

# Accelerated Cell Imaging and Classification on FPGAs for Quantitative-phase Asymmetric-detection Time-stretch Optical Microscopy

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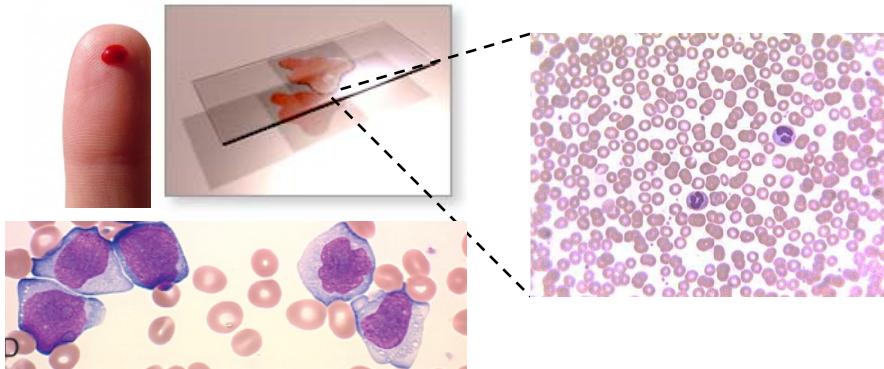
*FPT 2015 – 2015/12/07*



# High-throughput + High-content Imaging: Opportunities

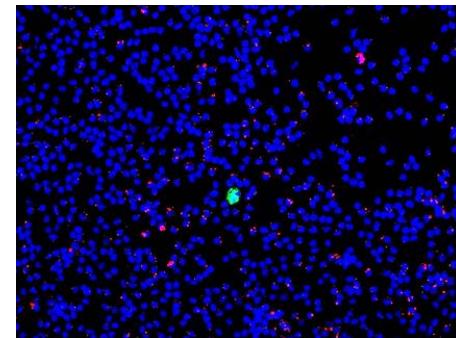
## Rare cancer cell detection

- **Extremely rare** → ~1 cell in billion's blood cells
- Applications: Early cancer detection, minimal residual disease detection



## Single-cell analysis

- Cell-to-cell differences in large population
- Applications: cancer research, stem cell biology, immunology...



**Speed of today's fastest cameras:**  
→ < 1000 cells per second possible

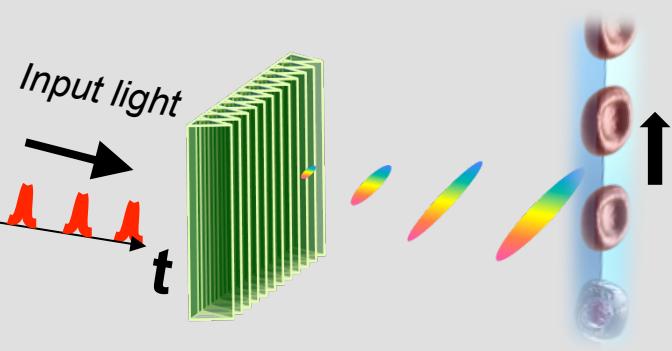
→ **2 months** to capture images of billions of cells



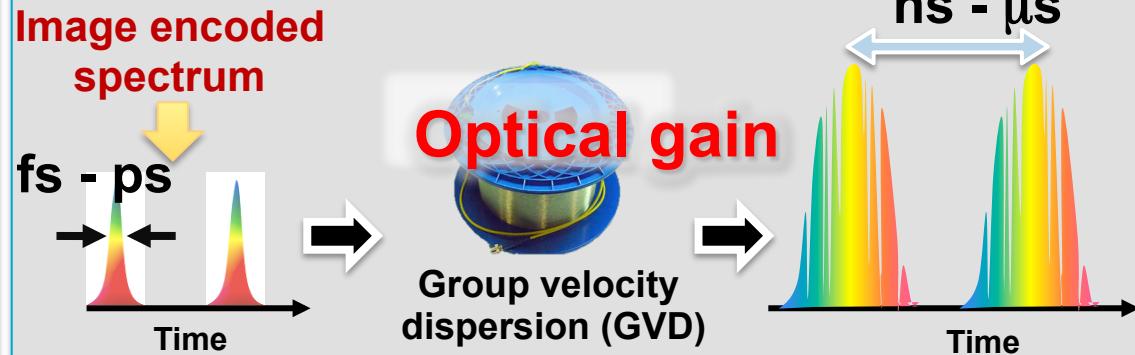
# ATOM

## Asymmetric-detection Time-stretch Optical Microscopy

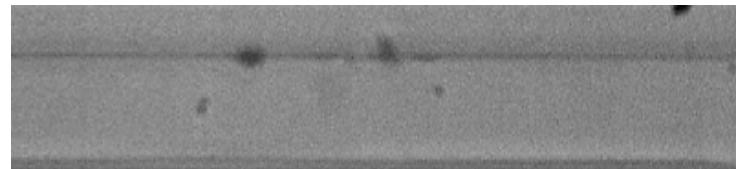
### Step 1: Spectral encoding



### Step 2: Optical time-stretch

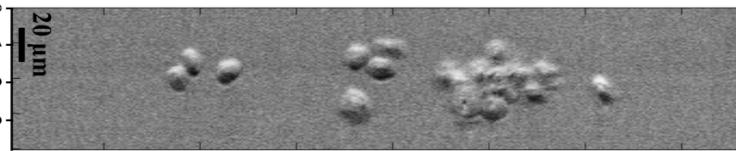


CMOS camera



Frame rate : 23 kfps  
Exposure time:  $\mu$ s  
Flow speed : 2 m/s

ATOM camera

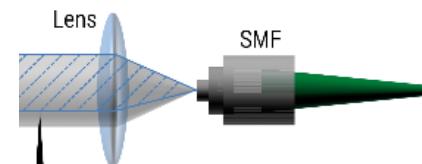
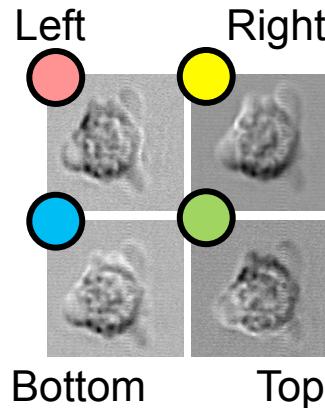
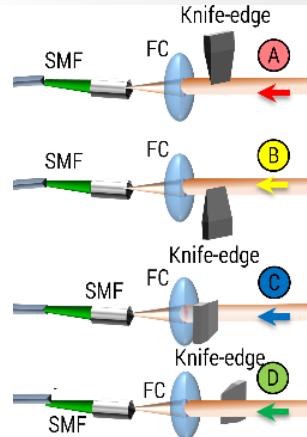


line scan rate: 26MHz  
Exposure time :~20ps  
Flow speed: 7 m/s

- Adjusting fiber coupling angle → Different phase-gradient contrast.
- Giving rise of 3-D appearance.
- Similar to Schlieren imaging – making invisible air/fluid flow visible

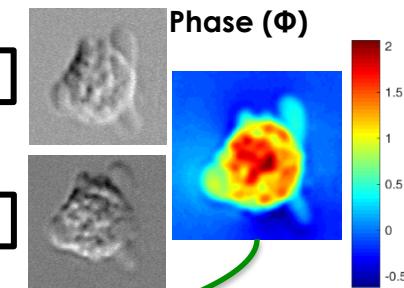
# QPI with ATOM Images (Q-ATOM)

System modification → Multiple oblique-detections → Complex Fourier integration → Quantitative phase map



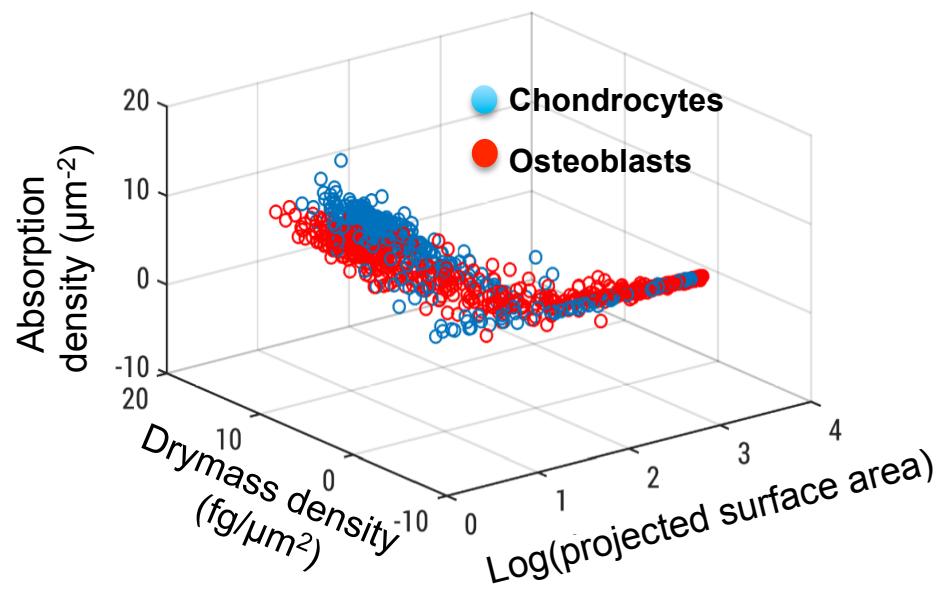
$$\begin{bmatrix} \theta_x(x,y) \\ \theta_y(x,y) \end{bmatrix} = -\frac{NA_i}{I_T} \begin{bmatrix} I_A + I_B \\ I_C - I_D \end{bmatrix}$$

$$\nabla\phi(x,y) = \frac{2\pi}{\lambda} \theta(x,y)$$

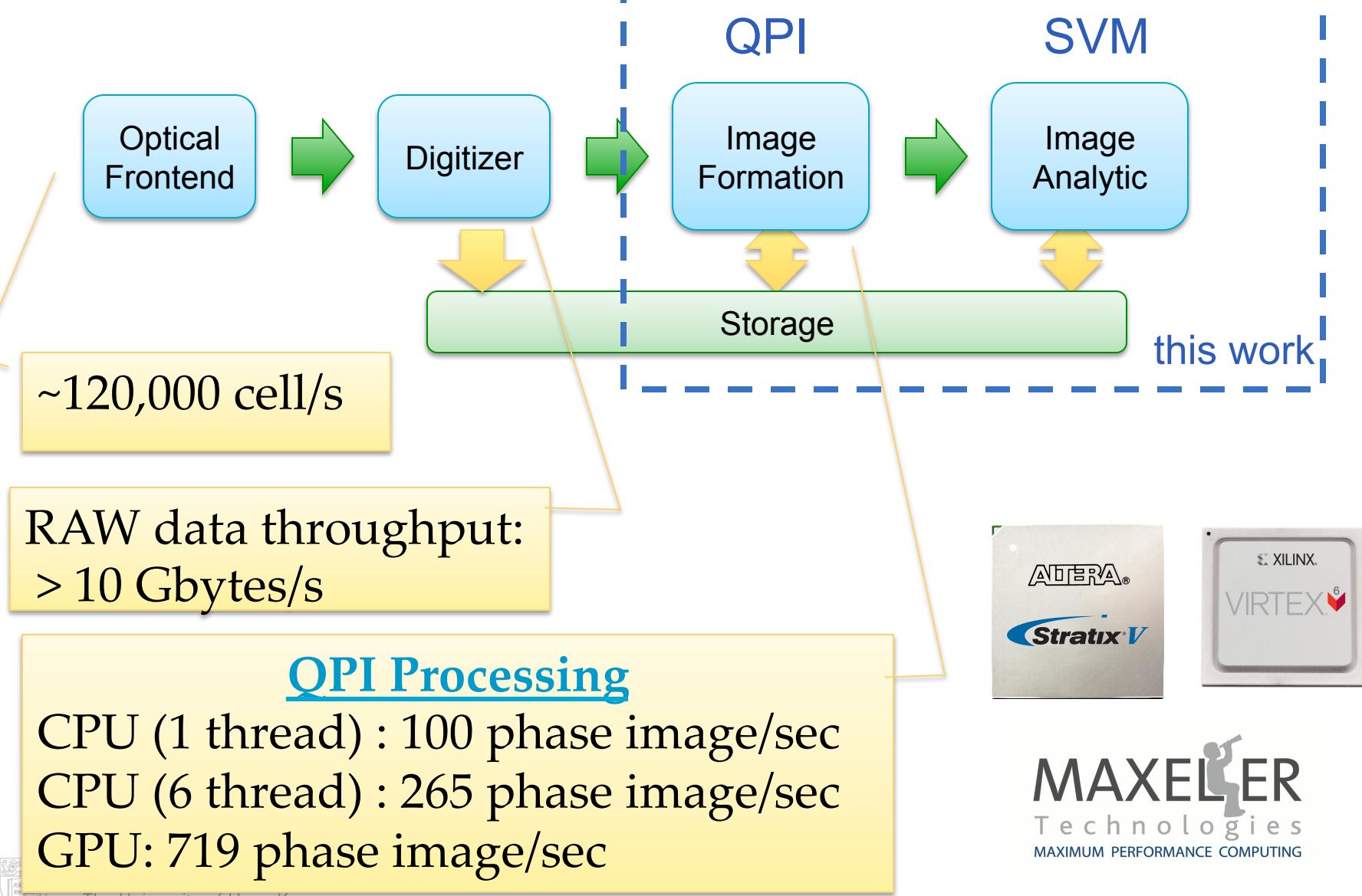


## Biophysical Quantities

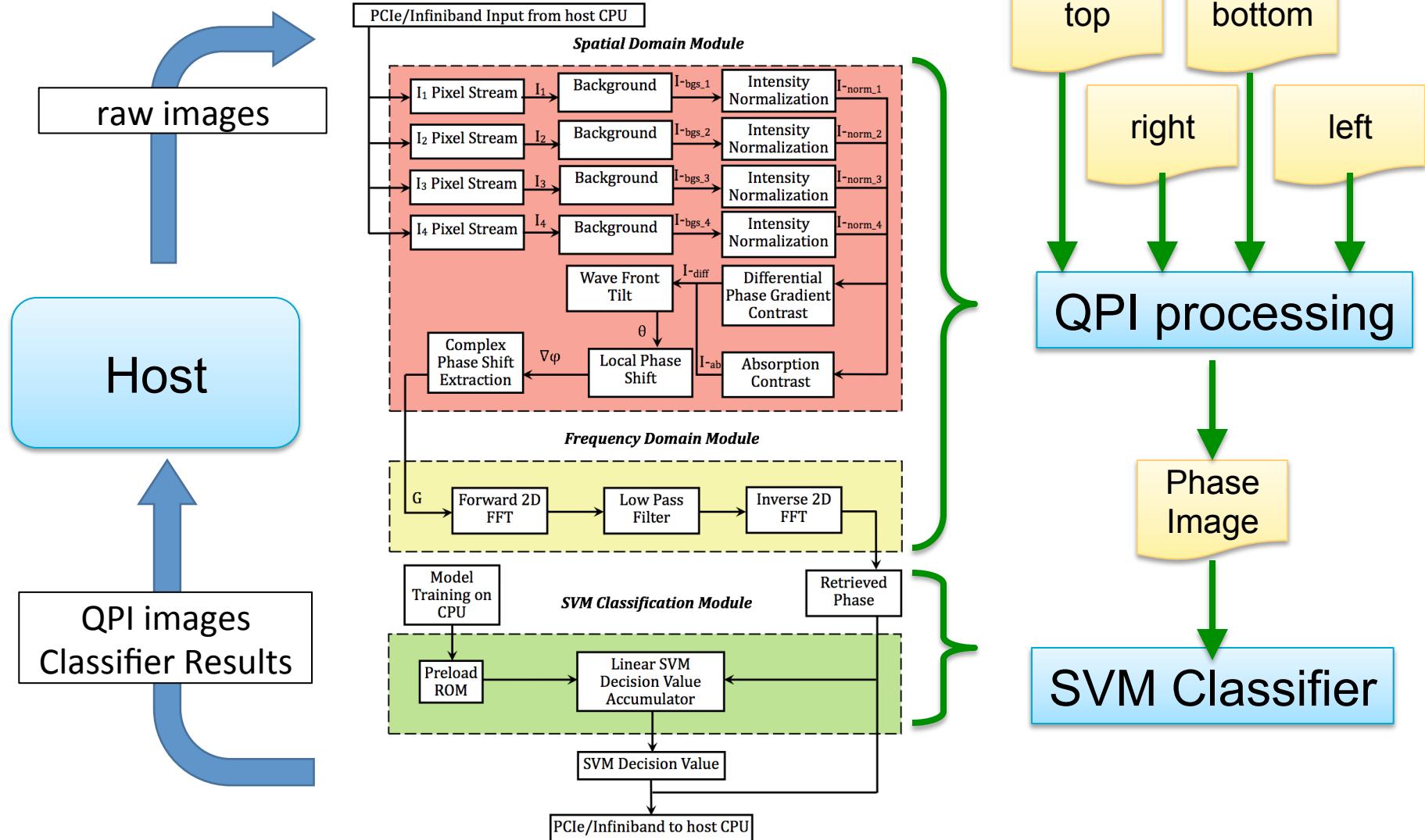
- size
- shape
- dry mass
- dry mass surface density
- phase volume
- sphericity



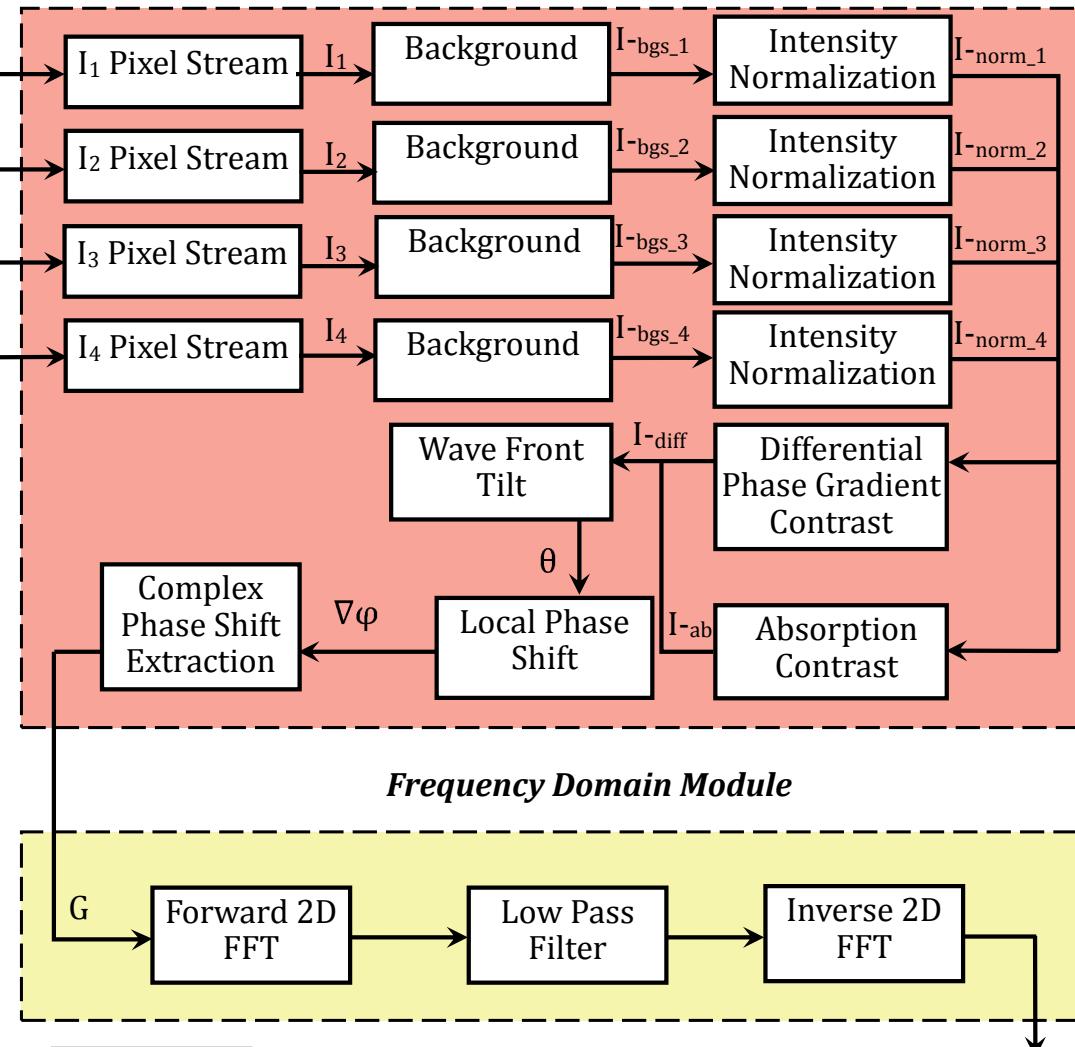
# The Need for Acceleration



# Architecture Overview



# Quantitative-phase Imaging (QPI)



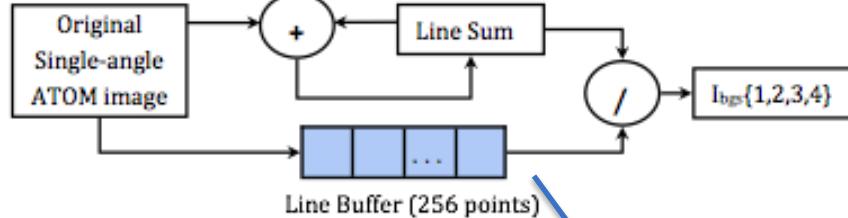
- **Spatial Domain**
  - Background subtraction
  - intensity normalization
  - differential phase gradient contrast
  - absorption contrast
  - wave front tilt
  - local phase shift
  - complex phase shift
- **Frequency Domain**
  - FFT
  - Low pass filter

Details in the paper...

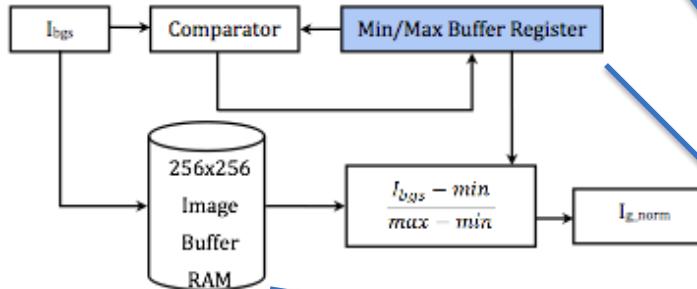


# Spatial Domain Modules (highlight)

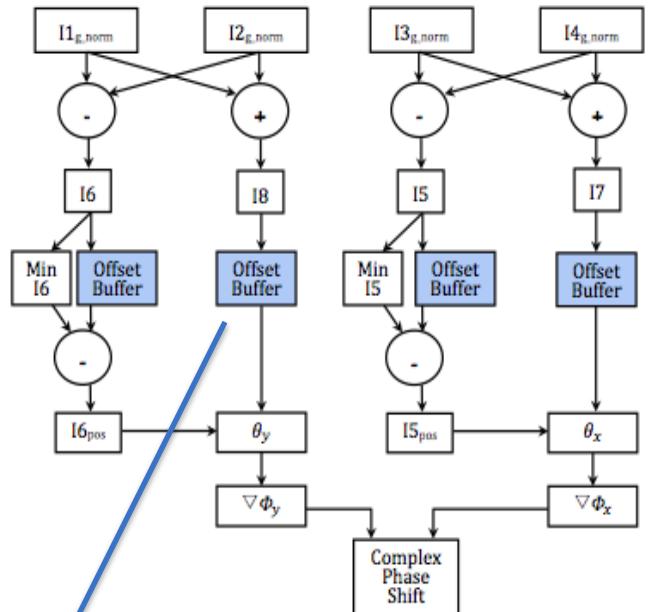
- Background subtraction



- Intensity Elimination



- Complex phase extraction

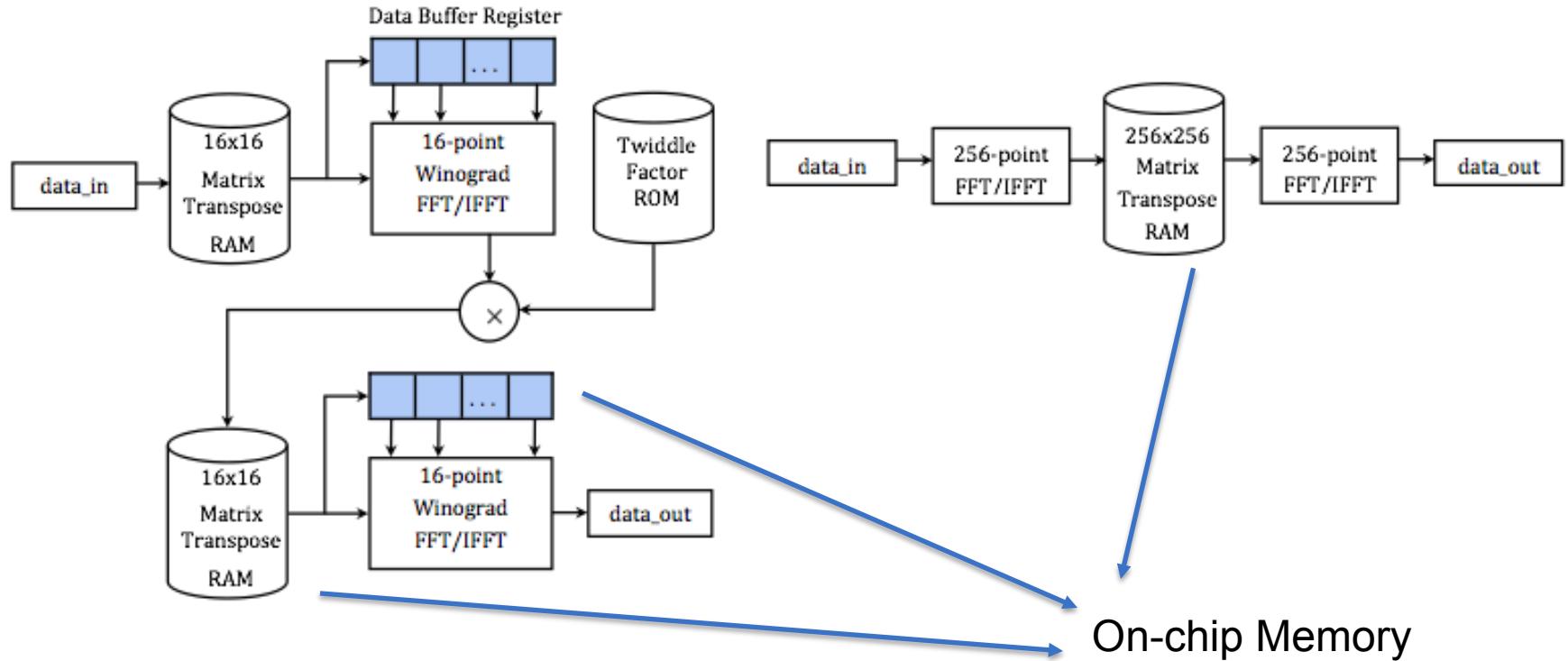


On-chip Memory



# Frequency Domain Modules

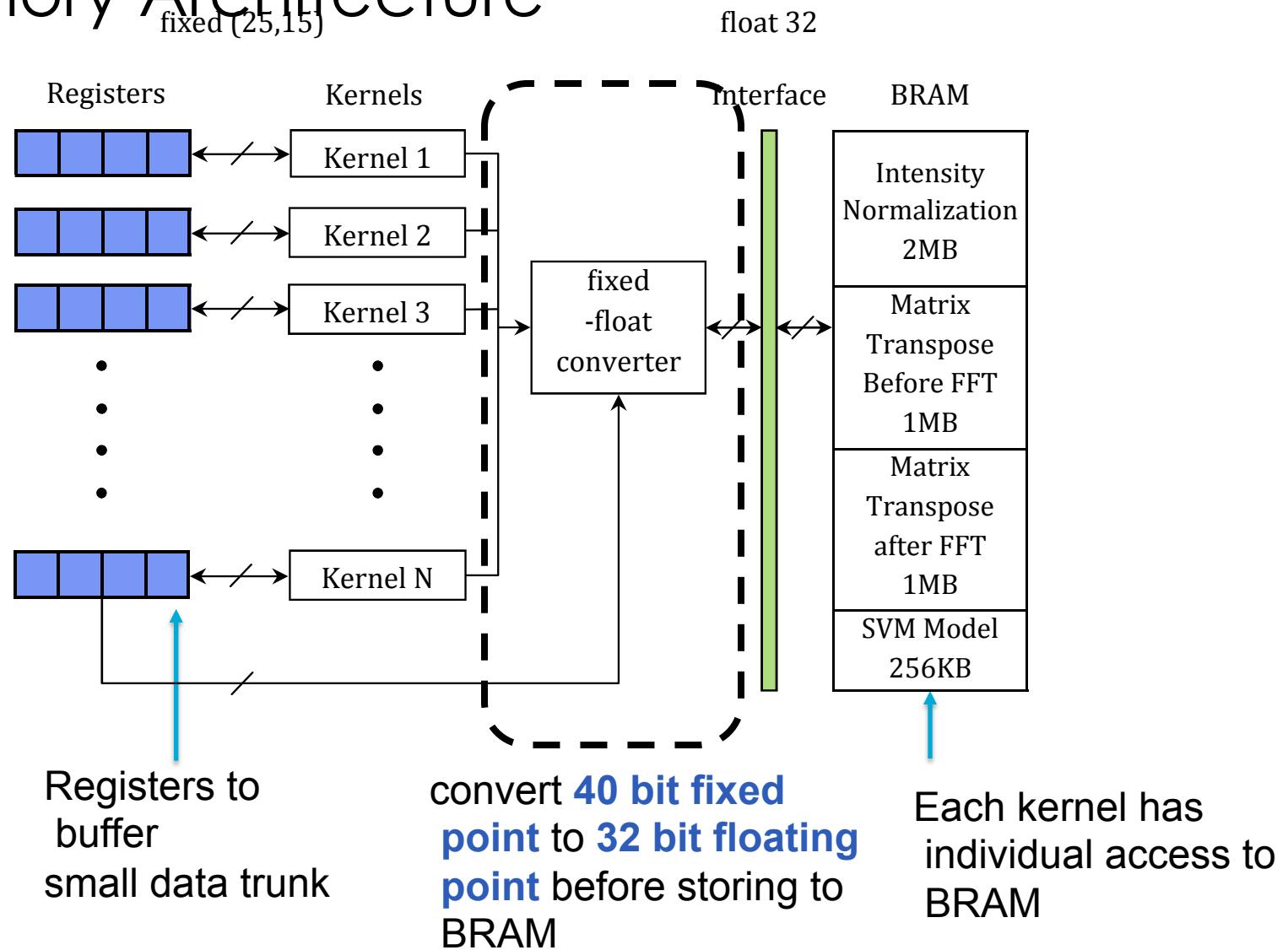
## ■ Radix-16 256-point 2D-FFT



On-chip memory limits performance



# Memory Architecture



# Multi FPGA

- Multi-FPGA design performance limited by I/O bandwidth

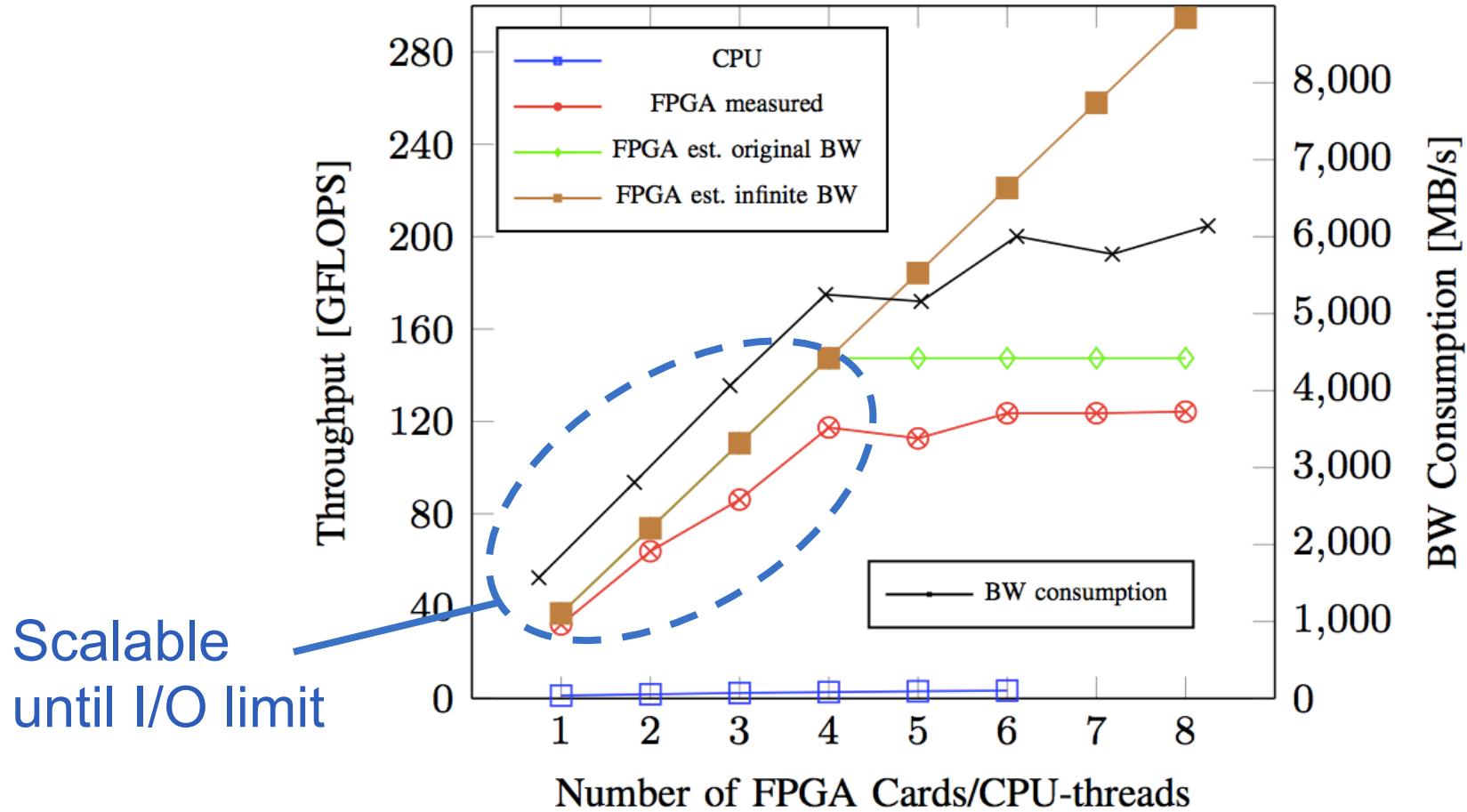
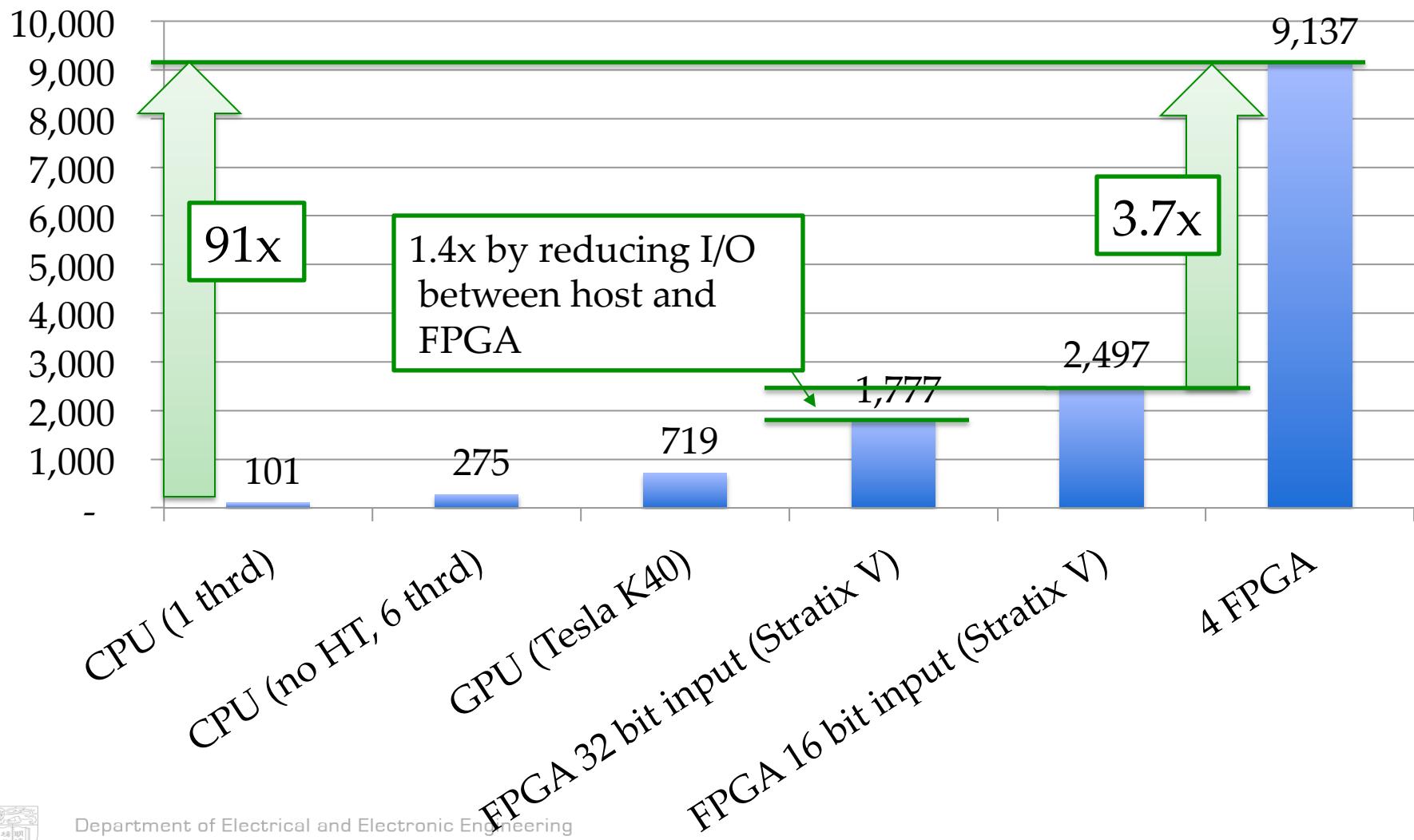


Fig. 7: Throughput of CPU and Multiple FPGA Cards

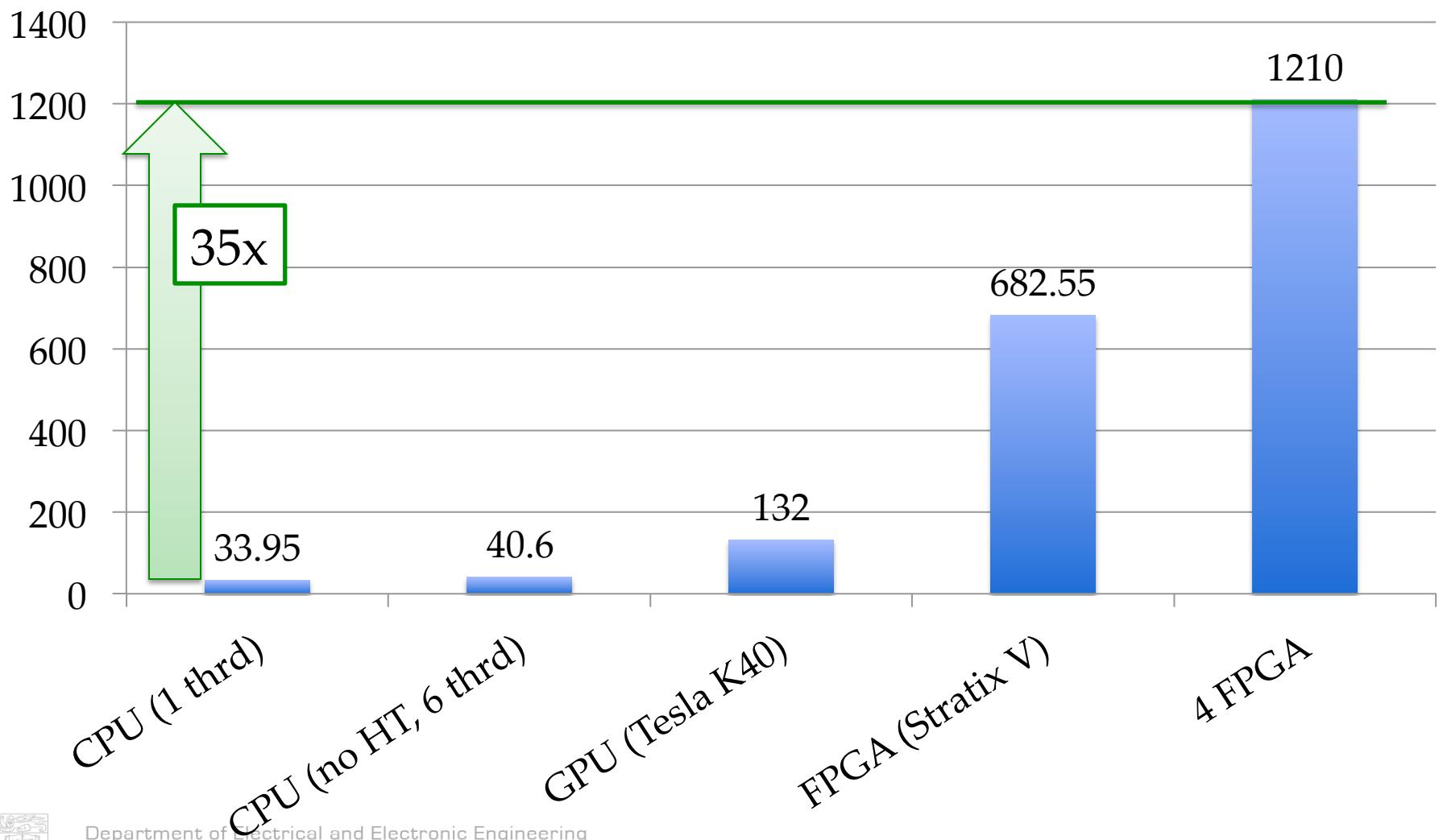
# Performance Comparison

Throughput (QPI images/s)



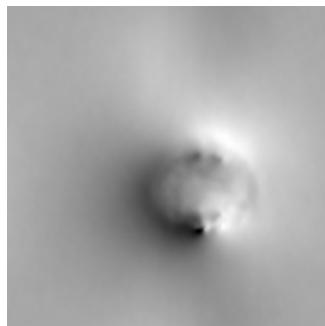
# Dynamic Power Efficiency Comparison

Power Efficiency (MOPS/W)

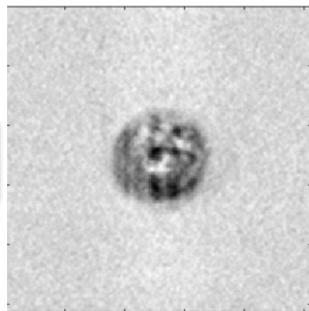


# Cell Classification

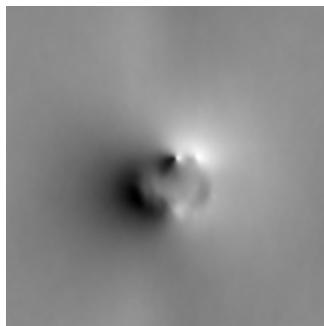
QPI



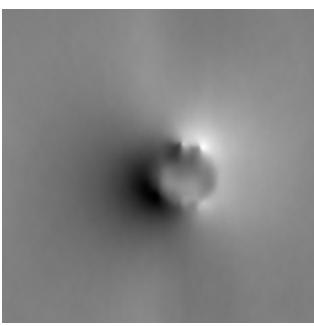
ATOM



Chondrocyte  
(OAC)



Osteoblast  
(OST)



Fibroblast  
(3T3)

- Linear SVM
  - L2-regularized L2-loss support vector classification
- Trained on CPU host
  - 10-fold cross validation
  - 2700 images
- Classify on FPGAs
  - 300 images
  - model preloaded in BRAM



# Classification Results

	OAC vs OST	OAC vs 3T3	OST vs 3T3
QPI images	90.01%	94.67%	91.84%
ATOM images	86.10%	91.20%	89.65%
Accuracy Improvement	3.91%	3.47%	2.19%

- Accuracy improved by 2.19-3.91%
- Performance limited by QPI processing



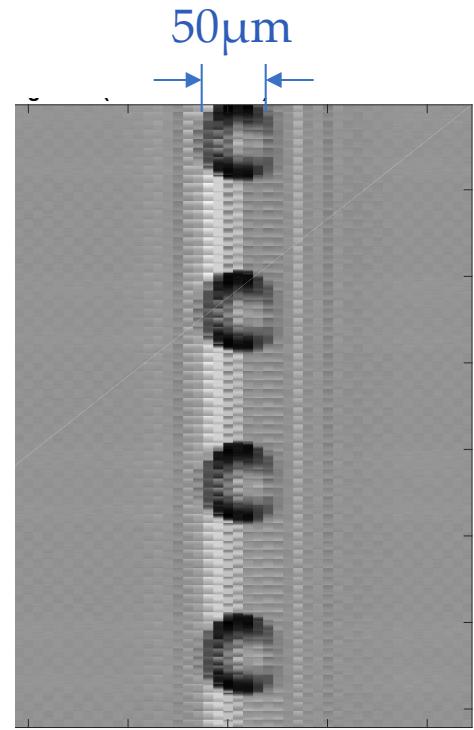
# Summary

- Q-ATOM provides great capabilities for next generation label-free single-cell analysis
- FPGA provides a scalable acceleration solution
  - Data capture
  - Image formation
  - Image analytic
- QPI processing:
  - Single FPGA: 25x over single CPU
  - 4 FPGAs: 33x over 6-thread CPU
- FPGA SVM classifier
  - Over 90% accurate at QPI processing speed



# Future Work

- Real-time process
- Deep learning on FPGA
- Throughput/Quality tradeoff
- Label-free biomarkers



Real-time image formation + object detection on  
FPGA at 3.2GS/s

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## Collaborators:

Dr. Andersum Shum (Mechanical Eng.)  
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Dr. Edmund Lam (Electrical & Electronic Eng.)  
Prof. Godfrey Chan (Paediatrics & Adolescent Medicine)  
Prof. Kathryn Cheah (Biochemistry)  
Prof. Denny Chan (Biochemistry)



# THANK YOU

Questions?



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The University of Hong Kong