Architecture of Embedded Systems

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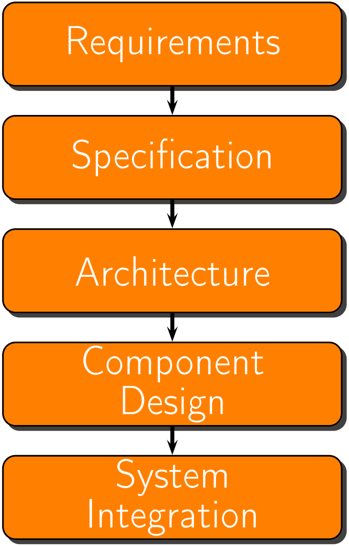
Outline

- Embedded System Design and Development Process
- 6 Stages of Creating an Embedded Architecture
  - Solid Technical Base
  - Architecture Business Cycles
  - Architectural Patterns & Reference Models
  - Architectural Structures
  - Document the Architecture
  - Analyze and Evaluate Architecture

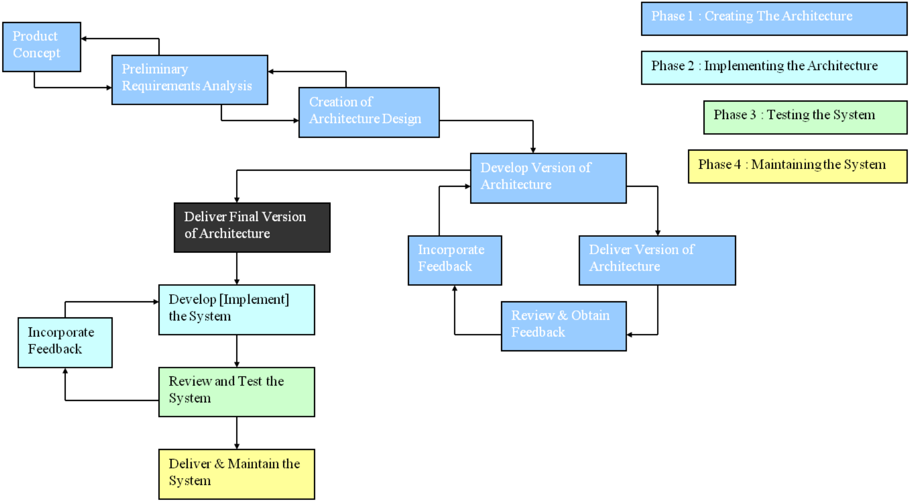
Levels of abstraction



Embedded System Design and Development Process

- Various models exist
- Noergaard proposes model based on the Waterfall and Spiral models
  - Creating the architecture
  - Implementing the architecture
  - Testing the system, and
  - Maintaining the system

Embedded Systems Design and Development Lifecycle Model



What is an Embedded Systems Architecture?

Embedded System Architecture

Is an abstraction of the embedded device that represents the embedded system as some combination of interacting elements.

- Typically doesn't show detailed implementation information
- Represented as some composition of interlacing elements

Sum of Elements = Embedded Architecture

An embedded architecture includes

- Elements of the embedded system
- Elements interacting with an embedded system
- The properties of each of the individual elements, and
- The interactive relationships between the elements

Elements of an Architecture

- Elements are representations of hardware and/or software
- Implementation details have been abstracted out
- Only behavioral and inter-relationship information
- Examples
  - Class
  - Layers
  - Kernel
  - Client/Server
  - Process
  - Memory
  - ...

Major Types of Elements

- Module
  - hardware and/or software that the system needs to function correctly
- Component and Connector
  - main hw/sw processing units, such as processors, a Java Virtual Machine, etc.
  - communication mechanism that inter-connects components, such as a hardware bus, or software OS messages, etc.
- Allocation
  - relationships between sw and/or hw elements, and external elements in various environments
  - e.g. where the software resides in the hardware

Why Care About The Architecture of an Embedded System?

- Powerful tool used to understand an embedded systems design or to resolve challenges faced when designing a new system
- Solid basis for analyzing and testing the quality of a device and its performance
- Accurately estimates and reduces costs through its demonstration of the risks involved in implementing the various elements
- Leveraged for designing future products with similar characteristics

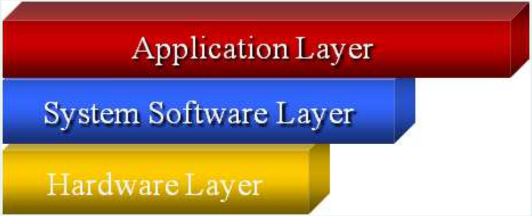
Importance of Architecture

- Every embedded system has an architecture, whether it is or is not documented
- It is a useful tool in understanding all of the major elements
  - why each component is there
  - why the elements behave the way they do
  - how they interact
  - how they behave in the real world
- Even if the architectural structures are rough and informal, it is still better than nothing!
- Many industry popular methodologies for creating architectures (adaptable to embedded systems)
  - Rational Unified Process (RUP), Attribute Driven Design (ADD), Object Oriented Process (OOP), ...

6 Stages of Creating an Embedded Architecture

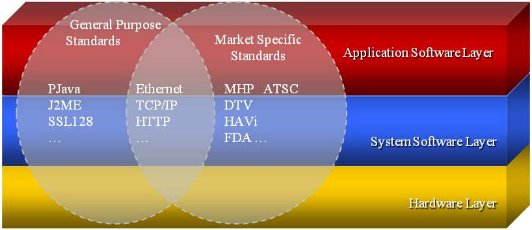
- Stage 1 : Having a Solid Technical Base
- Stage 2 : Understanding the Architectural Business Cycle of Embedded Systems
- Stage 3 : Defining the Architectural Patterns and Reference Models
- Stage 4 : Creating the Architectural Structures
- Stage 5 : Documenting the Architecture
- Stage 6 : Analyzing & Evaluating the Architecture

Embedded Systems Model

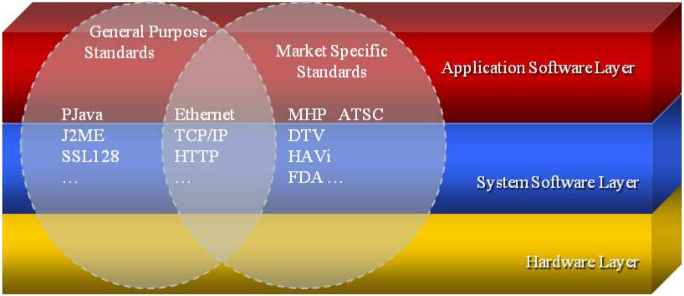


Know Your Standards (1/3)

- Standards dictate:
  - how the components should be designed
  - what additional components are required in the system to allow for their successful integration and function
- Can be classified as:
  - market-specific standards
  - general-purpose standards, or
  - standards that are applicable to both categories

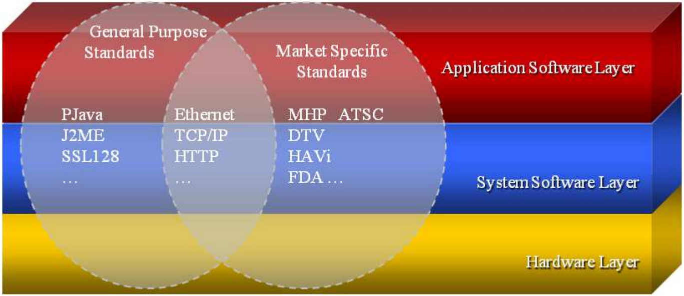


Know Your Standards (2/3)



- Market Specific
  - Consumer Electronics
  - Medical
  - Industrial Automation & Control
  - Networking & Communications
  - Automotive
  - Aerospace & Defense
  - Office Automation, ...

Know Your Standards (3/3)



- General Purpose
  - Networking
  - Programming Language
  - Security
  - Quality Assurance, . . .

Hardware Layer: Many Many Many Embedded Processors To Choose From

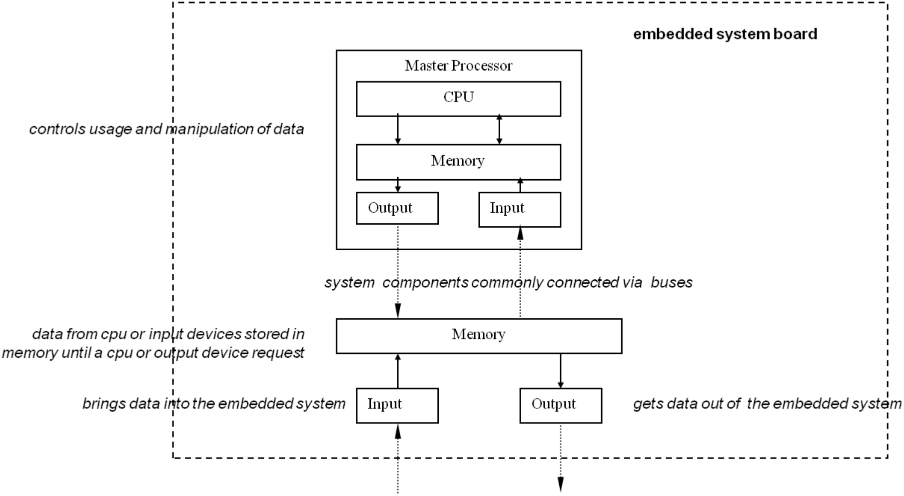
Architecture	Processor	Main Manufacturer
AMD	Au1xxx	Advanced Micro Devices
ARM	ARM7, ARM9, ...	ARM
ColdFire	5282, 5272, 5307, 5407,...	Motorola
M Core	MMC2113, MMC2114,...	Motorola
MIPS32	R3K, R4K, 5K, 16,...	MTI4kx, IDT, MIPS Technologies
NEC	Vr55xx, Vr54xx, Vr41xx	NEC Corporation
PowerPC (PPC)	82xx, 74xx,8xx,7xx,6xx,5xx,4xx	IBM, Motorola
68k	680x0, 683xx	Motorola
SuperH (SH)	SH3 (7702,7707, 7708,7709), SH4 (7750)	Hitachi
SHARC	SHARC	Analog Devices, Transtech DSP, Radstone
strongARM	strongARM	Intel
SPARC	UltraSPARC II	Sun Microsystems
TMS320C6xxx	TMS320C6xxx	Texas Instruments
x86	X86 [386,486,Pentium (II, III, IV)...]	Intel, Transmeta, National Semiconductor, Atlas,...
TriCore	TriCore1, TriCore2, ...	Infineon

...

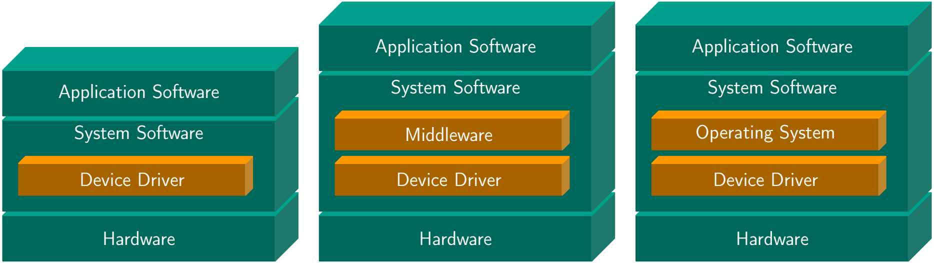
ISA Models

- Application Specific
  - Controller
  - Datapath
  - Finite State Machine with Datapath [FSMD]
  - Java Virtual Machine
  - ...
- General Purpose
  - Complex Instruction Set Computing [CISC]
  - Reduced Instruction Set Computing [RISC]
- Instruction Level Parallelism
  - Single Instruction Multiple Data [SIMD]
  - Superscalar Machine
  - Very Long Instruction Word (VLIW) Computing
  - ...

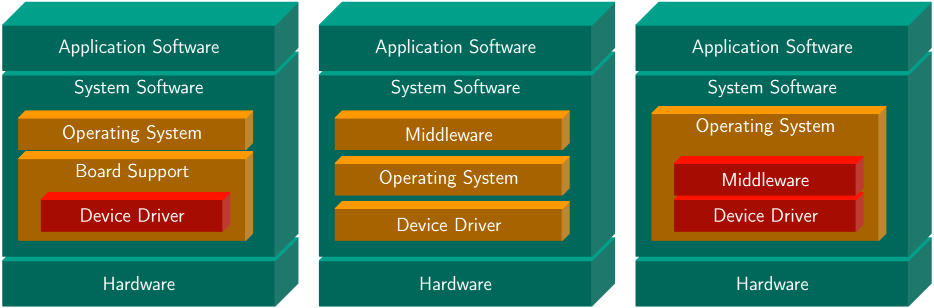
Implementing an ISA & Von-Neumann



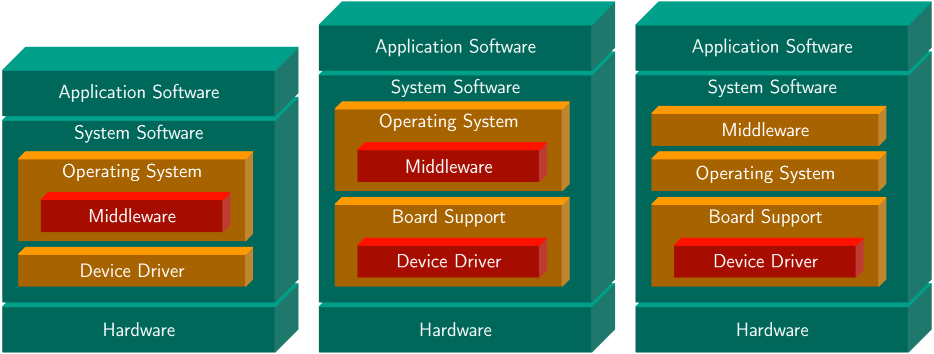
Embedded Software: The System Software Layer (1/3)



Embedded Software: The System Software Layer (2/3)



Embedded Software: The System Software Layer (3/3)



What are Device Drivers? (1/2)

Device drivers are architecture-specific or generic

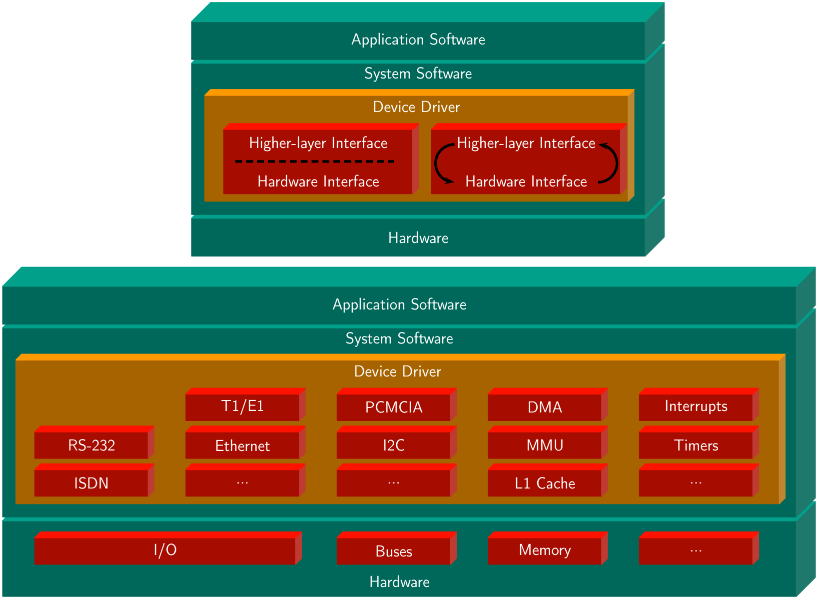
Architecture-specific device drivers

- Manages hardware integrated in the processor
- E.g. initialization and enable of on-chip memory, floating point hardware, ...

Generic device drivers

- Manages hardware on the board
- E.g. initialization and enable of off-chip memory, board buses, off-chip I/O, ...

What are Device Drivers? (2/2)

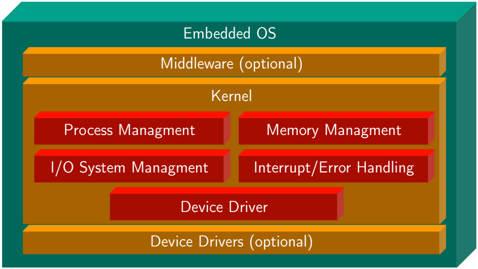


Most Common Types of Device Drivers Routines

- Hardware Startup - initialization of the hardware upon power-on or reset
- Hardware Shutdown - configuring hardware into its power-off state
- Hardware Disable - allowing other software to disable hardware on-the-fly
- Hardware Enable - allowing other software to enable hardware on-the-fly
- Hardware Acquire - allowing other software gain singular (locking) access to hardware
- Hardware Release - allowing other software to free (unlock) hardware
- Hardware Read - allowing other software to read data from hardware
- Hardware Write - allowing other software to write data to hardware
- Hardware Install - allowing other software to install new hardware on-the-fly
- Hardware Uninstall - allowing other software to remove installed hardware on-the-fly

Embedded Operating Systems

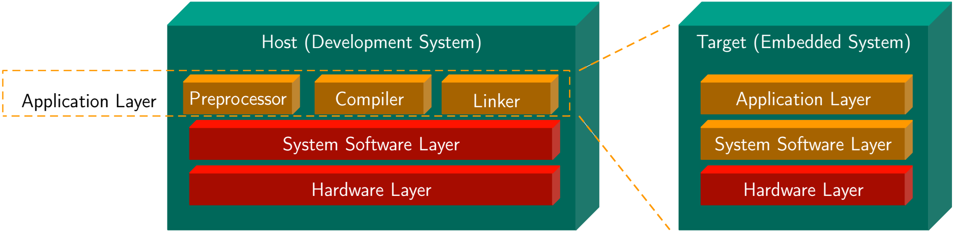
- Process Management
  - Process Implementation
  - Scheduling
  - Intertask Communication & Synchronization
  - ...
- Memory Management
  - Segmentation
  - Paging
  - Virtual Memory
  - System Security
  - ...
- I/O System Management
  - File System



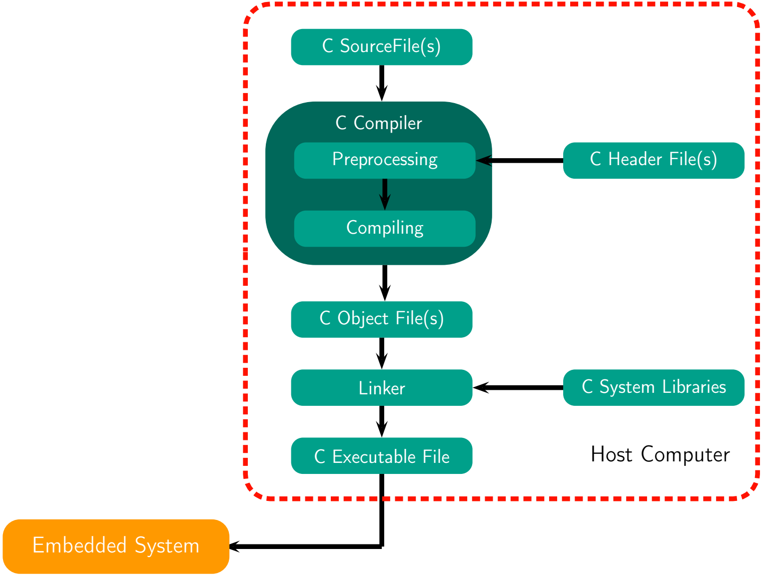
Evolution of Programming Languages

Generation	Language	Details
1st	Machine code	Binary (0,1) and hardware dependent.
2nd	Assembly language	Hardware-dependent representing corresponding binary machine code.
3rd	HOL (high-order languages)/ procedural languages	High-level languages with more English-like phrases and more transportable, such as C, Pascal, etc.
4th	VHLL (very high level languages)/ non-procedural languages	"Very" high-level languages: object-oriented languages (C++, Java,...), database query languages (SQL), etc.
5th	Natural languages	Programming similar to conversational languages, typically used in artificial intelligence (AI). Still in the research and development phases in most cases—not yet applicable in mainstream embedded systems.

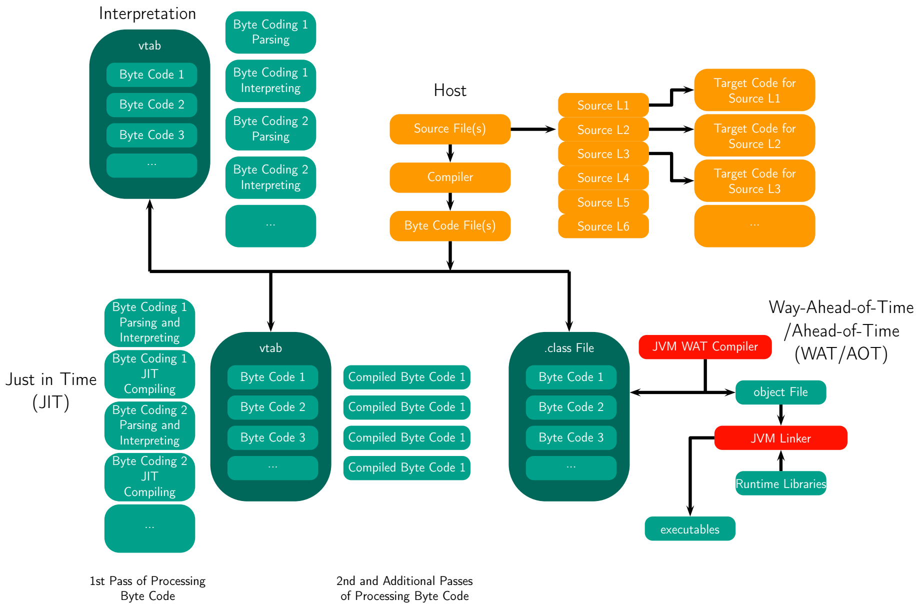
Translation of Code on Host (1/2)



Translation of Code on Host (2/2)



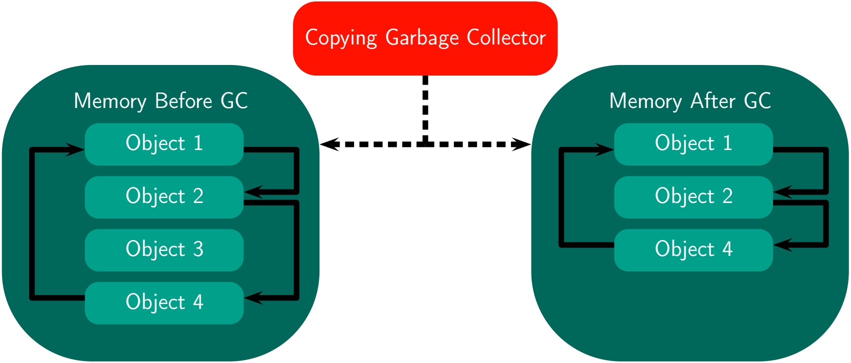
Translation of Code on Target (1/2)

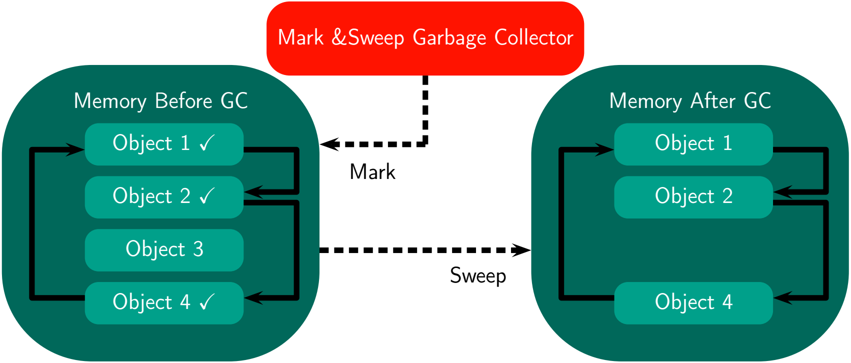


Translations of Code on Target (2/2)

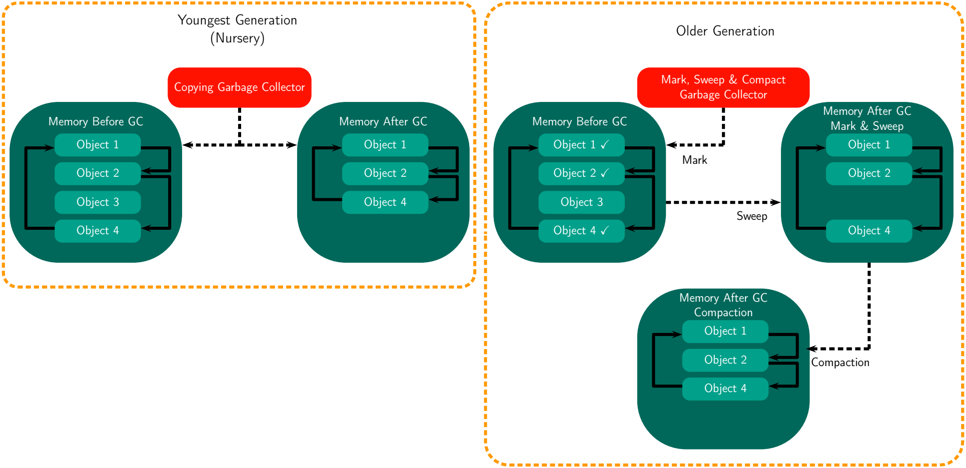
- Translating Code
  - Interpretation
  - Just-in-Time (JIT)
  - Way-Ahead-of-Time/Ahead-of-Time (WAT/AOT)
- Garbage Collection
  - Copying
  - Mark & Sweep
  - Generational

Garbage Collection : Copying



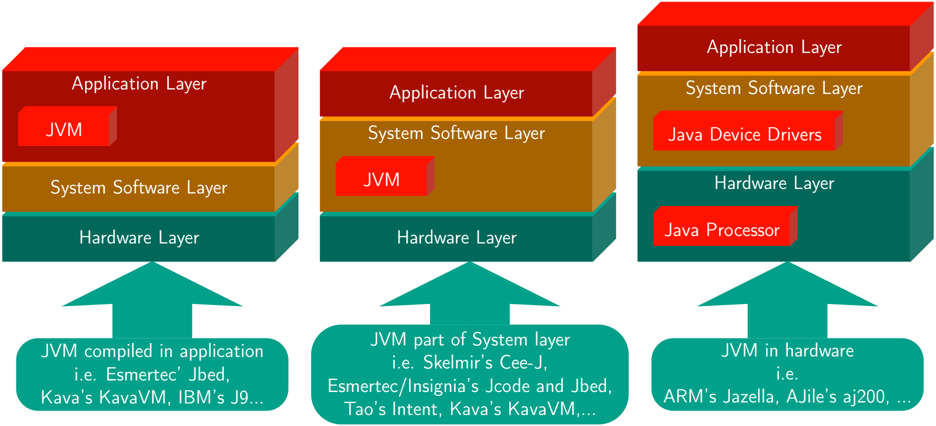

Mark &Sweep Garbage Collector
Memory Before GC
Object 1 ✓
Object 2 ✓
Object 3
Object 4 ✓
Mark
Sweep
Memory After GC
Object 1
Object 2
Object 4

Garbage Collection : Generational



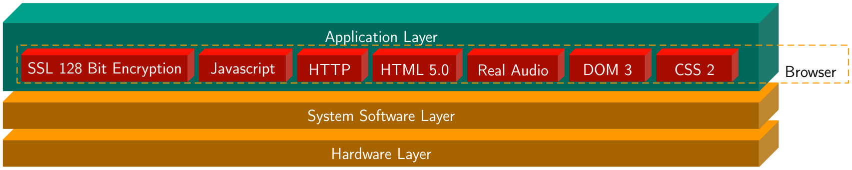
How can Java Add to An Embedded System's Architecture ?

- Standards (NanoVM, JStamp, MicroEJ, Java ME, . . .)
- Processing Bytecode (Interpretation, JIT, WAT/AOT)
- Garbage Collection (Copying, Mark&Sweep, . . .)

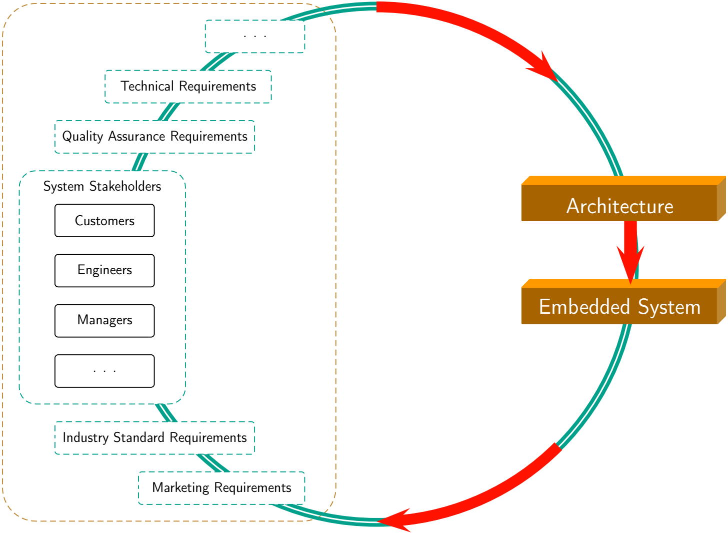


Scripting Languages

- Scripting Languages
  - Perl, JavaScript, HTML, ...
  - Processing Bytecode (Interpretation)



Stage 2 : Understanding the ABCs (Architecture Business Cycles)



Stage 2 : Understanding the ABCs (Architecture Business Cycles)

1. ABC influences drive the requirements of an embedded system
   - not limited to technical ones.
2. Identify all the ABC influences on the design
   - technical, business, political and/or social
3. Engaging the various influences as early as possible in the design and development lifecycle and gathering the requirements of the system
4. Determining the possible hardware and/or software elements that would meet the gathered requirements.

Stage 3 : Defining the Architectural Patterns & Reference Models

- Determine the components that meet
  - deadlines,
  - time-to-market,
  - cost, . . .
- Select a programming language
- Select a OS
- Select a master processor

Stage 4 : Define the Architectural Structures

- Decomposing the structures into smaller and smaller elements
- These decompositions are represented as some combination of various types of elements
- It is for the architects to decide which structures to select and how many to implement

Stage 5 : Document the Architecture

- At least two documents
- A document outlining the entire architecture
    - an overview of the embedded system
    - the actual requirements supported by the architecture
    - the definitions of the various structures
    - the inter-relationships between the structures
    - ...
- A document for each structure
    - which requirements are being supported by the structure
    - how these requirements are being supported by the design
    - any relative constraints, issues, or open items
    - representation of each of the various elements within the structure

Stage 6 : Analyze and Evaluate Architecture

- Architecture is analysed by an evaluation team
- Architects and evaluation team agree on the diferent scenarios for the architecture
- Results of the evaluation should be produced
  - list of requirements/scenarios
  - return on investment (ROI)
  - risks
  - strengths
  - problems
  - recommended changes to the architecture

Outline

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References

- Embedded Systems Architecture, Tammy Noergaard. Elsevier, 2005.

Next class

- The Embedded Computing Platform: Input/Output Interfaces