如何在MCX N94x上将客户ML模型与NPU无缝集成

第1版-2024年3月1日

应用笔记

文档信息

信息	· 内容
关键词	MCX N94x、NPU、机器学习(ML)
摘要	本文介绍了如何在FRDM-MCXN947板上将客户ML模型与NPU无缝集成。



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1 介绍

本文介绍了如何在FRDM-MCXN947板上将客户ML模型与NPU无缝集成。MCX N94x和MCX N54x系列基于运行 频率高达150MHz的双高性能Arm Cortex-M33内核,具有2MB的片上闪存和可选的完整ECC RAM,以及集成的 专有神经处理单元(NPU)。与单独使用CPU内核相比,集成NPU的机器学习(ML)吞吐量提高了40倍,显著缩 短了工作时间并降低了总体功耗。

表1.	要求
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软件要求	硬件要求
MCUXpresso IDE	FRDM-MCXN947开发板
elQ Toolkit	硬件调试器:USB-C
MCUXpresso SDK for	
FRDM-MCXN947	

2 NPU概述

elQ Neutron神经处理单元(NPU)是一种高度可扩展的加速器内核架构,可提供机器学习(ML)的加速。此架 构提供了功耗和性能优化的NPU,并可与恩智浦大多数微控制器和应用处理器产品组合无缝集成。

elQ Neutron NPU支持多种神经网络类型,例如CNN、RNN、TCN、Transformer网络等。elQ机器学习软件开发环境完全支持使用elQ Neutron NPU进行ML应用开发。MCX N94中所用的NPU是Neutron N1-16。其框图结构如图1所示。



图1. Neutron N1-16结构框图

elQ Neutron NI-16 NPU内置于MCX N94中, 配备了4个计算管道, 每个计算管道包含4个INT8 MAC(乘累加) 块, 共16个MAC块。因此, MCX N94能够以每秒4.8G(150MHz*4*4*2)的速度执行INT8运算。

MCUXpresso软件开发套件(MCUXpresso SDK)为开发人员提供了一个综合性软件包,其中包含预集成的 TensorFlow Lite for Microcontrollers (TFLM)。

Neutron库也集成到了TFLM中。表2列出了NPU所支持的运算符。

表2. NPU所支持的运算符

运算符	运算符输入类型	MCXN947/MCXN548 NPU
ADD	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有

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表2. NPU所支持的运算符(续)

运算符	运算符输入类型	MCXN947/MCXN548 NPU
AVERAGE_POOL_2D	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
CONV_2D	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
DEPTHWISE_CONV_2D	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
FULLY_CONNECTED	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
UNIDIRECTIONAL_SEQUENCE_LSTM	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	无
LOGISTIC (Sigmoid)	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
MAX_POOL_2D	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	有
MUL	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	无
SOFTMAX	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	无
SVDF	Float	无
	Uint8(PTQ)	无
	Int8(PCQ)	无

注:

• PTQ - 按张量量化(非对称8位量化)。

• PCQ - 按通道量化(对称8位量化)。

有关更多信息,请参阅SDK的middleware/eiq/doc中的每一个TensorFlow Lite用户指南。

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3 软件环境的搭建

软件环境的搭建是基于Windows的。

1. 下载MCUXpresso IDE,并选择要下载的Windows版本,如图2所示。

	NXP > Design > MCUXpres	so IDE > MCUXpresso IDE : Files		
	Software & Support Product List	Product Download		
	Product Search	MCUXpresso IDE		
	Order History	Files License Keys Notes	© Downlo	ad Help
	Recent Product Releases			
	Recent Updates	Show All Files		4 Files
	Licensing	+ File Description	File Size File Name	\$
	License Lists	+ MCUXpressoIDE_11.8.0 - Linux	1.3 GB	
	Offline Activation	+ MCUXpressolDE 11.8.0 - macOS x86.64	1 GB # MCUXpressoIDE 11.8.0 1165 x86-64 pkg	
	<	+ MCUXpressoIDE 11.8.0 - Windows	1.1 GB ± MCUXpressolDE 11.8.0 1165.exe	
	FAQ Download Help	K		
	Table of Contractor			
	Table of Contents			
	FAQs			
. MCUX 下载完成	(presso IDE的下载 成后,双击下载的:	安装包,选择安装位置,并执	行安装直至安装完成。	
2. MCUX 下载完质	《presso IDE的下载 成后,双击下载的 <u>:</u> 图: s	安装包,选择安装位置,并执 Setup - MCUXpresso IDE 11.8.0 [Build 1 [*] e lect Destination Location Where should MCUXpresso IDE be installed?	行安装直至安装完成。 165] – · ×	
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*注:使用*USB-C数据线为FRDM-MCXN947板供电和调试,如<u>图4</u>所示。USB-C数据线的另一端必须插入开发 计算机中。

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图5. 选择开发板

4. 选择elQ中间件,点击DOWNLOAD SDK,如图6所示。

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- GON Dasibuard	Build SDK for FRDM	I-MCXN947		
BUILD SDK	Generate a downloadable SDK archive	for use with desktop MCUXpresso Too	ls.	
Select Board / Processor	Developer Environment Settings			
Middleware (0) Examples (0)	Selections here (operating host system, toolchain or n	middleware) will impact files and examples projects	included in the SDK and Generated Projects	
Toolchain (Off)	Host OS	Toolchain / IDE		
 Processor Parametrics (Off) 	Windows	MCUXpres	sso IDE 🔹	
ADMINISTRATION	Coards		0 SELEC	TALL
Notifications	Search		Q SELEO	
Preferences	Name	Category	Description	
EXPLORE	SDMMC Stack	Middleware	Stack supporting SD, MMC, SDIO	
Application Code Hub	CANopen 🗹	Middleware	MicroCANOpen stack from Embedded Systems Acaden	iy
DOWNLOADS	CMSIS DSP Library	CMSIS DSP Lib	CMSIS DSP Software Library	
MCUXpresso IDE		Middleware	COMPHTIP	Controller
MCUXpresso for VS Code		modeware	Contraction	Controlled
MCUXpresso	elQ B	Middleware	eIQ machine learning SDK containing: - ARM CMSIS-N	N library (more)
Config Tools	emWin	Middleware	emWin graphics library	
Coffline data	□ Fatfs	Middleware	FAT File System stack	
MCUXpresso				
Secure Provisioning Tool				
Secure Provisioning Tool	FreeRTOS		Real-time operating system for microcontrollers from /	Amazon
Secure Provisioning Tool NTERNAL Deployed Releases	FreeRTOS		Real-time operating system for microcontrollers from J	Amazon
Secure Provisioning Tool NTERNAL Deployed Releases Hardware in Releases	FreeRTOS		Real-time operating system for microcontrollers from J DOWNLOAD SDK	Amazon
Secure Provisioning Tool NTERNAL Deployed Releases Hardware in Releases	FreeRTOS		Real-time operating system for microcontrollers from J DOWNLOAD SDK	Amazon
Secure Provisioning Tool NTERNAL i Deployed Releases ? Hardware in Releases SDK的下载	FreeRTOS		Real-time operating system for microcontrollers from A DOWNLOAD SDK	Amazon
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Secure Provisioning Tool NTERNAL i Deployed Releases Plandware in Releases SDK的下载 DK构建完成后	□ FreeRTOS ;,下载SDK压缩文件	· , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from A DOWNLOAD SDK	umazon
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Secure Provisioning Tool NTERNAL Deployed Releases P Hardware in Releases SDK的下载 DK构建完成后 Builder • Internal	□ FreeRTOS 5,下载SDK压缩文件	- , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from / DOWNLOAD SDK	kmazon
Secure Provisioning Tool NTERNAL i Deployed Releases ? Hardware in Releases SDK的下载 DK构建完成后 BUILder • Internal	□ FreeRTOS 〒, 下载SDK压缩文件 Create Jira ticket Witi K Dashboard	- , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from / DOWNLOAD SDK 2 配 SDK,2,14.0,F at.5.1ml - spit 完解的下标记录	kDM-MCXN947.sip
Secure Provisioning Tool NTERNAL i Deployed Releases SDK的下载 DK构建完成后 BUK构建完成后	□ FreeRTOS 〒, 下载SDK压缩文件 Create Jira ticket	- , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from A DOWNLOAD SDK 2 DOWNLOAD SDK Search	RDM-MCXN947.zip
Secure Provisioning Tool NTERNAL Deployed Releases SDK的下载 DK构建完成后 BUIlder • Internal CUXpresso SDI coess, Download, and Share yo	□ FreeRTOS 5,下载SDK压缩文件 Create Jra ticket 2 Wei K Dashboard zur requested SDK Builds.	[:] , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from J DOWNLOAD SDK Search	RDM-MCXN947.zip
Secure Provisioning Tool NTERNAL i Deployed Releases SDK的下载 DK构建完成后 BUIK在 ● Internal MCUXpresso SDI ccess, Download, and Share yo	□ FreeRTOS ☐ , 下载SDK压缩文件 ※ Create Jira Scket ※ Wei K Dashboard Sur requested SDK Builds. SDK_2.14.0_FRDM-MCXN947	⁻ , 如 <u>图7</u> 所示。	Real-time operating system for microcontrollers from J DOWNLOAD SDK	RDM-MC0N947.300
Secure Provisioning Tool NTERNAL Deployed Releases SDK的下载 DK构建完成后 Builder Internal ACUXpresso SDI ccess, Download, and Share yo	□ FreeRTOS 「、下载SDK压缩文件 K Dashboard wr requested SDK Builds. SDK_2.14.0_FRDM-MCXN947 Windows	·,如 <u>冬7</u> 所示。	Real-time operating system for microcontrollers from J DOWNLOAD SDK	RDM-MCXN947.zip

图7. 下载SDK压缩文件

6. 打开MCUXpresso IDE,将SDK文件拖放到MCUXpresso IDE的SDK安装窗口中进行安装,如图8所示。

CMSIS DSP Library, SDMMC Stack, elQ

Add SDK Description

L Download SDK

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4 转换客户模型

要使用NPU加速模型,必须首先使用elQ工具包中所含的Neutron Converter工具将模型进行转换。

在<u>EIQ-TOOLKIT</u>中下载elQ Toolkit安装包,双击下载的安装包,选择安装位置,然后执行安装直至安装完成,如<u>图9</u>所示。

elQ [®] Toolkit for Deployment ElQ-TOOLKIT Receive alerts ()	End-to-End Model E	Development and
Overview Software Details Documen	ation Design Resources ① Training Sup	port
User data eIC ** Toolki Bing You Own Data eIC Potal import dataset (Optional) Augment dataset Select and optimize Bing	User machine learning model L3 The eIQ Toolkit (eIQ Portal) an tool options as eIQ Toolkit ena optimize neurae your Don Model The eIQ Docktel	t enables machine learning development with an intuitive GUI d development workflow tools, along with command line host part of the eIQ ML software development environment. NXP's ables graph-level profiling capability with runtime insights to help al network architectures on target EdgeVerse™ processors.
图9. elQ Toolkit安装包		
转换客户模型有两种方法:		
• 使用命令行工具:neutron-co	nverter	
• 使用elQ门户应用程序		
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4.1 命令行工具:neutron-converter

1. 打开elQ工具包文件夹elQ_Toolkit_v2.1.0\bin\neutron-converter。此文件夹有两个版本的转换器。根据 SDK版本来选择匹配的转换器。对应关系如表3所示。

表3. SDK和转换器

SDK	转换器
SDK-2.13.1	v1.0.0
SDK-2.14.0	v1.2.0

2. 使用命令行输入转换器的文件夹,将客户模型复制到该文件夹中,然后执行命令以转换模型,如图10所示。

C:\Windows\System32\cmd.exe	×
Microsoft Windows [Version 10.0.19045.3803] (c) Microsoft Corporation. All rights reserved.	^ (
<pre>C:\nxp\eIQ_Toolkit_v2.1.0\bin\neutron-converter\v1.2.0>neutron-converter.exeinput custom_model.tflite Converting model with the following options: Input = custom_model.tflite Output = custom_model_converted.tflite Target = mcxn94x Run dependencies:</pre>	
C:\nxp\eIQ_Toolkit_v2.1.0\bin\neutron-converter\v1.2.0>	
图10. 执行转换命令	~

4.2 elQ门户应用程序

1. 打开elQ门户应用程序,并单击顶部的PLUG-INS按钮,如<u>图11</u>所示。

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			MARKEIPLACE	HELP		×
el	2					
•	OPEN PROJEC	T	×			
	COMMANE	LINE				
	el		COMMAND LINE			

2. 在转换服务器初始化成功后,关闭此窗口并在MODEL TOOL中打开客户模型。神经网络图将显示在窗口中,如<u>图12</u>所示。

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3. 点击左上角的菜单,在转换菜单中选择TensorFlow Lite For Neutron,如图13所示。

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4. 单击Convert按钮,并为转换后的模型选择保存路径。当转换成功后,转换后的图形会显示在窗口中,如<u>图14</u> 所示。

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- NeutronGraph节点。转换后的模型命名为custom_model_converted.tflite。
- 6. 转换后,运算符的数量会减少,量化因子的表达也更有效。模型转换前后的对比如表4所示。

表4. 转换前后的模型

	原始模型	转换后
文件大小	299КВ	227КВ
张量内存库(Tensor Arena)	157КВ	144КВ

5 将模型集成到示例工程中

1. 导入tflm_ciar10工程。要导入tflm_ciar10工程,请按照图15和图16中的步骤操作。

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X SDK Import Wizard	— 🗆 X
You have selected 1 project to import: 'frdmmcxn947 tflm cifar10'.	
The source from the SDK will be copied into the workspace. If you wa	nt to use linked files, please unzip the 'SDK_2.x_FRDM-MCXN947'
Import projects	
Project name prefix: frdmmcxn947	× Project name suffix:
Use default location	
Location: C:\LocalData\workspace\frdmmcxn947	Browse
Project Type	Project Options
○ C Project	SDK Debug Console O Semihost O UART O Example default Copy sources Import other files
Examples	🔤 🗹 💥 🖬 🖬
type to filter	
Name	Description Version ^
> E FreeMASTER_examples	
> 🗌 🗧 canopen_examples	
> _ = cmsis_driver_examples	
> = demo_apps	
> = driver_examples	
□ ■ mpp_camera_mobilenet_view_tfim	Image Classification with TensorFlow Lite Micro Example
$\Box \equiv mpp_camera_utratace_view_utrim$	MDD Camera View Example
	CIEAR-10 example for TensorFlow Lite Micro
	Keyword spotting example for TensorFlow Lite Micro
$\Box \equiv \text{tfm}$ label image	Label image example for TensorFlow Lite Micro
□	ModelRunner for TFlite
> Sels_pkc_examples	
>	×
	2
(?)	< <u>B</u> ack <u>N</u> ext > <u>Finish</u> Cancel
图16. 导入tflm_ciar10工程	

2. 将转换后的模型文件复制到工程文件夹中,创建名为model_data.s的程序集文件,并将模型文件包含到数据 部分custom_model_data中。导出第32行至第35行的指令,如<u>图17</u>所示。

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3. 修改model.cpp,改为使用客户模型数据,如<u>图18</u>所示。

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4. 修改model_cifarnet_ops_npu.cpp,确保客户模型所用的所有运算符都添加到s_microOpResolver中, 如图19所示。

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图19. 修改model_cifarnet_ops_npu.cpp

5. 准备一些测试数据,并使用如下Python脚本程序来加载选定的JPG文件(包含在CIFARI0测试数据集中),将 其解压并与数组定义一起导出为一个C语言数组。然后,将这个数组保存到与Python脚本文件处于同一文件夹 的bird.h文件中。确保图像的路径相对于执行脚本的位置是正确的,如<u>图20</u>所示。

1	import cv2
2	import numpy as no
3	<pre>img = cv2.imread('test/bird/batch 5 num 113.ipg')</pre>
4	img = cv2.resize(img. (128, 128))
5	img = cv2.cvtColor(img. cv2.COLOR BGR2RGB)
6	with open('bird.h', 'w') as fout:
7	print('#define STATIC IMAGE NAME "bird"', file=fout)
8	<pre>print('static const uint8 t bird [] = {', file=fout)</pre>
9	<pre>img.tofile(fout, ', ', '0x%02X')</pre>
0	<pre>print('};\n', file=fout)</pre>

图20. 执行脚本

6. 将头文件(bird.h)复制到工程的图像文件夹中,并修改image_loade.c。切换到使用Bird类图像数据, 如<u>图21</u>所示。

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7. 编译工程并将其下载到FRDM-MCXN947开发板。

6 结果

在开发板上运行程序的结果如图22所示,推理时间约为9毫秒,结果得分(置信度)为98%。



7 修订历史

表5. 修订历史

文档ID	发布日期	说明
AN14241 v.1	2024年3月1日	初版发布

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Date of release: 1 March 2024 Document identifier: AN14241