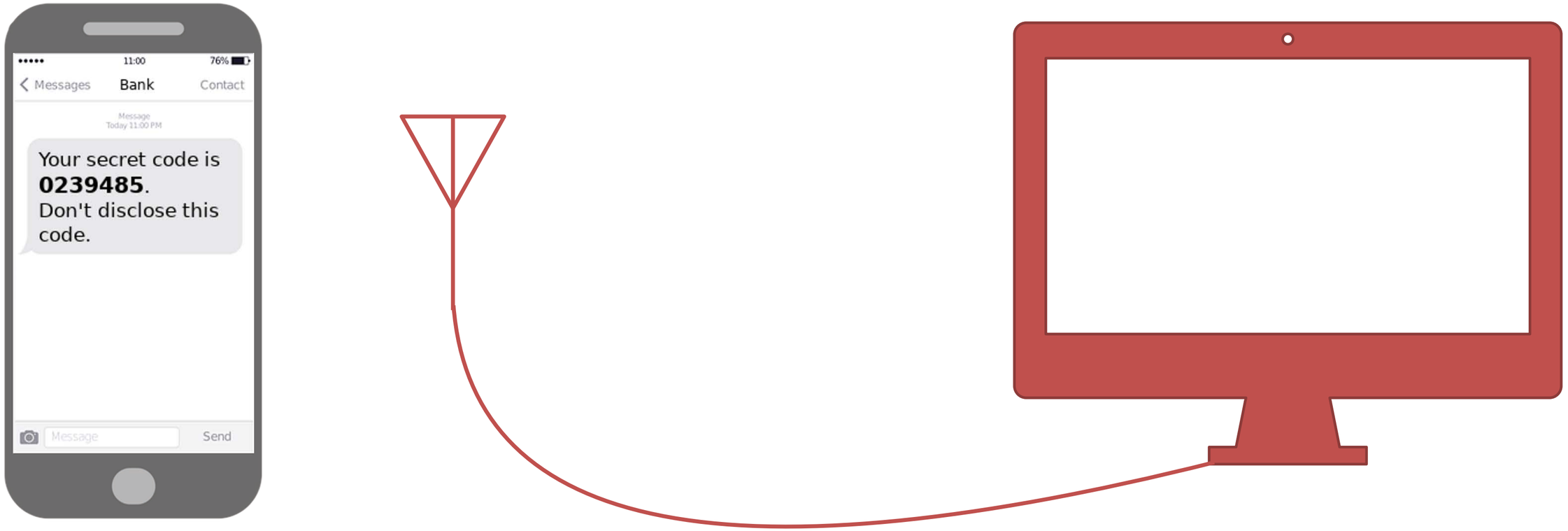


Use Cases

Use Cases



Use Cases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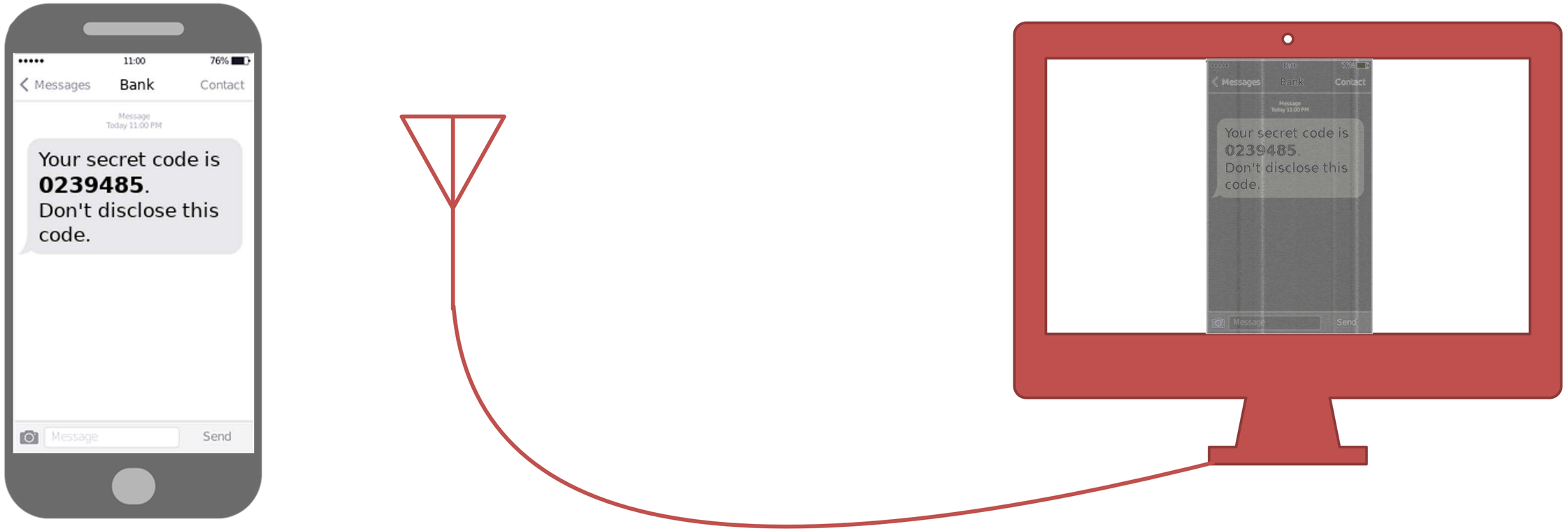
76%
Messages
Bank
Contact
Message
Today 11:00 PM
Your secret code is
0239485.
Don't disclose this
code.
Message
Send

Use Cases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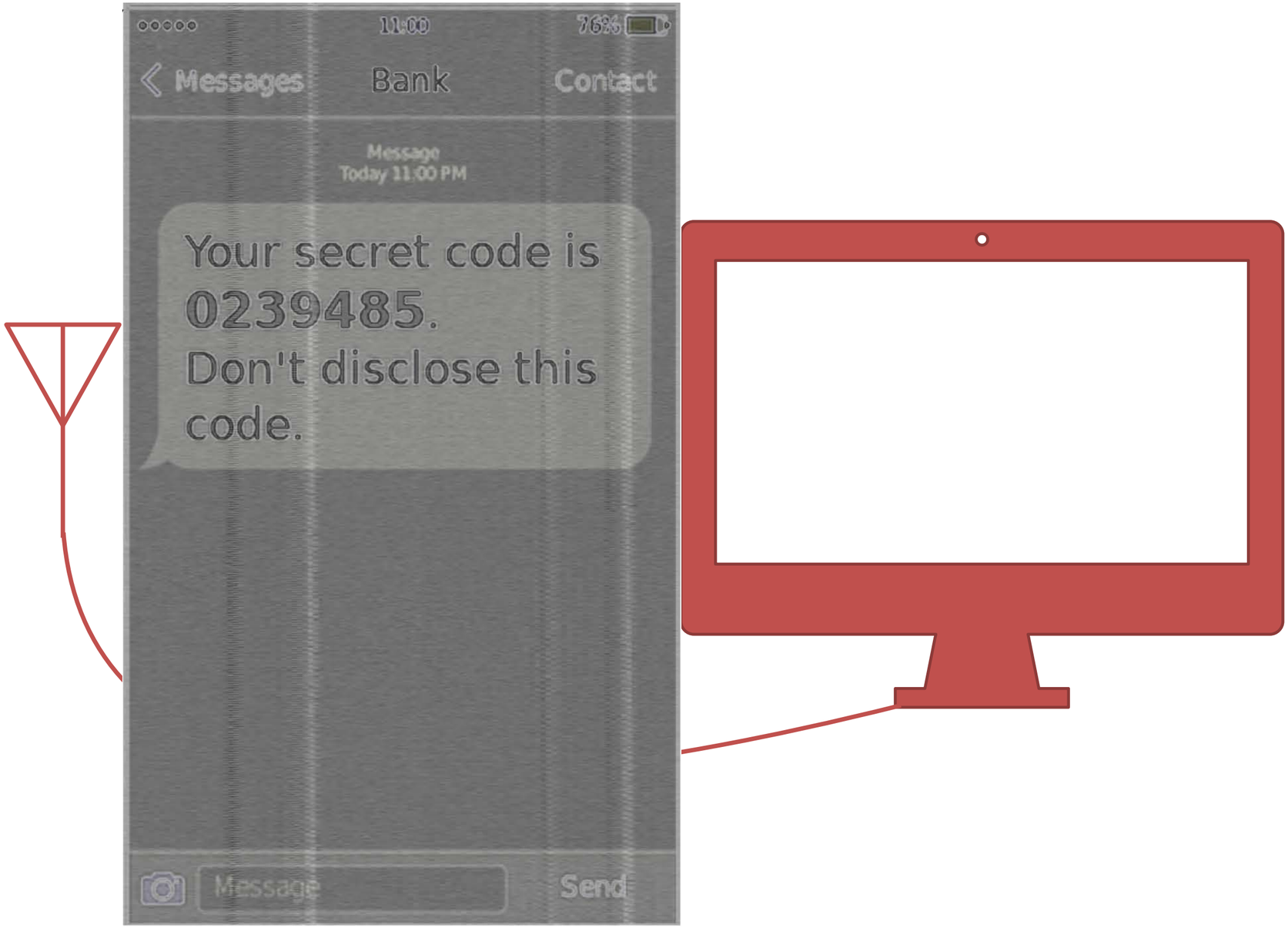
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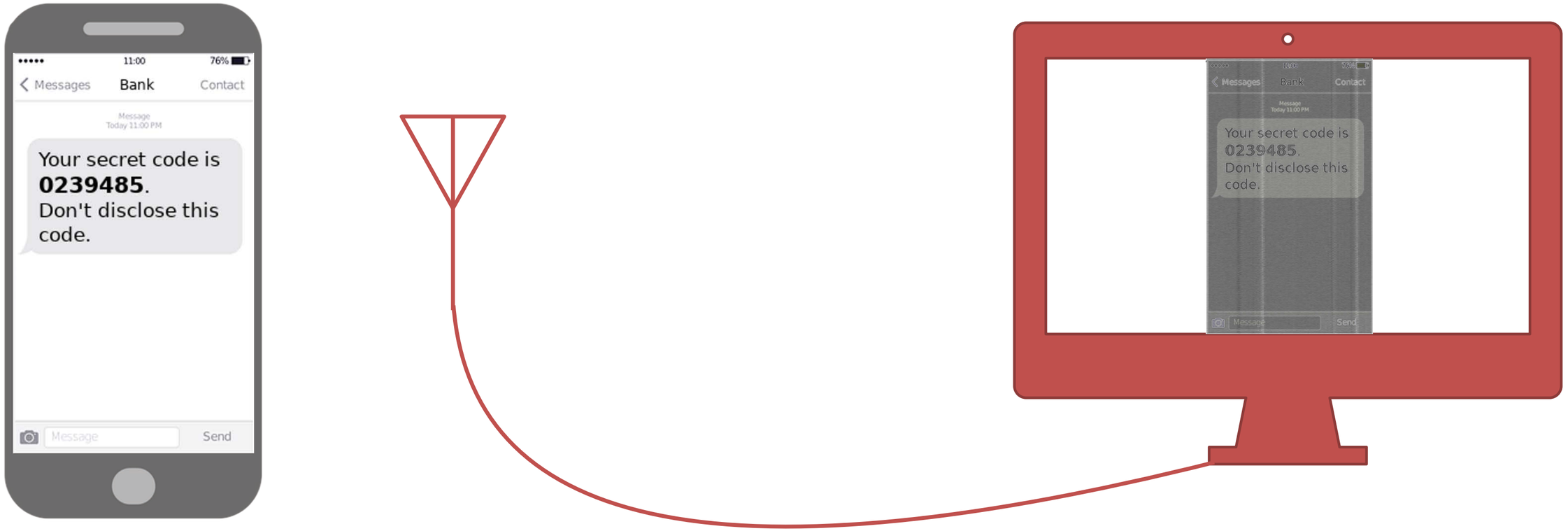
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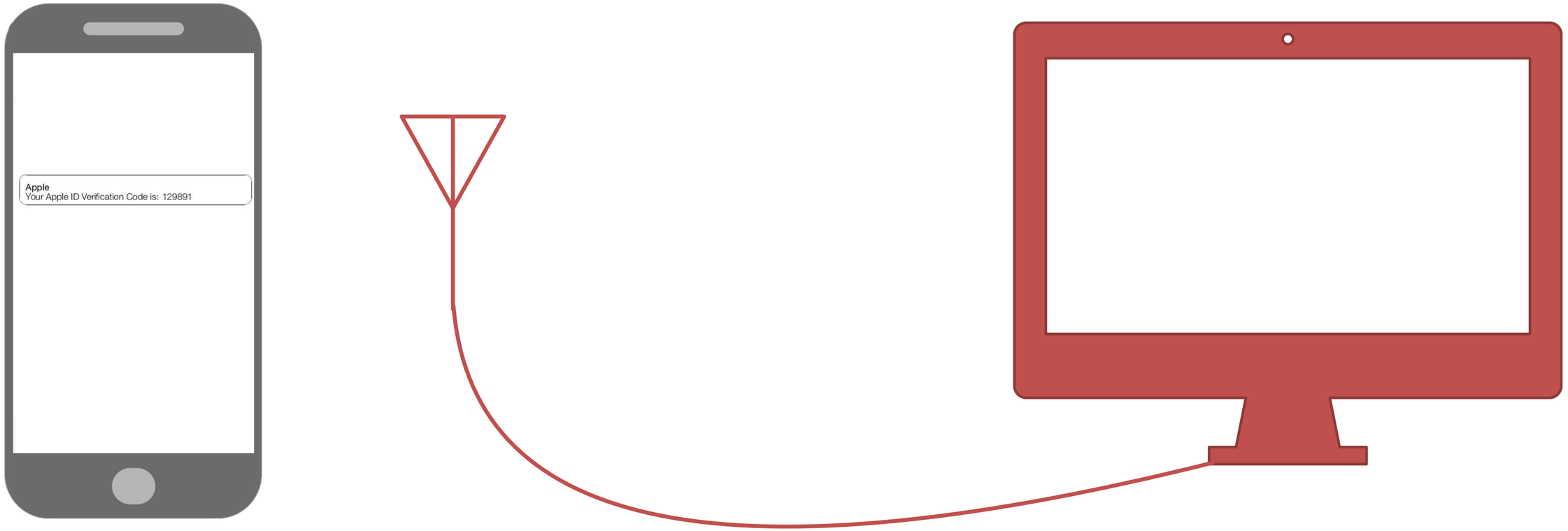
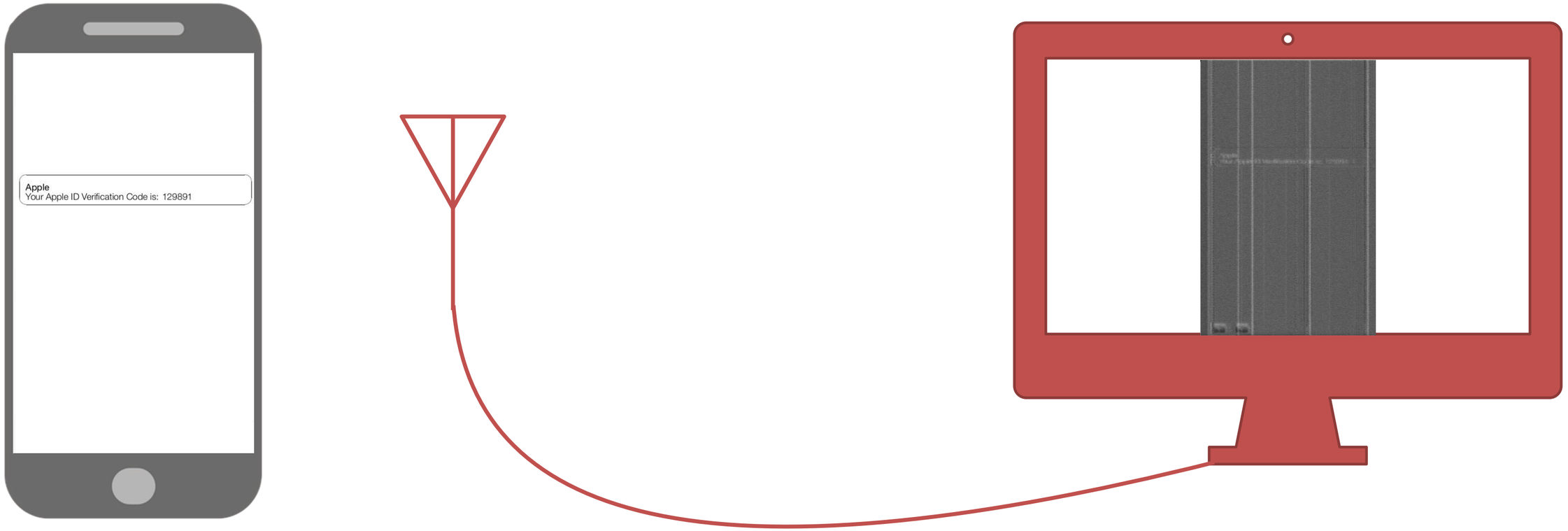
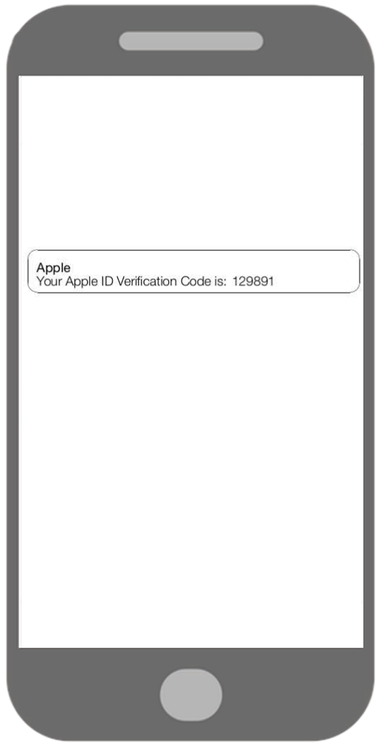
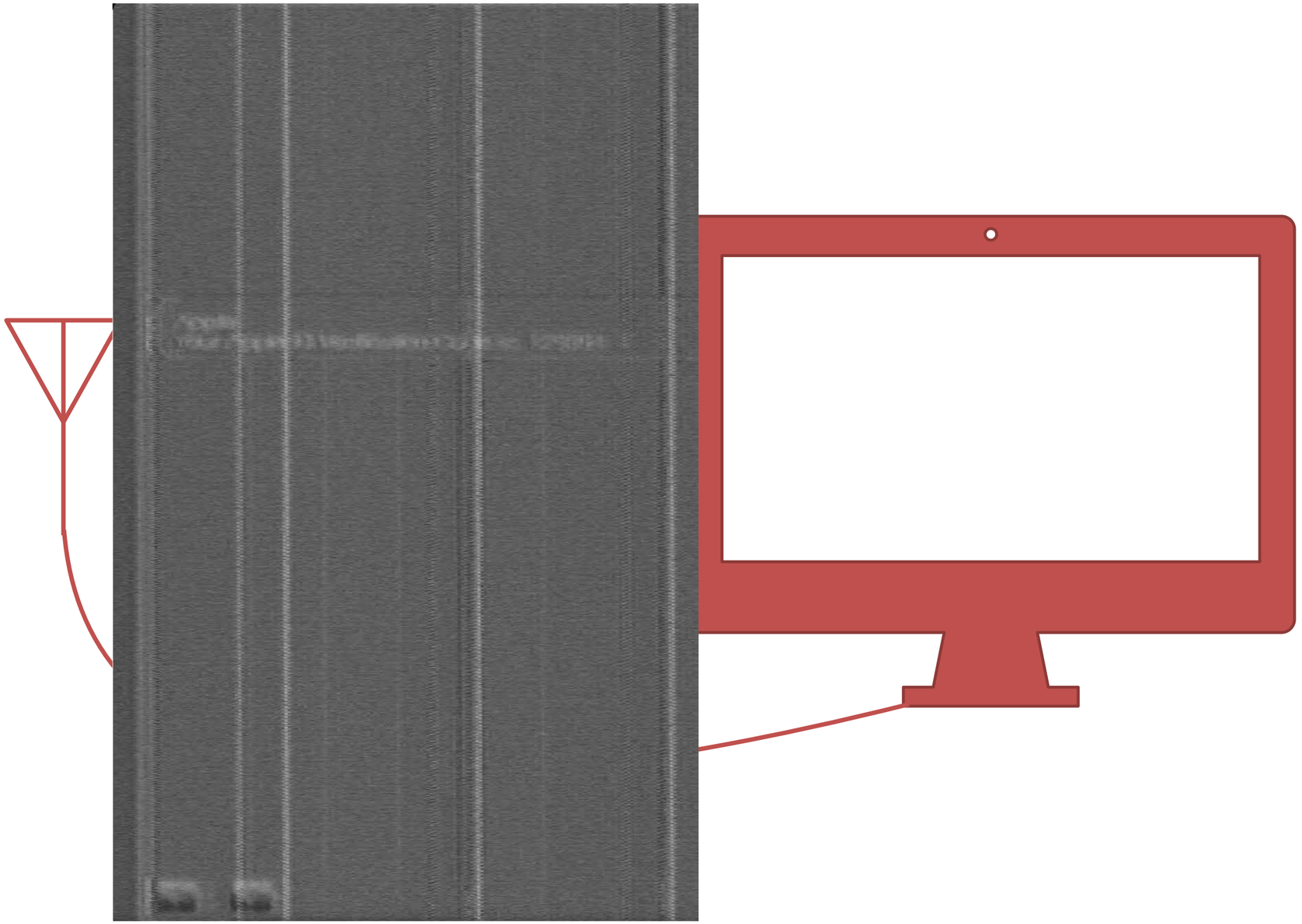


Use Cases



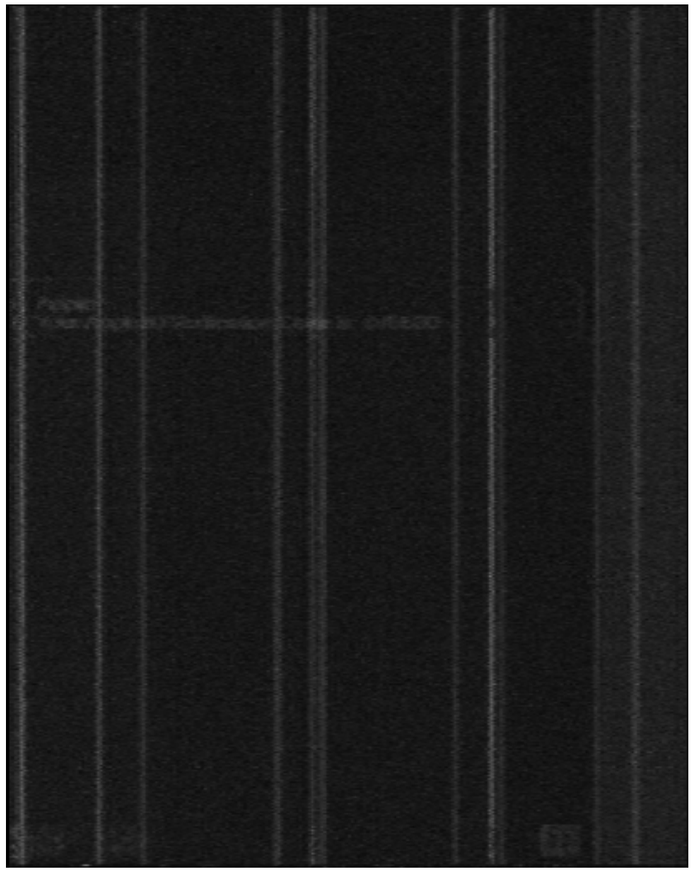
Use Cases





Finding the Security Code

Finding the Security Code



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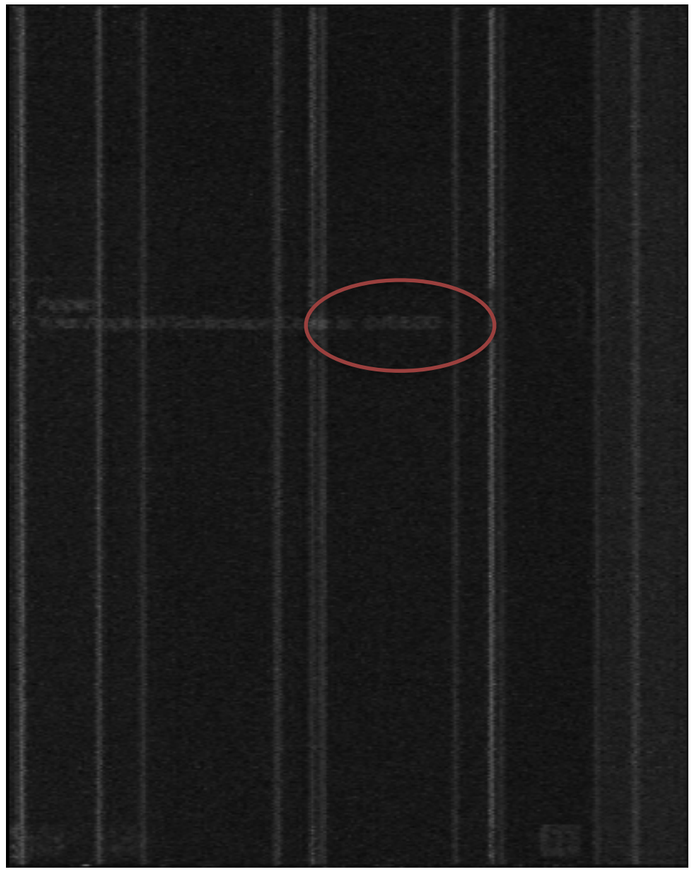

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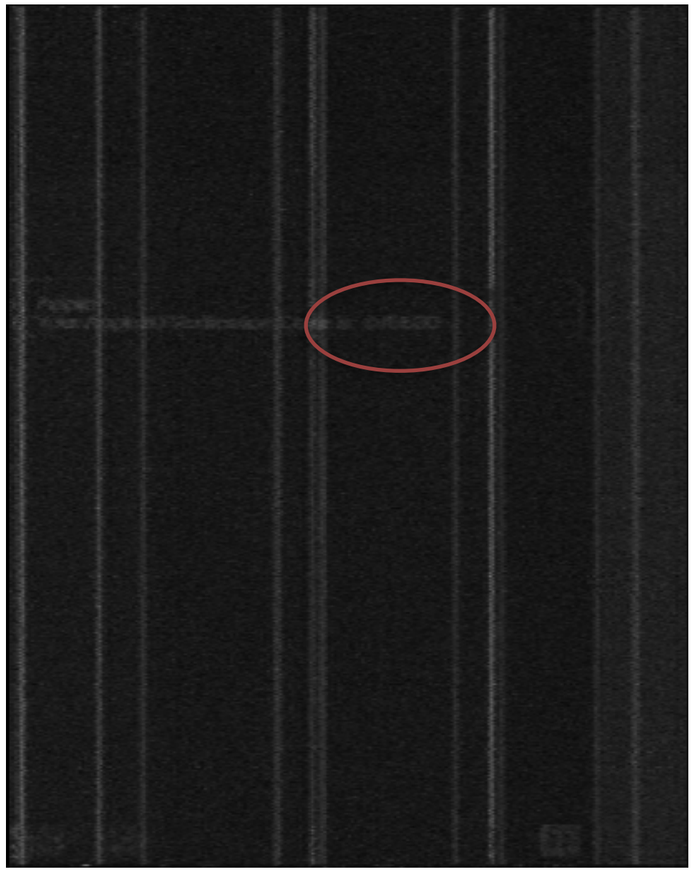
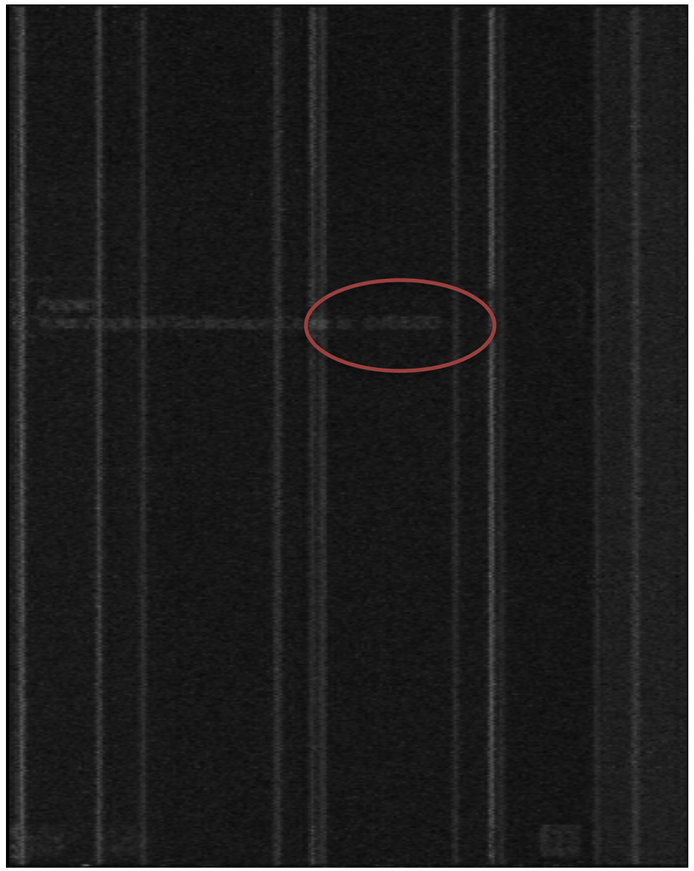
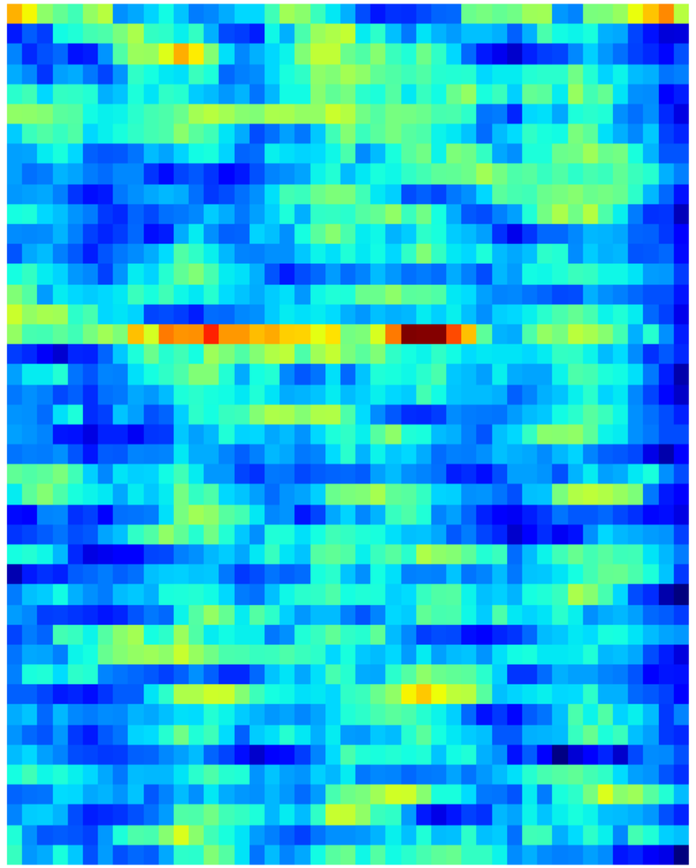


Sliding Window

Finding the Security Code



Sliding Window



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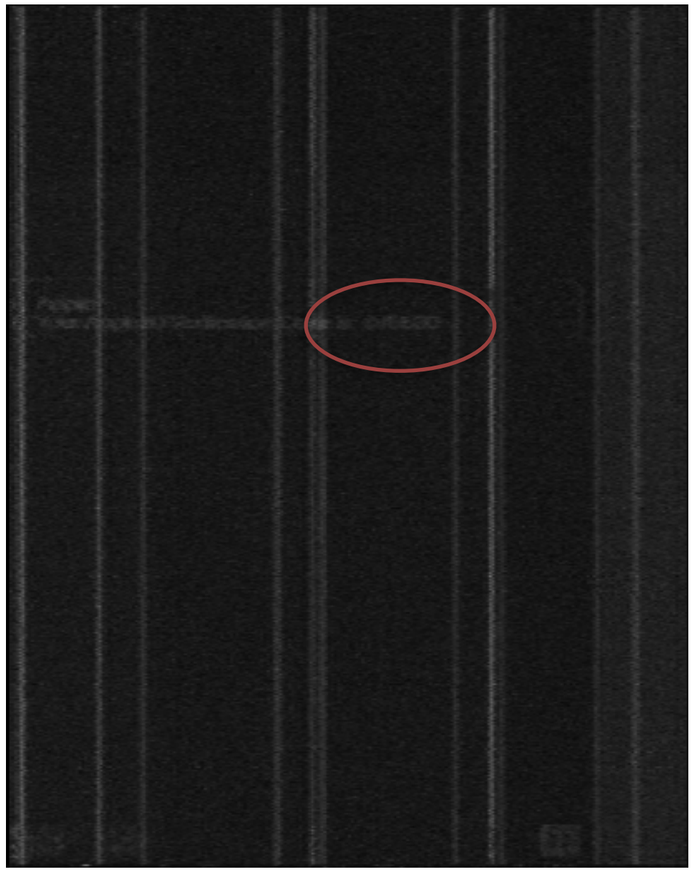

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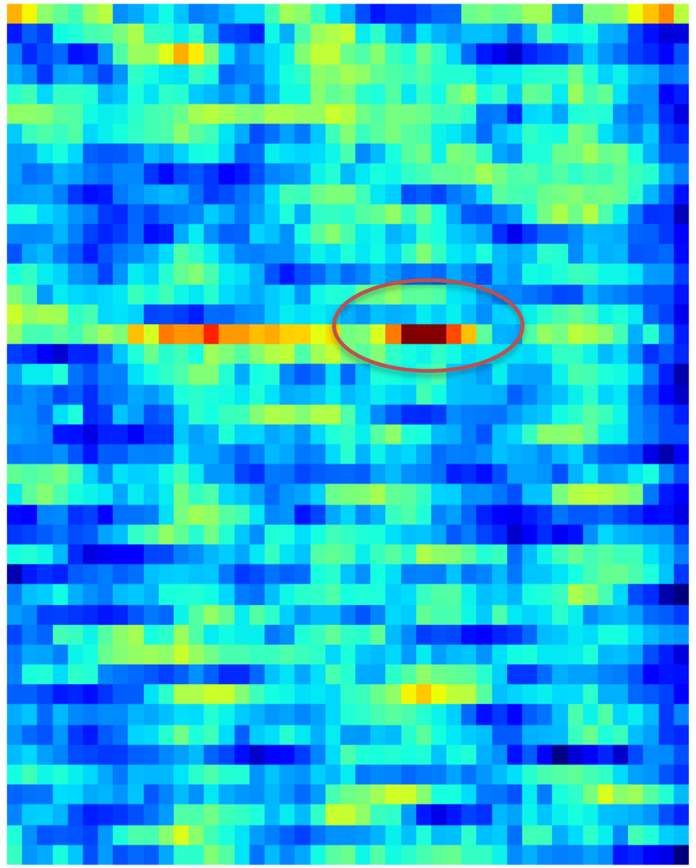

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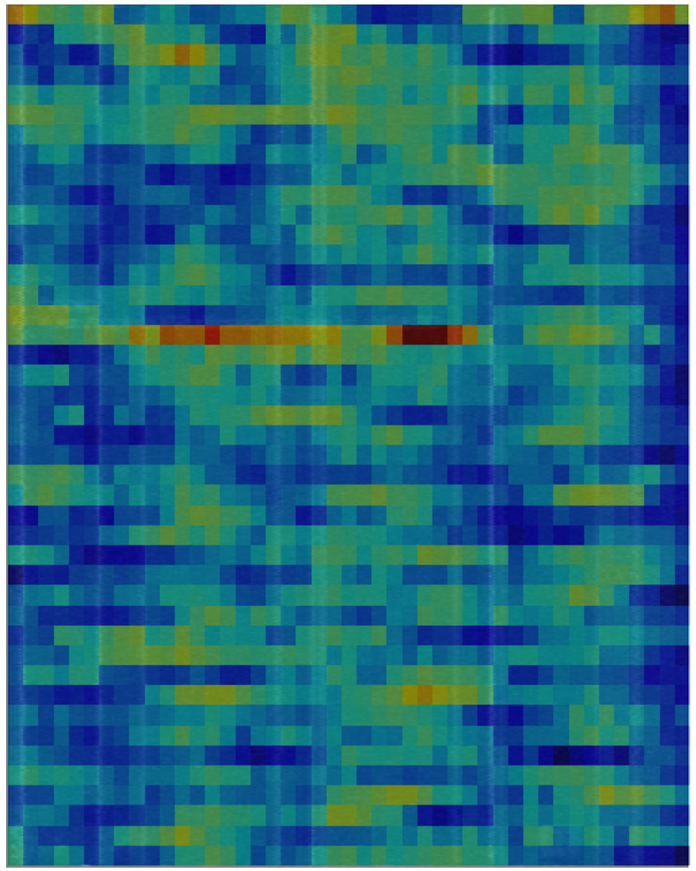

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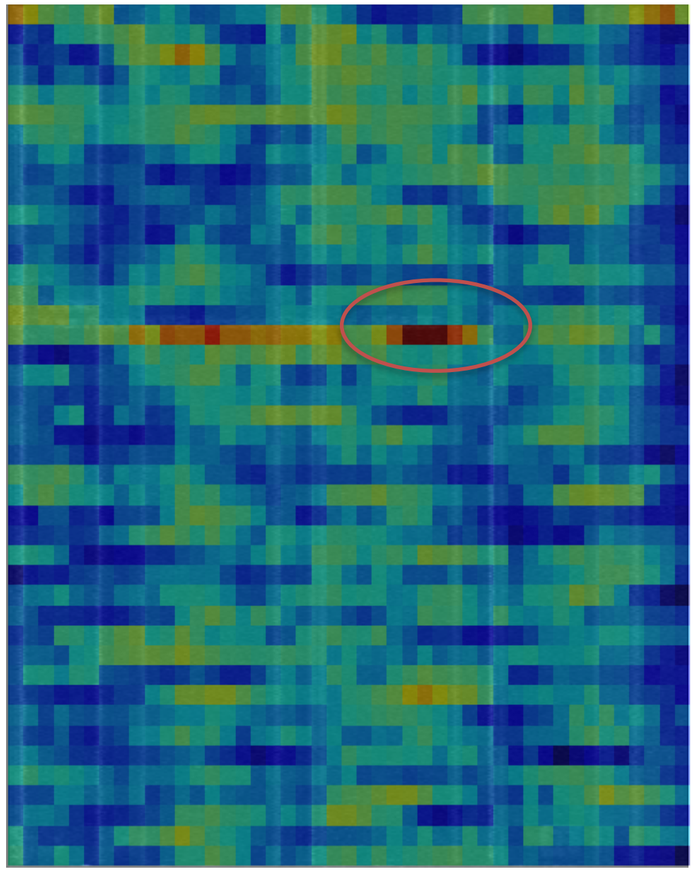

Obtaining Training Data

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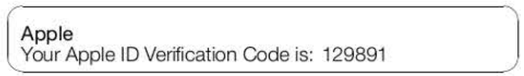
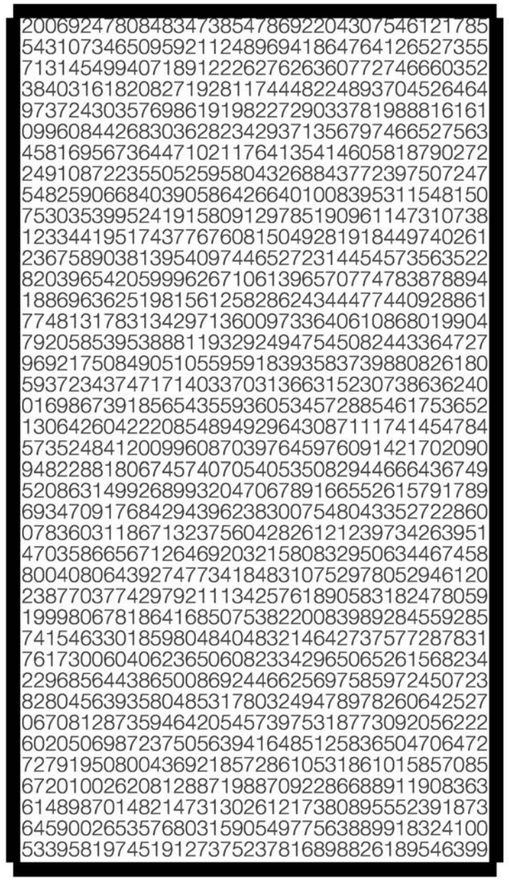


Obtaining Training Data



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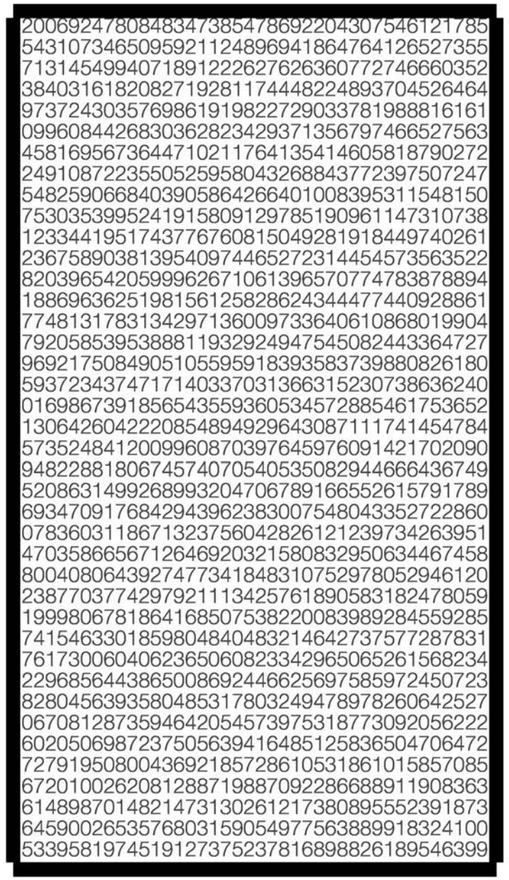
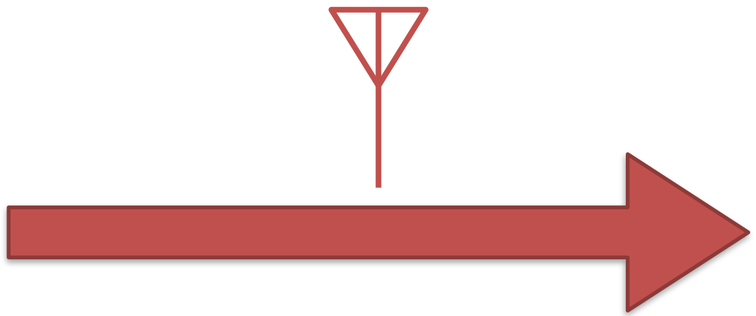
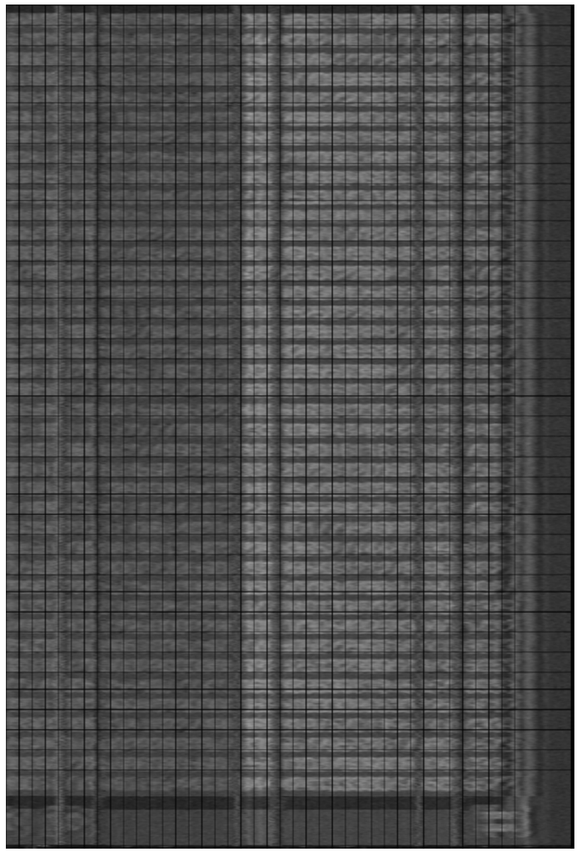
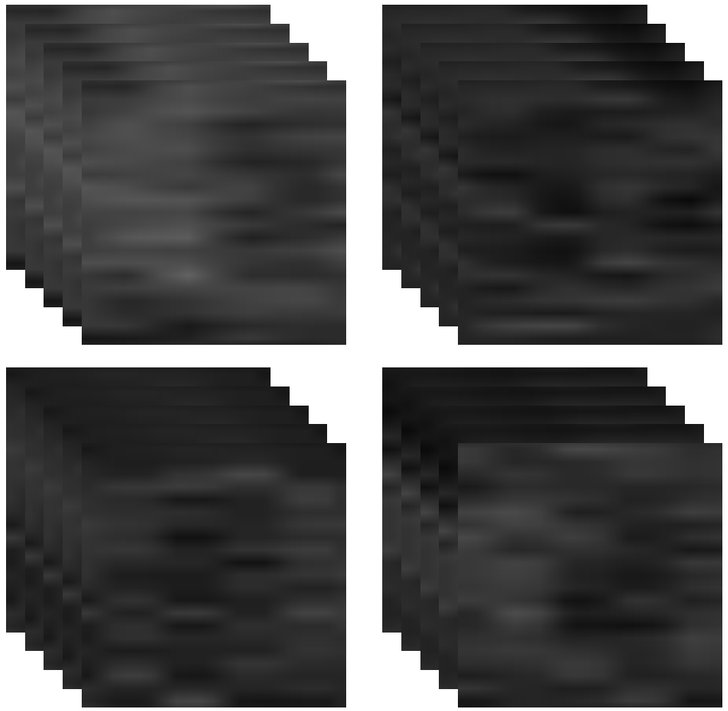






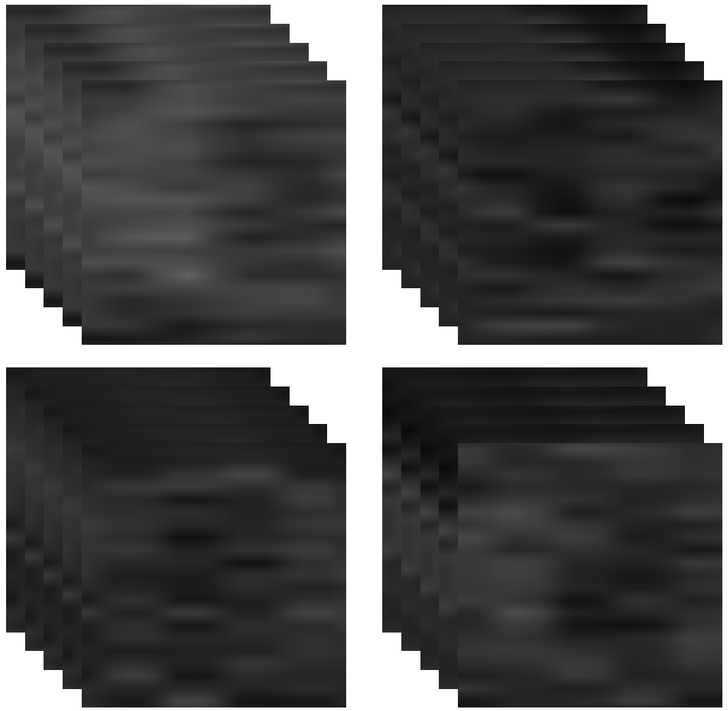
Machine Learning Training

Machine Learning Training



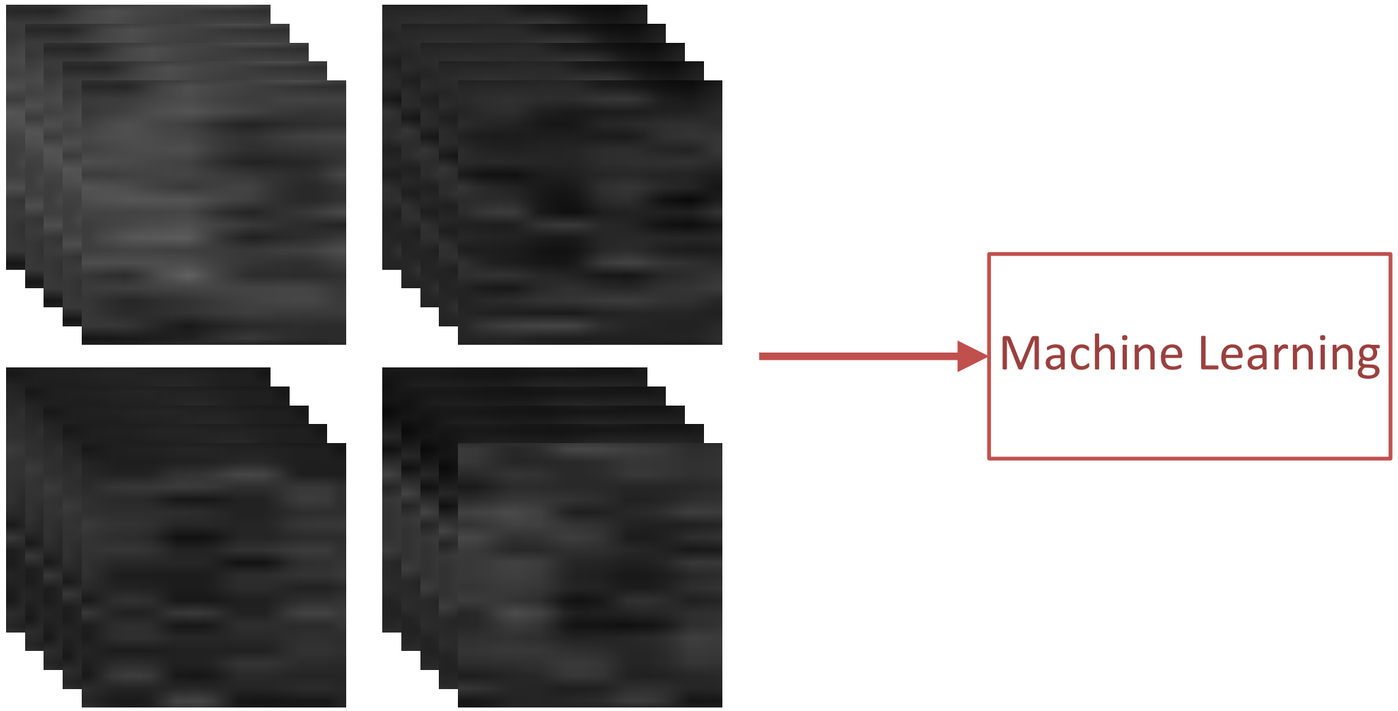
Machine Learning Training

“This is a digit 0”

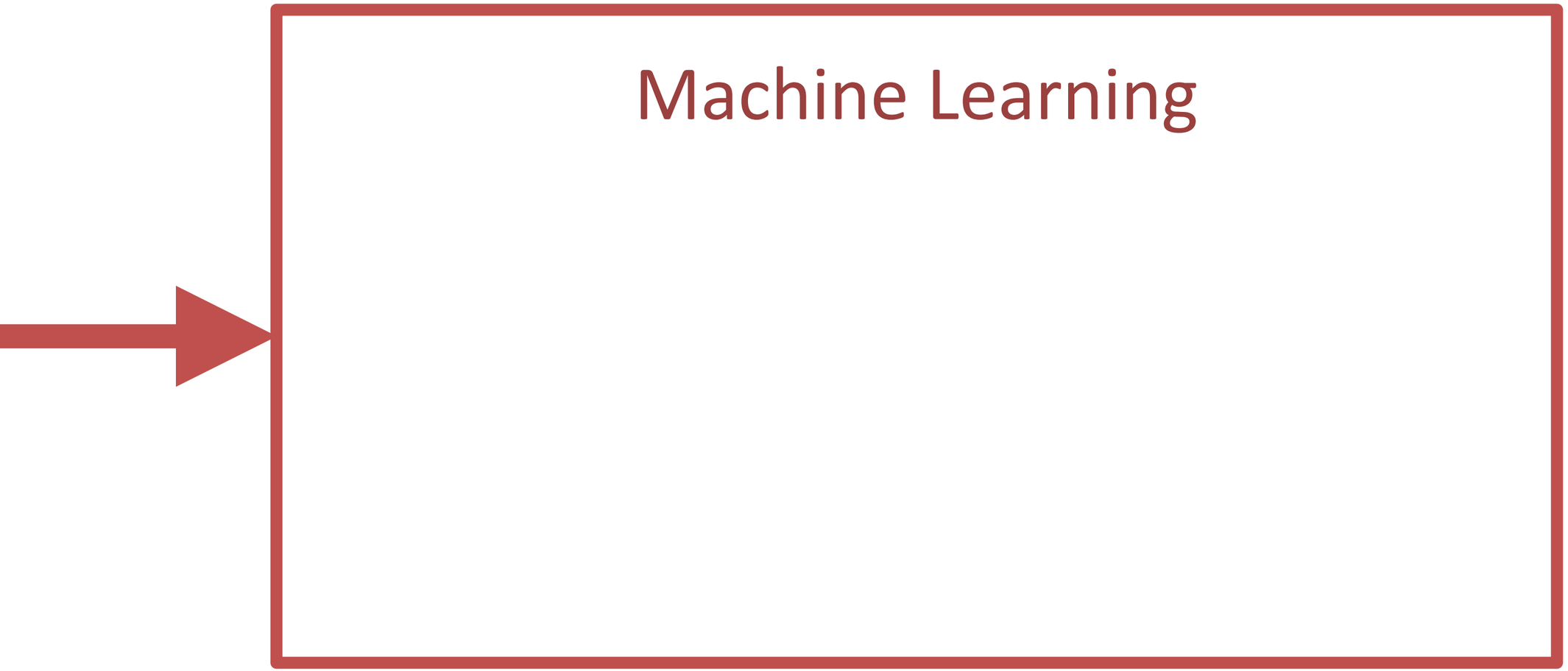


Machine Learning Training

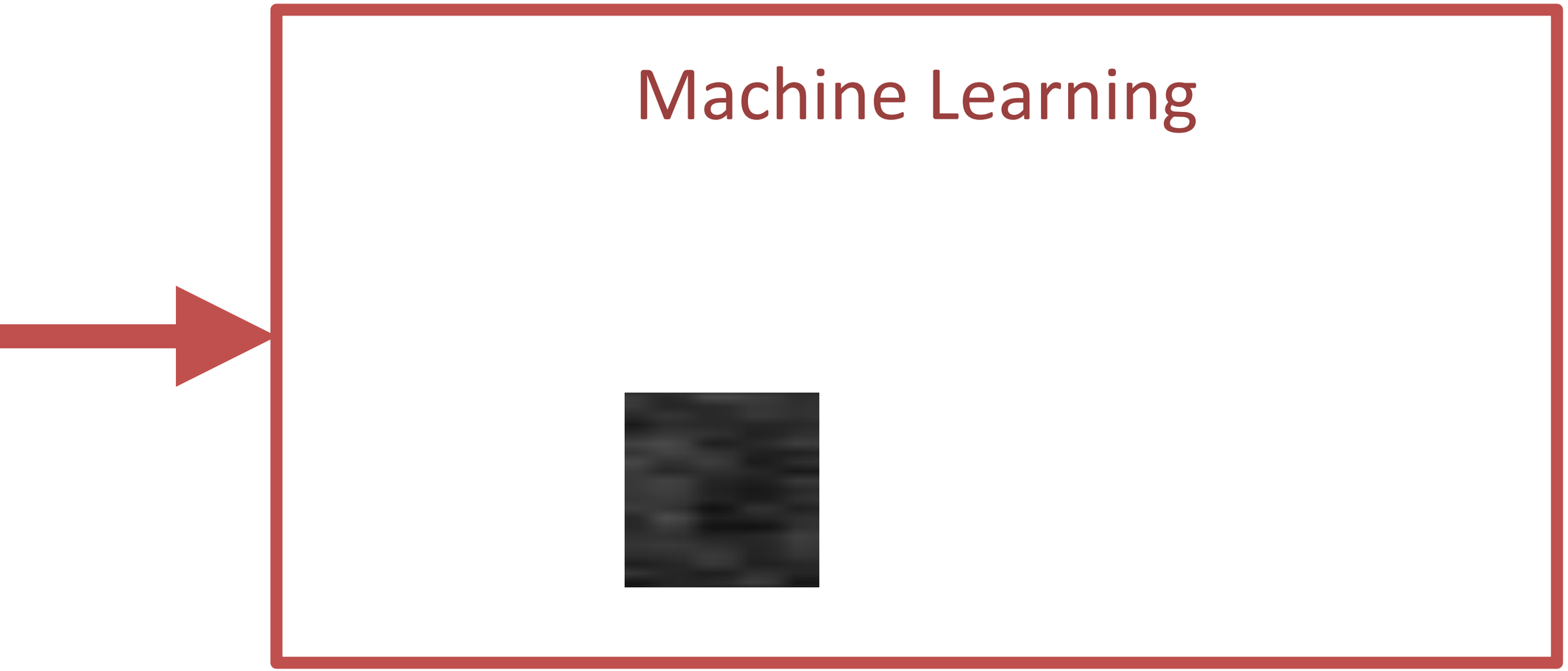
“This is a digit 0”



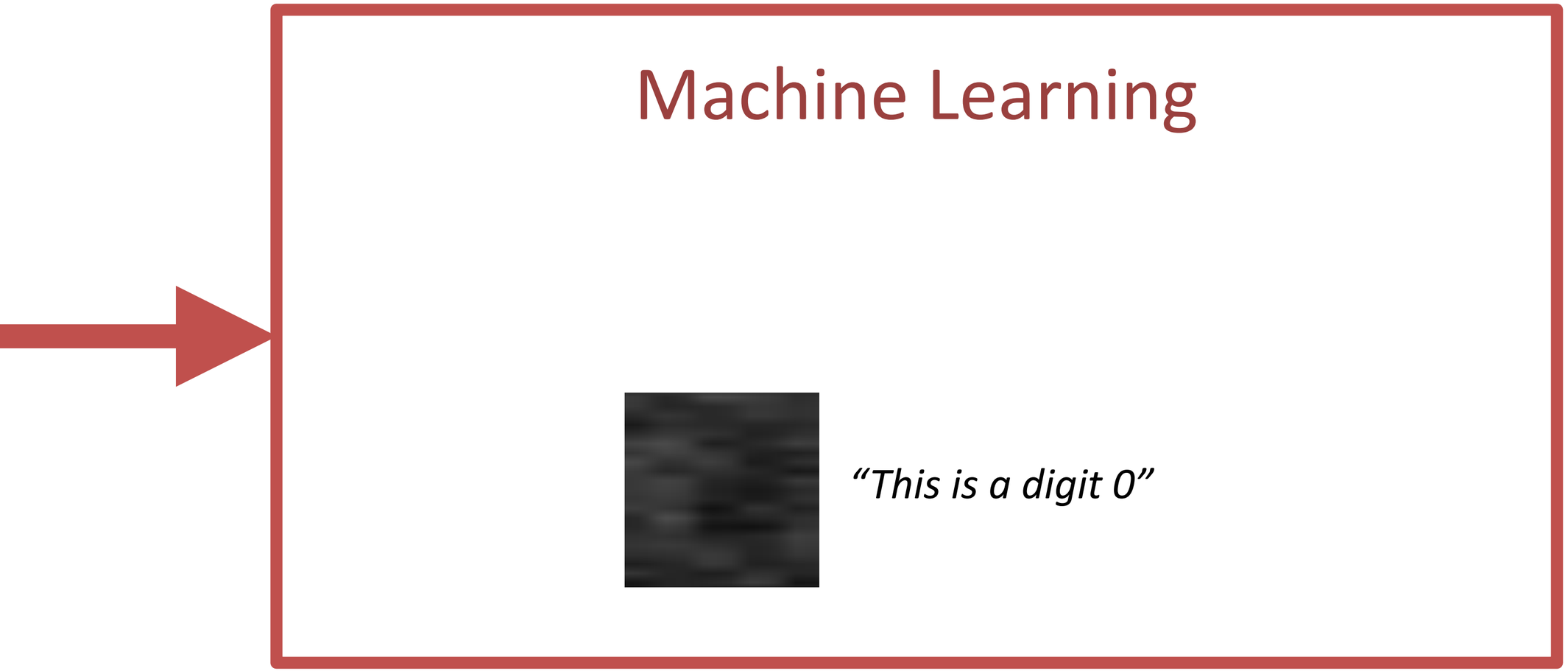
Machine Learning Training



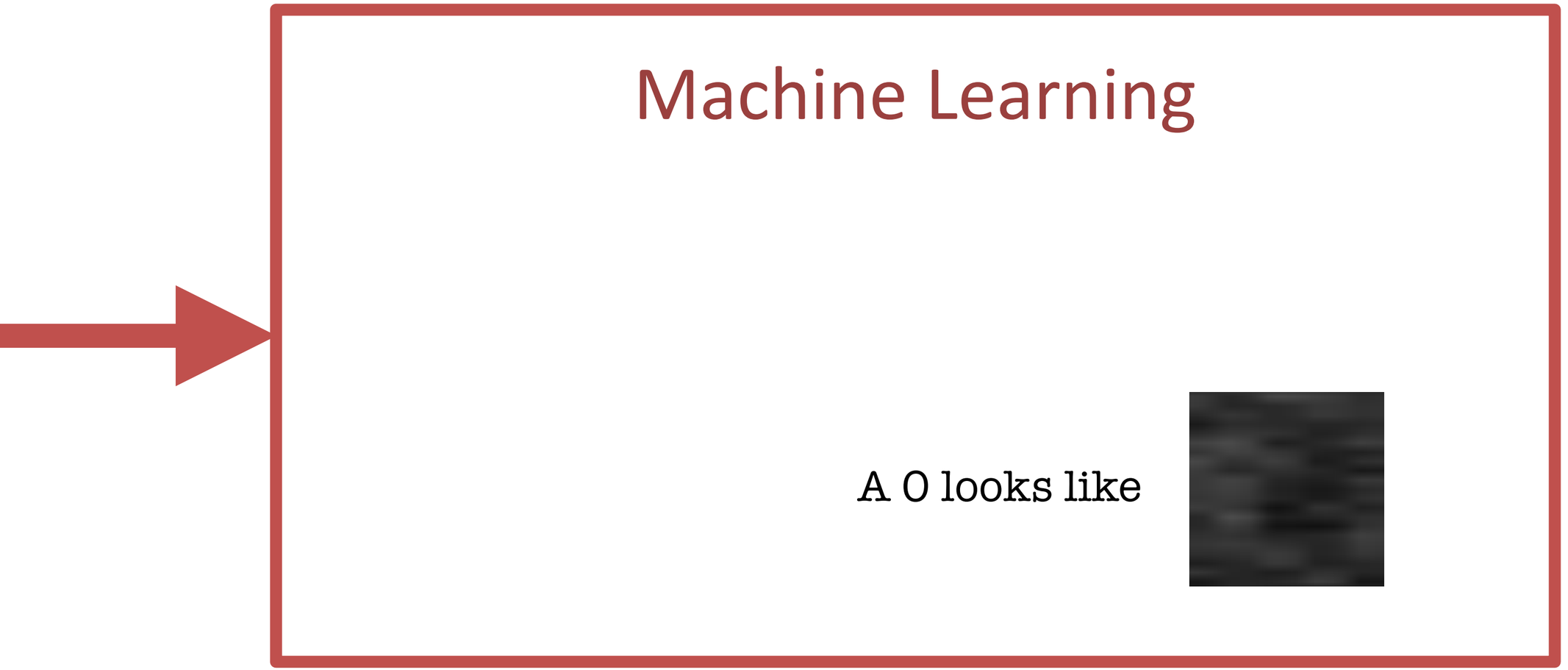
Machine Learning Training



Machine Learning Training

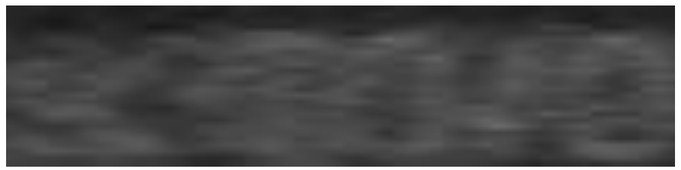


Machine Learning Training



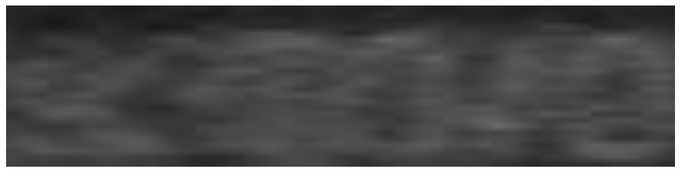
Machine Learning Classification

Machine Learning Classification



Machine Learning Classification

“What does this say?”



Machine Learning Classification

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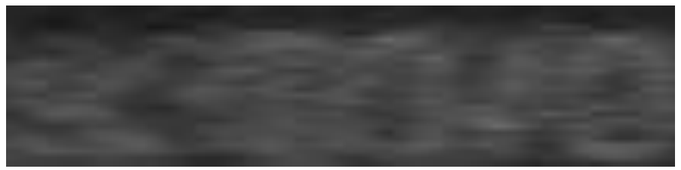

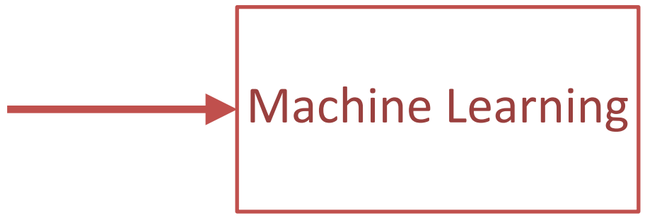

Machine Learning Classification

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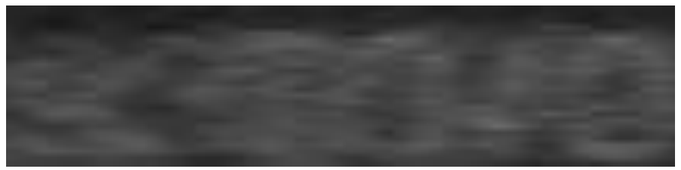

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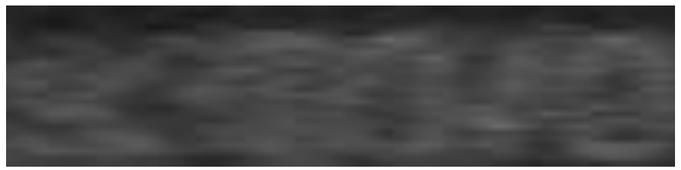

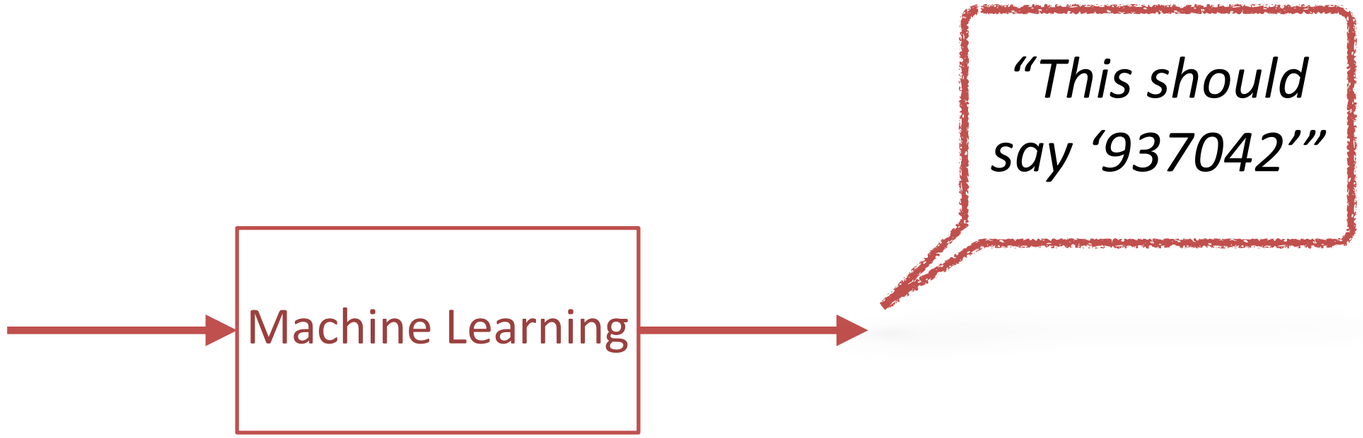

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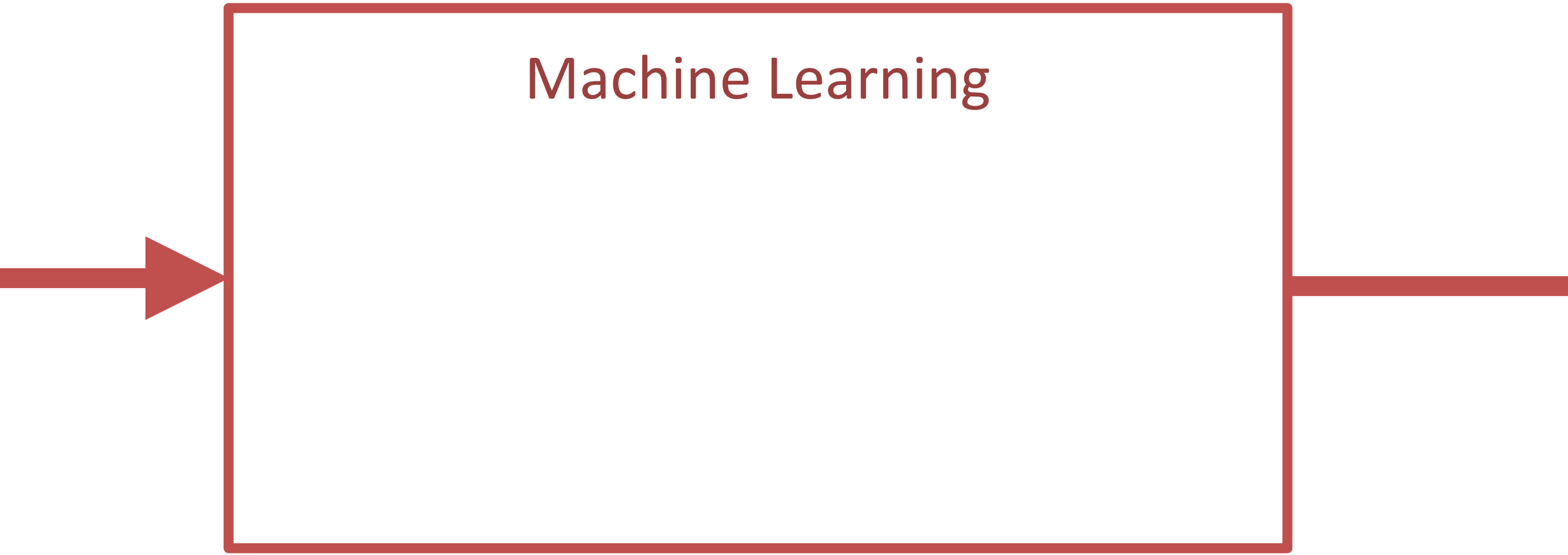
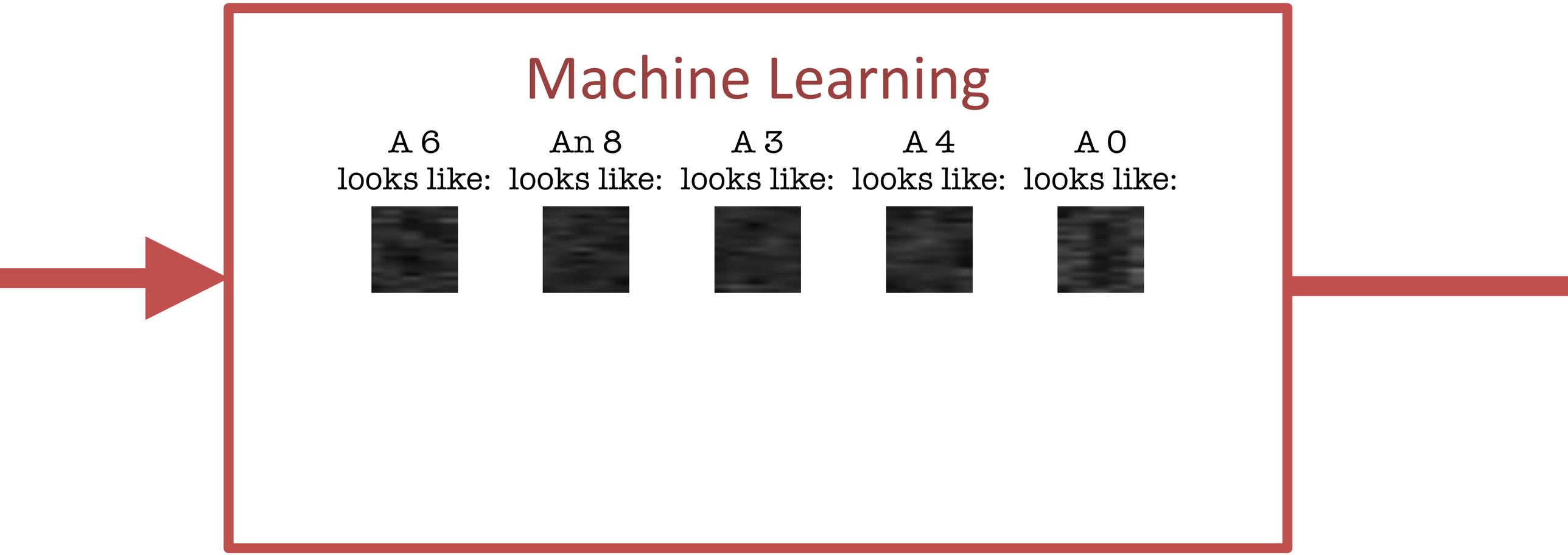
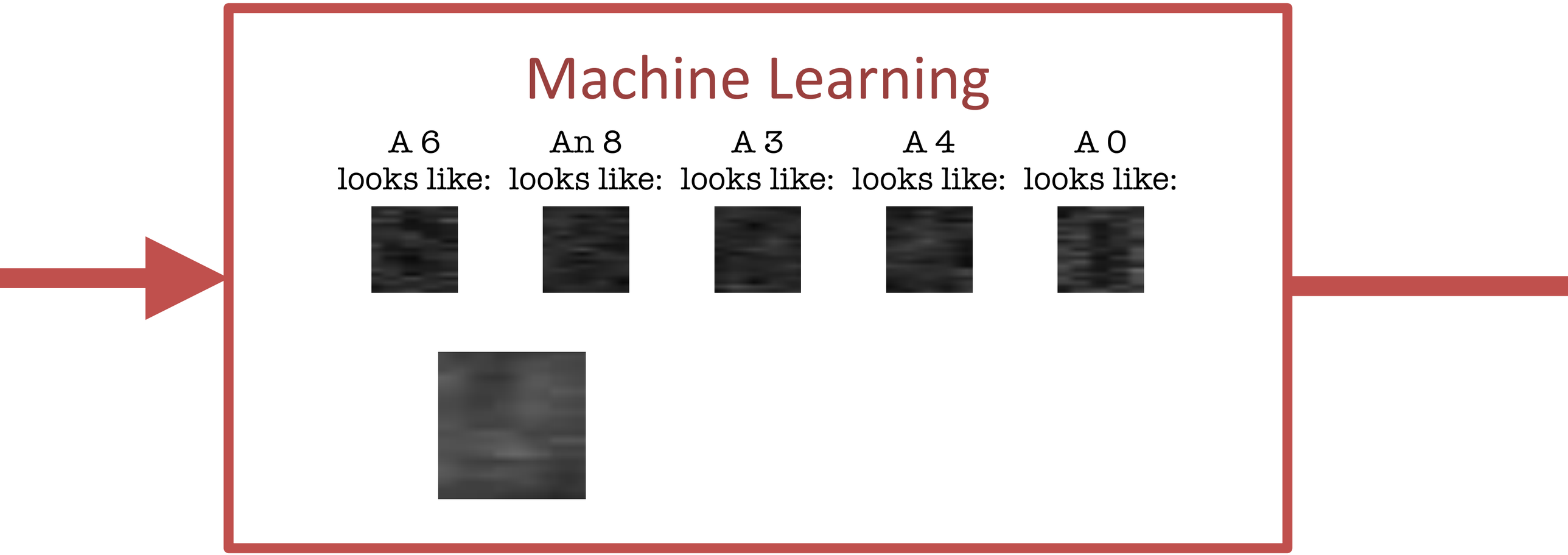


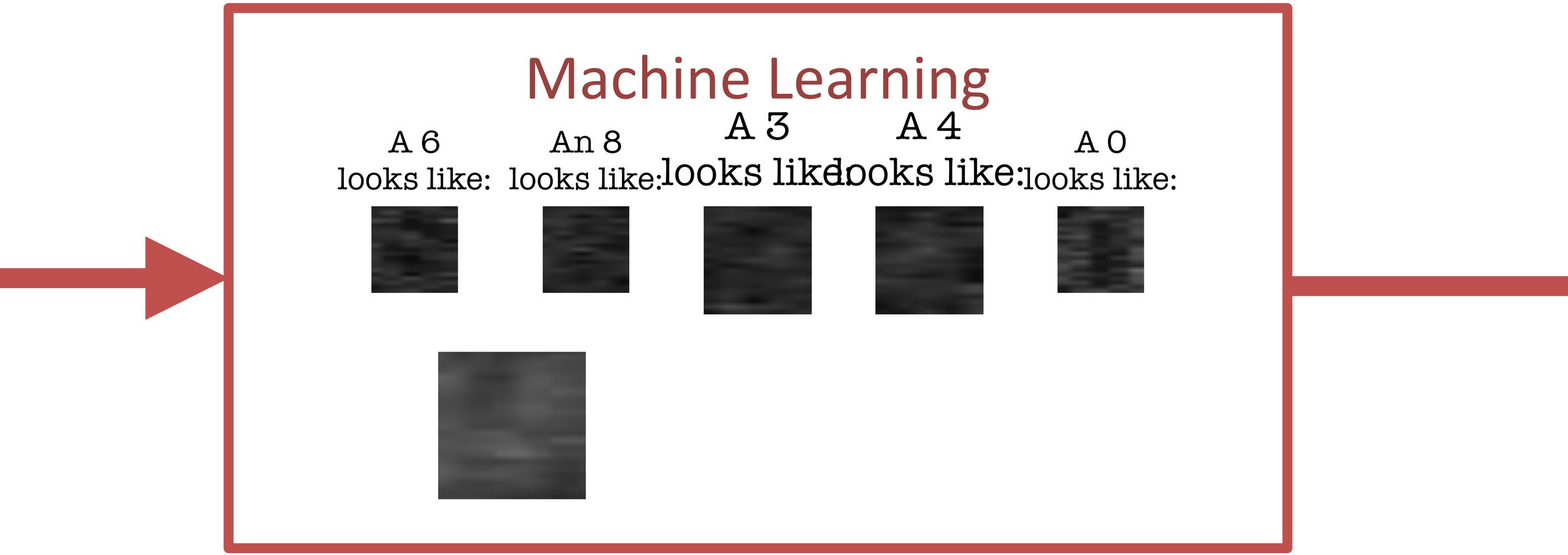
Machine Learning Classification



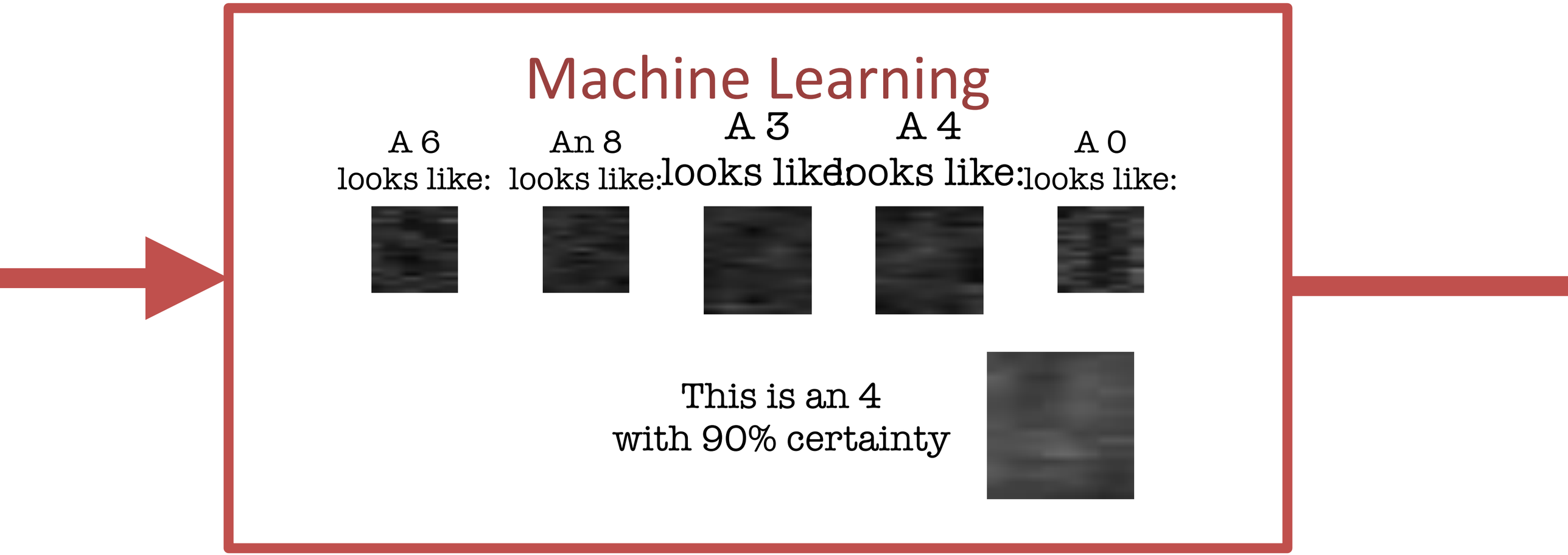
Machine Learning Classification



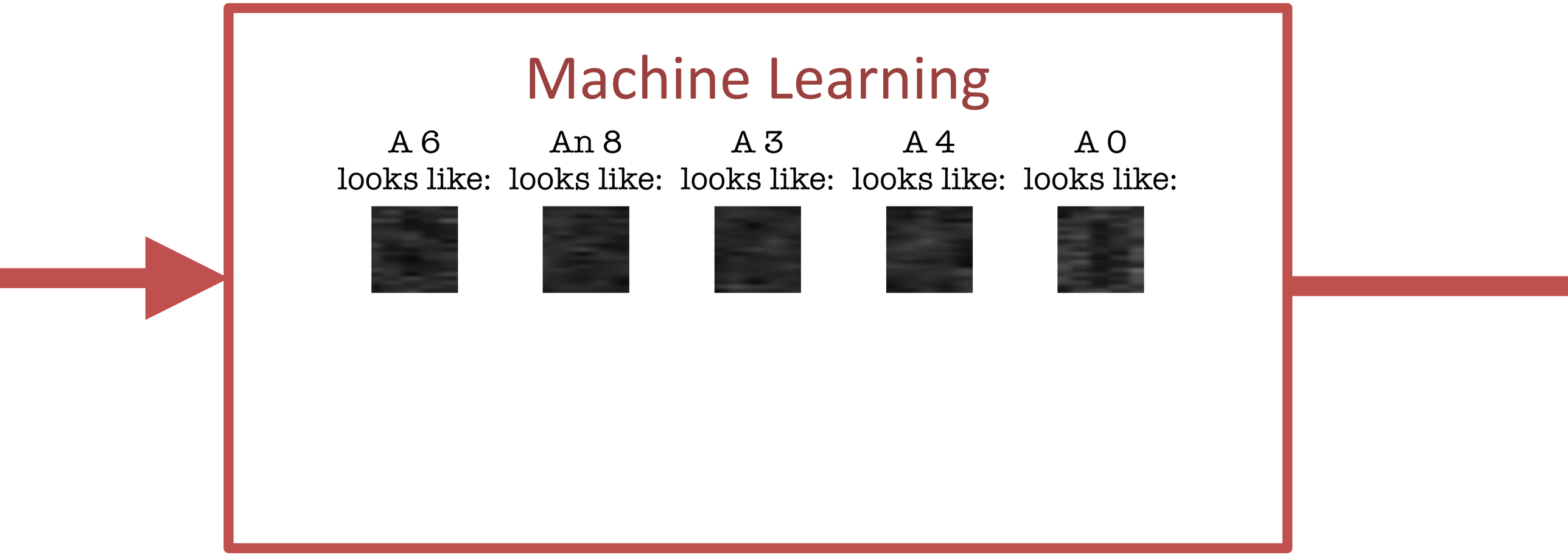
Machine Learning Classification



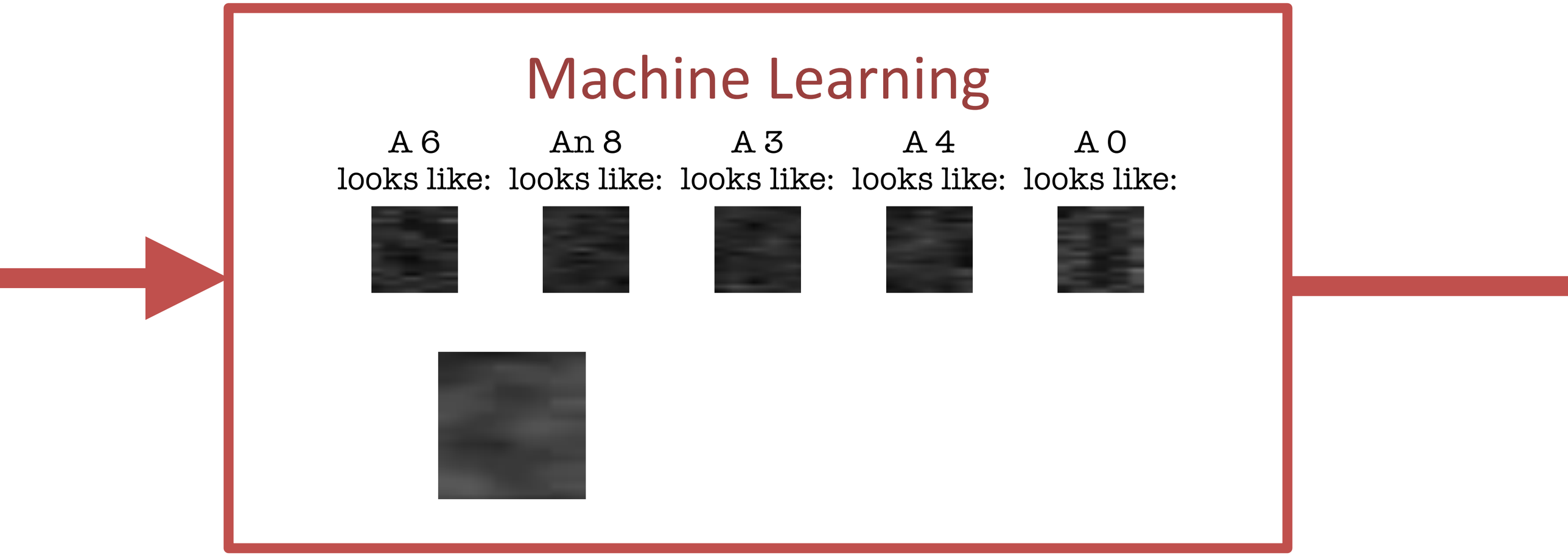
Machine Learning Classification



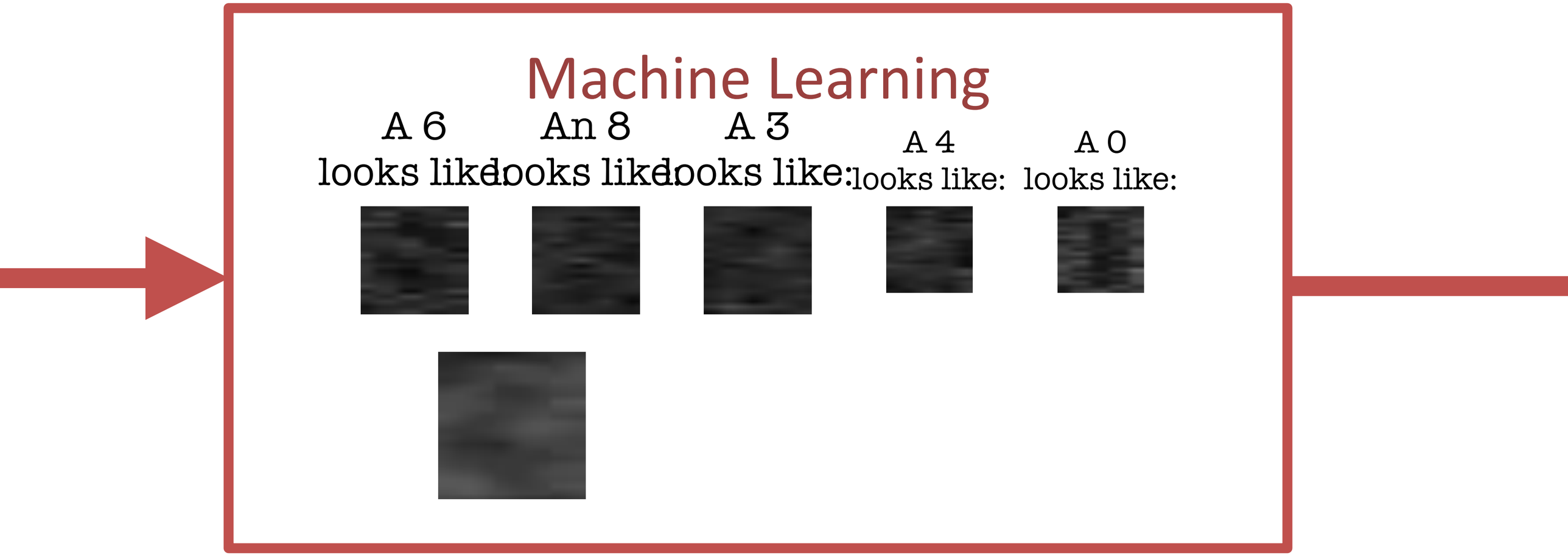
Machine Learning Classification



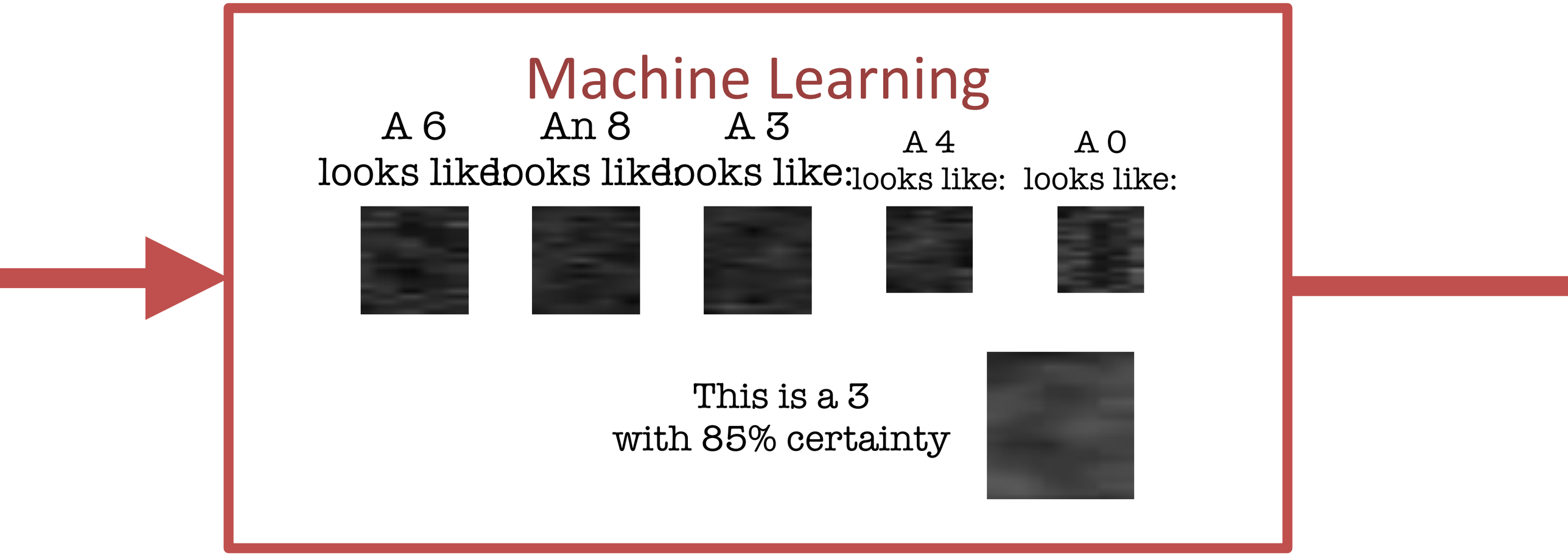
Machine Learning Classification



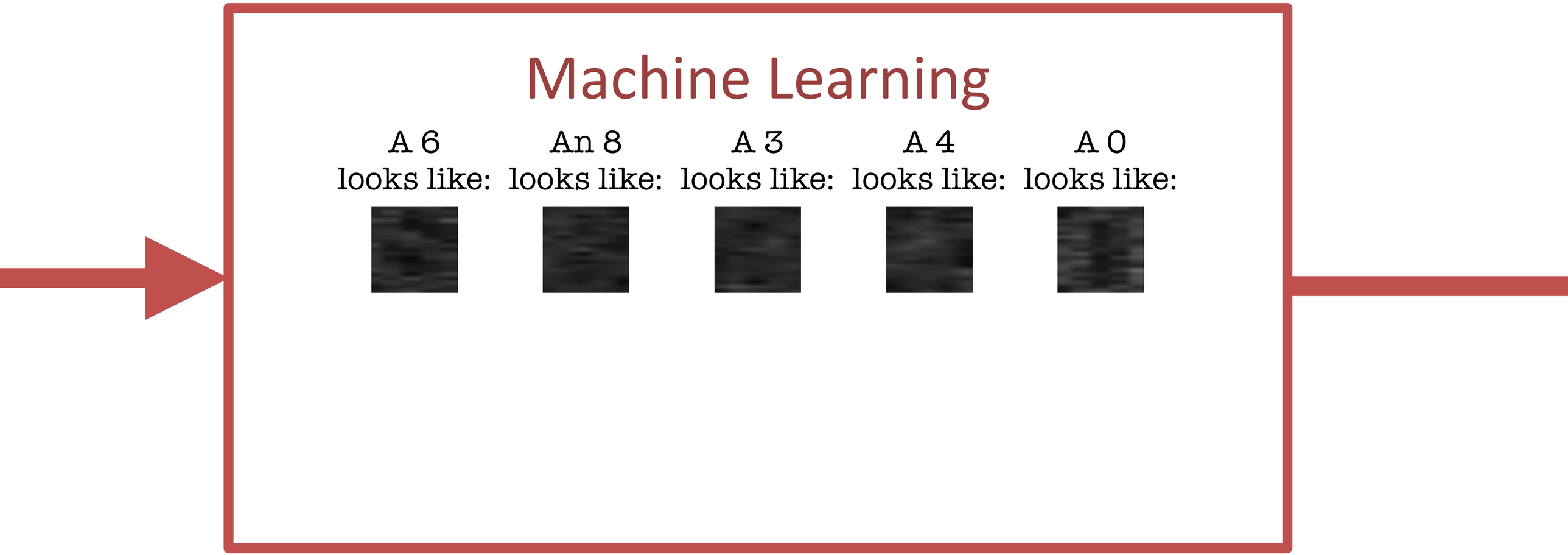
Machine Learning Classification



Machine Learning Classification



Machine Learning Classification



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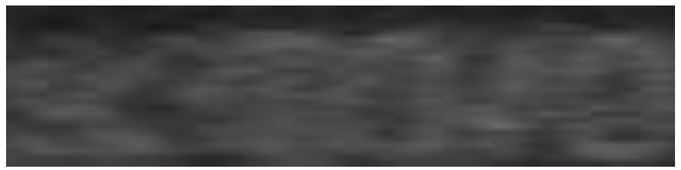

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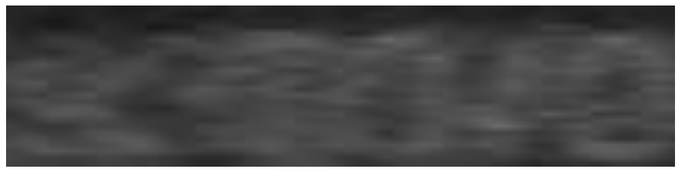

I am 90% sure
it is “937042”.

OUTLOOK

Outlook

Outlook

- Non-ideal antenna

Outlook

- Non-ideal antenna
  - Want to measure greater distances

Outlook

- Non-ideal antenna
  - Want to measure greater distances
  - Want to measure every phone

Outlook

- Non-ideal antenna
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- SDR setup requires optimizations

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  - Higher sample rates

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- SDR setup requires optimizations
  - Higher sample rates
  - Other measurement methods

Outlook

- Non-ideal antenna
  - Want to measure greater distances
  - Want to measure every phone
- SDR setup requires optimizations
  - Higher sample rates
  - Other measurement methods
- New testbed for machine learning

Take Home Message…

Take Home Message…

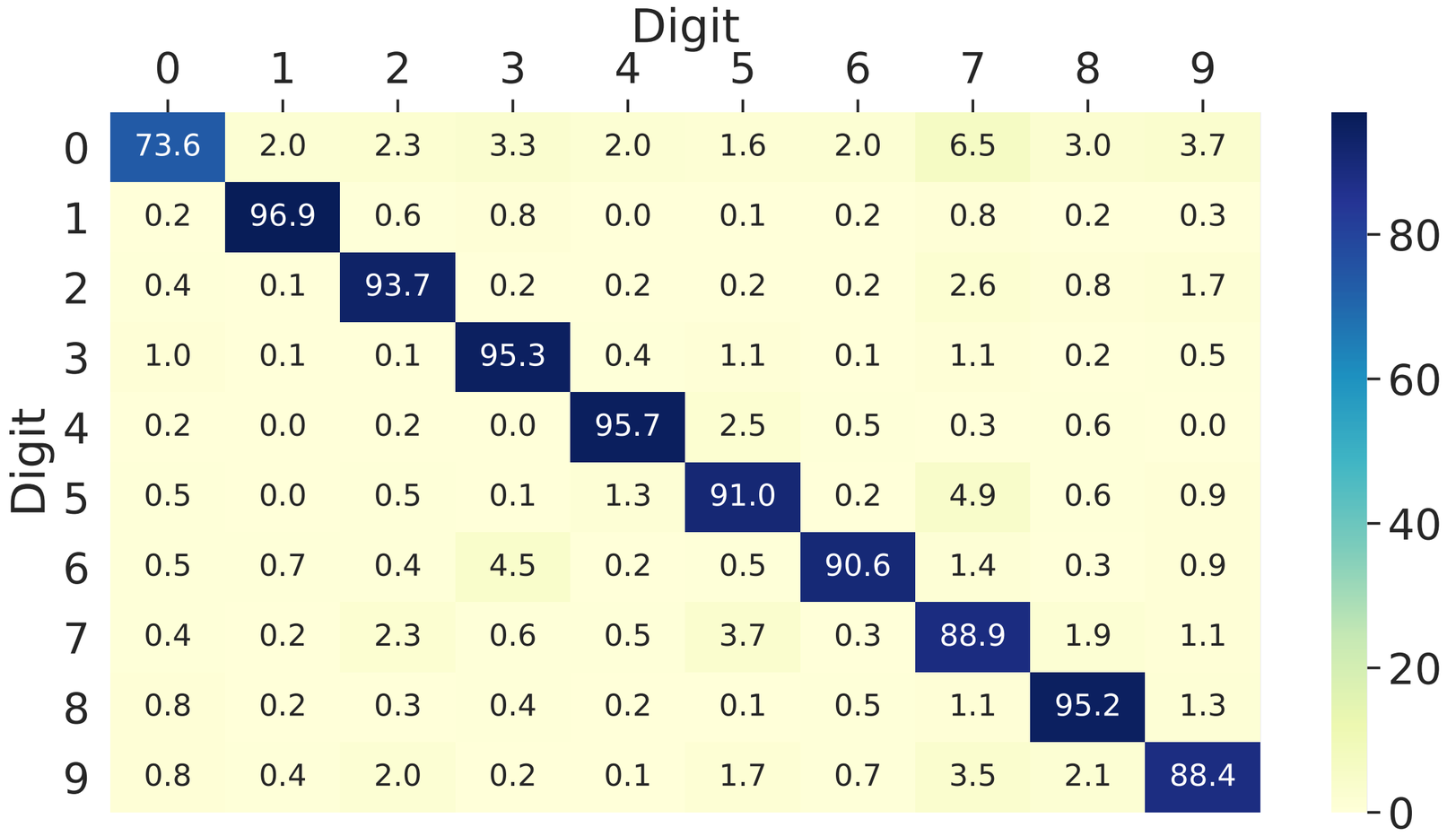
Screen Gleaning works!

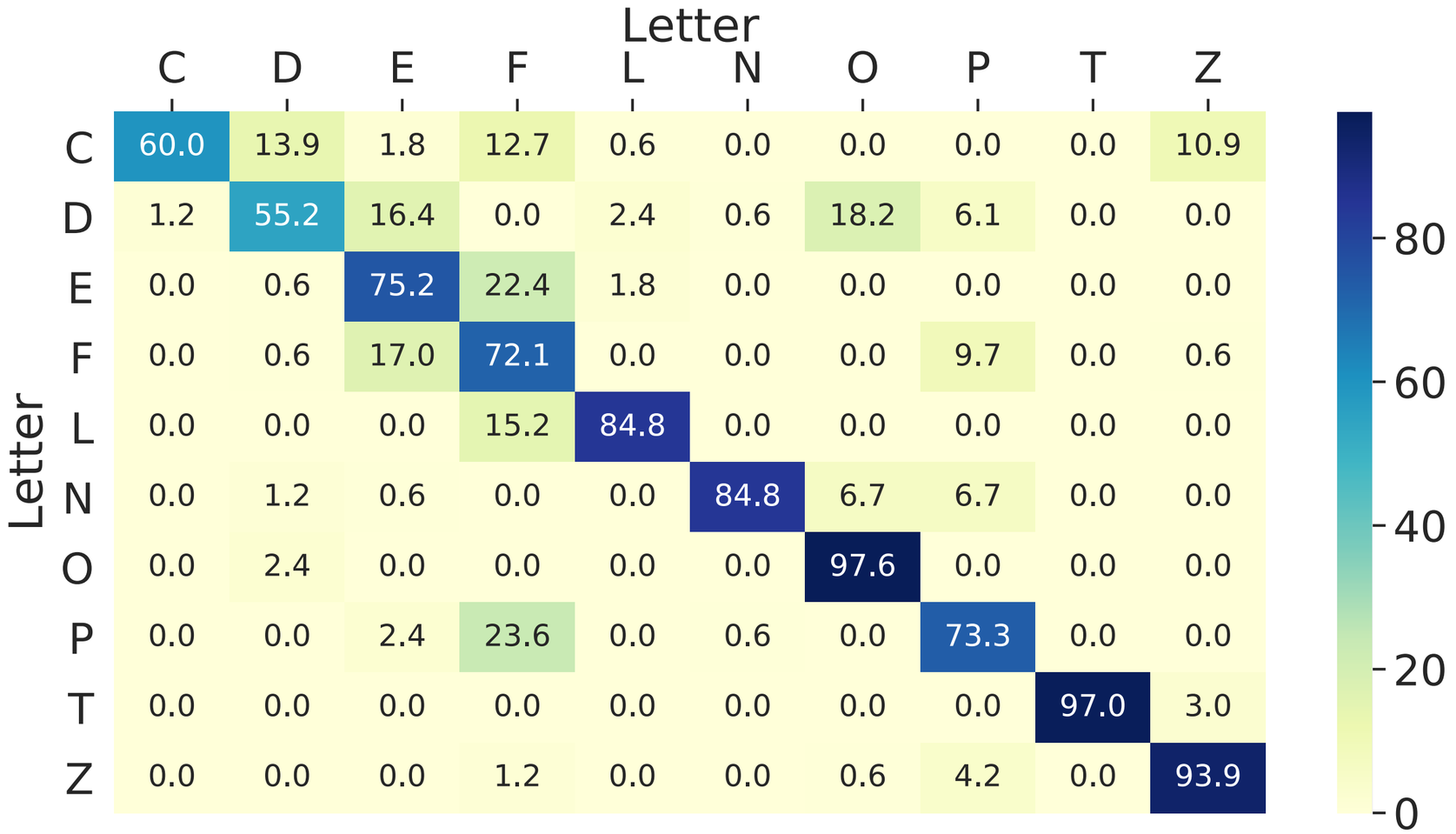
Take Home Message…

Screen Gleaning works!

Be careful with what you read on your phone…

DISCUSSION


Digit
0 1 2 3 4 5 6 7 8 9
Digit
0 73.6 2.0 2.3 3.3 2.0 1.6 2.0 6.5 3.0 3.7
1 0.2 96.9 0.6 0.8 0.0 0.1 0.2 0.8 0.2 0.3
2 0.4 0.1 93.7 0.2 0.2 0.2 0.2 2.6 0.8 1.7
3 1.0 0.1 0.1 95.3 0.4 1.1 0.1 1.1 0.2 0.5
4 0.2 0.0 0.2 0.0 95.7 2.5 0.5 0.3 0.6 0.0
5 0.5 0.0 0.5 0.1 1.3 91.0 0.2 4.9 0.6 0.9
6 0.5 0.7 0.4 4.5 0.2 0.5 90.6 1.4 0.3 0.9
7 0.4 0.2 2.3 0.6 0.5 3.7 0.3 88.9 1.9 1.1
8 0.8 0.2 0.3 0.4 0.2 0.1 0.5 1.1 95.2 1.3
9 0.8 0.4 2.0 0.2 0.1 1.7 0.7 3.5 2.1 88.4
80
60
40
20
0


Letter
C D E F L N O P T Z
Letter
C 60.0 13.9 1.8 12.7 0.6 0.0 0.0 0.0 0.0 10.9
D 1.2 55.2 16.4 0.0 2.4 0.6 18.2 6.1 0.0 0.0
E 0.0 0.6 75.2 22.4 1.8 0.0 0.0 0.0 0.0 0.0
F 0.0 0.6 17.0 72.1 0.0 0.0 0.0 9.7 0.0 0.6
L 0.0 0.0 0.0 15.2 84.8 0.0 0.0 0.0 0.0 0.0
N 0.0 1.2 0.6 0.0 0.0 84.8 6.7 6.7 0.0 0.0
O 0.0 2.4 0.0 0.0 0.0 0.0 97.6 0.0 0.0 0.0
P 0.0 0.0 2.4 23.6 0.0 0.6 0.0 73.3 0.0 0.0
T 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 97.0 3.0
Z 0.0 0.0 0.0 1.2 0.0 0.0 0.6 4.2 0.0 93.9
80
60
40
20
0