Actors for the Internet of Things

Pushing CAF to RIOT

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Agenda

1. General Background
2. Actors for the IoT
3. CAF on RIOT
4. Experimentation
5. Conclusion and Future Work
The Internet of Things (IoT)

● Network of appliances
  ○ Often constrained embedded devices
  ○ Act as sensors and actuators
  ○ Depend on machine-to-machine communication
  ○ Connected through Internet standards

● Typical communication patterns
  ○ Data collection: many-to-one
  ○ Control: one-to-many

● Platform for distributed applications
Problem Statement

● Highly distributed application design
● Development requires specialized knowledge
  ○ Communication, synchronization and scalability
  ○ Usually in low-level languages (such as C)
  ○ Error-prone and hard to debug
● Deployment is platform-specific
● No established programming model
Relevance of Research

- Ease application development
- Reduce the development overhead
- Professionalization
  - Reusability, Robustness, Portability
- Promote experimentally driven research
  - IoT environments often unpredictable
  - Reproducibility is not a given
  - Provide tools to test and deploy software
- Search for the glue of IoT programming
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Approach

● **Actors as base entities**
  ○ Run concurrently & in isolation
  ○ Can spawn new actors

● **Distributed runtime environment**
  ○ Network transparent message passing
  ○ Distributed error-handling

● **Network of actors as a design candidate**
  ○ Program distributed applications
The C++ Actor Framework

- Implementation of the actor model
- Available under Revised BSD or Boost license
- Small memory footprint
- Different runtime implementations
  - Memory management & scheduler
- Static type-checking
- Runtime inspection tools
Adaption to the IoT

- **Communication protocols**
  - Lossy links are common
  - Handle infrastructure failure
- **Requires suitable messaging layer**
  - Message exchange
  - Synchronization
  - Error propagation and mitigation
- **Security**
  - Nodes may contain private data
  - Encryption & authentication
Network Stack

C++ Actor Framework

- HTTP
- TLS
- TCP
- IPv4 / IPv6
- Ethernet / WLAN

- CoAP
- DTLS
- UDP
- IPv6 / 6LoWPAN
- 802.15.4 / Bluetooth LE
Transactional Layer

● Transactions
  ○ Each message exchange is independent
  ○ Even if it is fragmented

● CoAP
  ○ Duplicate message detection
  ○ Reliable message transfer
  ○ Fragmentation of large messages

● CAF
  ○ Message header compression
  ○ Error propagation
Support of Embedded OSs

- The friendly Operating System of the IoT
- POSIX compliance
- Energy efficient
- Real-time capable
- Development in C or C++
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Goal: CAF on RIOT
- libcaf_core
  - native port (done)
  - stm32f4discovery (WIP)
- Implement network stack in CAF (open)
- libcaf_io
  - native port (open)
  - stm32f4discovery (open)

Takes a surprising amount of time
Progress can be found on Github
- Branches are topic/riot and topic/caf
The First Idea

- Let’s use GCC to compile for native
  - Substitute pthread for RIOT’s pthread
  - “what(): Enable multithreading to use std::thread:
    Operation not permitted”
- Dig into GCC source code
  - if (!__gthread_active_p()) { /* err */ }
  - Removing the error check helps
- Turned to the libstdc++ mailing list
  - “Using a custom pthreads implementation is not
    expected, so it's not surprising if it doesn't work
    perfectly. (...)”
- Undesirable workflow anyways
Thread, Mutex and Condition

● Preserve API of the Standard Template Library (STL)
  ○ Few changes to CAF implementation
  ○ Familiar to most C++ developers

● Introduce new headers
  ○ STL or RIOT-based depending on build flag
  ○ Use caf namespace to prevent ambiguity
  ○ Omits pthread indirection

```c
#ifndef __RIOTBUILD_FLAG
// Our implementation
#else
// Include STL header, provide functions in caf namespace
#endif
```
Getting Threads to Run

- Mostly straight forward (e.g., clang, GCC, ...)
- Implemented thread stack as a member
  - Clang-built executable worked fine
  - GCC-built executable crashed when it entered main
  - Switched GDB to asm mode
  - Stack pointer incremented by an unbelievable amount
- The stack is allocated on the heap
  - A stack on a stack of the same size is a bad idea
  - Detach requires it to be no member
  - Questionable on embedded
How About Locks?

- Removed the destructor of unique_lock
  - Critical for its functionality (release the mutex)
  - My test was an example from the internet
  - Always unlocks the mutex manually (unnecessarily)
- Triggered me to write my own tests
  - Tests for thread, mutex and condition variable
  - Should have done this previously
Compiling CAF for RIOT

● Disabled features
  ○ Memory Management
  ○ CAF examples & unit tests

● Changes for the compiler
  ○ Include modules from RIOT
    ■ sys, core and cpu
    ■ Will be linked in a later step
  ○ Static and 32 Bit
  ○ Include C files with: extern “C”
Static Initialization

- A simple example with CAF on RIOT crashes
  - GDB points to comparison with uninitialized objects
  - These should have been initialized before main
  - Test reveals that static initialization is not working
- GCC offers an array with init functions
  - RIOT startup code never called them
- RIOT mailing list provided a fix for native
  - Only works for native with GCC
typedef void (*func_ptr)(void);
extern func_ptr __init_array_start[];
extern func_ptr __init_array_end[];
int size = __init_array_end - __init_array_start;
int i, flag = 0;
for (i = 0; i < size; i++) {
  if (__init_array_start[i] == startup) {
    flag = 1;
    continue;
  }
  if (flag == 1){
    (__init_array_start[i])();
  }
}
By now we have basic functionality on native
- Start actors and send messages
- But delayed messages never arrive

Time is measured differently on RIOT
- OS X/Linux use seconds since 1970-01-01
- RIOT uses time since system start

Most of the std::chrono is header only
- We can include the header
- Provide our own implementation
  - Timepoint class
  - Function to acquire the time
  - Breaks STL specification
Demo Time!
(native)
CMake Cross compiling

- CMake supports toolchain files
  - -DCMAKE_TOOLCHAIN_FILE
  - Configure architecture, processor, compiler and flags
  - Created a file for the stm32f4discovery

- CMake automatically tests the compiler
  - Test fails when using the arm-none-eabi
  - Module CMakeForceCompiler should fix this
  - Did not work for me, can be achieved manually
Moving to arm-none-eabi

- Startup files handle static initialization
- `libstdc++` for ARM is not complete
  - Can not provide hardware/OS dependent impl.
  - Does not include `to_string`
- Missing dso handle
  - Must be defined during startup to use global objects
- Actors use hardware address for their ID
  - `stm32f4` does not have one, make it random

```c
int getRandomNumber()
{
    return 4;  // chosen by fair dice roll.
    // guaranteed to be random.
}
```

[1]
Embedded Debugging

- There is a GDB for arm-none-eabi
- CAF with debug symbols is huge
  - Only link specific objects with debug
- Files not found to show code position
  - Moving code to the “right” path helps
- Some breakpoints can not be set
- No backtrace
Where we are now

- Extended STL functionality on RIOT
  - Thread, mutex, condition variable, (chrono)
  - Needs to be turned into a PR
- Limited support for CAF on RIOT
  - On native port all my tests succeeded
  - On hardware some problems persist
  - Work on IO did not start yet
Demo Time!
(stm32f4discovery)
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Exceptions

● Disabled in GCC for some architectures
  ○ Luckily not for the stm32f4discovery
● Exception cause the board to restart
● Requires memory specific region
  ○ Saved to eh_frame section
  ○ Found startup files only
  ○ Support for other boards in RIOT
● Did not work for the stm32f4discovery
Security

● Authentication, authorization and encryption
  ○ Establish encrypted channels (DTLS)
  ○ Generate key at local TA (key generation)
  ○ Authenticate runtime environments

● Challenges
  ○ Constrained power & energy
  ○ Nodes physically acquired

● Crypto is hard to do right
Test Environments

- Comfortable and fast vs. realistic and slow
- RIOT offers a native port
  - Not a realistic environment
- Few nodes in our lab
  - 7 Raspberry Pis running Linux
- FU Berlin *(DES Testbed)*
  - 60 nodes distributed in several rooms and floors
- INRIA Technology Institute in France
  - Connected through RIOT and Safest
  - 2700 nodes distributed through France
6LoWPAN USB Dongles

● IA-OEM-DAUB1
  ○ Drivers for Windows and Linux (*only old kernels*)
  ○ Not open, but include binary-blob

● atusb
  ○ Tip from the linux wpan IRC
    ■ Drivers not in mainline kernel (*but netnext*)
    ■ Merged our own kernel for the Raspberry Pi
  ○ The last one was delivered to us
  ○ Design is open, but expensive to produce only a few

● R-Idge
  ○ Suggested on the RIOT mailing list
  ○ Easy to use & available
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Conclusion

● Took much longer than I expected
  ○ Finding the thread mistake took me \(~1\ ½\) weeks
  ○ Spent a lot of time with the debugger

● Some mistakes could have been avoided
  ○ By a complete picture of the functionality
  ○ More test-cases (e.g., test-first)

● Will probably be faster next time (libcaf_io?)
Some Future Work

- Get this running on the stm32f4discovery
- Move threads, mutex, ... to RIOT
- Implement the network stack
- Port libcaf_io to RIOT
- Enable exceptions
- Include a security concept
- Do lots of testing
Thanks to Martin and Dominik, they helped a lot!


