MATLAB EXPO 2017

Déploiement embarqué et connectivité hardware avec MATLAB et Simulink

Paul Cox, MathWorks
Agenda

- Introduction
- Hardware Support Packages for MATLAB and Simulink
- Processor-in-the-Loop Execution
- Code Generation within the Internet of Things (IoT)
- Conclusion
- Questions
From algorithm to hardware: why and how?
From MATLAB and Simulink to Hardware

Automatic Code Generation

- C/C++ → CPU, DSP
- VHDL, Verilog → ASIC, FPGA
- ST → PLC

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Code Generation in Industry

ABB Accelerates the Delivery of Large-Scale, Grid-Connected Inverter Products with Model-Based Design

“Simulink and Embedded Coder enabled us to open the door to new markets. With increased productivity from extensive simulation and efficient code generation, we have confidence in our ability to produce the systems that larger customers are asking for in the time frames they want.”

— Dr. Robert Turner, ABB
Code Generation in Academia

NASA Interns Develop Guidance, Navigation, and Control Software for Quadcopter with Model-Based Design

Model-Based Design makes both working engineers and interns at NASA MSFC more productive. The students have more fun because they can run the GNC algorithms they create in Simulink on a real processor and quickly get things done.

NASA intern working with the quadcopter vehicle and ArduPilot Mega 2.5 hardware.
Code Generation Case Study: Bruitparif Medusa Noise monitoring distributed network
Code Generation Case Study: Bruitparif Medusa

- **Requirements**
  - Monitor noise levels and directions
  - Send live data to a central server
  - Low-power consumption device (< 5 W)
  - Minimal network traffic (< 5 kbps)

- **Solution**
  - Low-power microcontroller (STM32F4)
  - UDP communication over cellular network
  - Algorithm development with MATLAB/Simulink
    - Design and feasibility/performance analysis
    - Preparation for embedded deployment
    - Automatic Production Code Generation with Embedded Coder
  - Low memory and CPU utilization
Bruitparif - Software

2. Profiled Sections of Code

<table>
<thead>
<tr>
<th>Section</th>
<th>Maximum Execution Time</th>
<th>Average Execution Time</th>
<th>Maximum Self Time</th>
<th>Average Self Time</th>
<th>Calls</th>
</tr>
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<tbody>
<tr>
<td>bot_initialize</td>
<td>1060</td>
<td>1060</td>
<td>1060</td>
<td>1060</td>
<td>1</td>
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<tr>
<td>[+] bot_init</td>
<td>47048</td>
<td>47048</td>
<td>32869</td>
<td>32869</td>
<td>1</td>
</tr>
<tr>
<td>[-] bot [0.015625 0]</td>
<td>5405875</td>
<td>5373712</td>
<td>1575119</td>
<td>1568924</td>
<td>129</td>
</tr>
<tr>
<td>Select mic</td>
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<td>42530</td>
<td>42530</td>
<td>42530</td>
<td>129</td>
</tr>
<tr>
<td>Generated Filter Block</td>
<td>85125</td>
<td>84842</td>
<td>85125</td>
<td>84842</td>
<td>129</td>
</tr>
<tr>
<td>Generated Filter Block</td>
<td>57113</td>
<td>57105</td>
<td>57113</td>
<td>57105</td>
<td>129</td>
</tr>
<tr>
<td>Math Function</td>
<td>26042</td>
<td>23352</td>
<td>26042</td>
<td>23352</td>
<td>129</td>
</tr>
<tr>
<td>Math Function1</td>
<td>26161</td>
<td>23760</td>
<td>26161</td>
<td>23760</td>
<td>129</td>
</tr>
<tr>
<td>[+] arm_quad</td>
<td>60435</td>
<td>1568924</td>
<td>1568924</td>
<td>1568924</td>
<td>129</td>
</tr>
</tbody>
</table>

1. Function replacements in bot [hide]

The following table provides a mapping from the functions used from the selected Code Rep blocks in the model that triggered the replacement.

<table>
<thead>
<tr>
<th>Function</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>arm_biquad_cascade_df2T_f32</td>
<td>&lt;S3&gt;/Generated Filter Block</td>
</tr>
<tr>
<td>arm_cfft_radix2_f32</td>
<td>&lt;S5&gt;/IFFT</td>
</tr>
</tbody>
</table>

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Automatic code generation in IoT network nodes
Bruitparif – Pilot Project Results
Before Code Generation: Modeling and Simulation
Code Generation for UAV Team MAVerix at student competition

Awarded at IMAV 2013 and IMAV 2014!

2016: 8 km DHL flight tests!

Video source: Deutsche Post AG
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How do I connect MATLAB to hardware?

Since 2012: Hardware Support Packages!
C Code Generation-based Hardware Support Packages

- Texas Instruments C2000
- STmicroelectronics STM32F407 and STM32F746 Discovery boards
- Beaglebone Black
- Raspberry Pi 1, 2, 3
- Arduino (Uno, Due, Nano, Mini, Mega, too many to list!)
- NXP FRDM, STM32 Nucleo boards
- Android, iOS, and more!

Includes:
- Compiler Toolchain
- Peripheral configuration I/O Blocks
- External mode
- Processor-In-the-Loop PIL framework
- Example models and documentation

Include:
- Connectivity API
- Coming Soon: Code Generation

200+ user installs / month!

500+ user installs / month!

2000+ user installs / month!

250+ user installs / month!
Parrot AR Drone

Execute
Parrot AR Drone Hardware Support in Simulink
Deploying Simulink Model to Parrot AR Drone
Parrot Mini Drone Support in Simulink

16.30 Feedback Control Systems
An MIT Feedback Control Systems Class that Teaches with Palm-size Drones
http://fast.scripts.mit.edu/dronecontrol/
Using the Support Package Installer is Easy!
MathWorks Hardware Support Packages

MATLAB

MATLAB Coder

Simulink

Simulink Coder

Embedded Coder

HDL Coder

Raspberry PI
Arduino
Lego
Android

STM32 Disco
STM32 Nucleo
T I C2000

Xilinx Zync
Altrera SoC

Xilinx Zync
Altrera SoC

Apple iOS

STM32

Nucleo

TI C2000
iPhone iPad and Android Support

1) Audio processing
2) Image processing
3) Video processing
4) Mobile sensing
5) IoT with ThingSpeak
6) Wireless connectivity
Arduino board support from MATLAB and Simulink

- **UNO** (2012):
- **MEGA** (2013):
- **NANO** (2014a):
- **DUE** (2014):
- **Leonardo** (2014b):
- **Mega ADK**
- **Mini**
- **Fio**
- **Pro** (Mac OS X Support!)
- **Micro**
- **Esplora**

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Arduino Shields

Ethernet Shield  Wifi Shield  Motor Shield

Simulink Blocks

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Arduino

- **17a** – print/println support
- **16b** – Thingspeak read, PIL, enhanced external mode
- **15a** – Support from Linux

**New IO Block support:**
- I2C, SPI
- UDP/TCP to LEGO, Raspberry Pi, and Android/iPhone

**New boards:** Yun
Raspberry Pi

- 17a – New blocks: I2C, SPI, UART, TCP/IP, IMU, Pressure, Humidity, etc

- 16b - Support from Linux PC

- 16a – Pi 3 support

- 15b – Support from Mac

- 15a – Pi 2 support

Thingspeak Read/Write Support!
Linux Boards supported by MATLAB and Simulink

Raspberry Pi 1, 2, and 3

BeagleBone Black

Simulink Support Package for Raspberry Pi Hardware

Embedded Code Support Package for BeagleBone Black Hardware

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STM32 Board Support

- STM32 Discovery : F407 & F746
- STM32 Nucleo :
  - STM32F746
  - STM32F411
  - STM32F401
  - STM32F302
  - STM32F103
  - STM32F031
  - STM32L476
  - STM32L053
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How SIL and PIL Work

On-Target Simulation

Non-Real-Time Synchronization with Host at Each Time Step

Execution History
- Equivalence comparison
- Code coverage
- Execution timing (profiling)
Processor-in-the-Loop (PIL) profiling
Processor Benchmarks on various ARM Cortex CPUs

<table>
<thead>
<tr>
<th>Processor</th>
<th>Execution Time (us Avg/Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM335X</td>
<td>128/64</td>
</tr>
<tr>
<td>ATSAM3X8E</td>
<td>256/128</td>
</tr>
<tr>
<td>STM32F302</td>
<td>64/32</td>
</tr>
<tr>
<td>STM32F302 CMSIS</td>
<td>40/20</td>
</tr>
<tr>
<td>STM32F407</td>
<td>32/16</td>
</tr>
<tr>
<td>STM32F407 CMSIS</td>
<td>20/10</td>
</tr>
<tr>
<td>STM32F746</td>
<td>16/8</td>
</tr>
<tr>
<td>STM32F746 CMSIS</td>
<td>10/5</td>
</tr>
</tbody>
</table>

Function: Task0 of rwdemo_pmsmfoc

40 uS Limit
Deploy Simulink Model to Beaglebone Black
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### IoT Analytics Challenges

**Smart Connected Devices**
- Local embedded algorithms
- Data reduction

**Analytic IoT Platform**
- Online analytics
- Visualization and reporting

**Communication**
- Deploy analytics to cloud
- Deploy algorithm to device

**Algorithm Development**
- Historical analytics
- Sensor analytics

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IoT Analytics Solutions

Communications Network

Data Aggregation & Analytics

Deploy analytics to server/cloud

Deploy algorithms to nodes/devices

Hardware Support Packages

Smart Connected Devices

Algorithm Development Sensor Analytics

MATLAB
What Is ThingSpeak?

Web Site For People

Web Service for Devices
ThingSpeak

- New MathWorks web service hosted on AWS
- Lets you collect, analyze and act on data from “things”
- Over 130,000 users worldwide
- It has MATLAB for IoT Analytics
- It’s free to get started

https://thingspeak.com
Car-counting camera IoT example

Traffic Volume for the week of July 25

Vehicle Count per 15 second interval

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Custom Visualizations with ThingSpeak - Weather Station Example
Predictive Analytics Example with ThingSpeak

Predicted and Measured Ockway Bay Tide Chart

Channel ID: 137305
Author: maswery
Access: Public

Tide measurement and forecasting with the effect of wind predicted using neural networks.

- Tide
- Wind surge
- Neural network

MATLAB NEURAL NETWORK MACHINE LEARNING ALGORITHM

Deployment

On-Demand Surge Forecaster

THINGSPEAK IOT ANALYTICS PLATFORM

NWS Wind Forecast

NOAA Wind History

Recent Tide Level

Historical Wind and Tide Data

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ThingSpeak for Small Scale Deployment
Integrating MATLAB with Third Party IoT Cloud Platforms

- **Algorithm Development**
- **Sensor Analytics**
- **Gateway**
- **Smart Connected Devices**
- **Ingest**
- **Store**
- **IoT Platform**
- **Compute**
- **MATLAB Production Server**

External Data & Business Systems

Deploy analytics to cloud

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Key takeaways

Hardware support in MATLAB and Simulink …

- Code generation for prototype or production workflows

- Hardware Support Packages make it **easy to install and configure** the necessary software

- Supports many **Open Hardware Revolution** boards and mobile devices (iOS, Android)

- Enables smart sensors for the Internet of Things
Déploiement embarqué et connectivité hardware avec MATLAB et Simulink