
RENESAS

BARR group

The Embedded Systems Experts

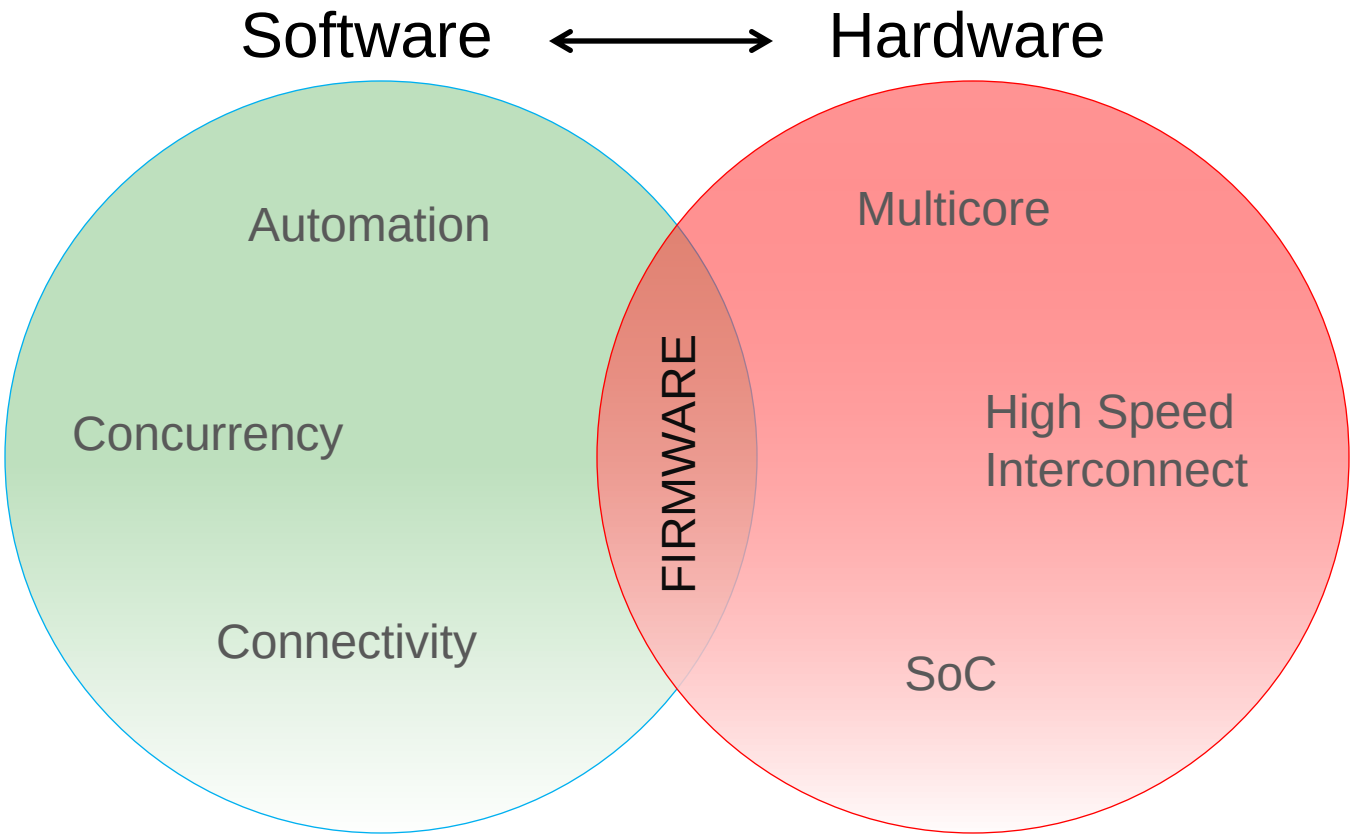
# Trends in Embedded Software Development

**Dan Smith**

**Principal Engineer, Barr Group**

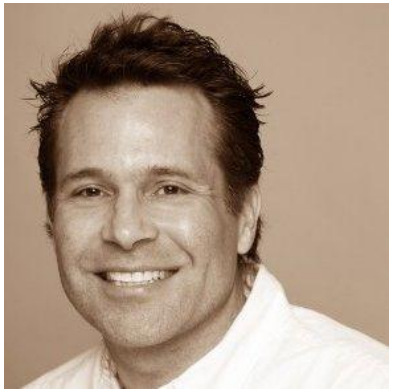
Renesas Electronics America Inc.

# Topic: "Trends in *Embedded Software*"




Advances in hardware and software impact each other

# About the Presenter



- Principal Engineer, Barr Group
  - Consulting – Architecture and Process
  - Product Development
  - Expert Witness
- B.S.E.E., Princeton University
  - Computer Architecture
  - Microprocessor Design
- Industry experience
  - Telecom & Datacom
  - Industrial Control
  - Low-power Devices & Consumer Electronics
- Range of processor architectures, RTOSs, etc.

# About Barr Group

- Internationally recognized leader in embedded systems
  - CTO – Michael Barr (Netrino, Embedded Systems Design, …)
- Focus on reliability and security
  - Training
  - Consulting on process and architecture
  - Design services

BARR group

The Embedded Systems Experts

- Renesas RX62N Development board
  - Center of 5-day Embedded Bootcamp course
  - Also available: "Bootcamp in a Box"


- More information:
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  - Email: embed@barrgroup.com
  - Phone: (866) 65-EMBED

# Foundation for this presentation

- **Personal experience**
  - 20+ years of embedded development
  - Wide variety of industries, code sizes, and processors
- **Barr Group experience**
  - Even wider range of experience and exposure
  - Survey of our customers and partners
- **Industry Research and Reports**
  - Necessary to stay on top of emerging trends
  - Identify emerging processes, architectures, standards…
- **Personal Connections & Contacts**
  - e.g. Michael Barr, former editor of "Embedded Systems Programming" magazine

# Renesas Technology & Solution Portfolio

# Role of firmware in embedded products

- Firmware is largest part of embedded product development…
  - *By staff / headcount*
  - *By cost*
  - *By time*

- Also considered to be riskiest
  - In terms of product security & stability
  - In terms of schedule slips

- Why?
  - Beginning without requirements
  - Changing requirements
  - We can always sneak in "one more feature"
  - We can always "fix it in the field"

# Importance of firmware correctness

- Quoting Jack Ganssle:

  - "Firmware is the most expensive thing in the universe"

- Quoting Michael Barr:

  - "Neither reliability nor security can be tested, debugged, or patched into a product. They must be designed into embedded systems"

- The bottom line:
  - Important to get firmware right (as close to "right" as possible)
    - the first time

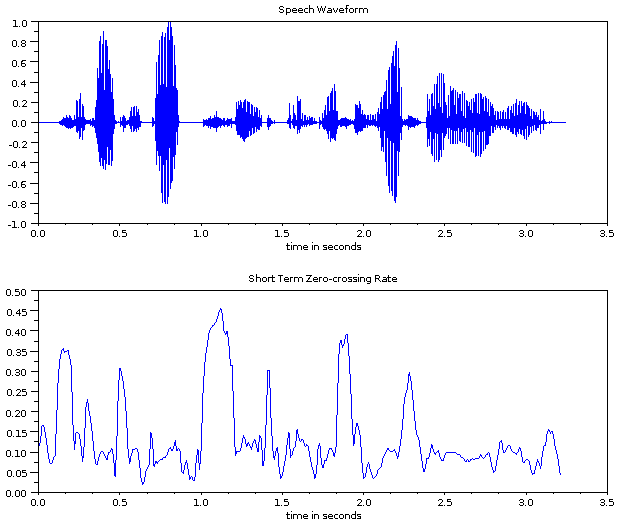
# What's driving the trends?

- More functionality being pushed into firmware
  - "Has to be done in hardware" – not necessarily!
  - Some products have a large up-front cost
  - Easier to update in the field
  - Easier to release feature upgrades ($$$)
- More powerful processors
  - Less focus on conserving bytes & CPU cycles
  - More focus on writing correct, robust, maintainable firmware
- Better tools
  - Easier than ever to prototype something quickly
  - More time focusing on product-specific requirements and functionality

# Signal processing

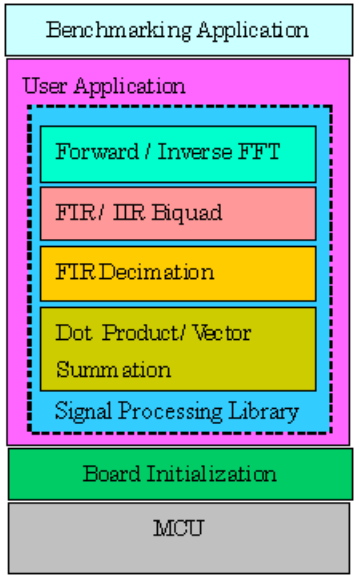
# Increased use of Signal Processing

- Not necessarily requiring DSP anymore
  - Microcontrollers are becoming more and more capable
  - Custom instructions, faster memories, bus architectures, etc.
- Multimedia is one driver
  - Audio encoding / decoding
  - Video encoding / decoding
  - Image processing
- Real-time control systems
  - Signal Conditioning / Filtering
  - Control loops



# Renesas MCUs and Signal Processing Library

- Dual CPU (MCU + DSP) can often be replaced by single MCU
  - Cost reduction, simpler design
- Renesas MCUs
  - SuperH (SH2A-FPU, SH4A)
  - RX Family (RX600)
    - MCU/DSP Hybrid (FPU,MAC,Barrel Shifter)
    - "Digital Signal Controllers"
  - M16C Family (R32C / 100)
- Renesas Signal Processing Library
  - Collection of the most useful routines
  - Abstract away complexities of underlying implementation
    - Focus on algorithms & system-level design
  - Fine-tuned and highly-optimized for Renesas CPUs
  - Floating point and fixed point
  - Callable from C and C++



# Test-driven development

# Test Driven Development (TDD) – what is it?

- A development methodology
  - Not a test methodology…
  - … although when done properly, resulting code is well-tested
- Development is driven (guided) by tests
  - Not the other way around
- Tests are written before the code
  - Forces the question: "How will I test this?"
  - Emphasizes importance of separating interface from implementation

# Test Driven Development (TDD) in one slide

- Short, iterative development cycles
  - Write test(s)
  - Run test(s) – FAIL (no logic in code)
  - Write code to make tests pass
  - Run tests – PASS
- Emphasis on writing the minimum code to pass tests
  - Tends to reduce YAGNI situations
- Emphasis on automation
  - Essential if battery of tests is to be run over & over again
- Refactoring done at end
  - Take a step back, improve internal structure without breaking anything

# Test Driven Development benefits

Assuming the process is followed properly

1. **All code is unit tested**

   or at least what is feasible

2. **Regression test suite is already developed**

   Did we break anything?

3. **Tests are automated**

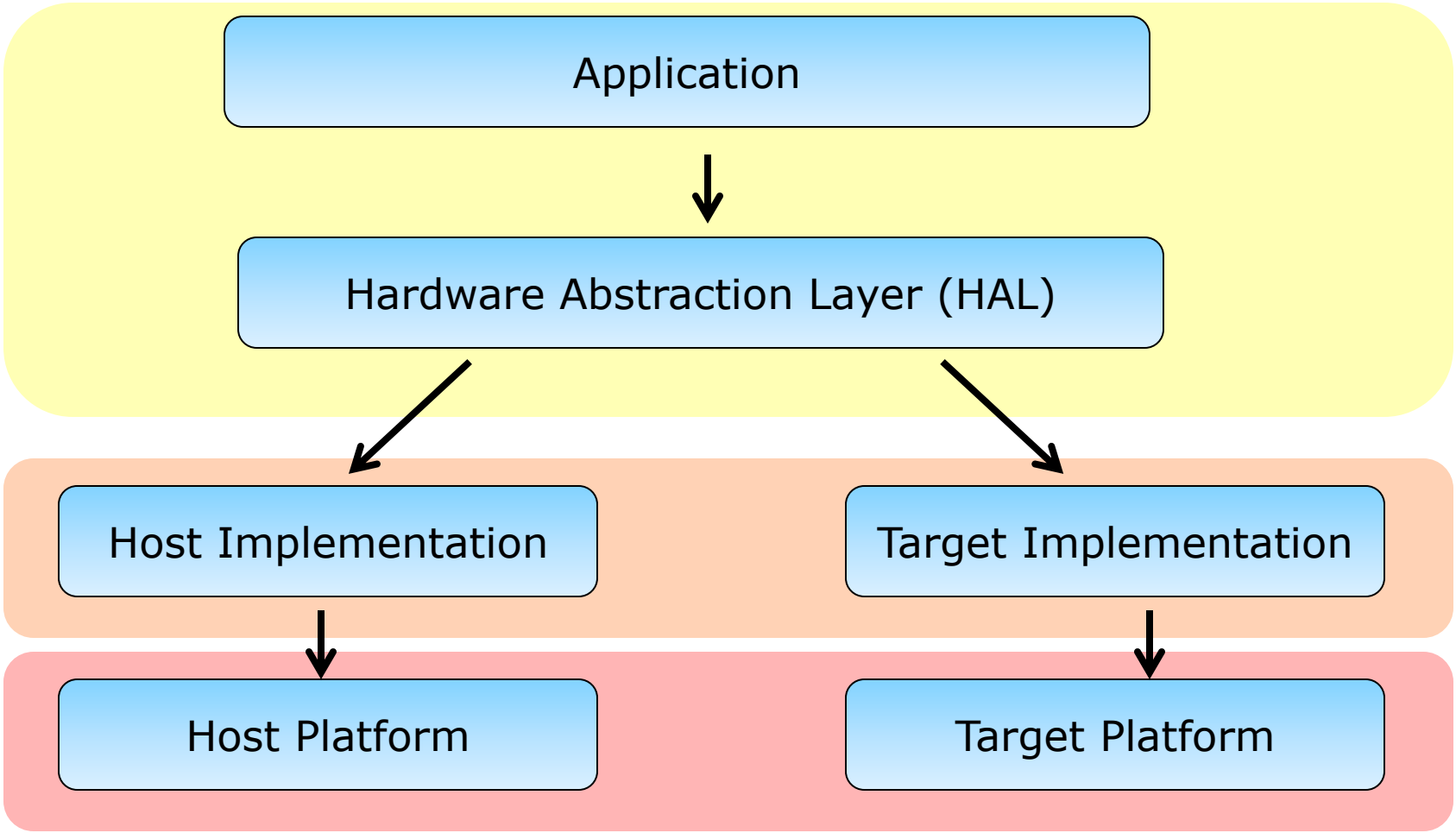
   No barrier to running a "health test" on current build

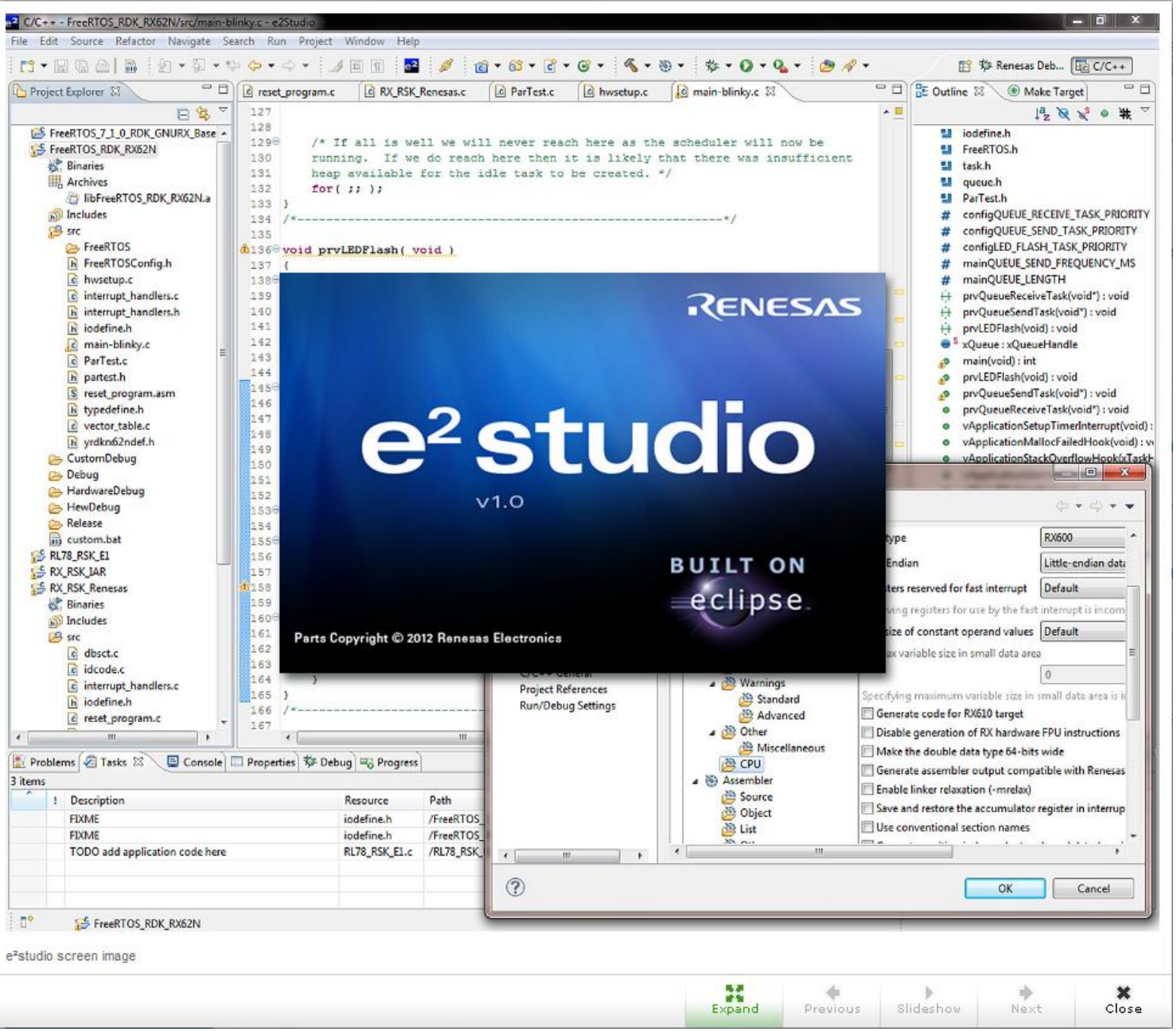
   Lack of automation is the single biggest obstacle

4. **Write code and run tests before target HW available**

   Test harness + removal of global state – simplifies testing

# Decoupling software from target platform






e²studio screen image

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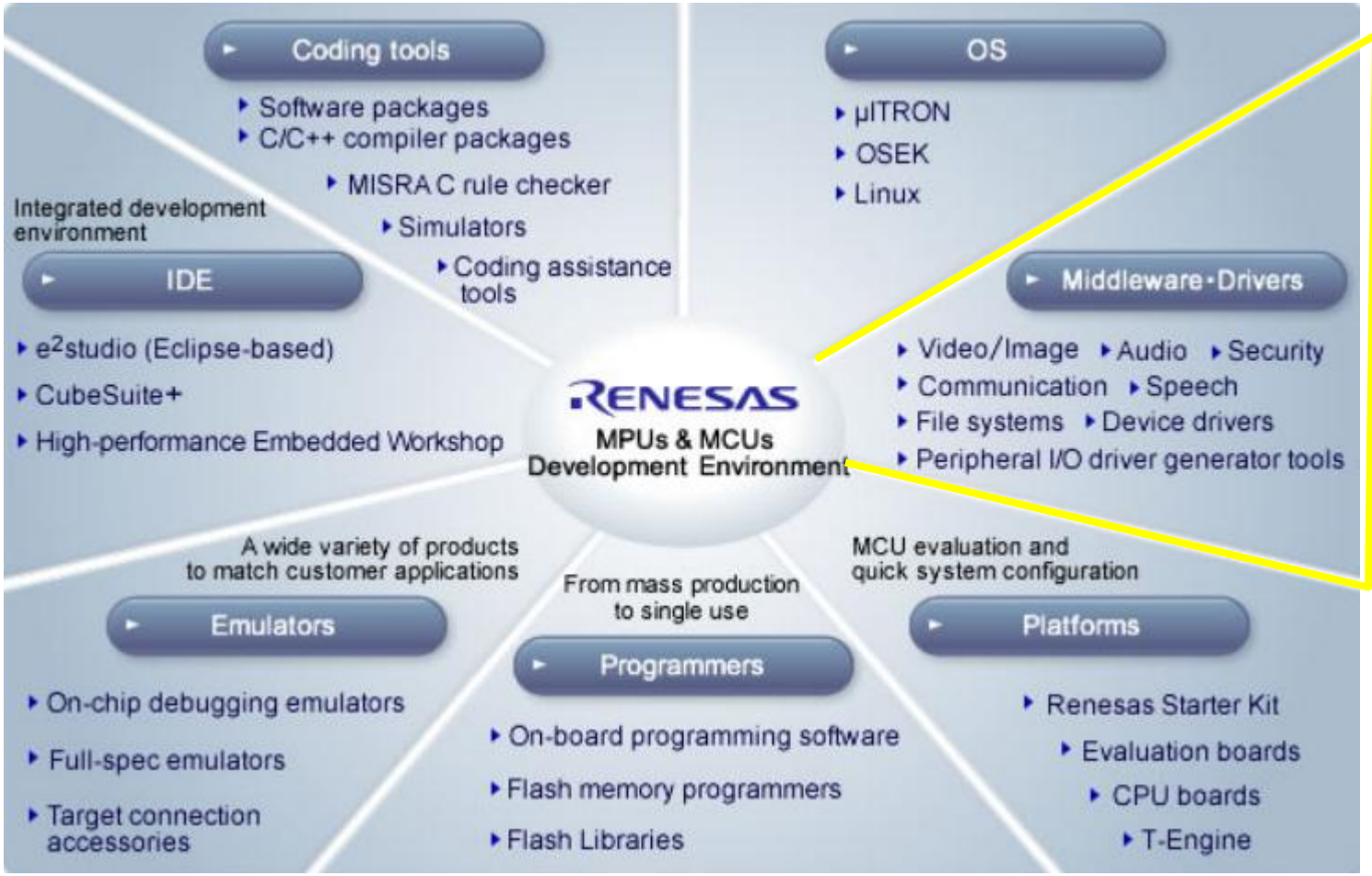
# Middleware and 3rd party firmware

# Increasing use of middleware

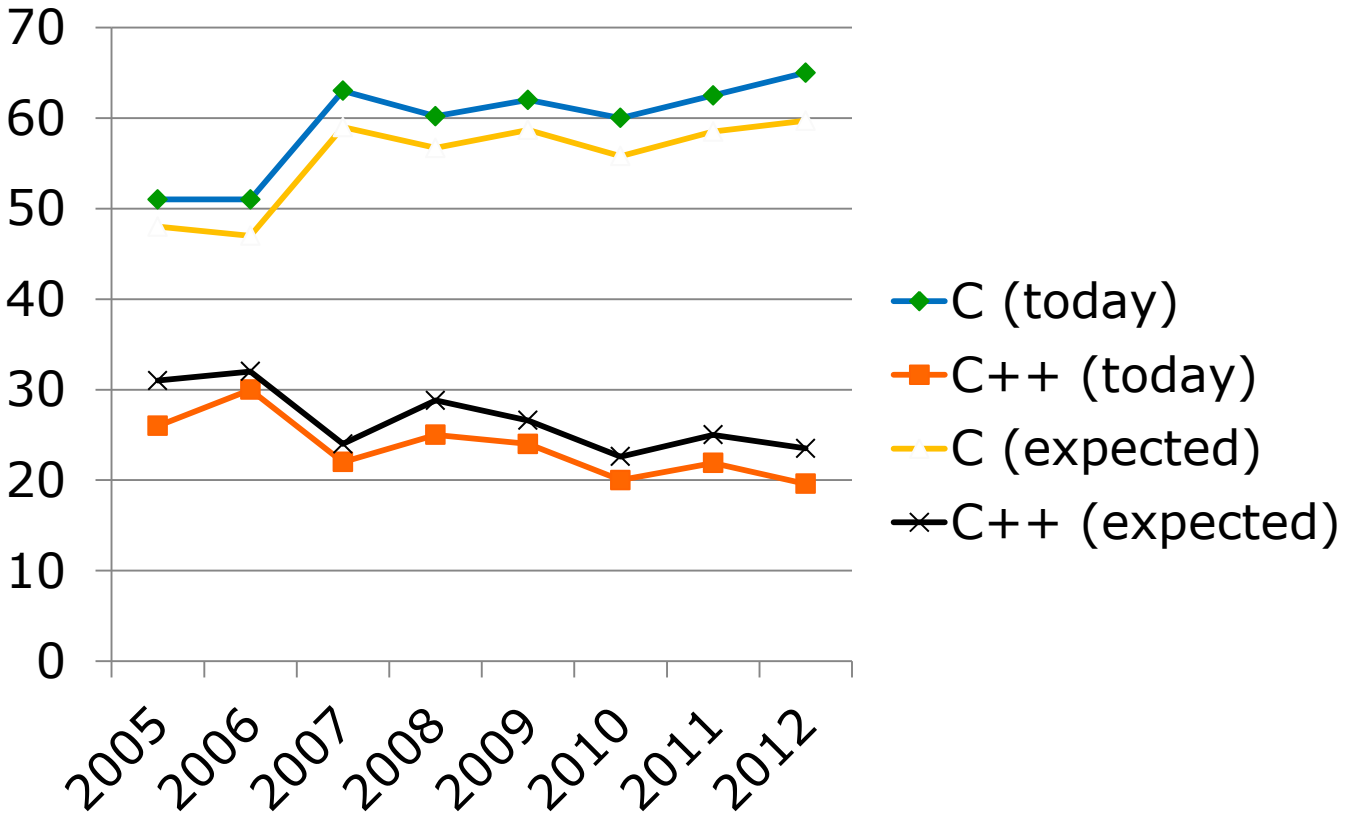
- Products are becoming more complex and capable
- Many capabilities are "enablers"
  - Network connectivity
  - Plugins / User Applications
  - Graphical User Interfaces
- Most companies aren't in the business of developing user interface toolkits, network stacks and frameworks
  - But they want to use them
- Development -- more ***integration*** activities than ever
  - Final product - combination of company's differentiating technology & 3rd-party enabling middleware

# Rich set of middleware and 3rd-party firmware



# Use of C and C++

# Trends in Programming Languages



# C & Embedded Systems

- A natural fit…
  - Ability to access & address memory directly
  - "volatile" keyword
  - Sometimes referred to as a "high level assembly language"
  - Gives you "enough rope to hang yourself"

- … but fewer graduates than ever are being taught C!
  - And even fewer how write robust real-time firmware in C
  - Is this a good thing or a bad thing for veteran C developers?

- New C standard – C11
  - Most features not specifically targeted at firmware
    - … but still useful
  - Toolset support still lagging

# Use of C++ in firmware development

- Usage of C++ increases with project complexity
  - 32 kilobytes or less:8%
  - Up to 256 kilobytes : 24%
  - Up to 1MB: 56%
  - Greater than 1MB: 71%
- Usage of C++ increases with processor architecture
  - 8-bit: 6%
  - 16-bit: 18%
  - 32-bit: 52%
- A couple of important notes
  - Numbers reflect percentage of projects using ***any*** C++
    - Virtually all of the projects above reported use of C as well
  - Much embedded C++ in use is very "C like"

# Use of C++ going forward (2012 and beyond)

- New C++ standard (C++11)
  - Finalized in late 2011
  - Compiler support just rolling out now

- Now you can write firmware in C++ that is:
  - Safer (*e.g.* static (compile-time) assertions)
  - Faster (*e.g.* rvalue references / move semantics)
  - Smaller (*e.g.* constant expressions)
  - Simpler (*e.g.* type inference ("auto"), range-based for, lambda)

- Change in CPU, change in programming language
  - Move from 8/16 bit to 32-bit
    - "Now we can use C++"
  - Typically involves change in hardware, tools, etc.
    - Good time to consider change in implementation language

# IDEs/toolsets and programming languages

- Use of both C and C++ supported
  - Possible to migrate from C to C++
  - Also possible to mix C & C++ in same application
- Major IDEs support both programming languages
  - e² Studio (Eclipse)
  - Renesas High-Performance Embedded Workshop (HEW)
  - IAR Embedded Workbench
  - Green Hills MULTI
- Not locked in to any particular toolset or language
  - Relatively easy to migrate to different IDE
  - C and C++ compilers mostly standards-compliant

# Use of open-source software

# Increased use of open-source software

- More and more projects using open source software
- Motivations:
  - Source code availability
  - Licensing cost
  - Control / freedom
- Often not considered:
  - Stability / maturity of software
  - Cost / value of engineer's time
  - License requirements
- Most often cited reason for using open-source:
  - Not being dependent on software vendor for bug fixes / updates

# A few examples: Open-source & embedded

- **Host Side**
  - Host operating system
    - Linux (also on target side for larger systems)
  - Build tools
    - GCC / G++ / LLVM
  - IDE
    - Eclipse
- **Target Side**
  - Bootloader
    - U-Boot Bootloader
  - RTOS
    - FreeRTOS
  - Filesystem
    - FatFs (ElmChan)
  - TCP/IP
    - lwIP, uIP

# Migration from 8/16 bit to 16/32 bit

# 8/16 bit CPUs

- **Not going away**
  - Extremely simple, high-volume, cost sensitive
  - But the cost difference is decreasing
    - Especially when considering roadmap
- The "hidden cost"
  - Extra effort spent on optimizing memory & CPU cycles
- CPU's architecture is often exposed to programmer
  - Code is typically not portable
  - More time working around architecture (e.g. bank switching)
- Development tools often limited
  - Legacy compilers
  - Often no support for C++
    - or even updated C (C99, C11)!

# The move to 32-bits

- Key drivers
  - Cost of 32-bit CPUs going down
    - Furthermore, CPU becoming smaller percentage of B.O.M.
    - Companies now consider indirect cost (development time)
  - Products becoming software-intensive
    - Inexpensive, fast, integrated flash memory
    - Focus is on productivity, cycle time, debugging
    - More sophisticated development tools
    - Ability to program in higher-level languages
    - Less concern about memory and processing speed
- 8/16 bit MCUs not going away
  - Extremely simple, high-volume, cost sensitive
  - Larger memories, faster clock speeds

# Renesas – 8/16/32 bit CPUs

- Renesas – rich MCU portfolio under one umbrella
  - One size does not fit all

- 8/16 bit CPU offerings
  - RL78, 78K, R8C
  - M16C, H8 / H8x, 720/740

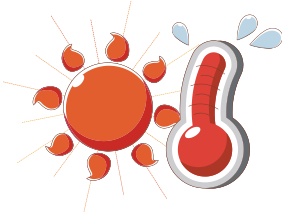

- 32 bit offerings
  - RISC: RX Family (RX600, RX200, …)
  - CISC: V850, SuperH


- Roadmap / migration path
  - Offerings for almost any power / performance requirement
  - Commonality in IDEs and peripherals reduces learning curve

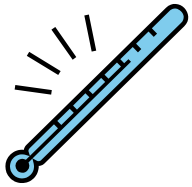
# Low Power Designs: The Firmware Aspect

# Motivation for low-power design

- Entire track at this conference on low power design
- What is heat?
  - Wasted energy!



- Reduced heat
  - Reduced cooling costs and complexity
  - Better reliability



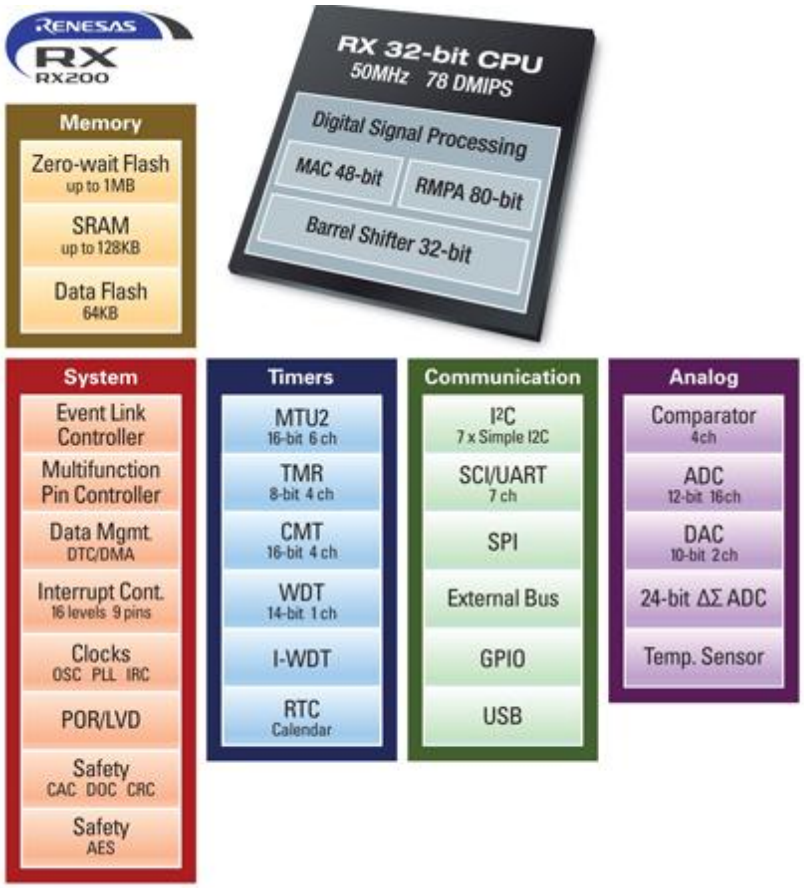
- Battery-powered devices
  - Longer run time
  - Smaller package

- Happier customers
  - Better for environment
  - Less expensive to operate

# Evolving role of firmware in low power devices

- Certainly, hardware design plays a large role
  - Often overlooked: role of software!
- Software is much easier to:
  - Patch / Change / Reprogram
  - Adapt & Evolve
  - Optimize
- Earlier: design hardware, write firmware, measure, panic!
- Today: design low-power firmware from outset
  - Emphasis on Hardware / Software co-design
  - Component selection – power down modes
  - Also important – internal MCU peripherals and clocks

# Renesas – high performance, low power




**Ultra-low voltage operation**

- 1.62V operation @ up to 20MHz, 31 DMIPS

**Low power consumption**

- 130µA/DMIPS (run mode), 1.3µA with RTC on
- 0.45µA with RTC off

**High performance**

- 1.56 DMIPS/MHz, 78 DMIPS @ 50MHz, 2.7V to 5.5V

**Zero wait-state Flash**

- 2KB block size, Erase/Write operation down to 1.62V
- Programmable at 1.62V
- Data flash programmable while code is executed (BGO)

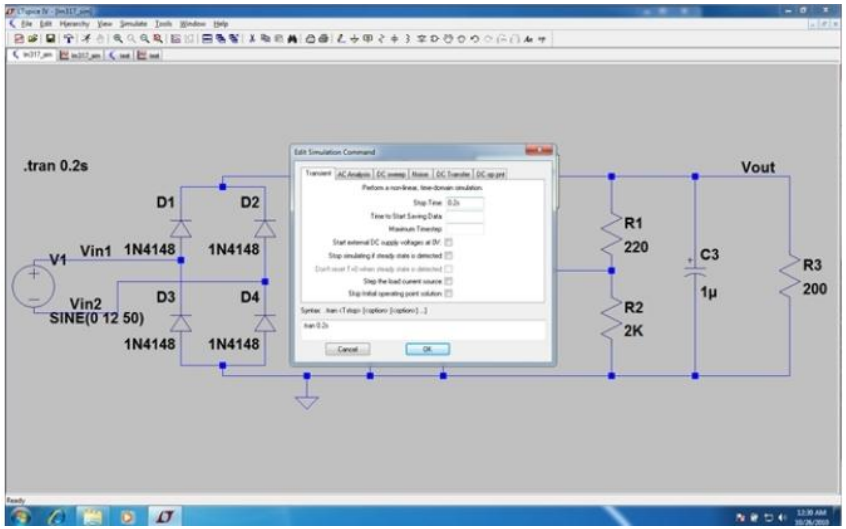
**Scalable**

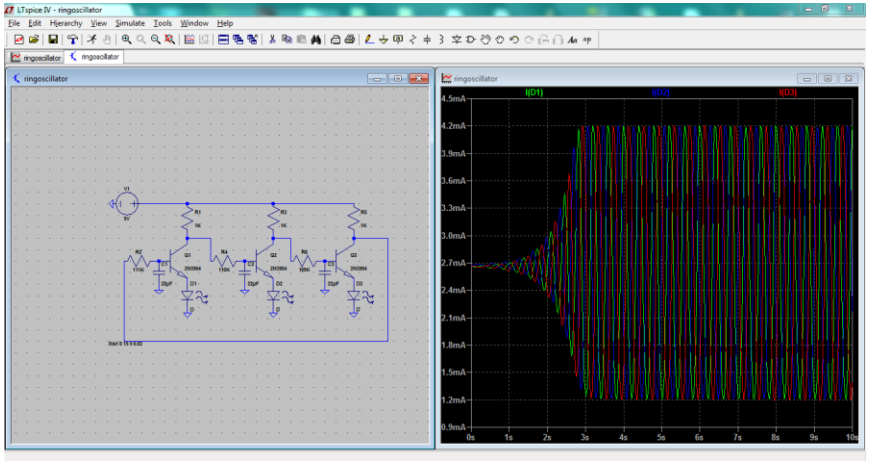
- 36-145 pins, QFP, LGA, QFN
- 32KB - 1MB
- Multifunction pin controller

# Modeling, Simulation, Code Generation, Frameworks

# Modeling & Simulation - Hardware

- Even important for simple circuits and hardware
- The interfaces & behavior of individual components are well-defined
  - Perfect for simulation
- Answers the question: "When I put this all together, will things behave the way I expect?"
- Faster & easier to test and debug than a real circuit

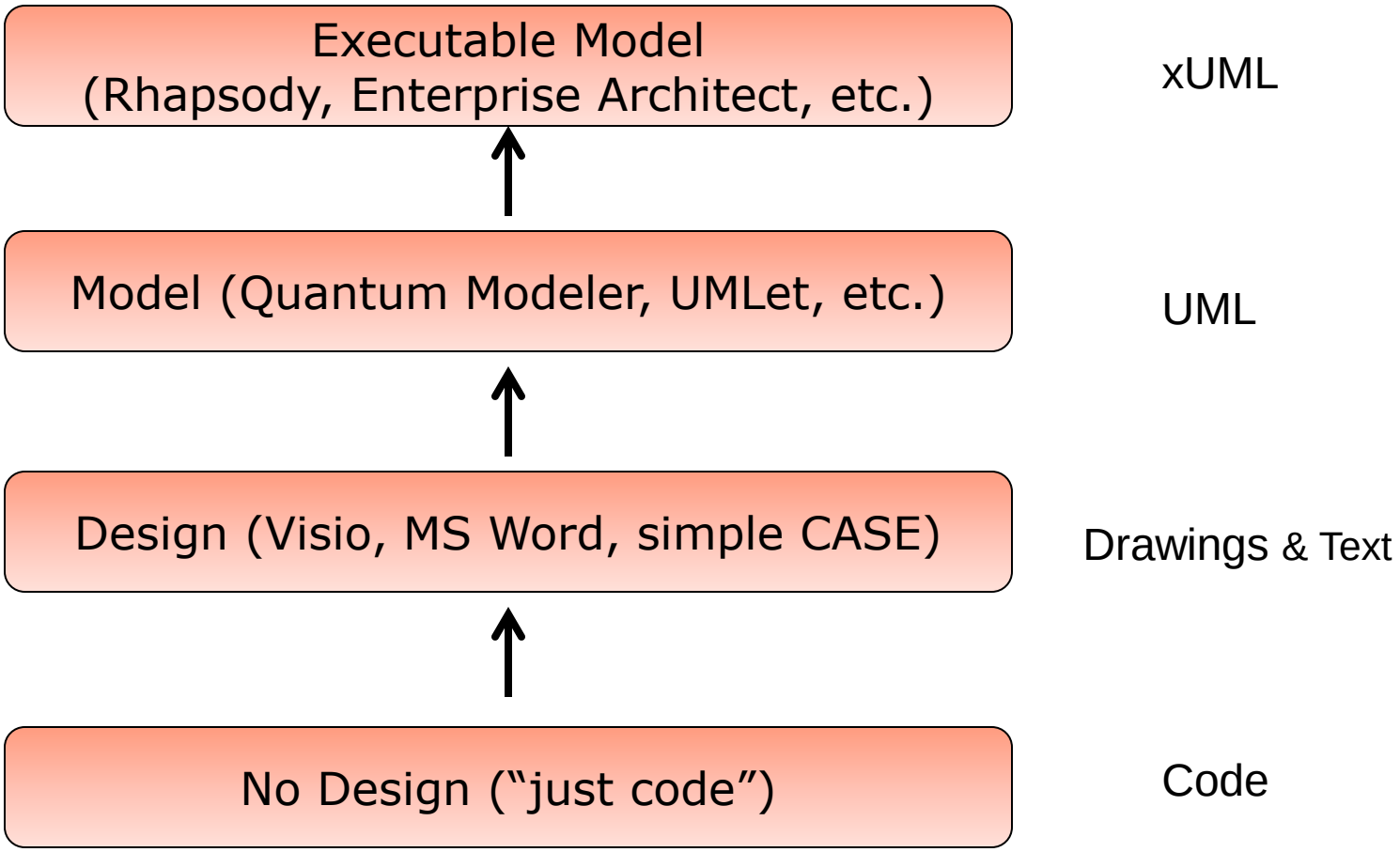


# Modeling & Simulation - Software

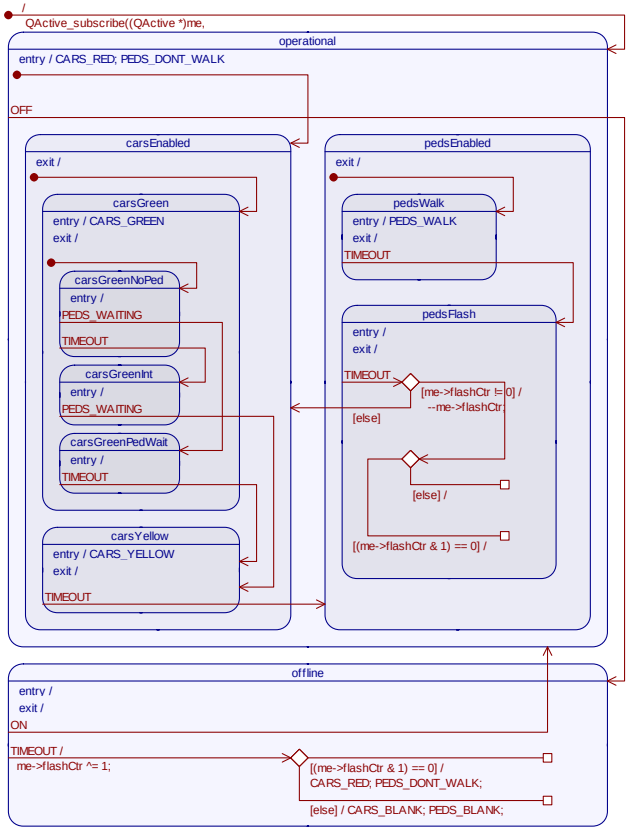
- Easier to get started
  - Not battling with nuances and quirks of new hardware
  - Friendly, robust, powerful environment
  - CPU & memory are essentially "unlimited"
  - Less intimidating
- Initial focus is not concerned with final target hardware
  - Task partitioning
  - Algorithm correctness
  - Data flow throughout system
- Getting these things right up front makes integration with new hardware easier (already proven correct on known HW)

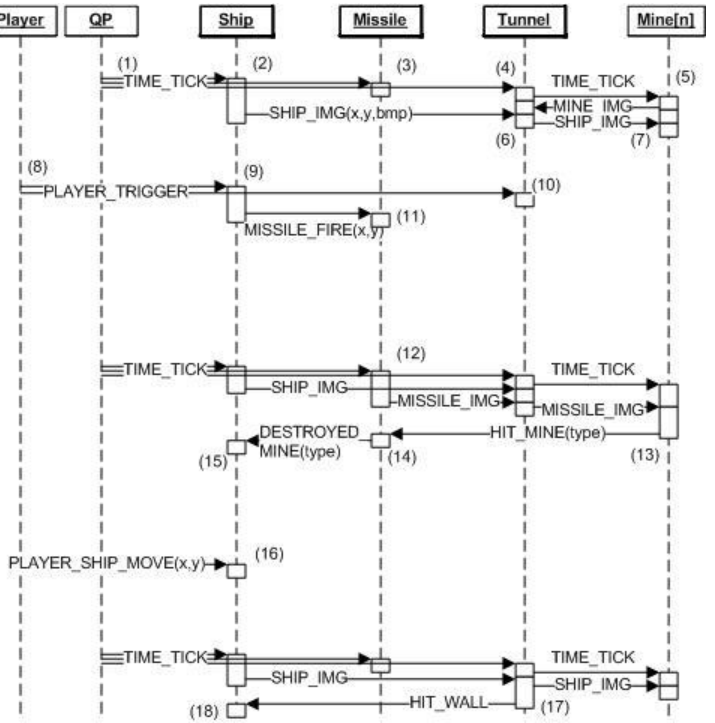
# Development / modeling sophistication



# UML (Unified Modeling Language)

- UML is the "lingua franca" in the modeling world
  - Statecharts (behavior)
  - Sequence Diagrams (interaction)
  - Class Diagrams (structure)



# UML & Embedded Systems

- UML used increasingly for modeling embedded systems
  - Myth: UML only useful for OO / C++ systems
- UML statecharts : powerful, widely-used
  - Most embedded systems are event-driven at their core
  - Support for hierarchy in states
    - Reduce complexity and code size
  - Entry & exit actions
    - Enforce invariants
  - Guard conditions
    - Evaluate extended state variables at run time
- UML sequence diagrams
  - Show interactions between objects / tasks / threads
  - Describe data exchange (and often timing) between actors

# One size does not fit all

- Wide range of tools (from Visio to Rhapsody)
  - Visio: pure drawing tool
    - Not even UML aware
    - Better than nothing, but not by much!
  - Rhapsody: full-blown modeling tool
    - And all the complexity and "ceremony" that comes with it
- Different tools have different capabilities and features
- Consider the Costs
  - Financial
  - Learning Curve
  - Maintenance

# Modeling & Design Tools

- Heavyweight tools
  - Typically support round-trip engineering and executable UML
  - Examples:
    - Rhapsody (IBM)
    - Enterprise Architect (Sparx Systems)
    - Visual Paradigm (only C++)
  - These tools usually supply (or require) a framework

- Lighter weight tools
  - Quantum Modeler (Quantum Leaps)
  - VisualState (IAR)
  - Focused more on creating correct, robust hierarchical state machines than full-blown UML system engineering
  - Code generation in C as well as C++
    - Targeted more at embedded systems

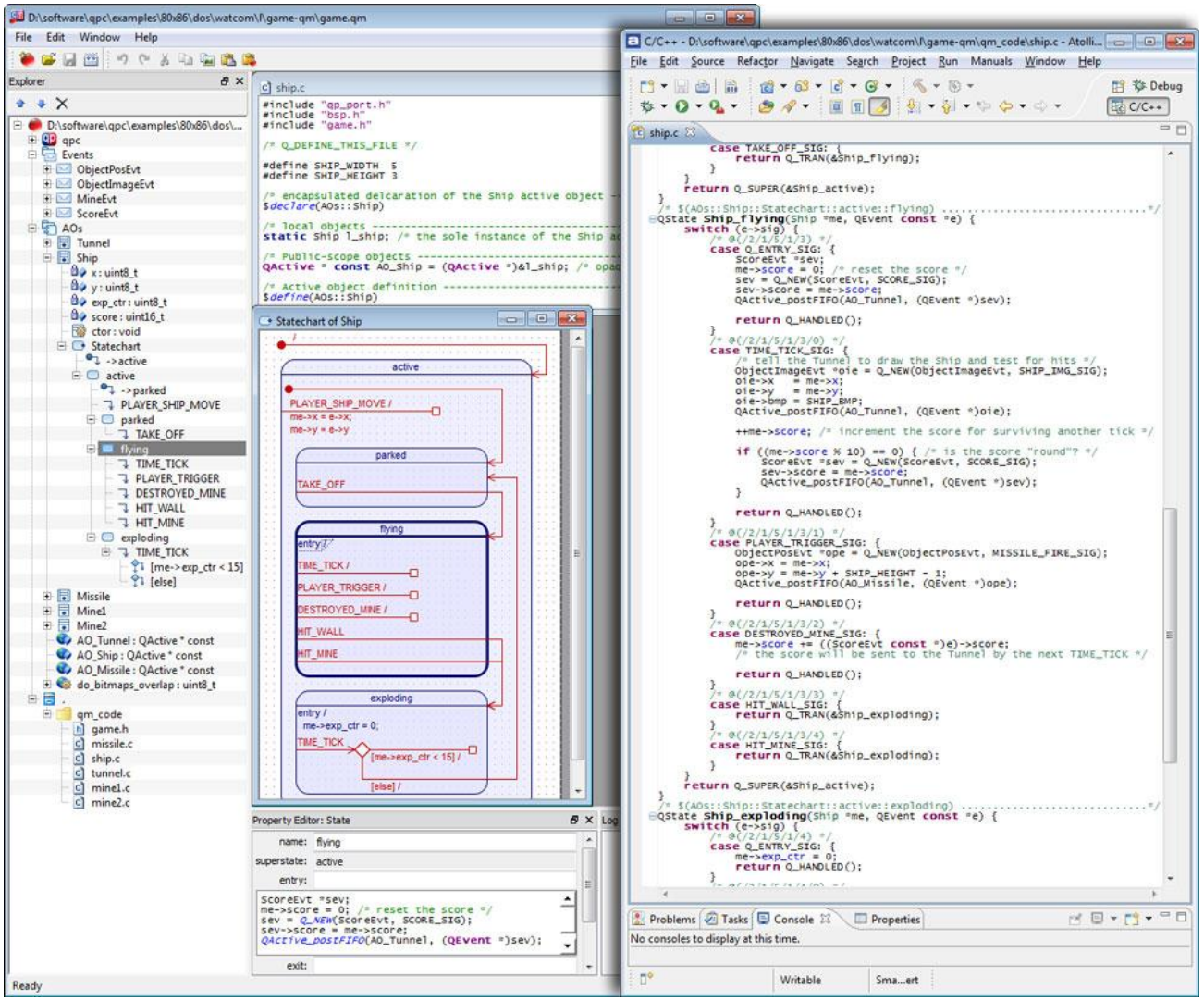
# Simulation and Modeling – Hidden Costs

- False sense of security
  - Not shaking out hardware
  - Timing issues are largely undiscovered
  - Memory/CPU limitations often not exposed
  - Less intimidating development & debugging
- Learning Curve
  - Complex tools impose a serious learning curve
  - Easy to become bogged down in options & drawing / layout
  - Beware of analysis paralysis!
- Move to target
  - Use architecture-independent data types (e.g. uint32_t)
  - Abstract away underlying hardware

# Code Generation

- One of the biggest motivations for modeling
  - UML-aware drawing tools are far better than Visio…
    - …but code generation is even better!
- With code generation, the design is the code
  - "Design Rot" not possible with majority of application logic
    - Fix/enhance code by modifying design & re-generating
- Testing burden doesn't disappear…
  - … but at least the tedium of coding up diagrams does
  - Just because a model simulation works, there is no guarantee that the target code will
    - Code generation can have flaws just like compilers
    - Integration issues with marginal hardware

# Code Generation Example (Quantum Modeler)



# Security and Reliability

# Greater Need For Reliability And Security

- More embedded systems than ever impact safety
  - Medical Devices (defibrillators, insulin pumps, radiation)
  - Transportation (avionics, rail, road vehicles)
  - Industrial Control (food processing, robotics, smelting)
  - Energy (electric grid, nuclear power plants)

- But the question is:
  - Are these industries and products as safe as they could be?
    - And safe as they ***should*** be?

- Reliability and security are the cornerstones of safety
  - And they have to be considered from the outset

- Yet systems are becoming **larger** and **more complex**
  - What can be done to make and keep products safe and secure?

# Reliability & its role in embedded systems

- Reliability – one definition
  - A product's resistance to malfunction or failure in the presence of any single failure
- Statistical analysis must demonstrate that a **double fault** is **infinitesimally small and improbable**
  - Not all faults are independent and unrelated!
  - Some industries even require mitigation of double faults
- A **reliable system** starts with **reliable hardware**
  - But how software handles hardware problems is key
- **An unreliable system can never be a safe system**
  - Is your system reliable? Does it need to be?

# Failure Mode and Effects Analysis (FMEA)

- Identify and understand failures and their consequences
- Risk = Likelihood x Consequences
- FMEA: Assign values for failure likelihoods and consequences
  - Identify most cost-effective areas for improving reliability
  - Highlight areas of greatest likelihood / consequences
- Minimize impact of failure on system
  - Redundancy
  - Fault Identification & Isolation
- Firmware must be robust in the face of uncertainty
  - Hardware faults, user input, harsh environments, etc.

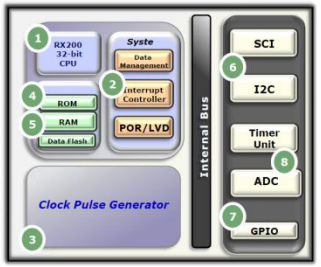
# Renesas & Safety: IEC 60730

- IEC 60730 (International Standard)
  - Intended to increase quality & robustness of devices
  - Defines classifications for automatic electronic controls
    - Class A – not intended … for equipment safety
    - Class B – prevent unsafe operation of controlled equipment

**IEC 60730-1 Class B[1] Requirements**

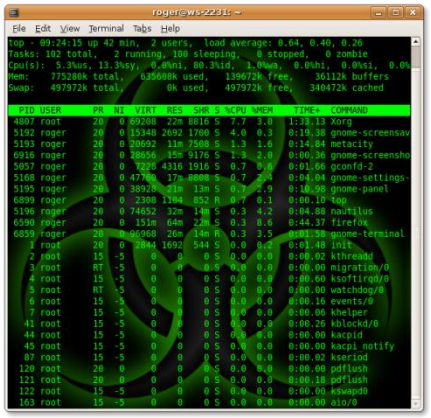
| | Controller's Module | Fault / Error |
|---|---|---|
| 1 | CPU Registers | |
| | CPU Program count | Stuck |
| 2 | Interrupt handling and execution | No interrupt or too frequent interrupt |
| 3 | Clock | Failure or Wrong frequency |
| 4 | ROM/Flash | All single bit faults |
| 5 | RAM | DC Fault |
| 6 | External Communication | Failure or not accurate |
| 7 | Input/output peripheral | Stuck or not accurate |
| 8 | Analog Circuits | Failure or not accurate |

Note 1: IEC60730-1 Specification Annex H– Table H.11.12.7




- Renesas RX200 family
  - Surpass requirements for Class B
  - Built in functions to ensure safe automatic electronic control of class B appliances
  - Examples: CPU registers, interrupt handling, memory tests, communication, I/O peripherals, A/D tests

# Security - The Risk




- Why?
  - Corporate espionage
  - Blackmail
  - Hackers (misuse leads to flakey or dangerous product)

- Security often an afterthought
  - "Closing the barn door after the horses have escaped"
- Difficult to retrofit security and patch holes
  - But the alternative requires more time up front

- Do you want to pay now?
  - Or 10x as much later?

# Increased Connectivity = Increased Vulnerability

- Connectivity everywhere in embedded devices
  - Wireless
    - WiFi, 3G/4G, Bluetooth, Zigbee, Satellite, etc.
  - Wired
    - Ethernet, CANbus, DeviceNET, USB, etc.

- Each of these is a potential attack vector
  - Medical devices (wireless attack on ICDs and insulin pumps)
  - Industrial control & automation (Stuxnet, Duqu, Flame,…)
  - Vehicles (OBD-II exploit)

- Don’t forget about physical access
  - JTAG port, soldered memory
  - Other attacks: side channel, brownout/glitch, thermal…
  - ***But we’re talking about software right now…***

# What can be done?

- Embedded Devices have an advantage
  - Don’t typically run arbitrary code
- Don’t write encryption software yourself
  - What business are you in?
  - Focus and competence
  - Keeping up-to-date
- Use a coding standard that prioritizes correctness over form
- Don’t do in software what can be done in hardware
- Renesas addresses security in multiple ways
  - Renesas middleware library (DES, AES, RSA, key exchange)
  - Secure MCUs – AE-x series and RS-4 series

# Wrap Up & Parting Thoughts

- Importance of firmware has never been greater
  - Develop more in less time without compromising correctness
- Modeling, code generation, frameworks
  - Design becomes code, no need to "re-invent the wheel"
- Security and reliability have never been more important
  - Difficult / impossible to retrofit
- Renesas is well-positioned to address all of these trends
  - Wide offering of MCUs and hardware platforms
  - Extremely broad "ecosystem"
    - Compilers, IDEs, middleware, RTOS, etc.
  - Be sure to work with FAEs, Salespeople, Distributors

# Reading and references

- Available for download:
  - *www.**vdc**research.com/_documents/11_esdt_**survey**_hl.pdf*

- Books:
  - "Embedded C Coding Standard", Michael Barr
  - "The CERT C Secure Coding Standard", Robert Seacord
  - "Practical UML Statecharts in C/C++, 2nd Edition: Event-Driven Programming for Embedded Systems", Miro Samek
  - "Test Driven Development for Embedded C", James Grenning
  - "C++ Primer, 5th Ed.", Lippman, Moo, LaJoie

# Questions?

# Please provide your feedback…

- Please utilize the “Guidebook” application to leave feedback

**or**

- Ask me for the paper form for you to use

# Thank you!

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