Analysis-aware Design of Embedded Systems Software

Mihai Florian
mflorian@cs.caltech.edu

Gerard J. Holzmann
gh@cs.caltech.edu

Overview

With this project we target the development of reliable safety critical embedded applications, such as used widely in aerospace, in automotive applications, and in medical devices.

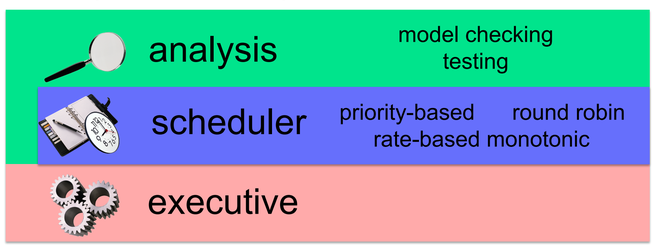
We have identified two core issues with the current state of the art:

1. embedded systems software is normally structured in a way that does not leverage available analysis tools. The software is developed in *an analysis-agnostic* style that often obfuscates the abstractions made and hampers analyses;
2. analysis tools do not leverage available knowledge of the *embedded systems' environment*. For example, embedded systems software relies critically on specific schedulers that differ significantly from those used on common desktop and mainframe platforms.

Approach

We address the above two core issues by designing and building a demonstration *environment for safety-critical embedded systems software development*.

1. The first issue is addressed by developing a *new executable specification language* that enforces a code structure that is analysis-friendly. Because scheduling disciplines can have an important influence on both execution and analysis, the language includes a *sublanguage for describing schedulers*.
2. The second issue is addressed by building an *analysis tool* that allows direct execution of specifications and also offers verification support based on model checking. The verification algorithms exploit the structure of the code and the schedulers introduced using the specification language. Constraining the analysis to traces that can occur in practice might lead to a significant performance improvement.



The architecture of our framework consists of three main components:

- an executive that keeps track of the current state and updates it by taking a step corresponding to an action from the language;
- a scheduler that, by looking at the current state, decides what actions can be taken next;
- an analysis tool (e.g. an interpreter or a model checker) that monitors the execution, picks an action from those returned by the scheduler, and instructs the executive to take the corresponding step.

Specification Language

We are developing a new specification language that is close to a systems implementation language (e.g. C), but has a formally defined semantics, provides higher-level abstractions and allows us to write formal specifications as part of the source code in the form of *interface standards* and *assertion requirements*. The language is also close to a typical specification language used in model checking (e.g. Promela), but is richer by providing functions and abstract data types.

```
process proc(priority : uint, steps : uint)
  sched by PrioSched
{
  function run() { ...  }
}
```

The specification language is statically typed and provides support for concurrency and channel-based message passing. The memory model used by the language relies on the notions of ownership and ownership transfer and avoids features that can obstruct formal verification attempts (e.g. explicit pointers and unsafe casts). The specification language also provides features used by the scheduling language: defining process attributes and assigning processes to schedulers.

Scheduling Language

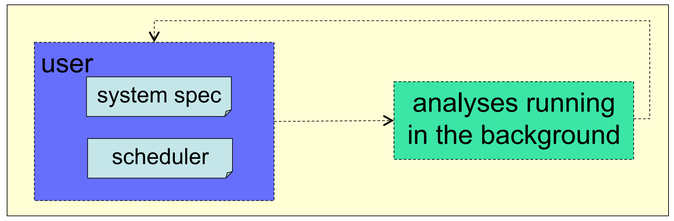
We are developing a constraint-based language for specifying common schedulers used in embedded systems. The language operates on predefined sets of processes, like the set of enabled processes, and can access the process attributes defined using the specification language.

Users can define libraries of schedulers, for example those corresponding to the scheduling policies in VxWorks or OSEK, and then reuse them for different applications.
The scheduling language is also suitable for specifying non-standard constraints that may be used to prioritize a verification search or to partition the search space, in an attempt to locate corner cases with potentially anomalous behavior.

```
nonpreemptive scheduler PrioSched
{
  Next = {p in Enabled | forall p' in Enabled ::
                         priority(p') <= priority(p)}
}
preemptive scheduler CountSched
{
  Next = {p in Enabled | forall p' in Enabled ::
                         abs(steps(p) - steps(p')) < 10}
  update(steps : uint) { steps = steps + 1 ; }
}
```

Analysis and Verification Support

We are developing an interactive development and analysis framework that supports both execution and verification based on model checking of specifications written in the new language.



The framework exploits the scheduling policies formalized explicitly as part of the design and focuses the analysis on the relevant behaviors. The framework supports the verification of the same application under a range of different scheduling policies. The analyses can proceed invisible to the user in the background, using swarm-based verification techniques.

Future Directions

We want to leverage parallelism that may be available through the use of GPUs and multiples execution cores or CPUs.

SUMMARY

In the past many different methodologies have been developed that support the analysis of software artifacts, and a different set of methodologies have been developed to support software development. We believe that we can gain significant benefits if we combine these two approaches into one methodology that links software development styles directly with existing capabilities of software analysis tools. We apply this methodology to the design and analysis of large complex multi-threaded embedded systems software.

REFERENCES

[1] M. Florian. A Framework for Systematic Testing of Multi-threaded Applications. Proc. PRDC 2011, to appear.
[2] G.J. Holzmann, R. Joshi, and A. Groce. Swarm verification techniques. IEEE Trans. on Software Engineering, accepted for publication, 2011.
[3] G.J. Holzmann. Reliable software development: extending the programmer's toolbox. Proc. ETAPS 2011, Saarbrucken, Germany.

LARS
NASA/JPL Laboratory
for Reliable Software

CMACS
NSF Expeditions in Computing