



Embedded Operating Systems

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Flexible Embedded Systems

- Features of Embedded Systems
 - Customized hardware with high scalability
 - Heterogeneous devices with unified interface
 - Application-aware designs for energy saving



Hardware and System Software Integration



Key Technologies for Systems

- ▶ Fast System Initialization
 - Keep the system and application states for users
 - Reduce the Initialization time of applications
- ▶ Energy-Efficient Designs
 - Adjust the frequencies of processors
 - Change the states of peripheral devices
- ▶ Performance Tuning Tools
 - Understand the hot spots of applications
 - Exploit the advantages of hardware

Course Roadmap

Basic Concepts

- Embedded System Design Concepts
- Embedded System Developing Tools and Operating Systems
- Embedded Linux and Android Environment



Core Technology

- Real-Time System Design and Scheduling Algorithms
- System Synchronization Protocols

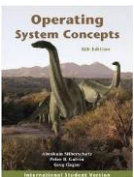
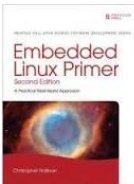
Real Exercises

- System Initialization and Memory Management
- Power Management Techniques and System Routine
- Embedded Linux Labs and Exercises on Linux



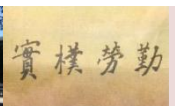
Syllabus

- ▶ **Lecturer:** Che-Wei Chang (張哲維)
- ▶ **Lecture Hours:** Tuesday 9:10 a.m. – 12:00 p.m.
- ▶ **Office Hours:** Tuesday 1:00 p.m. – 2:30 p.m.
- ▶ **Classroom:** Seminar Room 1
- ▶ **Reference Books and Slides:**
 - Jane Liu, “Real-Time Systems,” Prentice Hall, 2000.
 - Christopher Hallinan, “Embedded Linux Primer,” 2nd Edition, Prentice Hall, 2011.
 - Silberschatz, Galvin, and Gagne, “Operating System Concepts,” 9th Edition, John Wiley & Sons, 2013.



Grading and Resources

- ▶ Midterm: 25%
- ▶ Discussion and Quiz: 20%
- ▶ Final: 25%
- ▶ Project Presentation and Report: 30%
- ▶ Course Website:
<https://icechewei.github.io/webpage/teaching.html>



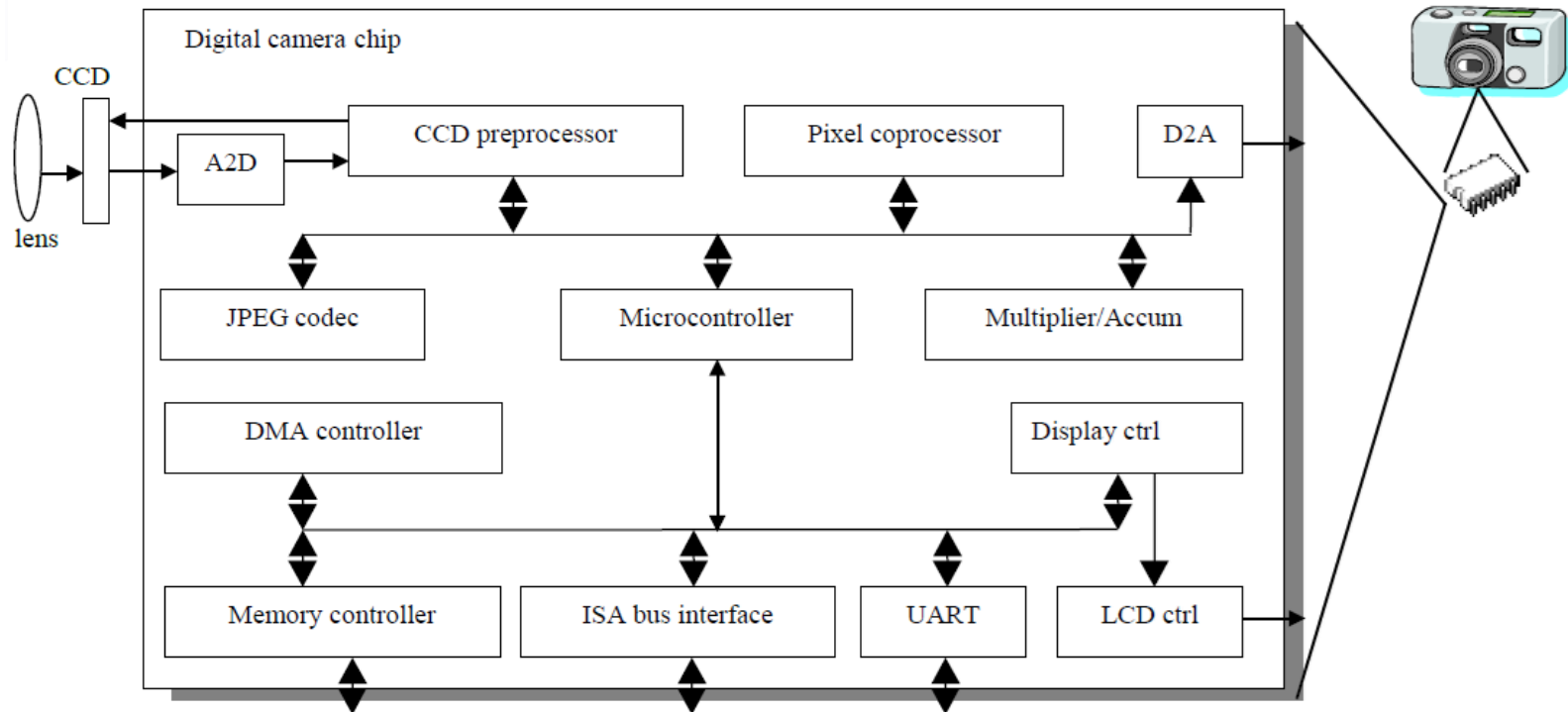


Embedded Systems — Overview

Definition of Embedded Systems

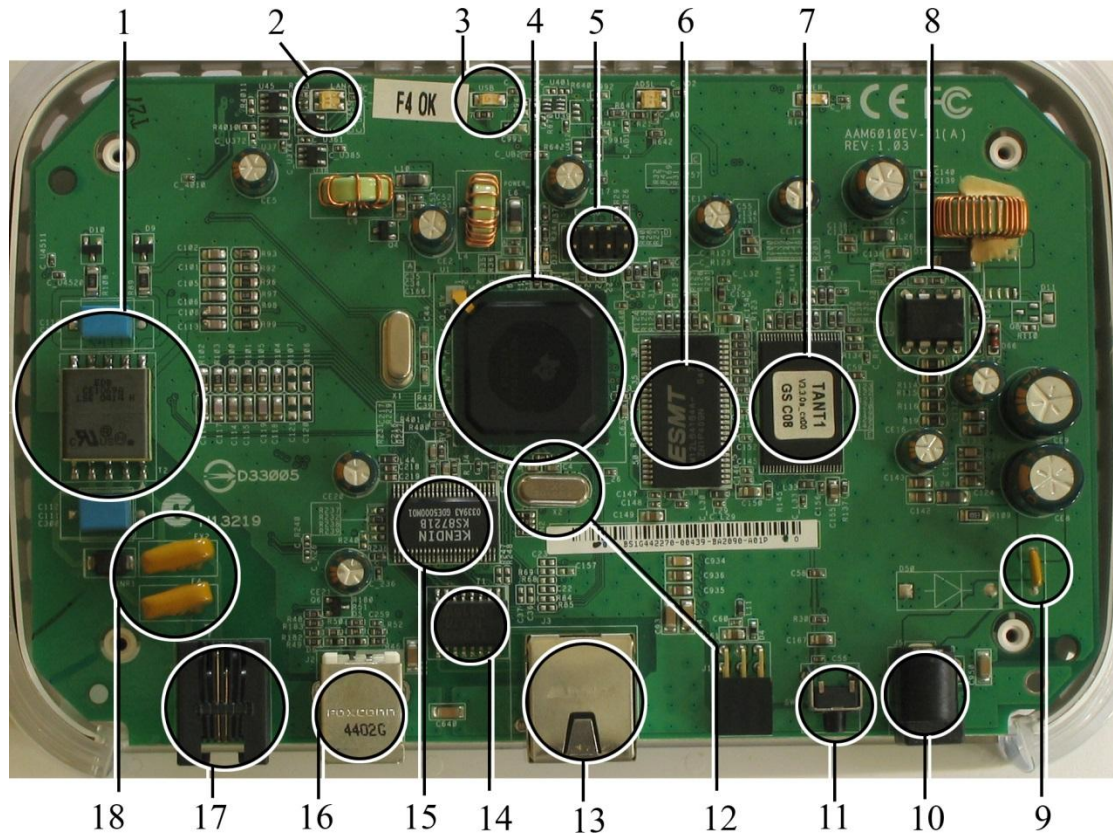
- ▶ It is difficult to define embedded systems
 - An embedded system is a digital system
 - An embedded system has computing processors
 - An embedded system runs dedicated functions
 - An embedded system is frequently used as a controller
- ▶ An embedded system is a **computer system** with some **dedicated functions** within a larger **mechanical or electrical system**, often with **real-time** computing constraints. - From Wikipedia

An Embedded System Example — A Digital Camera



- ▶ **Single-Functioned**: always a digital camera
- ▶ **Tightly-Constrained**: low cost, low power, small
- ▶ **Reactive and Real-Time**: short response time

An Embedded System Example — An ADSL Modem – From Wikipedia



- Microprocessor (4), RAM (6), and Flash Memory (7), ...

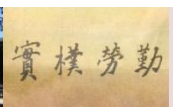
Design Challenge— Optimizing Performance Metrics

- ▶ Obvious Design Goal
 - Construct an implementation with desired functionality
- ▶ Performance Metrics
 - Performance metrics are the measurable features of a system's implementation
 - Simultaneously optimizing numerous design metrics is a challenging issue



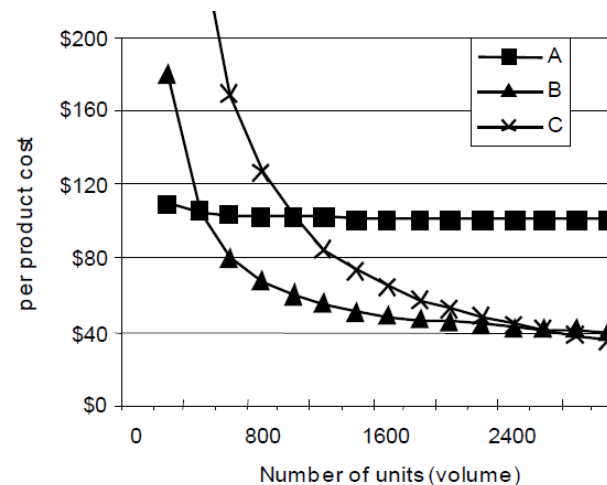
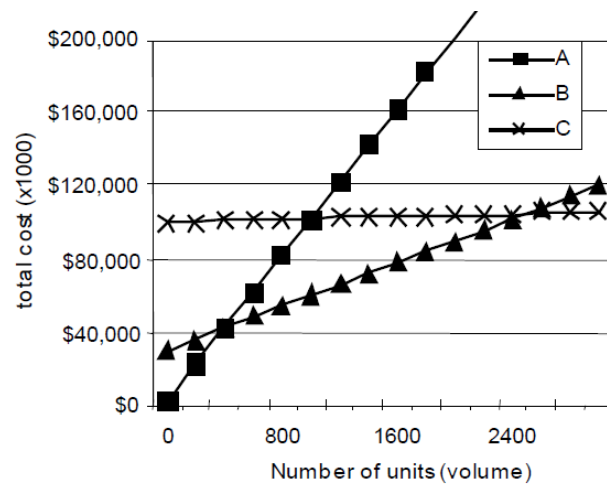
Common Performance Metrics

- ▶ **Unit Cost**: the monetary cost of manufacturing each copy of the system
- ▶ **NRE Cost** (Non-Recurring Engineering cost): the one-time monetary cost of designing the system
- ▶ **Size**: the physical space required by the system
- ▶ **Performance**: the execution time or throughput of the system
- ▶ **Power**: the amount of power consumed by the system
- ▶ **Flexibility**: the ability to change the functionality of the system without incurring heavy NRE cost
- ▶ **Time-to-Market**: the time required to develop a system to the point that it can be released and sold to customers
- ▶ **Maintainability**: the ability to modify the system after its initial release



NRE and Unit Cost

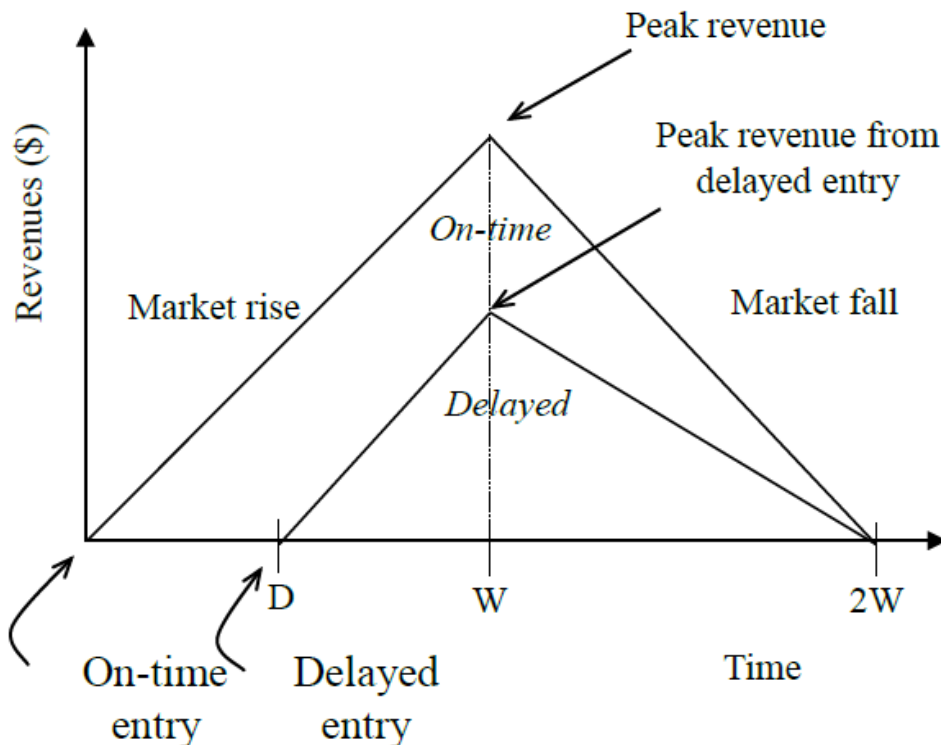
- ▶ Compare Technologies by Costs—the best solution depends on quantity of the product
 - Technology A: NRE=\$2,000, unit=\$100
 - Technology B: NRE=\$30,000, unit=\$30
 - Technology C: NRE=\$100,000, unit=\$2



- We must also consider **time-to-market**



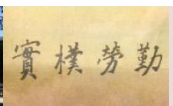
Delayed Market Entry



- ▶ A Simplified Revenue Model
 - Product life = $2W$, peak at W
 - The time of market entry defines a triangle, representing the market penetration
 - The triangle area represents the revenue
- ▶ Loss
 - The difference between the on-time and delayed triangle areas

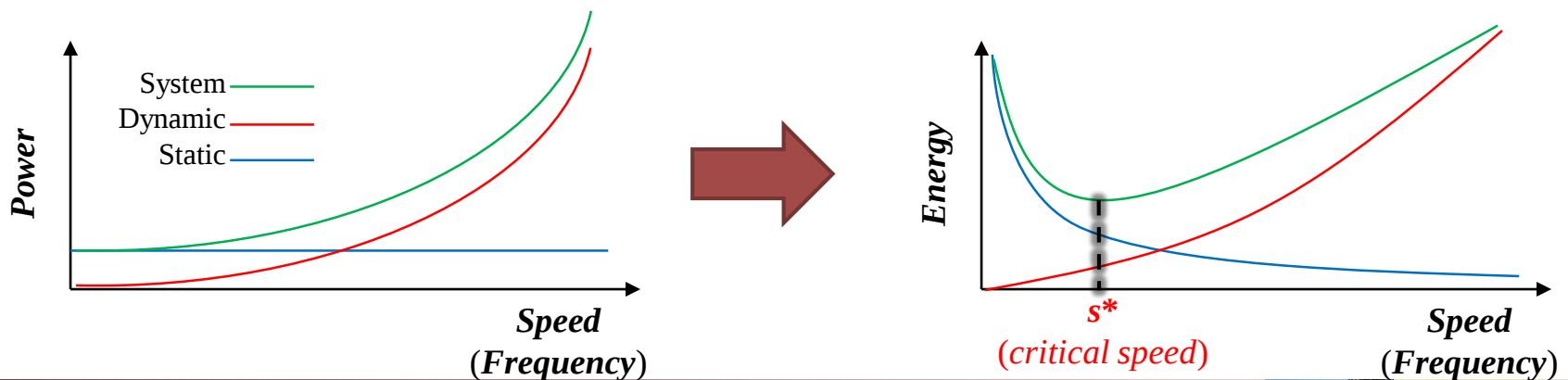
Performance Design Metrics

- ▶ Latency (response time)
 - Time between task start and end
 - e.g., Cameras A and B process an image in 0.5 seconds
- ▶ Throughput
 - Number of tasks per second
 - e.g. Camera A processes 2 images per second
 - Throughput can be more than latency seems to imply due to concurrency
 - e.g. Camera B may have two cores to process 4 images per second (by pipelining or multithreading on multiple cores)



Performance and Power

- ▶ Dynamic Power Consumption
 - Switching power and short-circuit power
 - Dynamic Voltage Frequency Scaling (DVFS)
- ▶ Static Power Consumption
 - Leakage power
 - Dynamic Power Management (DPM)



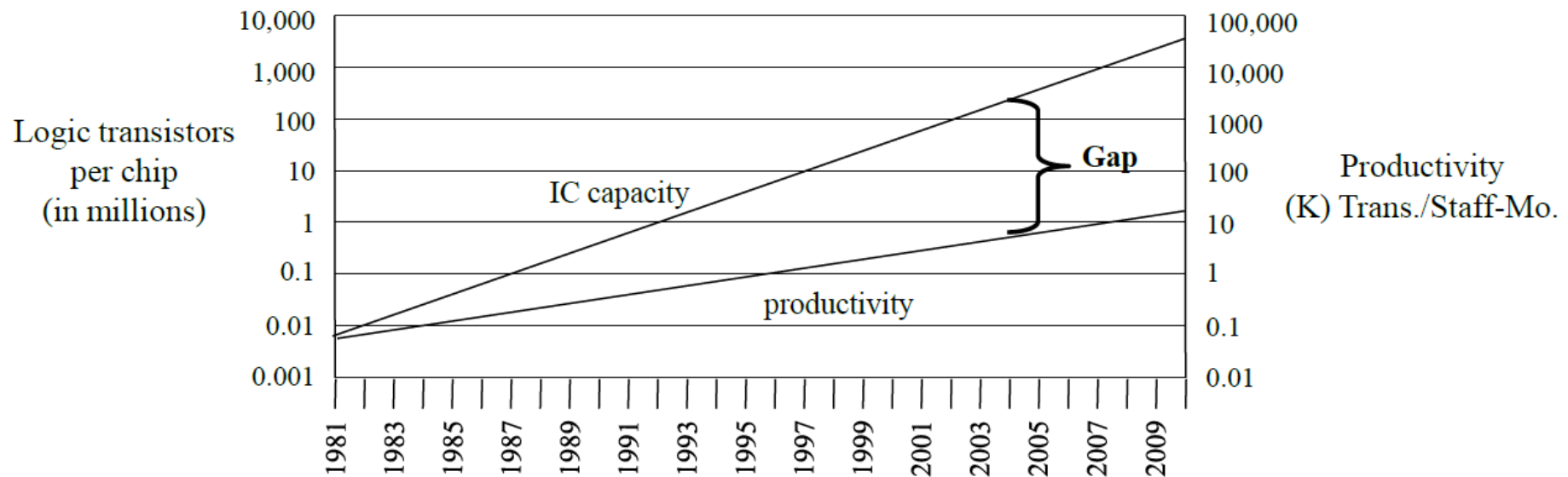
Solutions for a Specific Function

- ▶ General Purpose Processor
 - A flexible software solution
- ▶ Special Purpose Processor
 - Specialized processors for some application area, e.g., graphics processing units for 2D and 3D rendering
- ▶ Field Programmable Gate Array (FPGA)
 - An integrated circuit designed to be configured by customers after manufacturing
- ▶ Application-Specific Integrated Circuit (ASIC)
 - An integrated circuit customized for a particular use



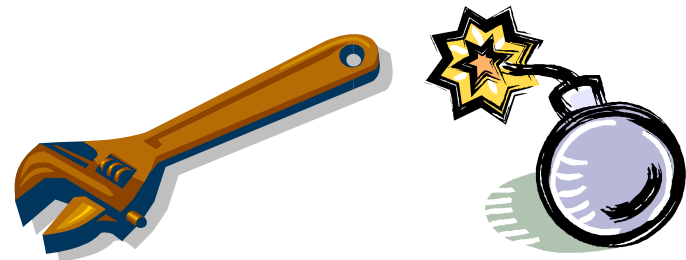
Design-Productivity Gap

- ▶ While designer productivity has grown at an impressive rate over the past decades, the rate of improvement has not kept pace with chip capacity



Building an Embedded System

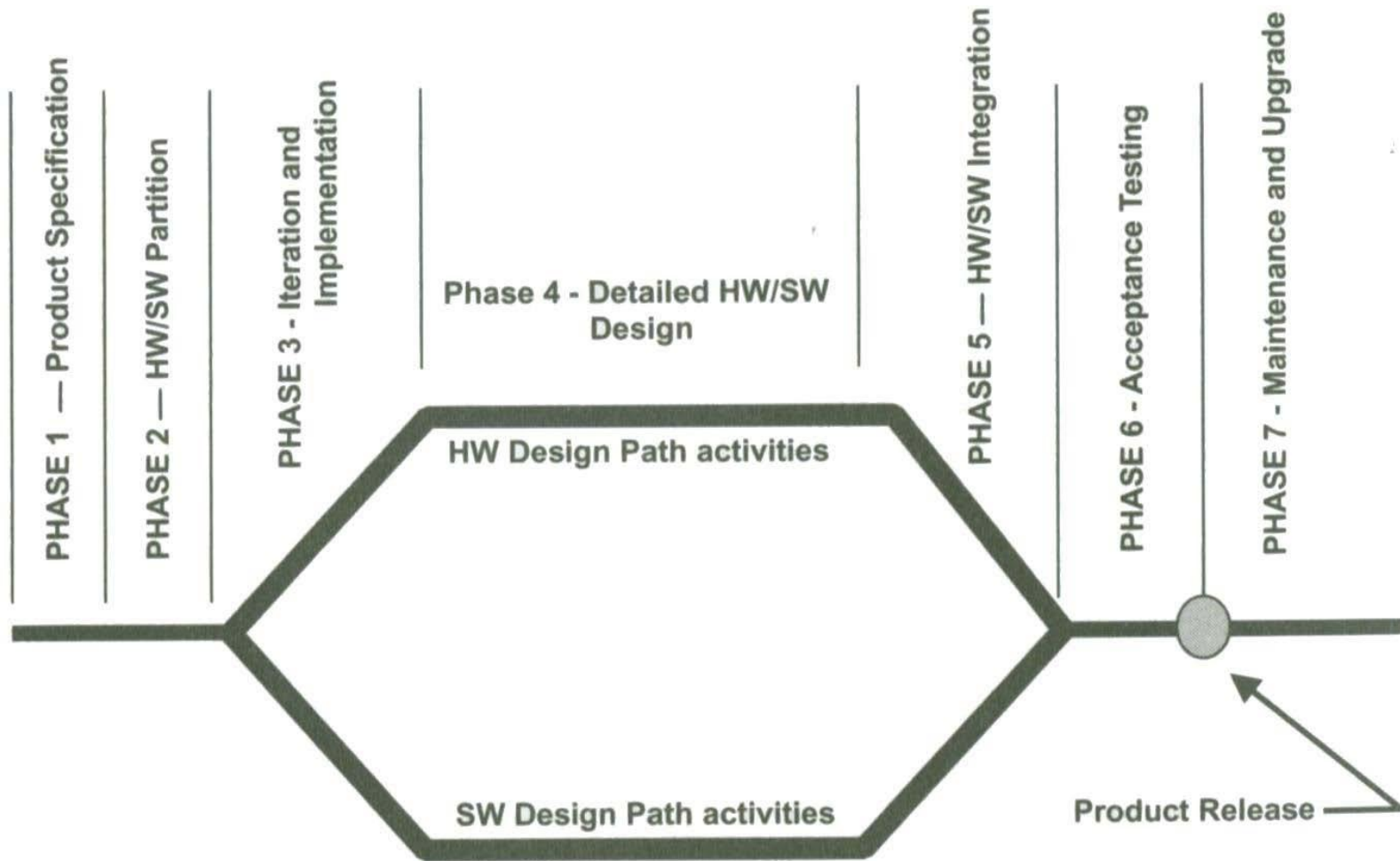
- ▶ Understand the embedded system design life cycle
- ▶ Be familiar with the real-time requirements of embedded systems
- ▶ Use embedded system developing tools to work more efficiently
- ▶ Include an embedded operating system with driver support for a complicated environment of applications





The Embedded Design Life Cycle

Workflow of Embedded Designs



Product Specification

- ▶ R&D Engineer View
- ▶ Marketing and Sale Department View
- ▶ Customer View
- ▶ Questionnaires
- ▶ Marketing Specialists

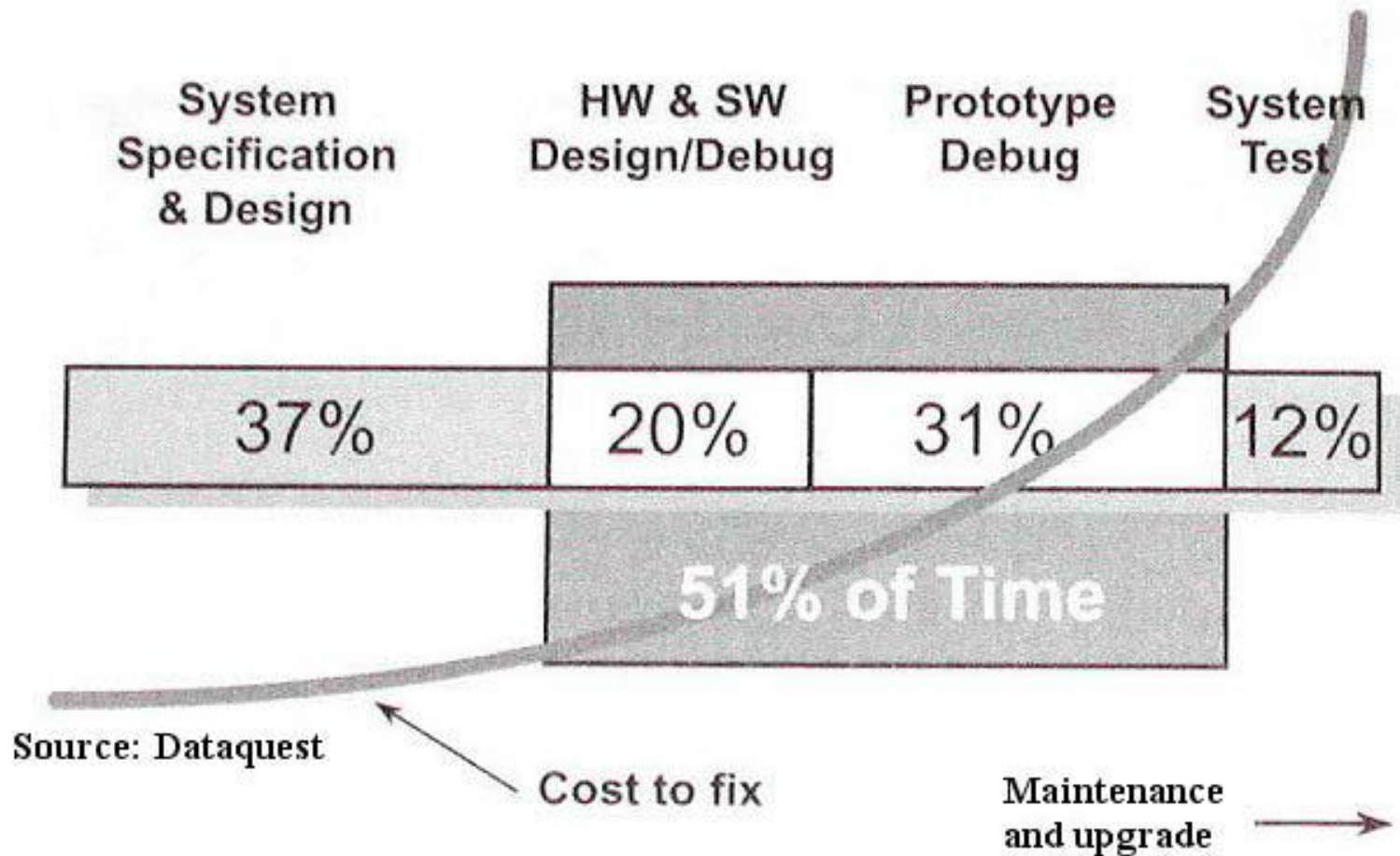


Partitioning Decision

- ▶ Complex optimization problem
- ▶ Many embedded system designs are required to be :
 - Price sensitive
 - Leading-edge technology
 - Non-standard
 - Market competitive
- ▶ These conflicting requirements make it difficult to create an optimal design



Detailed Hardware and Software Design



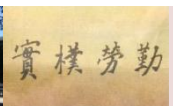
Debugging an Embedded System

► General Requirements

- Run control
- Memory substitution
- Real time analysis
- On-Chip Hooks
- OS Supports

► The Holy Grail of Embedded System Design

- Real time nature
- Accurately model or simulate is difficult





The Concept of Real-Time Embedded Systems

Introduction to Real-Time Systems

- ▶ What is a real-time system?
 - Any system where a timely response by the computer to the external environment is vital
- ▶ Examples:
 - Multimedia systems, virtual reality, games
 - Avionics, air traffic control, robots, automobiles, nuclear power plant
 - Stock market, trading system, information access, etc.



Real-Time Issues and Research

- ▶ Software Engineering
 - System Design Methodologies
 - Toolchain Designs
- ▶ Operating Systems
 - Many/Multi-Core Task Management and Scheduling
 - Task Synchronization
 - Energy-Efficient System Designs
 - File Systems and Storage Systems
- ▶ Programming Models
 - Heterogeneous/homogeneous Multiprocessor Programming
 - Better control over timing



An Example of Real-Time Designs

- ▶ A camera periodically takes a photo
- ▶ The image recognition result will be produced before the next period
- ▶ If there is an obstacle, the train automatically brakes

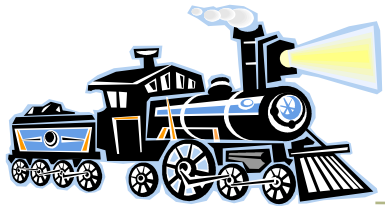
Time of a Period = $150/50 = 3\text{s}$

Distance of a Period = $(400 - 100)/2 = 150\text{m}$

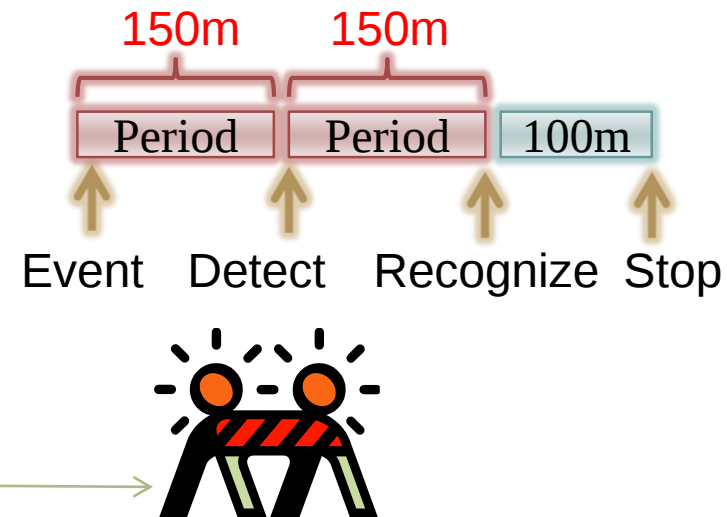
Braking: -12.5m/s^2

Max Seed: 50m/s

Distance to Stop
 $25 \times (50/12.5) = 100\text{m}$

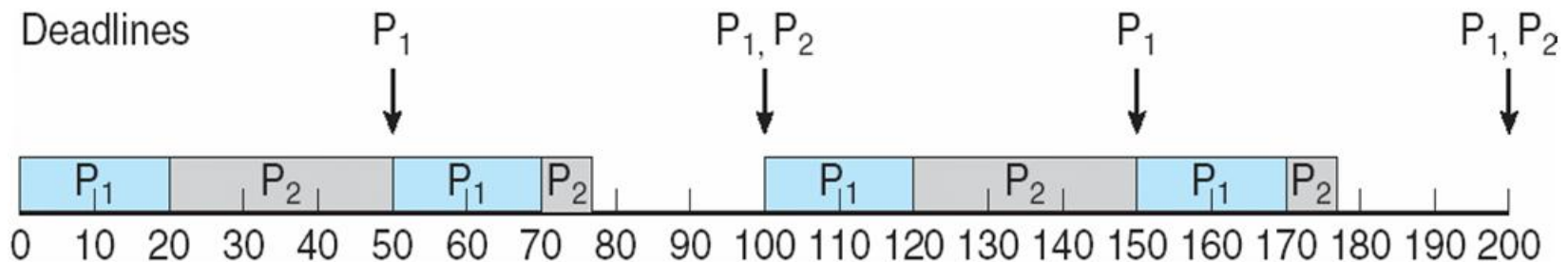


Camera Range: 400m



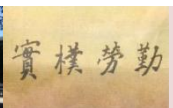
Rate Monotonic Scheduling

- ▶ A scheduler is needed if there is more than one real-time task
 - ▶ Rate monotonic scheduler: A static priority is assigned to each task based on the inverse of its period
 - A task with shorter period → higher priority
 - A task with longer period → lower priority
 - For example:
 - P_1 has its **period 50** and execution time 20
 - P_2 has its **period 100** and execution time 37
- P_1 is assigned a higher priority than P_2



Challenges of Real-Time Systems

- ▶ Are there other scheduling algorithms?
 - Yes, analysis should also be provided to choose a proper scheduling algorithm.
- ▶ Are there some aperiodic tasks?
 - Yes, we then need to jointly consider periodic and aperiodic tasks.
- ▶ Can tasks share some resources or data?
 - Of course, the synchronization protocols should be provided to protect the access to the shared resources and data.





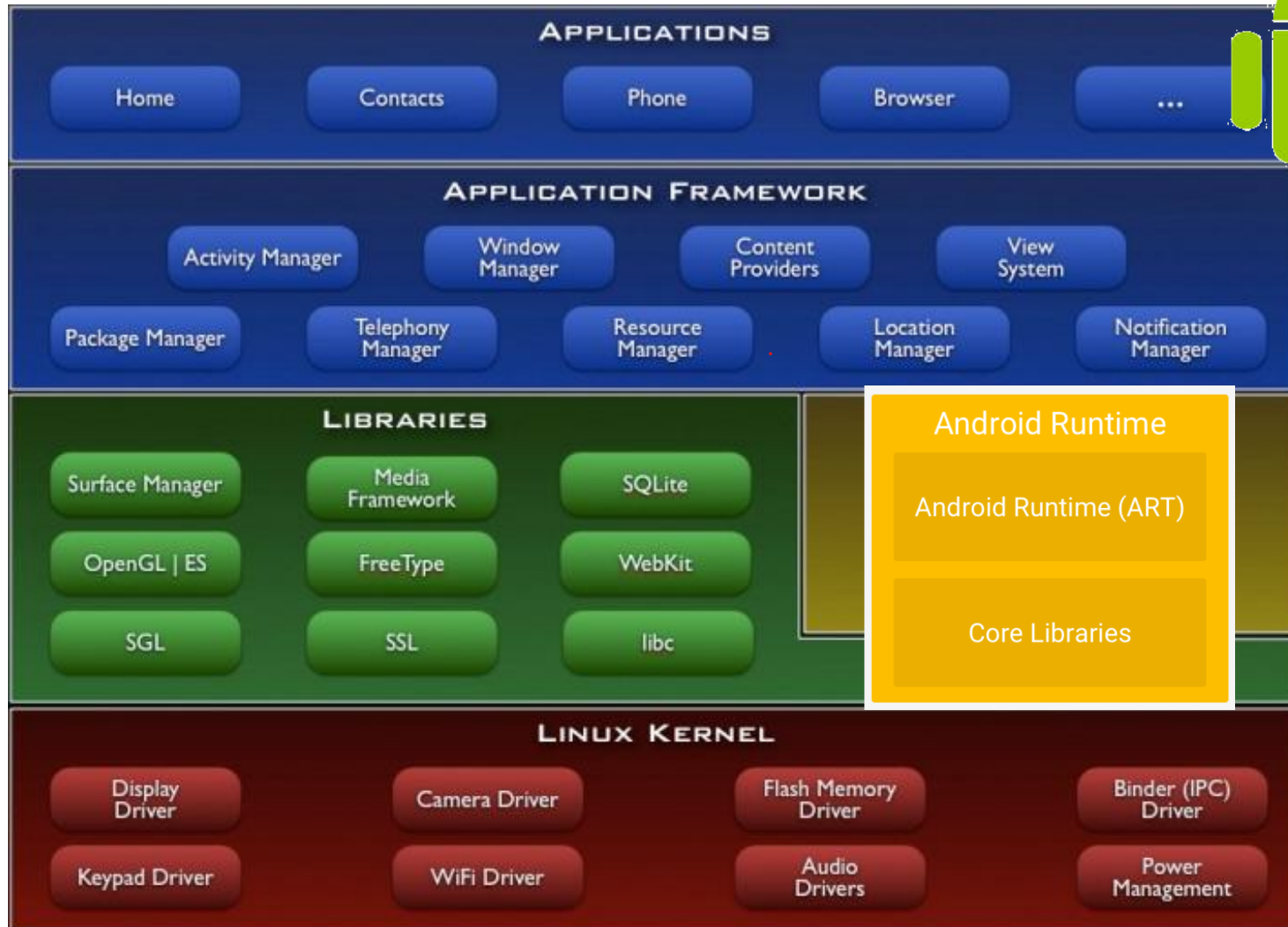
Embedded Operating Systems and Developing Tools

Apple iOS

- ▶ iOS is the operating system that runs iPhones, iPod Touches, iPads, and Apple TVs.
- ▶ The language used to develop the software for iOS is Objective-C (and Swift)
- ▶ Features
 - Home Screen
 - Multi-Touch
 - Not Fully Open-Sourced



Google Android



Real-Time Operating Systems

- ▶ A RTOS is an abstraction from hardware and software programming
 - Shorter development time
 - Less porting efforts
 - Better reusability
- ▶ Choosing an RTOS is important
 - High efforts when porting to a different OS
 - The chosen OS may have a high impact on the amount of resources needed
- ▶ Example: eCos, Nucleus, VxWork, QNX, OSE, RT-Linux, uC/OSII



Embedded System Development Tools

- ▶ Compiler Tools
 - Quality of code generator
 - Support particular features of the target hardware
- ▶ Hardware and Software Debugging Tools
 - ICE (In-Circuit Emulator), ROM emulator, logic analyzer, performance analyzer
 - GNU debugger, ARM RealView development suite, ...
- ▶ Performance Measuring Tools
 - Development suites
 - Power meters
 - Data acquisition devices





What is an embedded system?

Do you have your answer?