OpenCV on a GPU

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NVIDIA

NVIDIA

GPU access

- To access NVIDIA cluster send email to jlevites@nvidia.com
- Subject line: "OpenCV GPU Test Drive"
- Add your name and phone number

Webinar Feedback

Submit your feedback for a chance to win Tesla K20 GPU
https://www.surveymonkey.com/s/OpenCV_Webinar

More questions on OpenCV and GPUs

- Stay tuned with NVIDIA webinars:
  http://www.nvidia.com/object/cuda_signup_alerts.html
- Refer to OpenCV Yahoo! Groups

Outline

- OpenCV
- Why GPUs?
- An example - CPU *vs.* CUDA
- OpenCV CUDA functions
- Discussion
- Future
- Summary

OpenCV

Introduction

- Open source library for computer vision, image processing and machine learning
- Permissible BSD license
- Freely available (www.opencv.org)

Portability

- Real-time computer vision (x86 MMX/SSE, ARM NEON, CUDA)
- C (11 years), now C++ (3 years since v2.0), Python and Java
- Windows, OS X, Linux, Android and iOS

Usage

Usage:

- >6 million downloads, > 47,000 user group
- Google, Yahoo, Microsoft, Intel, IBM, Sony, Honda, Toyota

Applications:

- Street view image stitching
- Automated inspection and surveillance
- Robot and driver-less car navigation and control
- Medical image analysis
- Video/image search and retrieval
- Movies - 3D structure from motion
- Interactive art installations

Functionality

Desktop

- x86 single-core (Intel started, now Itseez.com) - v2.4.5 >2500 functions (multiple algorithm options, data types)
- CUDA GPU (Nvidia) - 250 functions (5x – 100x speed-up) http://docs.opencv.org/modules/gpu/doc/gpu.html
- OpenCL GPU (3rd parties) - 100 functions (launch times ~7x slower than CUDA*)

Mobile (Nvidia):

- Android (not optimized)
- Tegra – 50 functions NEON, GLSL, multi-core (1.6 – 32x speed-up)

**Shengen Yan, AMD Fusion Developer Summit 2012.*

Functionality

- Image/video I/O, processing, display (core, imgproc, highgui)
- Object/feature detection (objdetect, features2d, nonfree)
- Geometry-based monocular or stereo computer vision (calib3d, stitching, videostab)
- Computational photography (photo, video, superres)
- Machine learning & clustering (ml, flann)
- CUDA and OpenCL GPU acceleration (gpu, ocl)

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Why GPU?

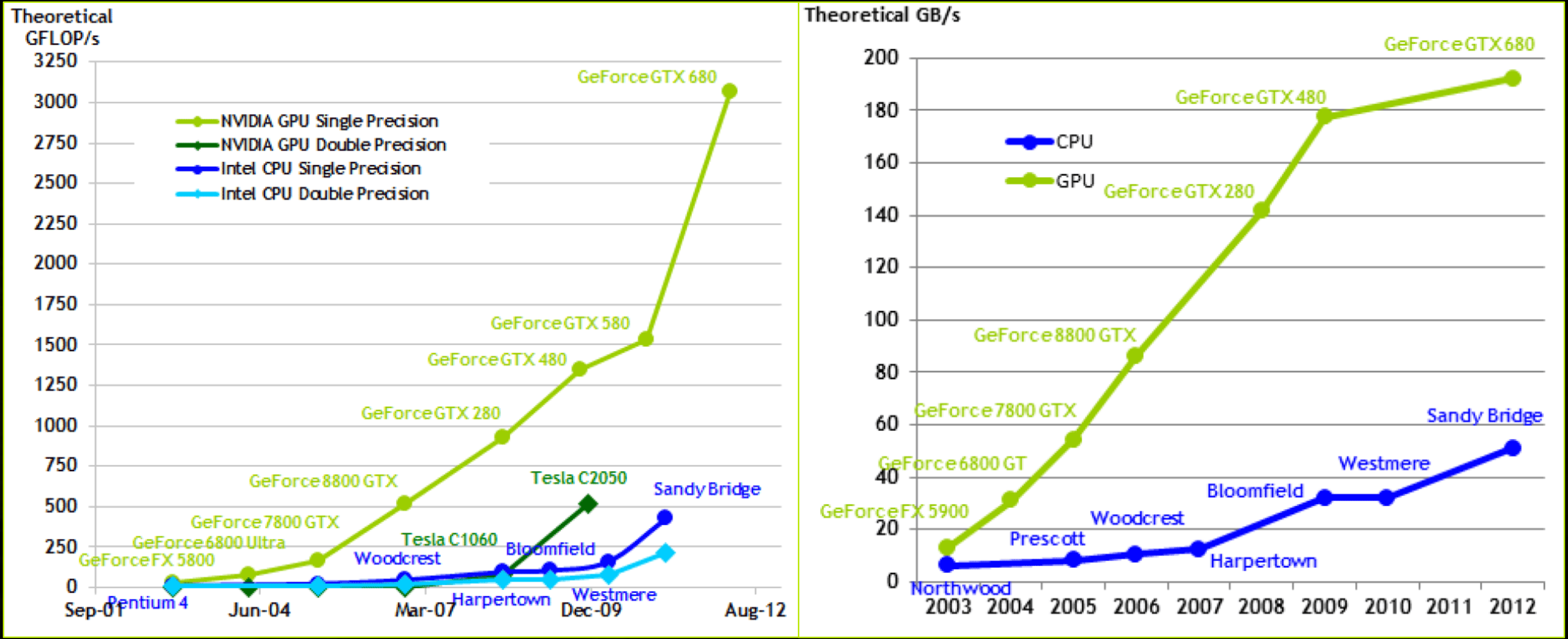
CPU

- Reached speed and thermal power limit!
- Incremental improvements (memory caches and complex architectures)
- Multi-core (4/8), but software rarely multi-core

GPU

- Highly parallel with 100s of simple cores
- Easier to extend by adding more cores
- Continue to grow exponentially!

GPU > CPU (compute and memory)



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*http://hemprasad.wordpress.com/2013/03/03/introduction-to-cuda-5-0/

GPU for OpenCV

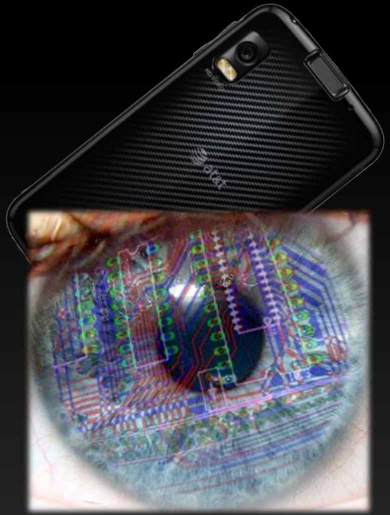
Graphics

Render Images From Scenes

Inverse Problems

Massively Parallel

Computer Vision



Understand Scenes From Images

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OpenCV CPU example

```
#include <opencv2/opencv.hpp>
using namespace cv;
int main() {
    Mat src = imread(“car1080.jpg”, 0);
    if (!src.data) exit(1);
    Mat dst;
    bilateralFilter(src, dst, -1, 50, 7);
    Canny(dst, dst, 35, 200, 3);
    imwrite(“out.png”, dst);
    return 0;
}
```

← **OpenCV header files**

← **OpenCV C++ namespace**

← **Load an image file as grayscale**

← **Allocate a temp output image**

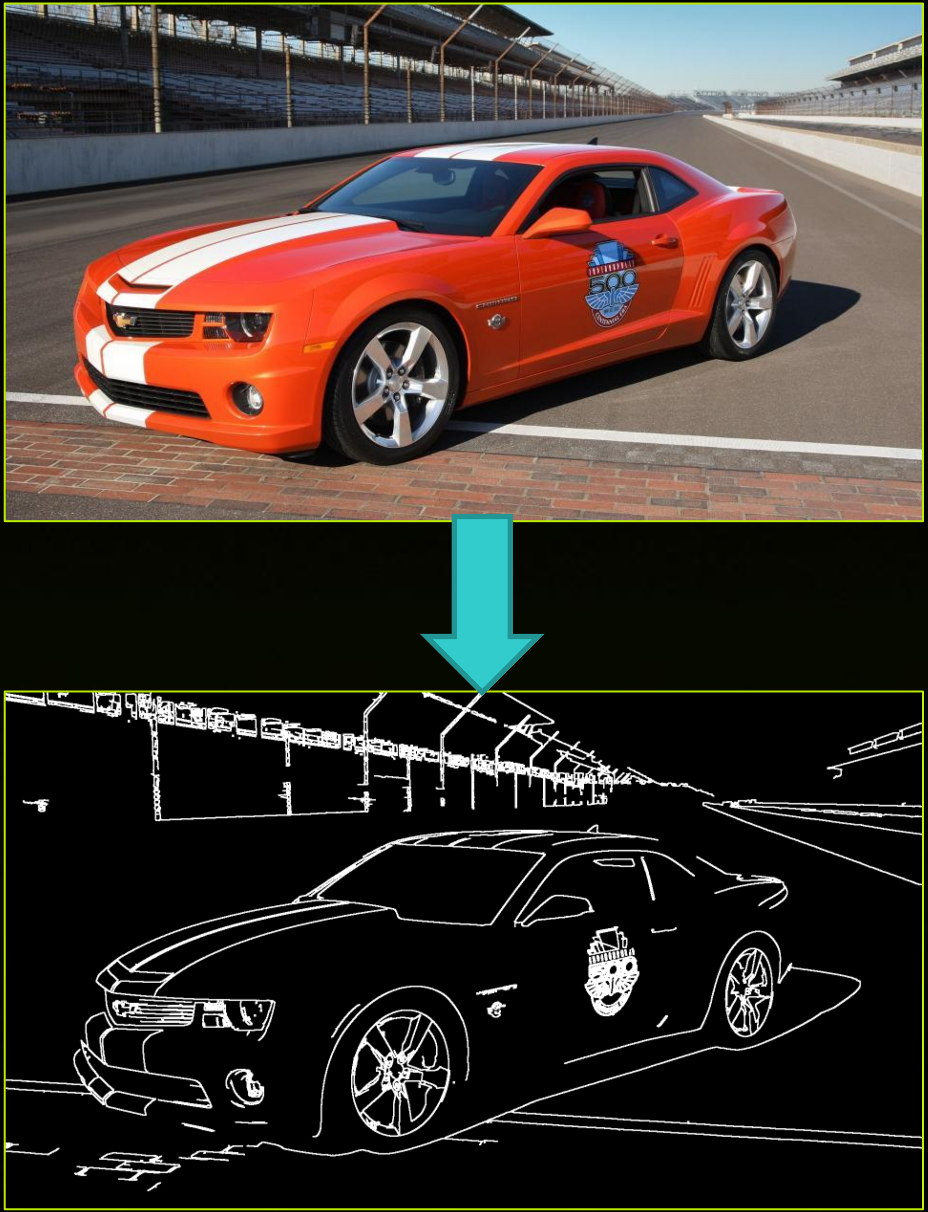
← **Blur the image but keep edges sharp**

← **Find the edges, drawn as white pixels**

← **Store to an image file**

OpenCV CPU example

```
#include <opencv2/opencv.hpp>
using namespace cv;
int main() {
    Mat src = imread(“car1080.jpg”, 0);
    if (!src.data) exit(1);
    Mat dst;
    bilateralFilter(src, dst, -1, 50, 7);
    Canny(dst, dst, 35, 200, 3);
    imwrite(“out.png”, dst);
    return 0;
}
```

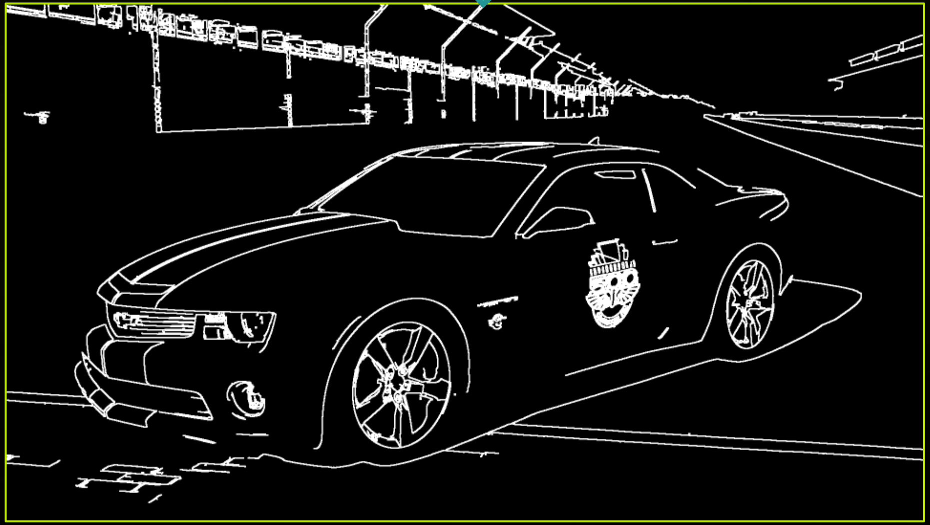


OpenCV CUDA example

```
#include <opencv2/opencv.hpp>
#include <opencv2/gpu/gpu.hpp>                          ← OpenCV GPU header file
using namespace cv;
int main() {
      Mat src = imread("car1080.jpg", 0);
      if (!src.data) exit(1);
      gpu::GpuMat d_src(src);                           ← Upload image from CPU to GPU memory
      gpu::GpuMat d_dst;                                ← Allocate a temp output image on the GPU
      gpu::bilateralFilter(d_src, d_dst, -1, 50, 7);    ← Process images on the GPU
      gpu::Canny(d_dst, d_dst, 35, 200, 3);             ← Process images on the GPU
      Mat dst(d_dst);                                   ← Download image from GPU to CPU mem
      imwrite("out.png", dst);
      return 0;
}
```

OpenCV CUDA example

```
#include <opencv2/opencv.hpp>
#include <opencv2/gpu/gpu.hpp>
using namespace cv;
int main() {
    Mat src = imread(“car1080.jpg”, 0);
    if (!src.data) exit(1);
    gpu::GpuMat d_src(src);
    gpu::GpuMat d_dst;
    gpu::bilateralFilter(d_src, d_dst, -1, 50, 7);
    gpu::Canny(d_dst, d_dst, 35, 200, 3);
    Mat dst(d_dst);
    imwrite(“out.png”, dst);
    return 0;
}
```



CPU vs. CUDA

NVIDIA

```
#include <opencv2/opencv.hpp>
using namespace cv;
int main() {
      Mat src = imread("car1080.jpg", 0);
      if (!src.data) exit(1);
      Mat dst;
      bilateralFilter(src, dst, -1, 50, 7);      ←2521ms
      Canny(dst, dst, 35, 200, 3);               ←19ms
      imwrite("out.png", dst);
      return 0;
}
```

```
#include <opencv2/opencv.hpp>
#include <opencv2/gpu/gpu.hpp>
using namespace cv;
int main() {
      Mat src = imread("car1080.jpg", 0);
      if (!src.data) exit(1);
0.5ms→ gpu::GpuMat d_src(src);
0ms→   gpu::GpuMat d_dst;
187ms→ gpu::bilateralFilter(d_src, d_dst, -1, 50, 7);
12ms→  gpu::Canny(d_dst, d_dst, 35, 200, 3);
       Mat dst(d_dst);
0.5ms→ imwrite("out.png", dst);
      return 0;
}
```

12.7x speedup!

TOTALS: CPU=2540ms CUDA=200ms*

**results obtained over many frames*

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CUDA Matrix Operations

Point-wise matrix math

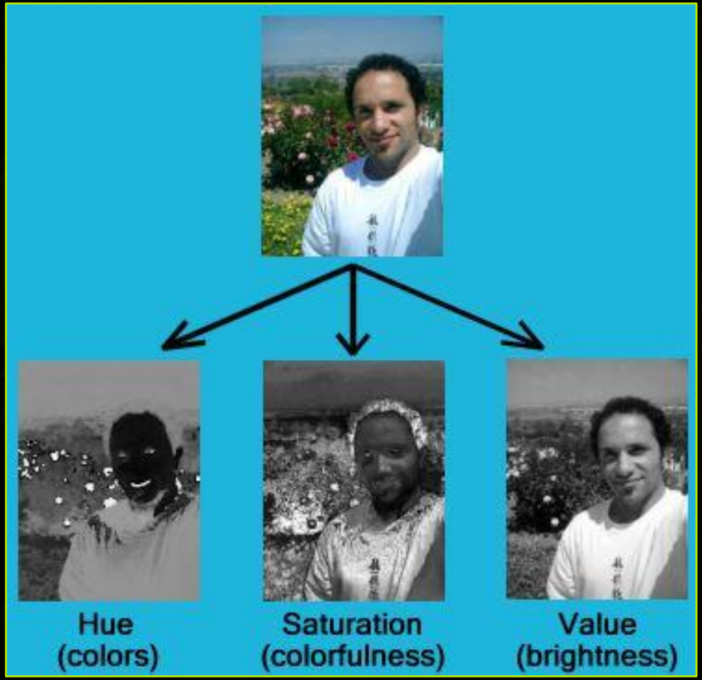
- gpu::add(), ::sum(), ::div(), ::sqrt(), ::sqrSum(), ::meanStdDev, ::min(), ::max(), ::minMaxLoc(), ::magnitude(), ::norm(), ::countNonZero(), ::cartToPolar(), etc..

Matrix multiplication

- gpu::gemm()

Channel manipulation

- gpu::merge(), ::split()



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*www.shervinemami.info/blobs.html

CUDA Geometric Operations

Image resize with sub-pixel interpolation

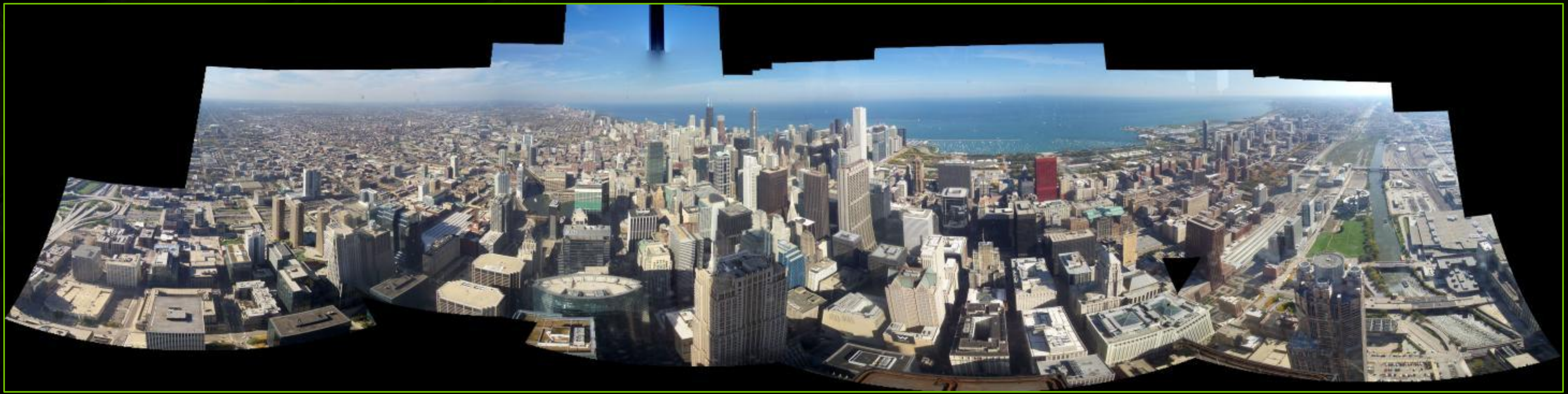
- gpu::resize()

Image rotate with sub-pixel interpolation

- gpu::rotate()

Image warp (e.g., panoramic stitching)

- gpu::warpPerspective(), ::warpAffine()



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www.skyscrapercity.com

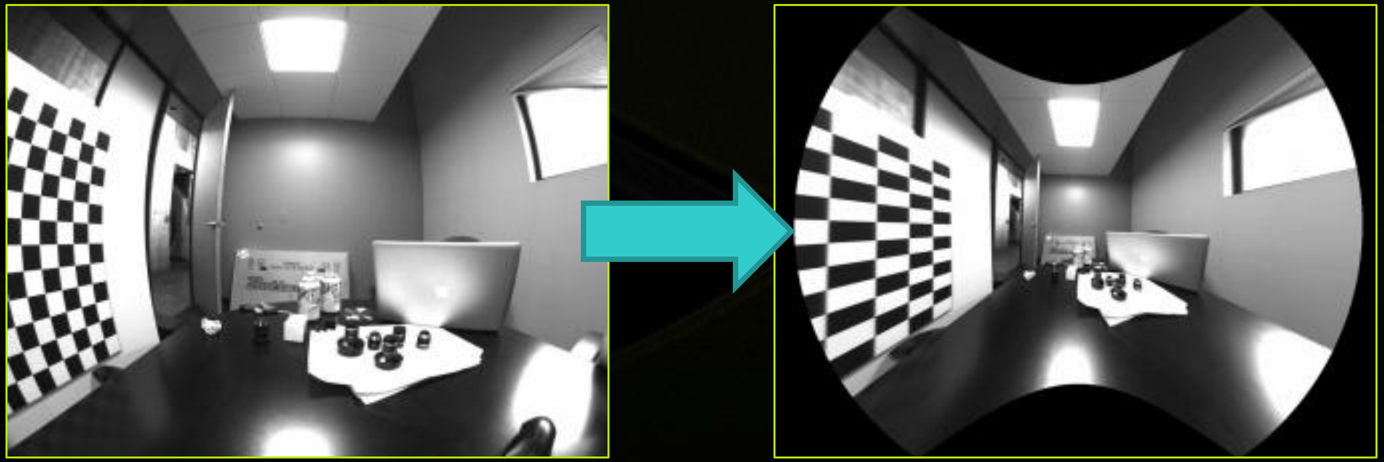
CUDA other Math and Geometric Operations

Integral images (*e.g.*, object detection and recognition, feature tracking)

- gpu::integral(), ::sqrIntegral()

Custom geometric transformation (*e.g.*, lens distortion correction)

- gpu::remap(), ::buildWarpCylindricalMaps(), ::buildWarpSphericalMaps()


*

**www.ivs.auckland.ac.nz/web/calibration.php*

CUDA Image Processing

Smoothing

- gpu::blur(), ::boxFilter(), ::GaussianBlur()

Morphological

- gpu::dilate(), ::erode(), ::morphologyEx()

Edge Detection

- gpu::Sobel(), ::Scharr(), ::Laplacian(), gpu::Canny()

Custom 2D filters

- gpu::filter2D(), ::createFilter2D_GPU(), ::createSeparableFilter_GPU()

Color space conversion

- gpu::cvtColor()

CUDA Image Processing

Image blending

- gpu::blendLinear()

Template matching (automated inspection)

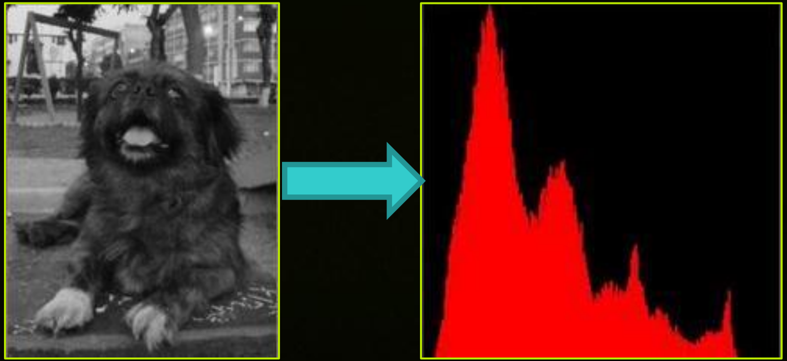
- gpu::matchTemplate()

Gaussian pyramid (scale invariant feature/object detection)

- gpu::pyrUp(), ::pyrDown()

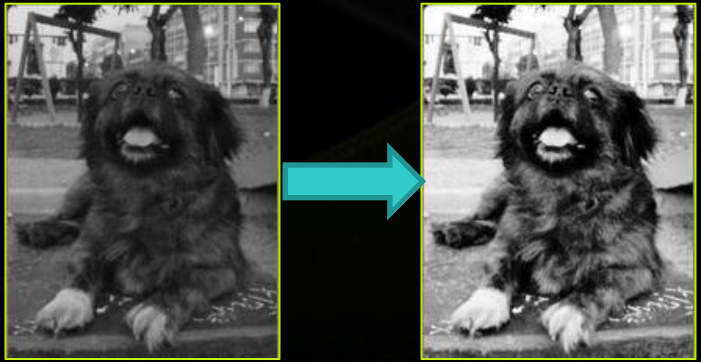
Image histogram

- gpu::calcHist(), gpu::histEven, gpu::histRange()


*

Contract enhancement

- gpu::equalizeHist()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**OpenCV Histogram Equalization Tutorial*

CUDA De-noising

Gaussian noise removal

- gpu::FastNonLocalMeansDenoising()

Edge preserving smoothing

- gpu::bilateralFilter()

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*www.cs.cityu.edu.hk/~qiyang/publications.html

CUDA Fourier and MeanShift

Fourier analysis

- gpu::dft(), ::convolve(), ::mulAndScaleSpectrums(), etc..

MeanShift

- gpu::meanShiftFiltering(), ::meanShiftSegmentation()

*

www.lfb.rwth-aachen.de/en/education/Workshop/t.schoenen.html

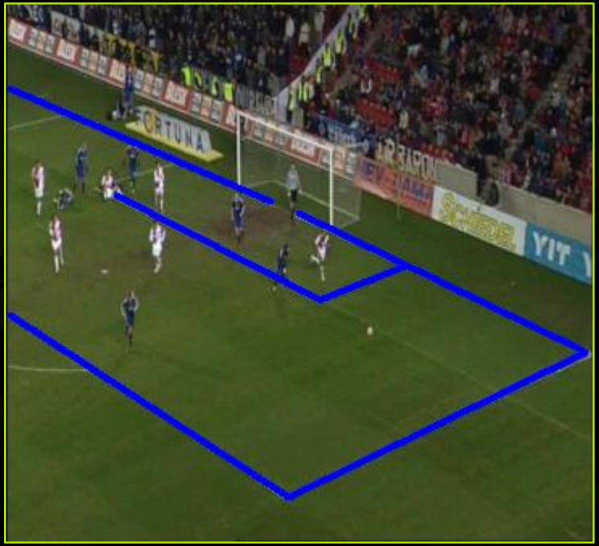
CUDA Shape Detection

Line detection (*e.g.*, lane detection, building detection, perspective correction)

- **gpu::HoughLines(), ::HoughLinesDownload()**

Circle detection (*e.g.*, cells, coins, balls)

- **gpu::HoughCircles(), ::HoughCirclesDownload()**



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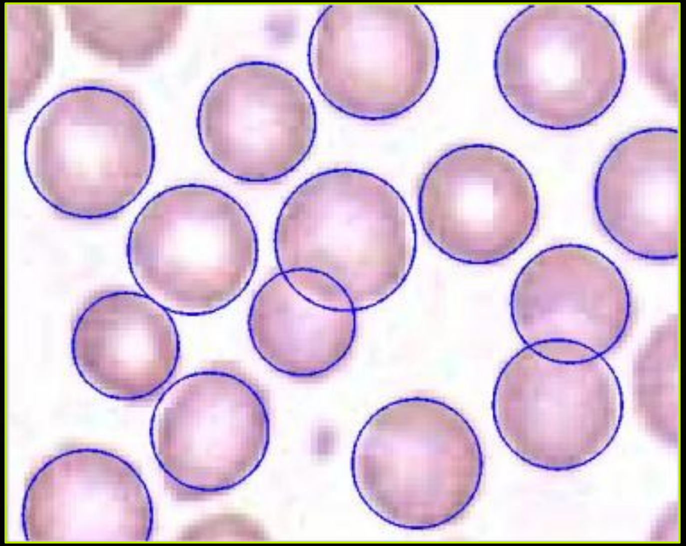
www.potucek.net/projects.html



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+www.cs.bgu.ac.il/~icbv071/StudentProjects.php

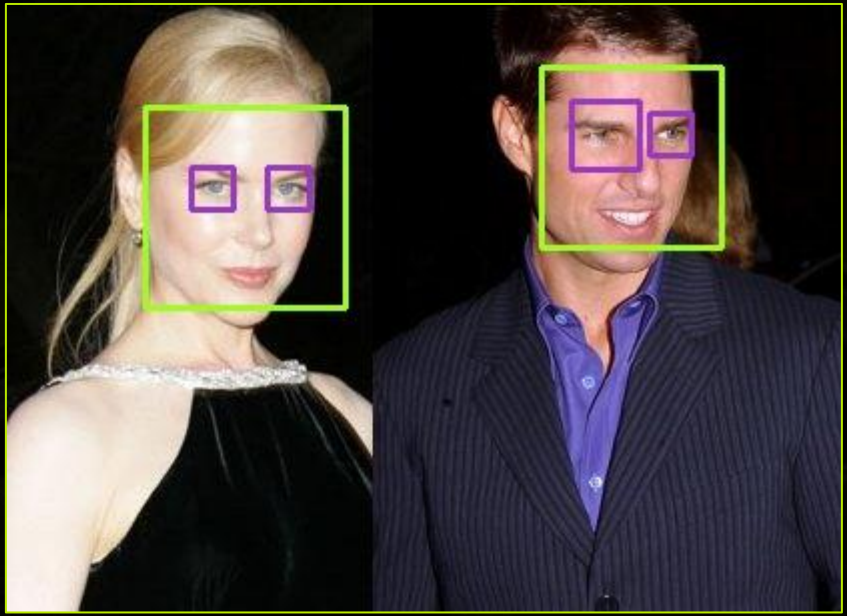
CUDA Object Detection

HAAR and LBP cascaded adaptive boosting (*e.g.*, face, nose, eyes, mouth)

- gpu::CascadeClassifier_GPU::detectMultiScale()

HOG detector (e.g., person, car, fruit, hand)

- gpu::HOGDescriptor::detectMultiScale()



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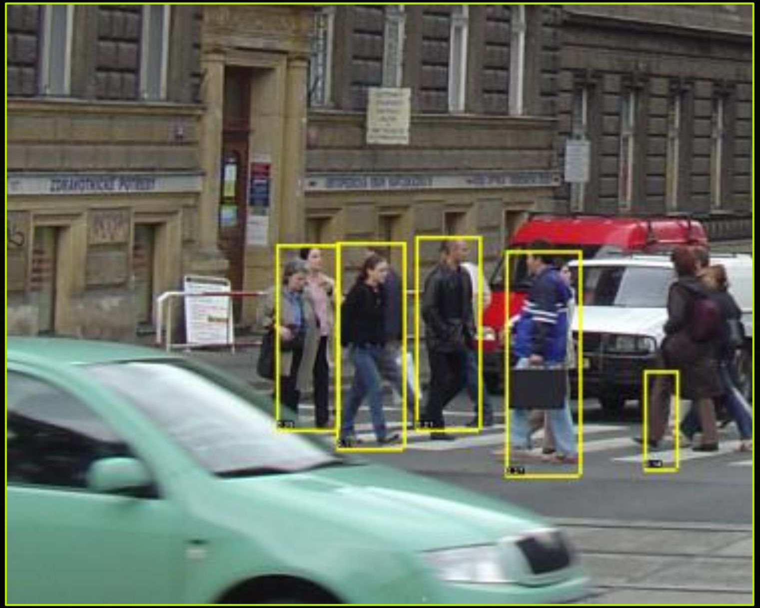

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**glowingpython.blogspot.com/2011/11/*

+src: www.cvc.uab.es/~dvazquez/wordpress/?page_id=234

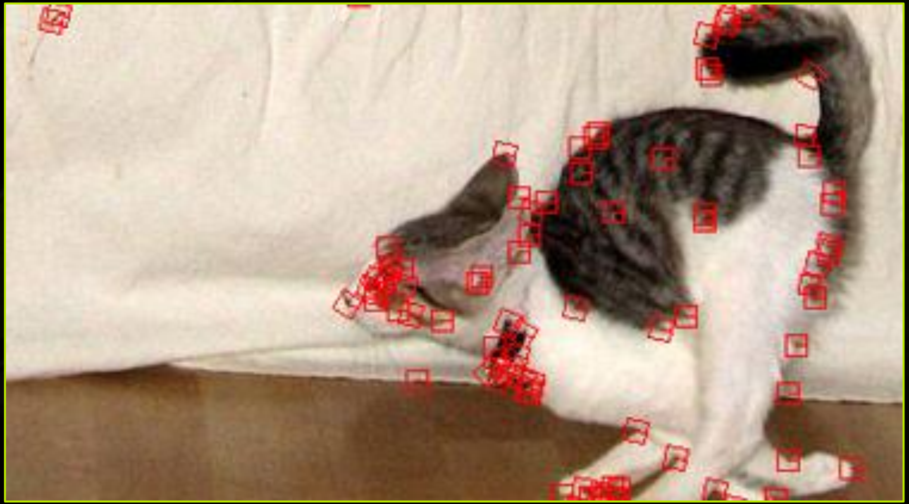
CUDA Object Recognition

Interest point detectors

- gpu::cornerHarris(), ::cornerMinEigenVal(), ::SURF_GPU, ::FAST_GPU, ::ORB_GPU(), ::GoodFeaturesToTrackDetector_GPU()

Feature matching

- gpu::BruteForceMatcher_GPU(), ::BFMatcher_GPU()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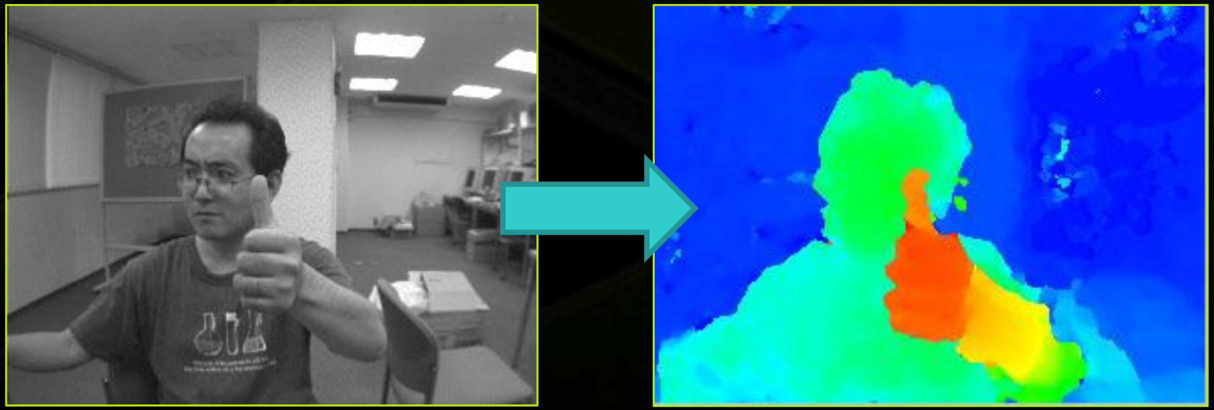
**Kathleen Tuite, CSE576 Project, U of W, 2008.*

CUDA Stereo and 3D

- RANSAC (e.g., object 3D pose, structure from motion, stereo vision)
  - gpu::solvePnPRansac()
- Stereo correspondence (disparity map)
  - gpu::StereoBM_GPU(), ::StereoBeliefPropagation(), ::StereoConstantSpaceBP(), ::DisparityBilateralFilter()
- Represent stereo disparity as 3D or 2D
  - gpu::reprojectImageTo3D(), ::drawColorDisp()



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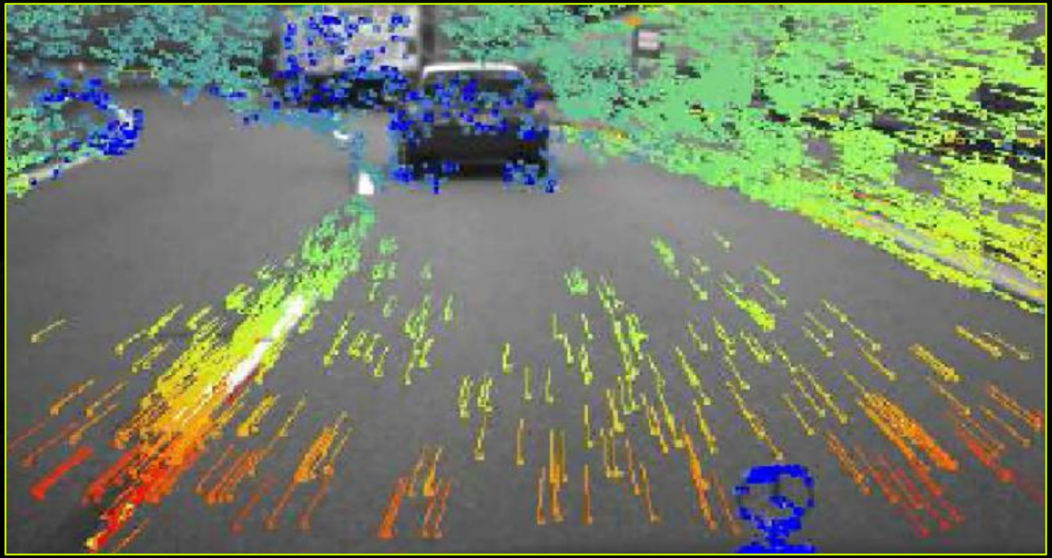
*www.cyverse.co.jp/eng/

CUDA Optical Flow

- **Dense/sparse optical flow (with simple block matching, pyramidal Lucas-Kanade, Brox, Farnebac, TV-L1)**
  - **gpu::FastOpticalFlowBM(), ::PyrLKOpticalFlow, ::BroxOpticalFlow(), ::FarnebackOpticalFlow(), ::OpticalFlowDual_TVL1_GPU(), ::interpolateFrames()**
- **Applications: motion estimation, object tracking, image interpolation**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www.scs.ch/blog/en/2013/01/dsp-optimisation-optical-flow/

CUDA Background Segmentation

- **Foregrdound/background segmentation (*e.g.*, object detection/removal, motion tracking, background removal)**
  - gpu::FGDStatModel, ::GMG_GPU, ::MOG_GPU, ::MOG2_GPU

*

*www.technologytell.com/apple/96538/inpaint-pro-4-appidemic/

Custom CUDA code

- CPU OpenCV provides access to image pixels to write custom functions
- ~ GPU-accelerated pixel access to write custom CUDA kernels – requires knowledge of CUDA
- http://docs.opencv.org/modules/gpu/doc/gpu.html

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CUDA Advantages

- Similar to CPU code – same API
- Great for long parallel operations and low data transfers – slowest CPU functions
- Significant boosts on GPU (*e.g.*, bilateralFilter() – 12.7x speedup)
- Makes CPU compute bound CV tasks feasible in real-time (*e.g.*, stereo vision, pedestrian detection, dense optical flow)
- Runtime check and use of CUDA acceleration

CUDA Disadvantages

- Only 250 functions
- Limited data types
  - GPU: 8-bit & 32-bit grayscale
  - CPU: +16-bit (HDR) & 32-bit color, ROI
- Explicitly program for CUDA
- Handle data transfers between CPU and GPU
- Only on NVIDIA GPU
- Some serial operations not sped up, *e.g.*, Canny()
- CUDA has startup delay

CUDA Start Up Delay

- First CUDA call initializes CUDA module
- Typical first call – CPU to GPU transfer (~2000ms and 1ms after that)
- Affects single frame applications, videos OK

Serial functions on CUDA

- Serial functions don’t port well
- Equivalent efficient CUDA parallel algorithms exist (*e.g.*, image sums, intergal images, histogram) – see www.moderngpu.com or Udacity’s CS344
- Serial GPU code saves transfer time
- CUDA CV algorithms actively being researched
- New CUDA generations (hw+sw) allow more algorithms

GPU Memory Access

Dedicated GPU	Integrated GPU
Own high speed memory	Shares CPU’s slow memory
High data transfer time	Free data transfers
Higher memory BW (~10x)	Lower memory BW
Desktops/workstations	Laptops
Functions with lots of processing	Functions with little processing

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Future - CUDA on Mobile

- Tegra with CUDA GPU (Logan) – mobile CUDA openCV possible!
- Low power and area (automotive, mobile)
- Kayla[1] and Jetson[2] (Tegra 3 + dGPU)
- Currently on mobile (Tegra) – NEON, GLES, and multi-threading(OpenCV4Tegra)
- Custom NEON/GLES programming hard, CUDA easier

[1] www.nvidia.com/object/seco-dev-kit.html
[2] www.nvidia.com/object/jetson-automotive-developement-platform.html

Future - Khronos OpenVX

- "OpenVX" - new standard for hw accelerated CV
  - Khronos (e.g., OpenGL, OpenCL, OpenVG)
  - NVIDIA, Texas Instruments, Samsung, Qualcomm, ARM, Intel
  - For mobile acceleration hw (CPU, GPU, DSP, fixed-function)
- Graph model *vs.* synchronous programming model
- CV nodes linked in graph at initialization, efficient hw specific processing pipeline automatically generated
- OpenCV to use OpenVX internally to better use hw acceleration

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Summary

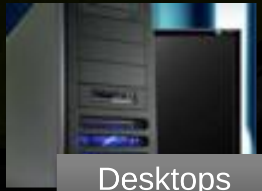
- OpenCV a well established comprehensive library
- GPU > CPU and growing
- Many CV algorithms great for GPU
- CUDA OpenCV - 250 functions, custom GPU kernels
- http://docs.opencv.org/modules/gpu/doc/gpu.html
- OpenVX extends beyond GPU (DSP, fixed function hw)

GPU Everywhere!

Tablets

Kayla

Jetson



Desktops

Cloud & Supercomputers

- Tegra Tablets, Smartphones, Shield
  - Tegra 3 CPU & GPU, running Android, WinRT or Linux.
- Kayla Development Board
  - Tegra 3 CPU + laptop GPU, running Linux.
- Jetson Automotive Platform
  - Tegra 3 CPU + laptop GPU, running Linux.
- Desktop
  - Intel or AMD CPU with GeForce, Quadro or Tesla GPUs.
- Cloud & Supercomputer centers
  - Amazon Cloud with Fermi GPUs, Nvidia GRID

GPU access

- To access NVIDIA cluster send email to jlevites@nvidia.com
- Subject line: “OpenCV GPU Test Drive”
- Add your name and phone number

Webinar Feedback

Submit your feedback for a chance to win Tesla K20 GPU
https://www.surveymonkey.com/s/OpenCV_Webinar

More questions on OpenCV and GPUs

- Stay tuned with NVIDIA webinars:
  http://www.nvidia.com/object/cuda_signup_alerts.html
- Refer to OpenCV Yahoo! Groups

Questions

Upcoming GTC Express Webinars

June 12 - Easily Accelerating Existing Monte Carlo Code: CVA and CCR Examples

June 20 - GPU Accelerated XenDesktop for Designers and Engineers

June 26 - Understanding Dynamic Parallelism at Any Scale with Allinea's Unified Tools

July 9 - NVIDIA GRID VCA: A Turnkey Appliance for Design and Engineering Applications

July 10 - Introduction to the CUDA Toolkit as an Application Build Tool

Register at www.gputechconf.com/gtcexpress