



# DEEP LEARNING-BASED OBJECT DETECTION FOR EFFLORESCENCE RECOGNITION IN MASONRY

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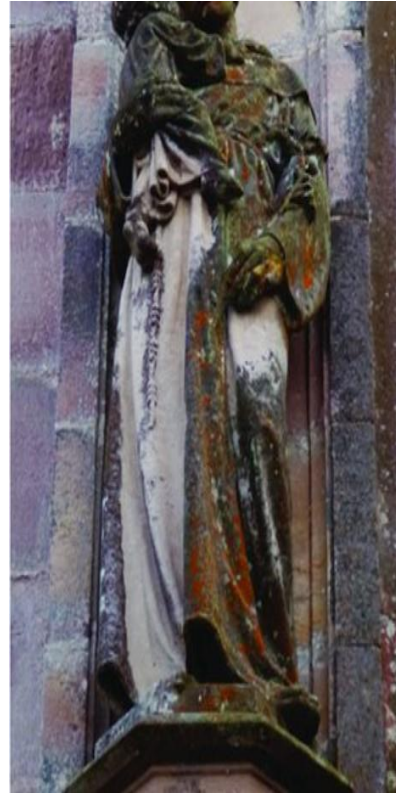
- 1 | Introduction & Research Context
- 2 | Problem Statement & Research Questions
- 3 | Methodology
- 4 | Results
- 5 | Conclusion & Recommendation
- 6 | Lessons Learned & Future Work

# INTRODUCTION & RESEARCH CONTEXT

## HERITAGE PRESERVATION AND DAMAGE DETECTION



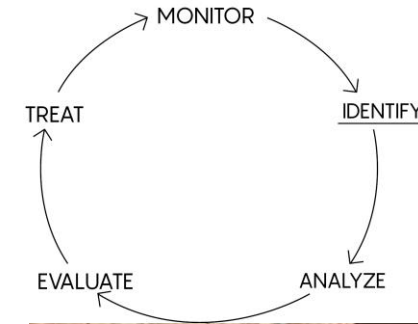
**ARCHITECTURAL  
CONSERVATION**



**ENVIRONMENTAL  
VULNERABILITY**



**PRESERVATION  
CHALLENGES**



**SUSTAINABLE  
CONSERVATION**

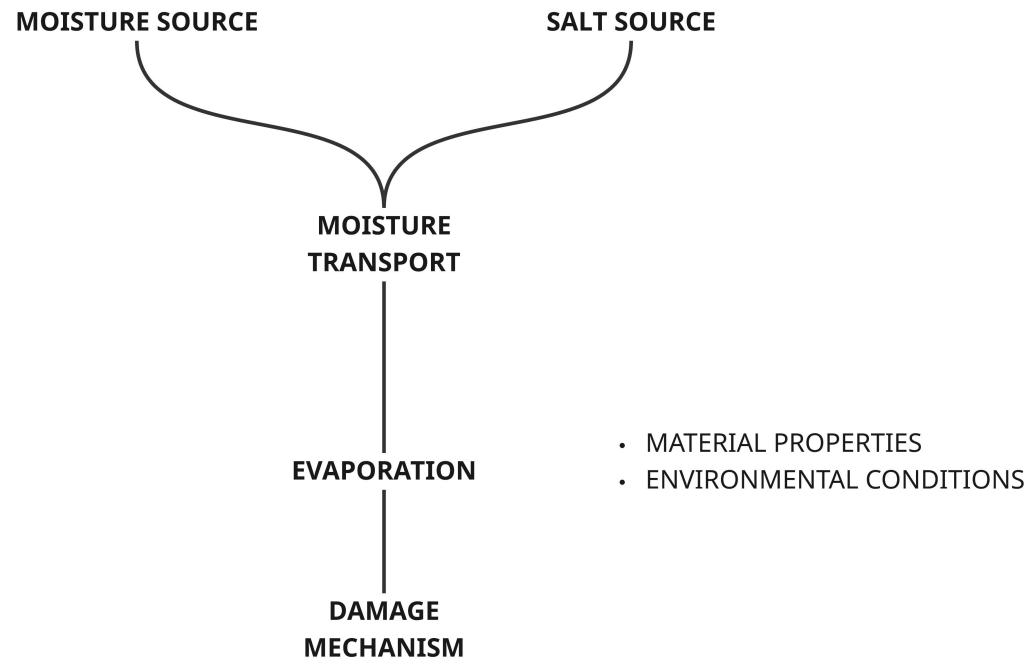


**HERITAGE  
MASONRY**

# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: DEFINITION & CONTEXT

*“Deposit of (soluble) salt crystals visible on the surface of the (dry) material”*



# MOISTURE SOURCE



**GROUNDWATER**



**SURFACE WATER**



**PRECIPITATION**



**ATMOSPHERIC  
MOISTURE**



**INFILTRATION &  
LEAKAGE**

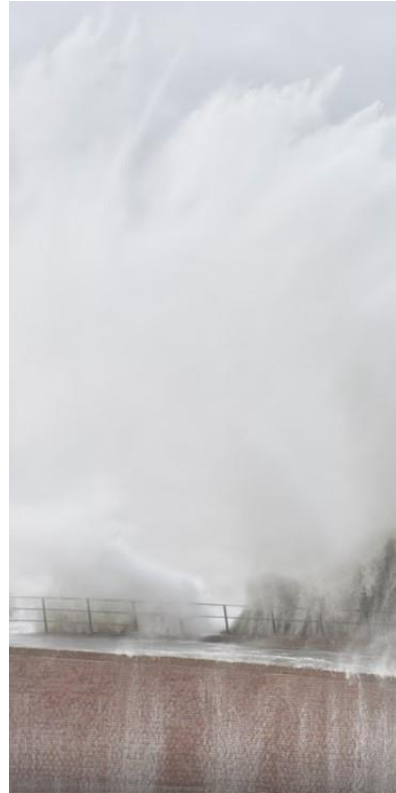


**FLOODINGS**

# SALT SOURCE



**MATERIAL**



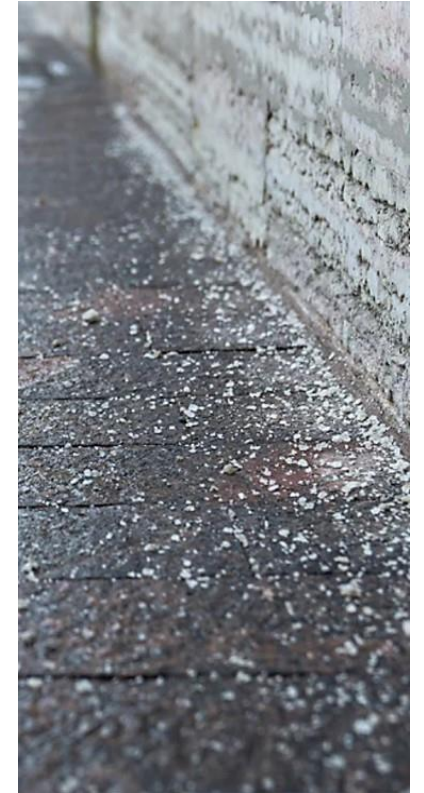
**AEROSOL**



**EXCREMENTS**



**GROUNDWATER /  
SURFACE WATER**



**DE-ICING SALTS**

# MOISTURE TRANSPORT

- SOLUBILITY OF DIFFERENT SALTS
- CAPILLARY ACTION (RISING DAMP)
- PORE SIZE (DISTRIBUTION)
- DRYING SPEED
- INTERFACE BRICK VS MORTAR
  
- SEEPAGE (LEAKAGE)

# EVAPORATION

- EVAPORATION FRONT
- CRYSTALLISATION PRESSURE

**DAMAGE**

**MECHANISM**

# DAMAGE MECHANISM



**POWDERING**



**SPALLING**



**CRUMBLING**



**BLISTERING**



**ALVEOLIZATION**



**EROSION**



**EXFOLIATION**

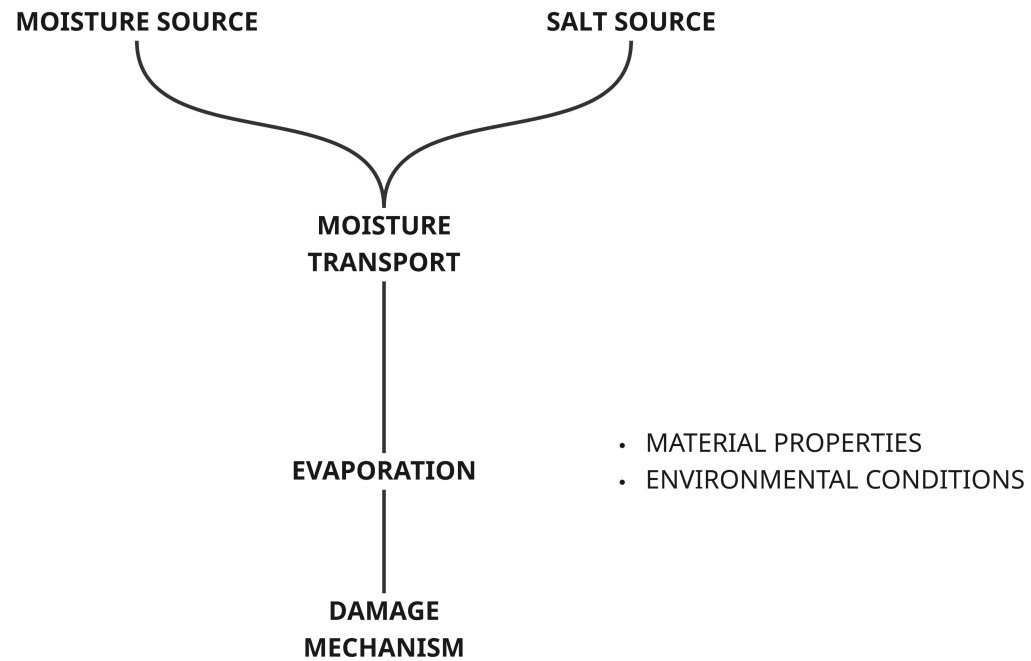


**DELAMINATION**

# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: DEFINITION & CONTEXT

*“Deposit of (soluble) salt crystals visible on the surface of the (dry) material”*



# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: EFFECT



*Development of salt crystallization damage over a period of 5 years (Van Hees et al., 2020)*

**Year 1**

# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: EFFECT



*Development of salt crystallization damage over a period of 5 years (Van Hees et al., 2020)*

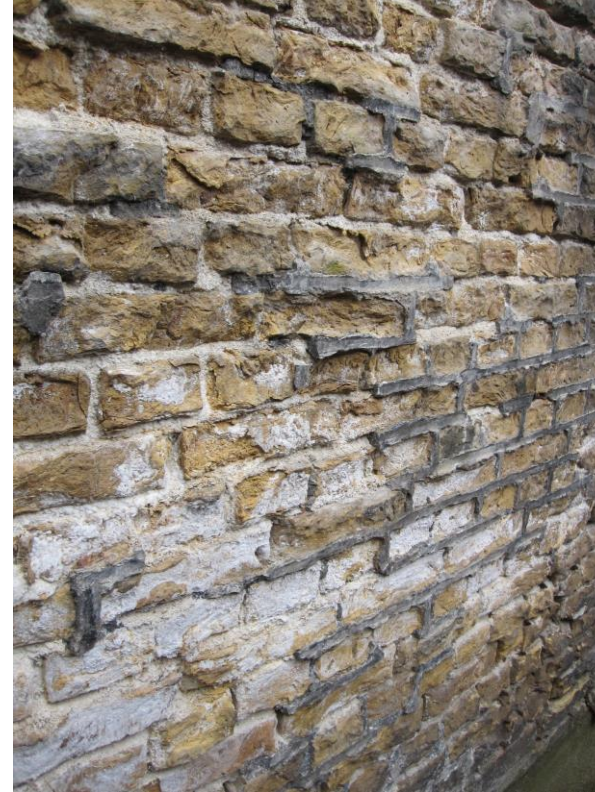
**Year 5**

# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: CONTEXT



**< 5 years old**



**> 80 years old**

# INTRODUCTION & RESEARCH CONTEXT

## EFFLORESCENCE: SIMILARITY



**ENCRUSTATION**



**BIOLOGICAL GROWTH**



**GRAFFITI**

# PROBLEM STATEMENT & RESEARCH QUESTIONS

PS

The **manual** process of surveying **resource-intensive** lacks **scalability** requires **expert** evaluation, leading to **inefficiencies** and potential **subjective** inaccuracies in **assessing** the conditions while tracking **changes** over time, highlighting the need for reliable, **automated** deep learning-based **detection methods** on **efflorescence** related damage in **heritage** buildings.

RQ

*How can **deep learning** models be applied to **improve** the **detection** of **efflorescence** in **masonry** buildings in the Netherlands?*

# PROBLEM STATEMENT & RESEARCH QUESTIONS

## SUB RESEARCH QUESTIONS

SRQ

What are the **visual characteristics** of **efflorescence** on masonry, and how do these factors present **challenges** for **detection**?

Which deep **learning models** are most suitable for detecting and **classifying efflorescence** on masonry, based on **performance criteria**?

What is the effect of **variables** (such as image quality, lighting, and orientation) on the **performance** of the **model**?

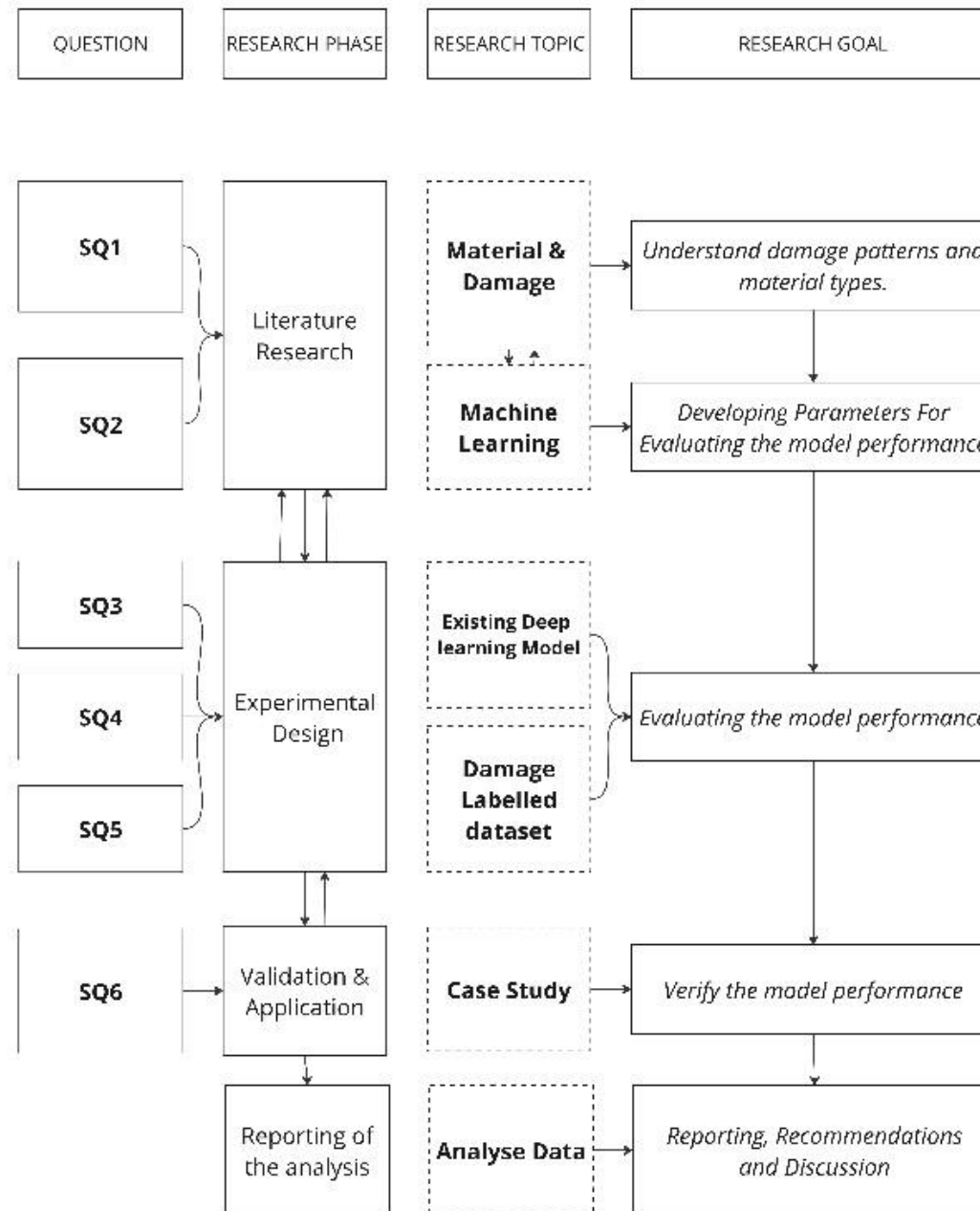
How can we **improve** model **performance** by addressing **misclassification** of similar damage types and **co-occurrence** with **efflorescence**?

How can the **integration** of **thermal (IR)** imagery **improve** the detection accuracy and reliability of **efflorescence** in masonry?

How well does the **enhanced model** perform when **evaluated** on unseen data and applied to real-world **case studies** of **efflorescence**?

# METHODOLOGY

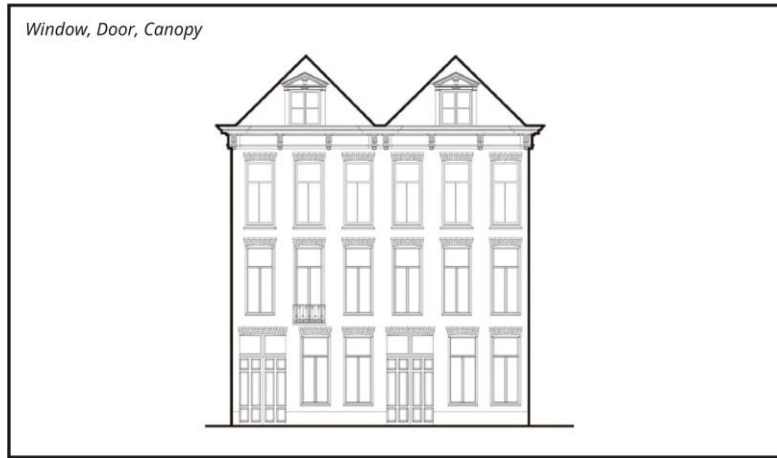
## RESEARCH PHASING



# RESULTS

## MACHINE LEARNING

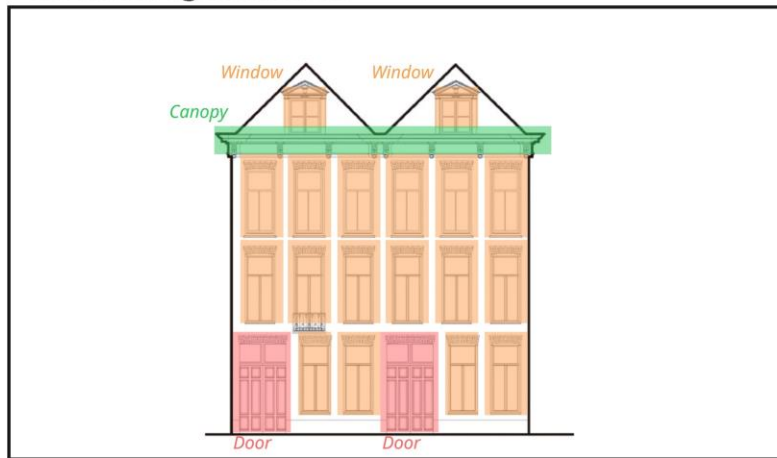
### Classification



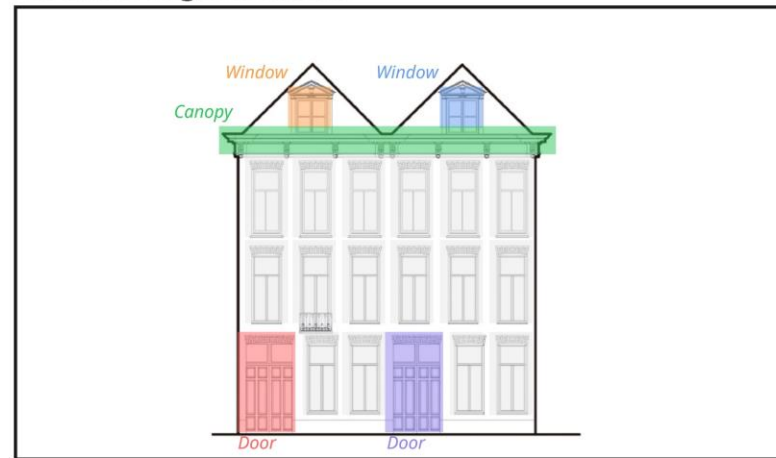
### Object Detection



### Semantic Segmentation



### Instance Segmentation



# RESULTS

## MACHINE LEARNING

### Early layers

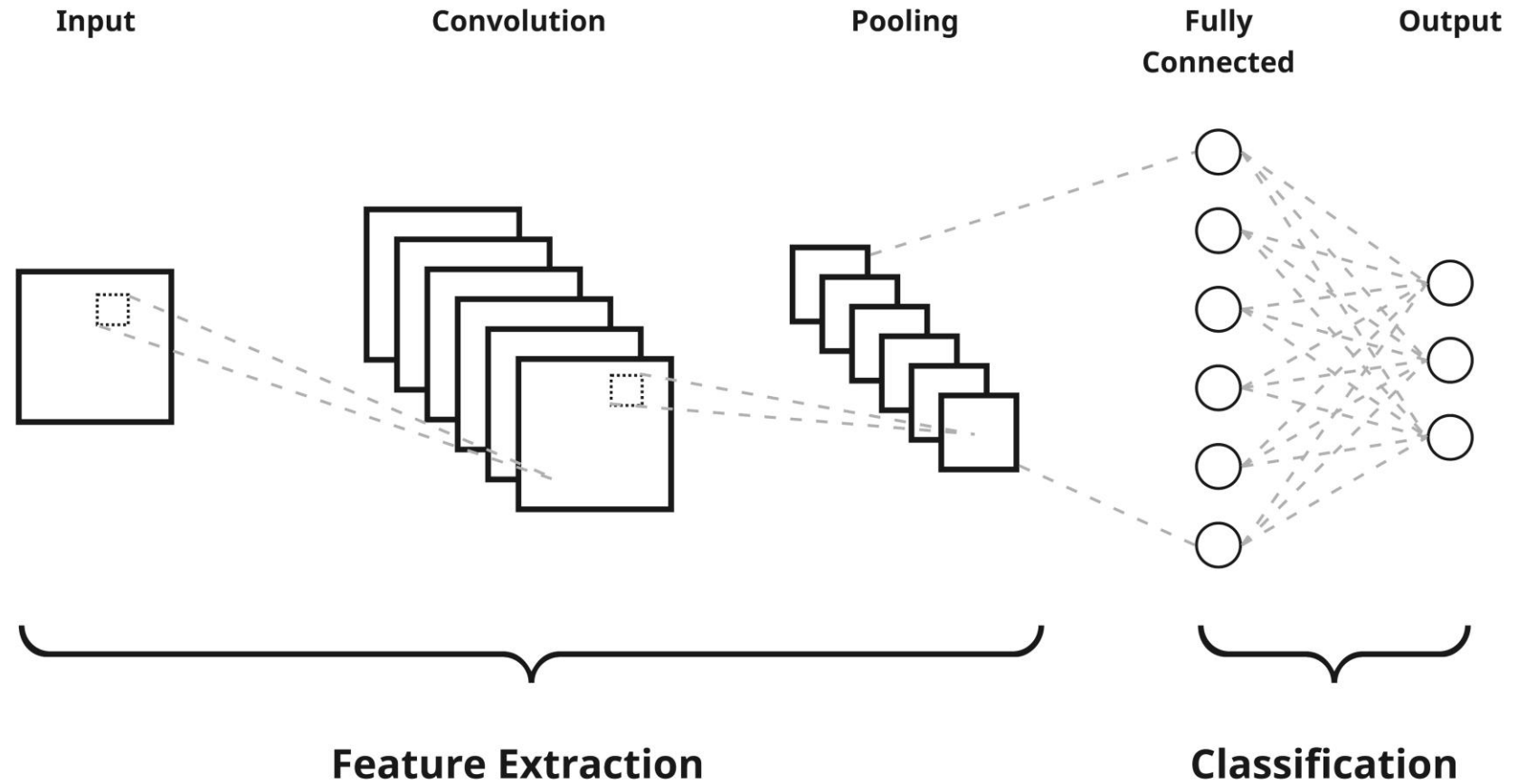
- Edge detection
- intersection of edges
- textures / lines
- colour gradients

### Middle layers

- shapes
- patterns
- objects

### Deeper layers

- object parts
- complex objects



# RESULTS

## MACHINE LEARNING

### Early layers

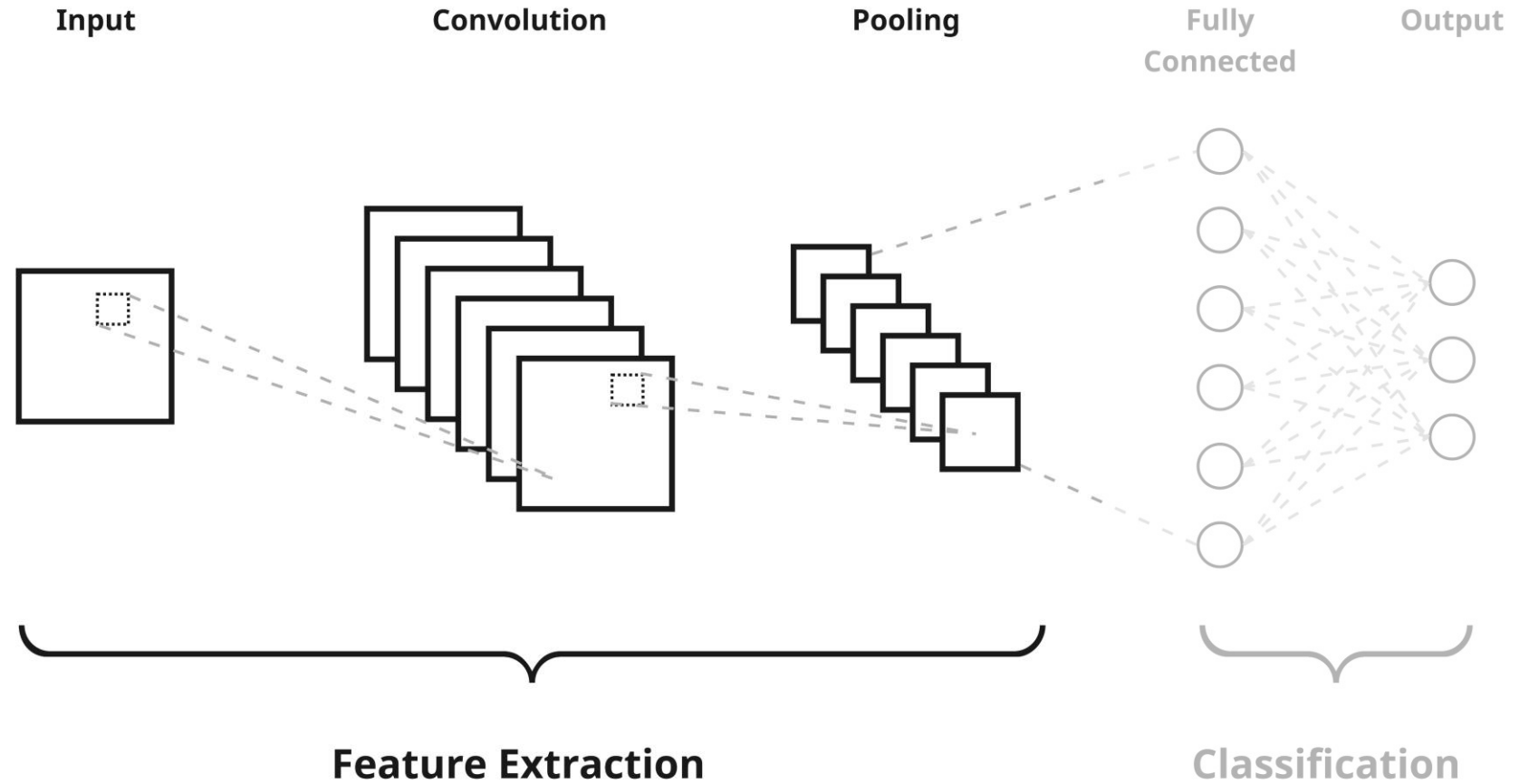
- Edge detection
- intersection of edges
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### Middle layers

- shapes
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### Deeper layers

- object parts
- complex objects



# RESULTS

## MACHINE LEARNING



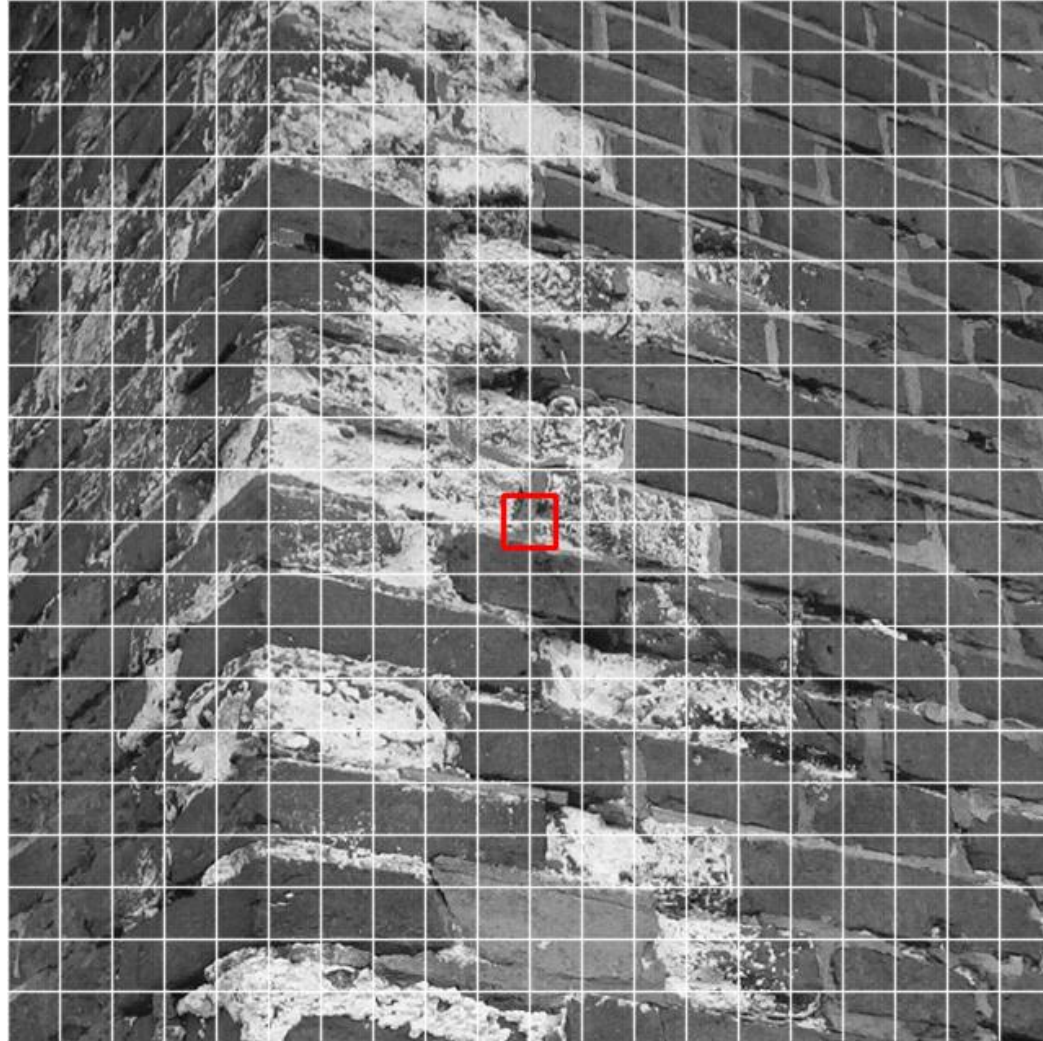
# RESULTS

## MACHINE LEARNING



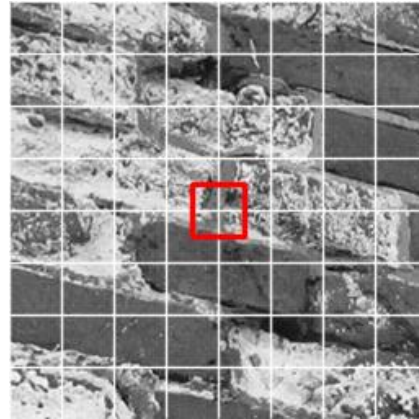
# RESULTS

## MACHINE LEARNING



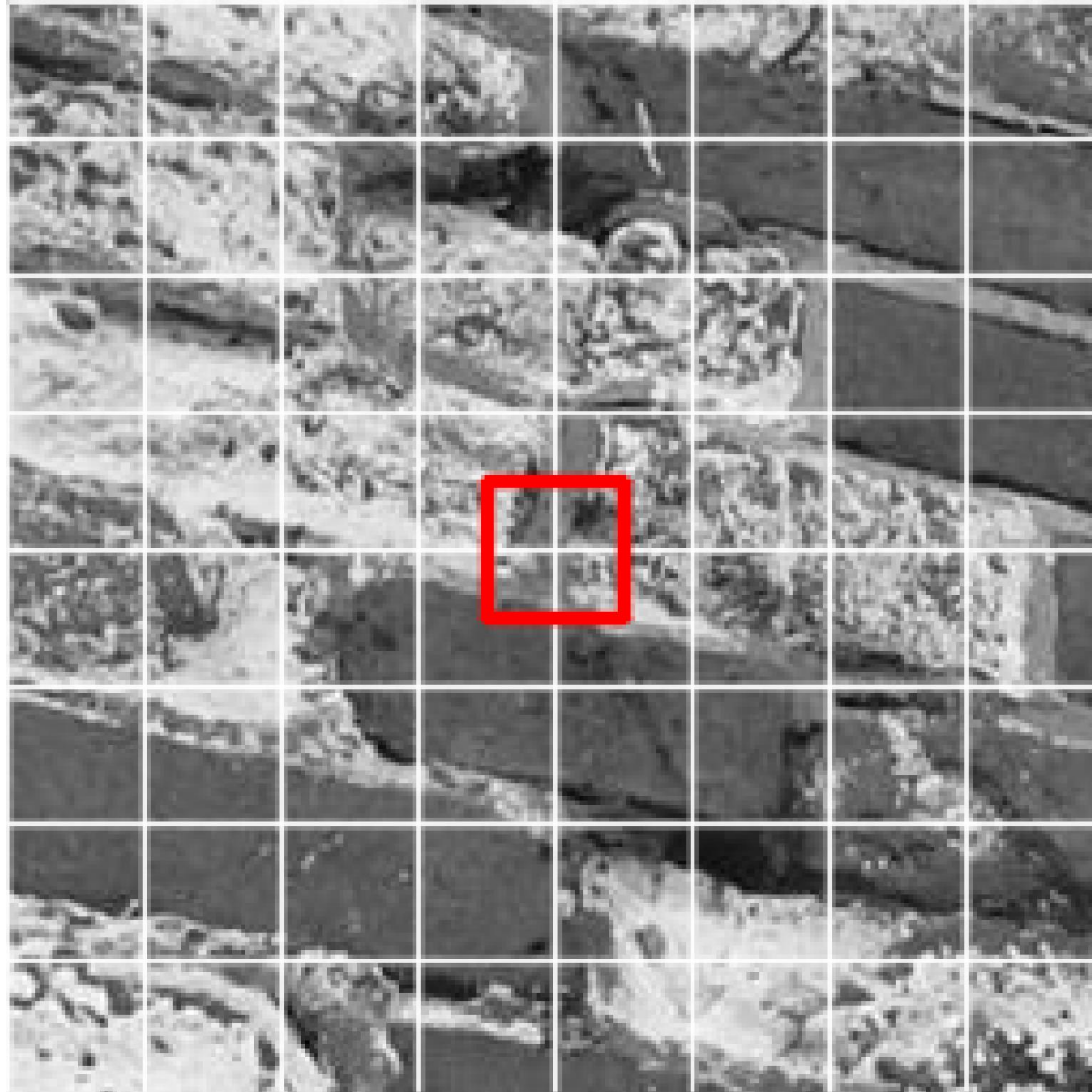
# RESULTS

## MACHINE LEARNING



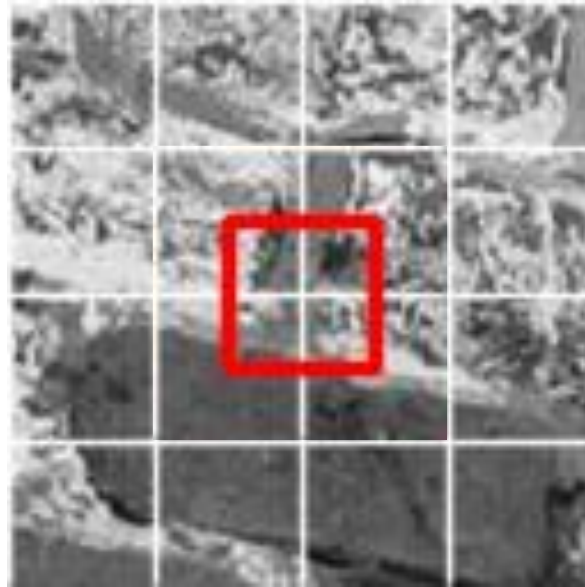
# RESULTS

## MACHINE LEARNING



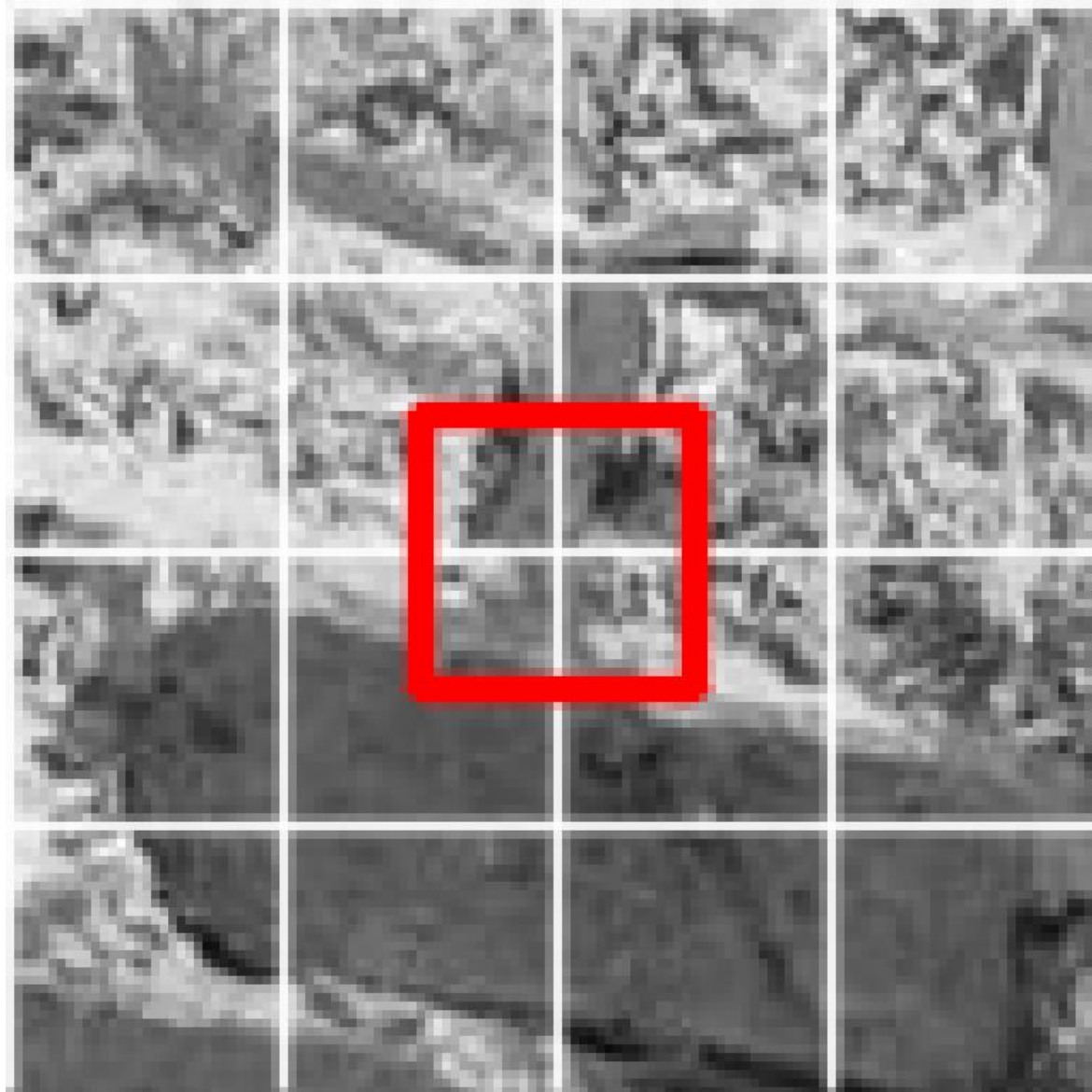
# RESULTS

## MACHINE LEARNING



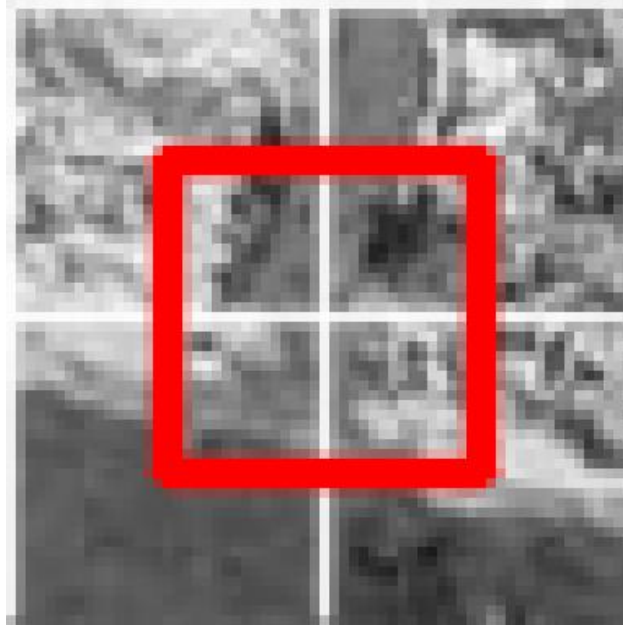
# RESULTS

## MACHINE LEARNING



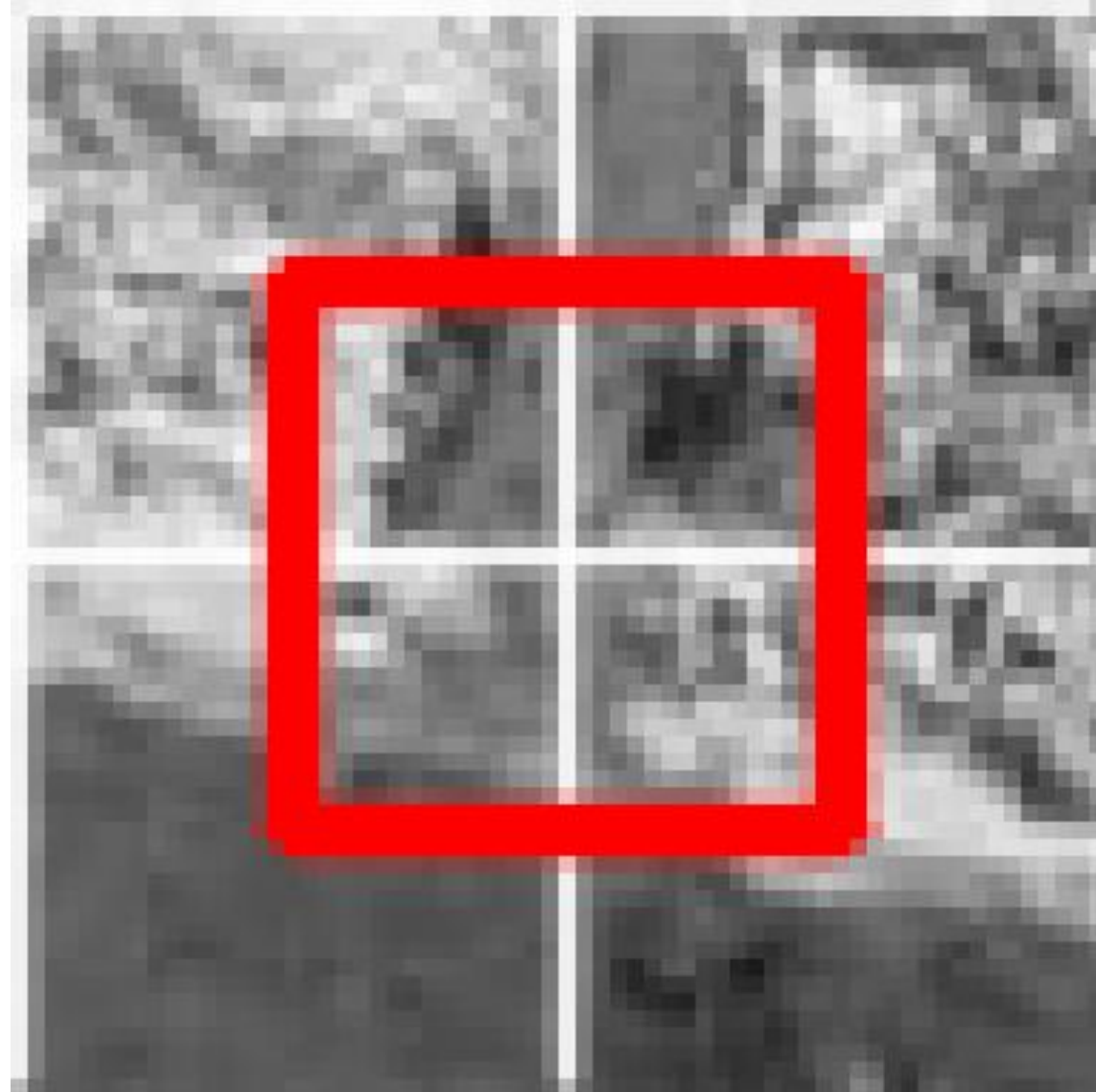
# RESULTS

## MACHINE LEARNING



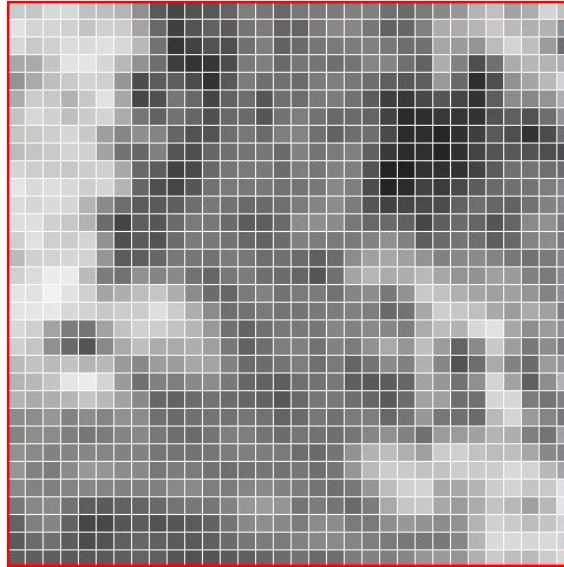
# RESULTS

## MACHINE LEARNING



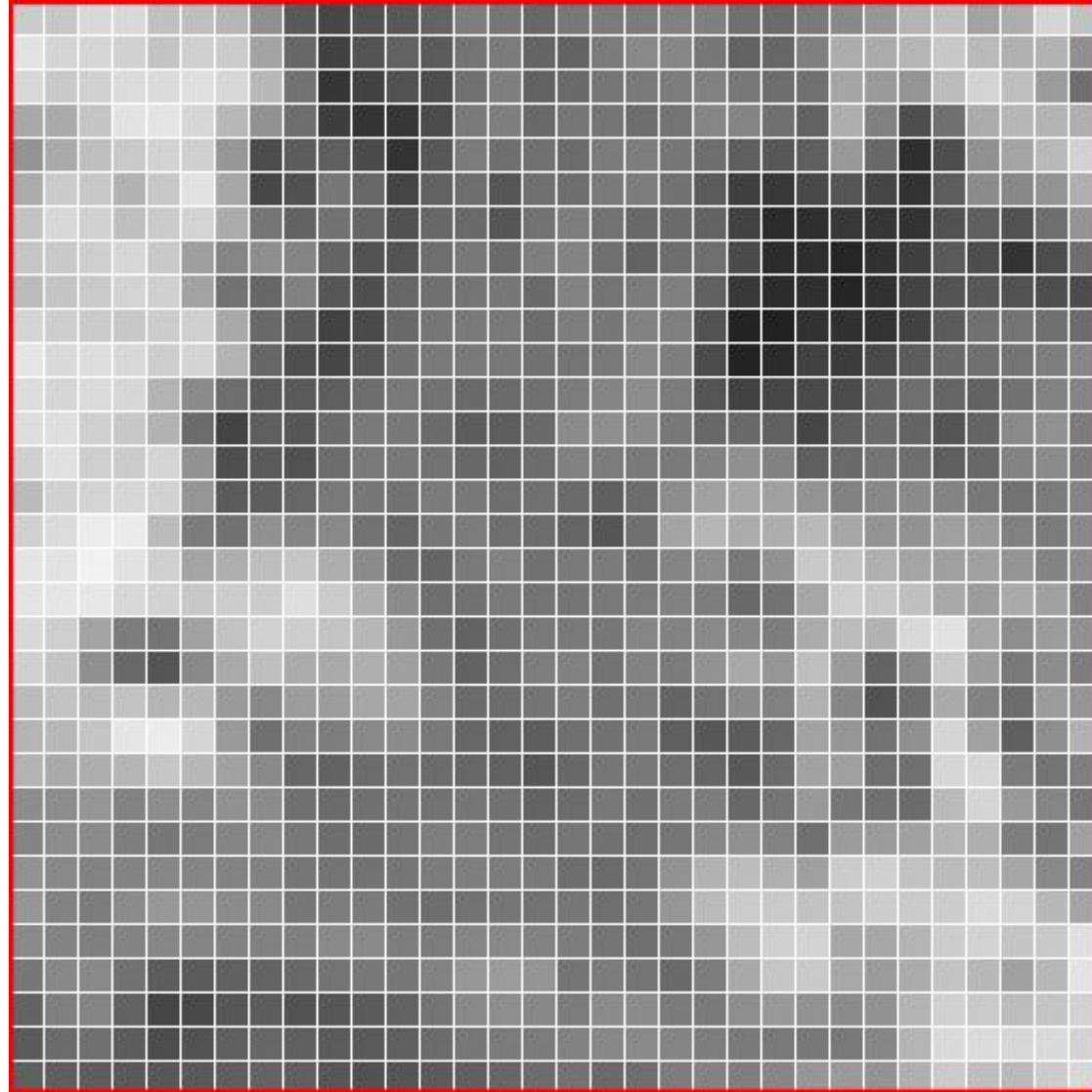
# RESULTS

## MACHINE LEARNING



# RESULTS

## MACHINE LEARNING



# RESULTS

## MACHINE LEARNING

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# RESULTS

## MACHINE LEARNING

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# RESULTS

## MACHINE LEARNING

68	80	79	70	79	89	66	29	32	47	41	28	39	44	34	44	44	48	50	45
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90	89	95	89	82	65	69	75	78	69	55	43	41	48	52	45	48	49	45	53

# RESULTS

## MACHINE LEARNING

66	76	65	85	76	75	72	57	36	29	33	35	40	50	47	41	48	49	49	51	51	44	43	48	54	60	71	76	64	69	64	76
89	84	84	82	77	82	85	65	41	26	34	39	37	46	49	40	40	49	54	53	47	39	41	51	68	68	72	75	73	70	70	57
90	79	82	86	86	88	85	72	46	22	27	33	31	45	50	39	42	47	48	50	51	48	44	45	65	61	59	74	81	75	62	44
67	67	77	89	80	88	72	58	44	25	21	22	31	48	50	42	47	46	44	46	53	53	44	39	69	51	31	44	68	72	71	69
58	67	75	78	83	80	60	31	37	38	30	21	35	49	44	45	43	49	50	47	44	38	35	38	60	42	19	31	57	65	73	58
68	80	76	70	70	88	66	29	32	47	41	28	39	44	34	44	44	48	50	45	37	25	23	29	34	28	21	37	55	54	58	69
75	85	82	75	86	85	68	47	39	45	41	32	41	42	34	46	50	46	42	43	40	27	18	19	23	22	21	33	38	33	44	58
78	79	82	84	78	63	53	57	53	40	33	34	44	48	43	50	52	44	39	44	44	30	18	19	16	20	25	36	31	21	31	44
74	77	79	83	83	64	46	41	51	35	32	41	44	46	47	42	52	46	49	51	39	23	18	20	15	20	27	34	35	33	31	31
54	82	80	79	82	82	67	42	37	27	30	42	47	48	48	43	50	47	51	51	33	15	14	20	20	21	27	37	45	46	44	43
90	86	87	83	82	84	73	41	32	28	35	45	48	48	48	45	46	48	54	50	31	15	18	27	24	30	37	42	44	46	50	53
87	85	86	84	71	55	44	37	36	38	44	48	46	42	43	44	49	53	56	49	34	27	29	30	31	39	44	41	39	45	51	53
87	88	82	79	70	43	27	38	35	43	48	48	43	37	37	42	55	57	55	48	41	42	39	28	38	43	40	34	40	55	57	49
82	88	81	84	84	58	32	36	33	43	48	48	46	41	39	43	51	49	48	48	51	57	51	38	42	46	44	38	41	52	55	50
78	82	83	84	83	59	37	37	41	48	47	45	49	48	44	45	43	38	43	56	64	66	64	58	51	54	55	52	48	46	49	53
82	86	93	92	74	49	45	57	53	54	46	41	47	49	44	43	41	34	44	65	72	68	69	72	66	58	58	63	61	51	49	54
90	89	95	89	82	65	69	75	72	60	55	43	41	48	52	45	48	49	45	53	56	48	58	78	76	69	65	63	64	59	52	56
90	90	91	85	85	78	82	80	88	80	69	55	44	45	48	46	46	48	49	51	50	42	46	66	81	76	76	67	62	67	64	51
85	82	65	50	46	64	77	82	82	77	72	60	45	40	44	48	48	47	53	52	55	53	50	68	74	70	85	89	66	56	62	57
82	77	57	42	34	54	67	75	68	67	69	63	48	39	44	50	51	46	52	49	58	67	59	75	62	40	55	79	62	48	56	50
74	77	79	77	71	72	61	54	62	62	66	65	52	43	43	46	50	44	48	40	46	55	51	70	53	33	44	67	52	43	62	59
71	72	77	90	83	88	61	44	51	50	54	55	48	41	39	37	44	45	48	38	35	37	41	64	59	46	57	84	64	38	57	70
71	67	69	72	78	72	64	54	41	39	43	46	43	41	39	35	41	47	48	44	41	36	43	64	63	44	45	84	84	49	46	51
56	56	59	52	56	53	57	55	44	43	45	46	46	47	45	40	43	48	45	49	50	41	46	60	47	45	43	73	81	61	53	47
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58	54	52	52	53	53	52	51	47	46	46	47	49	50	50	48	44	43	46	58	70	74	69	63	80	82	77	74	75	66	54	52
59	52	49	55	60	59	55	54	47	50	49	45	44	46	47	46	47	44	47	59	73	84	79	77	77	82	88	83	86	82	72	65
55	52	51	52	53	53	51	51	51	55	55	50	49	53	54	52	50	46	44	48	60	74	82	81	66	66	71	81	81	77	78	88
48	54	54	45	37	36	39	40	42	46	48	47	52	60	62	59	46	49	46	42	50	67	78	78	66	62	68	77	72	64	72	80
40	51	53	39	28	29	35	37	33	35	36	39	46	54	56	54	49	55	55	49	48	56	60	58	55	58	71	82	80	74	77	83
36	43	44	37	31	33	38	41	38	37	36	38	43	47	49	49	51	54	55	53	50	48	48	48	48	53	71	80	86	84	88	82
38	38	37	36	35	36	38	40	38	35	33	34	37	38	41	43	46	42	44	50	52	50	53	60	61	58	69	86	75	73	80	83

# RESULTS

## MACHINE LEARNING

88	78	85	85	76	75	72	57	36	29	33	35	40	50	47	41	48	49	49	51	51	44	43	48	54	60	71	76	64	69	84	76
89	84	84	82	77	82	85	65	41	26	34	39	37	46	49	40	40	49	54	53	47	39	41	51	68	68	72	75	73	70	70	57
90	79	82	86	86	88	85	72	46	22	27	33	31	45	50	39	42	47	48	50	51	48	44	45	65	61	59	74	81	75	62	44
67	67	77	89	80	88	72	58	44	25	21	22	31	48	50	42	47	46	44	46	53	53	44	39	69	51	31	44	68	72	71	69
58	67	75	78	83	80	60	31	37	38	30	21	35	49	44	45	43	49	50	47	44	38	35	38	60	42	19	31	57	65	73	58
68	80	76	70	70	88	66	29	32	47	41	28	39	44	34	44	44	48	50	45	37	25	23	29	34	28	21	37	55	54	58	69
75	85	82	75	88	85	68	47	39	45	41	32	41	42	34	46	50	46	42	43	40	27	18	19	23	22	21	33	38	33	44	58
78	79	82	84	78	63	53	57	53	40	33	34	44	48	43	50	52	44	39	44	44	30	18	19	16	20	25	36	31	21	31	44
74	77	78	83	82	64	46	41	51	35	32	41	44	46	47	42	52	46	49	51	39	23	18	20	15	20	27	34	35	33	31	31
54	82	80	78	82	52	67	42	37	27	30	42	47	48	48	43	50	47	51	51	33	15	14	20	20	21	27	37	45	46	44	43
90	86	87	83	82	88	71	41	32	28	35	45	48	48	48	45	46	48	54	50	31	15	18	27	24	30	37	42	44	46	50	53
87	85	86	84	71	55	44	37	36	38	44	48	46	42	43	44	49	53	56	49	34	27	29	30	31	39	44	41	39	45	51	53
87	88	82	78	70	43	27	38	35	43	48	48	43	37	37	42	55	57	55	48	41	42	39	28	38	43	40	34	40	55	57	49
82	88	81	84	84	58	32	36	33	43	48	48	46	41	39	43	51	49	48	48	51	57	51	38	42	46	44	38	41	52	55	50
78	82	83	84	83	59	37	37	41	48	47	45	49	48	44	45	43	38	43	56	64	66	64	58	51	54	55	52	48	46	49	53
82	86	93	92	74	49	45	57	53	54	46	41	47	49	44	43	41	34	44	65	72	68	69	72	66	58	58	63	61	51	49	54
90	89	95	89	82	65	69	75	72	60	55	43	41	48	52	45	48	49	45	53	56	48	58	78	76	69	65	63	64	59	52	56
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85	82	65	50	46	64	77	82	82	77	72	60	45	40	44	48	48	47	53	52	55	53	50	68	74	70	85	89	66	56	62	57
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74	77	79	77	71	72	61	54	62	62	66	65	52	43	43	46	50	44	48	40	46	55	51	70	53	33	44	67	52	43	62	59
71	72	77	90	83	88	61	44	51	50	54	55	48	41	39	37	44	45	48	38	35	37	41	64	59	46	57	88	64	38	57	70
71	67	69	72	78	72	64	54	41	39	43	46	43	41	39	35	41	47	48	44	41	36	43	64	63	44	45	84	81	49	46	51
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58	54	52	52	53	53	52	51	47	46	46	47	49	50	50	48	44	43	46	58	70	74	69	63	80	82	77	74	75	66	54	52
59	52	49	55	60	59	55	54	47	50	49	45	44	46	47	46	47	44	47	59	73	88	79	77	77	82	88	83	86	82	72	65
55	52	51	52	53	53	51	51	51	55	55	50	49	53	54	52	50	46	44	48	60	74	82	81	66	66	71	81	81	71	78	88
48	54	54	45	37	36	39	40	42	46	48	47	52	60	62	59	46	49	46	42	50	67	78	78	66	62	68	77	72	64	72	80
40	51	53	39	28	29	35	37	33	35	36	39	46	54	56	54	49	55	55	49	48	56	60	58	55	58	71	82	78	74	77	83
36	43	44	37	31	33	38	41	38	37	36	38	43	47	49	49	51	54	55	53	50	48	48	48	48	53	71	88	86	84	88	82
38	38	37	36	35	36	38	40	38	35	33	34	37	38	41	43	46	42	44	50	52	50	53	60	61	58	69	86	75	73	80	83

# RESULTS

## MACHINE LEARNING

66	76	65	85	76	75	72	57	36	29	33	35	40	50	47	41	48	49	49	51	51	44	43	48	54	60	71	76	64	69	64	76
89	84	84	82	77	82	85	65	41	26	34	39	37	46	49	40	40	49	54	53	47	39	41	51	68	68	72	75	73	70	70	57
90	79	82	86	86	88	85	72	46	22	27	33	31	45	50	39	42	47	48	50	51	48	44	45	65	61	59	74	81	75	62	44
67	67	77	89	80	88	72	58	44	25	21	22	31	48	50	42	47	46	44	46	53	53	44	39	69	51	31	44	68	72	71	69
58	67	75	78	83	80	60	31	37	38	30	21	35	49	44	45	43	49	50	47	44	38	35	38	60	42	19	31	57	65	73	58
68	80	76	70	70	88	66	29	32	47	41	28	39	44	34	44	44	48	50	45	37	25	23	29	34	28	21	37	55	54	58	69
75	85	82	75	86	85	68	47	39	45	41	32	41	42	34	46	50	46	42	43	40	27	18	19	23	22	21	33	38	33	44	58
78	79	82	84	78	63	53	57	53	40	33	34	44	48	43	50	52	44	39	44	44	30	18	19	16	20	25	36	31	21	31	44
74	77	79	83	82	64	46	41	51	35	32	41	44	46	47	42	52	46	49	51	39	23	18	20	15	20	27	34	35	33	31	31
54	82	80	78	82	82	67	42	37	27	30	42	47	48	48	43	50	47	51	51	33	15	14	20	20	21	27	37	45	46	44	43
90	86	87	83	82	84	71	41	32	28	35	45	48	48	48	45	46	48	54	50	31	15	18	27	24	30	37	42	44	46	50	53
87	85	86	84	71	55	44	37	36	38	44	48	46	42	43	44	49	53	56	49	34	27	29	30	31	39	44	41	39	45	51	53
87	88	82	78	70	43	27	38	35	43	48	48	43	37	37	42	55	57	55	48	41	42	39	28	38	43	40	34	40	55	57	49
82	88	81	84	84	58	32	36	33	43	48	48	46	41	39	43	51	49	48	48	51	57	51	38	42	46	44	38	41	52	55	50
78	82	83	84	83	59	37	37	41	48	47	45	49	48	44	45	43	38	43	56	64	66	64	58	51	54	55	52	48	46	49	53
82	86	93	92	74	49	45	57	53	54	46	41	47	49	44	43	41	34	44	65	72	68	69	72	66	58	58	63	61	51	49	54
90	89	95	89	82	65	69	75	72	60	55	43	41	48	52	45	48	49	45	53	56	48	58	78	76	69	65	63	64	59	52	56
90	90	91	85	85	78	82	80	88	80	69	55	44	45	48	46	46	48	49	51	50	42	46	66	81	78	76	67	62	67	64	51
85	82	65	50	46	64	77	82	82	77	72	60	45	40	44	48	48	47	53	52	55	53	50	68	74	70	85	89	66	56	62	57
82	77	57	42	34	54	67	75	68	67	69	63	48	39	44	50	51	46	52	49	58	67	59	75	62	40	55	79	62	48	56	50
74	77	79	77	71	72	61	54	62	62	66	65	52	43	43	46	50	44	48	40	46	55	51	70	53	33	44	67	52	43	62	59
71	72	77	90	83	88	61	44	51	50	54	55	48	41	39	37	44	45	48	38	35	37	41	64	59	46	57	84	64	38	57	70
71	67	69	72	78	72	64	54	41	39	43	46	43	41	39	35	41	47	48	44	41	36	43	64	63	44	45	84	84	49	46	51
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58	54	52	52	53	53	52	51	47	46	46	47	49	50	50	48	44	43	46	58	70	74	69	63	80	82	77	74	75	66	54	52
59	52	49	55	60	59	55	54	47	50	49	45	44	46	47	46	47	44	47	59	73	84	79	77	77	82	88	83	86	82	72	65
55	52	51	52	53	53	51	51	51	55	55	50	49	53	54	52	50	46	44	48	60	74	82	81	66	66	71	81	81	71	78	88
48	54	54	45	37	36	39	40	42	46	48	47	52	60	62	59	46	49	46	42	50	67	78	78	66	62	68	77	72	64	72	80
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38	38	37	36	35	36	38	40	38	35	33	34	37	38	41	43	46	42	44	50	52	50	53	60	61	58	69	86	75	73	80	83

# RESULTS

## MACHINE LEARNING

66	76	65	85	76	75	72	57	36	29	33	35	40	50	47	41	48	49	49	51	51	44	43	48	54	60	71	76	64	69	64	76	
69	64	64	62	77	62	65	65	41	26	34	39	37	46	49	40	40	49	54	53	47	39	41	51	68	68	72	75	73	70	70	57	
60	79	62	66	66	68	65	72	46	22	27	33	31	45	50	39	42	47	48	50	51	48	44	45	65	61	59	74	61	75	62	44	
67	67	77	69	60	69	72	58	44	25	21	22	31	48	50	42	47	46	44	46	53	53	44	39	69	51	31	44	68	72	71	69	
58	67	75	74	63	60	60	31	37	38	30	21	35	49	44	45	43	49	50	47	44	38	35	38	60	42	19	31	57	65	73	63	
68	66	76	70	70	66	66	29	32	47	41	28	39	44	34	44	44	48	50	45	37	25	23	29	34	28	21	37	55	54	58	69	
75	65	62	75	66	65	68	47	39	45	41	32	41	42	34	46	50	46	42	43	40	27	18	19	23	22	21	33	38	33	44	58	
70	75	62	64	74	63	53	57	53	40	33	34	44	48	43	50	52	44	39	44	44	30	18	19	16	20	25	36	31	21	31	44	
74	77	79	63	63	64	46	41	51	35	32	41	44	46	47	42	52	46	49	51	39	23	18	20	15	20	27	34	35	33	31	31	
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60	60	61	65	65	74	62	60	68	60	69	55	44	45	48	46	46	48	49	51	50	42	46	66	61	76	76	67	62	67	64	51	
65	62	65	50	46	64	77	62	62	77	72	60	45	40	44	48	48	47	53	52	55	53	50	68	74	70	65	69	66	56	62	57	
62	77	57	42	34	54	67	75	68	67	69	63	48	39	44	50	51	46	52	49	58	67	59	75	62	40	55	79	62	48	56	50	
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# RESULTS

## MACHINE LEARNING

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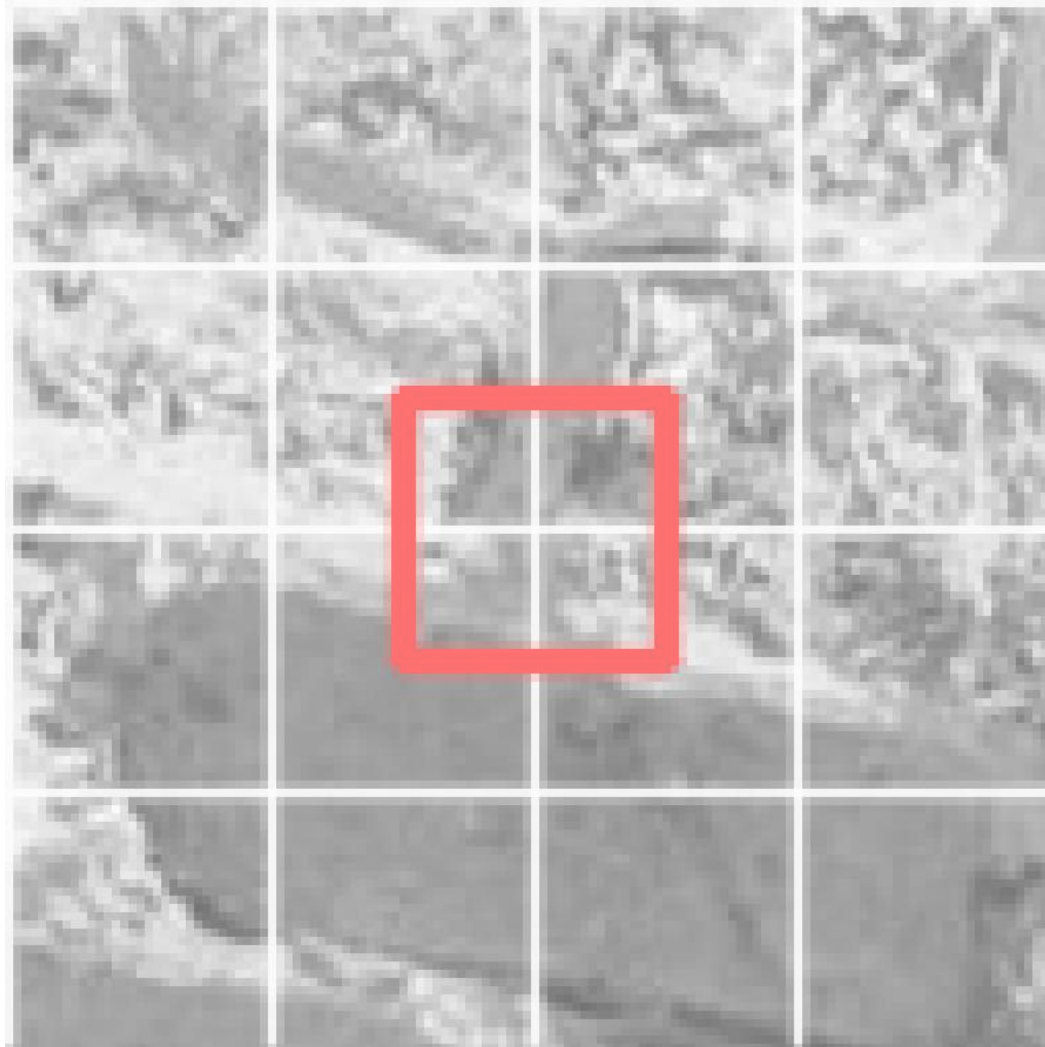
# RESULTS

## MACHINE LEARNING



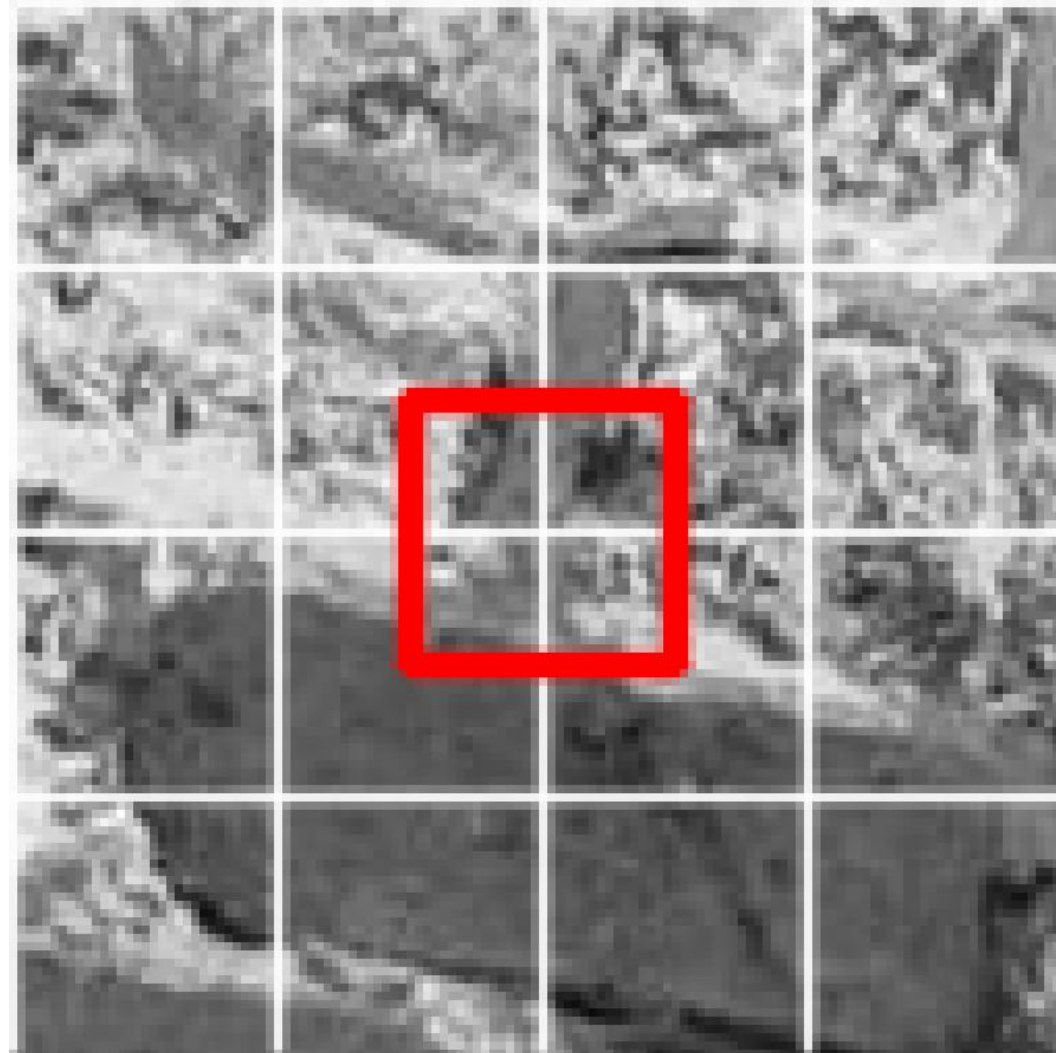
# RESULTS

## MACHINE LEARNING

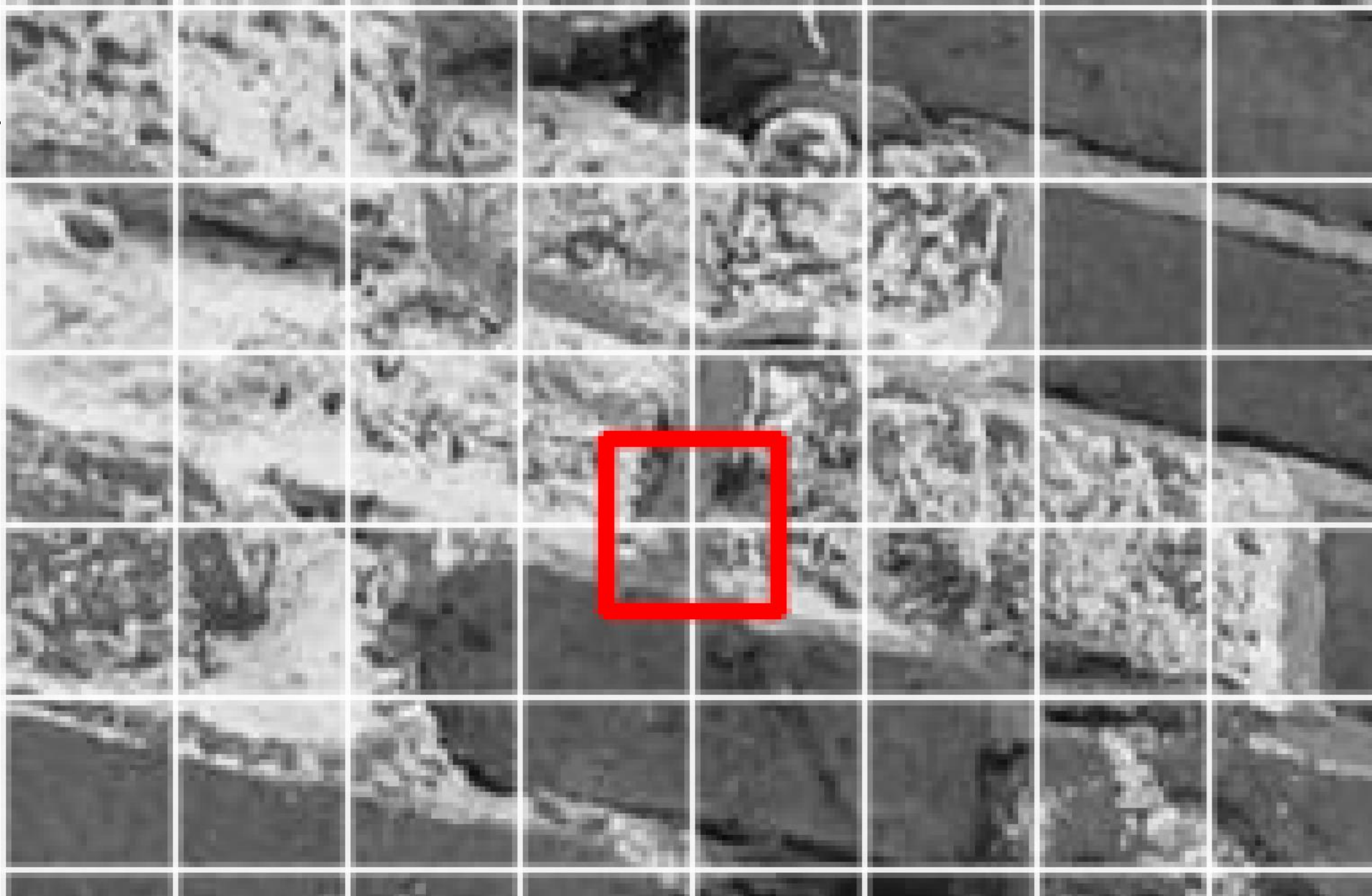


# RESULTS

## MACHINE LEARNING

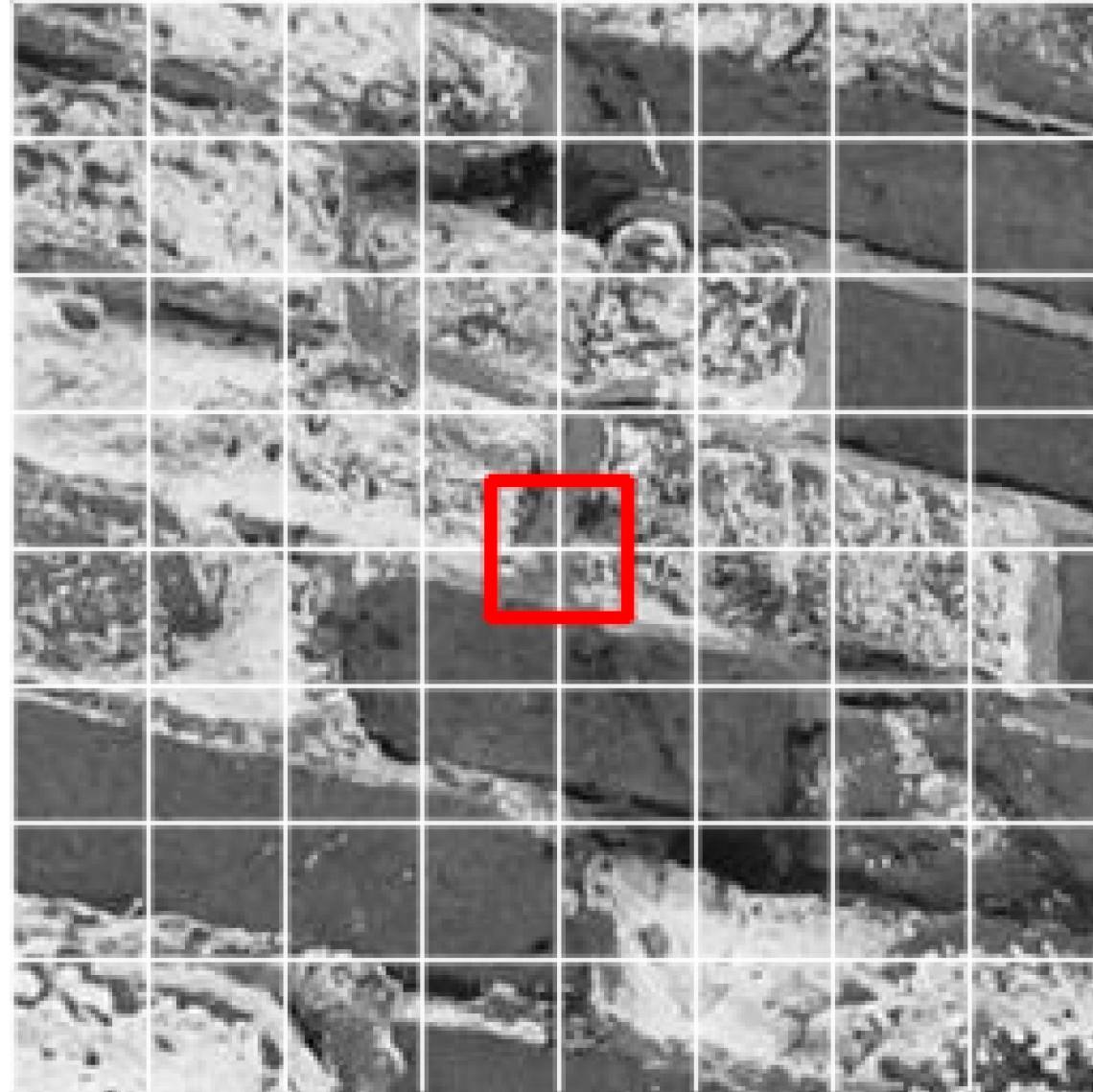


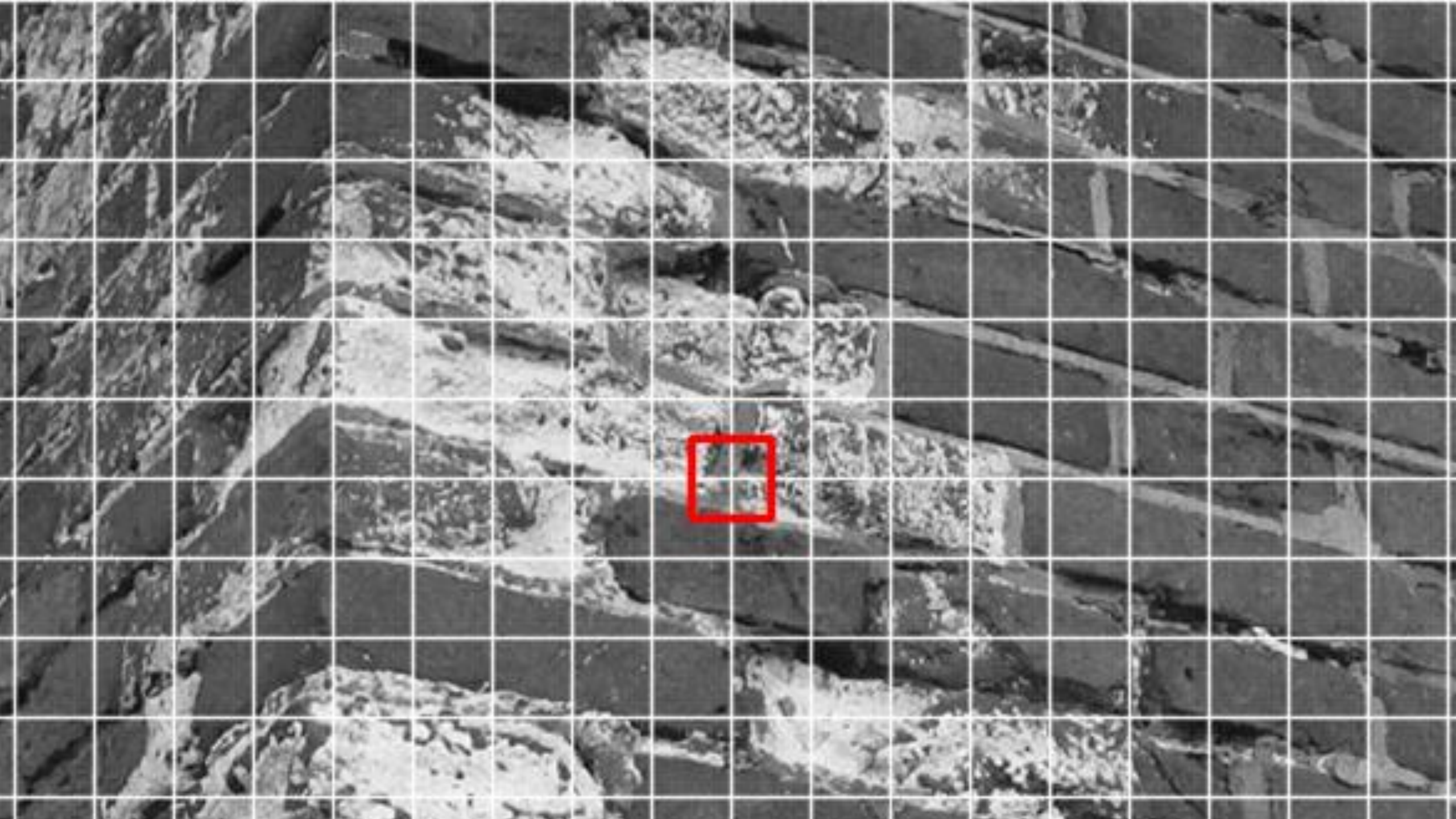
**RES**  
MACI



# RESULTS

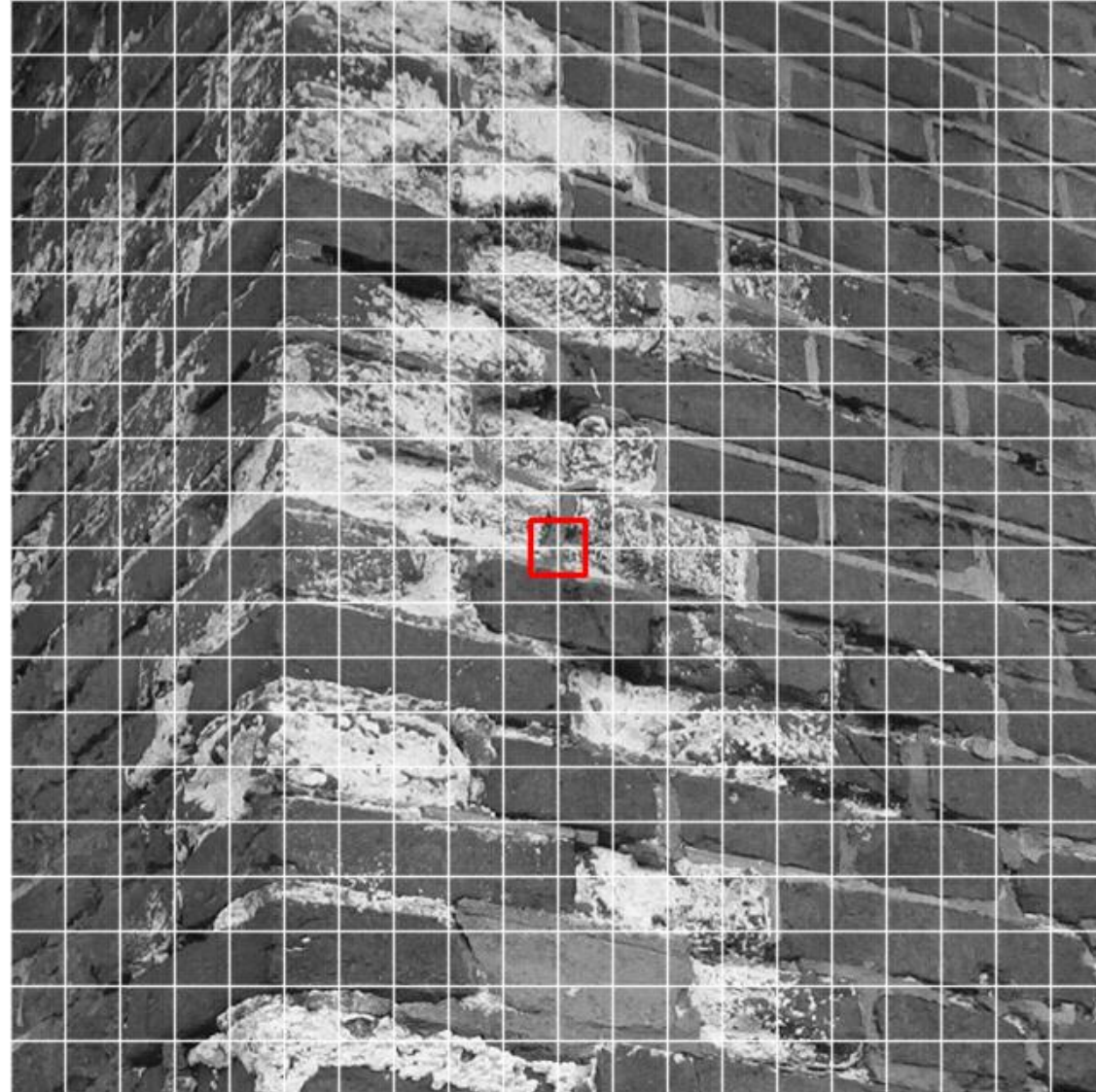
## MACHINE LEARNING





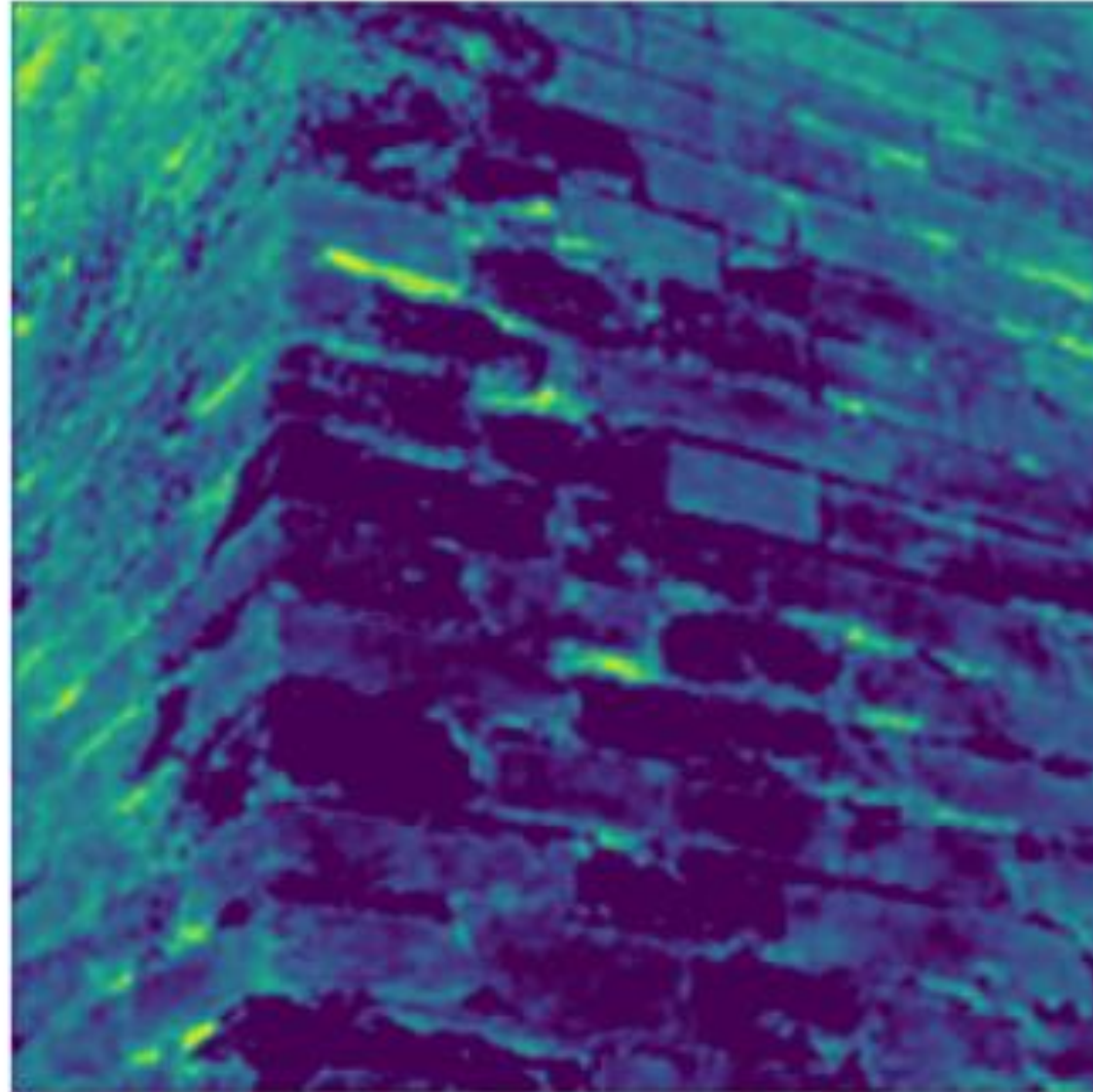
# RESULTS

## MACHINE LEARNING



# RESULTS

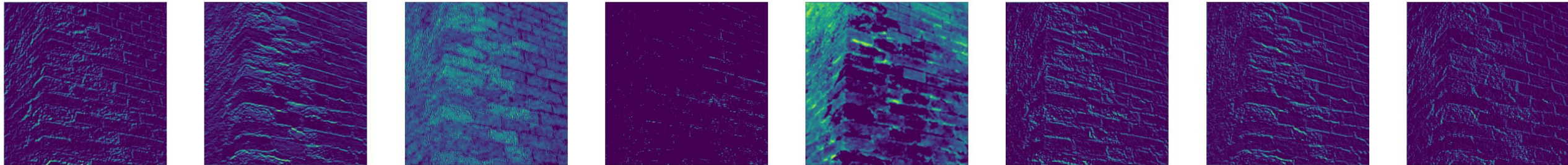
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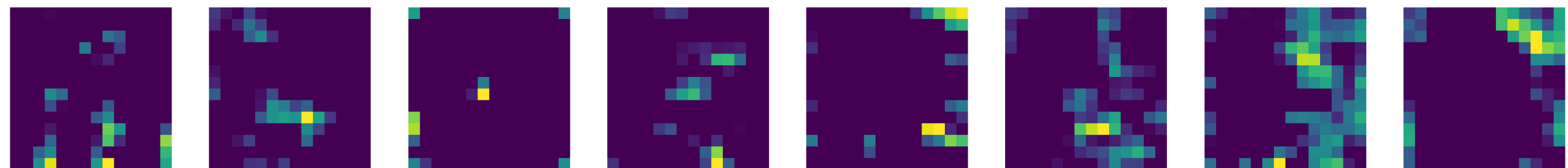
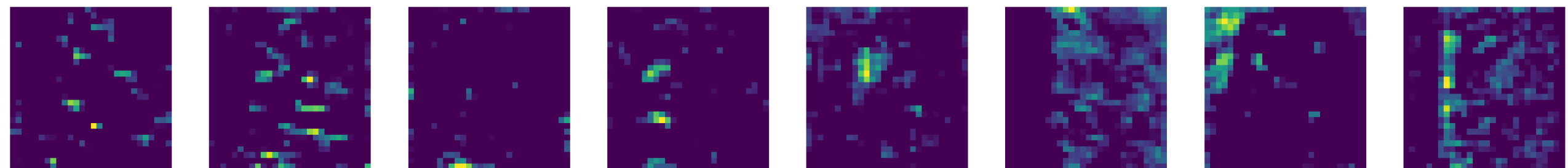
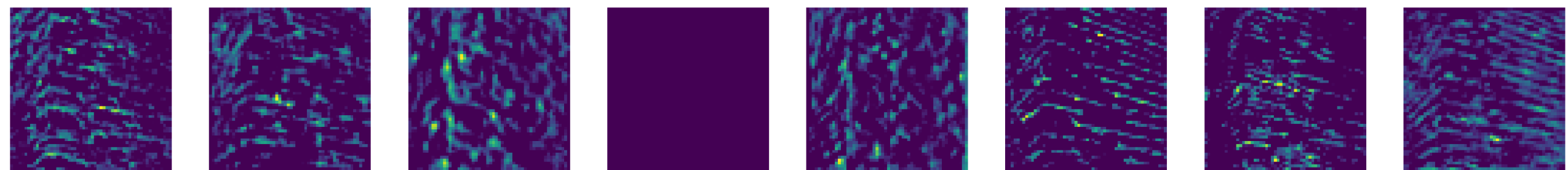
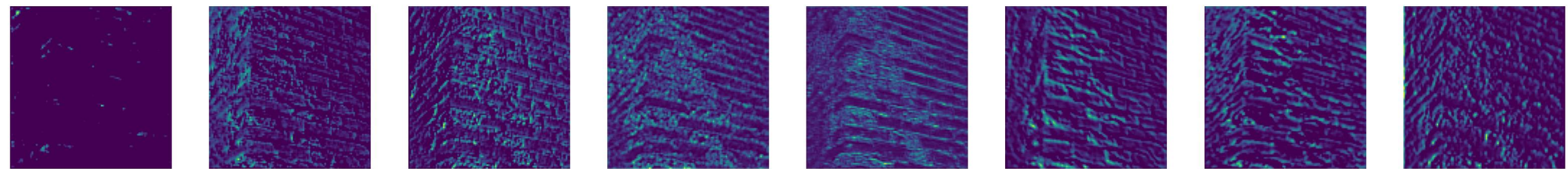
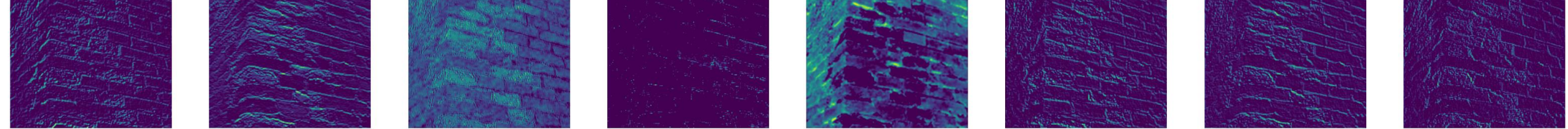


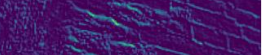
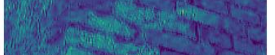
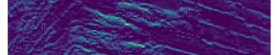
# RESULTS

## MACHINE LEARNING

block1\_conv1

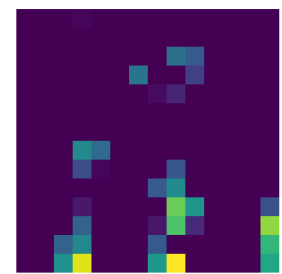
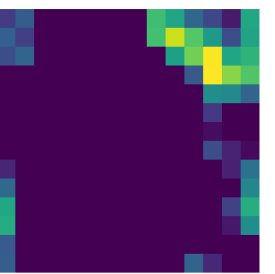
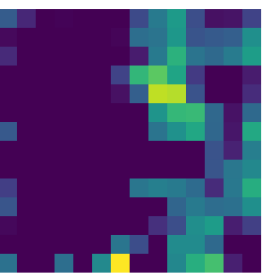
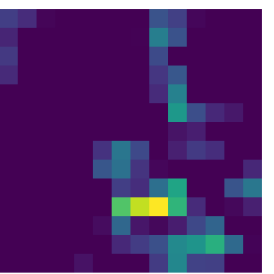
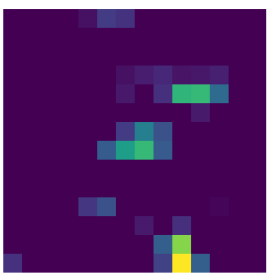
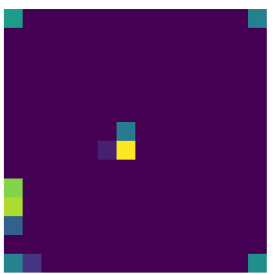
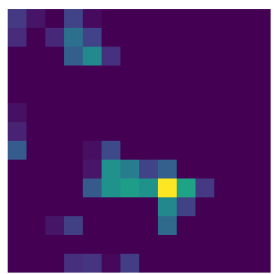
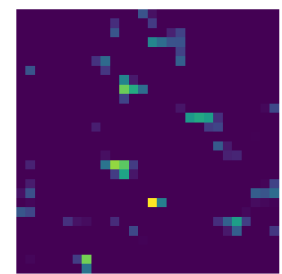
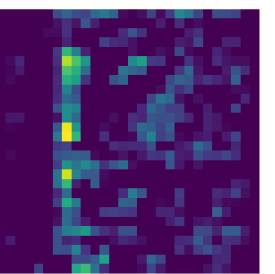
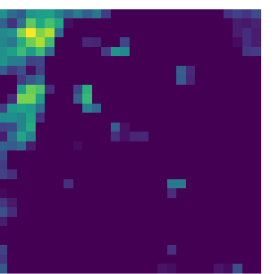
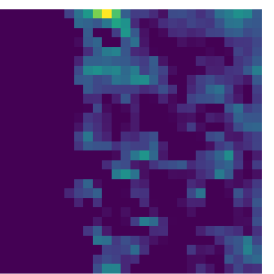
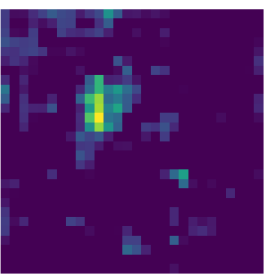
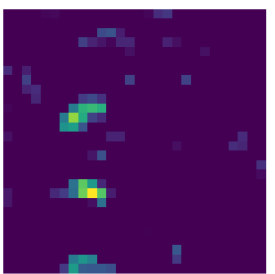
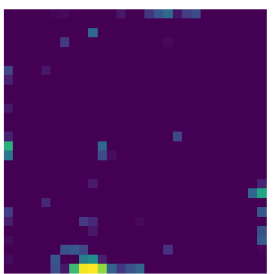
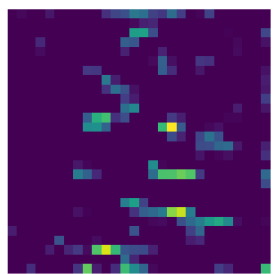
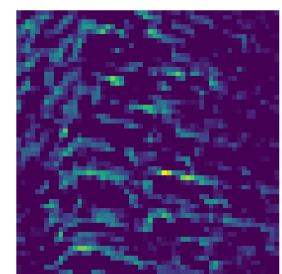
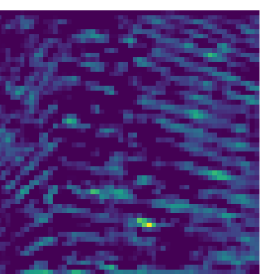
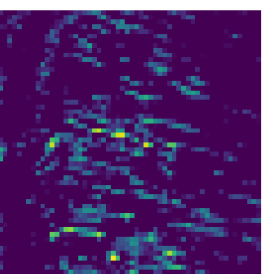
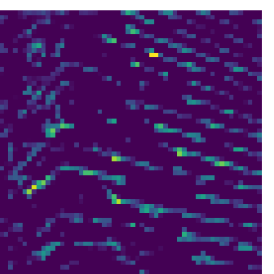
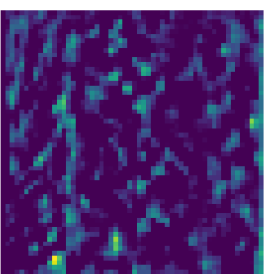
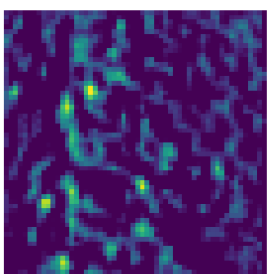
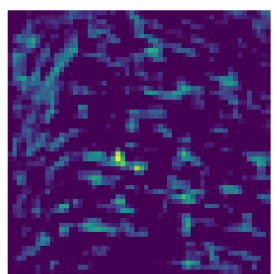
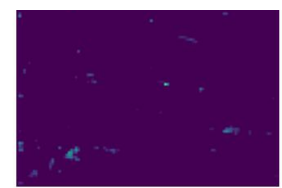
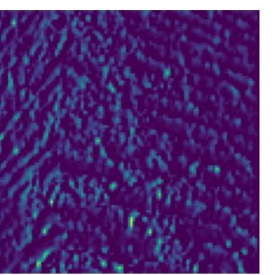
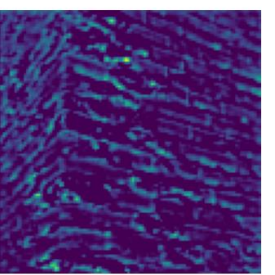
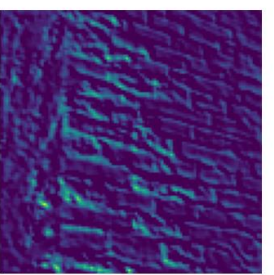
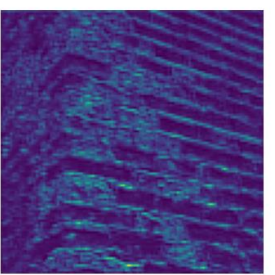
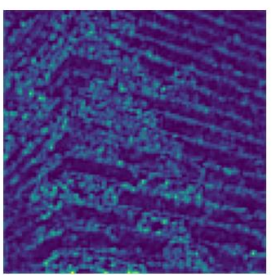
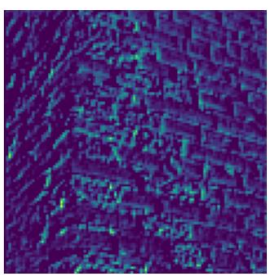
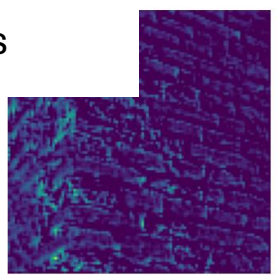
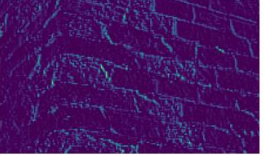
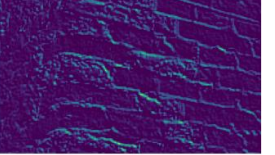
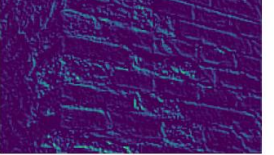
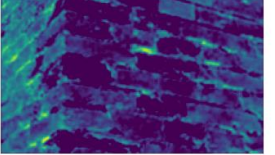
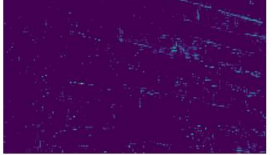
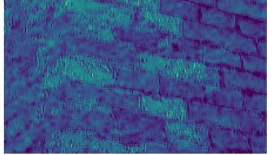
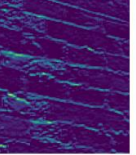


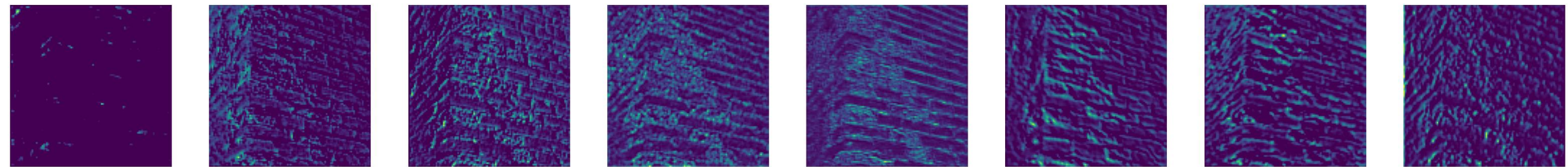
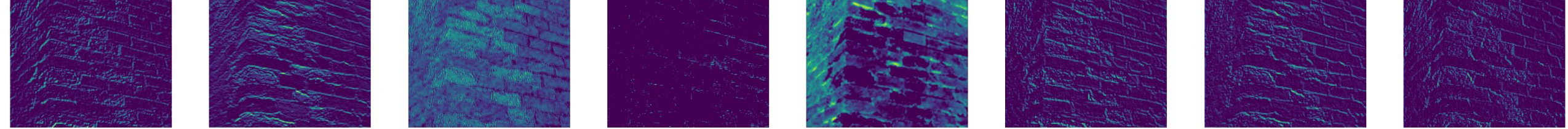




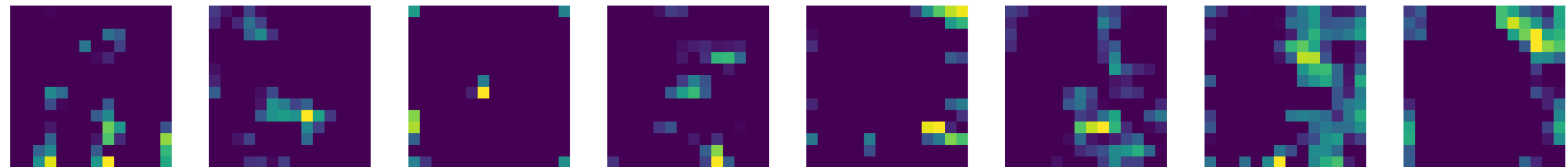
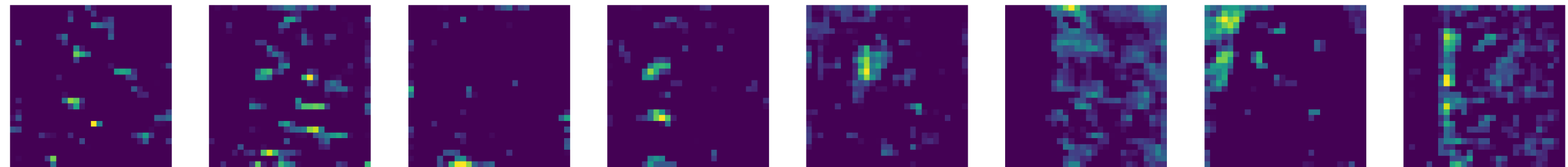
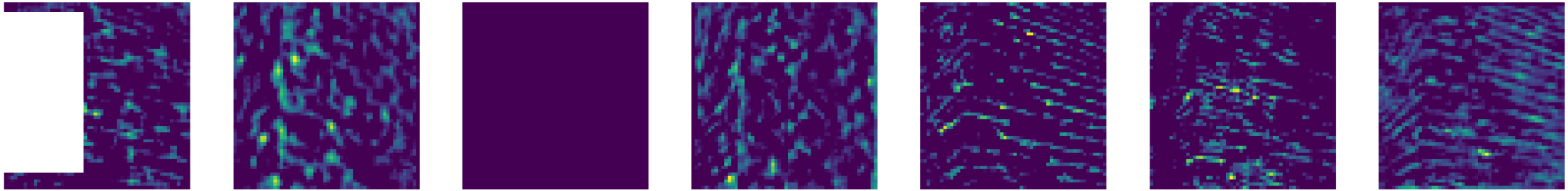
### Early layers

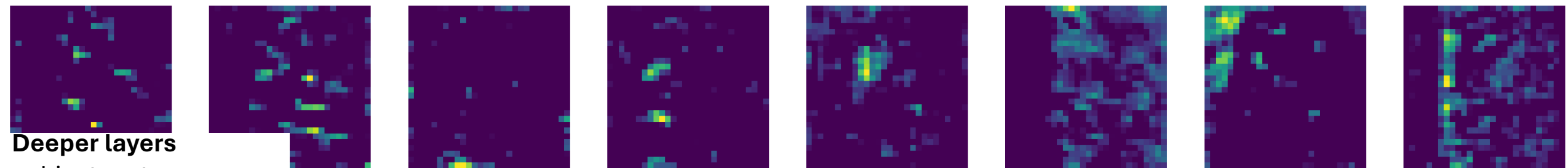
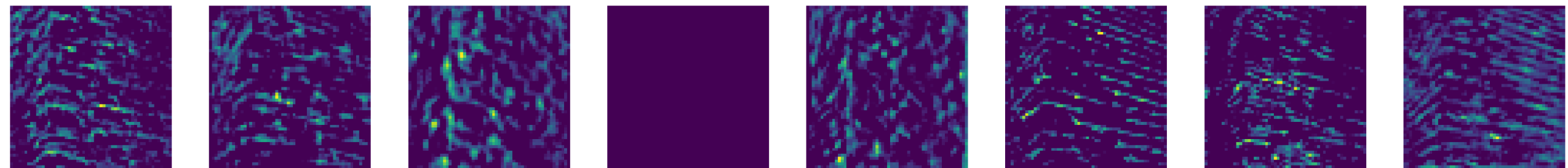
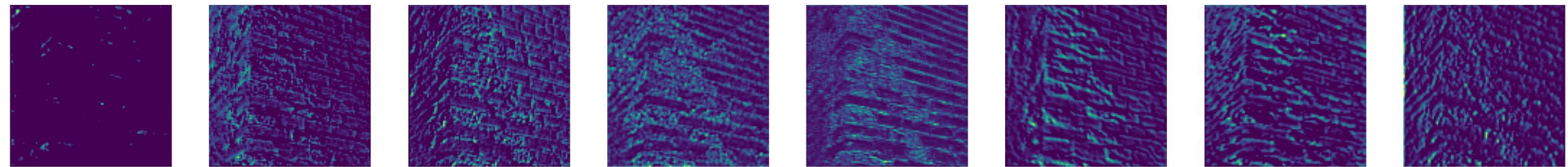
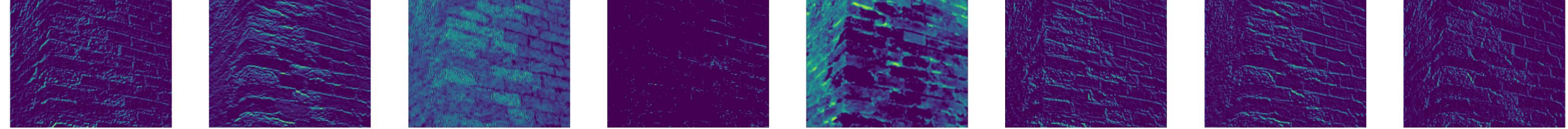
- Edge detection
- intersection of edges
- textures / lines
- colour gradients





**Middle layers**  
- shapes  
- patterns  
- Objects





**Deeper layers**

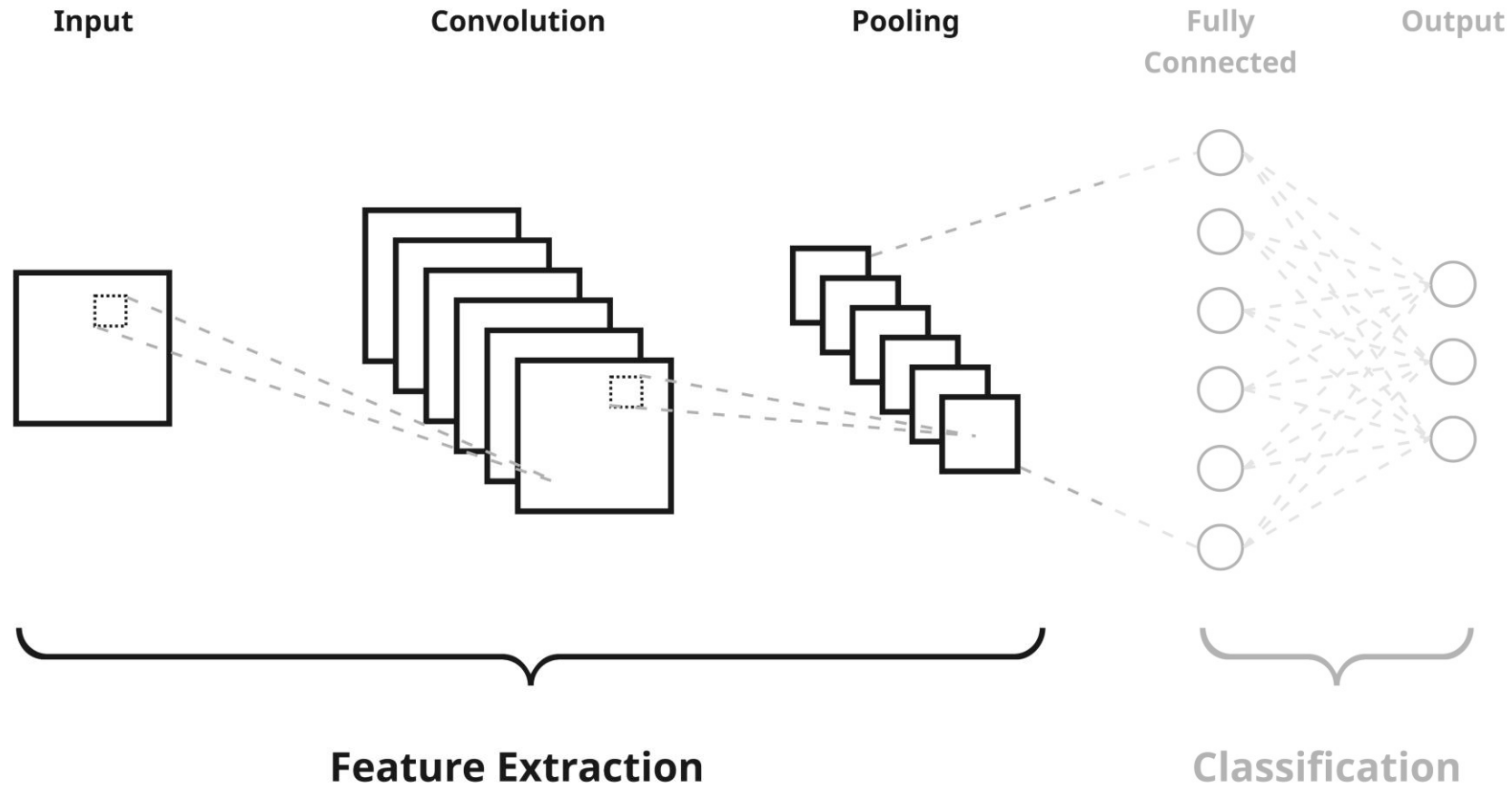
- object parts

- complex objects



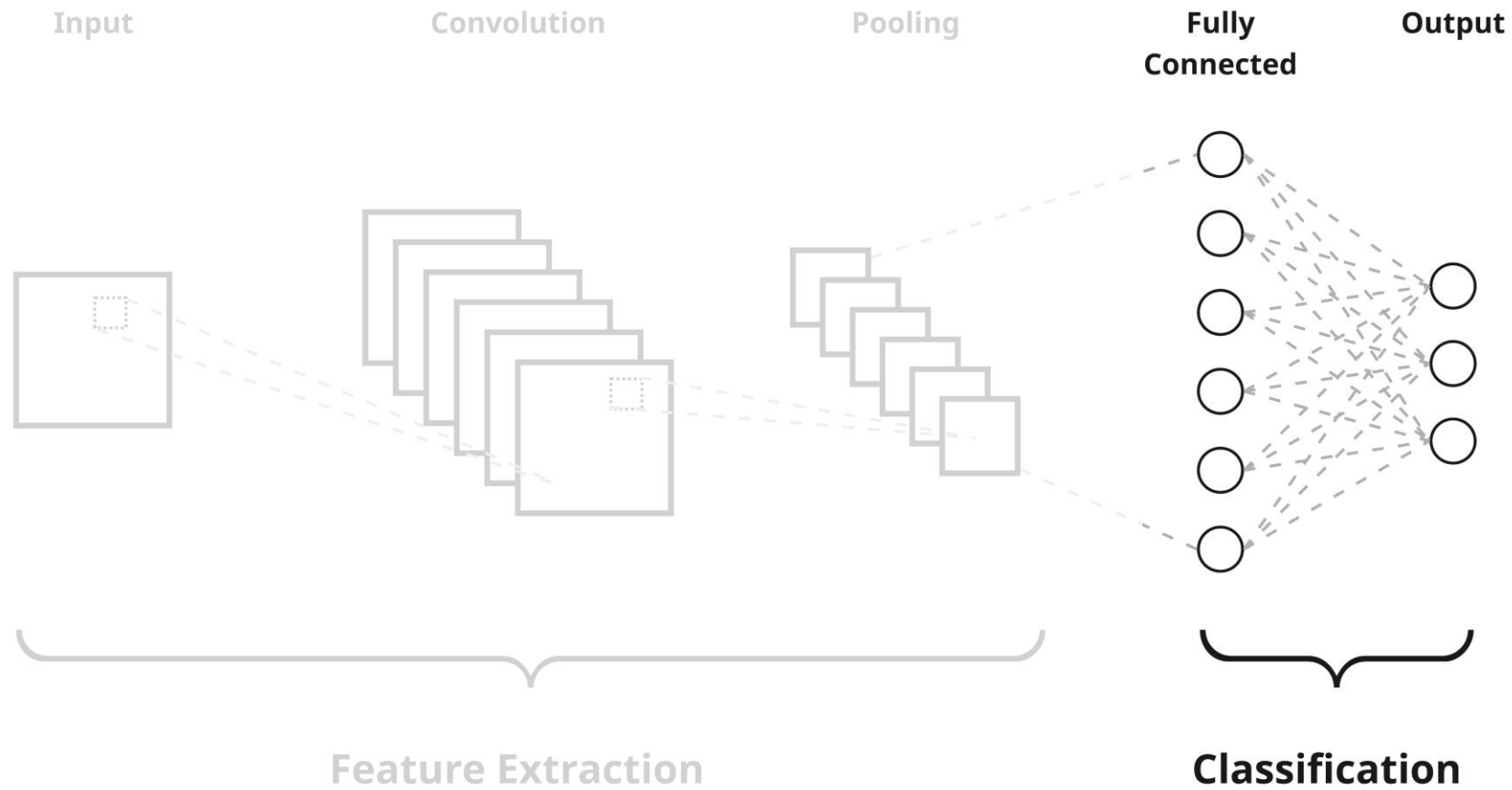
# RESULTS

## MACHINE LEARNING - CNN



# RESULTS

## MACHINE LEARNING - CNN



# RESULTS

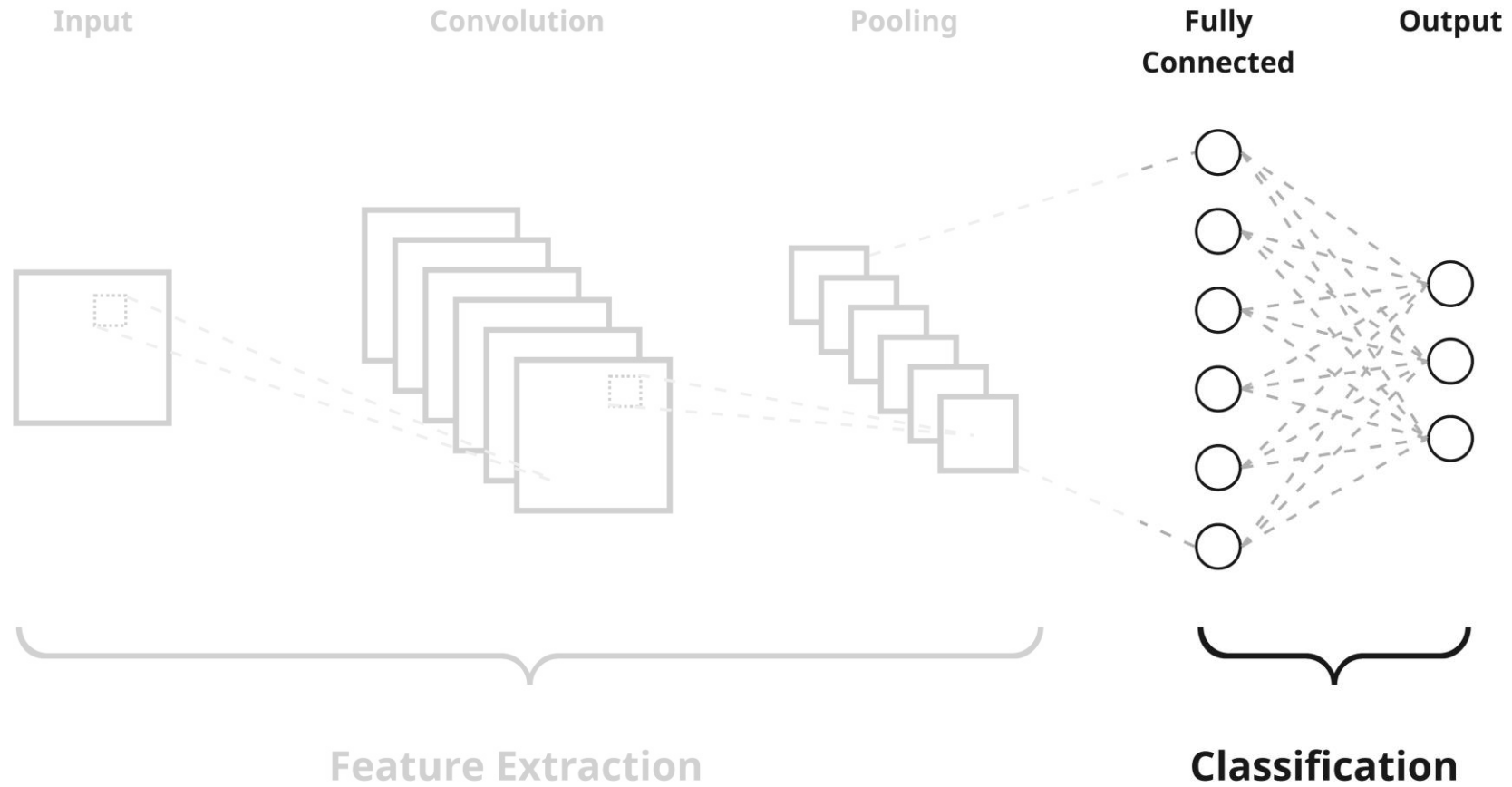
MACHINE LEARNING - CNN



**Efflorescence**  
**91%**

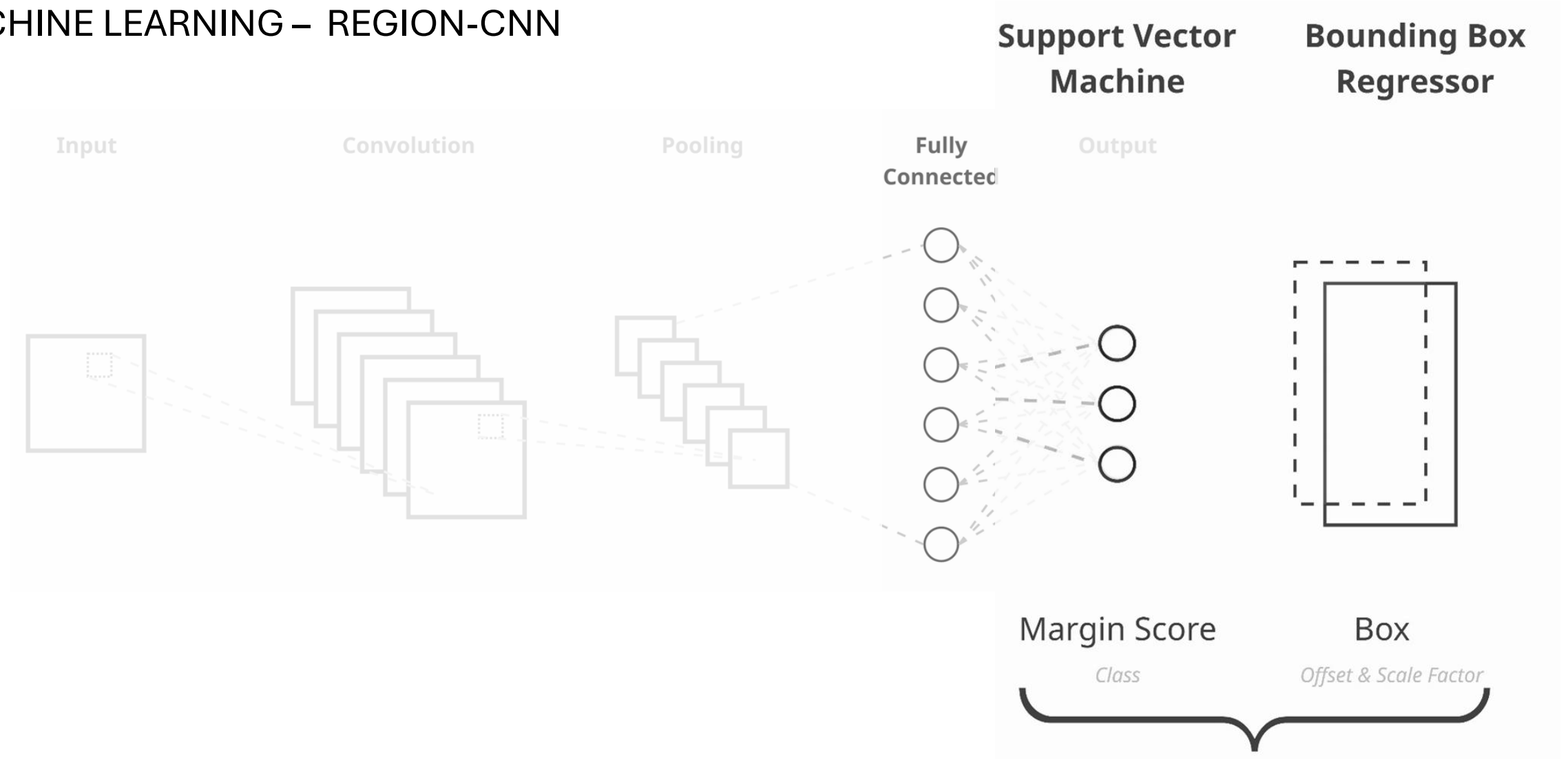
# RESULTS

## MACHINE LEARNING - CNN



# RESULTS

## MACHINE LEARNING – REGION-CNN



# RESULTS

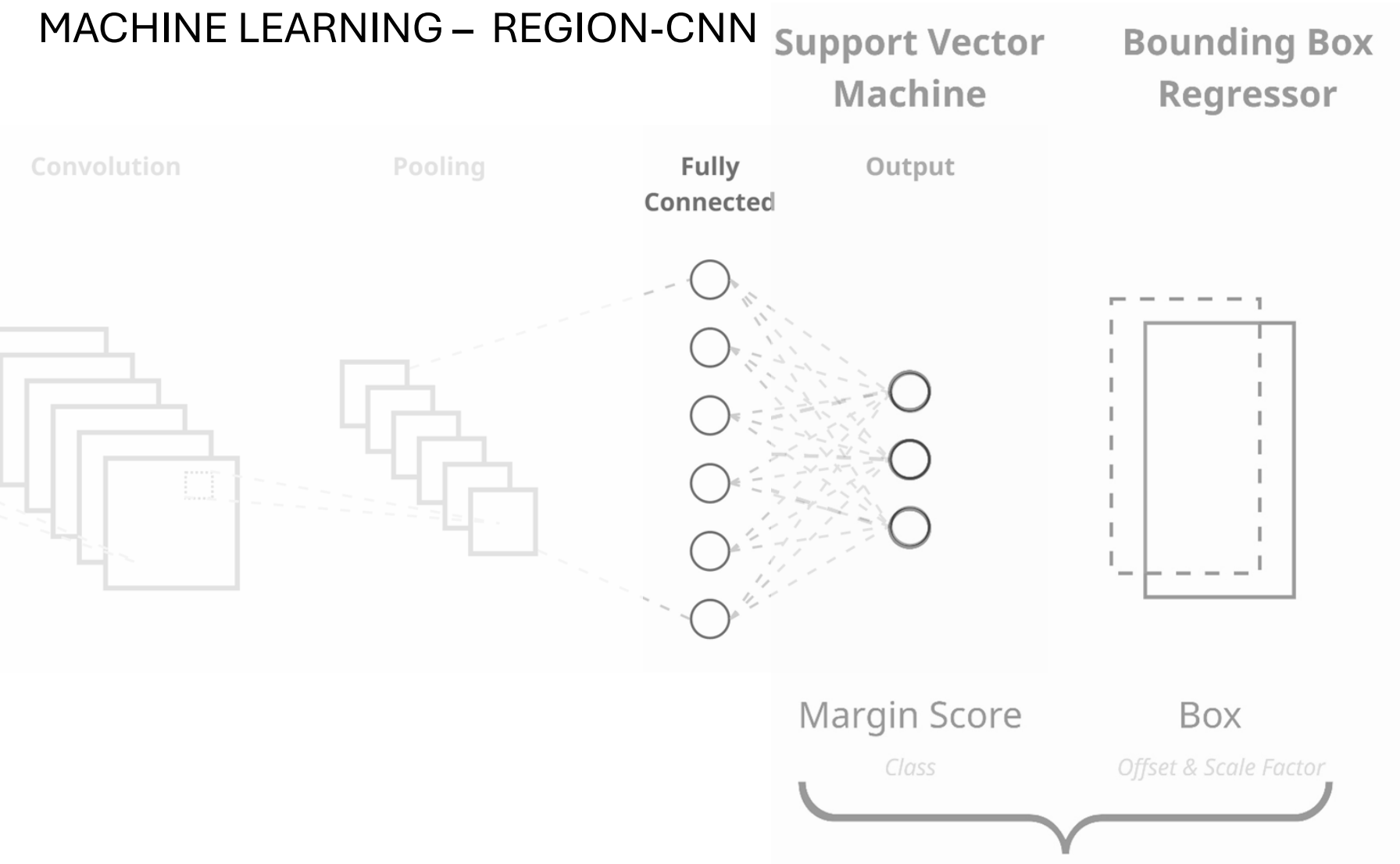
MACHINE LEARNING – REGION-CNN



**Efflorescence**  
**91%**

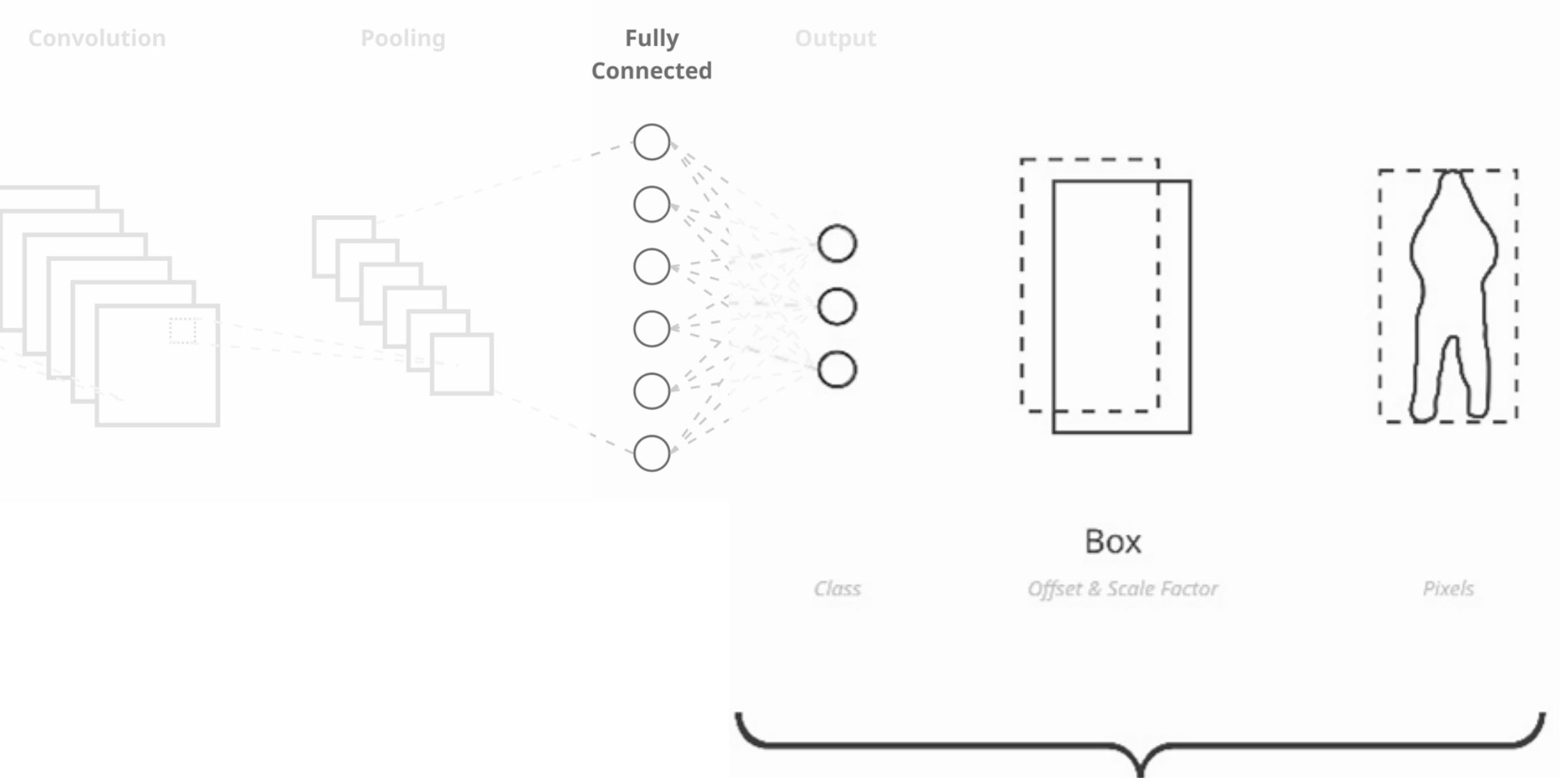
# RESULTS

## MACHINE LEARNING – REGION-CNN



# RESULTS

## MACHINE LEARNING MASK-RCNN



# RESULTS

## MACHINE LEARNING MASK-RCNN



**Efflorescence**  
**91%**

# RESULTS

## MACHINE LEARNING

- Scale variations
- lightning conditions
- Image quality and resolution
- Perspective and angle
- Color inconsistencies
- Uncontrolled backgrounds



# METHODOLOGY

## EXPERIMENTS & HYPOTHESIS

**H1: Integrating thermal imaging** as an additional channel (to detect moisture presence like rising damp or leakage) improves efflorescence detection accuracy compared to using only RGB data.

**H2: Including similar damage classes** (graffiti, lichens, encrustation) in the model improves the ability to distinguish efflorescence from **visually similar damage types**.

**H3: Including co-occurring damage types** (e.g., powdering, scaling) as a separate class in the model improves the detection of efflorescence and show statistical significance.

**H4: Variations in image quality, angle, and distance negatively affect model performance** in detecting efflorescence.

# METHODOLOGY

## EVALUATION METRICS

### **EPOCH:**

One full pass through the entire dataset during training.

### **PRECISION:**

High precision = few false alarms

### **RECALL**

Of all the actual cases of efflorescence in the image, how many did the model successfully find

### **Intersection over Union (IoU):**

compares predicted and ground truth masks/ boxes by the overlap area divided by the union area

### **mAP:**

A standard score used in object detection that combines precision across different thresholds.

(mAP@0.5 means the prediction is considered correct if it overlaps at least 50% with the true area.)

$$Precision = \frac{TP}{(FP + TP)}$$

$$Recall = \frac{TP}{FN + TP}$$

$$IoU = \frac{Area\ of\ Overlap}{Area\ of\ Union}$$

$$mAP_{@0.5} = \frac{1}{K} \sum_{i=1}^K AP_i$$

# METHODOLOGY

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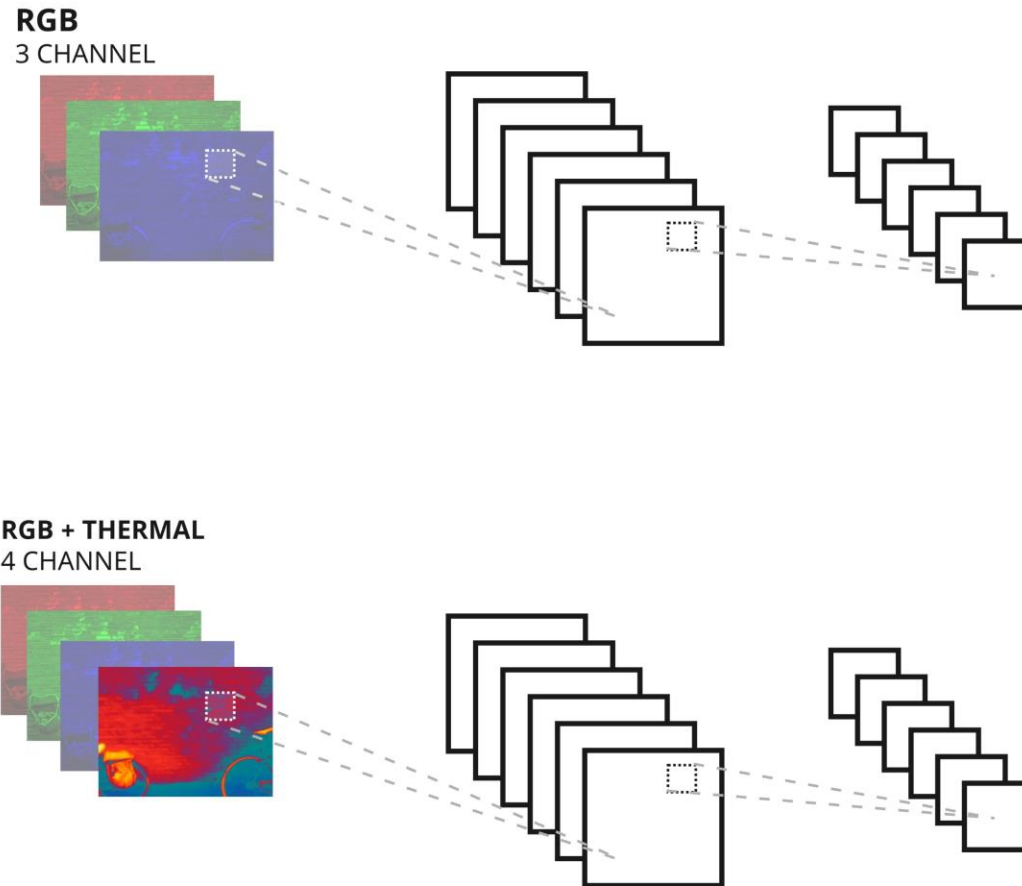
A standard score used in object detection that combines precision across different thresholds.

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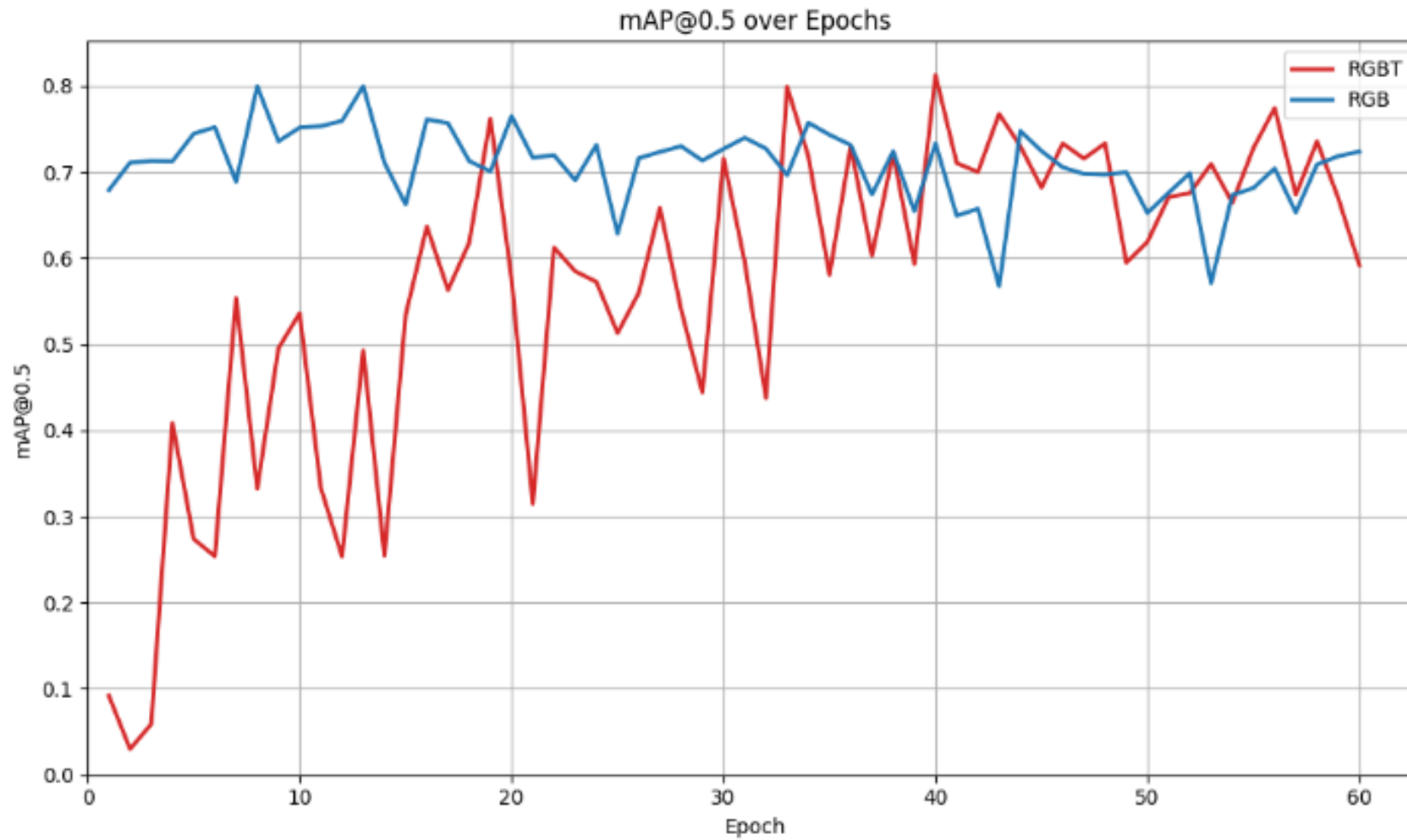
# RESULTS

## H1: THERMAL IMAGING VS RGB – SET UP



# RESULTS

## H1: THERMAL IMAGING VS RGB



# RESULTS

## H1: THERMAL IMAGING VS RGB

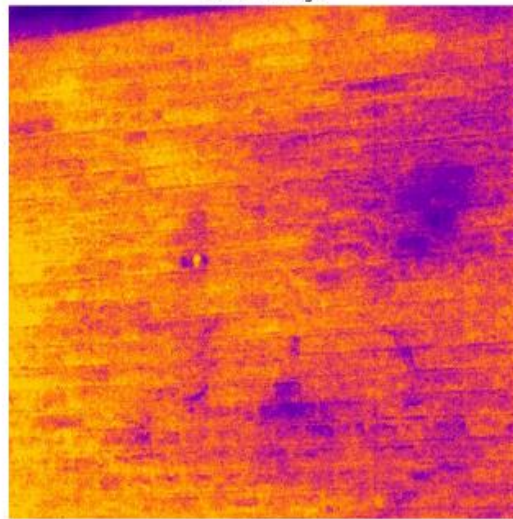
### RGB

7a863d01531cf6d725ce7cbd3.jpg Predictions



### RGBT

Thermal Image



IR image: 032B\_DC.jpg rfeb51fcb7a863d01531cf6d725ce7cbd3.jpg DC (RGB) Image



Predictions



# RESULTS

## H1: THERMAL IMAGING VS RGB

- RGB learns faster and stabilizes earlier.
- RGBT achieves higher precision
- RGBT performs better for contexts where false positives are costly)
- RGBT may benefit from more thermal-specific augmentation, better channel normalization, or architectural tuning

# RESULTS

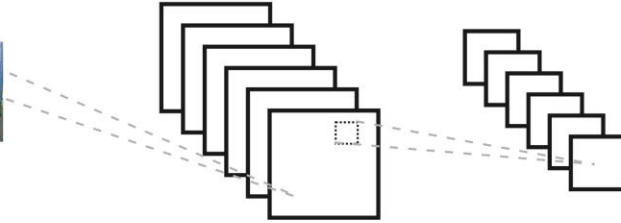
## H2: SIMILAR CLASSES

**EFFLORESCENCE**  
105 images



+

**GRAFFITI**  
105 images

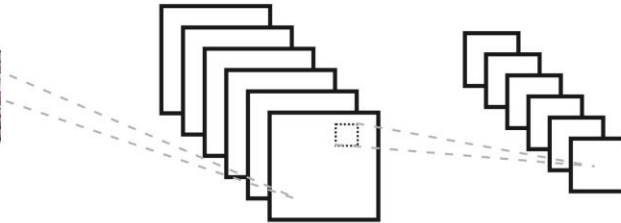


**EFFLORESCENCE**  
65 images



+

**LICHENS**  
65 images

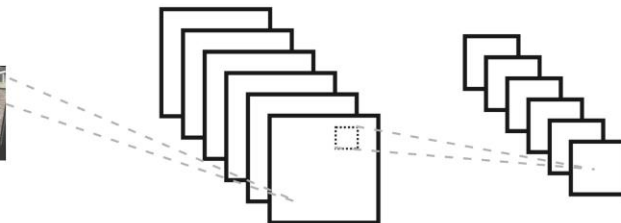


**EFFLORESCENCE**  
327 images



+

**ENCRUSTATION**  
327 CHANNEL



# RESULTS

## H2: SIMILAR CLASSES



# RESULTS

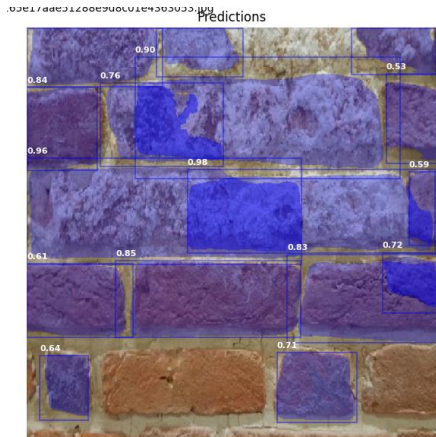
## H2: SIMILAR CLASSES

### GRAFFITI

DC (RGB) Image



DC (RGB) Image



### ENCRUSTATION

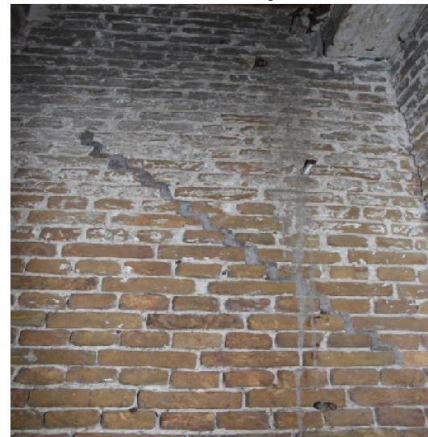
DC (RGB) Image



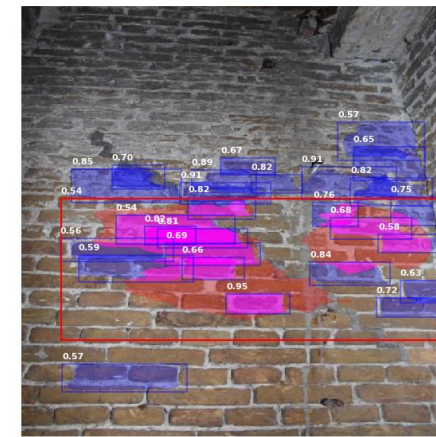
Predictions



DC (RGB) Image



Predictions

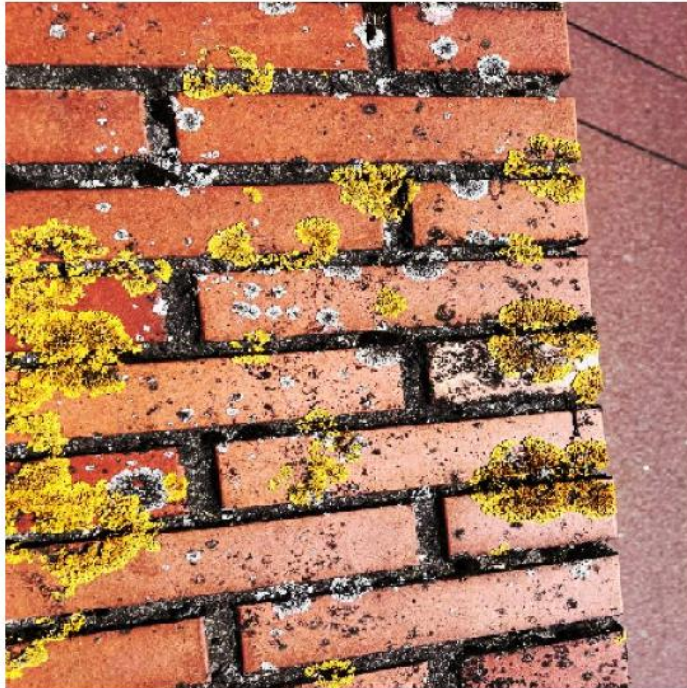


# RESULTS

## H2: SIMILAR CLASSES

### LICHENS

DC (RGB) Image



.554510a67a03a12710c11a40c.jpg Predictions



# RESULTS

## H2: SIMILAR CLASSES

### Graffiti

- Strong color contrast & defined edges
- High precision early in training

### Lichens & Encrustation

- High precision but unstable causes under detection
- Models perform conservative, predict when confidence is high

### Loss behavior

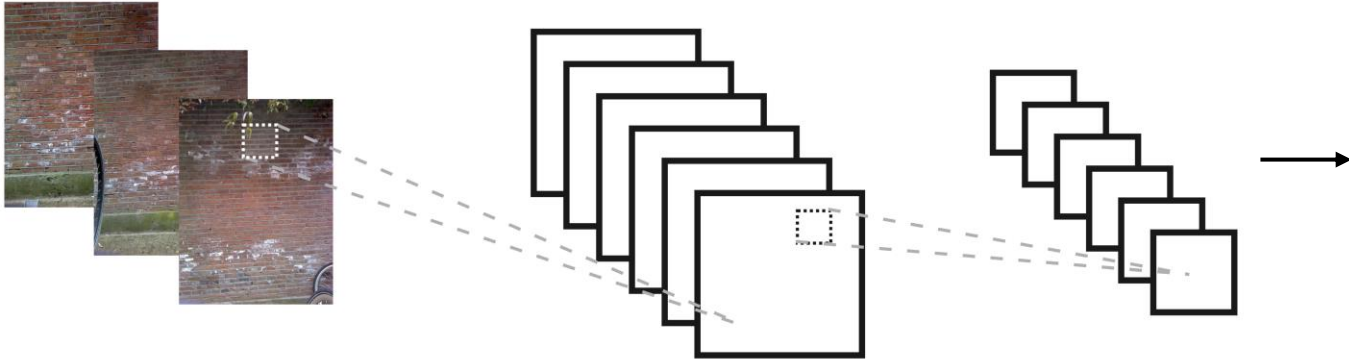
- Graffiti & efflorescence: mask/class losses converge clearly
- Lichens & encrustation: segmentation struggles with irregular/diffuse shapes

# RESULTS

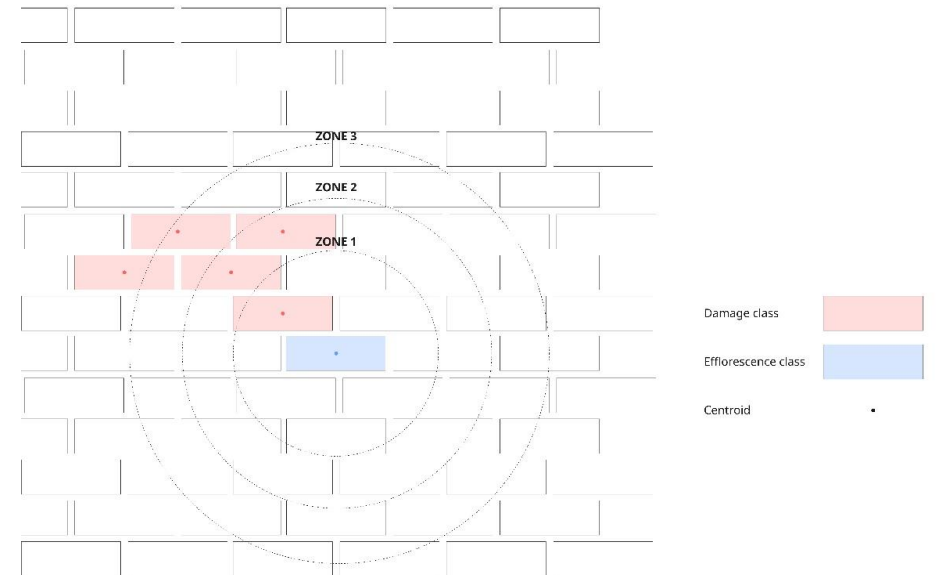
## H3: DAMAGE CO-OCCURANCE – SET UP

### DAMAGE & EFFLORESCENCE

151 images

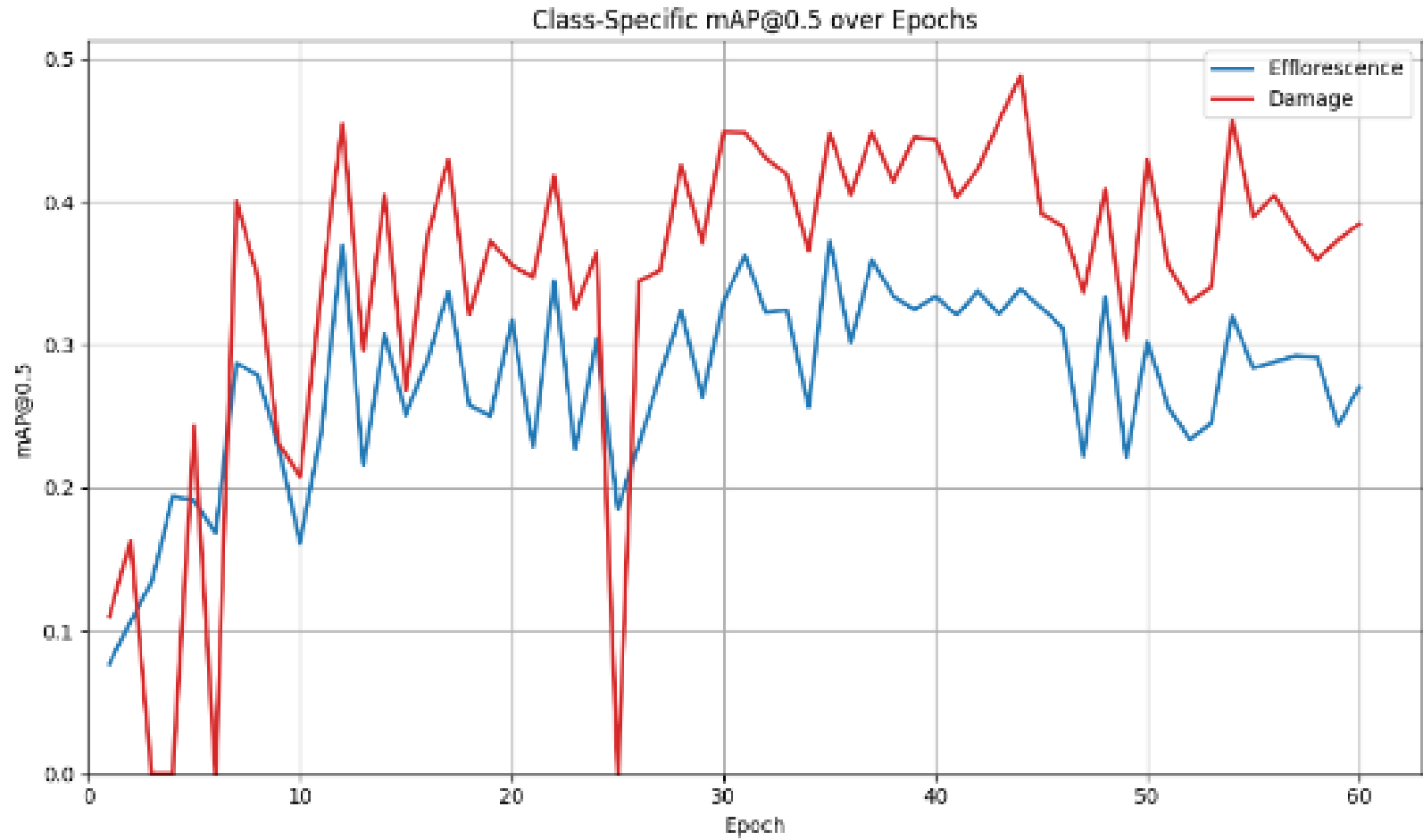


### PREDICITONS



# RESULTS

## H3: DAMAGE CO-OCCURANCE



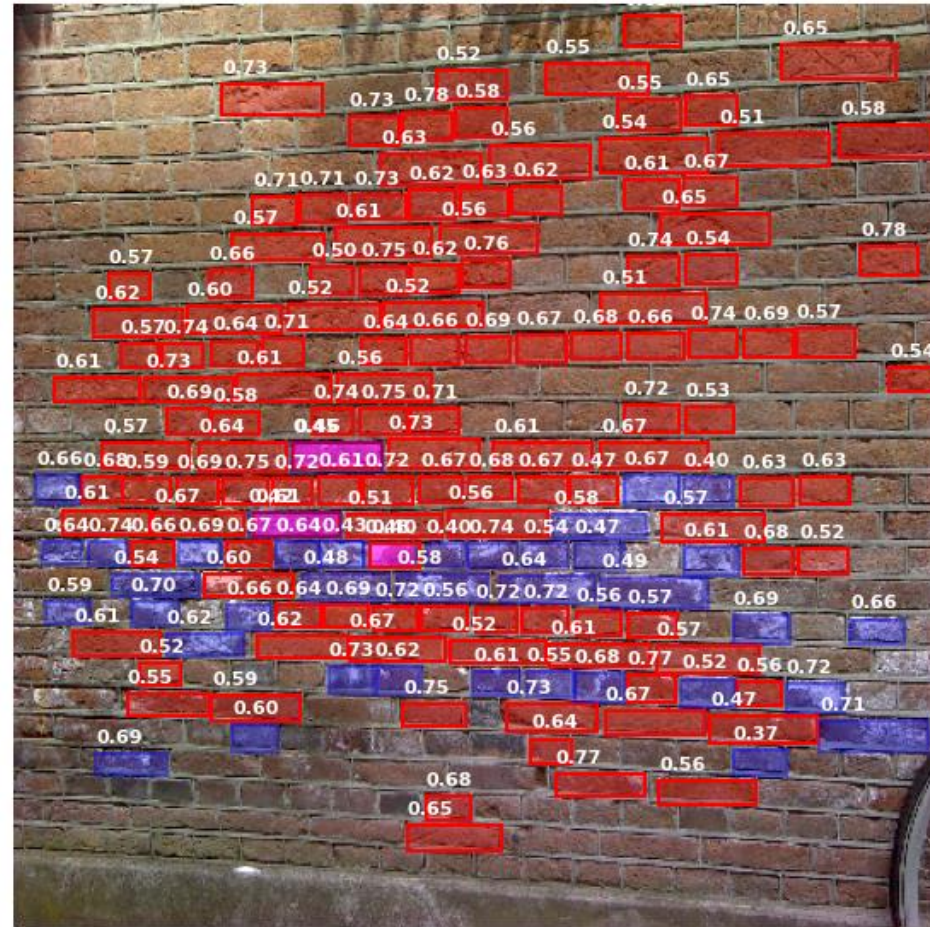
# RESULTS

## H3: DAMAGE CO-OCCURANCE

DC (RGB) Image

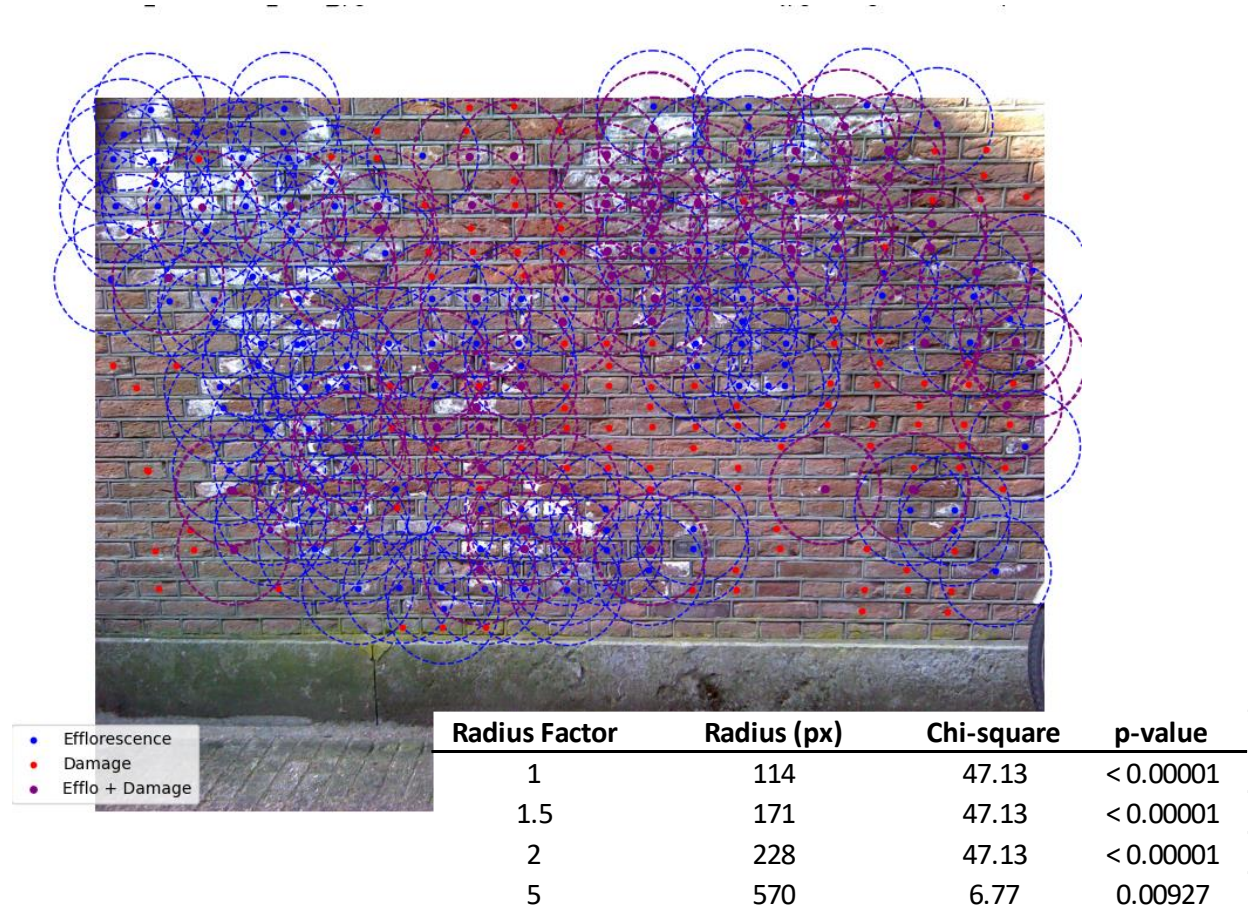


Predictions



# RESULTS

## H3: DAMAGE CO-OCCURANCE



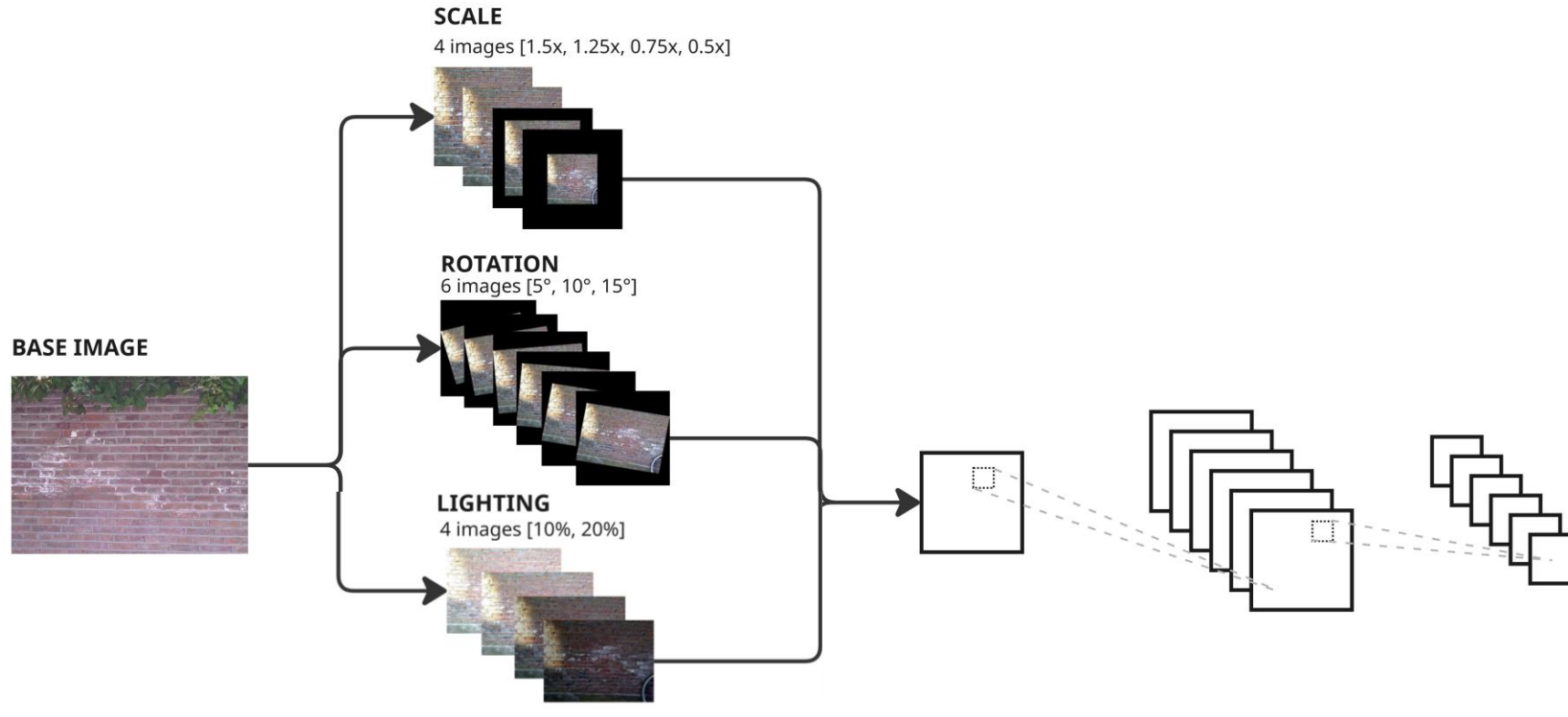
# RESULTS

## H3: DAMAGE CO-OCCURANCE

- Efflorescence and damage had limited convergence and moderate segmentation
- Damage outperforms efflorescence in mAP
- Class imbalance which caused high loss, unstable precision/recall
- Indicates model struggles to learn two co-occurring patterns in the same region

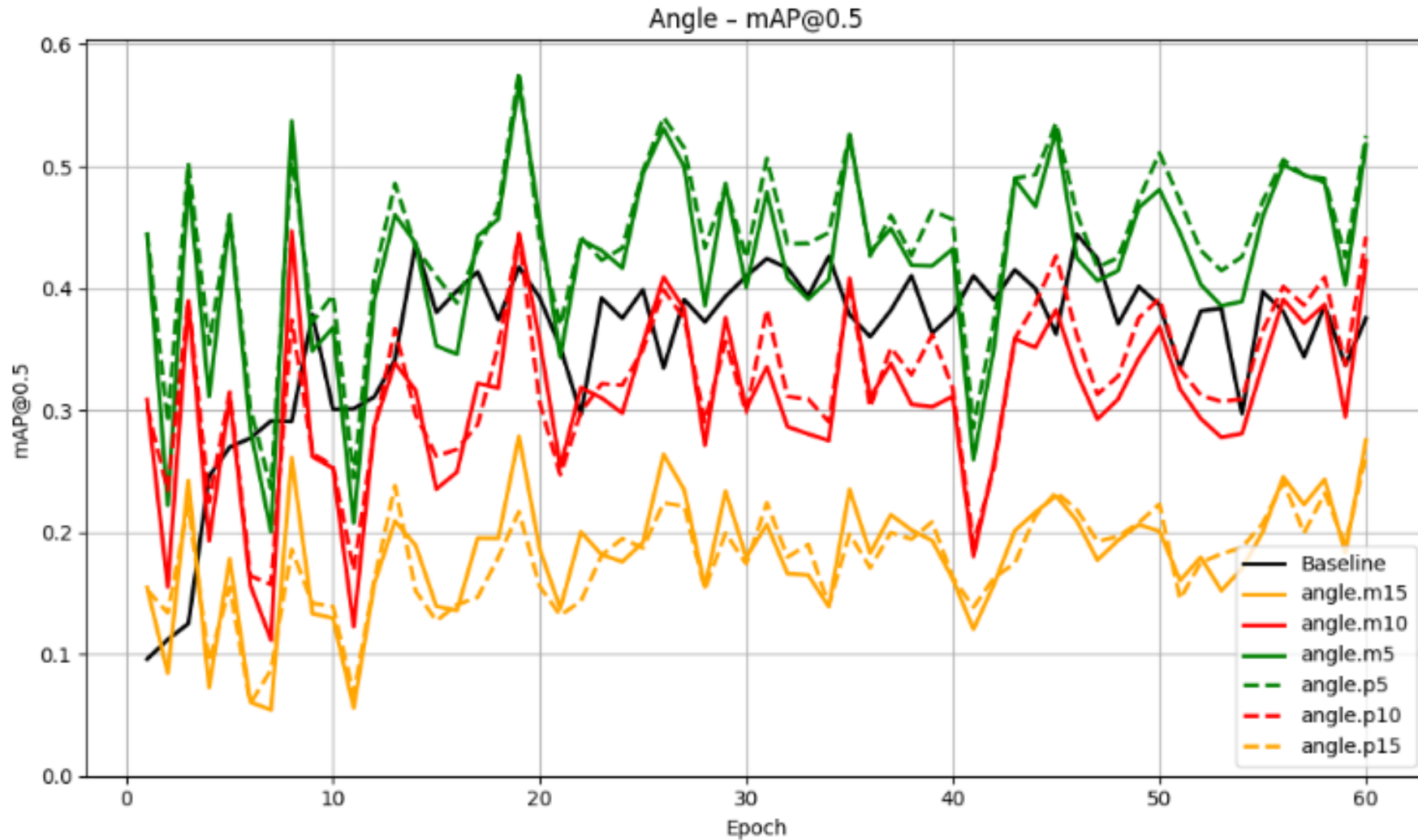
# RESULTS

## H4: IMAGE QUALITY- SET UP



# RESULTS

## H4: IMAGE QUALITY – ANGLE SHIFT



# RESULTS

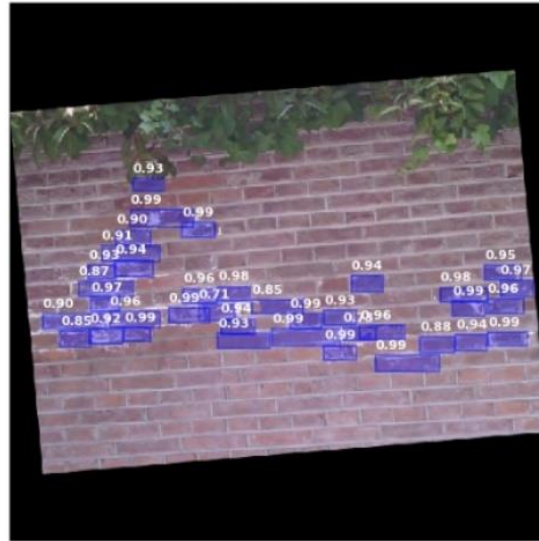
## H4: IMAGE QUALITY – ANGLE SHIFT

Rotation

Base image



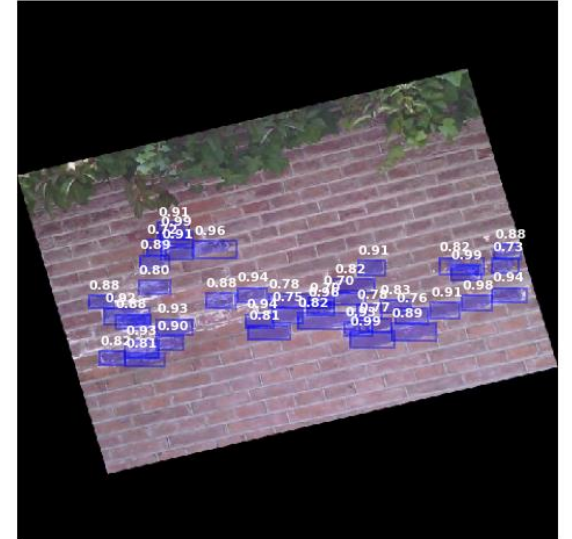
5°



10°

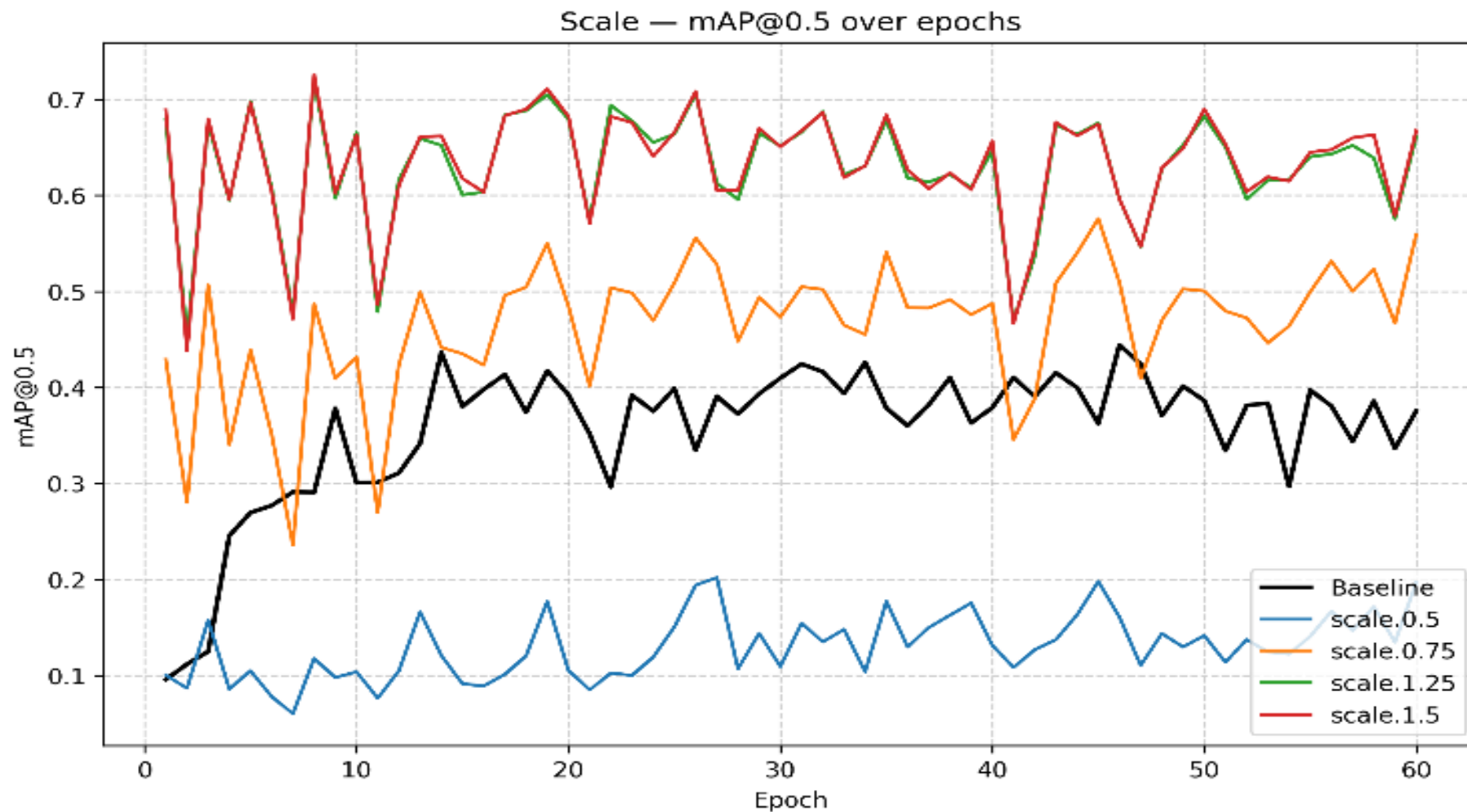


15°



# RESULTS

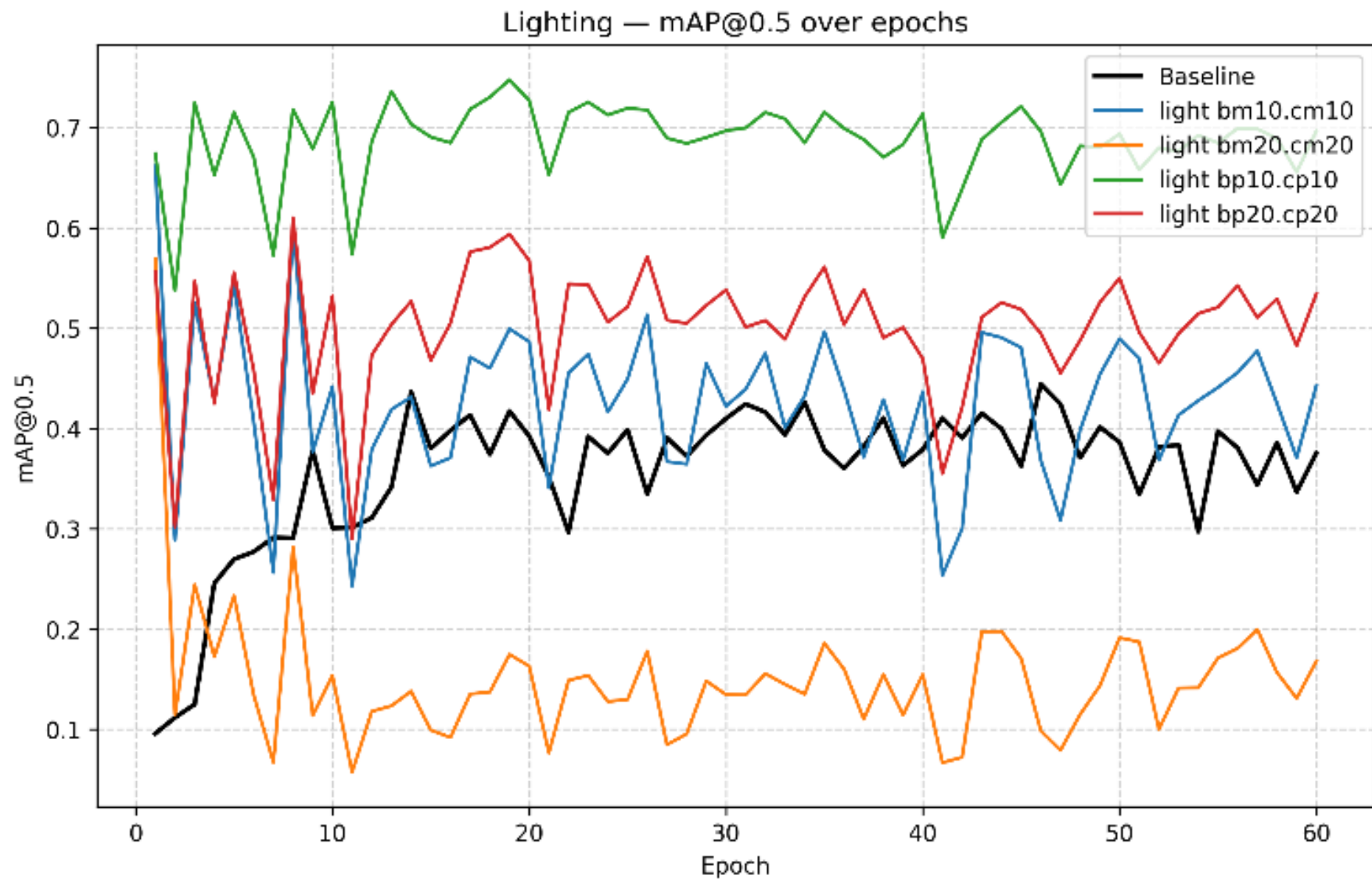
## H4: IMAGE QUALITY – SCALE





# RESULTS

## H4: IMAGE QUALITY – LIGHTING





# RESULTS

## H4: IMAGE QUALITY – LIGHTING

- Mild rotations are tolerated, but deviations beyond  $\pm 10^\circ$  disrupt mask alignment due to perspective distortion. Rotation-aware augmentations or architectures are needed.
- Upscaling (1.25 $\times$ –1.5 $\times$ ) improves confidence and density of predictions, while downscaling (0.5 $\times$ ) degrades segmentation accuracy. High-resolution inputs are critical.
- Darker inputs (–20%) collapse detection, while slight increases in brightness (+10%) enhance performance. Model lacks lighting invariance and depends on training luminance/contrast.

# CONCLUSION & RECOMMENDATIONS

## MAIN RESEARCH QUESTION

*How can **deep learning** models be applied to **improve** the **detection** of **efflorescence** in **masonry** buildings in the Netherlands?*

- Deep learning can support reliable efflorescence detection on masonry
- Mask R-CNN best suited for precise masks, contextual learning
- Performance drops with poor resolution, decreased lighting, or steep angles
- Misclassification with lichens/encrustation remains a challenge
- Thermal fusion raises precision but lowers recall, needs refinement
- Reliable deployment requires diverse, high-quality annotations

# LESSONS LEARNED & FUTURE WORK

## DISCUSSION

### TECHNICAL

- More powerful hardware and **deeper backbones** (resnet101) and larger batch sizes.
- Increase **training epochs** and incorporate different **learning strategies** like active learning, mix precision training.
- Try **frame works** (Swin transform, Segformer etc)

### DATASET & ANNOTATION

- Expand dataset with additional classes like **efflorescence in the joint.**
- **Additional damage types** according to **MDCS** and maybe differentiate between brick types to adjust performance
- Apply / research towards **data augmentation strategies** tailored to **weathering.**
- Train models with a **dataset** consisting of images taken **over time**

# LESSONS LEARNED & FUTURE WORK

## DISCUSSION

### COLLABORATION AND APPLICATION

- Evaluate models with **expanding on urban level mapping** and **drone-based inspection**
- Continue **open data** and **code sharing**
- Promote the creation of **public datasets** from **MDCS** to enhance research capabilities
- Provide educational materials or **labeling guidelines** for **consistent annotations**

### ENVIRONMENTAL / CONTEXTUAL

- Incorporate **geospatial** and **environmental metadata**
- Include **5th channel depth** information from **pointclouds** for additional features
- **Standardized image acquisition protocols** for MDCS future proofing  
Additional thermal patterns to **distinguish capillary** action vs leakage



# THANK YOU

Valentijn Camiel Cloo

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