Parallel Monte Carlo search for Hough transform

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Motivation

- The problem
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  - Theoretical foundation: variations of Hough Transform (**HT**)
  - Target computing environment: parallel architectures in general.
  - Input assumptions: given is a set of pixels, representing image points abstracted from R^2 plane. We do not deal with how the pixels were obtained.
  - Output: a set of pairs of coordinates defining lines.

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  - Input assumptions: given is a set of pixels, representing image points abstracted from R^2 plane. We do not deal with how the pixels were obtained.
  - Output: a set of pairs of coordinates defining lines.
  - Theoretical limits: solvable in $O(kN^2)$, where k is a constant that reflects the accuracy and is made explicit as it can get arbitrarily large.

Good for HEP and Physics?

- Atlas project tracking of muons traversing the Cathode Strip Chambers [1].
- Track reconstruction in CMS[2]
- Astronomy [4].

Proposed investigation

- Survey **HT** variations.
  - Many variations from initial Hough's idea, not just one.
  - Many algorithms for each of them.
  - Not many parallel algorithms and none with documented tests.

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  - Not many parallel algorithms and none with documented tests.
- Work in this paper
  - Investigate parallel algorithms for variations of **HT**.
  - Different parallel architectures: multi-GPU, multicore, Xeon-Phi, distributed memory.
  - Different parallel programming paradigms: arrayFire, Thrust, OpenAcc, OpenMP, MPI.

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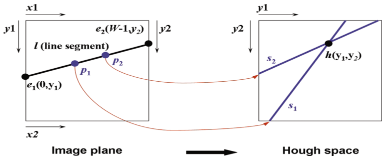
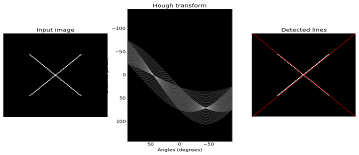
Standard transform as introduced by Hough

- Based on map from the (x, y) plane of the given points to (m, k) plane m and k ranging over the i possible slopes and intercepts of the lines.
- Each point in (x, y)-plane determines a line in (m, k)-plane.
- A bundles of lines intercepting in the (m, k)-plane define collinearity for the points associated with them in the (x, y)-plane.
- A combinatorial algorithm is immediately suggested. Complexity?



Duda-Haart-Hough Transform (**DHHT**)

- Introoduced by Richard Duda nad Peter Haart as an alternative mapping to the Hough transformi [3].
- Represent lines and points by their polar coordinates.
- Map in point in (x, y) to the (ρ, θ)-plane.
- Each point in the (x, y)-planedefines a sinusoid in the (ρ, θ)-plane.
- The intersection of two or more sinusoids indicates collinearity of the respective points.
- Algorithm: compute the sinusoid defined by each point and scan for intersections between sinusoid.



The Radon transform

- It can be seen as generalized form of the Hough transform.
- For a discrete image, a projection is computed as the sum of data lying in a unit-wide strip.
- Replaces HT vote counting with intensity addition.
- As in HT, integral along $x \cos\theta + y \sin\theta$

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Dynamic Combinatorial **HT**

- Implement **DHHT**.
- Exhaustive scan of each point to detect other collinear points.
- Target: find peaks of $(r, theta)$ pairs, where many lines intersect.
- Consider points in sequence and for each point p compute (r_i, θ_i) for the line defined by p and any other point p_i.
- Intersection of maximum peak $(r, theta)$ considered to define a line. All its points remove from further computations.
- Computation of all pairs (r_i, θ_i) can be made in parallel, however work for each point can be quadratic.
- Work for all points can be cubic.
- Prohibitive for example for a sample with 2^{20} foreground pixels?
- Work complexity can be improved by sampling.

Standard Duda-Haart-Hough algorithm

- Computation performed over discrete values for $(r, theta)$.
- For each discrete θ and each (x, y), a pair $(r, theta)$ is computed and a matrix of intersection counts is accumulated.
- Matrix $(r, theta)$ scanned for peak.
- Threshold can be used to decided which pairs $(r, theta)$ are considered to define lines. Example: OpenCV, and the Intel implementation of the Hough Transform.
- Accumulation and scan of matrix can be parallel.
- Problem: in principle, there is no mathematical limit for the granularity of θ intervals. No upper limit for work to be performed.
- Solution: θ scanned with finer granularity only in regions with higher density of data. It demands point indexing or clustering.

Fast and adaptive **HT**

- Sample voting by regions of space.
- Increase *resolution* of θ for regions with many accumulated votes.
- Split points in space to consider string cluster or to postpone computations in well separated regions.
- Standard **DHHT** or dynamic combinatorial **DHHT** can be considered.

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The essential steps of in a **DHHT** algorithm

- Voting: for each point and each possible angle θ find the respective $(r, theta)$ pair.
- Vote counting: count number of intersections for each $(r, theta)$.
- Vote scanning:
  - OpenCV: select all pairs $(r, theta)$ that exceed a given threshold.
  - Hough: find pairs that represent local maxima.

Complexity limits

- Voting
  - The easy step.
  - No interference involved.
  - Theoretical work upper bound in $O(n)$, for n pixels.
  - Practical scaling: $O(n/p)$, p being number of processors.

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  - Solutions
    - Impose mutual exclusion: mutex, compare-and-swap, others.

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  - Solutions
    - Impose mutual exclusion: mutex, compare-and-swap, others. Sequential algorithm, in worst case can become quadratic.
    - Concurrent writing for a leader election. Same upper bound as mutual exclusion.
    - Avoid data interference. For example, parallel on range of θ.

The parallel architectures and their programming models

- Multi-core
    - OpenMP
    - Thrust
    - OpenACC
- Multi-gpu
    - OpenMP
    - Thrust
    - ArrayFire
    - OpenACC
- Intel Xeon-phi
    - OpenMP
    - OpenACC
- Distriubuted memory
    - MPI
    - Coarrays

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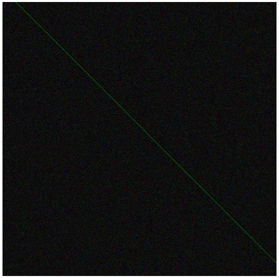
A line with Gaussian noise at 37 amplitude

- Image generated with cimg *noise(37)*



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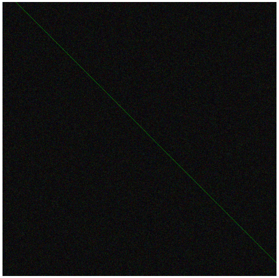
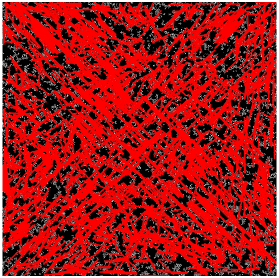


- 200K lines detected with standard HT, using OpenCV.
- Disclaimer: Noise removal could have been applied.

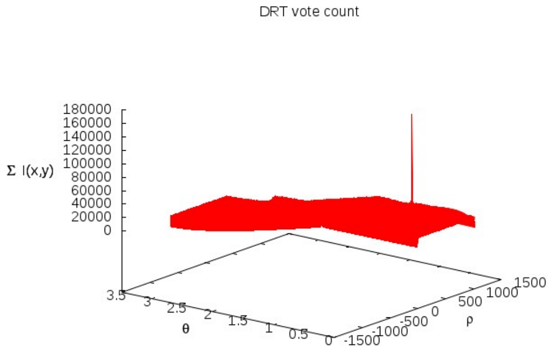
Probabilistic HT in OpenCV

- More than 2000 lines detected.



- Again: no tweaking done with noise removal or threshold setting.

DRT: The vote count



- $\theta \in [0..\pi)$
- $\sum I(x, y)$ sums intensity in one image strip.

Preliminary performance tests

- Run on gcc (-fopenmp) $-O3$, GNU Linux Centos 7, Intel Xeon E5-2680 v3 (2.50GHz).
- Best speed-up at 5.04 on 6 cores, (efficiency 84%).
- Drop in efficiency from 6 to 12 cores. Explained by cache/hit miss.
- Drop from 12 to 24 cores: cache hit/miss and non locality of data across physical processors.
- Huge drop in performance for 4096x4096 due again hit/miss ratio in processor's caches.

Pixels	1 core	6 cores	12 cores	24 cores
512x512	1.011s	0.249s	0.155s	0.096s
1024x1024	7.762s	1.548s	0.843s	0.460s
2048x2048	87.31s	24.07s	14.92s	8.181s
4096x4096	1144s	272.3s	154.6s	83.92s

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- Tests ongoing for Aproximate DRT show 4Kx4K pixels on 4 cores at: 4.6s.
- Tests also being performed for a dual gpu architecture and 24 multi-core.

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On going work

- Approximate DRT now being test.
- Both HT and DRT can be improve by expoiting locality in regions with higher density of data.
- Parallel indexing higher order data is theme of our companion poster in CHEP'2016.
- DRT algorithm can used to compute inverse Radon Transform. An efficient parallel algorithm offers promise in radio-astronomy and electon microscopy, for example.
- Question: Can *reals* instead of floats improve either HT for DRT?
  - Unums for *reals*.
  - Sparse matrices needed.

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