Accelerating Satellite Image Based Large-Scale Settlement Detection with GPU

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GPU Technology Conference 2013

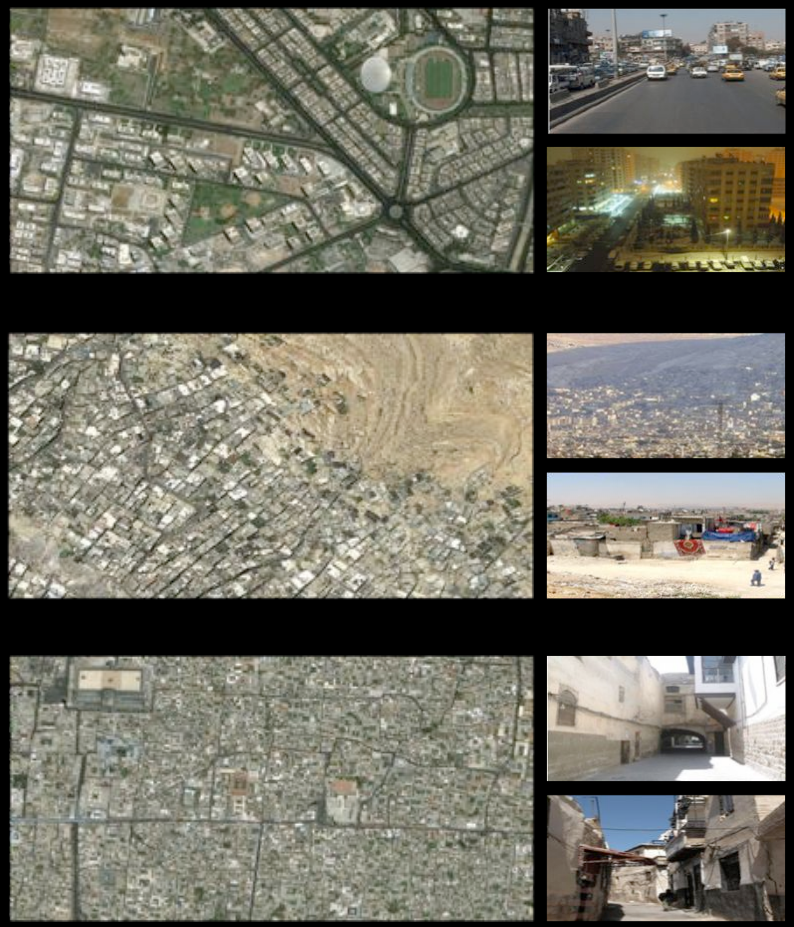
San Jose, CA

Introduction

- Advanced geospatial models built on settlement characteristics such as size, shape, location, growth can reveal social stability and political durability.

- Automated settlement detection process involves extracting, representing, and identifying patterns characterizing settlements in image data.

- Strong demand to understand the settlement characteristics from aerial imagery.

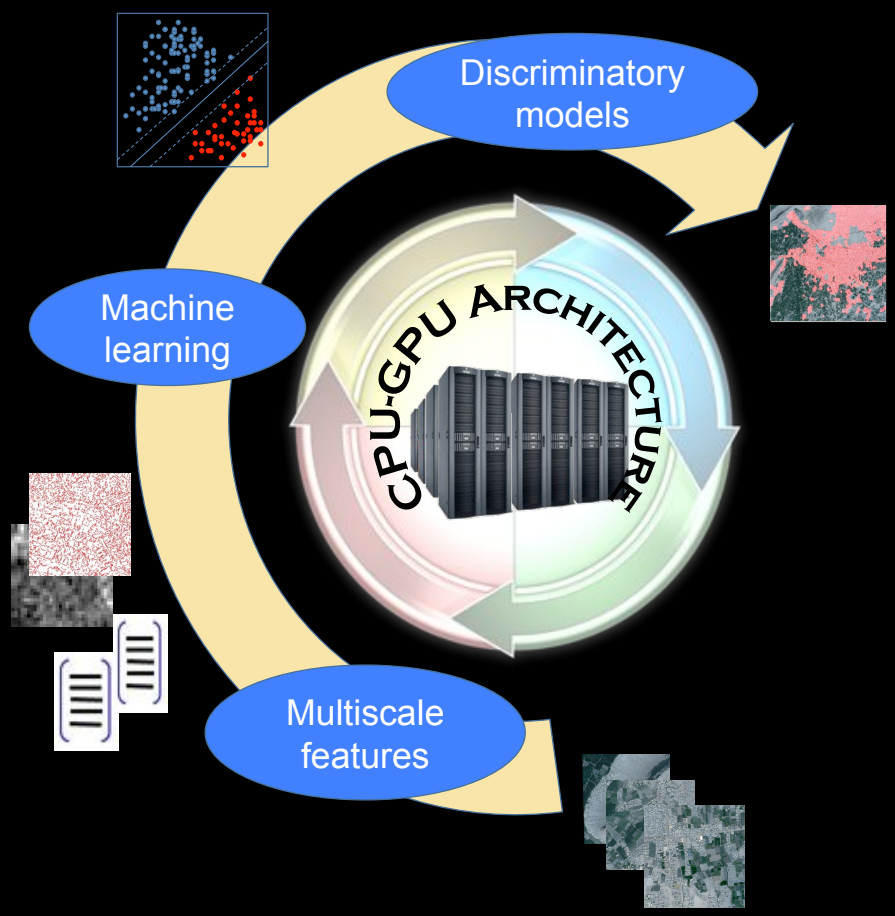


Problem

- Land surface ~150 Million km^2 translates into roughly 600 Trillion pixels to be processed with 0.5 m imagery.
- Pixel to feature descriptor mapping is an expensive, but key step in automated scene analysis.
- Application of settlement detection algorithms on large image databases can easily saturate the processing capabilities of conventional CPUs.

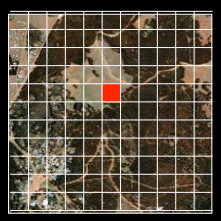
Large Scale Data Analysis

- Parallel feature extraction using Single Instruction Multiple Threads (SIMT) architecture of GPU.
- Efficient GPU implementation of multiscale features.
- Exploitation of multi-GPU architecture for large-scale image analysis.
- Reduce redundant data transfers and computations.

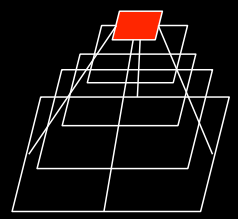


Settlement Mapping Process

Geographic Information Science and Technology



Divide Image into pixel blocks



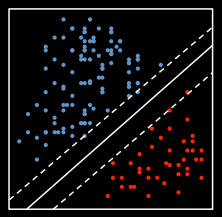
Compute Multi-scale features for each pixel block

HOG Statistics
(5 features x 5 scales)

Pixel Block Intensity
Mean and Variance
(2 features x 5 scales)

GLCM Contrast
(1 feature x 1 scale)

Each pixel block mapped to 36-dimensional vector



Apply linear SVM Model

Output Settlement Image

Features are computed for each scale :

$$d^s = \{\ h^s_{i,j}, c^s_{i,j}, g_{i,j}\ ; s = 0,1,..N\}$$

N is the total number of scales.
i,j represent the index of the pixel blocks

For each pixel-block at every scale, we reduce the high-dimensional feature vectors to a scalar value by projecting the feature vector onto the SVM decision plane,

$$z^s = (W^T)^s\ d^s$$

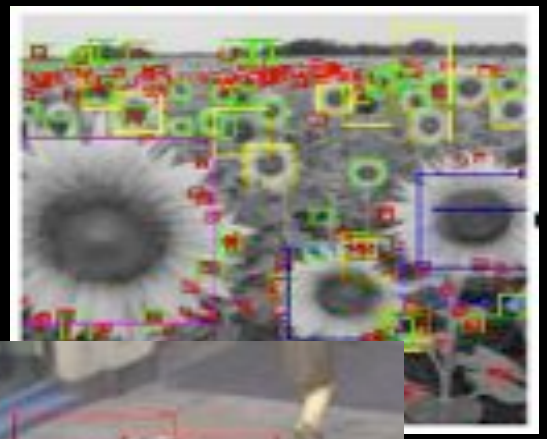
SVM decision function is given by $f(z) = \sum_{s=0}^{N} z^s + b$

At each pixel-block ***(i,j)*** the SVM decision function simply becomes $f(z_{i,j}) > 0$ for settlement.

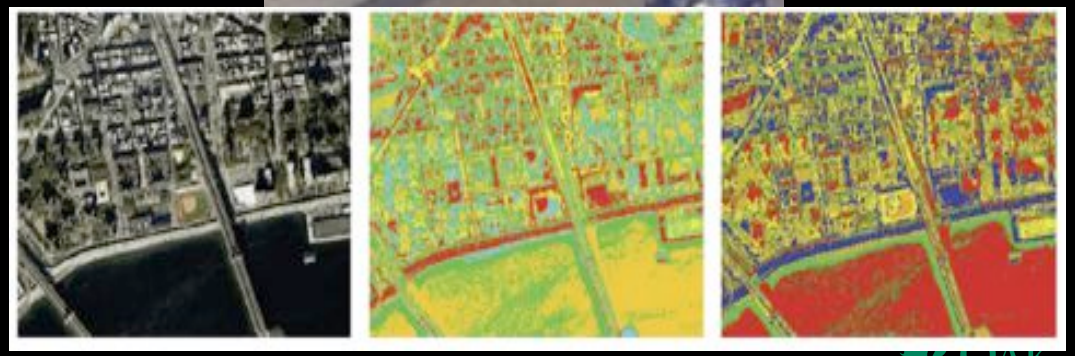
W and *b* are SVM model parameters

GPU Based Vision Systems

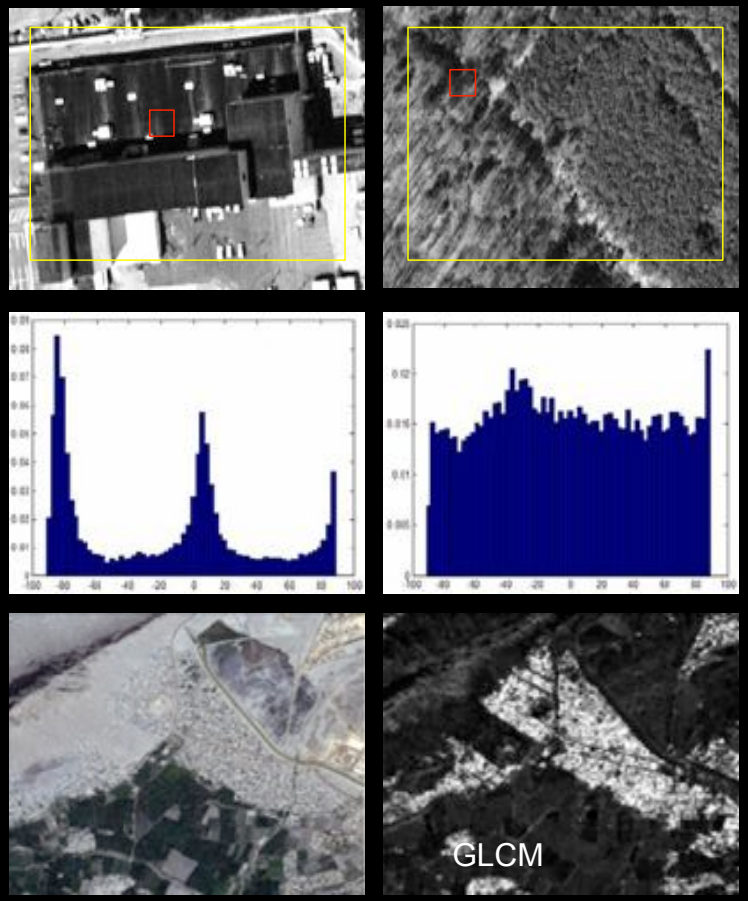
- Cornelius et al. - Scale invariant feature descriptor generation and matching on a GPU
- Bernabe et al. - satellite image classification on GPU, but limited to pre processing filtering, post processing
- GPU based HOG for Pedestrian Detection
- Parallel GLCM by shahbahrami et al. but targeted to a Cell processor



Significant speedups have been achieved in all cases



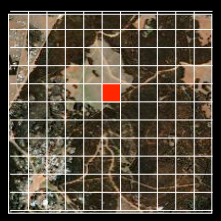
Computer Vision Challenges



- With high-resolution imagery, pixel features are not discriminatory.
- Multi-scale features provide accurate settlement characterization.
- We aggregate three low level features from 5 spatial scales.
  - Histogram of Gradient Orientations (HOG) : *h*
  - Local pixel intensity statistics (Spectral) : *c*
  - Gray-Level Co-Occurrence Matrix (GLCM) : *g*
- A linear support vector machine (SVM) classifier is used to map the feature vector (*z*) to one of the binary classes (settlement and non-settlement).

Settlement Mapping Process

Geographic Information Science and Technology



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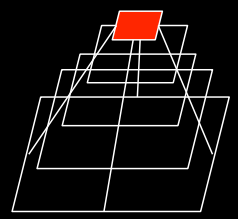

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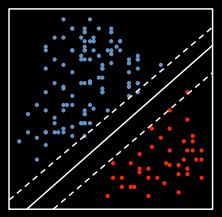

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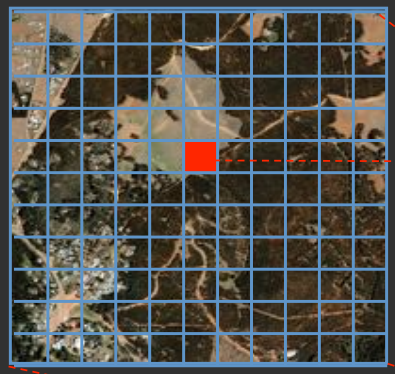
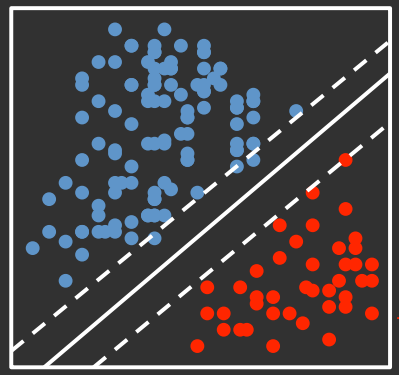
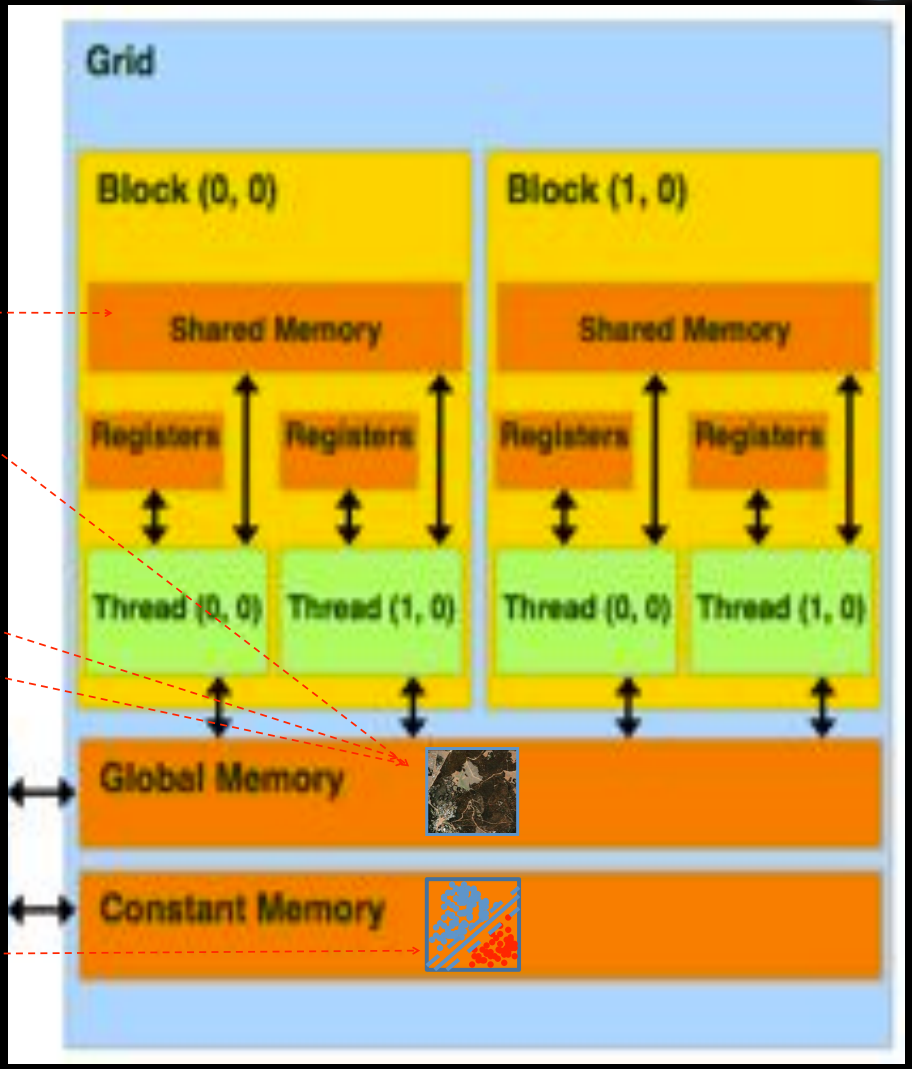
DATA LOCALITY

HOST (CPU)







HISTOGRAM OF ORIENTATIONS

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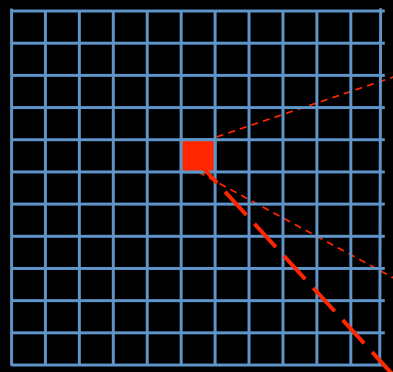
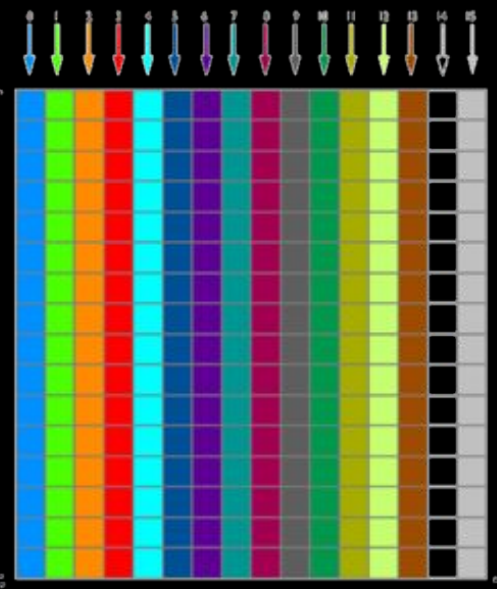
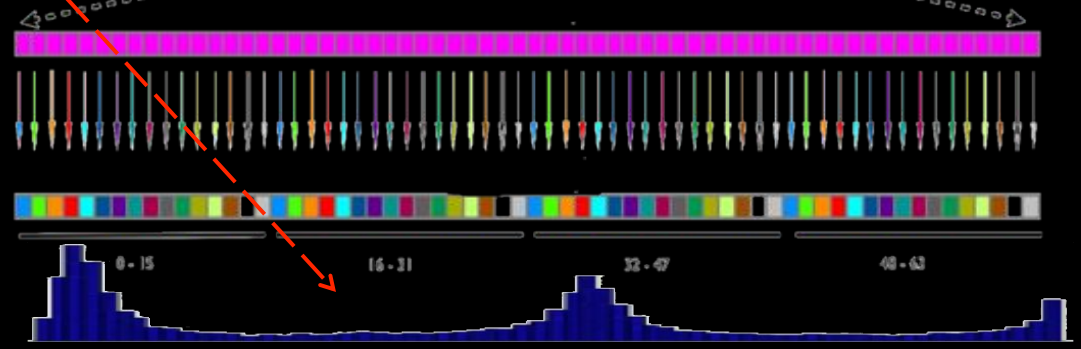
Gradient data



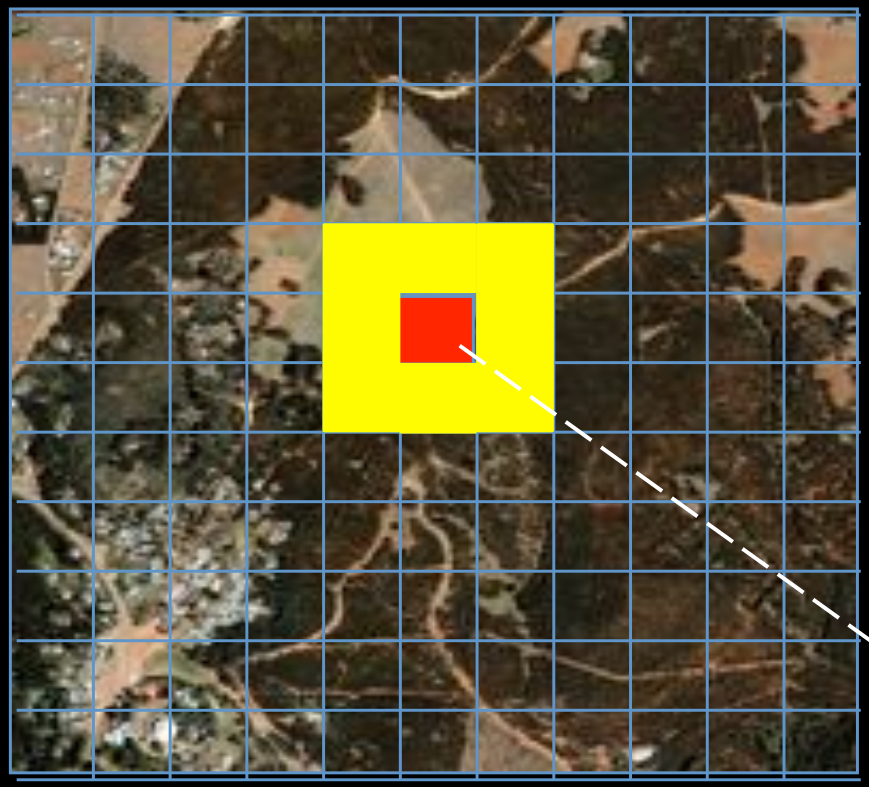


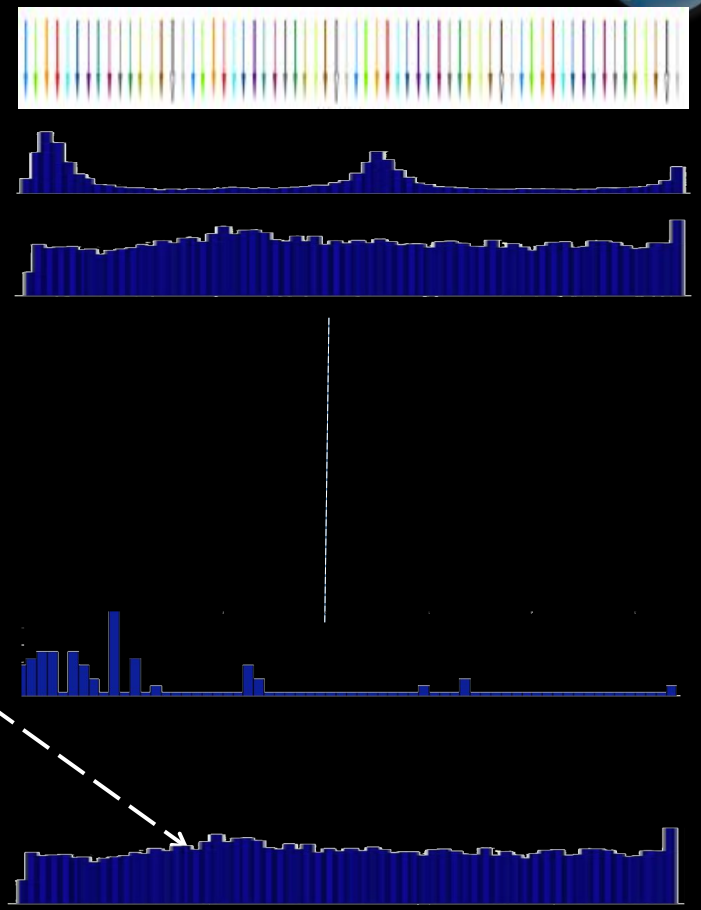


M is the pixel Block size.

```
for j = 1 to M do
    index = (j, baseidx, M)
    OA_bin = OA[index]
    HIST_shared[OA_bin]+=GR[index]
end for
Sync
for k = 1 to Size(HIST)/M do
    stride = M
    Update HIST_global[baseidx; k; stride]
end for
Sync
```

MULTISCALE HOG

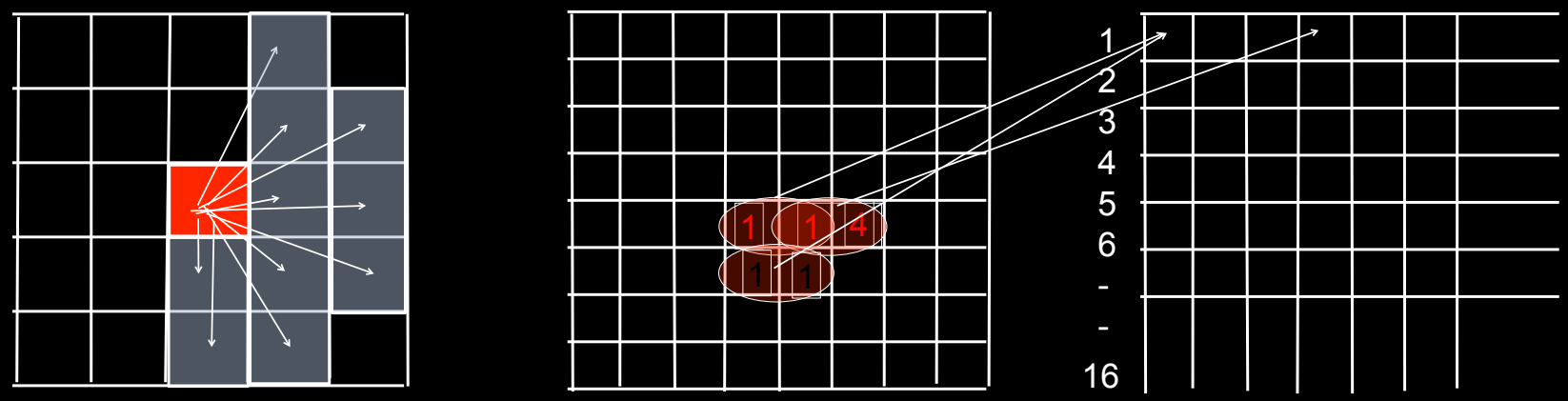




Histogram for scale 2

- 64 threads compute the mean of the base scale histograms
- No Memory Conflicts
- Reduced redundancy

GLCM



N threads working
NxN quantized pixel block
In Shared Memory

$$con(c) = \sum_{m=1}^{Q}\sum_{n=1}^{Q}(m-n)^2\mathbf{P}(c)_{m,n}$$

$$\mathbf{g}^0_{i,j} = con(k)(\mathbf{c}(1)^0_{i,j})^2$$

P is the normalized co-occurrence matrix
Q represents the number of quantized gray levels.
$c(1)^0_{i;j}$ represents the mean pixel intensity for the pixel-block at (i; j) and k = arg $\min_k$ con(c).

Hardware

Xeon + Tesla 4U Server

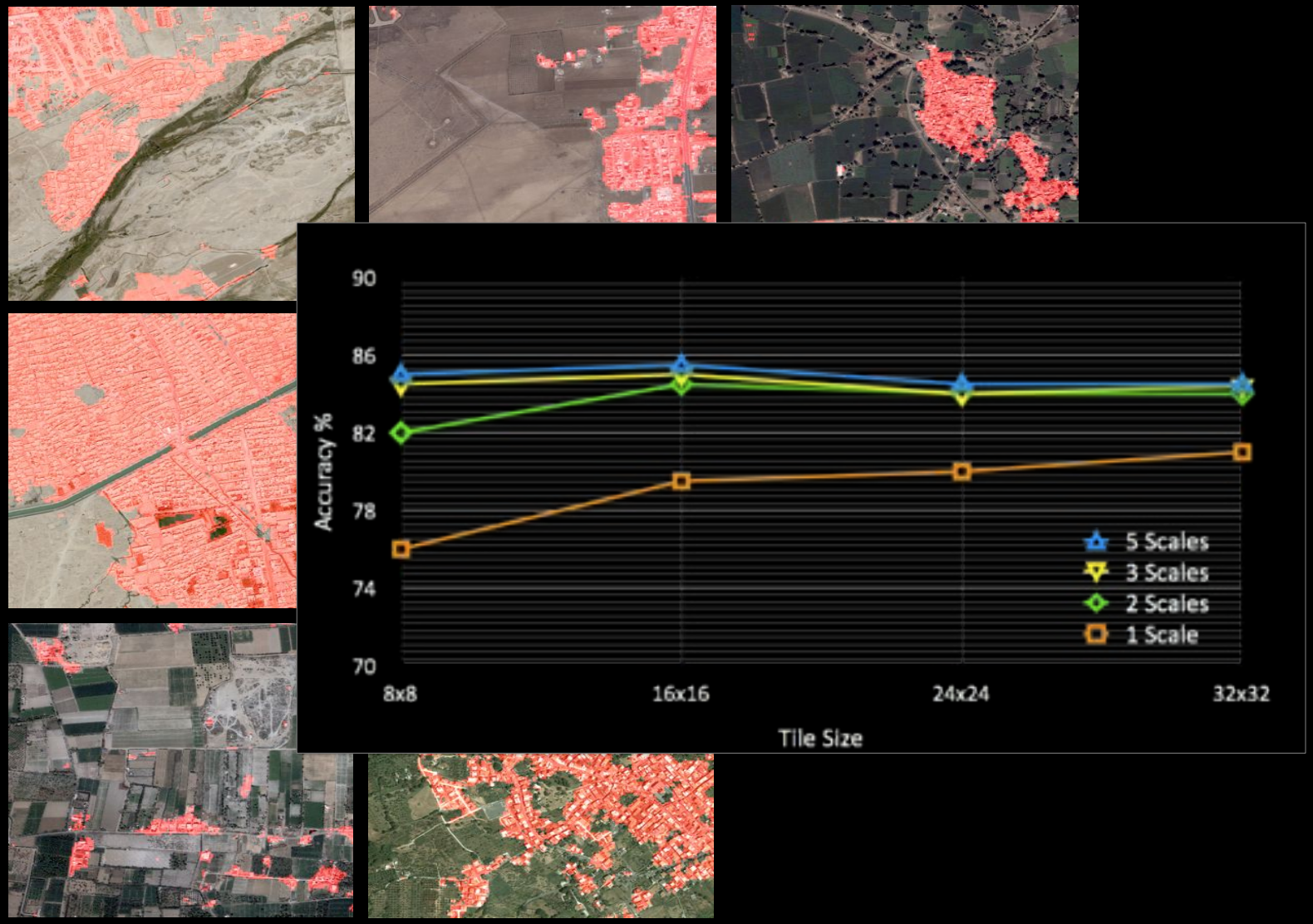
- CPU
  - 2 Intel Xeon E5620 Westmere
    - 2.4 GHz Quad Core
    - 48 GB DDR3 Memory
- GPU
  - 4 Nvidia Tesla C2075
    - 448 CUDA cores
    - 6 GB GDDR5 Memory

Validation

- Settlement Detection Model learned from a dataset consisting of 60 scenes
- Each Scene
- - represents settlement structures from different parts of the globe
- - Size : 2048 x 2048 at 0.6 m spatial resolution
- Tested on a dataset consisting of 55 scenes with 86% accuracy
- Results validated with CPU implementation.

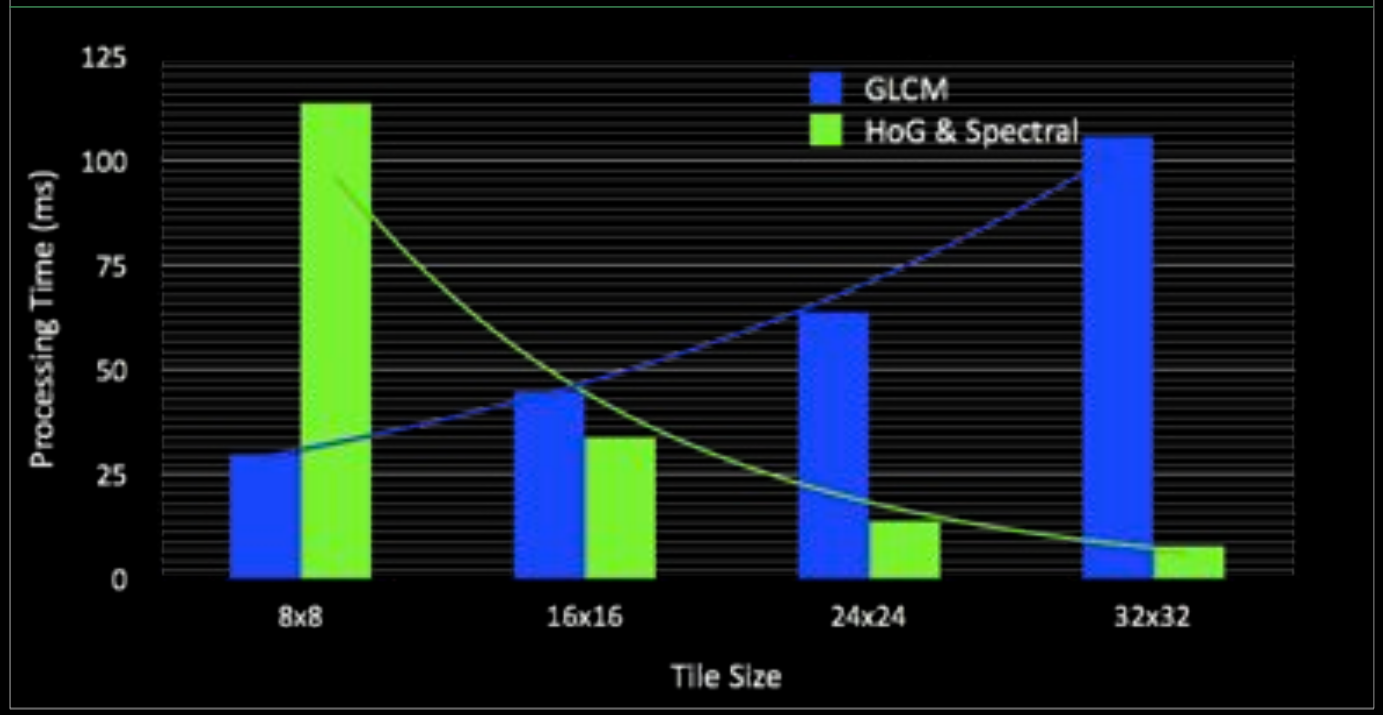
Few scenes

ACCURACY

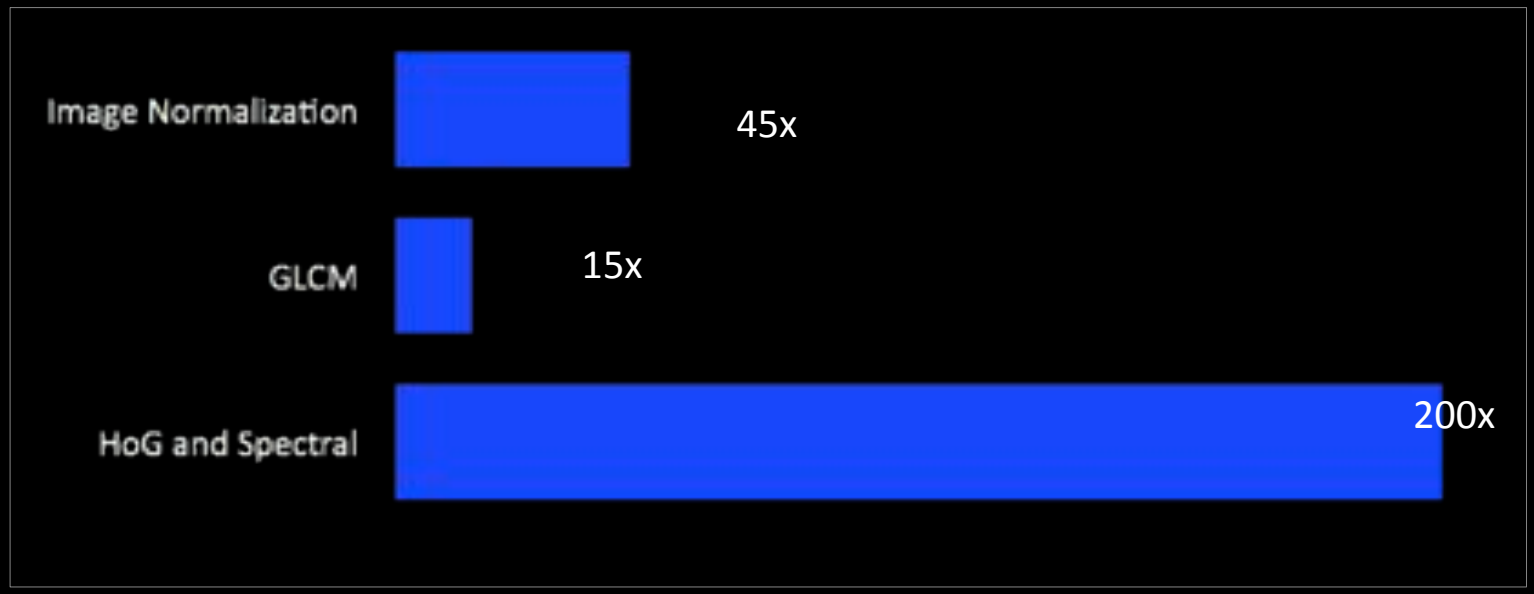

90
86
82
78
74
70
Accuracy %
8x8
16x16
24x24
32x32
Tile Size
5 Scales
3 Scales
2 Scales
1 Scale

PROCESSING TIME

FEATURE RUNTIME



SPEEDUP



LAHORE SETTLEMENT EXTRACTION

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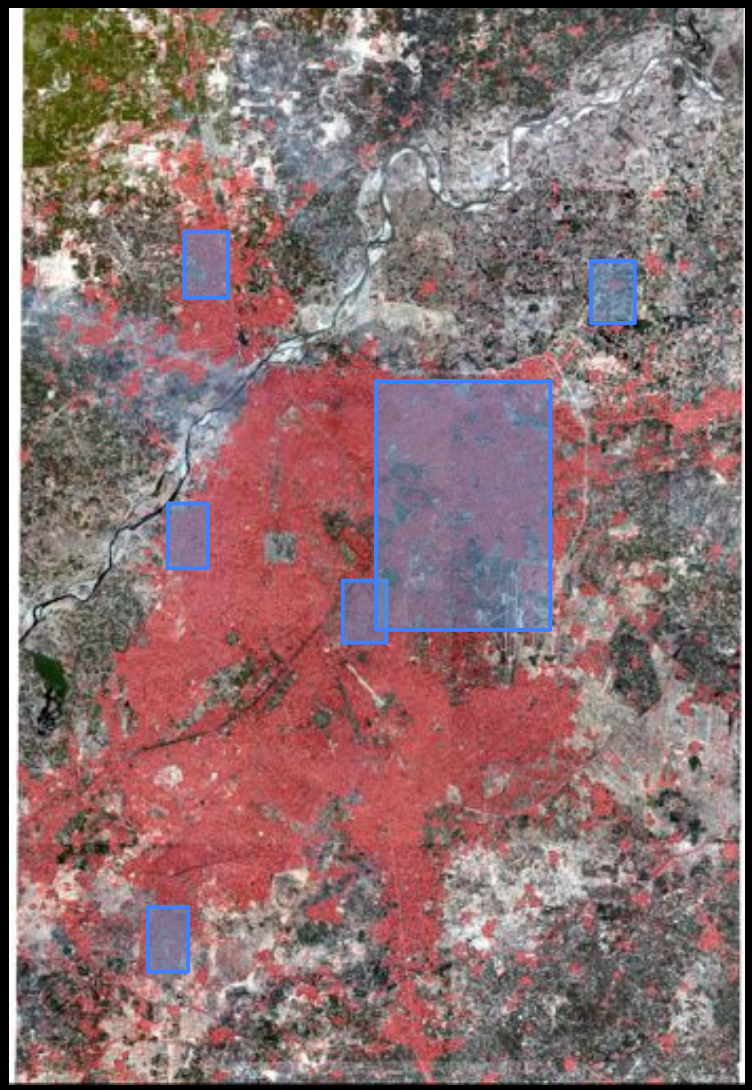
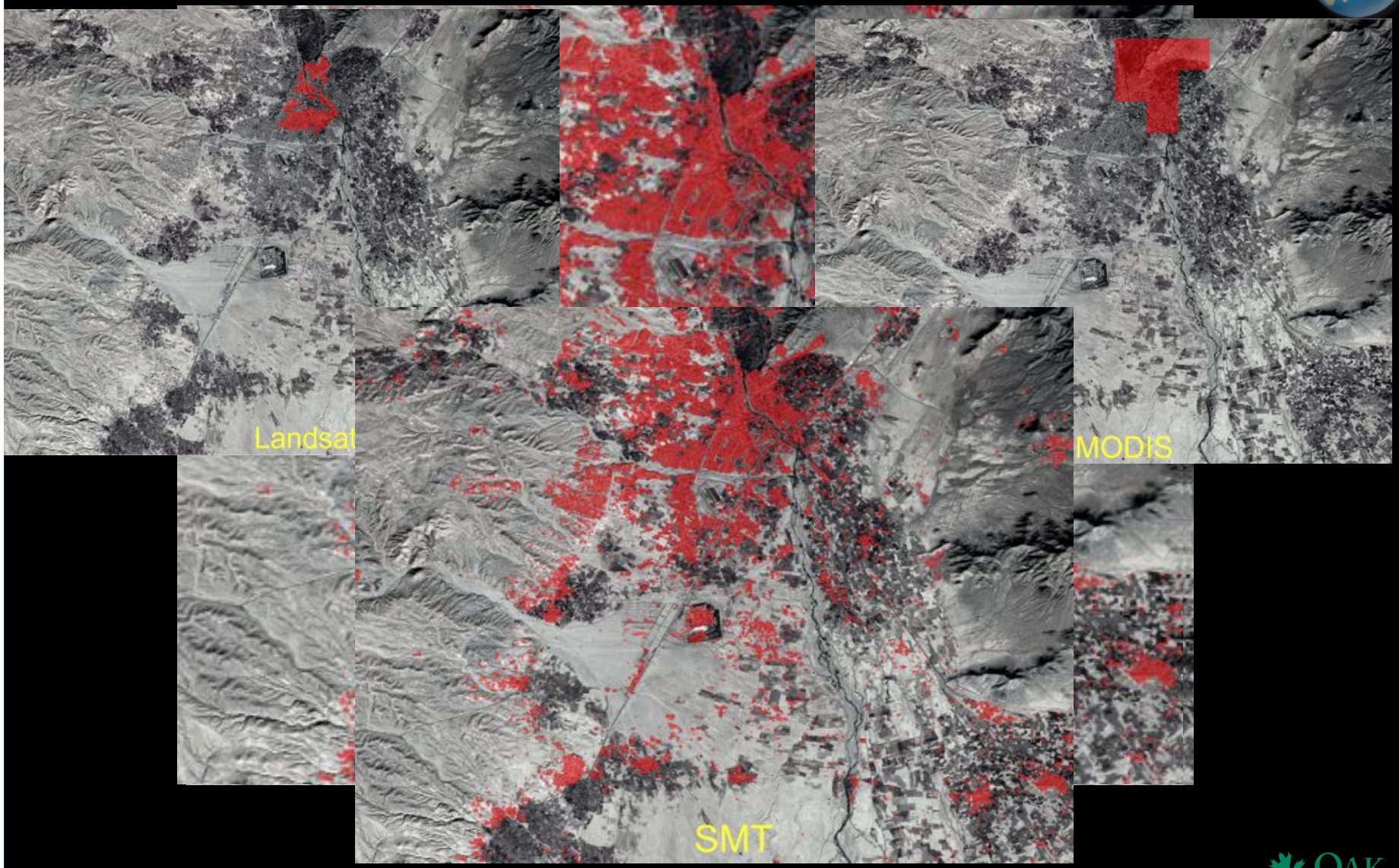
- Data
  - 0.6 m spatial resolution
  - RGB bands processed
- Processed 1200 sq. km in 56 sec
- Wall to Wall processing

```
Non-settlement accuracy (class 0) is 96.7281%
Settlement accuracy (class 1) is 82.3651%
Overall Accuracy = 0.93
*********************************************
            Predicted
*********************************************
   Actual          0          1
         0      71869       2431
         1       4535      21181
*********************************************
Class      Recall    Precision    Harmonic Mean
  0          0.97        0.94         0.95
  1          0.82        0.90         0.86
```

LAHORE




Landsat
MODIS
SMT

NEXT

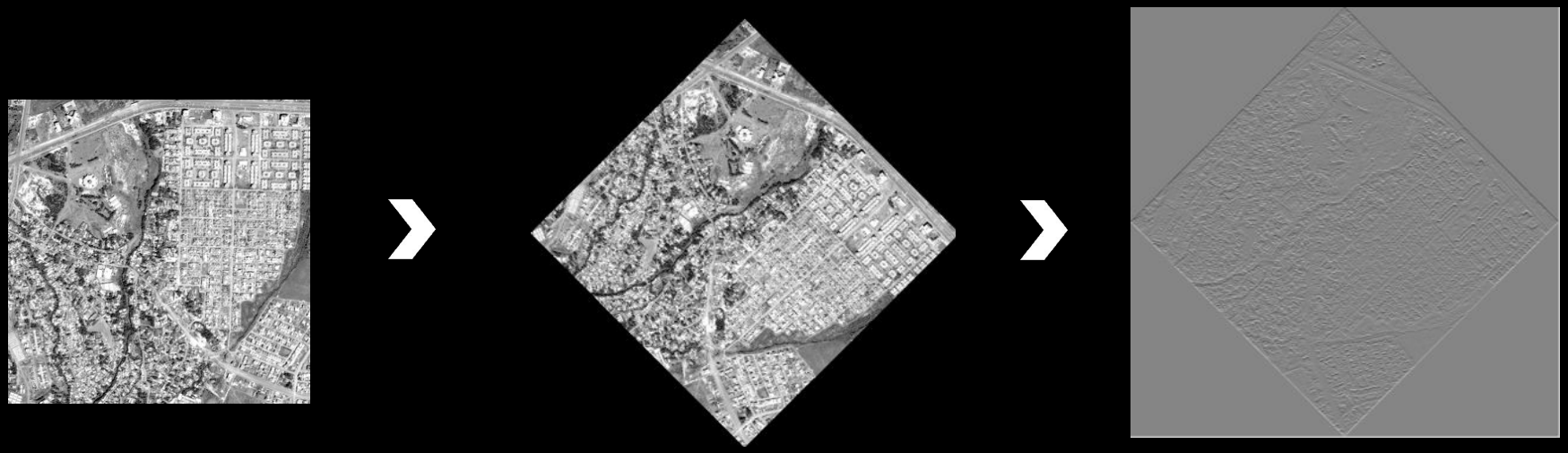
- Increase the accuracy.

Implemented filter responses of the Leung-Malik set. The LM set consists of 48 filters.

Speedup of separable filter response GPU implementation over non separable filter response ~40x

- So what about non separable filters????
- Solution : rotate the image at the cost of extra processing time but still get a speedup of ~30x over non separable

MPI+GPU implementation to tackle country scale imagery on a cluster - already in place. ☺



THANK YOU