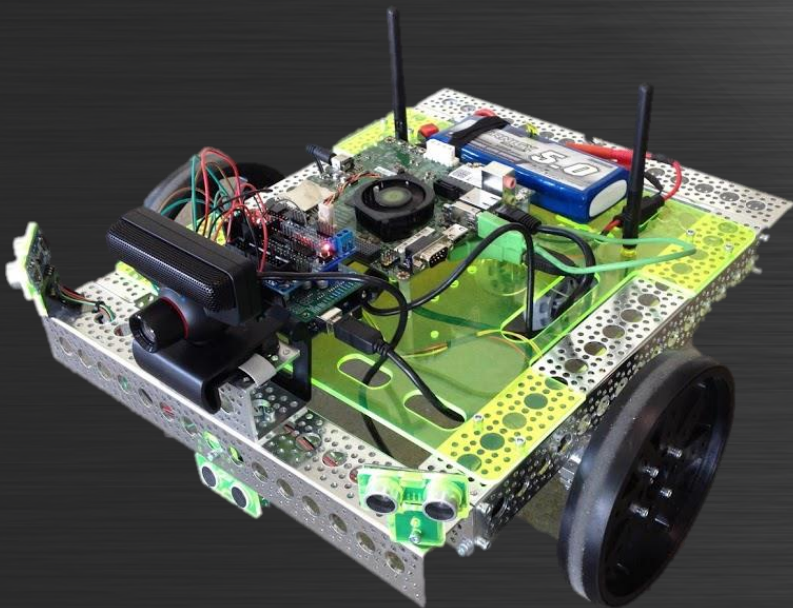




CAL POLY
SAN LUIS OBISPO



Robotics Teaching Kit with 'Jet' for Educators

Joe Bungo (NVIDIA) and John Seng (CalPoly)

AGENDA

Introduction to NVIDIA's GPU Educators Program and GPU Teaching Kits

Robotics Teaching Kit with 'Jet' Syllabus Overview

Introduction to 'Jet'

'Jet' Teaching Kit Contents

Cal Poly Activities, Q&A

GPU EDUCATORS PROGRAM

Advancing STEM Education with Accelerated Computing

"What an amazing resource for educators in GPU computing! The GPU Teaching Kit has a wealth of resources that allow both experienced and new teachers in parallel computing easily incorporate GPUs into their current course or design an entirely new course."

Prof. John Owens, UC-Davis

"The GPU teaching kit covers all aspects of GPU based programming.. the epitome for educators who want to float a course on heterogeneous computing using graphics processors as accelerators."

Dr. Tajendra Singh, UCLA

"Teaching resources such as these will be invaluable in helping the next generation of scientists and engineers know how to fully harness the capability of this exciting technology."

Dr. Alan Gray, University of Edinburgh

"The Teaching Kit covers all the needed content of a GPU/computing course.. The projects and quiz designs are handy, saving a lot of time and effort. Moreover, the whole structure is well organized to lead students step by step in CUDA programming. I highly recommend integrating it into a related syllabus."

Dr. Bin Zhou, University of Science and Technology of China

FLAGSHIP OFFERING: GPU TEACHING KITS

Breaking the Barriers to GPU Education in Academia

Co-develop with academic partners

Comprehensive teaching materials

Lecture slides and notes

Lecture videos

Hands-on labs/solutions

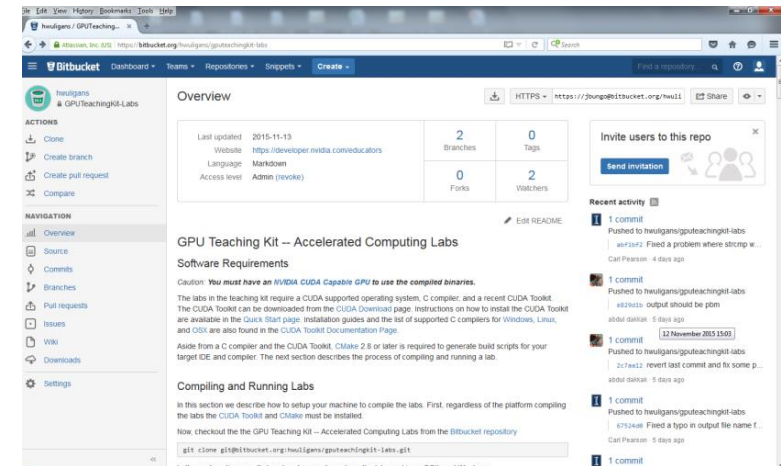
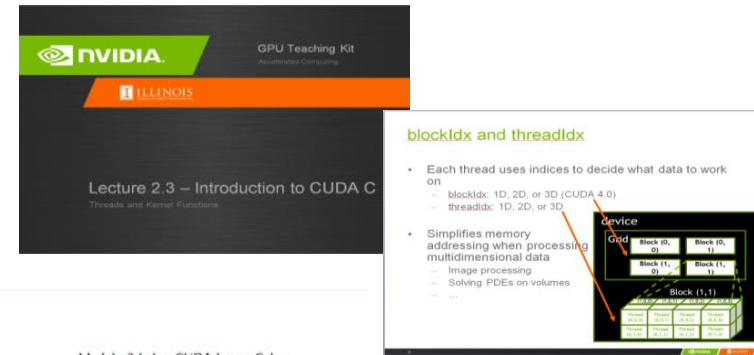
Larger coding projects/solutions

Quiz/exam questions/solution

Possible GPU resource

Software tools

Textbooks and/or e-books



FLAGSHIP OFFERING: GPU TEACHING KITS

Breaking the Barriers to GPU Education in Academia

Different kits for different courses

Accelerated/parallel computing
Robotics

Machine/Deep learning

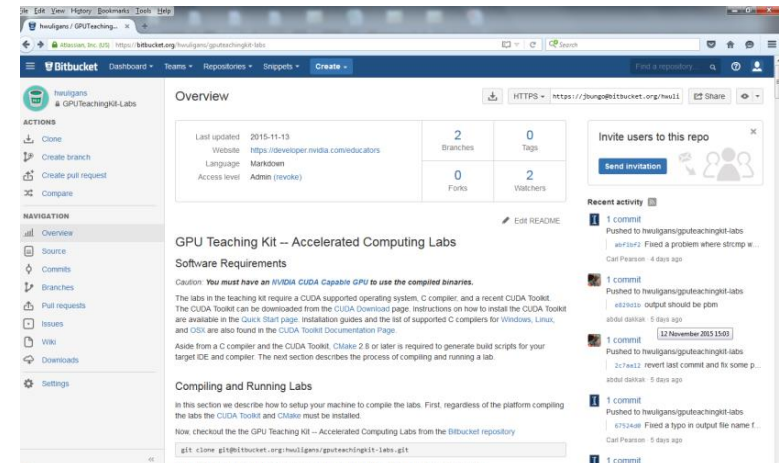
Computer graphics

Computer architecture

Computational domain sciences

Etc.

Localization plans in progress



OTHER PROGRAM OFFERINGS

Collaborative Opportunities and Supporting Expertise

Instructor workshops, conferences, sponsorships and exhibits

Enablement web pages

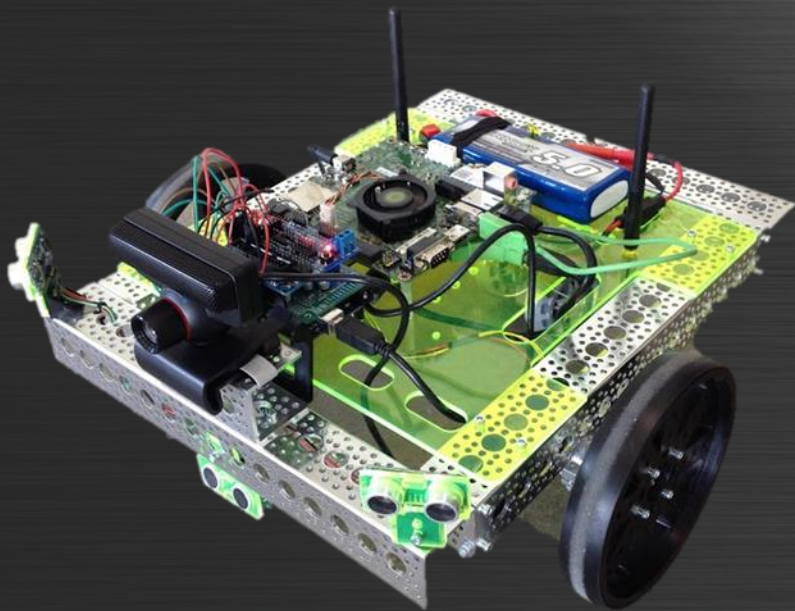
Getting started guides/videos

Email updates

Feedback and enhancement requests



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Robotics Teaching Kit with 'Jet'

Available to Instructors Now!
developer.nvidia.com/educators

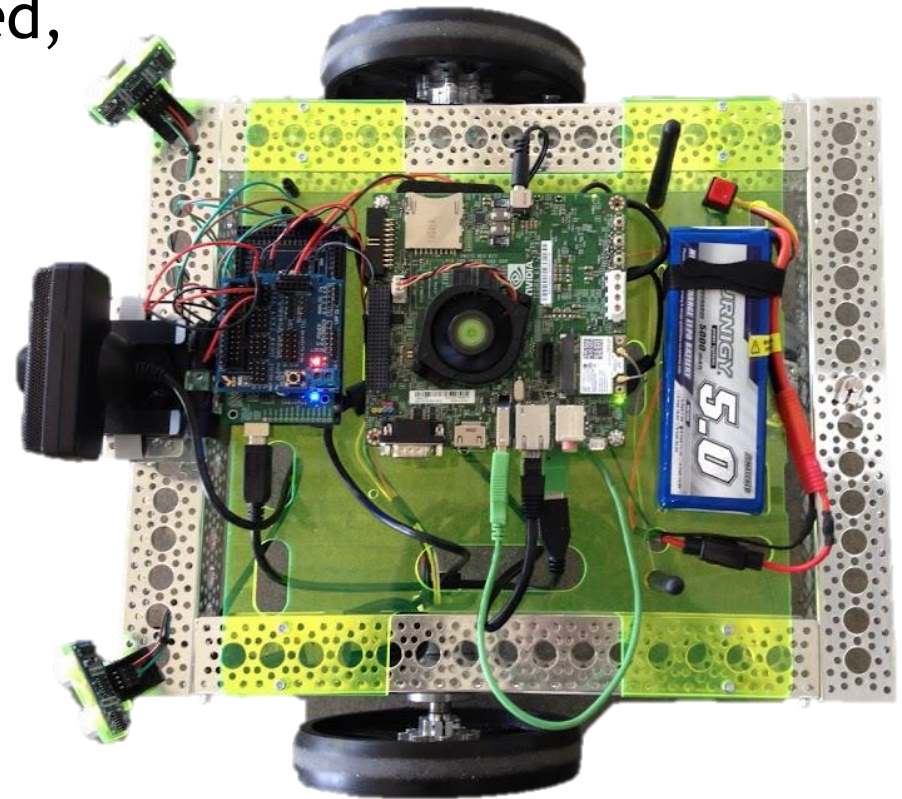
ROBOTICS TEACHING KIT

Module Goals

Learn interdisciplinary, GPU-accelerated,
autonomous Robotics

Technical subjects

- Sensors
- Computer Vision
- Machine Learning
- Dead Reckoning
- Path Planning
- Localization
- Control
- Obstacle Avoidance



TEACHING KIT MODULES

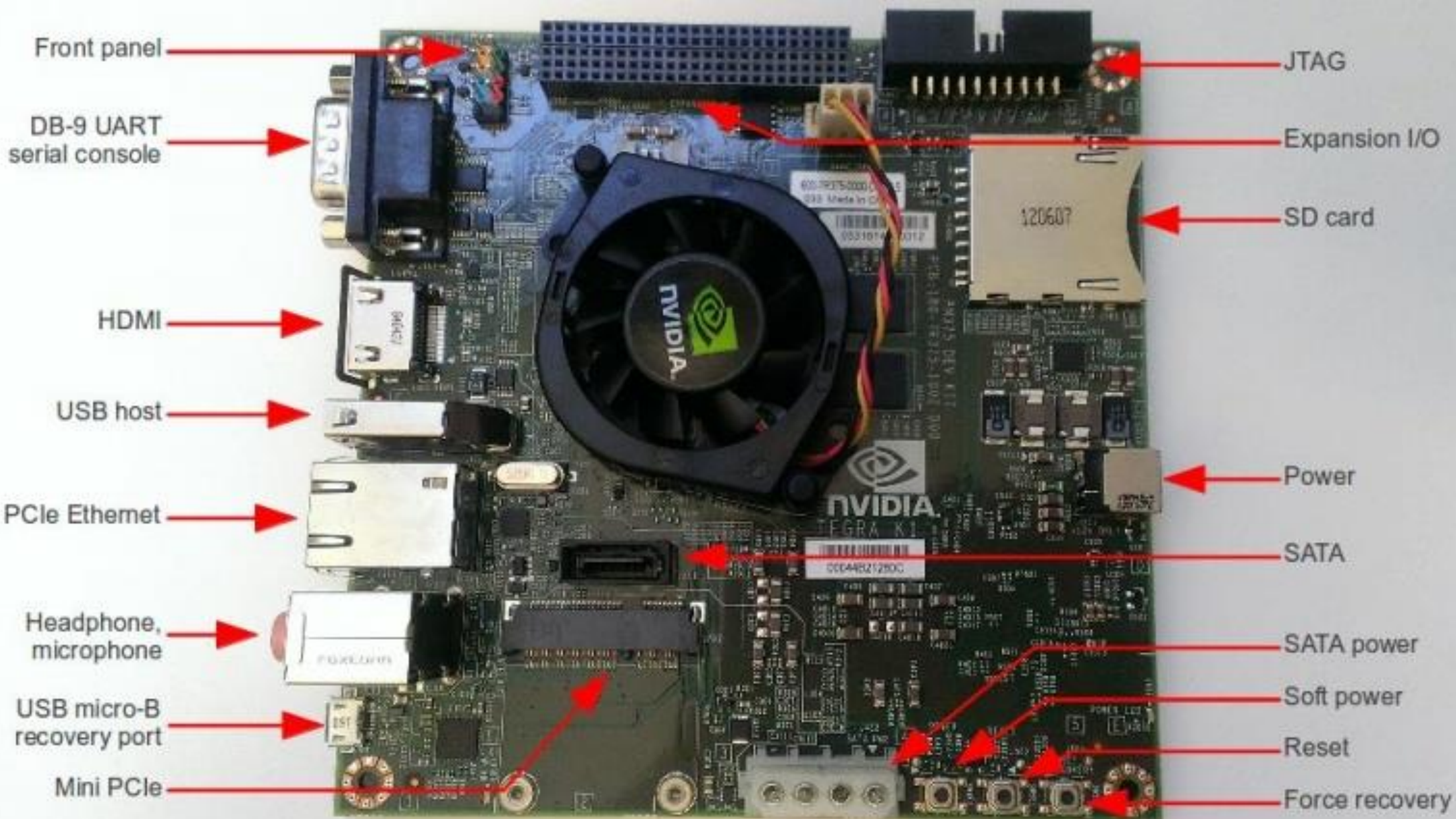
Robotics with 'Jet'

Module 1 Course Introduction	<ul style="list-style-type: none">• Course Introduction and Overview• Introduction to Robotics• Jetson TK1/TX1 and Toolkit Basics• Introduction to 'Jet'• ROS	Current Release
Module 2 Sensors and Actuators	<ul style="list-style-type: none">• Sonar• Camera• Accelerometer• Gyroscope	Current Release
Module 3 Computer Vision	<ul style="list-style-type: none">• Introduction to Computer Vision• Image Representation• Edge Detectors• Hough Transform• Image Filtering and Moments	Current Release
Module 4 Machine Learning	<ul style="list-style-type: none">• Machine Learning with Neural Networks• Neural Networks Models• cuDNN• Training and Usage	Future Release

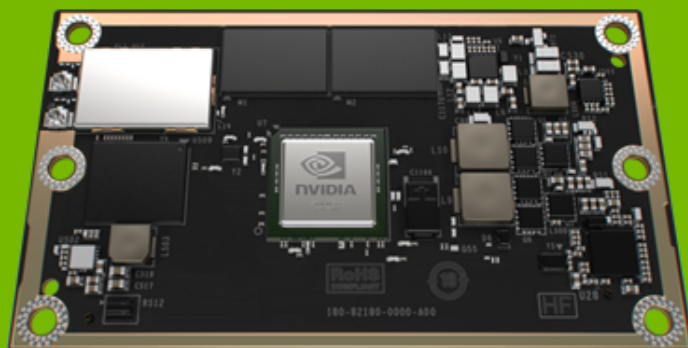
TEACHING KIT MODULES

Robotics with 'Jet'

Module 5 Dead Reckoning	<ul style="list-style-type: none">• Dead Reckoning• Odometry Model for Differential Drive	Future Release
Module 6 Path Planning	<ul style="list-style-type: none">• Path Planning• Wavefront Path Planning	Future Release
Module 7 Robot Localization	<ul style="list-style-type: none">• Robot Localization• Monte Carlo Localization• Particle Filters	Future Release
Module 8 Control	<ul style="list-style-type: none">• Control• PID Control	Future Release
Module 9 Obstacle Avoidance	<ul style="list-style-type: none">• Smooth Obstacle Avoidance• Obstacle Avoidance and Navigation	Future Release
Module 10 Final Project	<ul style="list-style-type: none">• Motivation• Robot Capture the Flag Game	Current Release



Jetson TX1



	JETSON TX1
GPU	1 TFLOP/s 256-core Maxwell
CPU	4x 64-bit ARM A57 CPUs 1.6 GHz
Memory	4 GB LPDDR4 25.6 GB/s
Video decode	4K 60Hz H.264
Video encode	4K 30Hz H.264
CSI	Up to 6 cameras 1400 Mpix/s
Display	2x DSI, 1x eDP 1.4, 1x DP 1.2/HDMI
Wi-Fi	802.11 2x2 ac
Networking	1 Gigabit Ethernet
PCI-E	Gen 2 1x1 + 1x4
Storage	16 GB eMMC, SDIO, SATA
Other	3x UART, 3x SPI, 4x I2C, 4x I2S, GPIOs
Power	10-15W, 6.6V-19.5VDC
Size	50mm x 87mm

JET OVERVIEW

Chassis

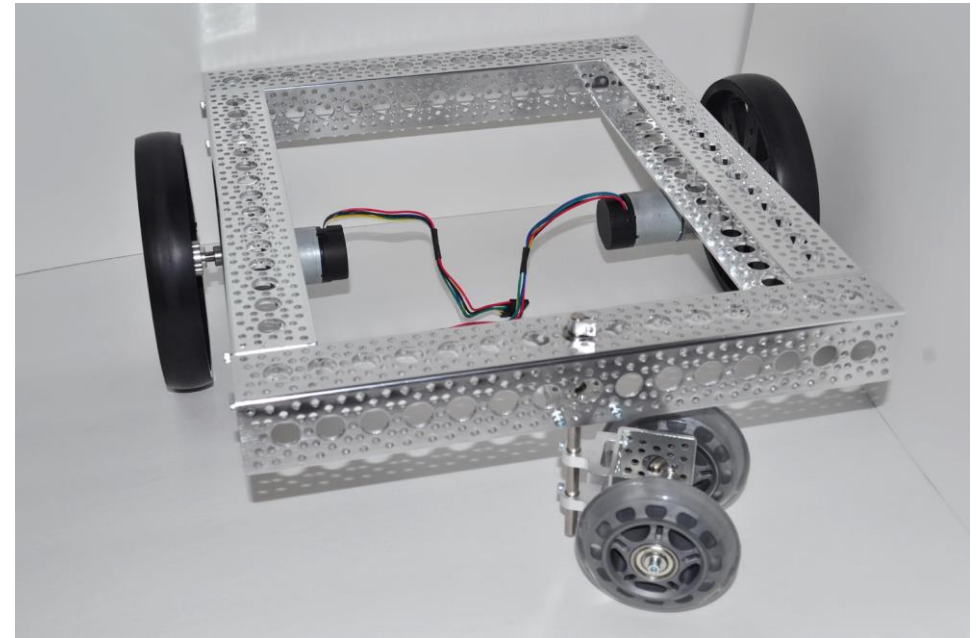
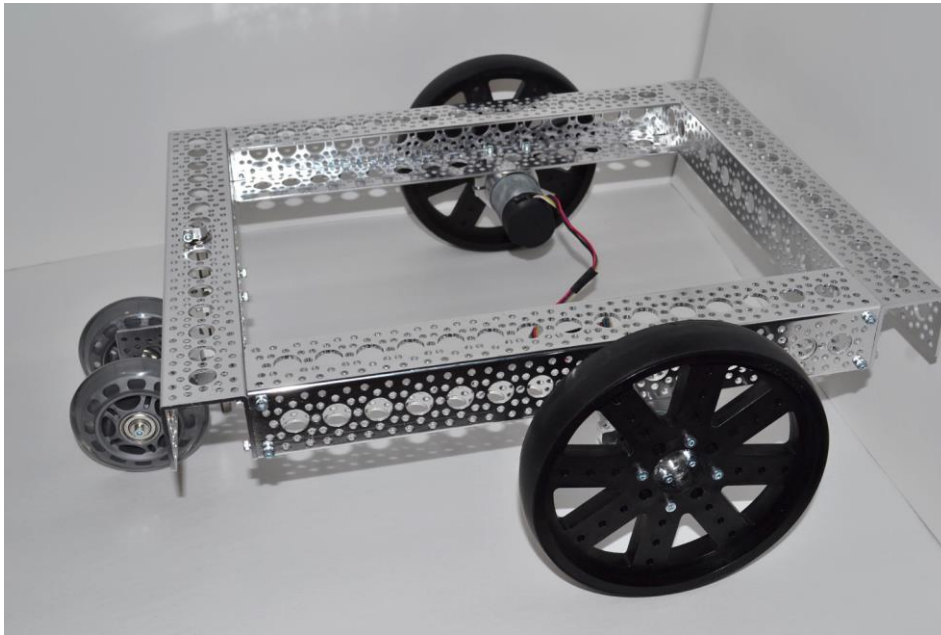
Jet chassis is constructed using Actobotics parts

These are machined metal parts with various aluminum channel, hubs, wheels, and brackets.



JET OVERVIEW

Chassis



JET OVERVIEW

Electronics

Jet electronics consists of:

NVIDIA Jetson TK1/TX1

Arduino Mega

H-bridge and motors

3 sonar sensors

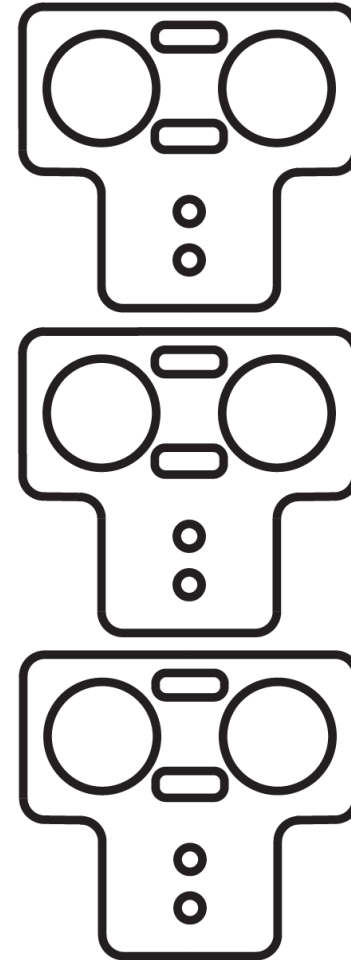
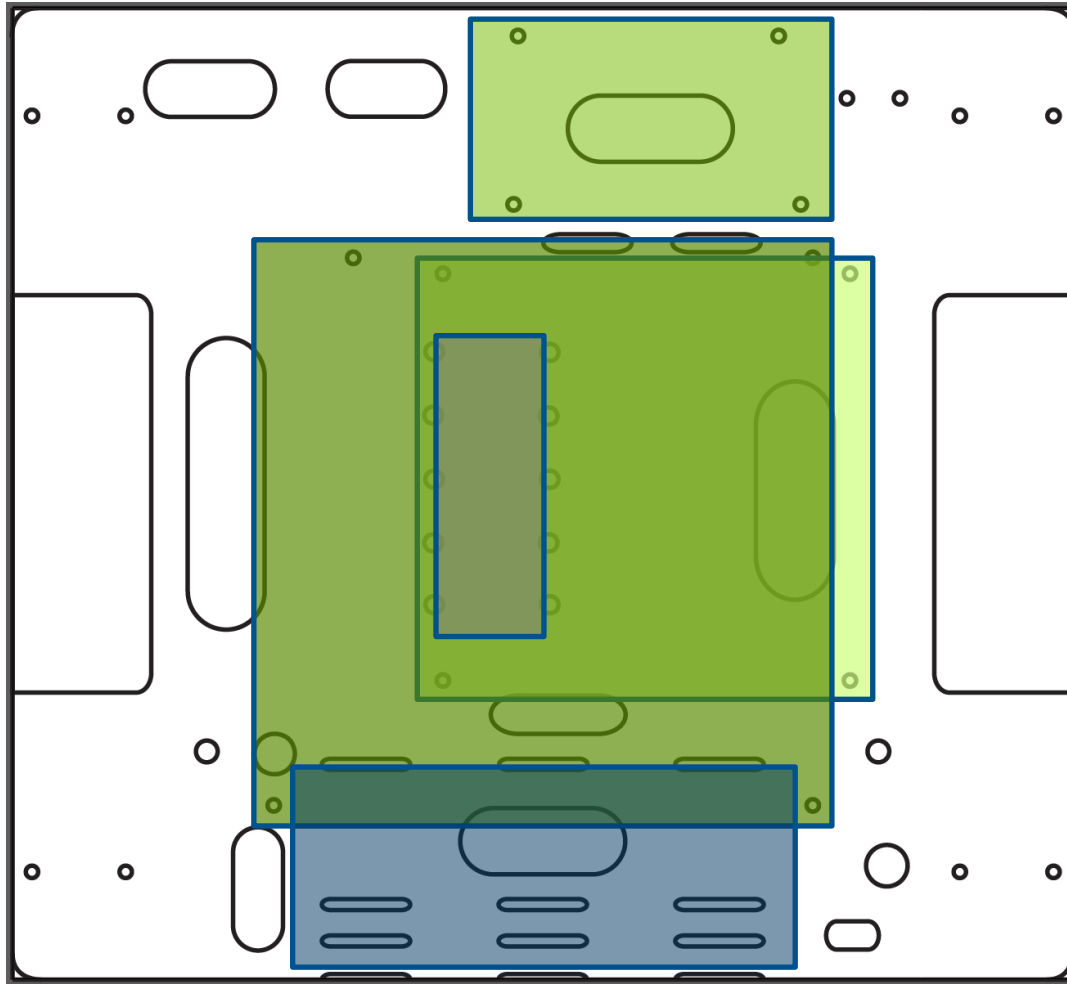
GY-521 accelerometer/gyroscope

Single Webcam

3S (11.1V) 5000mAh LiPo battery



JET OVERVIEW



JET OVERVIEW

Software

Jet runs ROS

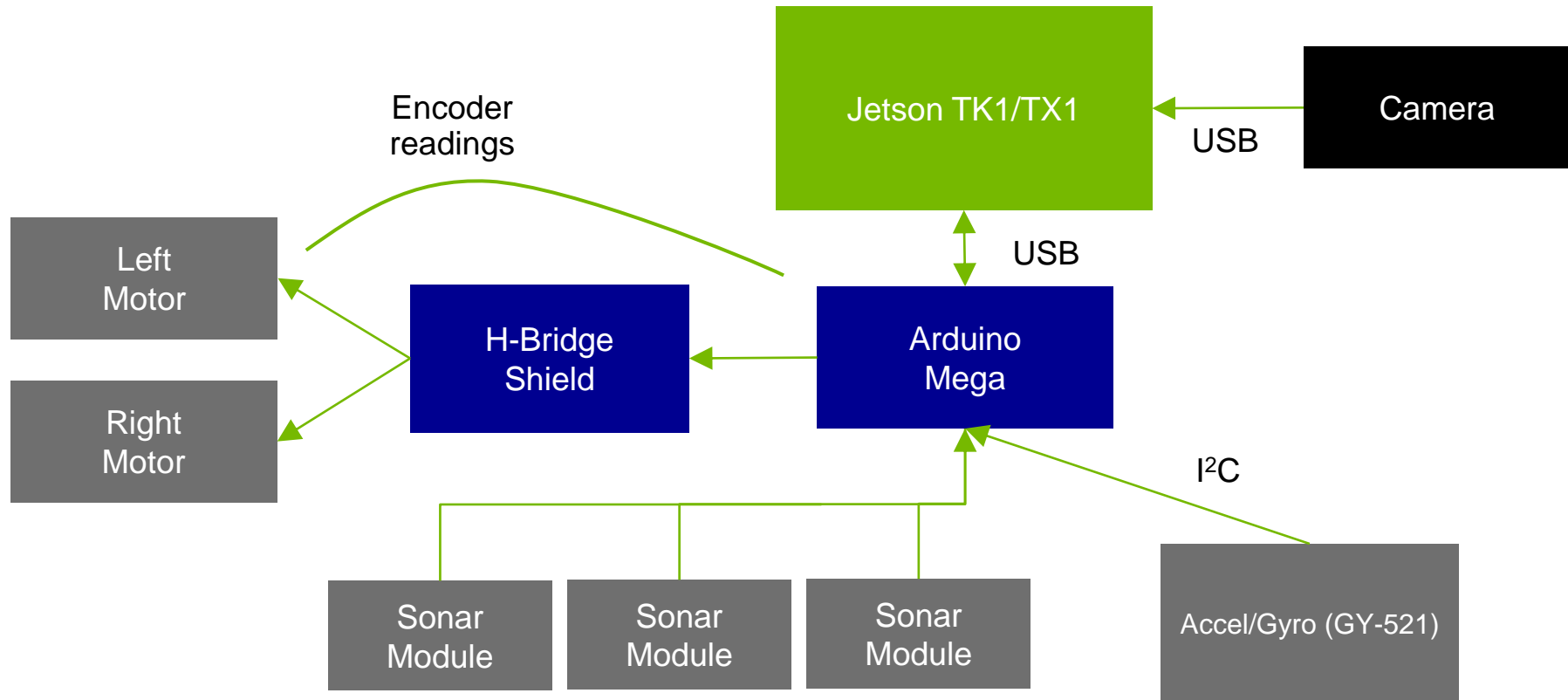
Lecture material includes ROS introduction

Lab assignments provide starter code



JET OVERVIEW

Architecture Design



CURRENT JET BOM

Retail prices shown

Amazon lists:

<http://amzn.com/sl/16YHGMBK62X6G> (TK1)

<http://amzn.com/sl/2QNJMQAAMVYRN> (TX1)

Single-source, discounted bundle coming soon!

Bill of Materials	Category	Source	Cost	Quantity	Subtotal
Battery	electronics	Amazon	\$35.76	1	\$35.76
Battery charger	electronics	Amazon	\$25.60	1	\$25.60
Jetson TK1	electronics	Amazon	\$192.00	1	\$192.00
Arduino Mega	electronics	Amazon	\$17.99	1	\$17.99
Pololu motor	electronics	Pololu	\$39.99	2	\$79.98
Pololu H-bridge	electronics	Amazon	\$49.95	1	\$49.95
Camera (placeholder)	electronics	Amazon	\$4.99	1	\$4.99
Camera mount	electronics	Amazon	\$4.49	1	\$4.49
Mini-PCIe wireless	electronics	Amazon	\$28.00	1	\$28.00
USB hub	electronics	Amazon	\$6.99	1	\$6.99
Power cable	electronics	Pololu	\$1.95	1	\$1.95
Sonar sensors (3pcs)	sensors	Amazon	\$8.50	1	\$8.50
Gyro (GY-521)	sensors	Amazon	\$3.35	1	\$3.35
Sensor shield	electronics	Amazon	\$14.50	1	\$14.50
Jumper wire	electronics	Amazon	\$9.99	1	\$9.99
Wireless antenna	electronics	Amazon	\$8.50	1	\$8.50
16AWG wire		Amazon	\$6.70	1	\$6.70
HXT connector	electronics	Amazon	\$5.99	1	\$5.99
1" standoffs		Servocity	\$0.79	4	\$3.16
1/2" standoffs		Servocity	\$0.59	4	\$2.36
12" channel	chassis	Amazon	\$9.99	4	\$39.96
clamping motor mount	chassis	Servocity	\$6.99	2	\$13.98
6" wheels	chassis	Amazon	\$9.99	2	\$19.98
1/4" screws	chassis	Amazon	\$1.69	3	\$5.07
6-32 nuts	chassis	Servocity	\$0.05	24	\$1.20
90 dual mount bracket	chassis	Servocity	\$5.99	2	\$11.98
6mm wheel hubs	chassis	Amazon	\$7.99	2	\$15.98
hub adaptor	chassis	Amazon	\$4.99	2	\$9.98
1/4" shaft clamping collar	caster	Servocity	\$4.99	1	\$4.99
1.5" channel	caster	Amazon	\$2.99	1	\$2.99
caster wheel	caster	Amazon	\$2.59	2	\$5.18
flanged standoff A (pair)	caster	Amazon	\$2.99	1	\$2.99
non-flanged bearing	caster	Amazon	\$1.99	2	\$3.98
parallel tube clamp	caster	Amazon	\$5.99	2	\$11.98
1/4" bearing pillow block	caster	Amazon	\$6.49	1	\$6.49
1/4" flanged ball bearings	caster	Servocity	\$2.39	1	\$2.39
5" x 1/4" D shaft	caster	Amazon	\$2.49	1	\$2.49
Fuse	electronics	Servocity	\$3.99	1	\$3.99
power switch	electronics	Amazon	\$1.99	1	\$1.99
power jack	electronics	Servocity	\$3.99	1	\$3.99
Total					\$678.34

Jetson Robot

192.168.100.100:5000

Search


Star



Menu






Jetson Robot

Settings

Help



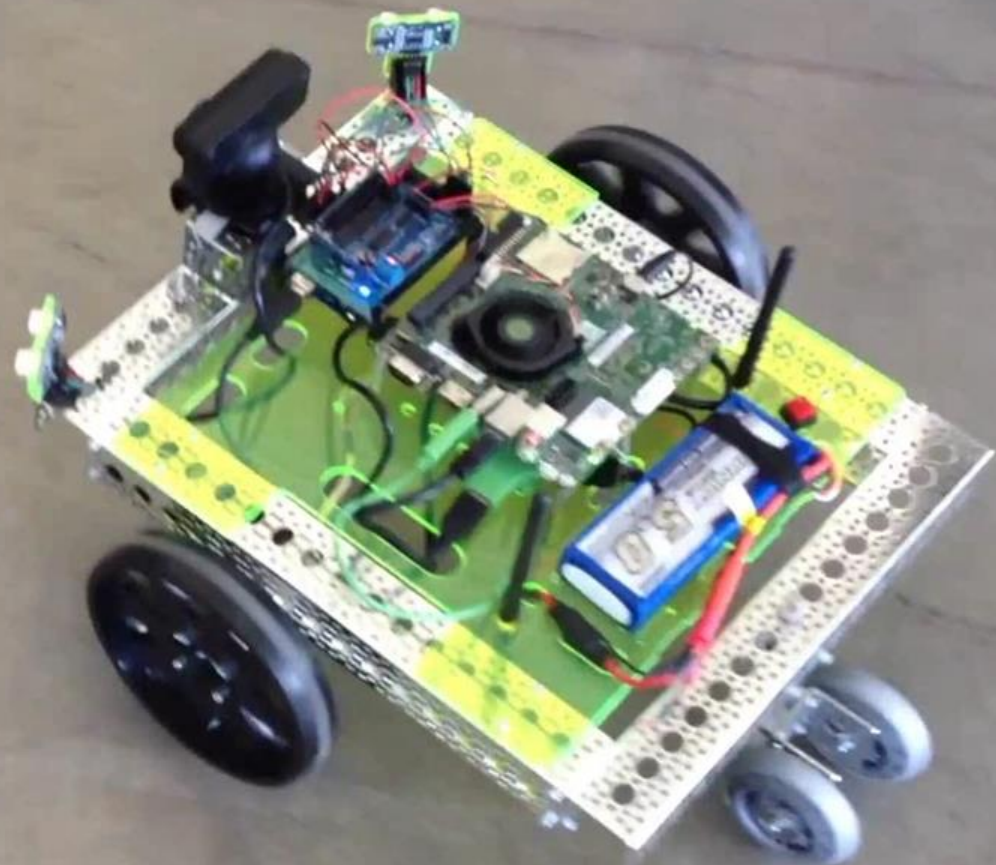




Speed (0 to 400)

Duration (in ms)

Video Source



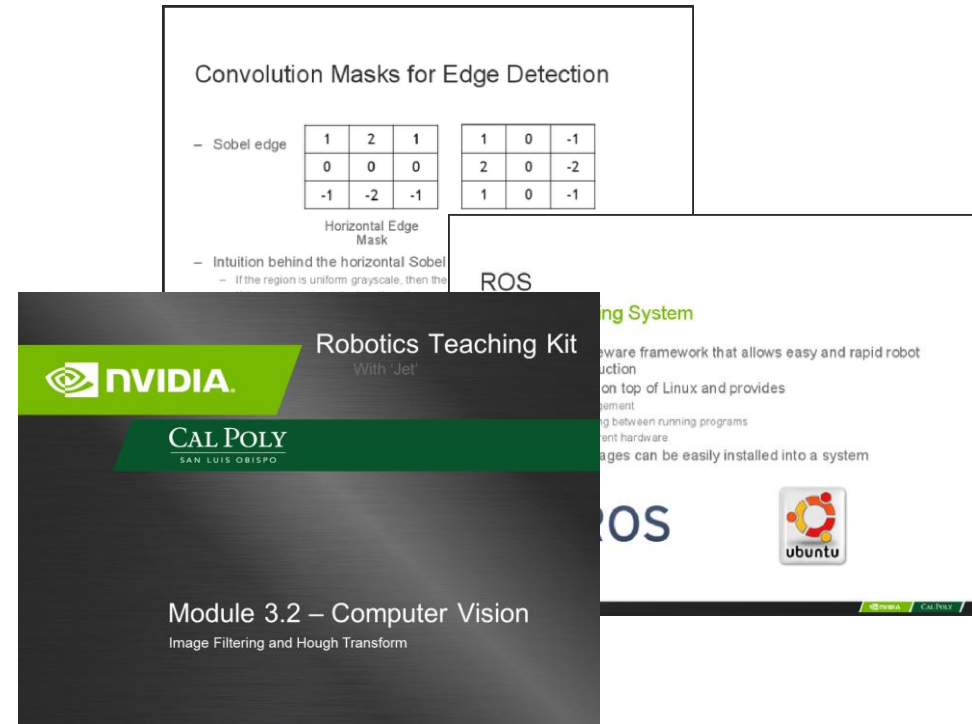
TEACHING KIT CONTENTS

Lecture Slides

Current Release: **14** total slide decks from **4** modules

Later Release: **~30** total slide decks from **10** modules +
Embedded audio narrations

.pptx format



TEACHING KIT CONTENTS

Hands-on labs/solutions

1-2 week assignments

Includes description, objectives, prerequisites and open-ended questions

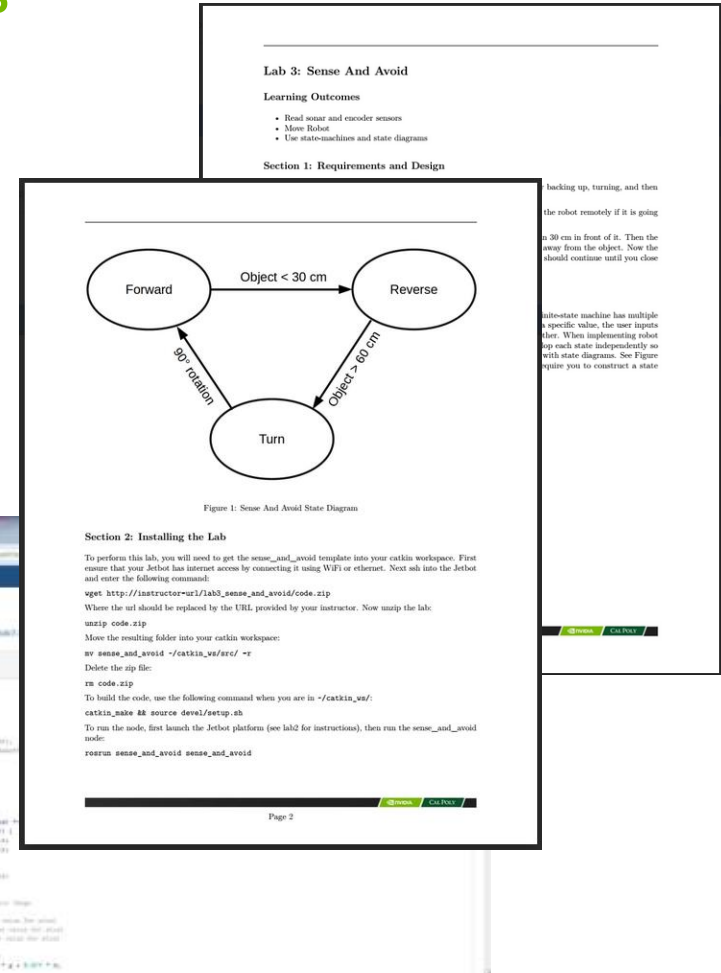
Includes Pseudo-code and solution code templates

Latest source code and instructions always on BitBucket

Current Release: 5 total labs from 4 modules

Later Release: ~12 total labs from 10 modules

.docx and .pdf formats



TEACHING KIT CONTENTS

Quiz questions/answers

Multiple choice, including rationale for answers

Students should be able to answer from lecture content

Current Release: 3 total quiz questions/answers from 4 modules

Later Release: 9 total quiz questions/answers from 10 modules

.docx and .pdf formats

Module 1: Answers

1. What types of computing cores are available on the Jetson TK1?
There are 4 ARM A15 cores, 1 low power ARM core, and 192 CUDA
2. How can you remotely connect to the Jetson TK1?
 - Command line: using ssh
 - Graphical: using a vnc client
3. Describe the reasons for having the Arduino Mega run alongside the TK1.
The Arduino Mega handles low-level embedded functionality such as controlling the motors.
4. What components are directly connected to the battery?
The Jetson TK1 and the H-bridge shield.
5. Describe the capabilities of ROS nodes.
ROS nodes are processes that perform some computation. They can be publishing the sensor value. They can also be used to send commands
6. What does it mean for ROS Topics to be 'strongly typed'?
Topics can only send messages that are only of the correct type for the
7. What command is used to clean out any recently compiled ROS nodes?
catkin_make clean
8. Describe the relationship between the Ubuntu Linux OS and ROS.
Linux is the actual running OS kernel. ROS is a framework that runs on top of Linux and provides messaging between ROS processes.
9. How are ROS nodes started?
The can be started using the roslaunch command.
10. How can you know what topics are available on a ROS system?
rostopic list

Module 3: Answers

1. Apply the horizontal Sobel edge detector to the following image patch. Use border values to extend the image where necessary.
10 | 20

30 | 40
Answer
-80 | -80

-80 | -80
2. Apply the averaging blur filter to the following image patch. Use border values to extend the image where necessary. Round output values to nearest integer.
10 | 20

30 | 40
Answer
16 | 23

27 | 30
3. Name the advantages and disadvantages of processing images at a higher resolution.
Advantages: more information, higher quality picture
Disadvantages: slower, more processing
4. Threshold the following grayscale image using 127 as the threshold.
50 | 100

150 | 200
Answer
0 | 0

1 | 1
5. Apply the Gaussian blur filter to the following image patch. Use border values to extend the image where necessary. Round output values to the nearest integer.
10 | 20

30 | 40
Answer
14 | 21

20 | 36
6. All the lines running through a single point in Cartesian become what in the Hough space?
A curve
7. In Hough space, how are likely lines selected?

Page 1

TEACHING KIT CONTENTS

Larger coding projects/solutions

3-4 week, open-ended, multidisciplinary,
final semester projects

Not tied to specific modules

Current Release: 1 total
project/solution/report

Later Release: ~3 total
projects/solutions/reports

.docx and .pdf formats

Solutions in source code

Harvester Project

Overview

The goal of this project is to program the JetBot to move all of the colored balloons into their respective goals. Each robot will have 1 minute to score as many balloons as possible.

Physical Design

A sample layout for the arena is shown in Figure 1. The arena after the robot has successfully moved all of the balloons is shown in Figure 2. The edges of the arena should be made with a tape that is distinct from the ground color. The goals should be cardboard boxes that are either painted or covered in colored construction paper for the red and blue goals. The balloons should be sufficiently large so that the robots can readily identify them.

Figure 1: Competition Start

Project Guidelines
Robotics Teaching Kit with 'Jet'

Purpose of the Project

The purpose of a project assignment is to apply interdisciplinary robotics concepts to a substantial piece of code than possible in the labs. This could take many forms:

- Thorough performance analysis and improvement of existing robot architectures
- Program 'Jet' to compete in a competition against other robots.
- Reproduce some existing robotics research work
- Do novel robotics research

At the end of the day, the goal is to demonstrate thorough command of robot programming and a substantial piece of code than possible in the labs. This could take many forms.

Project Outline

Broadly, a successful application-parallelization project might take the following form:

Broad Outline
Choose an application.
Determine what part of the application is taking the majority of the time.
Determine one or more data-parallel approaches to solving the problem.
Create multiple implementations of the approach.
Measure the performance and execution characteristics of the implementations for

OTHER RESOURCES

qwikLABs

Live, hands-on, self-paced learning environment to reinforce the concepts contained in the Teaching Kit

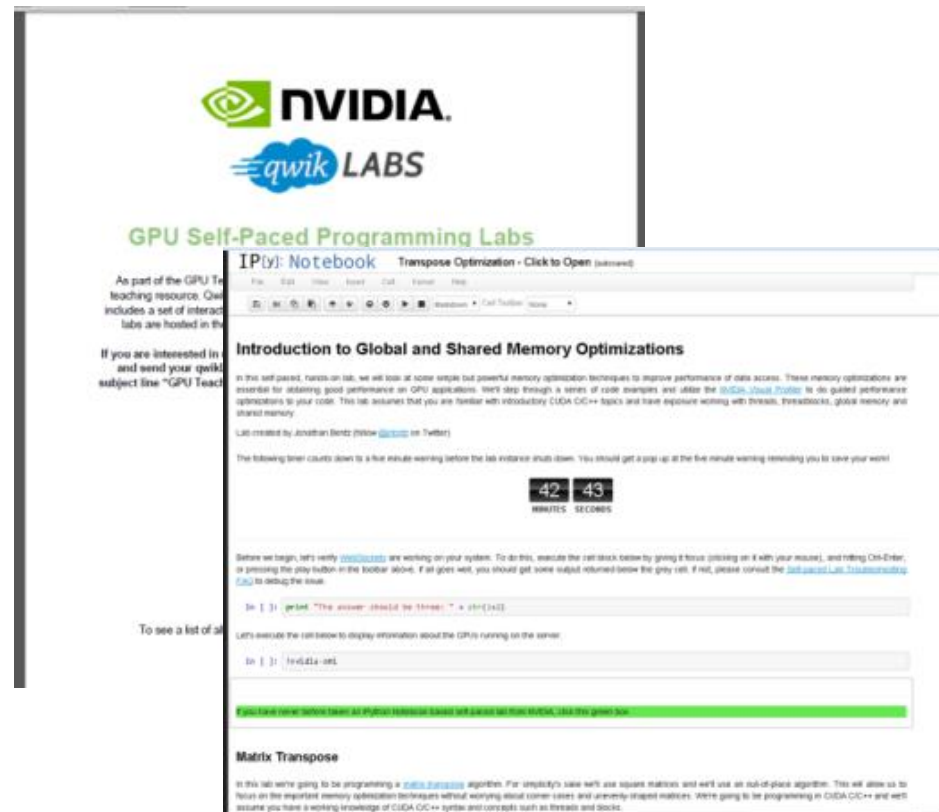
Labs includes interactive instructions, coding and Q/A

Hosted in the cloud

Students only needs a web-browser and internet access

Labs are timed

Free tokens with Teaching Kit



TEACHING KIT CONTENTS

Lecture Videos

Useful for “flipped” course and self-paced learning

Stream individually or download as .mp4 from

Coming in a future release!

GPU Teaching Kit — Accelerated Computing

PDF Slides
Lecture 4-4 tiled-matrix-multiplication-kernel.pdf
PowerPoint Slides
Lecture 4-4 tiled-matrix-multiplication-kernel.pptx

Handling Arbitrary Matrix Sizes in Tiled Algorithms

PDF Slides
Lecture 4-5 tile-boundary-condition-2015.pdf
PowerPoint Slides
Lecture 4-5 tile-boundary-condition-2015.pptx

Labs

- Basic Matrix Multiplication
Module 4-1 BasicMatrixMultiplication.pdf
- CUDA Tiled Matrix Multiplication
Module 4-2 TiledMatrixMultiplication.pdf

Book Chapters

- Chapter 4 - Memory and Data Locality
3rd Edition-Chapter04-memory-model-2-2-2016.pdf

Module 5: Thread Execution Efficiency

In this module we explore how CUDA threads execute on SIMD Hardware and how to analyze the performance impact of control divergence.

Lectures and Videos

Warps and SIMD Hardware

PDF Slides
Lecture 5-1-warps-simd.pdf
PowerPoint Slides
Lecture 5-1-warps-simd.pptx

Performance Impact of Control Divergence

PDF Slides
Lecture 5-2-control-divergence.pdf
PowerPoint Slides
Lecture 5-2-control-divergence.pptx

Quiz

Module 5 Quiz
Module 5 Quiz.pdf

Book Chapters

Some Observations (1)

```
1. void computeSuccesful("P", const float *M, const float *N, int Mx, int Nx, int Nc)
2. {
3.     // Compute the sum of the products of the two matrices
4.     for (int i=0; i<Mx; i++)
5.         for (int j=0; j<Nx; j++)
6.             for (int k=0; k<Nc; k++)
7.                 sum[i*Nx+j] += M[i*Nc+k]*N[k*Nx+j];
8.     // Compute the sum of the products of the two matrices
9.     for (int i=0; i<Mx; i++)
10.        for (int k=0; k<Nc; k++)
11.            sum[i*Nx+k] += M[i*Nc+k]*N[k*Nx+k];
12. }
13.
14. // Compute the sum of the products of the two matrices
15. // The code is almost identical to the sequential version,
16. // except for the two lines with #pragma at line 3 and line 5.
```

RGB Color Image Representation

- Each pixel in an image is an RGB value
- The format of an image's row is (r g b) (r g b) ... (r g b)
- RGB ranges are not distributed uniformly
- Many different color spaces, here we show the constants to convert to AdobeRGB color space

an ing block

```
- Convert recurrences from sequential:
for (j=1; j<out[j]; j++)
    out[j] = out[j-1] + f(j);

- into parallel:
forall(j) { temp[j] = f(j); }
scan(out, temp);

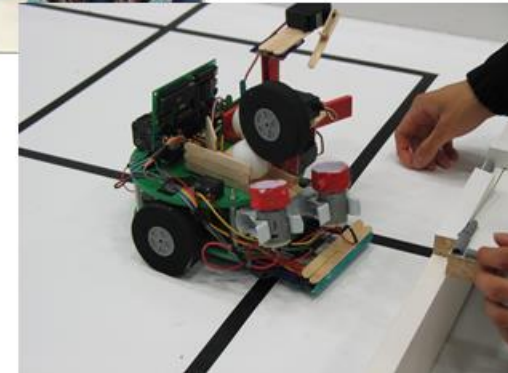
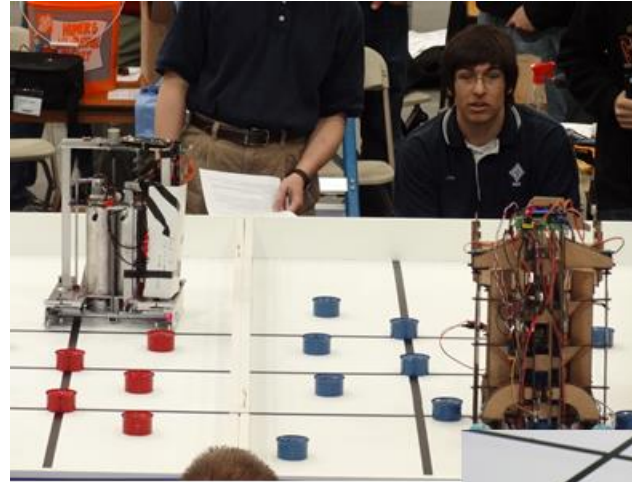
- Useful for many parallel algorithms:
    * Radix sort
    * Quickselect
    * Merge sort
    * Linear selection
    * Selection
    * Histograms, ...
```

RELATED CAL POLY ACTIVITIES

Robotics at Cal Poly is a multi-disciplinary area

Encourage students to learn by actively engaging in projects

Students learn best by applying theory to real robot designs





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Q&A

Available to Instructors Now!

developer.nvidia.com/educators