Tiny Runtime to Run Model-Based Software on CubeSats

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Short abstract: The presented project extends TASTE, ESA's open-source model-based software development toolchain, with support for MSP430, a family of cheap low-power space-grade MCUs used in small satellites. The goal is achieved via establishing a mapping between FreeRTOS and TASTE constructs, implementing code generation via templates, optimizing/replacing the existing middleware and integrating an Ada compiler for the target platform. The results are validated by implementing in TASTE a demonstration software for a mock CubeSat, based on a MSP430 kit.

Keywords: TASTE, MSP430, MBSE, FreeRTOS, Kazoo, CubeSat, ASN1SCC, Capella

Background. ESA's TASTE [1] MBSE toolchain uses AADL, ASN.1, SDL and MSC languages to describe a system's architecture, data model, behaviour and test cases respectively [2]. AADL, SDL and MSC, while stored textually, can be manipulated via graphical tools. ASN.1 code can be edited using an IDE [3] or generated from a model created in Capella. The models can be used for documentation generation, static analyses, testing and generation of deployable binaries. The latter requires TASTE support for the given platform – code generation templates, middleware, compilers, etc. At the beginning of the project, only several 32- and 64-bit targets were supported, such as RTEMS Leon 3 and Linux x86. MSP430 is a family of cheap, ultra-low-power, mixed-signal microcontrollers, which includes space-grade radiation hardened parts (e.g. MSP430FR5969 rated for 50krad, with non-volatile FRRAM). The above traits make them good candidates for deployment in small satellites. Features distinguishing MSP430 from the existing TASTE targets are 16-bit architecture and very small amount of memory (2kB SRAM and 64kB FRAM for MSP430FR5969). N7 Space is an active TASTE Steering Committee member, bringing experience from perspectives of both user (deployment of ASN.1 models in PROBA3 payload for TC/TM transcoding) and contributor (ASN1SCC improvements and asn1scc.IDE development, PUS C ASN.1 generator and Capella-to-TASTE plugin).

Extending TASTE with MSP430 support. Before the recent introduction of the Kazoo tool, the TASTE method to generate code from AADL models relied heavily on the hardcoded use of Ocarina [2]. Kazoo is a new tool in TASTE toolchain and it implements a new approach to generate code: it uses a templating engine to generate code, build scripts, derived models, and other artefacts giving much more flexibility to the end user, including the possibility to create backends to support new platforms.

The code generated by Ocarina uses PolyORB-HI/Ada or PolyORB-HI/C as a platform independent middleware which provides constructs required by TASTE. One of the disadvantages of PolyORB is huge memory requirements, which makes impossible to use it on small platform like MSP430.

The newly implemented support for MSP430 in TASTE is based on FreeRTOS real-time operating system for microcontrollers [4]. All constructs required by TASTE were implemented using FreeRTOS features. This approach allows to reuse templates created in this project for other platforms (including tiny ones) which are currently supported by FreeRTOS or could be easily added in the future. Even the MSP430 support itself required adding a new port, which proved to be a reasonably simple process.

For entities modelled in SDL (Specification and Description Language) TASTE toolchain uses OpenGEODE [2] to generate Ada source code. While creating TASTE model of a realistic CubeSat test application targeting MSP430, the support for Ada language was not yet ready for the platform, therefore, OpenGEODE's feature to generate C source code was refreshed and improved.

One of the big challenges after abandoning PolyORB in the generated code was to provide compatibility for communication with the code which still uses old middleware. To solve this issue new compatible device drivers were created: one for MSP430 and one for PolyORB. These drivers utilize a new simplified protocol to exchange messages.

After establishing generic code patterns required for mapping models into FreeRTOS objects, the tools forming the TASTE toolchain required some improvements and fixes:

- capabilities of Kazoo were extended to allow generation of code for all TASTE constructs;
- the ASN1SCC tool was extended with support to generate code for 16-bit platforms;
- OpenGEODE C code generation issues regarding case-sensitivity were fixed and support for cases where more than one function is modelled in SDL was added.

The documentation of all the tools and the aforementioned process is available on TASTE wiki [2].

TASTE, while AADL, ASN.1 and SDL based, supports also several other implementation languages such as C and Ada. Additionally, SDL is integrated into the final binary via intermediate transformation to C or Ada code. The existing freely available Ada compilers either do not support MSP430 or are considered legacy software. In order to provide a seamless open-source support for Ada user-routines and SDL-to-Ada generation, an Ada compiler was assembled. AdaCore's GNAT LLVM [5] is used to translate Ada into LLVM bytecode, which is then translated by LLVM [6] into MSP430 assembly, finally compiled by Texas Instruments GCC [7]. The entire process is wrapped via a Python script serving as a frontend.

Validation. In order to validate the developed target support, a mock CubeSat-class satellite was designed in Capella [7], demonstrating basic power supply monitoring, thermal management, mode management and simple payload handling. This model was then manually translated into TASTE interface and deployment views, as well as SDL diagrams. PUS-C compliant-by-construction TC/TM data model was prepared in PUS-C Population Tool [8] and automatically transformed into ASN.1. Low-level hardware handling was implemented using C. The resulting binaries were deployed and tested on a flatsat build around the MSP430FR5969 LaunchPad Evaluation Kit.

Summary. TASTE is now extended with support for MSP430FR5969 MCU, enabling an MBSE-based approach in small/low-cost satellites, such as CubeSats. The performed work validates the benefits of the Kazoo template-based approach and can be a starting point for supporting other MCUs, as well as reducing the memory footprint on the existing targets.

References

[1] TASTE - A tool-chain targeting heterogeneous embedded systems, using a model-based development approach (https://taste.tools/)
[2] TASTE Wiki (https://taste.tuxfamily.org/wiki/)
[3] asn1scc.IDE - Qt Creator plugin for asn1scc - ASN.1/ACN compiler for embedded systems (https://n7space.github.io/asn1scc.IDE/)
[4] FreeRTOS - Real-time operating system for microcontrollers (https://www.freertos.org/)
[5] GNAT LLVM (https://github.com/AdaCore/gnat-llvm)
[6] The LLVM Compiler Infrastructure (https://llvm.org/)
[7] GCC - Open Source Compiler for MSP Microcontrollers (http://www.ti.com/tool/MSP430-GCC-OPENSOURCE)
[8] Capella (https://www.eclipse.org/capella/)
[9] *Deployment of the PUS-C Standard in Projects supported by an Automatic Generation Toolset (PUS-Gen)* Maxime Perrotin, Serge Valera, Michal Kurowski, Arnaud Bourdoux - ADCSS 2018