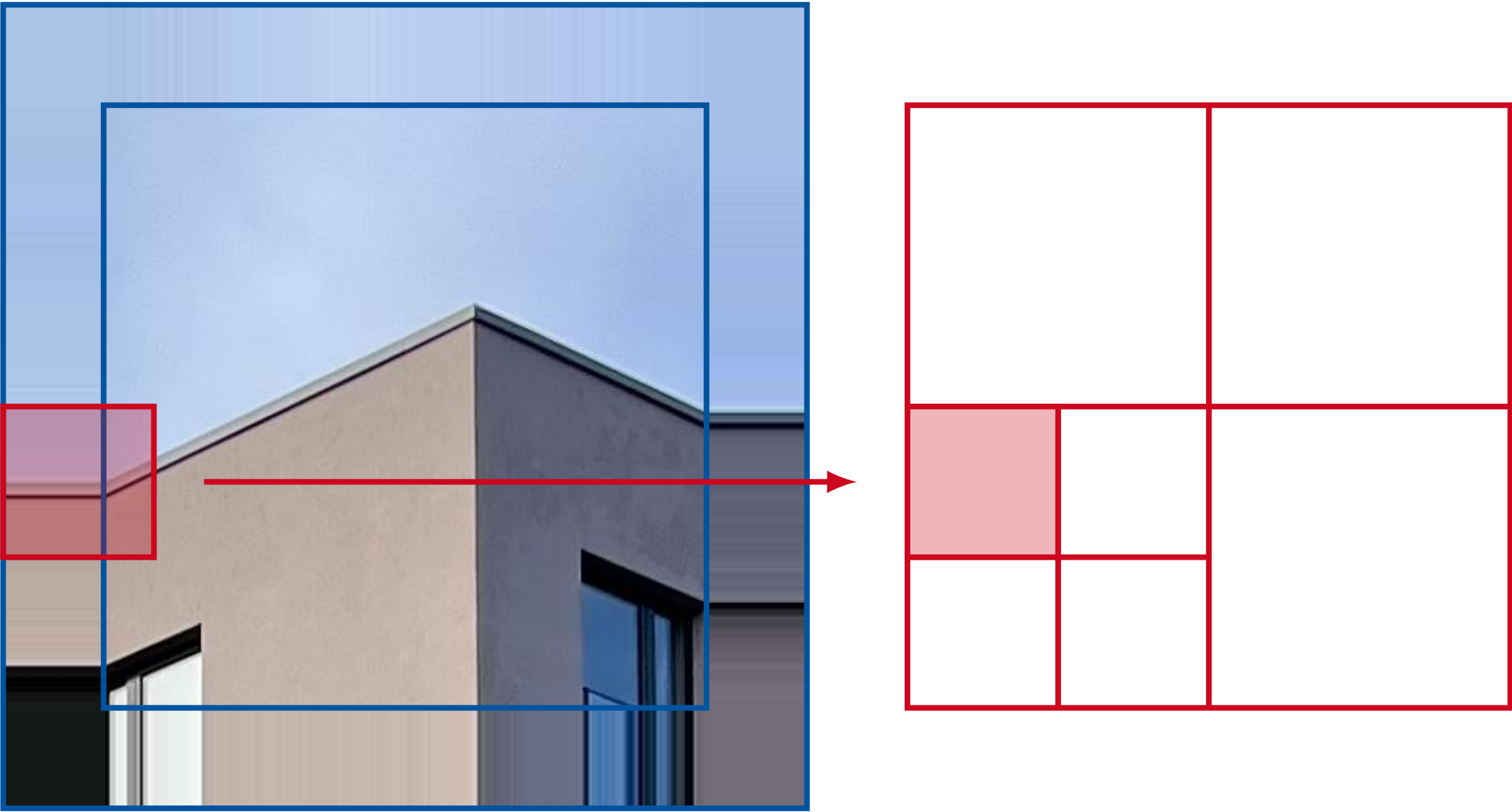


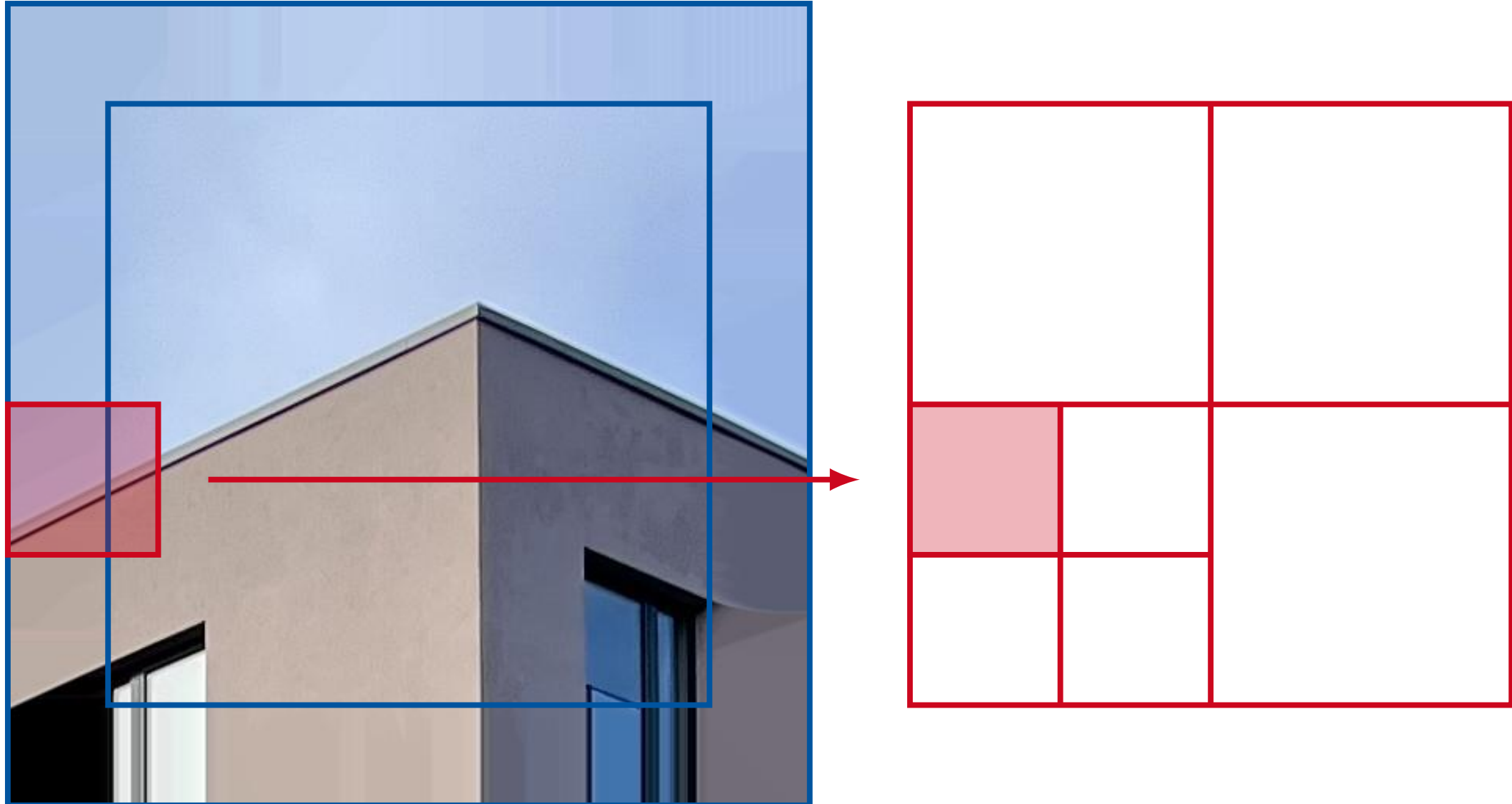
JVET-AH0168 - Template Matching Picture Boundary Padding

Nicolas Neumann and Mathias Wien

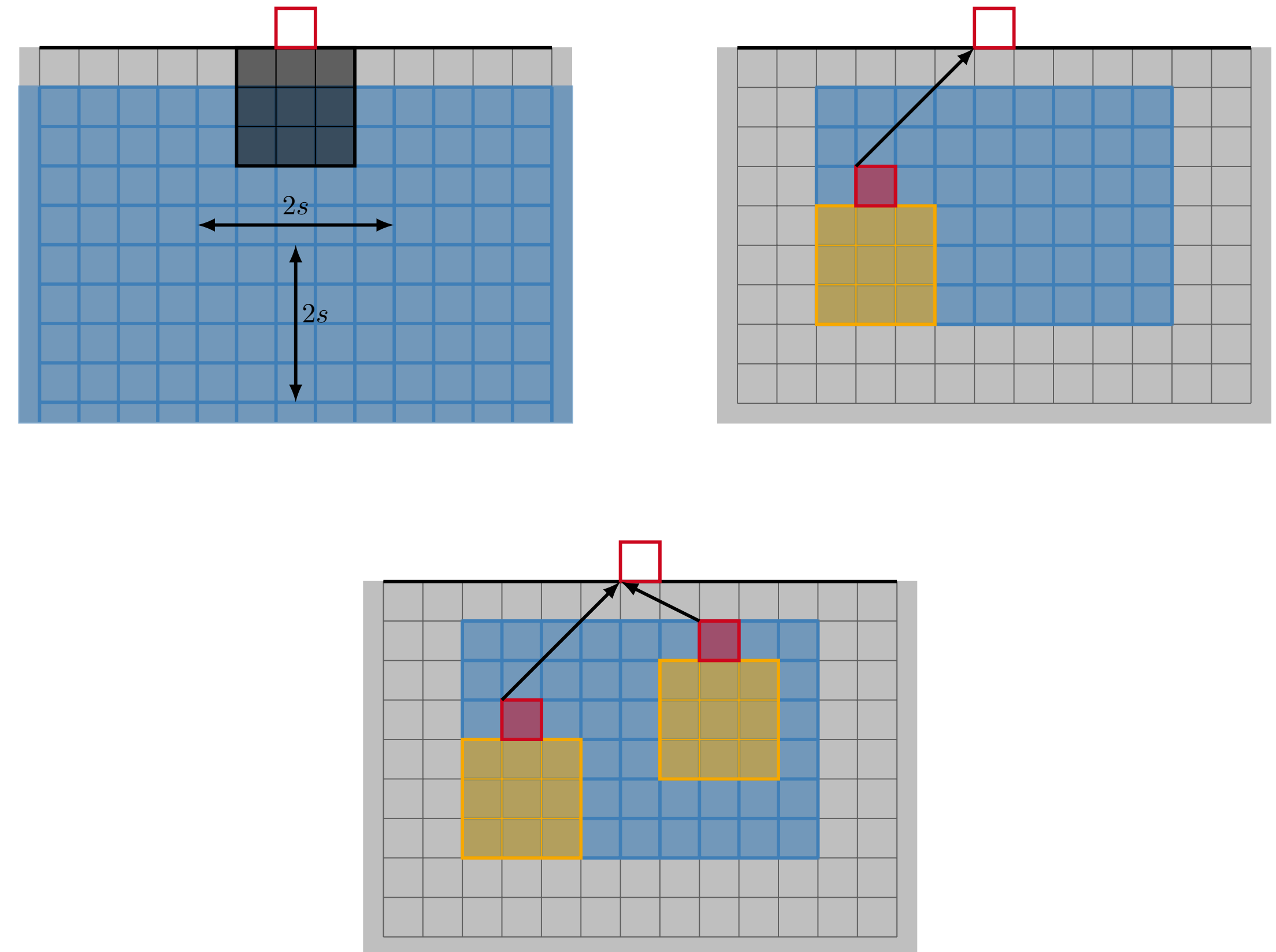
Standard Padding



Template Matching Padding

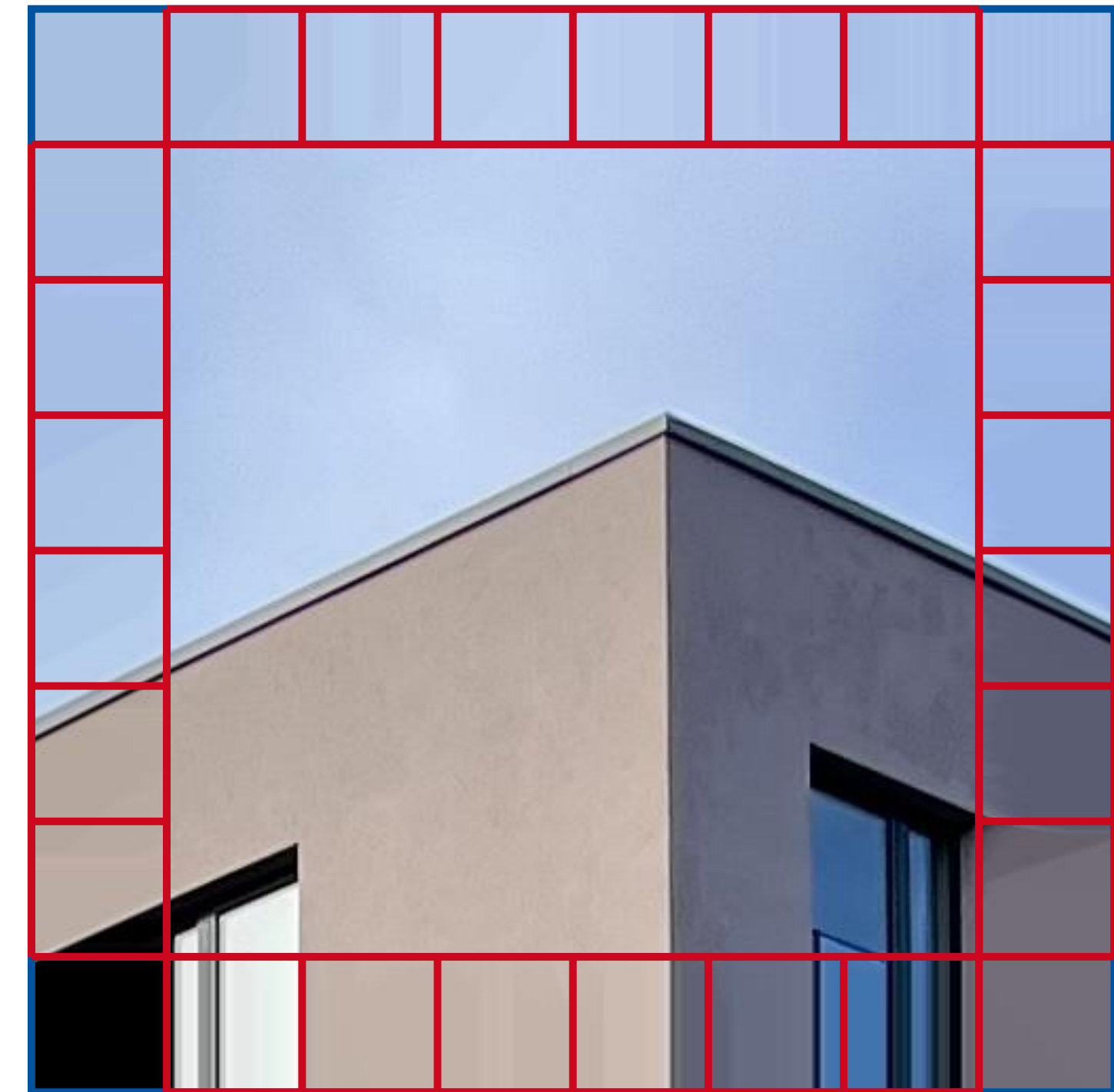


- Target block to be predicted
- Template adjacent to target block
- Find matching structure (candidate)
- Extract source block and use as prediction



Template Matching-based Reference Picture Padding

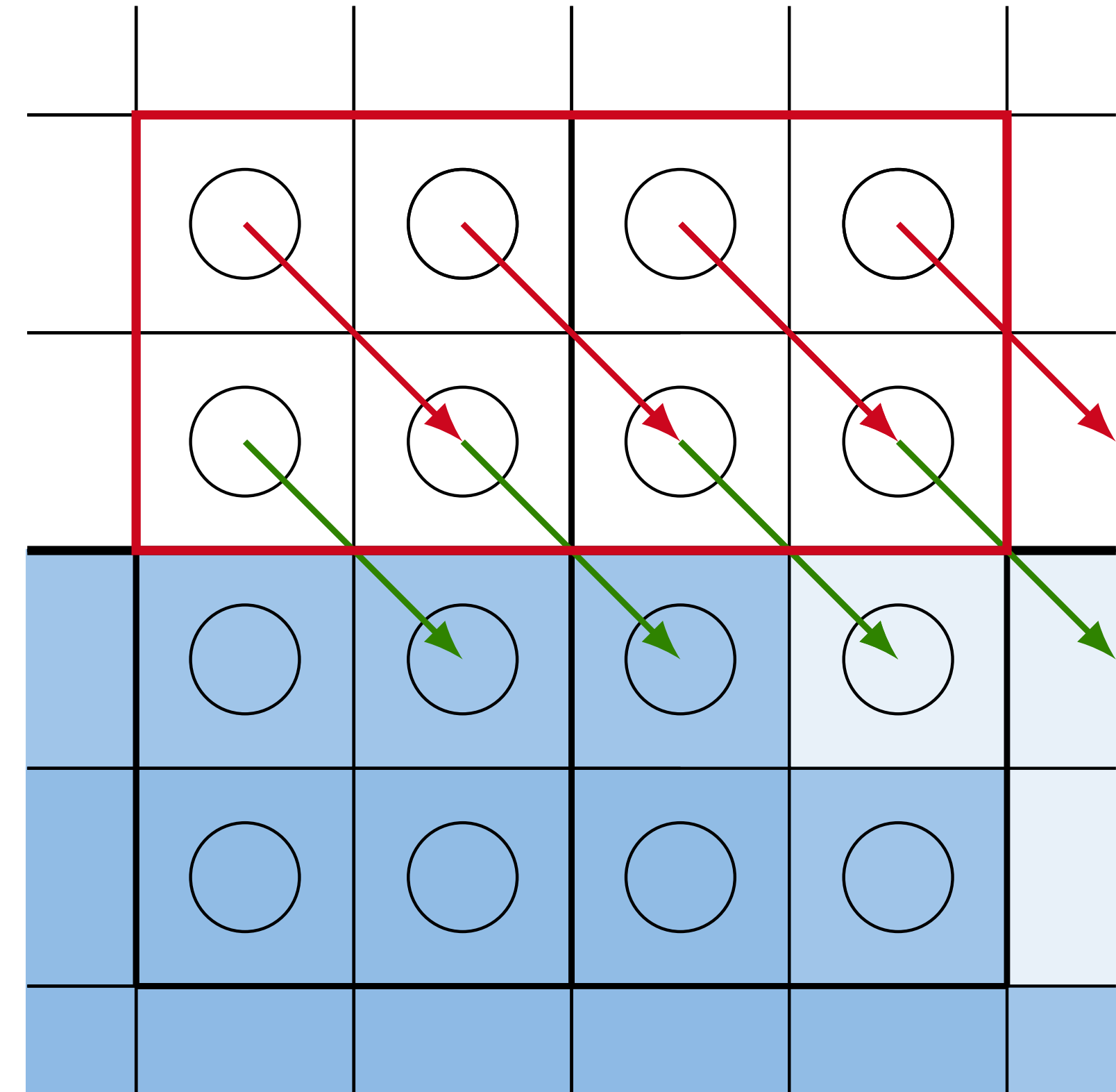
- Divide the area surrounding the reference picture into target blocks and do prediction
- Complexity needs to be managed



Virtual Target Block Increase

- Target block size defines forbidden area
- Forbidden area ensures availability of source block pixels

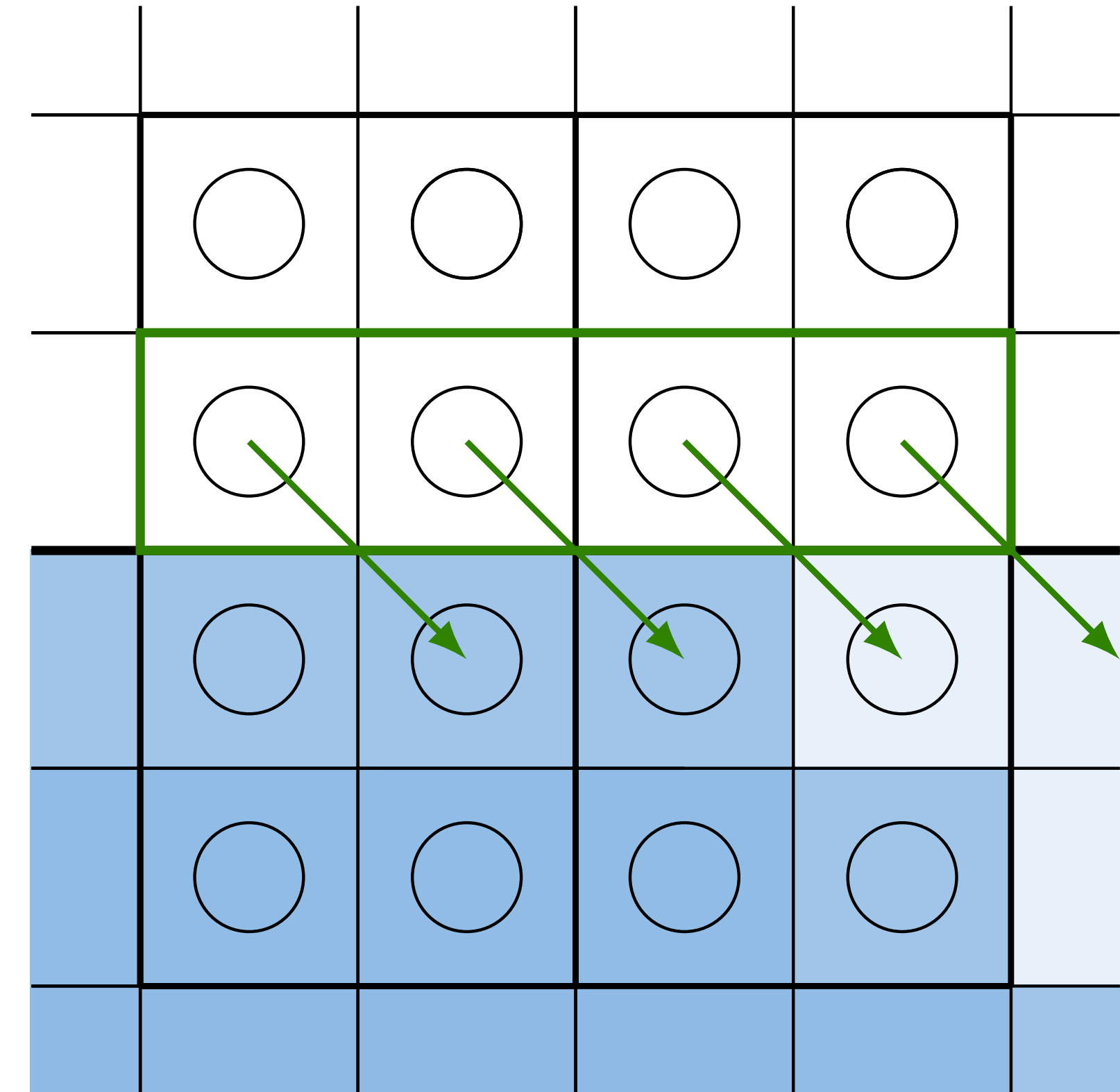
Complexity Reduction of Template Matching



Virtual Target Block Increase

- Assume Target block / forbidden area of 1 pixel depth and execute search and store displacement vectors in memory

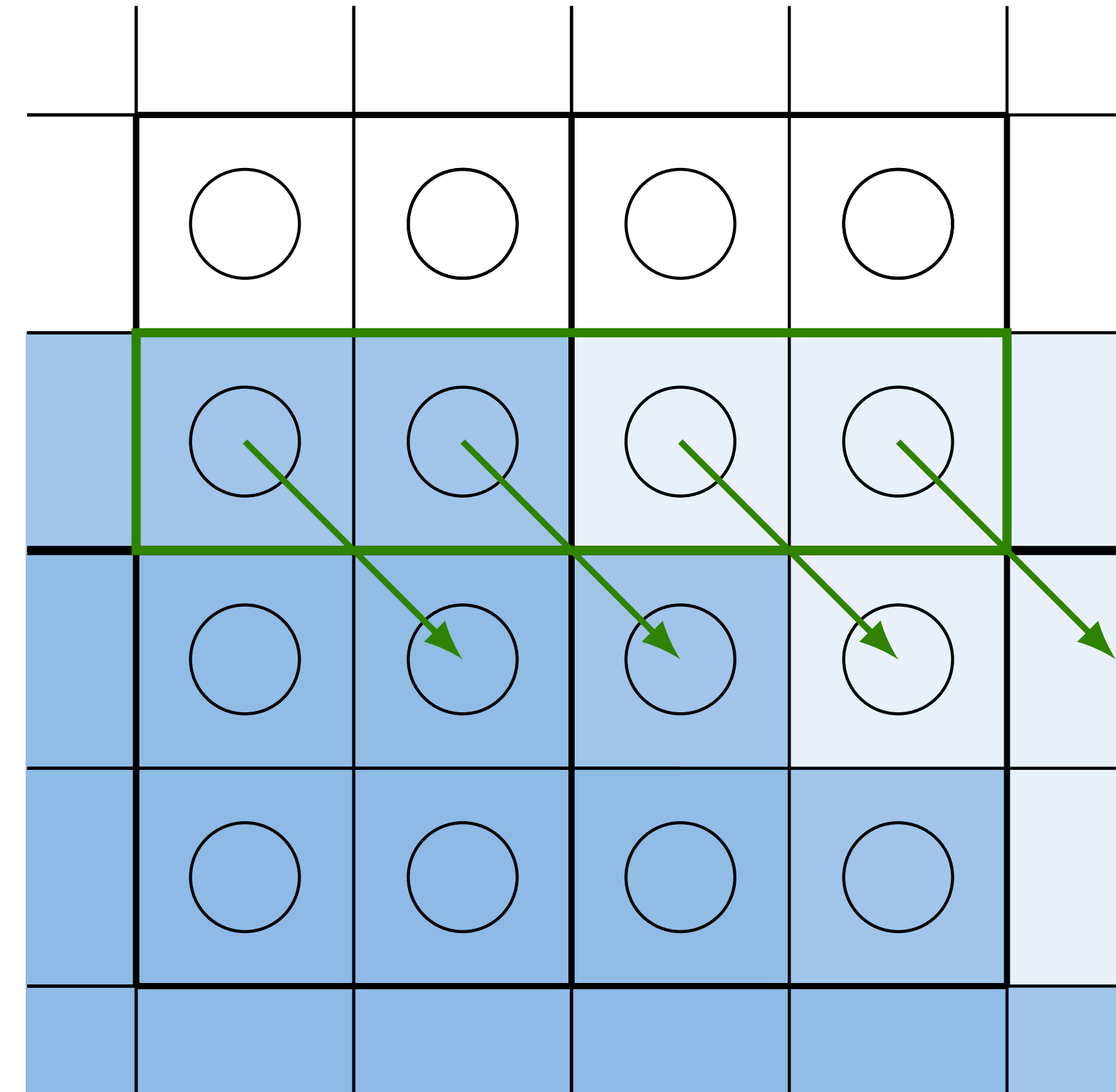
Complexity Reduction of Template Matching



Virtual Target Block Increase

- Predict first line of pixels

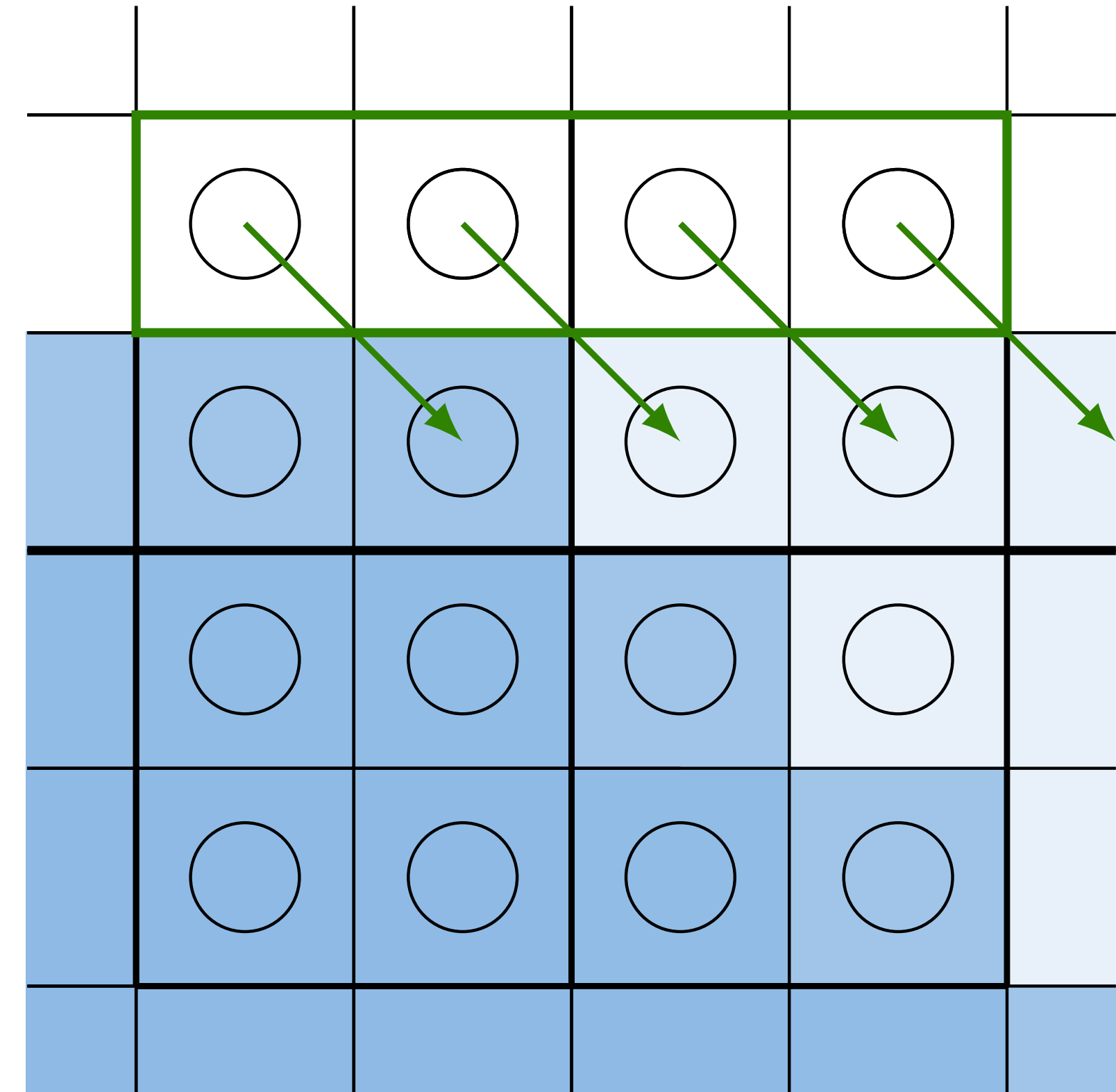
Complexity Reduction of Template Matching



Virtual Target Block Increase

- Predict next line with stored displacement vectors
- Process can be repeated for defined number of lines

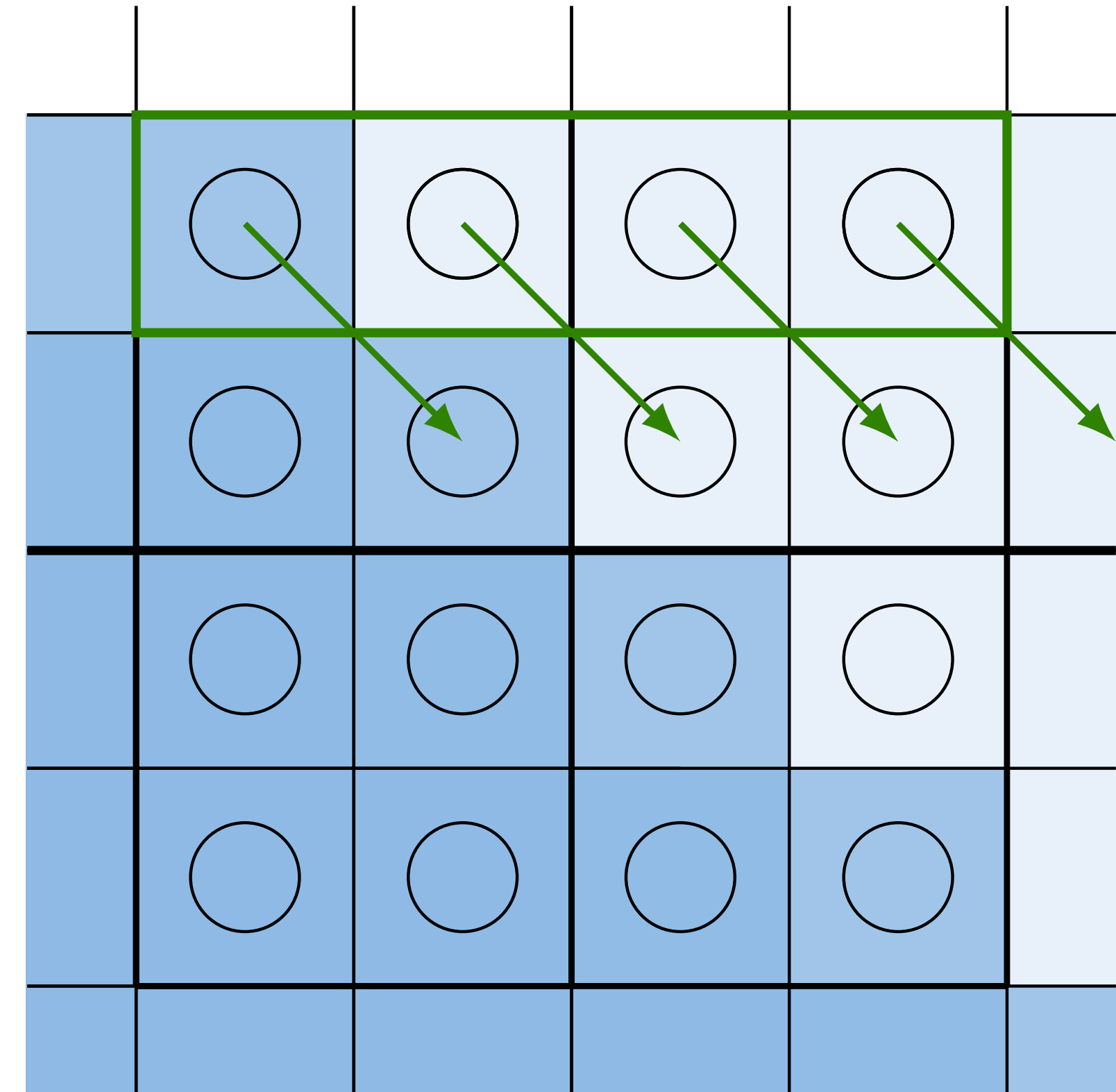
Complexity Reduction of Template Matching



Virtual Target Block Increase

- Predict next line with stored displacement vectors
- Process can be repeated for defined number of lines

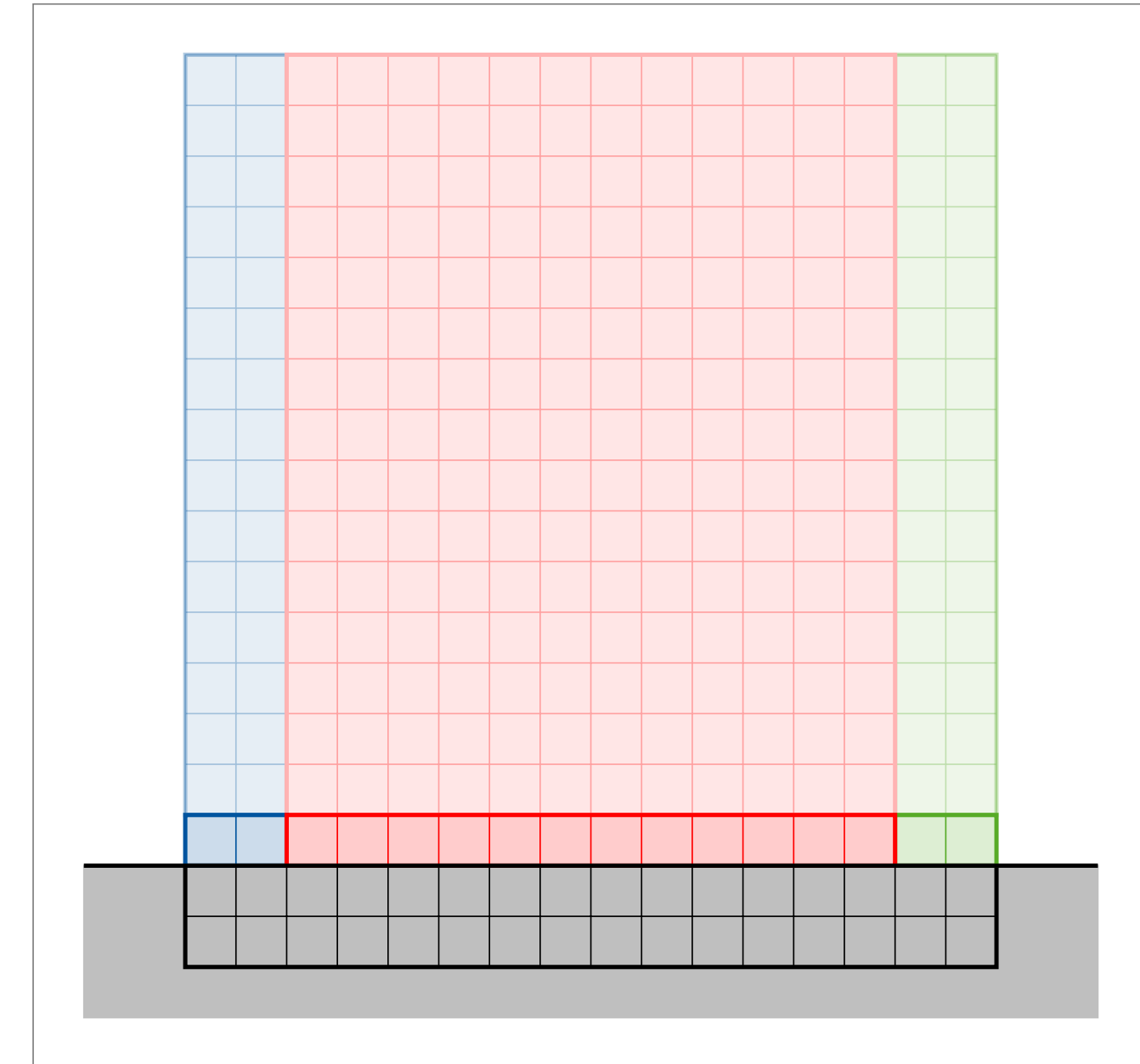
Complexity Reduction of Template Matching



Parameters

- For this experiment:
 - Target Block Size 12x16 (with virtual increase)
 - Template Size 16x2
- Scheme is flexible, multiple configurations could be designed and usage signaled in bitstream

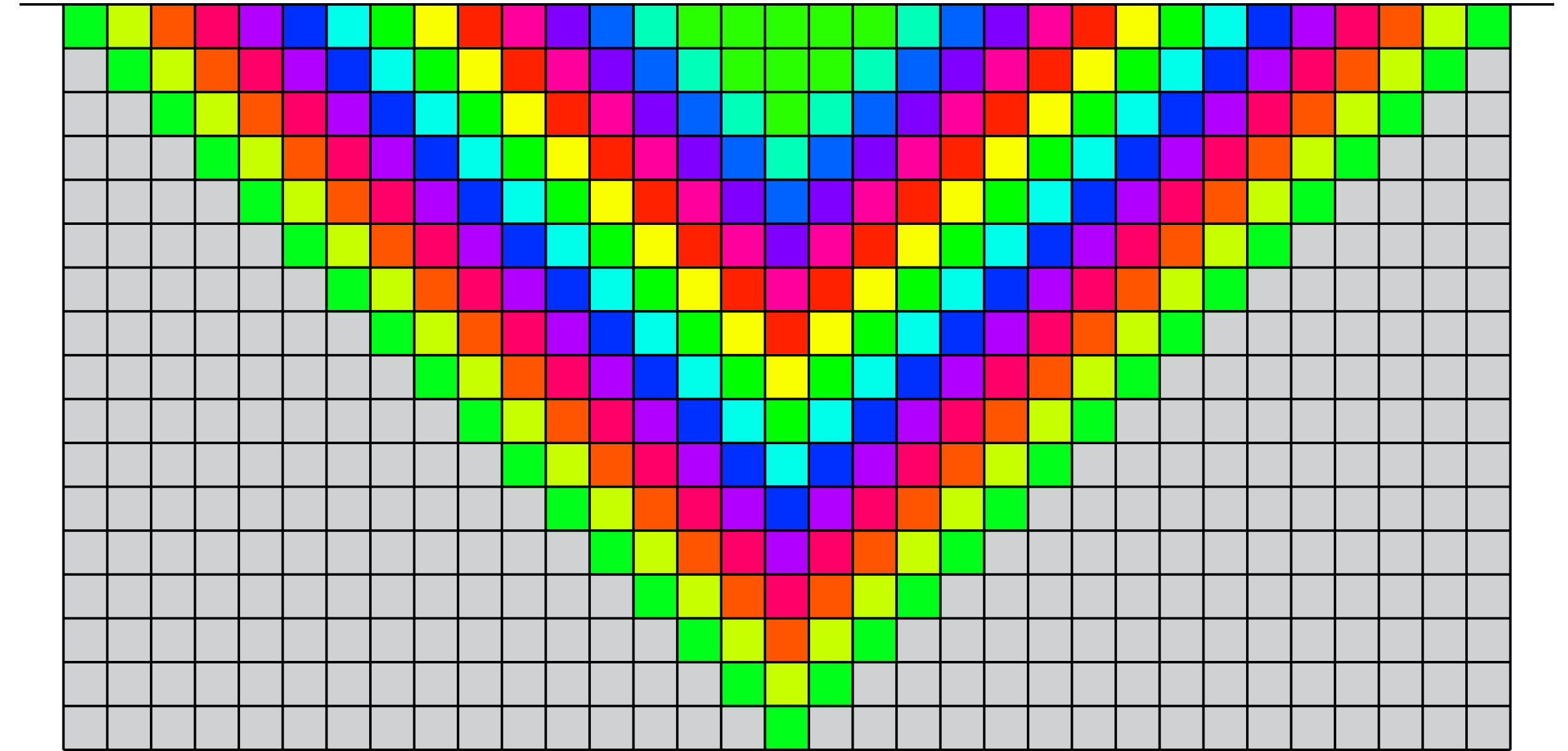
Complexity Reduction of Template Matching



Template Matching Search Area

- Search area is grown progressively, can be stopped by early termination
- Fixed parameters for test
 - Stopping criterion: SAD Threshold of 24
 - Search area: Triangle area minimum size 3 and maximum size 12
- Parameters can be configured and signaled in the bitstream for more flexibility
- Averaging 1-4 best candidates with SAD-based selection process

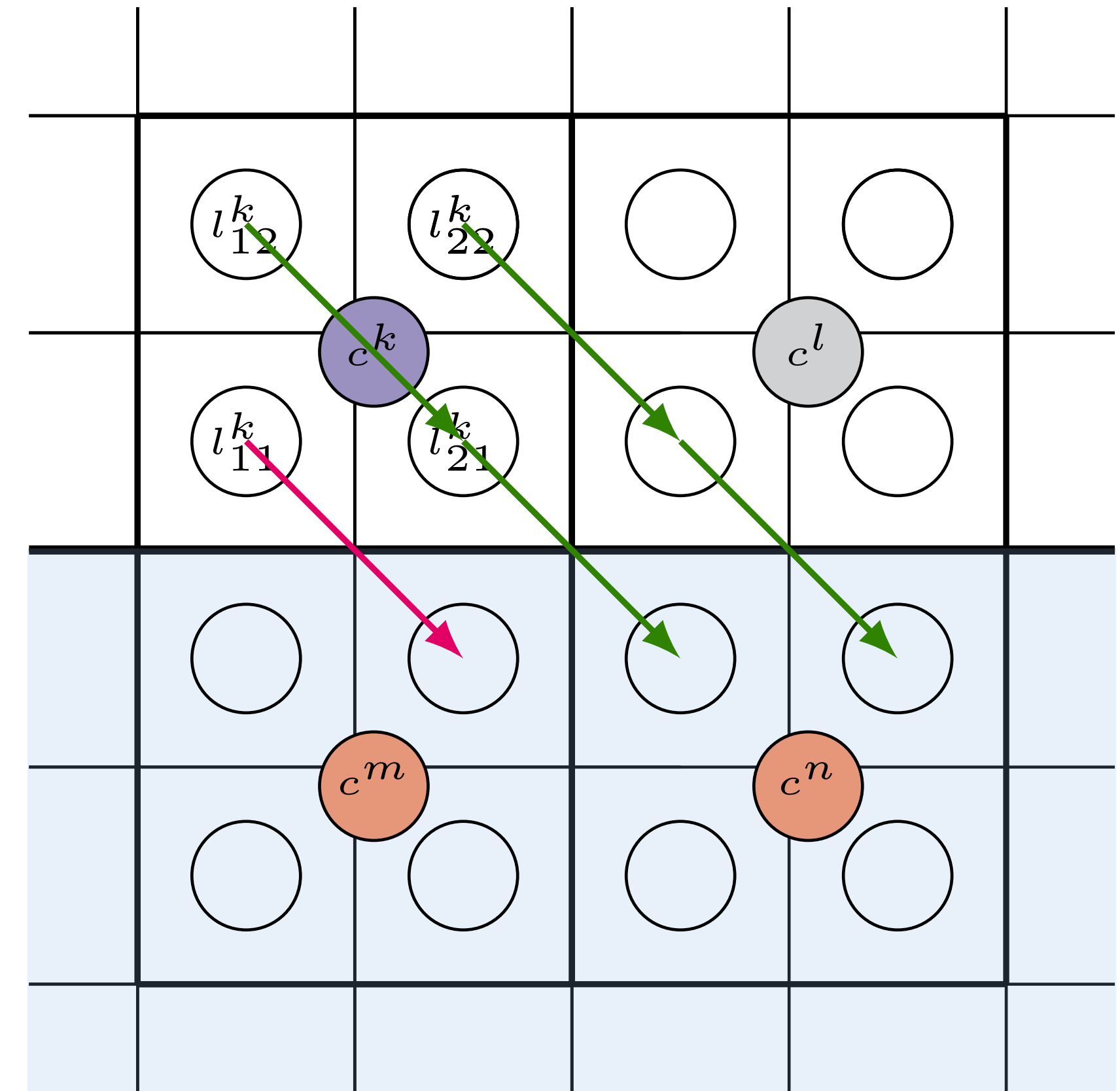
Early Termination of TM-Search



Search only on Luma

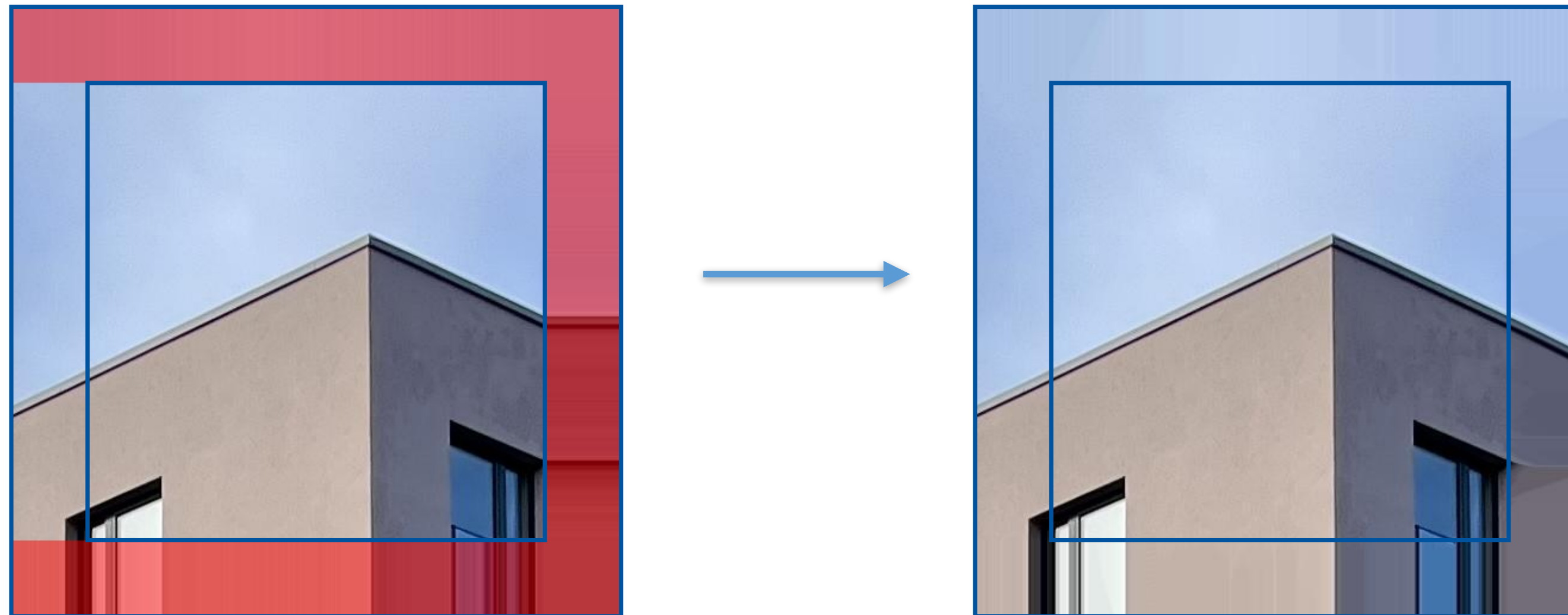
- search on luma only
- up- and downsampling for chroma subsampling?
- Chroma can be calculated directly without need for up- and downsampling

Complexity Reduction of Template Matching



Motion Compensated Padding and Template Matching Padding

- Motion compensated padding (JVET-AA0096) currently used in ECM
- Area where MC padding is not applicable is filled with TM padding (combined approach)



- Test results are provided based on VTM due to simulation time
- Tools other than MC padding are orthogonal, MC padding results are included in the tests for comparison
- 3 Methods:
 - Motion Compensated Padding
 - Template Matching Padding
 - Combined
- Padding margin for all methods: 16 pixels (repetitive padding beyond that)
- 3 Tests are conducted:
 1. CTC on SDR
 2. Subpicture Partitioning (similar to JVET-M1032) of A1 + A2 Sequences
 3. Subpicture Partitioning of 360 Sequences
- Encoder runtime increase is significantly lower (~100%) because complexity for encoder and decoder are same but not reported due to heterogenous cluster

MC-Padding

	Random access Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1	-0.24%	-0.25%	-0.19%		103%
Class A2	-0.18%	-0.11%	-0.19%		103%
Class B	-0.34%	-0.20%	-0.26%		105%
Class C	-0.29%	-0.29%	-0.24%		110%
Class E					
Overall	-0.28%	-0.22%	-0.23%		106%
Class D	-0.74%	-0.59%	-0.53%		119%
Class F	-0.04%	-0.02%	-0.06%		105%

	Low delay B Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1					
Class A2					
Class B	-0.01%	0.02%	0.04%		102%
Class C	-0.07%	0.00%	0.11%		106%
Class E	0.02%	-0.25%	0.05%		103%
Overall	-0.02%	-0.05%	0.07%		103%
Class D	-0.06%	-0.12%	0.06%		107%
Class F	-0.22%	0.56%	-0.45%		101%

TM-Padding

	Random access Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1	-0.08%	-0.04%	-0.14%		101%
Class A2	-0.01%	0.07%	-0.08%		101%
Class B	-0.07%	0.10%	0.01%		101%
Class C	-0.11%	-0.02%	-0.03%		103%
Class E					
Overall	-0.07%	0.04%	-0.05%		102%
Class D	-0.19%	0.06%	-0.09%		101%
Class F	-0.02%	0.05%	0.00%		101%

	Low delay B Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1					
Class A2					
Class B	-0.07%	0.15%	0.33%		101%
Class C	-0.08%	-0.09%	-0.03%		103%
Class E	-0.03%	0.56%	-0.28%		103%
Overall	-0.06%	0.17%	0.06%		102%
Class D	-0.52%	-0.38%	-0.97%		108%
Class F	-0.28%	0.08%	-0.50%		102%

Combined

	Random access Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1	-0.28%	-0.19%	-0.12%		104%
Class A2	-0.18%	-0.10%	-0.14%		103%
Class B	-0.36%	-0.26%	-0.20%		106%
Class C	-0.31%	-0.27%	-0.28%		112%
Class E					
Overall	-0.29%	-0.22%	-0.19%		107%
Class D	-0.79%	-0.46%	-0.63%		122%
Class F	-0.02%	0.00%	-0.02%		108%

	Low delay B Main10				
	Over VTM-23.0			EncT	DecT
	Y	U	V		
Class A1					
Class A2					
Class B	-0.07%	0.21%	-0.27%		103%
Class C	-0.07%	0.02%	0.07%		107%
Class E	-0.09%	-0.43%	-0.33%		105%
Overall	-0.07%	-0.01%	-0.17%		105%
Class D	-0.40%	-0.49%	-1.56%		110%
Class F	-0.15%	0.66%	-0.48%		103%

Random access Main10				
Over VTM-23.0				
	Y	U	V	EncT DecT
MC	-0.28%	-0.22%	-0.23%	106%
TM	-0.07%	0.04%	-0.05%	102%
Combined	-0.29%	-0.22%	-0.19%	107%

Low delay B Main10				
Over VTM-23.0				
	Y	U	V	EncT DecT
MC	-0.02%	-0.05%	0.07%	103%
TM	-0.06%	0.17%	0.06%	102%
Combined	-0.07%	-0.01%	-0.17%	105%

Test 2 - Class A1 and A2 partitioned into Subpictures

Results

- For Test 2 and 3 the Sequences are partitioned into 384x384 subpictures (analogous to CE-12: Tile Set Boundary Handling JVET-M1032)
- Reference subpicture padding with different methods is applied (FoodMarket left out) and padding applied at all subpicture boundaries
- Older VTM Version 13 used because tests were conducted earlier

Test 2 - Class A1 and A2 partitioned into Subpictures

Results

MC-Padding

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	-0.22%	-0.28%	-0.30%		
CatRobot	-0.86%	-0.69%	-0.81%		
DaylightRoad2	-1.85%	-1.46%	-1.59%		
ParkRunning3	-1.12%	-1.15%	-1.15%		
Tango2	-1.39%	-1.18%	-1.19%		
Overall	-1.09%	-0.95%	-1.01%		126%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	0.03%	0.00%	-0.01%		
CatRobot	-0.20%	0.13%	-0.13%		
DaylightRoad2	-0.17%	-0.50%	0.14%		
ParkRunning3	-0.05%	-0.13%	-0.09%		
Tango2	-0.02%	-0.35%	0.07%		
Overall	-0.08%	-0.17%	0.00%		112%

TM-Padding

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	-0.03%	-0.13%	-0.14%		
CatRobot	-0.52%	-0.38%	-0.50%		
DaylightRoad2	-0.40%	-0.13%	-0.33%		
ParkRunning3	-0.25%	-0.44%	-0.31%		
Tango2	-0.87%	-1.08%	-0.74%		
Overall	-0.41%	-0.43%	-0.40%		101%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	-0.10%	0.17%	-0.07%		
CatRobot	-0.57%	-0.56%	-0.67%		
DaylightRoad2	-0.20%	-0.39%	-0.02%		
ParkRunning3	-0.33%	-0.28%	-0.37%		
Tango2	-0.53%	-0.60%	-0.51%		
Overall	-0.35%	-0.33%	-0.33%		103%

Combined

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	-0.28%	-0.34%	-0.37%		
CatRobot	-1.01%	-0.84%	-1.00%		
DaylightRoad2	-1.97%	-1.52%	-1.75%		
ParkRunning3	-1.24%	-1.35%	-1.18%		
Tango2	-1.56%	-1.42%	-1.48%		
Overall	-1.21%	-1.09%	-1.16%		134%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Campfire	-0.14%	0.49%	-0.22%		
CatRobot	-0.59%	-0.77%	-0.82%		
DaylightRoad2	-0.24%	-0.01%	0.34%		
ParkRunning3	-0.24%	-0.28%	-0.26%		
Tango2	-0.35%	-0.38%	-0.37%		
Overall	-0.31%	-0.19%	-0.27%		121%

Test 3 - 360 Sequences (CMP) partitioned into Subpictures

Results

MC-Padding

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	-1.15%	-1.03%	-1.01%		
BranCastle2	-0.70%	-0.91%	-0.89%		
Broadway	-1.17%	-1.02%	-1.04%		
ChairliftRide	-1.69%	-1.47%	-1.23%		
Gaslamp	-0.04%	-0.02%	-0.05%		
Harbor	-0.03%	-0.01%	-0.08%		
KiteFlite	-0.03%	-0.03%	-0.03%		
Landing2	-0.56%	-0.70%	-0.85%		
SkateboardInLot	-0.74%	0.43%	-0.56%		
Trolley	-0.02%	-0.03%	0.02%		
Overall	-0.61%	-0.48%	-0.57%		125%

TM-Padding

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	-0.37%	-0.25%	-0.32%		
BranCastle2	-0.17%	-0.19%	-0.37%		
Broadway	-0.60%	-0.42%	-0.73%		
ChairliftRide	-0.36%	-0.38%	-0.33%		
Gaslamp	0.00%	0.01%	-0.06%		
Harbor	-0.02%	0.03%	-0.14%		
KiteFlite	0.00%	-0.01%	0.00%		
Landing2	-0.33%	-0.30%	-0.43%		
SkateboardInLot	-0.20%	0.15%	-0.61%		
Trolley	-0.01%	-0.05%	0.03%		
Overall	-0.21%	-0.14%	-0.30%		101%

Combined

	Random access Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	-1.27%	-1.23%	-1.22%		
BranCastle2	-0.75%	-0.98%	-0.98%		
Broadway	-1.32%	-1.15%	-1.14%		
ChairliftRide	-1.82%	-1.66%	-1.43%		
Gaslamp	-0.06%	-0.08%	-0.13%		
Harbor	-0.06%	-0.02%	-0.15%		
KiteFlite	-0.04%	-0.04%	-0.02%		
Landing2	-0.66%	-0.89%	-0.84%		
SkateboardInLot	-0.77%	0.08%	-1.77%		
Trolley	-0.05%	-0.08%	-0.03%		
Overall	-0.68%	-0.61%	-0.77%		131%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	-0.18%	-0.43%	-0.29%		
BranCastle2	-0.35%	-0.54%	-0.42%		
Broadway	-0.28%	-0.15%	-0.02%		
ChairliftRide	-0.27%	-0.41%	-0.77%		
Gaslamp	-0.03%	0.17%	0.04%		
Harbor	-0.02%	0.12%	-0.07%		
KiteFlite	-0.02%	0.11%	0.30%		
Landing2	-0.25%	-0.03%	-0.46%		
SkateboardInLot	-0.21%	0.34%	0.19%		
Trolley	-0.03%	-0.01%	0.31%		
Overall	-0.16%	-0.08%	-0.12%		114%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	0.32%	-0.68%	-0.23%		
BranCastle2	-0.15%	-0.25%	0.05%		
Broadway	-0.89%	-0.09%	-0.08%		
ChairliftRide	-0.52%	-0.75%	-1.19%		
Gaslamp	-0.09%	-0.05%	0.02%		
Harbor	-0.12%	-0.08%	-0.42%		
KiteFlite	-0.03%	-0.12%	0.22%		
Landing2	-0.35%	-0.04%	-0.30%		
SkateboardInLot	-0.26%	1.13%	0.28%		
Trolley	-0.12%	-0.24%	0.12%		
Overall	-0.22%	-0.12%	-0.15%		103%

	Low delay B Main10				
	Over VTM-13.0			EncT	DecT
	Y	U	V		
Balboa	0.02%	-0.71%	-0.21%		
BranCastle2	-0.42%	-0.72%	-0.82%		
Broadway	-0.51%	-0.58%	-0.27%		
ChairliftRide	-0.52%	-0.70%	-0.85%		
Gaslamp	-0.10%	-0.05%	-0.10%		
Harbor	-0.14%	0.01%	-0.25%		
KiteFlite	-0.04%	-0.07%	0.13%		
Landing2	-0.39%	-0.31%	-0.37%		
SkateboardInLot	-0.31%	0.90%	-1.70%		
Trolley	-0.08%	-0.20%	0.06%		
Overall	-0.25%	-0.24%	-0.44%		122%

Test 2 (regular video)

	Random access Main10				
	Over VTM-13.0				DecT
	Y	U	V	EncT	
MC	-1.09%	-0.95%	-1.01%		126%
TM	-0.41%	-0.43%	-0.40%		101%
combined	-1.21%	-1.09%	-1.16%		134%

	Low delay B Main10				
	Over VTM-13.0				DecT
	Y	U	V	EncT	
MC	-0.08%	-0.17%	0.00%		112%
TM	-0.35%	-0.33%	-0.33%		103%
combined	-0.31%	-0.19%	-0.27%		121%

Test 3 (360 video)

	Random access Main10				
	Over VTM-13.0				DecT
	Y	U	V	EncT	
MC	-0.61%	-0.48%	-0.57%		125%
TM	-0.21%	-0.14%	-0.30%		101%
combined	-0.68%	-0.61%	-0.77%		131%

	Low delay B Main10				
	Over VTM-13.0				DecT
	Y	U	V	EncT	
MC	-0.16%	-0.08%	-0.12%		114%
TM	-0.22%	-0.12%	-0.15%		103%
combined	-0.25%	-0.24%	-0.44%		122%

Conclusion

- TM Reference Picture Padding outperforms MC Padding in low delay configuration, especially if used for subpicture padding in both BD-rate and decoder runtime increase
- Combination of MC and TM padding improves BD-rate in random access configuration
- Decoder runtime increase for TM padding is lower than for MC padding, combination comes with little added complexity
- Encoder runtime increase is significantly lower ($\sim 100\%$) because complexity for encoder and decoder are same but not reported due to heterogenous cluster
- Similar results for ECM is expected (MC-padding only non-orthogonal method, which is studied in the tests)
- Therefore, further study in an Exploration Experiment is proposed

Thanks for your attention!