Safe Virtual Machine

for C in less than 3 KiBytes

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From Deep Space to Deep Sea

Push Button High Reliability

Outline

- History of Altreonic
- Design of the Safe Virtual Machine for C (SVM)
- Integrating the SVM in the OpenComRTOS-Suite
- Performance Figures
- Conclusions
- Further Work

History of Altreonic

- Eonic (Eric Verhulst): 1989 – 2001
  - Developed Virtuoso a Distributed RTOS
  - Communicating Sequential Processes as foundation of the “pragmatic superset of CSP”
  - Open License Society: 2004 – now
  - R&D on Systems and Software Engineering
  - Developed OpenComRTOS using Formal Methods
- Altreonic: 2008 – now
  - Commercialises OpenComRTOS
  - Based in Linden (near Leuven) Belgium

Design goals for the SVM

- Distributed heterogenous systems are hard to maintain
  - Each target runs different binary, staticly compiled
  - Different compilers, different versions, different CPU variants
  - If system is large, probability that some nodes will fail or present issues is high
  - Still, system must remain operational during maintenance
- Dynamic code loading, independently of target CPU
- Back-up functionality for mis-behaving tasks
- Boundary conditions:
  - C is most often used embedded programming language
  - Memory resources are strictly limited

Design of the SVM

- Execution engine for OpenComRTOS Tasks, written in ANSI-C.
  - The C-Code gets translated into a binary using a standard C compiler
  - The SVM interprets this binary format.
- One Instance of the SVM executes in one OpenComRTOS Task, as Guest-Task.
- OpenComRTOS virtualises hardware for the SVM Guest-Task

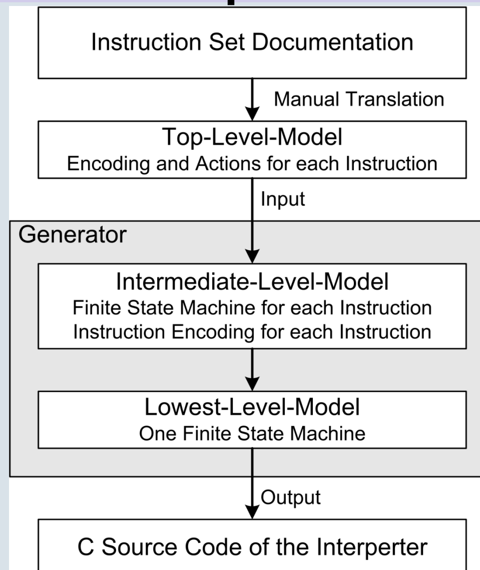
Selecting a VM Instruction Set

- **Criteria on the Instruction Set (IS):**
  - Compact byte code, i.e. small binaries
  - Not too many instructions
  - Availability of good toolchains / compilers
- **Instruction Sets evaluated**: MIPS, ARM Thumb-1, and Xilinx Microblaze
- **Chosen Instruction Set:** ARM Thumb-1:
  - Compact instruction set, all instructions, except one, only have 16bit
  - Widely used within the industry
  - But it can be any other IS as well

From the IS to the Interpreter Source Code – step 1

- The complete Instruction Set (IS) was modeled in a Domain Specific Language.
- The VM source code gets generated.
- The generator tool chain was written in Haskell.

From the IS to the Interpreter Source Code – step 2



Top Level Model of Push 1

```
Command "push"
  (Opcode ["1011","0","10"])
  [Operand "LR" 8 8,
   Operand "reg_list" 7 0]
  push
```


Top Level Model of Push 2

```
push = do
  when' (v "LR" .== i1) $
    do
      r "SP" .-= i4
      m [r "SP" .+ i0] .= r "LR"
  for' ([("i",i0),("j",i1)], v "i" .< i8,
   do {v "i" .+= i1;v "j" .<<= i1}) $

    when'((v "reg_list" .& v "j") .> i0)$
      do
        r "SP" .-= i4
        m [r "SP" .+ i0] .= rv "i"
```

Integrating the SVM in the OpenComRTOS-Suite

- Building the binary
- Virtualising the underlying OS and hardware
- Using the SVM inside an OpenComRTOS-System

Building the Binary

- OpenComRTOS is designed to support heterogeneous systems, i.e. systems that consist of different CPU-Architectures, which are called a `Platform’
- The SVM is just another platform that OpenComRTOS must support
- The SVM-Platform provides all the necessary support code in order to compile and link an OpenComRTOS-Task to form a binary file which can be loaded into the SVM.
- Furthermore, access libraries for all components that have been developed for OpenComRTOS can be used from within an SVM-Task.

Virtualising the underlying OS 1

- OpenComRTOS has two principal entities:
  - Tasks:
    - Prioritised (256 priorities are available);
    - Tasks do not share memory;
    - Tasks communicate with Hubs using Packets.
    - Also the Kernel is a task
  - Hubs:
    - Generic synchronisation primitive in OpenComRTOS
    - Hubs operate system-wide, but transparently → Virtual Single Processor (VSP) programming model.

Virtualising the underlying OS 2

- Services offered by Hubs
  - Event – Synchronisation on a Boolean value;
  - Semaphore – Synchronisation with a counter;
  - Port – Synchronisation and exchanging a packet, i.e. data transport (CSP Channel like);
  - Resource – Locking mechanism, with ownership;
  - FIFO – Buffered packet communication;
  - User defined Hubs are possible!

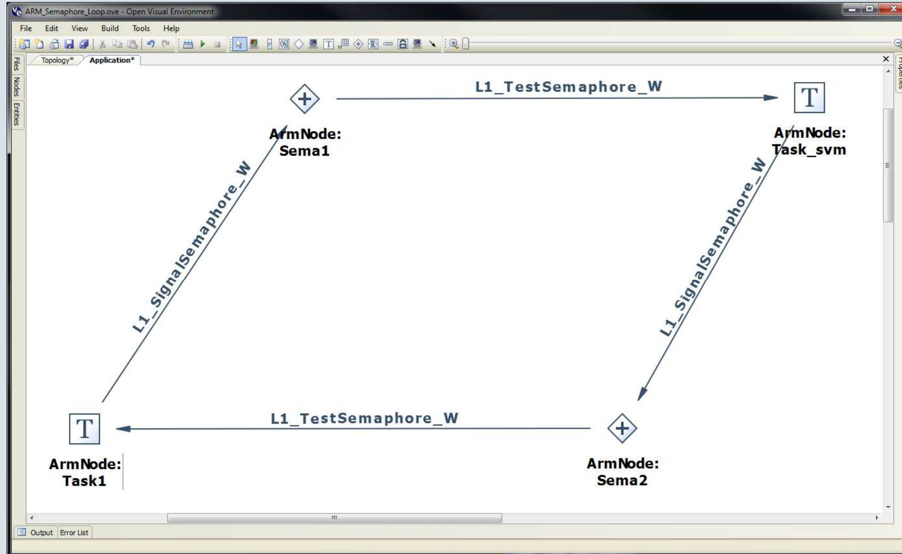
Virtualising the underlying OS 3

- Accessing to the underlying OS-API is done by using a Software Interrupt (SWI instruction ARM Thumb-1)
- Due to the OpenComRTOS API, being represented by the exchange of L1_Packets, only one function had to be provided: L1_buildAndInsertRequest()
- Additionally the SVM-Platform gets currently an extension to allow Guest-Tasks direct access to the memory of the Host
- Using the native OpenComRTOS, the SVM tasks have full access to underlying hardware, including other processing nodes in the network

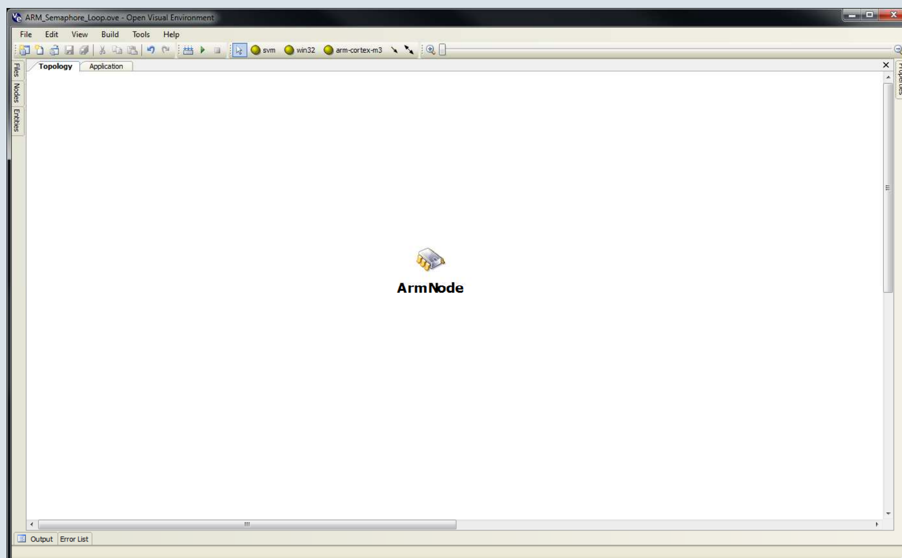
Using the SVM

- The SVM consist of two elements:
  - Topology: SVM-Platform:
    - OpenComRTOS Virtualisation
    - Build System
    - Component access libraries
  - Application: SVM-Component:
    - Virtual Machine Task
    - Control Task

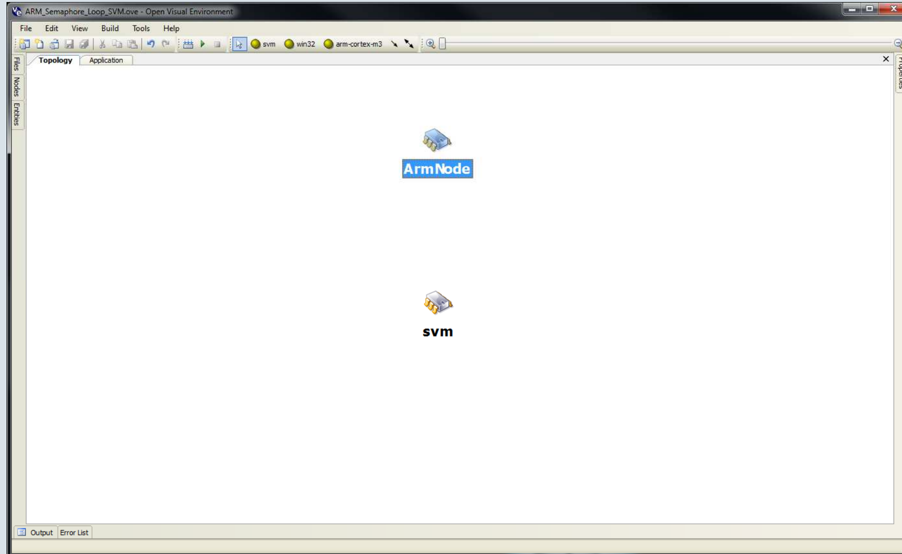
Using the SVM 1



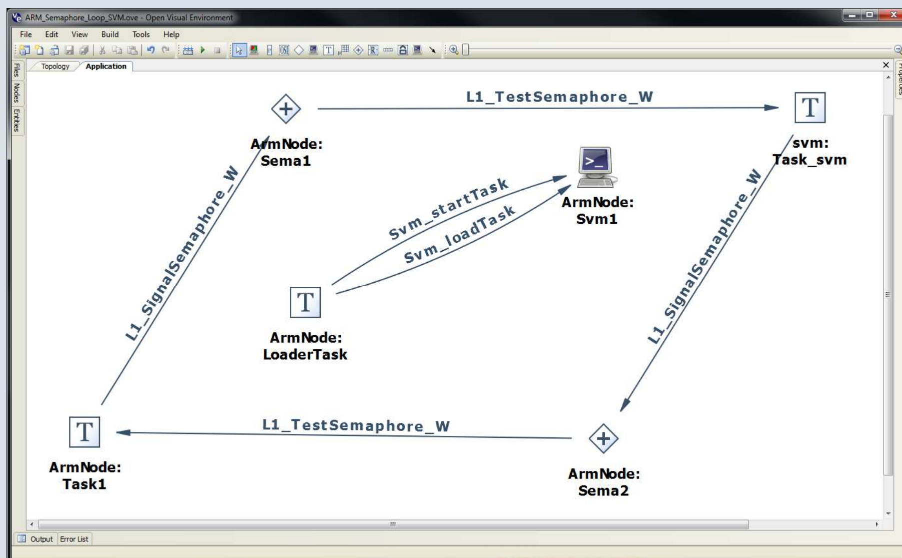
Using the SVM 2



Using the SVM 3



Using the SVM 4



Using the SVM 5

```
 3 #include<SvmService/SvmClient.h>
 4 #include<StdioHostService/StdioHostClient.h>
 5
 6 void Task2_ep(L1_TaskArguments Arguments)
 7 {
 8     L1_BYTE   buffer[1024];
 9     L1_UINT32 readBytes = 0;
10     L1_UINT32 fileHandle = 0;
11     /* Opening the executable file, for reading and in binary format */
12     if(RC_FAIL == Shs_openFile_W(Shs1, "Task_svm.bin", "rb", &fileHandle))
13     {
14         printf("Could not open file.\n");
15         exit(-1);
16     }
17     /* Copying the contents of the executable file into the local buffer */
18     Shs_readFromFile_W(Shs1, fileHandle, buffer, 1024, &readBytes);
19     /* Closing the file after reading */
20     Shs_closeFile_W(Shs1, fileHandle);
21     /* Loading the task into the program memory of the SVM. */
22     Svm_loadTask(Svm1, buffer, readBytes);
23     /* Starting the execution */
24     Svm_startTask(Svm1);
25 }
26
```


Performance Figures

- Memory Requirements of the isolated SVM.
- Comparing the memory requirements of a System with and without using the SVM.
- Performance Degradation, caused by the SVM.

Memory Requirements of the SVM

Optimisation	Code	Data
-O3	3,818 Byte	476 Byte
-Os	2,838 Byte	476 Byte

Compiled for ARM-Cortex-M3, using the Code Sourcery 2009q1 arm-none-eabi toolchain. The figures include the Supervisor and Interpreter tasks, and their helper functions. It does not include any data memory for the Guest-Task.

Impact on Memory Requirements

Semaphore Loop without Safe Virtual Machine:

Filename	Text	Data	Bss	Dec	Hex
ArmNode	4068	892	1708	6668	0x1a0c

Semaphore Loop with the Safe Virtual Machine:

Filename	Text	Data	Bss	Dec	Hex
ArmNode	8140	1736	4736	14612	0x3914
Task_svm	696	24	60	780	0x30c

Compiled for ARM-Cortex-M3, using the Code Sourcery 2009q1 arm-none-eabi toolchain, with compiler optimisation –Os.

Performance impact

- In the previously presented system, the runtime of the Semaphore loop increased by a factor of 7.26
- Depends on:
  1. The native code was compiled for ARM-Thumb-2 which might give better performance
  2. The current Instruction decoder implementation is not ideal, caused by the irregularity of the ARM-Thumb-1 Instruction set (not a restriction in HW, but for SW)

SVM application domain

- Not intended for high speed computations!
  - Dynamic code with small memory requirements
  - Target independent execution
- Typical use:
  - Diagnostics, post-deployment
  - Back-up tasks for natively failing application tasks
  - Run-time monitoring and logging
  - Execute existing binary code without compilation
    - Might require regenerating SVM for other IS.

Conclusions

- Generating the source code of the Virtual Machine, from High-level models made it easy to get the SVM code right.
- We can adjust the SVM to support almost any instruction set, by developing a top-level model of it.
- The OpenComRTOS Architecture made it easy to implement the OS-Virtualisation.
- The SVM brings OS-Virtualisation to deeply embedded systems (minimal overhead of 8kiByte)
- The SVM is useful in many Scenarios:
  - Isolating OpenComRTOS Tasks from each other.
  - Diagnostic of the Host-System
  - Runtime reconfiguration, for high reliability systems.

Further Work

- Automatic Stack monitoring by the SVM.
- Mobility of SVM-Tasks, i.e. moving tasks during runtime from one SVM instance to another instance.
- Native execution of SVM-Tasks, if the CPU supports the ARM-Thumb-1 instruction set.
- Improving the performance of the instruction decoder.

Questions?

Thank You for your attention

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"If it doesn't work, it must be art.
If it does, it was real engineering"