Embedded Systems Design with Platform FPGAs

Principles & Practices

Dr. Bassam Jamil

Adopted and updated from
Ron Sass and Andrew G. Schmidt

Chapter 1 — Introduction

Chapter 1 Learning Objectives

Topics

- embedded systems concepts
- programming hardware and software
- challenges that embedded system designers face
- FPGA characteristics

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  - an integrated circuit (IC) device
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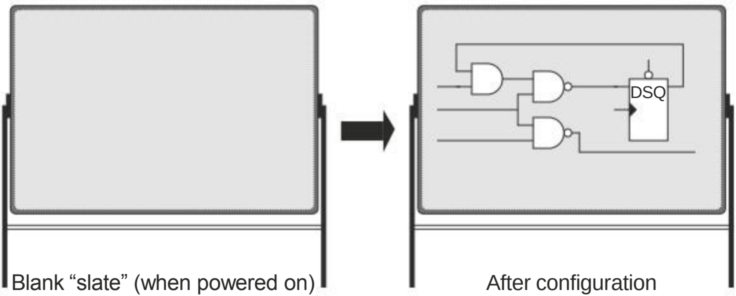
  - that can configured in circuit
- in other words, it is a device whose function is not fixed at manufacture but rather can be configured (and often repeatedly reconfigured) after it has been installed

FPGA — a “Blank Slate”



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- the aim of this class is to provide a foundation for building embedded systems on a Platform FPGA device

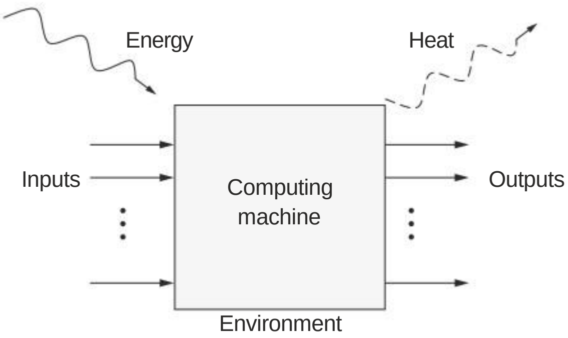
Embedded Systems

- What is a computing machine?
- How is embedded different from general-purpose?
- Mixing hardware and software — different execution models

Abstract Computing Machine

- first of all, it is a machine
  - first were mechanical
  - later electro-mechanical
  - nowadays, electronic
- environment provides
  - inputs
  - energy
- machine produces
  - outputs
  - heat

Abstract Computing Machine Illustrated



Computing Machine

- **computing machine** — a device consisting of a some control or processing mechanism that responds to inputs by signaling its outputs
- implicit in the machine is an encoding that gives meaning to the inputs and outputs
- the modern definition includes the ability to be controlled by a stored program

Hardware versus Software

- $\boxed{\textbf{hardware}}$ — the physical implementation of a computing machine
  - the stuff that exists in the physical world
  - you can touch it — it is concrete

[1] although physical representations of software, such as print-outs, do exist

Hardware versus Software

- **hardware** — the physical implementation of a computing machine
  - the stuff that exists in the physical world
  - you can touch it — it is concrete
- **software** — a specification that describes the behavior of the machine
  - it is a set of rules, directives, commands that operates the machine
  - as such it is abstract and doesn't exist in the physical world[1]

[1] although physical representations of software, such as print-outs, do exist

Software Terms

- a **program** — is an expression of software written in a specific language
    - for example, an assignment might be to create a program
    - the language (C or MATLAB, for example) defines the syntax and semantics of valid programs
- as a verb (in the software world) **programming** refers to act of creating software; i.e.
    - “I will be programming until lunch.”
    - or “He was programming the computer.”

Hardware Terms

- FPGAs are part of a family of devices that are collectively referred to as programmable logic
  - it makes sense as a noun because these devices leave the factory with no fixed function
  - however, the early devices didn't use a language — the engineer simply picked which fuses

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  - "Use this device to program your EEPROM."
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- To avoid confusion, we prefer to use the verb **configure** to refer to the act of programming an FPGA

FPGAs Terms

Modern Field-Programmable Gate Arrays further muddy the waters...

- modern FPGAs have millions of configuration bits
- simply not practical to manually set the configuration bits
- instead, designers use a Hardware Description Languages (HDL)
  - an **HDL** is a programming language used to describe the behavior of hardware
  - as such, it shares the same characteristics as software (it is abstract, has syntax, and semantics)
  - but designers still typically call it hardware!

Hardware Design Terms

- in the case of FPGAs, “hardware” is often used as shorthand for “hardware design”
- a (hardware) **design** is the specification of a digital circuit that can be transformed into an FPGA configuration
- a **core** is a design that has potential as a reuseable component
  - could be as simple as a “multiplier core”
  - or as complex as a “processor core”
- organizations that sell cores will call them IP cores where IP stands for Intellectual Property

FPGA-specific Design Terms

- a **hard core** in FPGA lingo refers to a core that has been implemented in CMOS transistors and provides a single fixed-function resource on an FPGA
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- NOTE:
  - note that this is different from the ASIC world where they mean something else
  - at one time, a vendor referred to hard core as a **diffused IP core**
  - sometimes, **block** is synonymous with core (as in, “your design requires a multiplier block”)
  - **hard macros** are something completely different (we’ll introduce them later)

Embedded versus General-Purpose

- an **embedded computing system** (or just embedded system) is a computer that is integral to a larger, enclosing product
- in contrast, a **general-purpose computing system** is a computer that is an end-product of itself

General Characteristics

General-Purpose	Embedded
◦ standard peripherals ◦ 3rd party software ◦ purchased as a 'computer'	◦ specialized peripherals ◦ single vendor software ◦ product has different name (i.e., "phone")

Embedded Systems Examples

Mobile Phone

Embedded Systems Examples

Security Camera

Embedded Systems Examples

Payment
Capture

Embedded Systems Examples

Tablet

Embedded Systems Examples

Components in
Data Centers

Embedded Systems Examples

Vehicle
Electronics

Embedded Systems Examples

Home
Routers

Embedded Systems Examples

Laptops

Embedded Systems Examples

Some Supercomputer Components

Embedded Systems Examples

BTW: What do all these have in common?

Embedded Systems Examples

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... they run UNIX/Linux

Execution Models

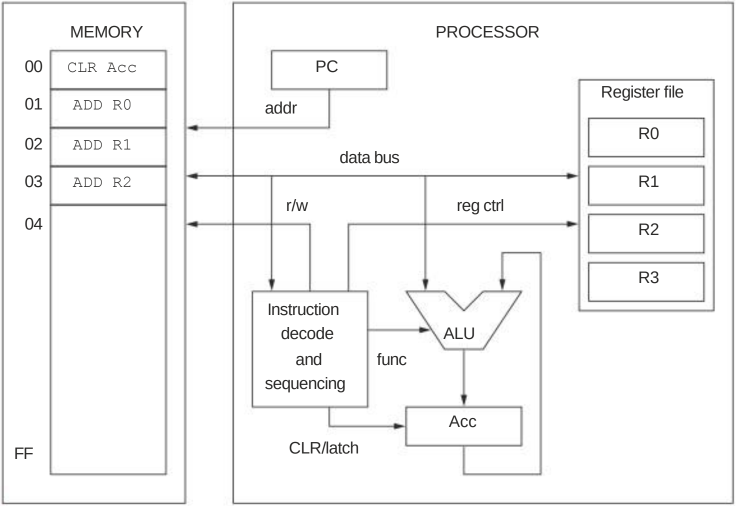
- since embedded systems are part of a larger product,
  - they interact with wide range of specialized peripherals (application-specific actuators, sensors)
  - often require the functionality to be split between hardware and software components
- however, hardware and software use different execution models

Software/hardware designs and models

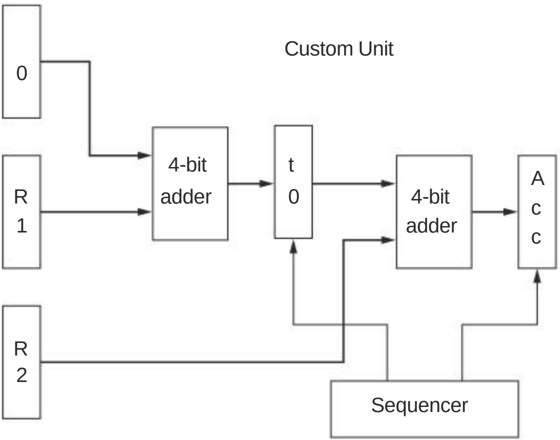
- Software design:
  - Sequential model: fetch-execute model with addressable memory.
  - Serialized operations.
  - Operations completed in order
- Hardware design
  - Naturally parallel and must include synchronization

Sequential Model for: R0+R1+R2→Acc

(AKA: von Neumann stored program computer model



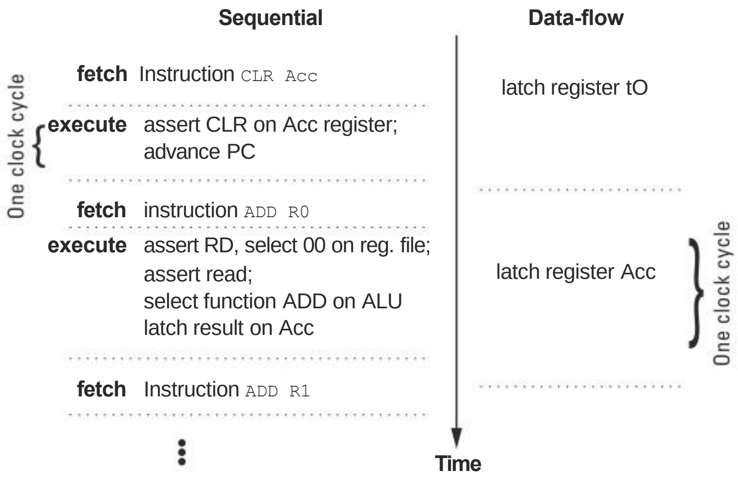
Dataflow Model for: R0+R1+R2→Acc



Execution Models Explained

- sequential
  - uniform time steps
  - (typically) one instruction completes before next is started
  - data movement is general
- dataflow
  - data may not move uniformly through system
  - data flows along pre-assigned (or restricted) paths between computation units

Sequential v. Dataflow Timing



- we will return to this concept multiple times

Design Challenges

1. Design Life Cycle
2. Measure of Success
   a) Speed
   b) Energy and Power
   c) Total energy
   d) Power and Heat
   e) Size and packaging
3. Costs
   a) NRE

Design Challenges

- designing embedded systems is more challenging than programming ordinary applications
  - software starts at power up and must run until powered off
  - products usually have a hardware design component
  - an additional hardware/software integration step
  - debugging can be more difficult.
- moreover, the embedded systems are evaluated over a larger range of metrics than ordinary applications.
- and, finally, the costs of completing an embedded systems project tend to be more complex.

Before we show how Platform FPGAs can be useful to embedded systems designers, we will review the challenges that embedded systems designers face.

Project Management

- often embedded systems designers are involved with all aspects of the project
- this can include several non-technical tasks such as
- as we close the first chapter, we briefly visit some of topics

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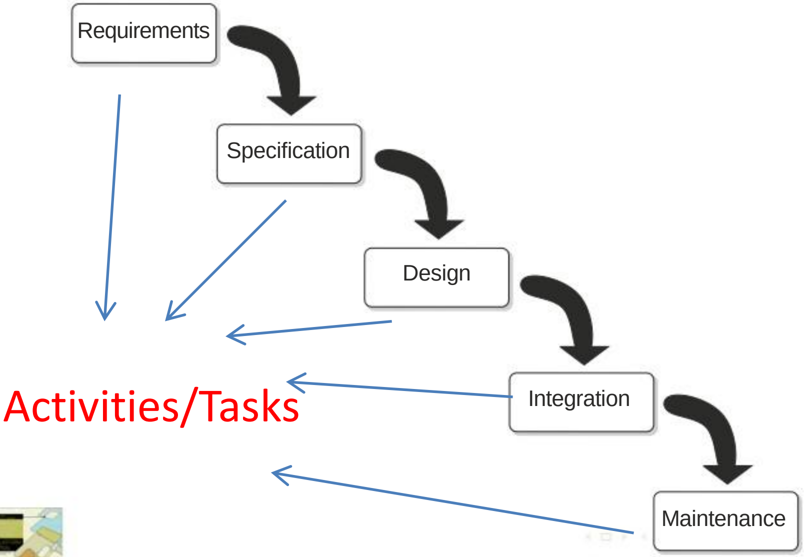
Project Lifecycle: Waterfall model



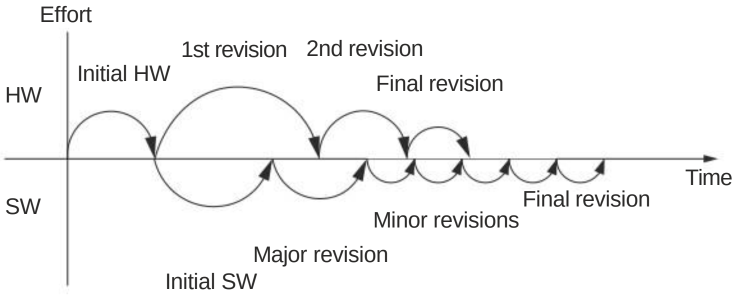
Waterfall Model

- There many different development models; the “waterfall” model is probably the simplest
    - other models includes:

- basic ideas:
    - complete each stage before advancing
    - the cost of going backwards (up the waterfall) to fix a — for example, a requirements mistake — is very steep

- mostly, the model helps a designer consciously think about organizing the project’s activities

Hardware and Software Revision Rates



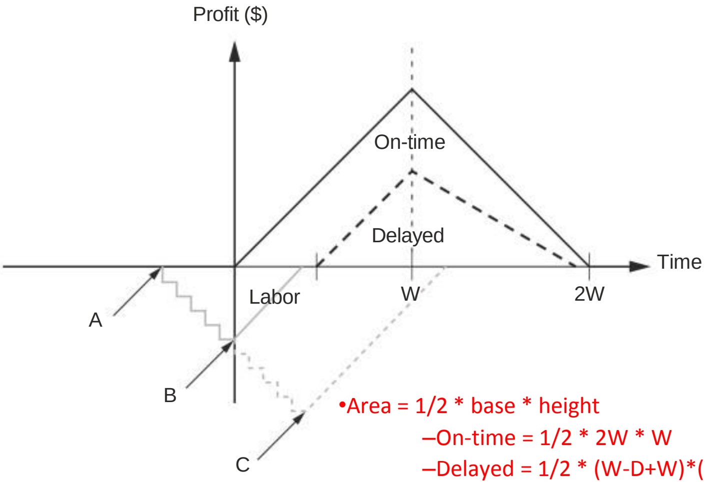
Development Philosophies

- embedded system projects tend to bring different groups of people together with different approaches
- philosophies
  - hardware designers usually have very expensive non-recurring costs; they tend to test extensively and revise cautiously
  - software developers have the advantage of fast turn around (i.e. compilation time is fast); they tend revise quickly
- on traditional embedded systems projects, these philosophies can clash but the two groups have to be tightly coupled
  (for example, some software development can't begin until the hardware board is delivered)
- Platform FPGA projects have the opportunity to blend these approaches

Cost of Missing Deadlines

- programmers and engineers that let deadlines slip are sometimes ignorant of the costs associated with it
  - some products (such as consumer electronics) have annual cycles that are critical to sales
    i.e., bring a product to market before the end of year Holidays is extremely important
  - many projects are financed which means that additional work days are incurring additional finance charges
  - some products have a peak demand — missing the window means that some potential sales are lost forever
- at the least, designers should be cognizant of the issues if not actively involved in these aspects of the project

Costs Illustrated



- Area = 1/2 * base * height
  - On-time = 1/2 * 2W * W
  - Delayed = 1/2 * (W-D+W)*(W-D)
- Percentage revenue loss =
  $(D(3W-D)/2W^2)*100\%$

Chapter-In-Review

Chapter 1 addressed:

- What is an embedded system?
- Why are embedded systems different?
- How does Platform FPGAs help?

Specifically, the topics covered:

- embedded systems concepts
- programming hardware and software
- challenges that embedded system designers face
- FPGA characteristics

Chapter 1 Terms

FPGA Field Programmable Gate Array

platform FPGA an FPGA device that includes sufficient resources and functionality to host an entire system on a single device

computing machine a device consisting of a some control or processing mechanism that responds to inputs by signaling its outputs; implicit in the machine is an encoding that gives meaning to the inputs and outputs

embedded computing system a computing system that is integral to a larger, enclosing product; in contrast to general-purpose computing the embedded computing system is not intended to be an end-product of itself

Chapter 1 Terms

general-purpose computing system is a product itself and, as such, the end-user directly interacts with it

hardware refers to the physical implementation of a computing machine

software is a specification that describes the behavior of the machine, generally written in a programming language (such as C, MATLAB, Java, etc.)

program software written in a specific programming language that is the representation of desired machine behavior

processor is hardware that implements the sequential execution model

design is the digital circuit that is programmed (or configured) into an FPGA

Chapter 1 Terms

hardware description language (HDL) is a programming language used to describe the behavior of hardware and is the most common form of design entry today

IP core intellectual property that refers to a hardware specification which, depending on how it is expressed, can be used to manufacture an integrated circuit (hard core) or configure the resources of an FPGA (soft core); diffused IP core is a hard core embedded in an FPGA integrated circuit

hard core is an FPGA-specific term for an IP core where the logical operations and interconnection have been specified and mapped to the components of particular device; thus the core has a fixed shape and location on the chip

Chapter 1 Terms

soft core is an FPGA-specific term for an IP core where the logical operations and interconnection is specified but these operations have not been mapped to a particular device

module any self-contained operation that has an interface and some functional description

block a hard block is a core that has been implemented in CMOS transistors and soft block is a core that has been implemented in the function generators and memories of an FPGA device