FPGA-based Real-Time Super-Resolution System for Ultra High Definition Videos

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FCCM 2018

Ultra High Definition (UHD) Technology

UHD Television

UHD Projector

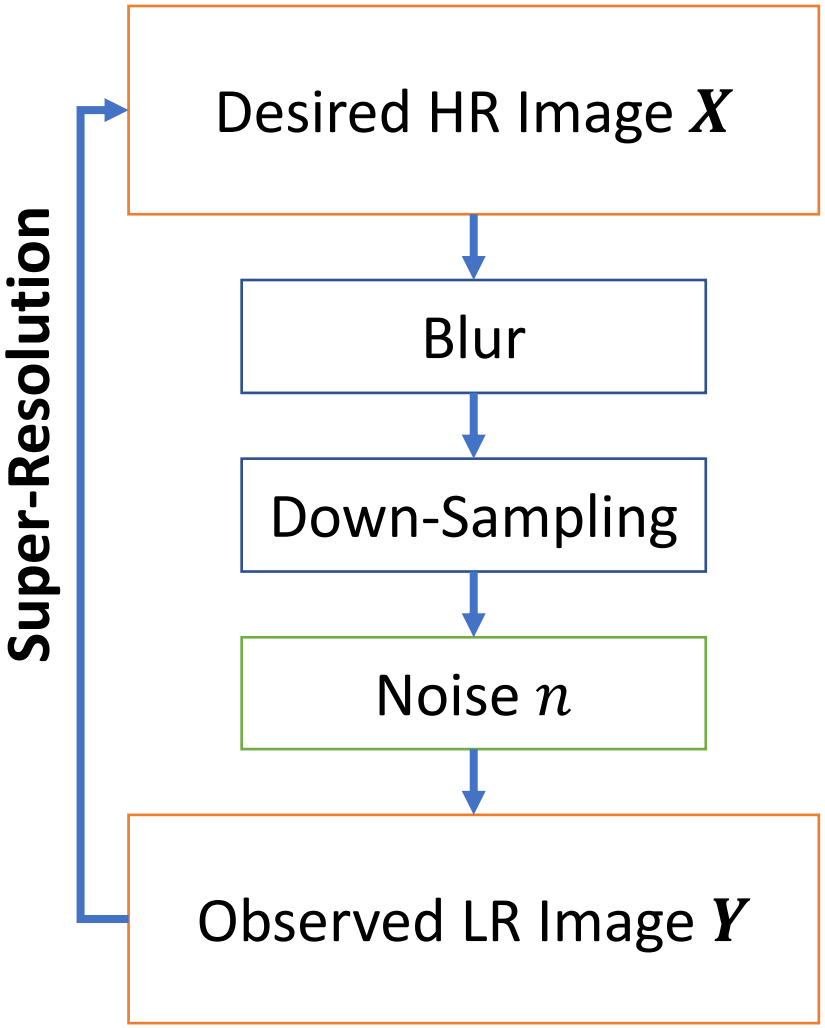
Content?

- Limited Creators
- High network bandwidth cost
- Huge storage cost

UHD Phone

UHD Camera

High-Resolution <---> Low-Resolution



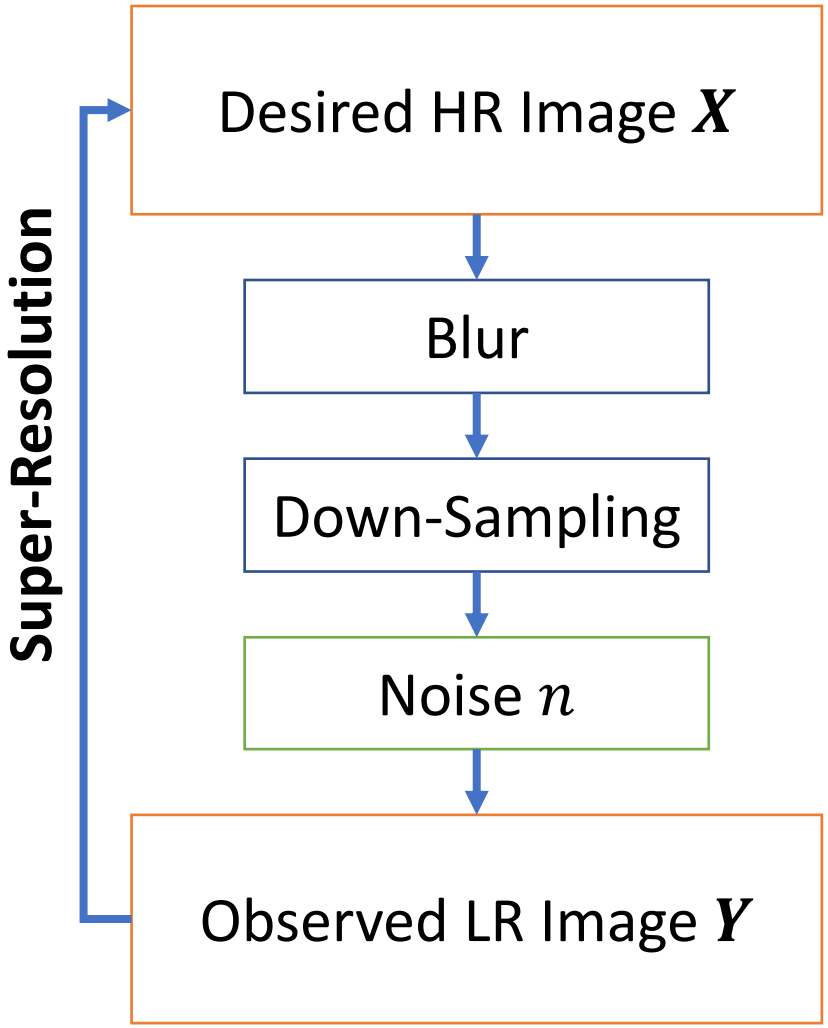
Spectrum of Super Resolution Methods

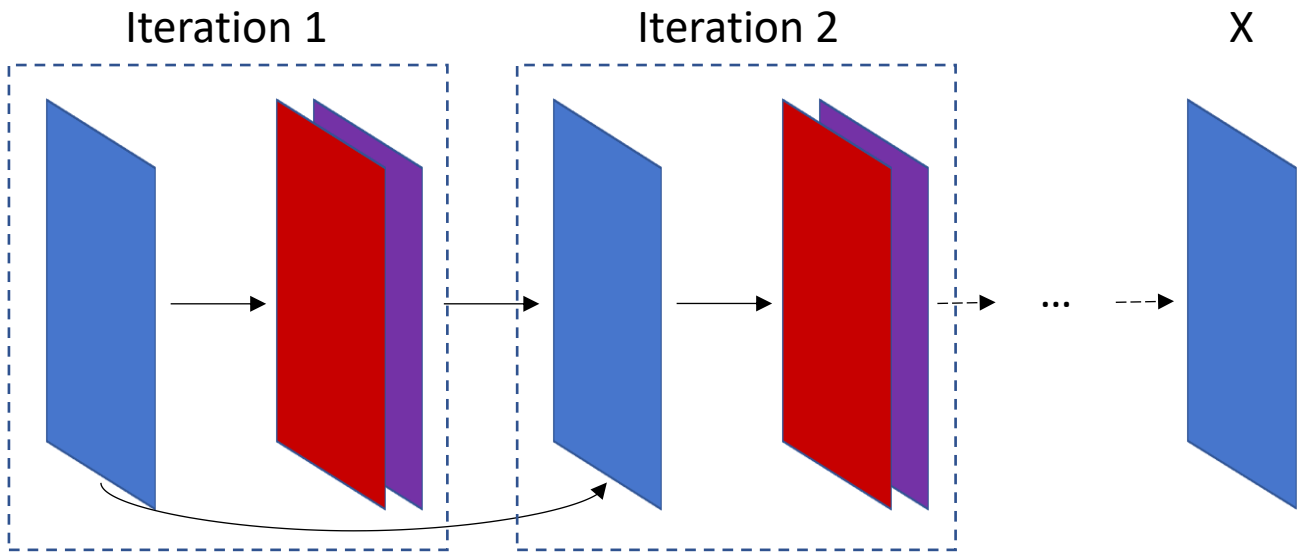
Simple

Complicated

Interpolation	Model-based	Example-based
• Fast • Easy to implement • Blurry results	• Interpretable • High complexity • Assumed known blur kernel/noise	• State-of-the-art quality • High complexity • Training data needed

Model-based Method is also Compute-Intensive

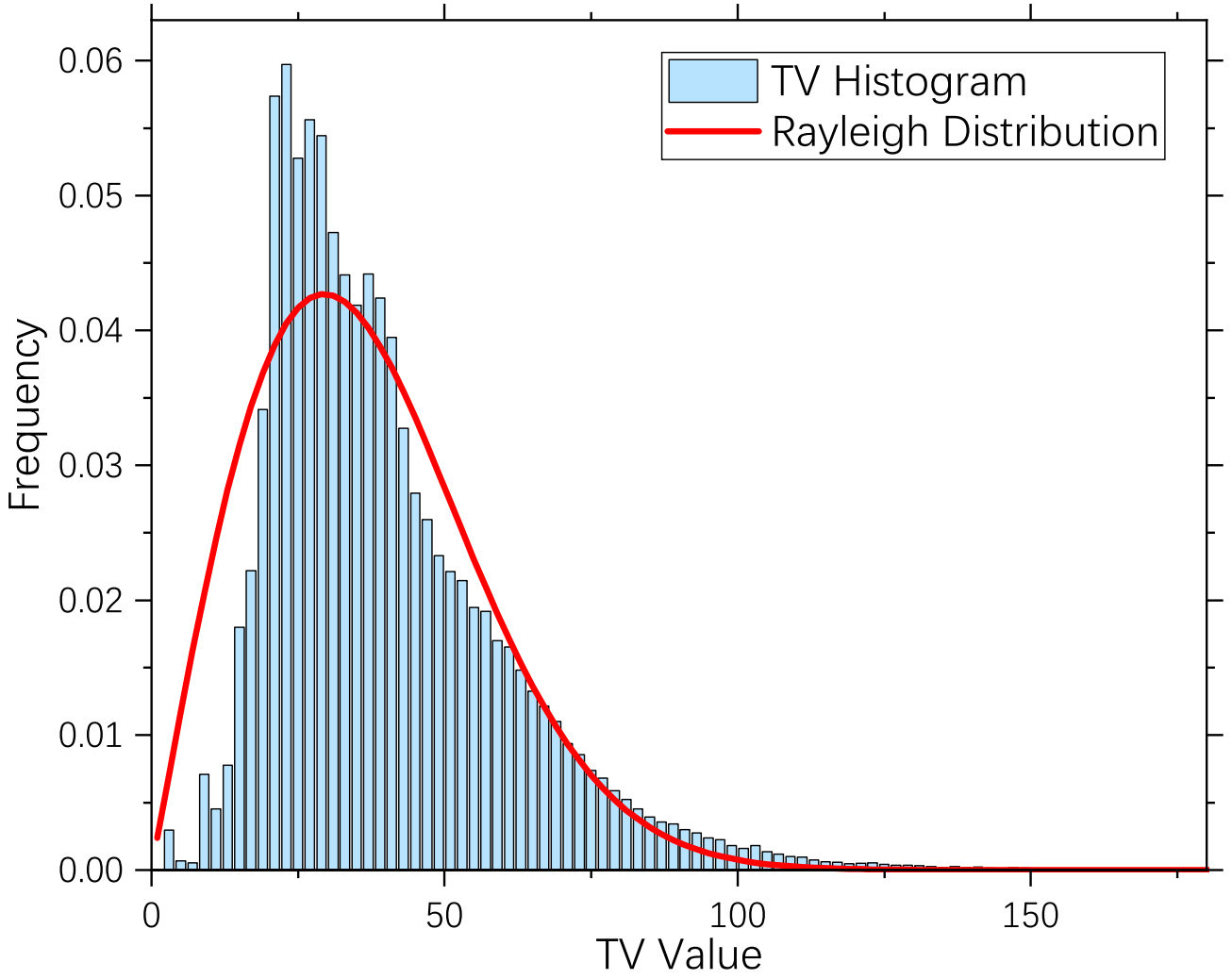




Model-based methods may not be needed

- The computation also has a layered structure
- We can use a neural network to approximate

Total Variation Distribution



Fact:

Blocks contain DIFFERENT amount of information (NOT equally important)

Insight:

Use DIFFERENT upscaling methods for different blocks

A Hybrid Algorithm

INPUT: LR Image $\boldsymbol{Y}$

1. Crop $\boldsymbol{Y}$ into sub-images $\{\boldsymbol{y}\}$

2.1. $\boldsymbol{x}$ <- Upscale($\boldsymbol{y}$) IF $\boldsymbol{M}(\boldsymbol{x}) > \boldsymbol{T}$

2.2. ELSE $\boldsymbol{x}$ <- CheapUpscale($\boldsymbol{y}$)

3. Mosaic $\boldsymbol{X}$ with $\{\boldsymbol{x}\}$

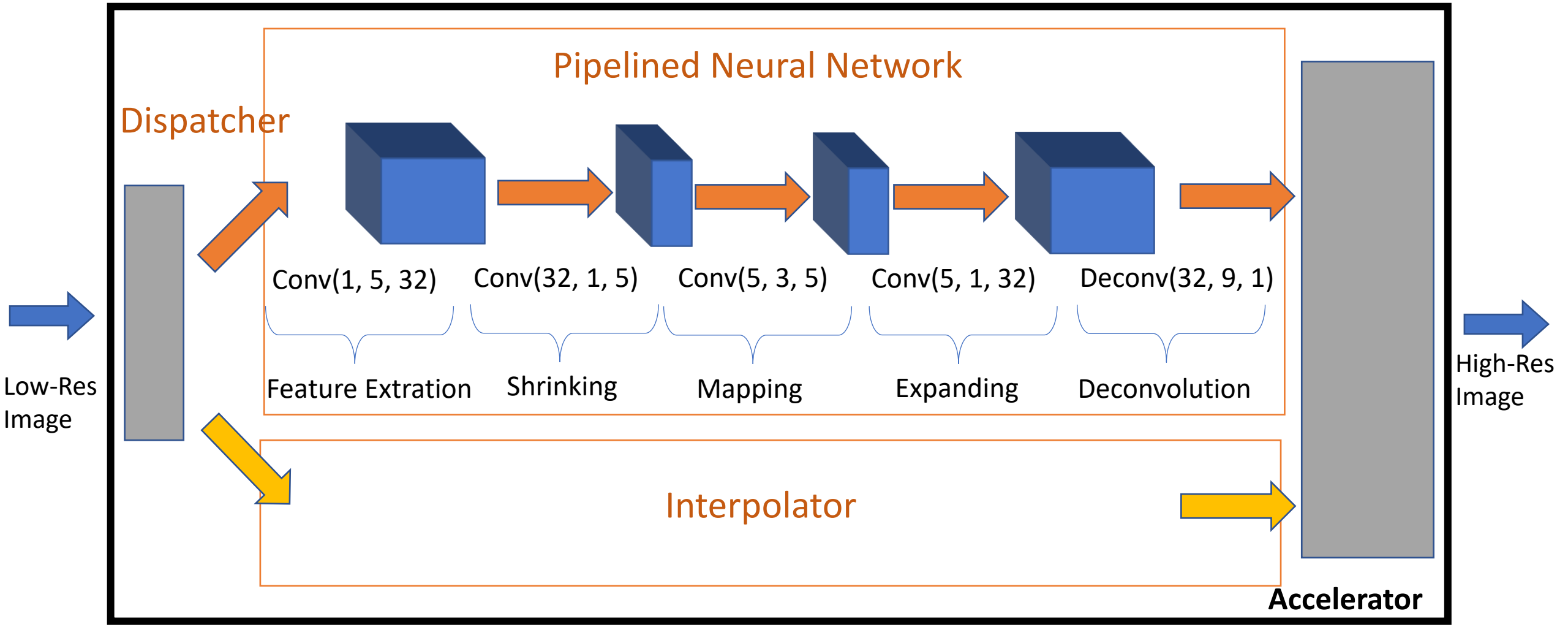
OUTPUT: HR Image $\boldsymbol{X}$

M: Total Variation (TV)

Upscale: FSRCNN-s

CheapUpscale: Intepolation

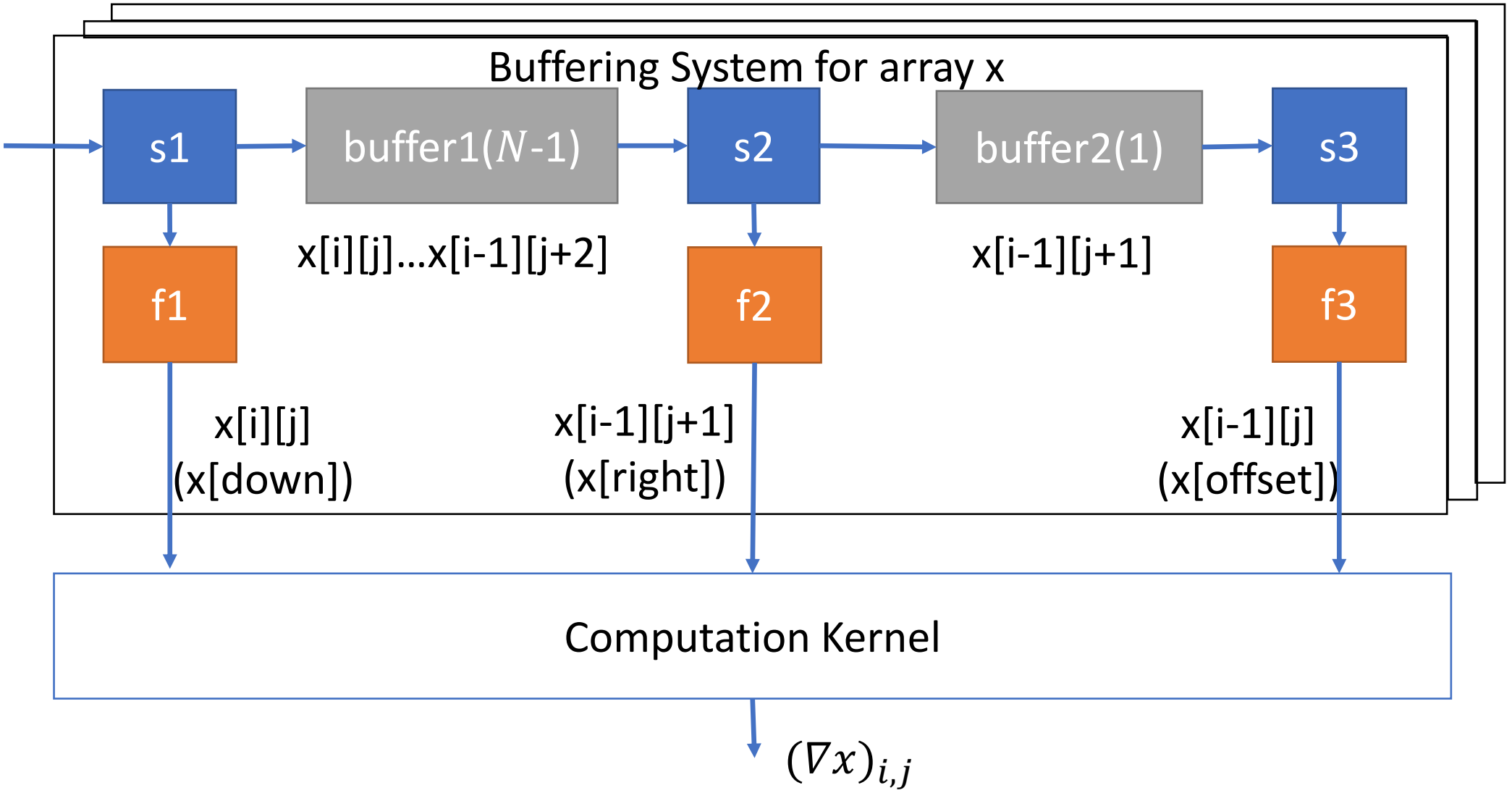
Overall System



Stencil Access of TV Computation

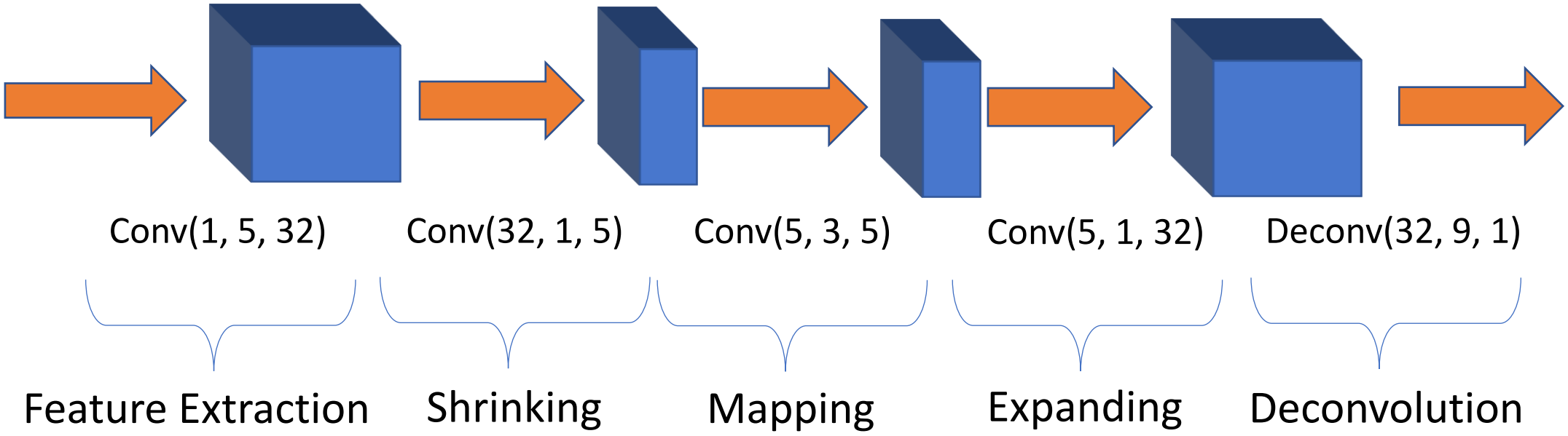
$$(\nabla x)_{\text{offset}} = abs(x[\text{right}] - x[\text{offset}]) + abs(x[\text{down}] - x[\text{offset}])$$

Micro-architecture for Stencil Computation

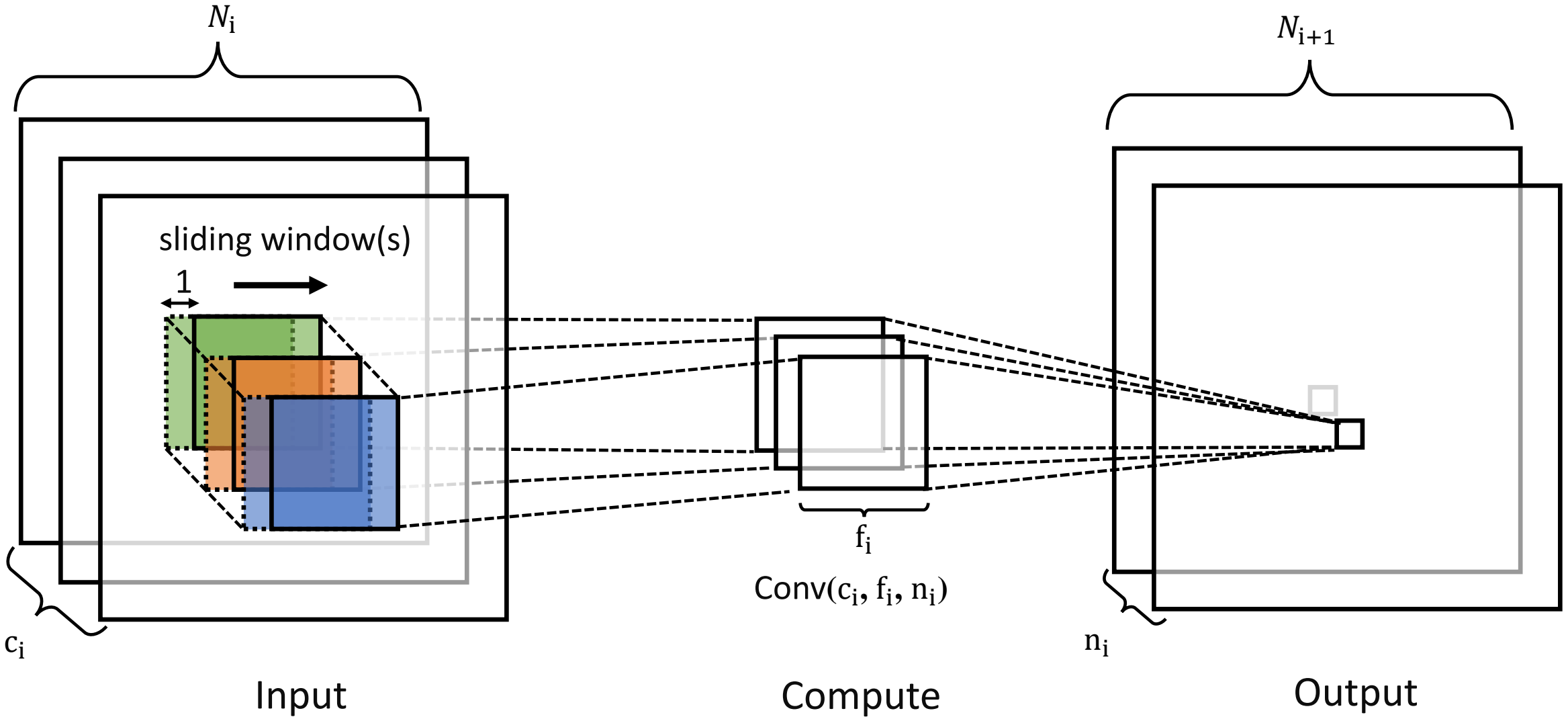


Convolutional Neural Network

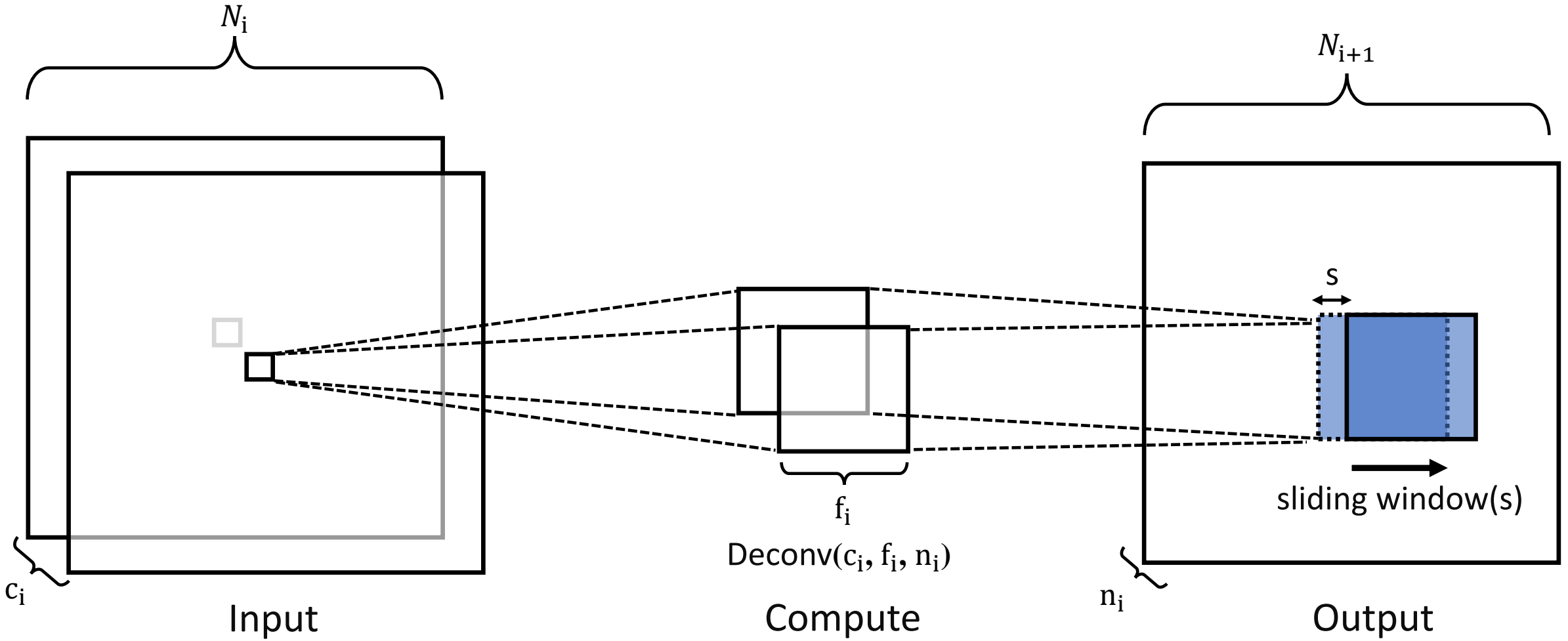
Pipelined Neural Network



Convolution



Deconvolution



Pipeline Balancing

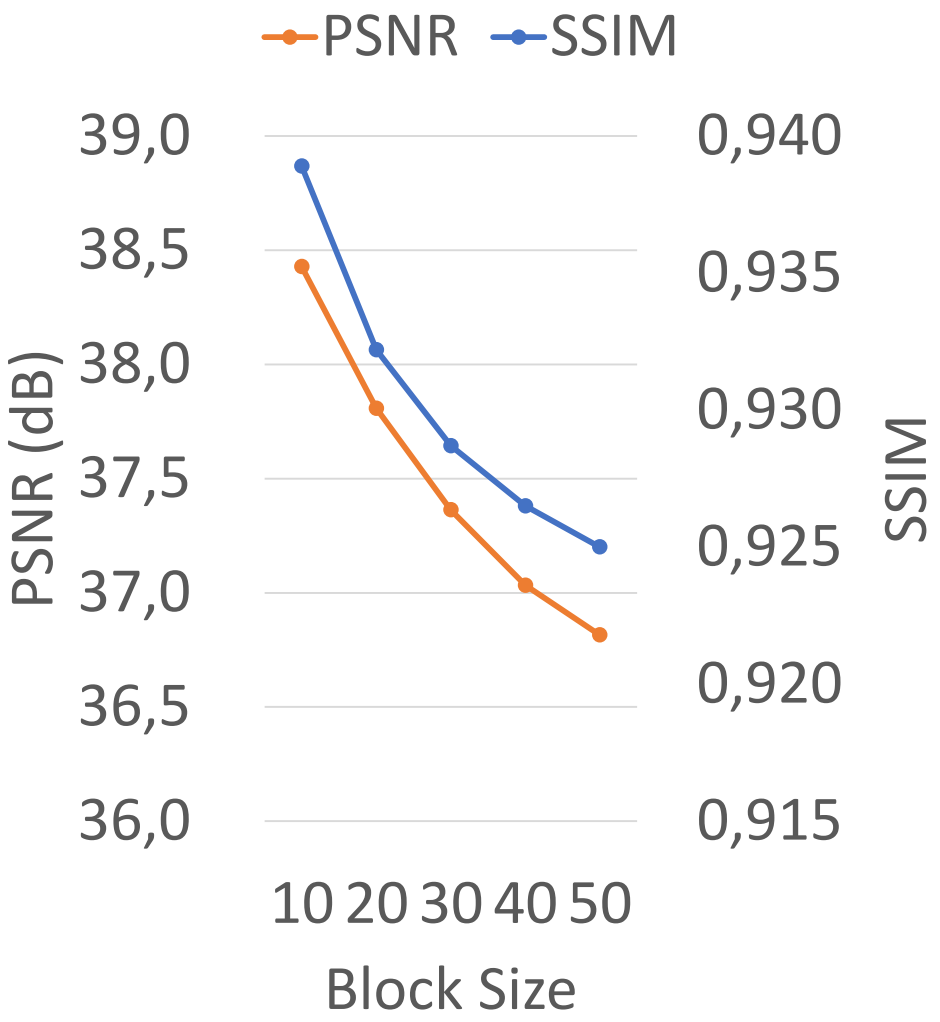
Layer	c_i	f_i	n_i	N_i	#Mult.	Ideal #DSP	Ideal II	Alloc. #DSP	Alloc. II
Extraction	1	5	32	36	819200	201	4076	200	4096
Shrinking	32	1	5	32	163840	40	4096	32	4096
Mapping	5	3	5	32	202500	50	4050	45	4500
Expanding	5	1	32	30	144000	35	4115	32	4500
Deconvolution	32	9	1	30	2332800	573	4072	519	4500
Overall	-	-	-	-	3662340	899	4115	828	4500
Available (ZC706)	-	-	-	-	-	900	-	900	-

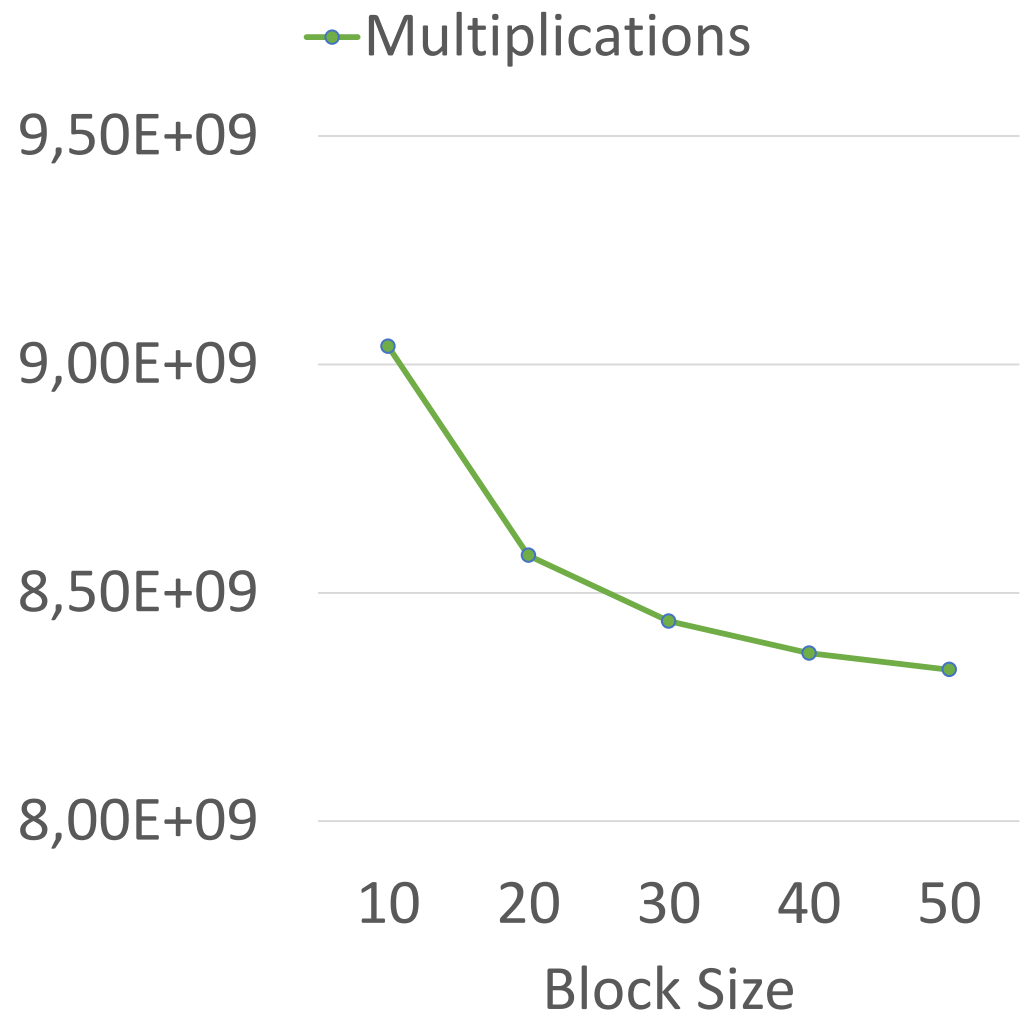
Sub-image Size

- Padding
  - $N_i \equiv k + \sum_i^{\#Conv}(f_i - 1)$

- If sub-image size too small
  - Large border-to-block ratio
  - Limited by memory bandwidth
- If sub-image size too large
  - Large feature maps
  - Limited by on-chip BRAM capacity

Sub-image Size vs. Performance vs. #mult.





Overall Comparisons

- Compared six configurations

No.	Preprocessing	Upscaling	#Mult.	PSNR(dB)	SSIM
1	None	Interpolation	6.6*10^7	35.51	0.9138
2	None	Neural Network	8.2*10^9	38.55	0.9421
3	Blocking	Interpolation	6.6*10^7	35.51	0.9138
4	Blocking	Neural Network	8.4*10^9	38.55	0.9420
5	Blocking	Mixed-Random	2.2*10^9	36.10	0.9211
6	Blocking	Mixed-TV	2.2*10^9	37.36	0.9287

>100x

+3.04dB

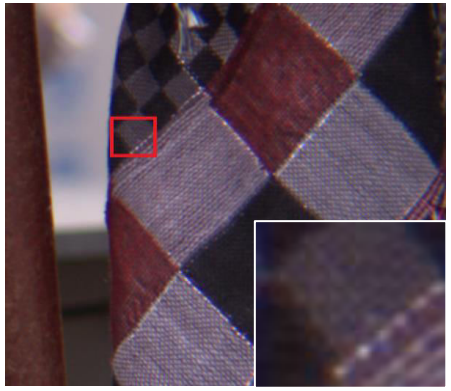
No Performance Loss

+1.26dB

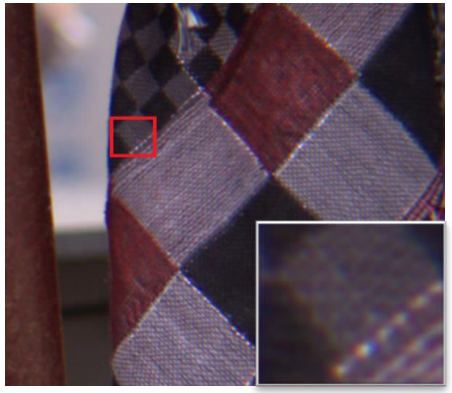
-75%

-1.19dB

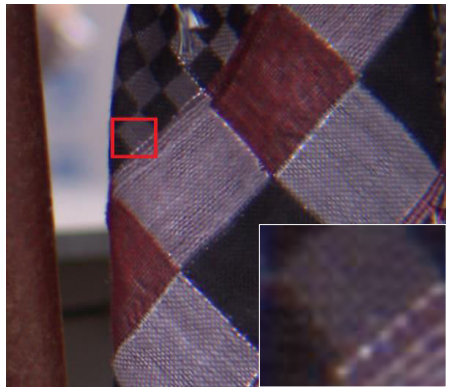
Example Outputs



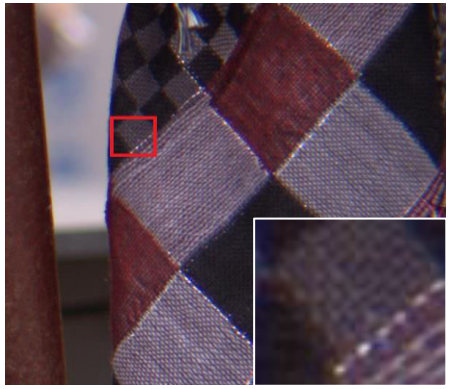
Configuration 1
None/Interpolation



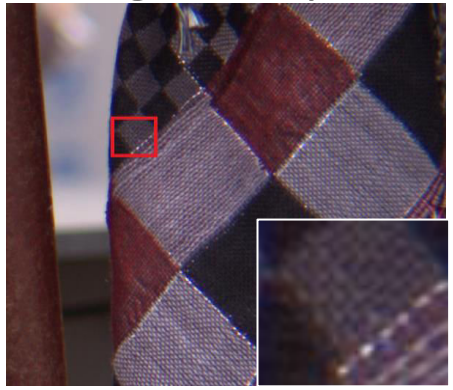
Configuration 3
Blocking/Interpolation



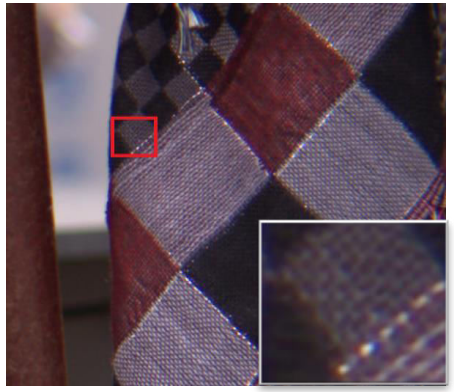
Configuration 5
Blocking/Mixed-Random



Configuration 2
None/Neural Network



Configuration 4
Blocking/Neural Network



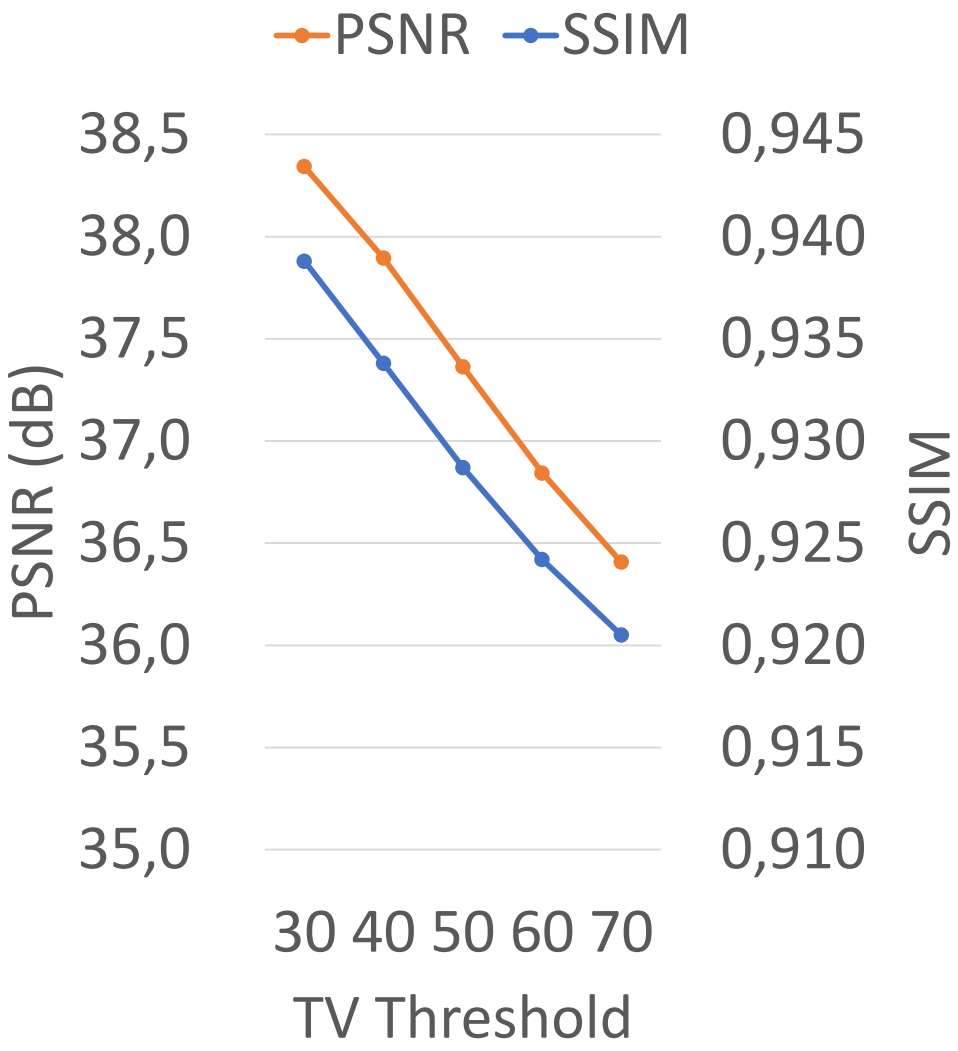
Configuration 6
Blocking/Mixed-TV

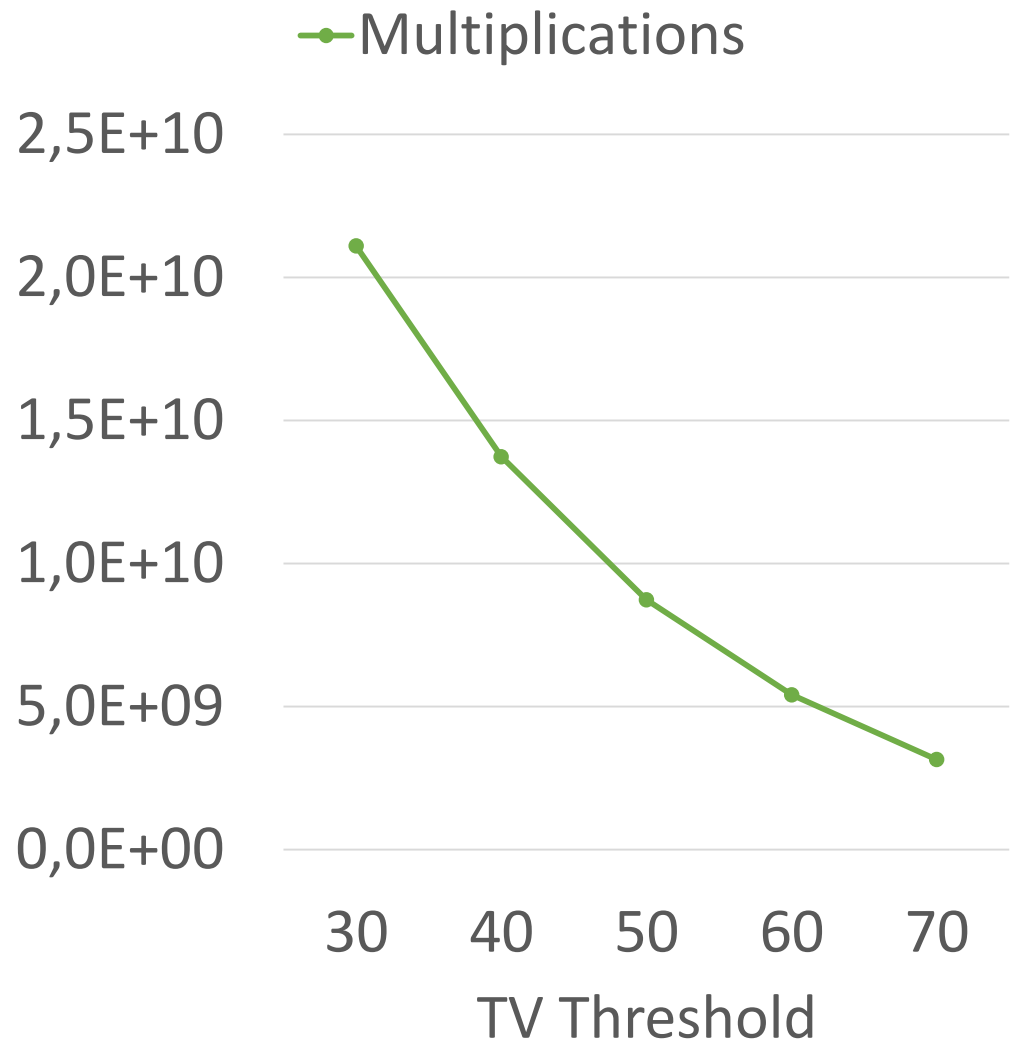
Summary Flow

- Crop each frame into blocks
  - Suitable for low-level (pixel-level) tasks
  - GOOD: on-chip buffer friendly
  - BAD: Computation overheads
- Dispatch blocks according to TV value
  - Micro-architecture for buffering system
- Fully-pipelined CNN for upscaling
  - Sliding window for convolution/deconvolulution
  - Pipeline balancing
- Performance
  - Full-HD (1920x1080) -> Ultra-HD (3940x2160): 31.7fps

Thank you!

TV Threshold vs. Performance vs. #mult.





Resource Utilizations

Component	BRAM	DSP	FF	LUT
Dispatcher	1	2	618	1138
Neural Network	178	844	63149	98439
Interpolator	0	10	1414	3076
Total	327	858	66261	103714
Available	1090	900	437200	218600
Utilization (%)	**30**	**95**	**15**	**47**