embedded VISION SUMMIT

Implementing Real-Time Hyperspectral Imaging

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NATIONAL INSTRUMENTS™

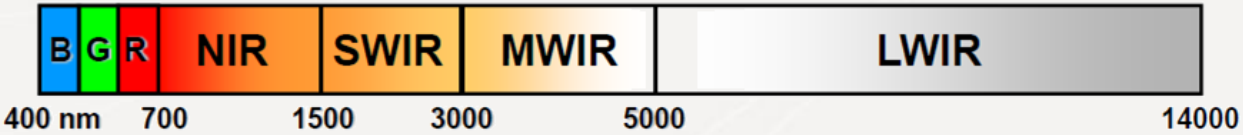
National Instruments

- Provider of integrated hardware and software tools to accelerate productivity, innovation, and discovery.
- $1.14 billion in revenue in 2012
- 6,850 employees in 40+ countries
- No industry > 15% of revenue
- More than 35,000 companies served annually
- Over 16 years of vision and motion experience

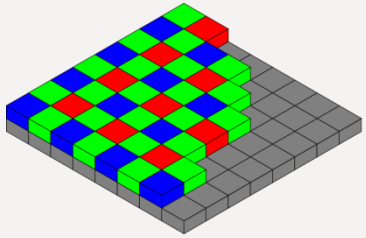
Agenda

- Hyperspectral imaging and applications
- Challenges encountered with real-time implementation
- Techniques used to solve challenges
- Key lessons learned

What is Hyperspectral Imaging?

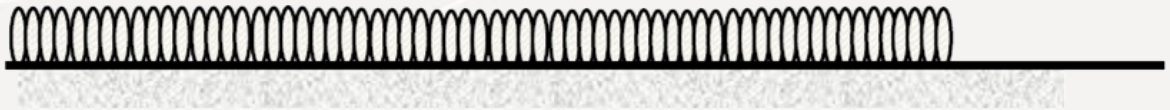


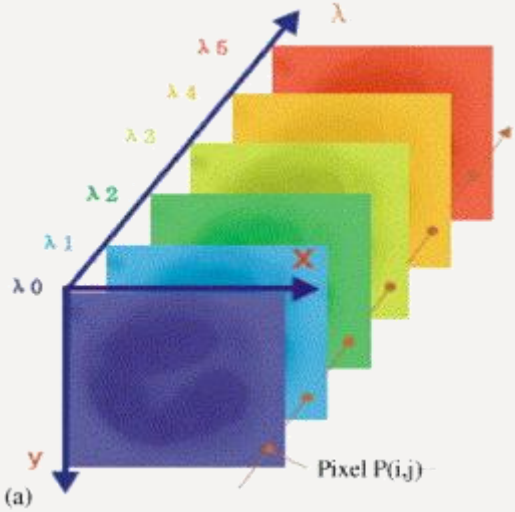
LOW **Panchromatic**: one very wide band



MED **Multispectral**: several to tens of bands

HIGH **Hyperspectral**: hundreds of narrow bands





Early Bruise Detection of Apples

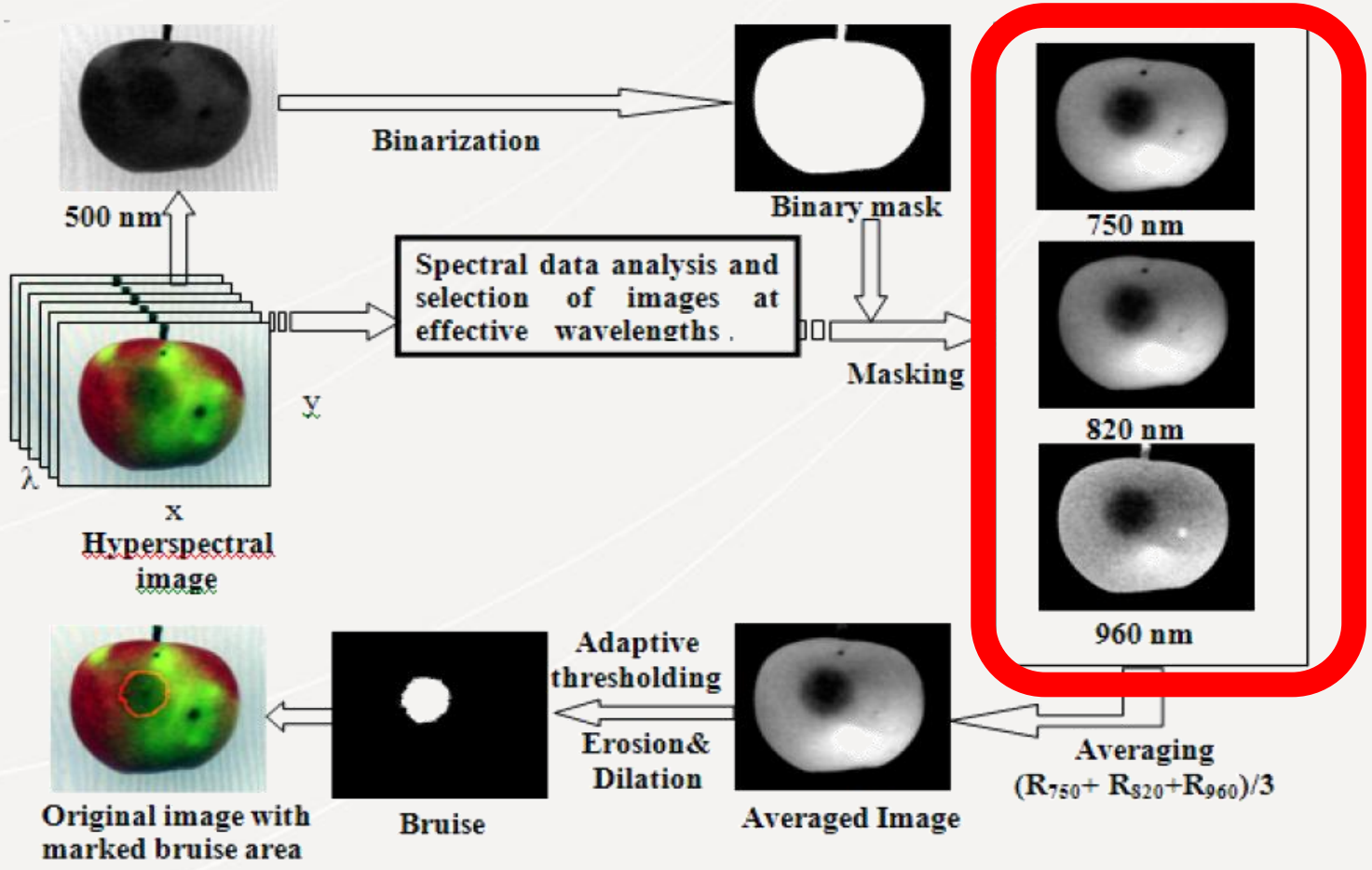
- The impact bruise may not be visible immediately when the impact applies.
  - The symptom appears after a certain period of time.

- Early detection of such an impact bruise is needed in order to improve the product quality.

Image at 750nm
(Near Infrared Spectrum)

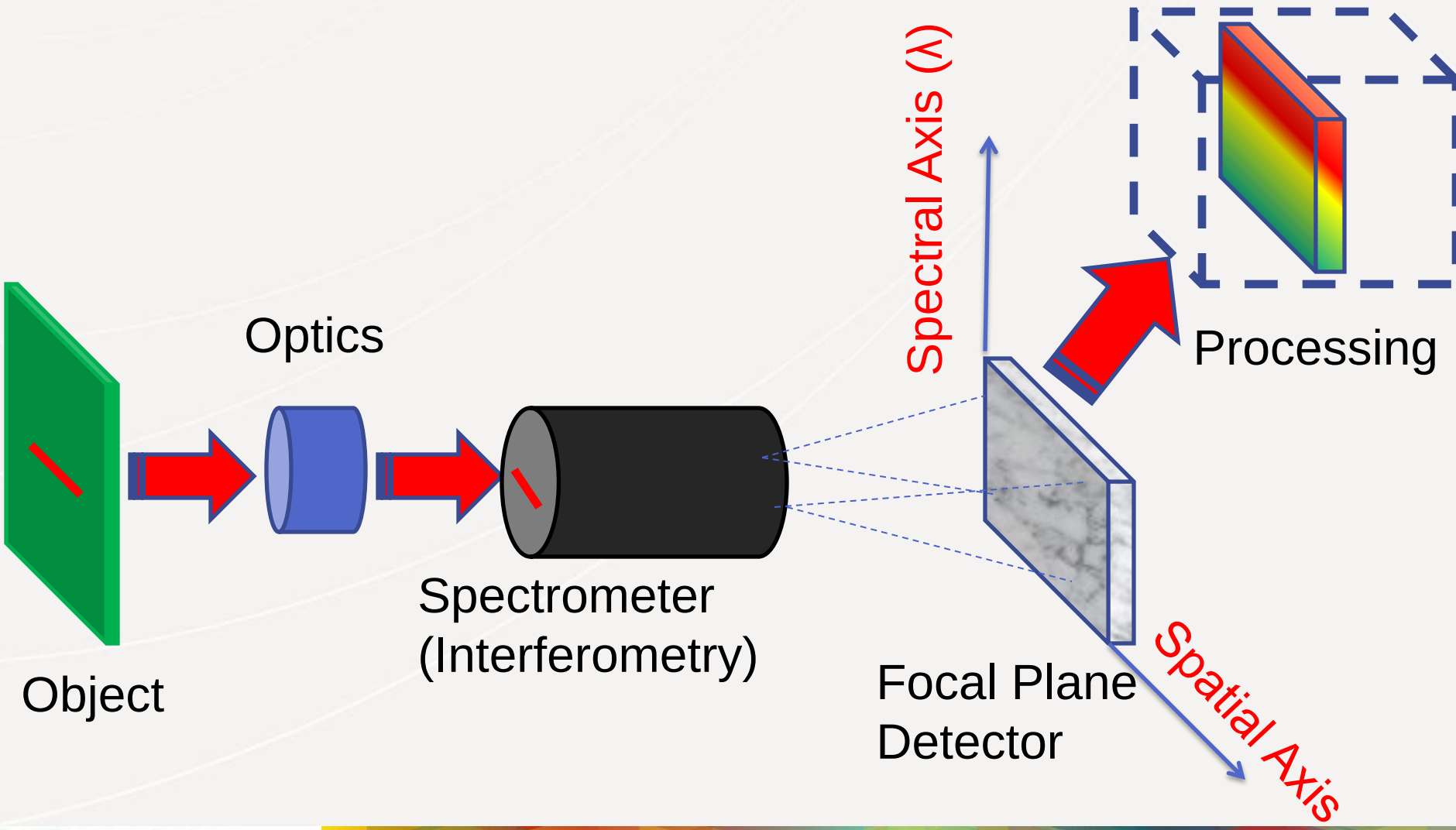
RGB Image
(Visible Spectrum)

Bruise Detection of Fruits

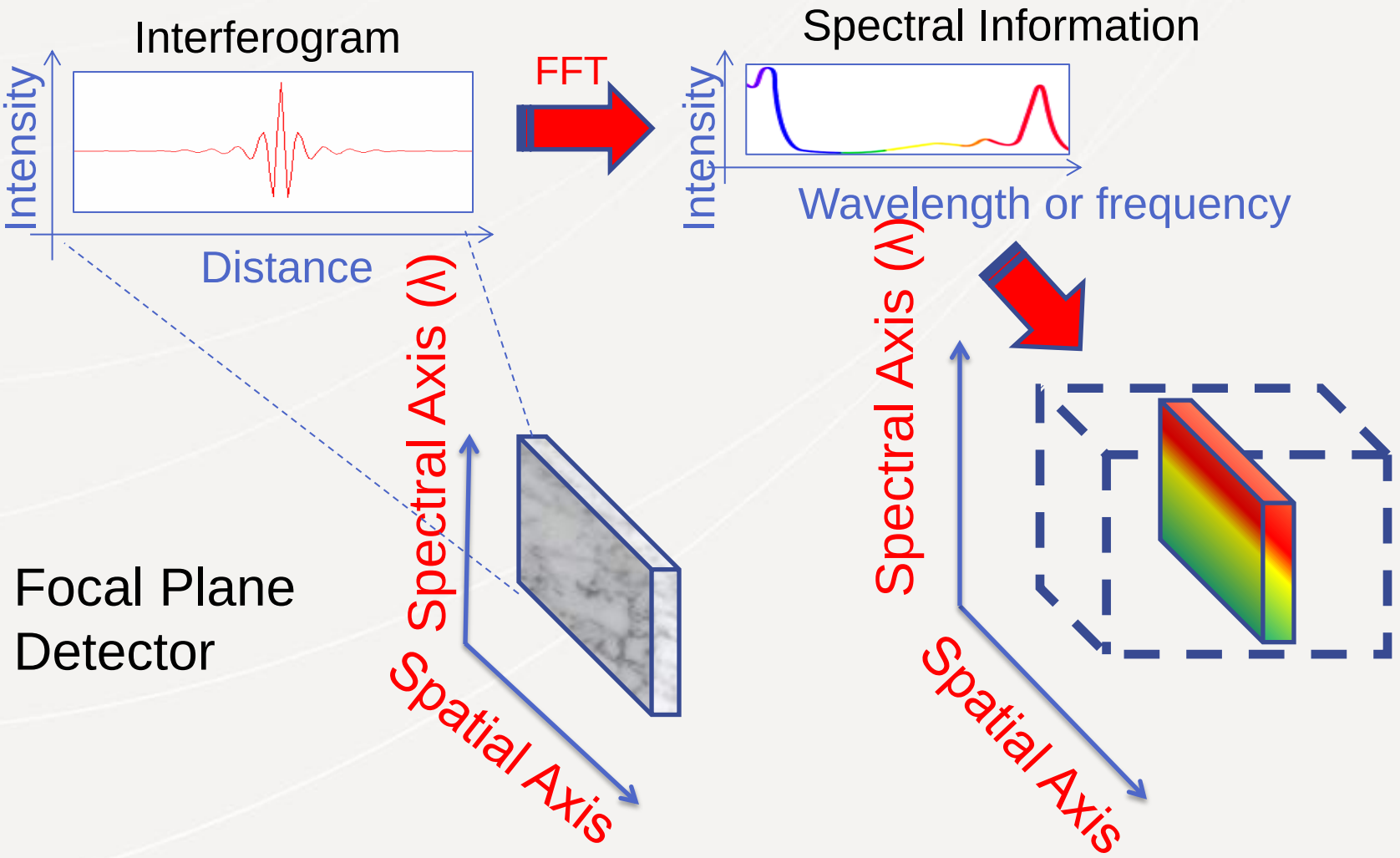


Source: Hyperspectral Images Application

Internals of Hyperspectral Imaging



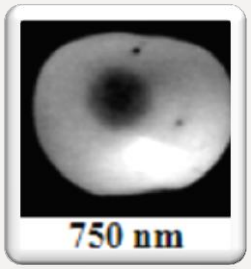
Internals of Hyperspectral Imaging



Hyperspectral Imaging on Manufacturing Line

Camera

Image at specific λ



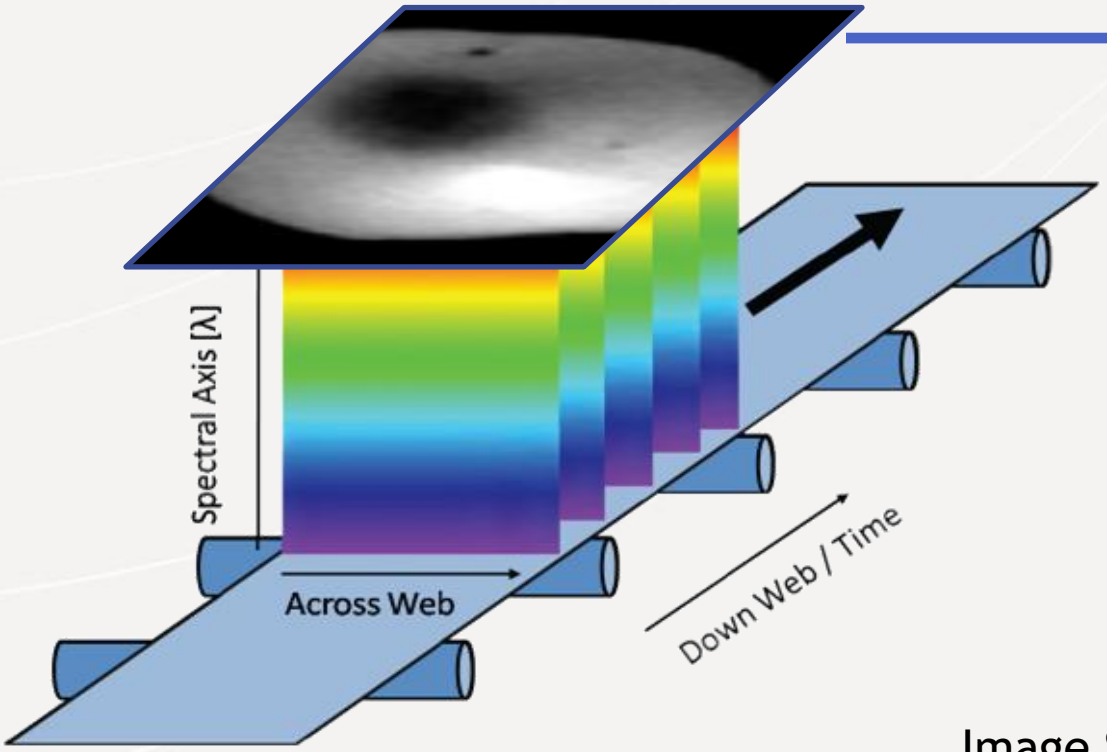
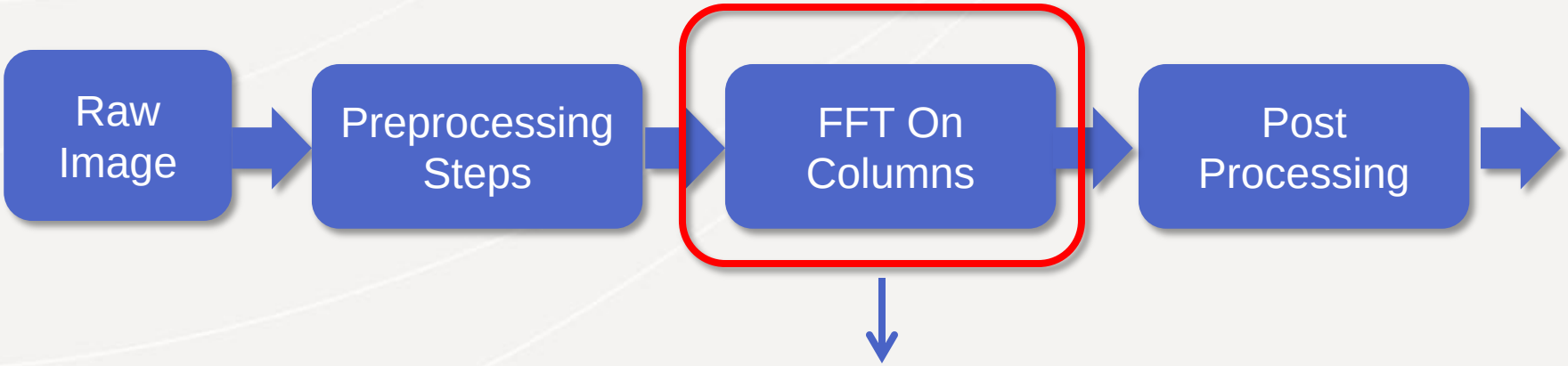


Image Source: HSI Middleton

Hyperspectral Image Processing

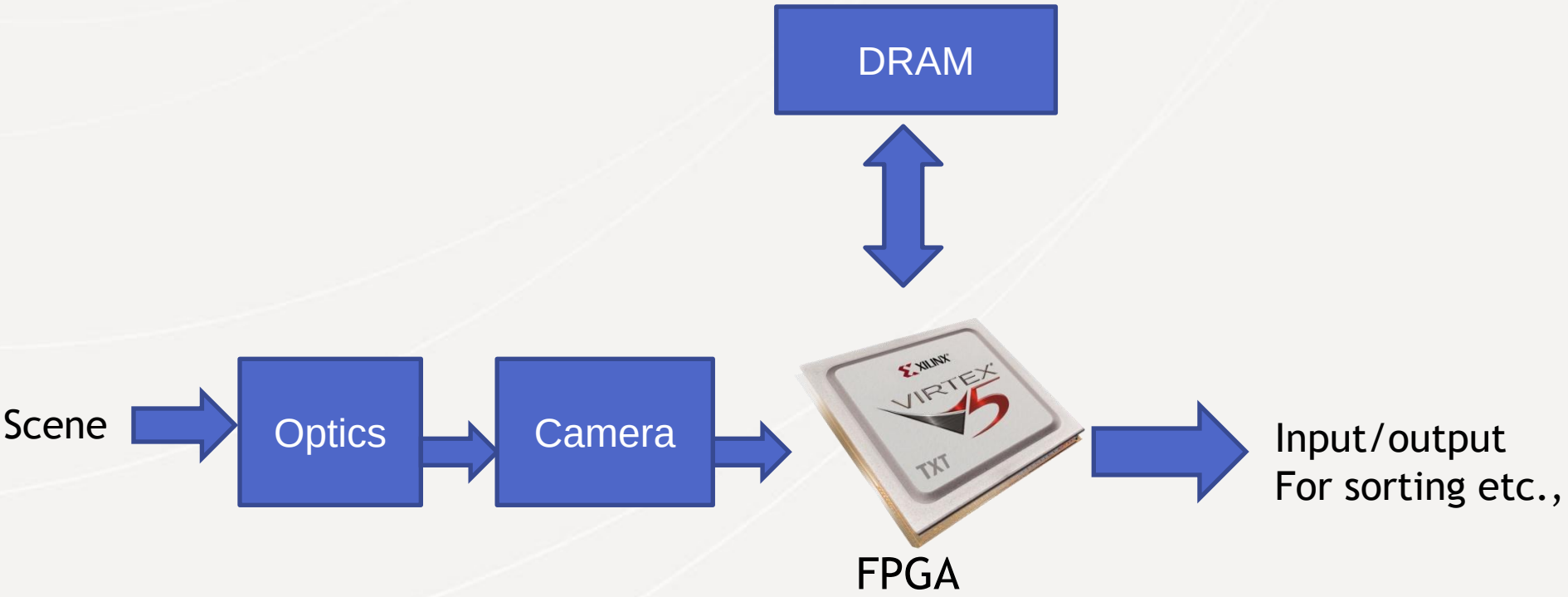
System Requirements

Image Size = **1,000x800 Pixels (Each Pixel = 14-bit)**
Frame Rate = **300 Frames/sec**
Data Throughput ~ **600 MB/s**



Due to Fourier Transform-based Spectrometer

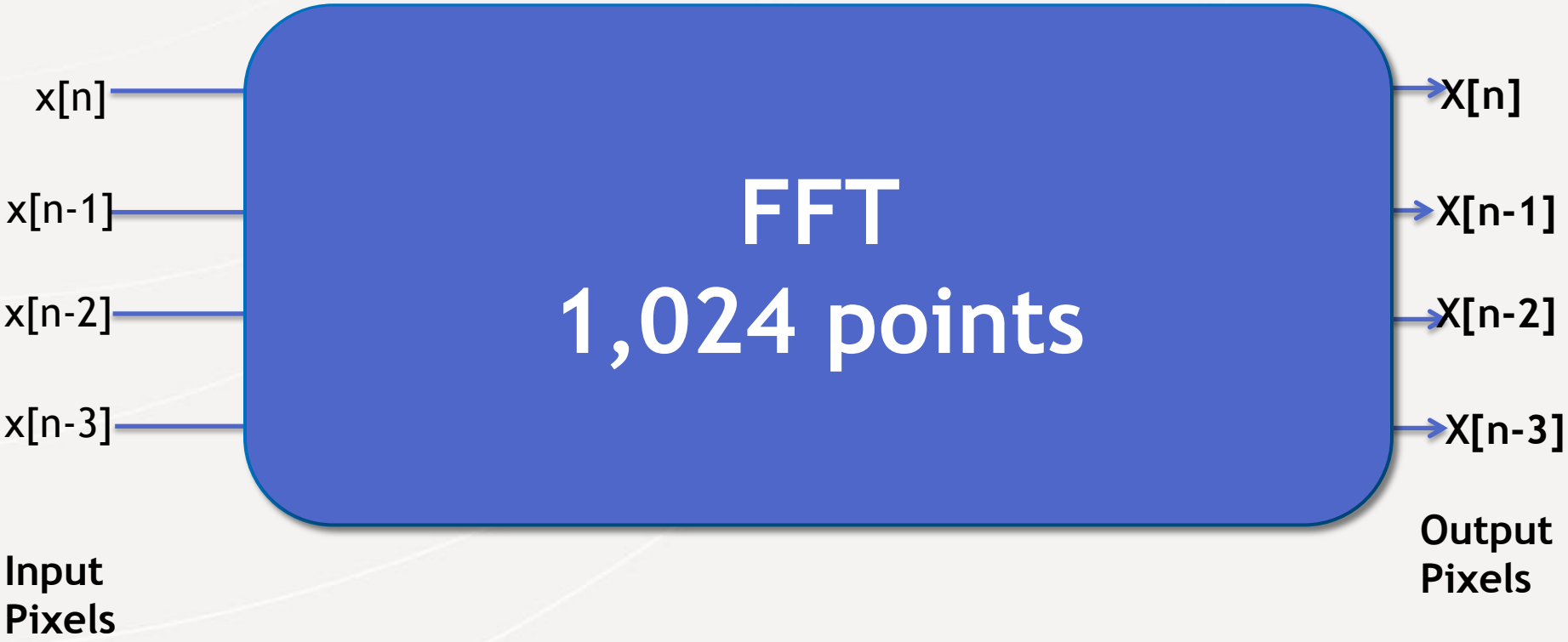
Application System Diagram



Row-Wise FFT @ 300 Frames/sec

Camera configuration used: 4 pixels at 75 MHz from camera

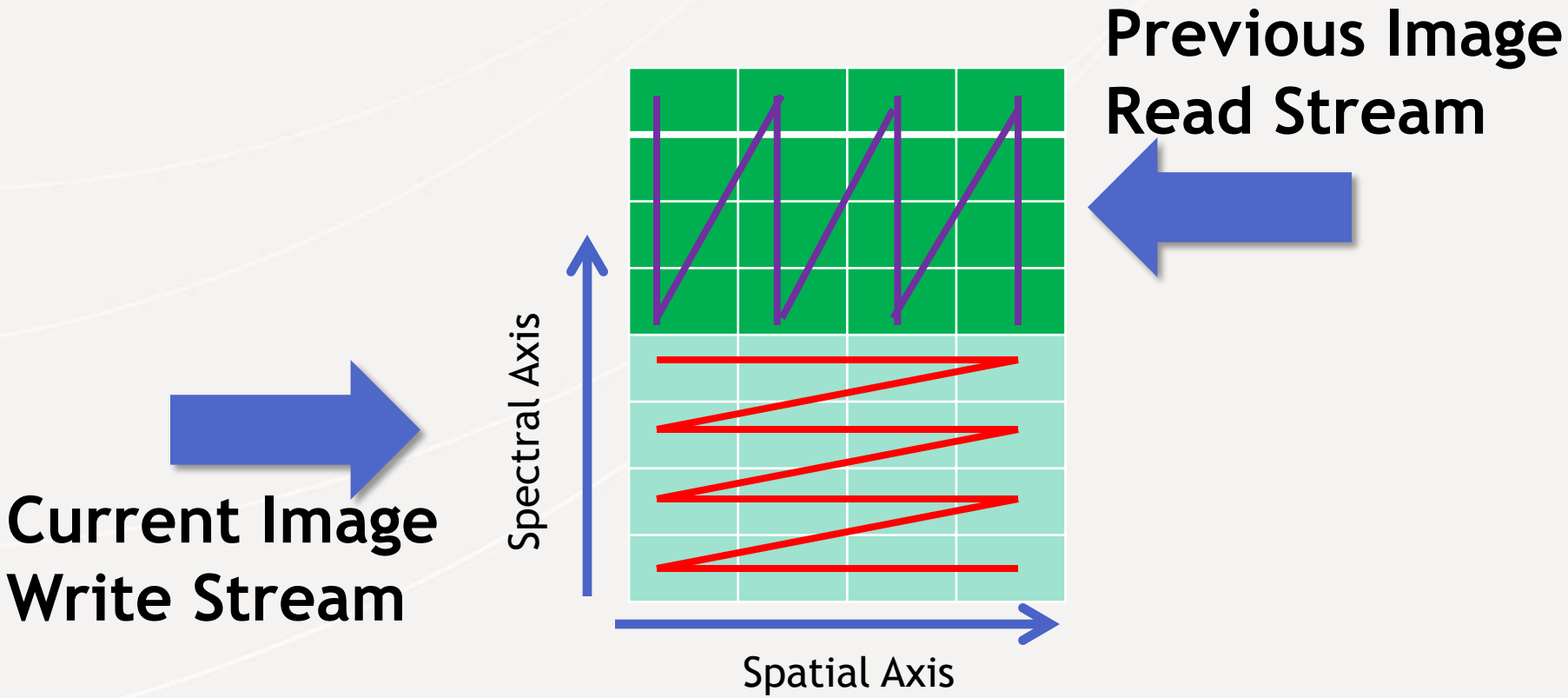
Row-Wise FFT with 4 Pixels at 75MHz



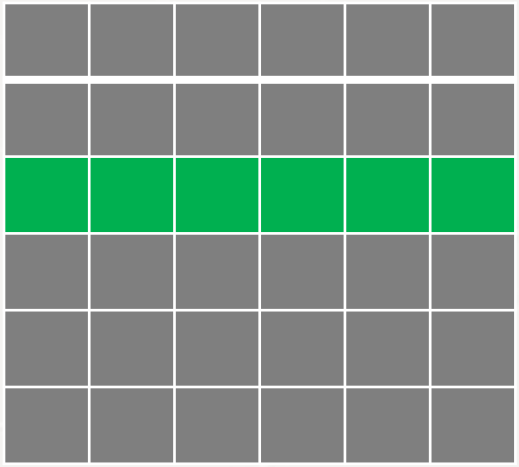
FPGA Parallel Processing for High Speeds

Streaming Image (Matrix) into Memory

- Double buffering
- Processing in parallel with image acquisition
- DRAM read and write share time slots



Accessing elements of Column from External DRAM



1.6 GB/s

Accesses pixels along rows sequentially

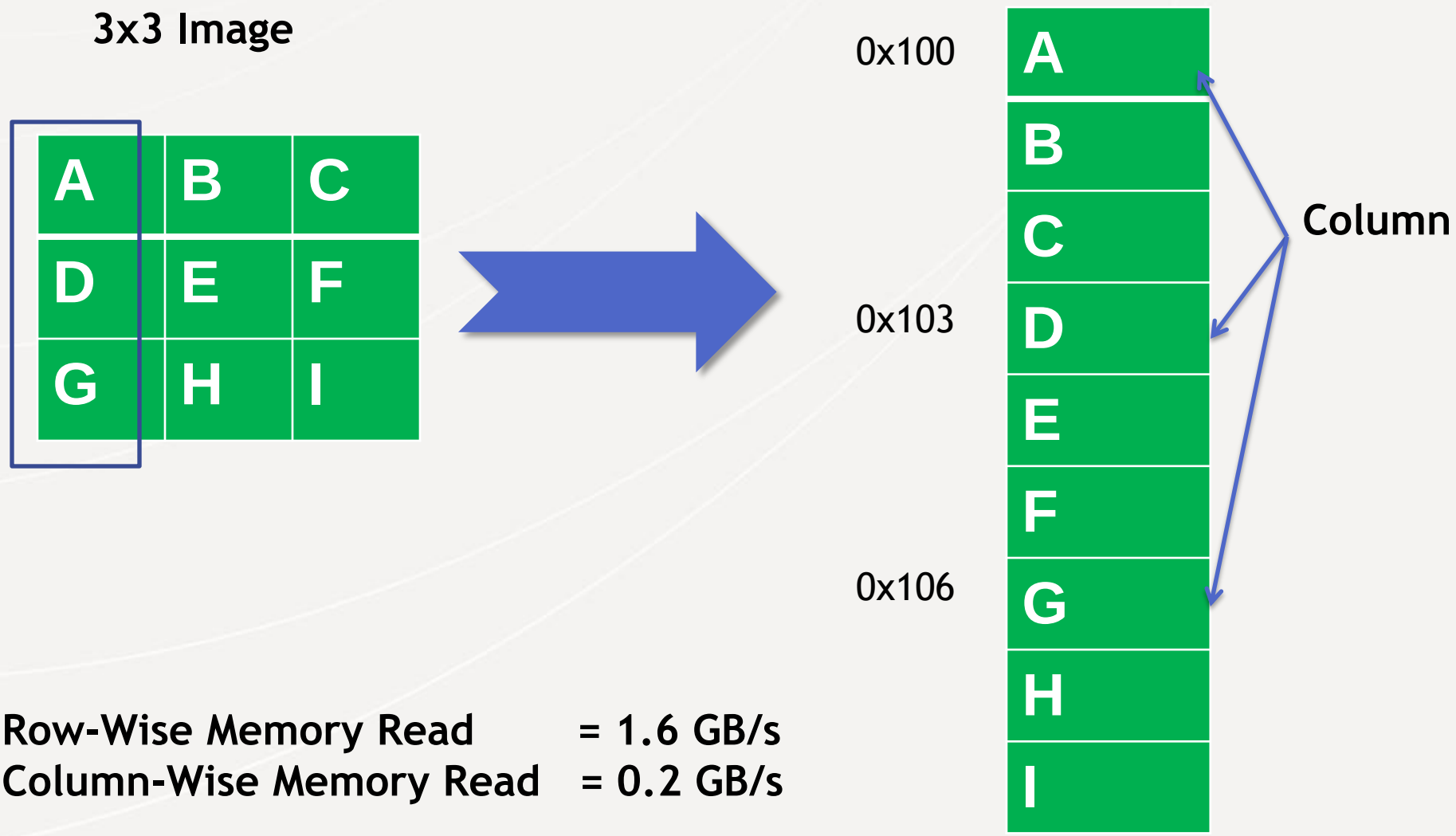
FPGA --- DRAM (from camera)

0.2 GB/s

Accesses pixels along column sequentially

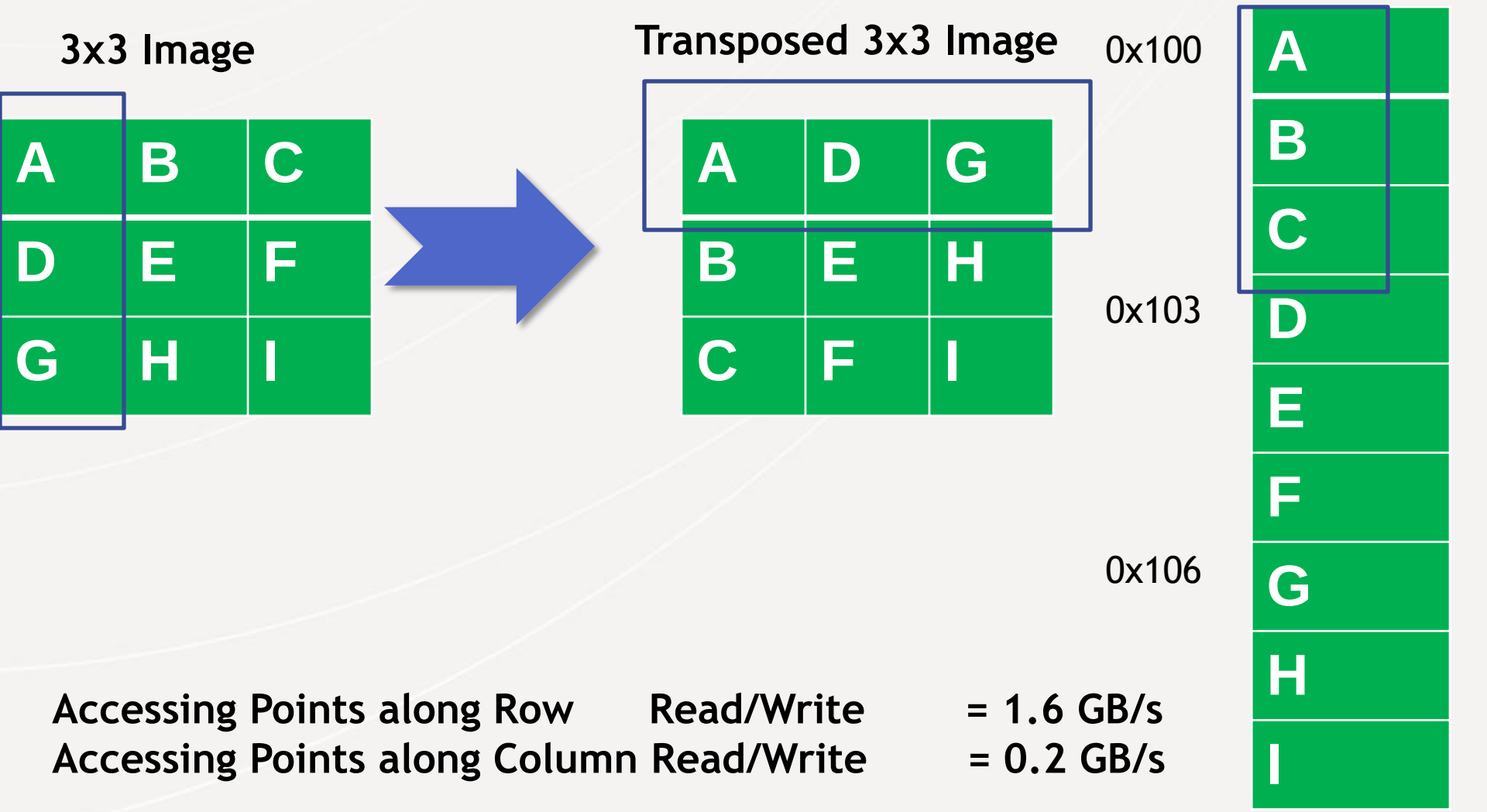
DRAM --- FPGA (for FFT)

Challenges with accessing data in Columns of Image



Row-Wise Memory Read = 1.6 GB/s
Column-Wise Memory Read = 0.2 GB/s

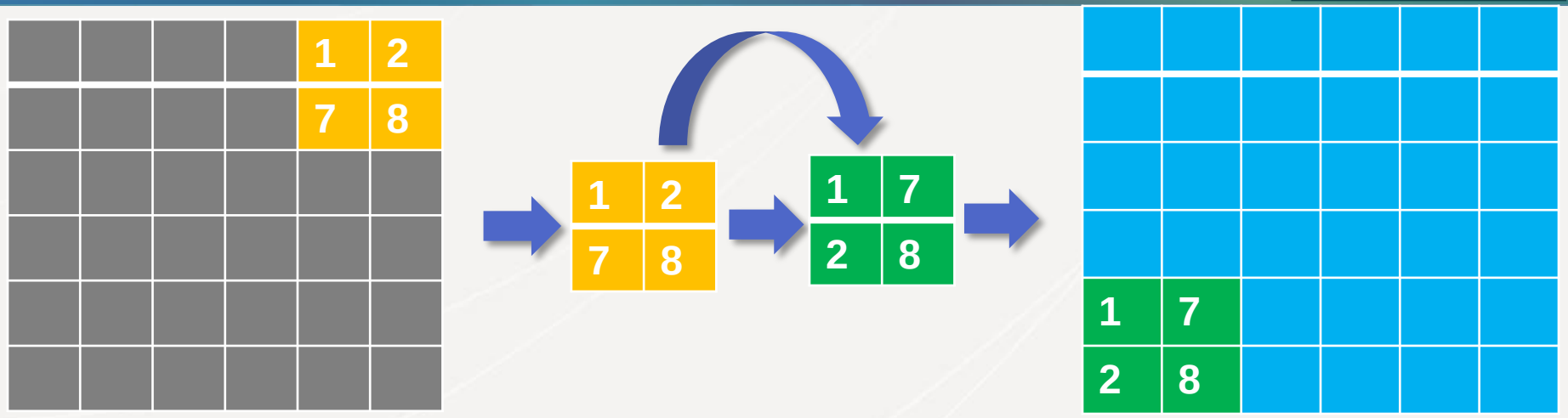
Transpose



Accessing Points along Row Read/Write = 1.6 GB/s
Accessing Points along Column Read/Write = 0.2 GB/s

Efficient Memory Access Techniques

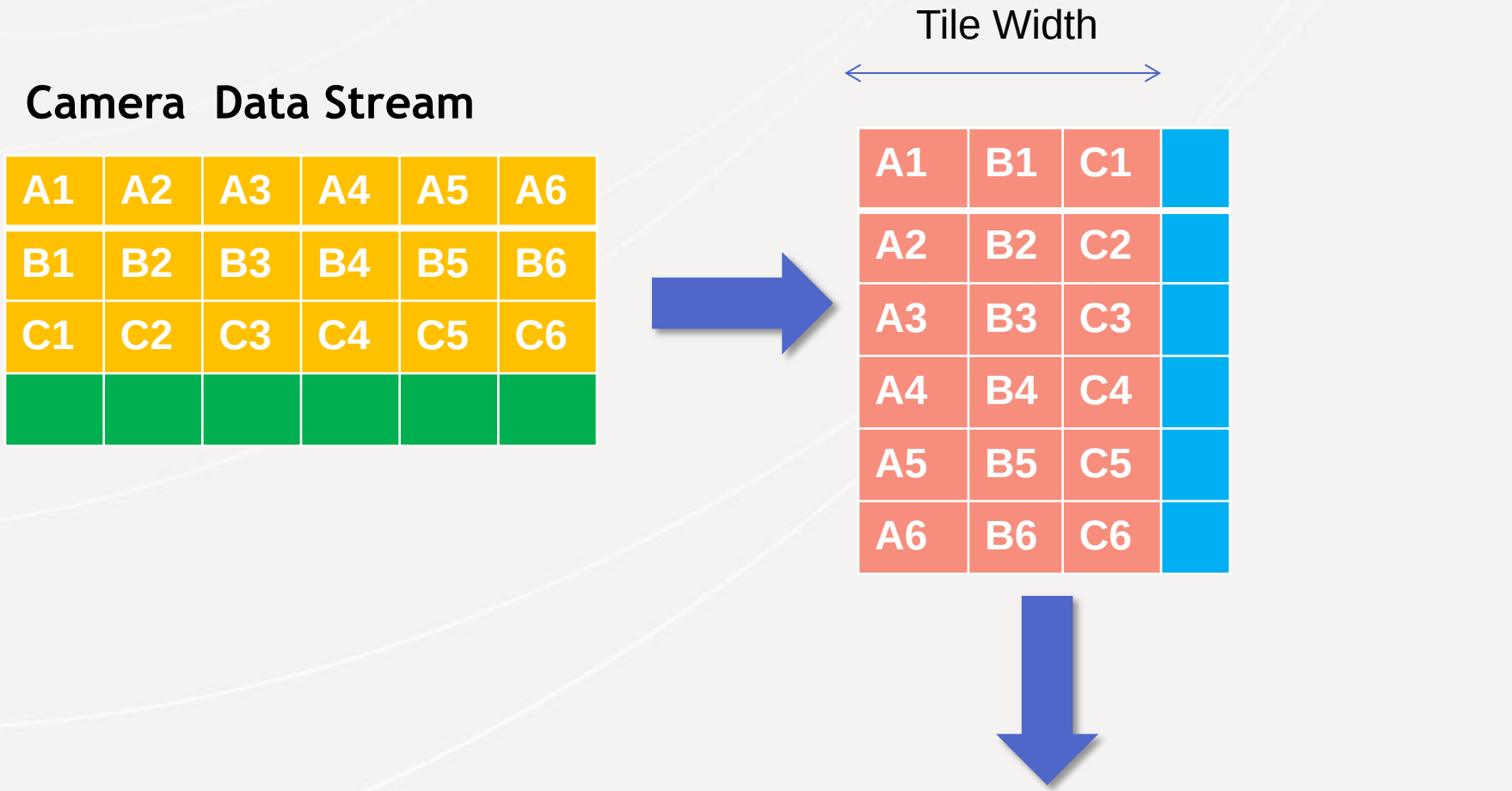
Matrix Transpose Tiled Approach



Column Read	Tile Size (Pixels)	Benchmark (MB/s)
Straight Forward	Column	115
Tiled	**16x16**	**179**
Tiled	**64x64**	**408**
Tiled	**128x128**	**532**
Tiled	**256x256**	**604**

*Benchmarks are done with write time share of 50%

FPGA Streaming Architecture



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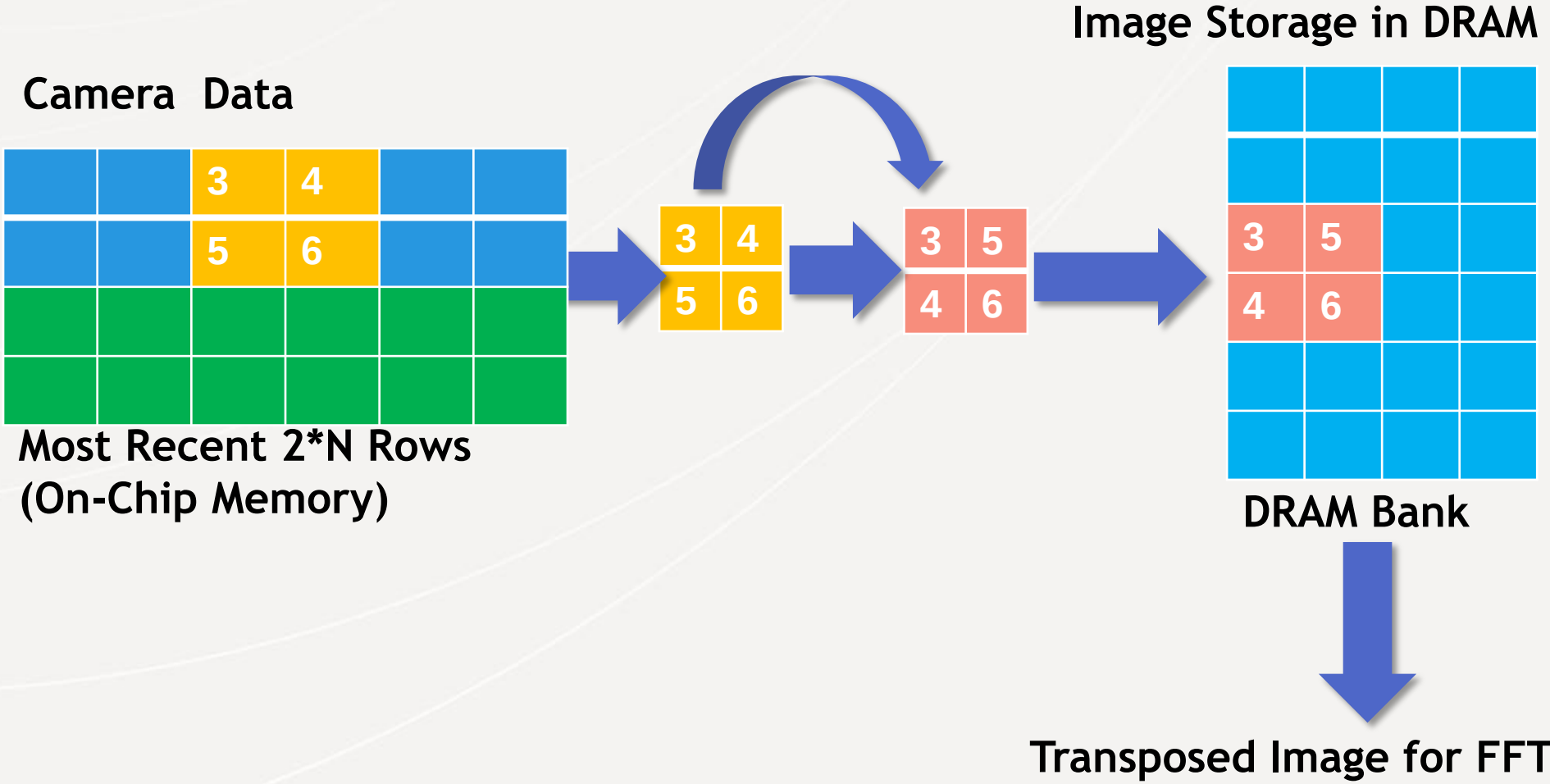

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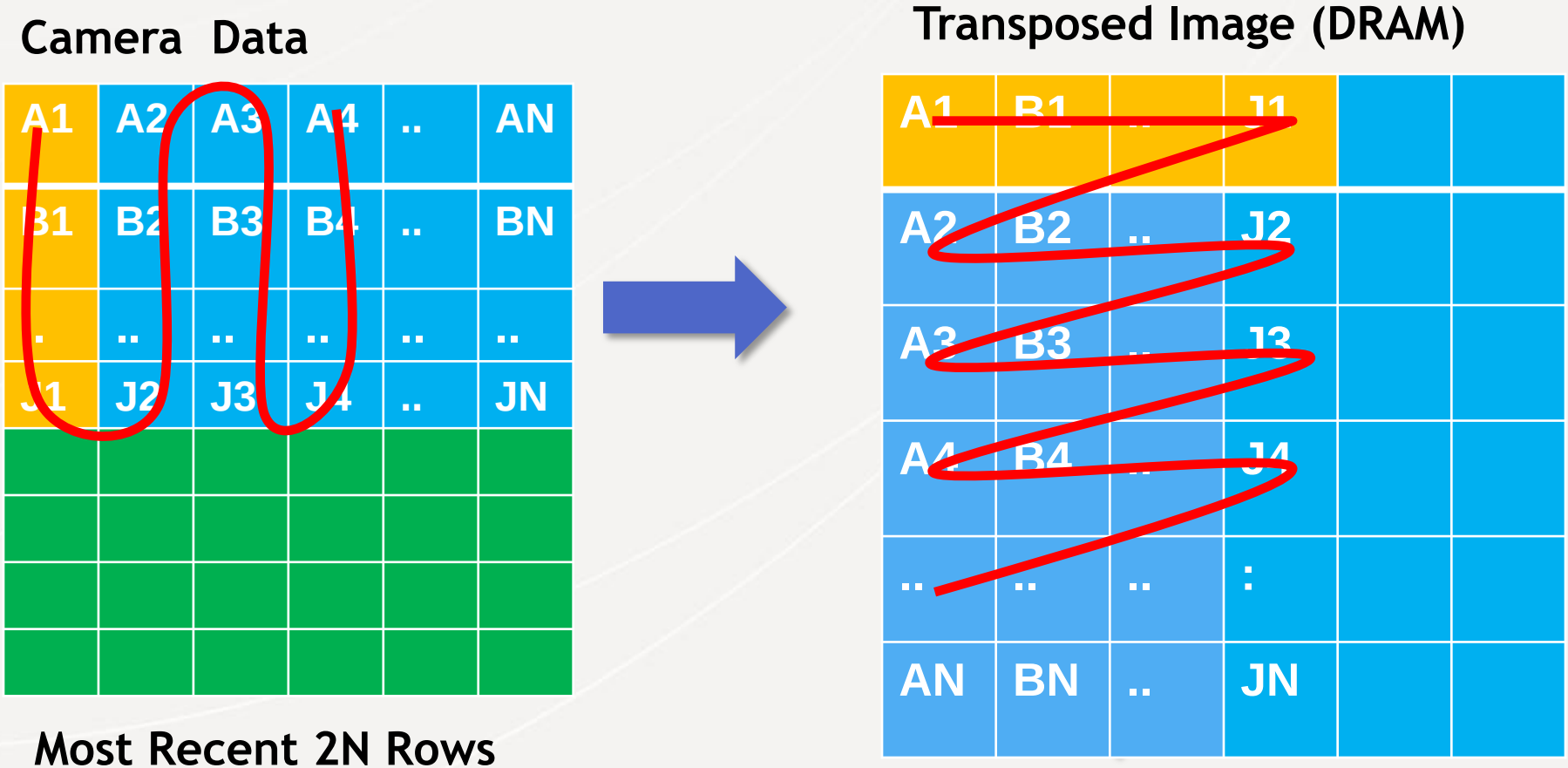

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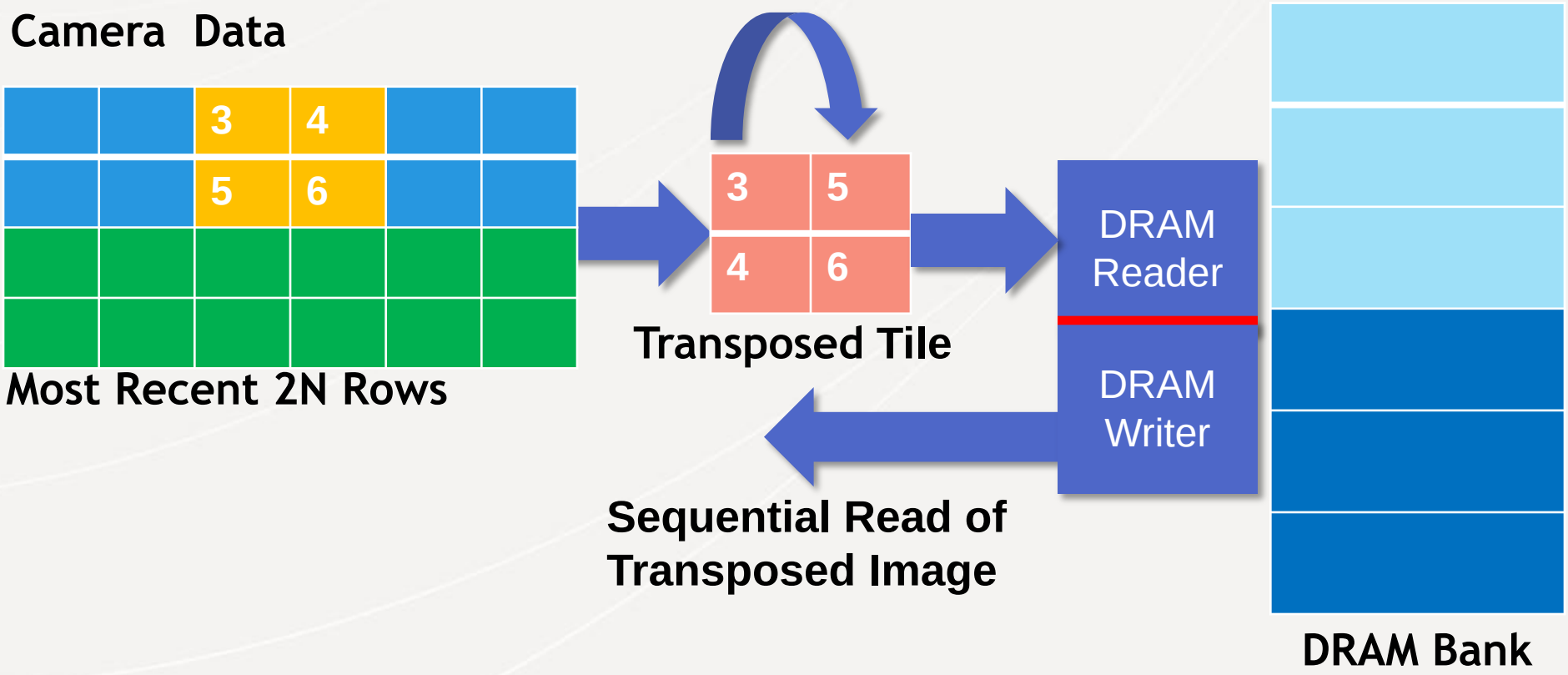
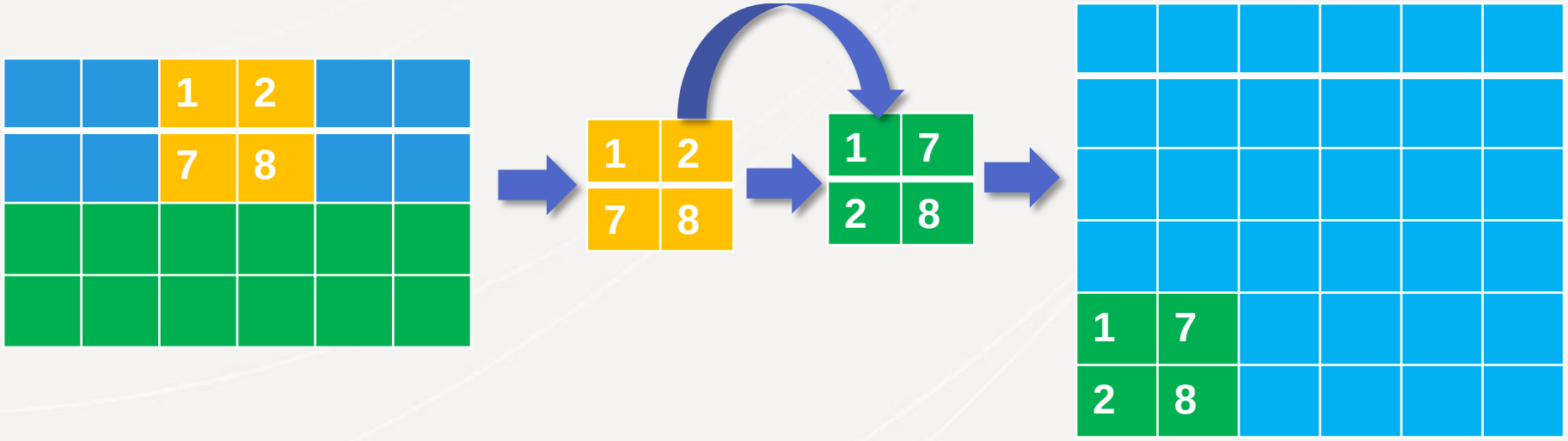


DRAM writer writes tiles in columns
DRAM reader reads pixels in rows

Matrix Transpose : Resource Usage



Tiled Read	Tile Size (Pixels)	Benchmark (MB/s)	Estimated On-Chip Memory (% of Memory Used)
Straight Forward	Column	115	
Tiled	32x32	174	12.5%
Tiled	64x64	408	25%
Tiled	128x128	532	50%
Tiled	256x256	604	105%

*Benchmarks are done with write time share of 50%

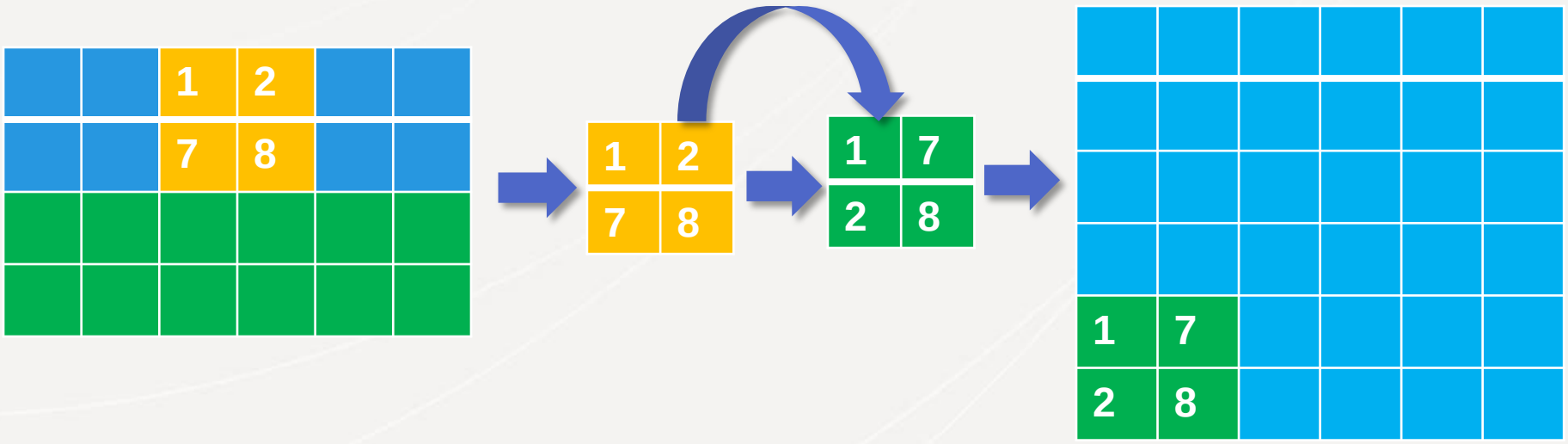
DRAM Time Share for Improving Throughput

- For Tile Size of 128x128:
  Write Share = 50% (1us), Read Share = 50% (1us)
  DRAM Write Speed = 532 MB/s
  DRAM Read Speed = 800 MB/s

- For Tile Size of 128x128:
  Write Share = 58%(1.16us) , Read Share = 42% (0.84us)
  DRAM Write Speed = 660 MB/s
  DRAM Read Speed = 640 MB/s

Tiled	256x256	604	105%
Tiled	128x128	640	50%

Matrix Transpose : Resource Usage



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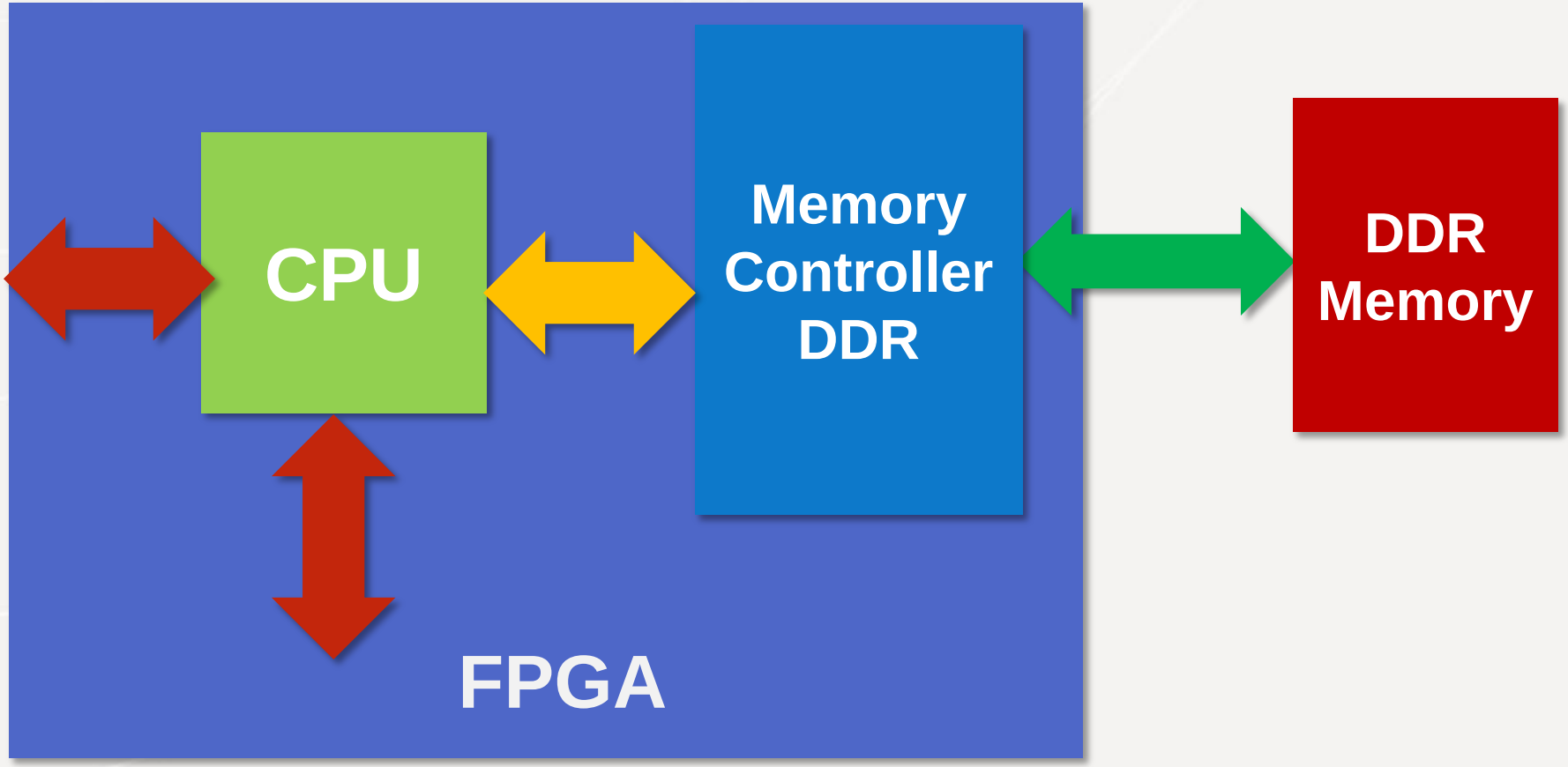
Heterogeneous Architecture

System On Chip (FPGA+CPU on same die)



Conclusions

- Communication is as important as computation on embedded targets
- Understanding memory abstractions is key to image processing applications
- FPGAs with more on-chip memory are great for image processing applications

Resources for Further Investigation

- *F.Brachet,C.Buil*, "Conception and Development of Static Fourier Transform Spectrometer Breadboard"
- *Laurent Rousset-Rouviere, Christophe. Coudrain, Sophie Fabre,* "SYSIPHE, An Airborne Hyperspectral Imaging System for the VNIR-SWIR-MWIR-LWIR Region"
- *Julie Dai*, "Hyperspectral Images Applications"

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