Designing Embedded Systems

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Basic Architectures

Control Unit

- Custom logic
- FPGAs (Field-Programmable Gate Arrays)
- Microcontrollers
- Microprocessors
- DSPs (Digital Signal Processors)
- ASIPs (Application Specific Instruction-set Processors)
- Multicore? (symmetric vs. asymmetric)
- Typical word size: 8/16/32-bit

Why Microprocessors?

- Microprocessors
  - ARM, MIPS, PowerPC, SuperH, Cell, Atom, …
  - Mostly less than 1GHz
- Microprocessors are often very efficient:
  - Can use same logic to perform many different functions
- Microprocessors simplify the design of families of products

The Performance Paradox

- Microprocessors use much more logic to implement a function than does custom logic
- But microprocessors are often at least as fast:
  - Heavily pipelined
  - Large design teams
  - Aggressive VLSI technology, …

Power

- Custom logic uses less power, but CPUs have advantages:
  - Modern microprocessors offer features to help control power consumption
  - Software design techniques can help reduce power consumption
- Heterogeneous systems
  - Some custom logic for well-defined functions, CPUs + software for everything else

RAM

- SRAM
  - Easier to integrate on the same chip as processor
- DRAM
  - SDRAM (Synchronous DRAM): SDR/DDR/DDR2/DDR3
  - Mobile SDR/DDR SDRAM
  - RDRAM (Rambus DRAM)
- NVRAM (Non-Volatile RAM)
- Future NVRAMs: PRAM, MRAM, FeRAM
- Cache memory
- SPM (Scratch Pad Memory)

ROM

- Mask-programmed
  - Connections programmed at fabrication
- OTP (One-time programmable) ROM
  - Connections programmed after manufacture by use
- EPROM (Erasable programmable ROM)
- EEPROM (Electrically erasable programmable ROM)

Flash Memory

- NOR Flash
- NAND Flash
- Fusion memory: OneNAND Flash
- e-MMC: MoviNAND, iNAND
- Cards (MMC, SD, CF, …)

Interfacing

- ARM AMBA (Advanced Microcontroller Bus Architecture)
- ISA (Industry Standard Architecture)
- PCI (Peripheral Component Interconnect)

- I²C (Inter-IC) bus
- USB

Common Peripheral Devices

- Interrupt controller
- DMA controller
- Timer/Counter
- Real-time clock
- Watchdog timer
- UART (Universal Asynchronous Receiver Transmitter)
- IrDA (Infrared)
- Ethernet (wired/wireless)
- Bluetooth

Recent Trends

- Increasing computation demands
- Increasingly networked
- Increasing need for flexibility

- Getting complex
- Increasingly platform-based
  - Hardware architecture + associated software

Design Process

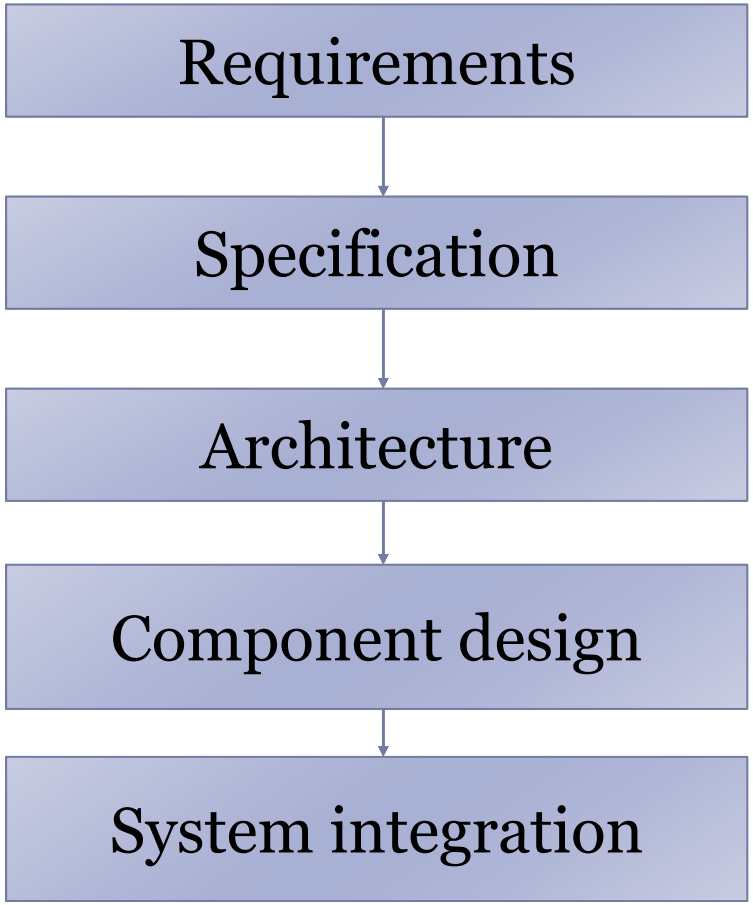
Design Methodologies

- A procedure for designing a system
- Understanding your methodology helps you ensure you didn't skip anything
- Compilers, software engineering tools, computer-aided design (CAD) tools, etc., can be used to
  - Help automate methodology steps
  - Keep track of the methodology itself

Design Goals

- Performance
  - Overall speed
  - Deadlines
- Functionality and user interface
- Manufacturing cost
- Power consumption
- Other requirements (physical size, etc.)

Design Process

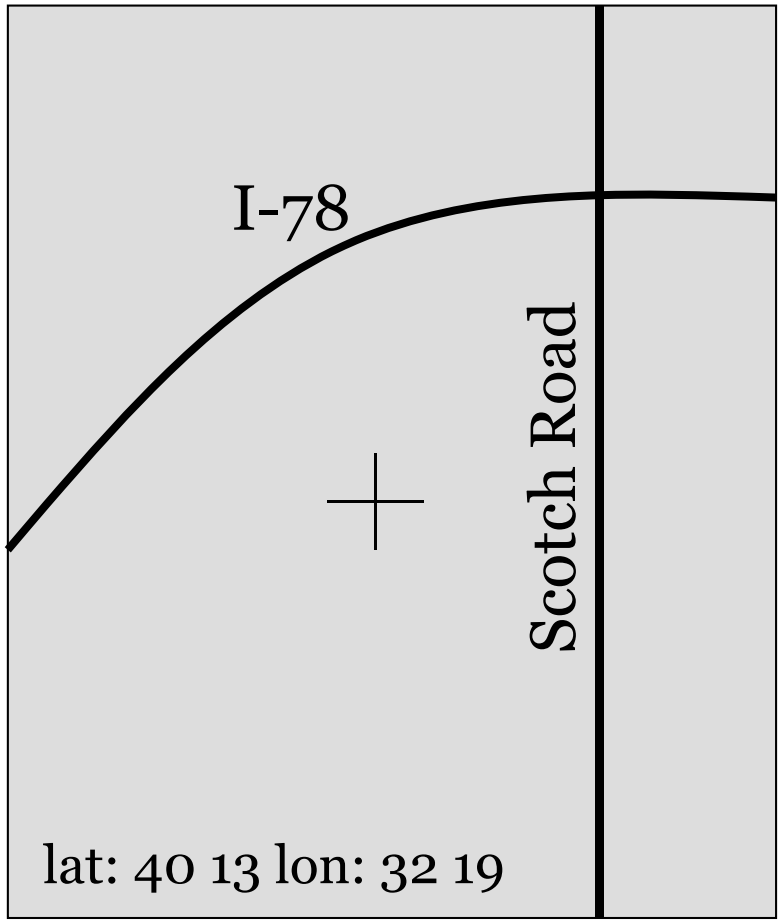


Approaches

- Top-down design
  - Start from most abstract description
  - Work to most detailed
- Bottom-up design
  - Work from small components to big system
- Real design uses both techniques

GPS Moving Map (GPS-MM)

- Moving map obtains position from GPS, paints map from local database



Requirements (1)

- Plain language description of what the user wants and expects to get

- May be developed in several ways:
  - Talking directly to customers
  - Talking to marketing representatives
  - Providing prototypes to users for comment

Requirements (2)

- Functional requirements
  - Output as a function of input
- Non-functional requirements
  - Time required to compute output
  - Cost
  - Physical size and weight
  - Power consumption
  - Reliability, …

GPS-MM Requirements (1)

- Functionality
  - For automotive use
  - Show major roads and landmarks
- User interface
  - At least 400x600 pixel screen
  - Three buttons max.
  - Pop-up menu
- Cost
  - Street price: around $100

GPS-MM Requirements (2)

- Performance
  - Map should scroll smoothly
  - No more than 1 sec power-up
  - Lock onto GPS within 15 seconds
- Physical size/weight
  - Should fit in hand
- Power consumption
  - Should run for 8 hours on four AA batteries

GPS-MM Requirements (3)

Name	GPS moving map
Purpose	Consumer-grade moving map for driving use
Inputs	Power button, two control buttons
Outputs	Back-lit LCD display 400x600
Functions	Uses 5-receiver GPS system Three user-selectable resolutions Always displays current latitude and longitude
Performance	Updates screen within 0.25 seconds upon movement
Manufacturing cost	$30
Power	100mW
Physical size and weight	No more than 2” x 6”, 12 ounces

Specification

- A more precise description of the system
  - Should not imply a particular architecture
  - Provides input to the architecture design process
- May include functional and non-functional elements
- UML (Unified Modeling Language)

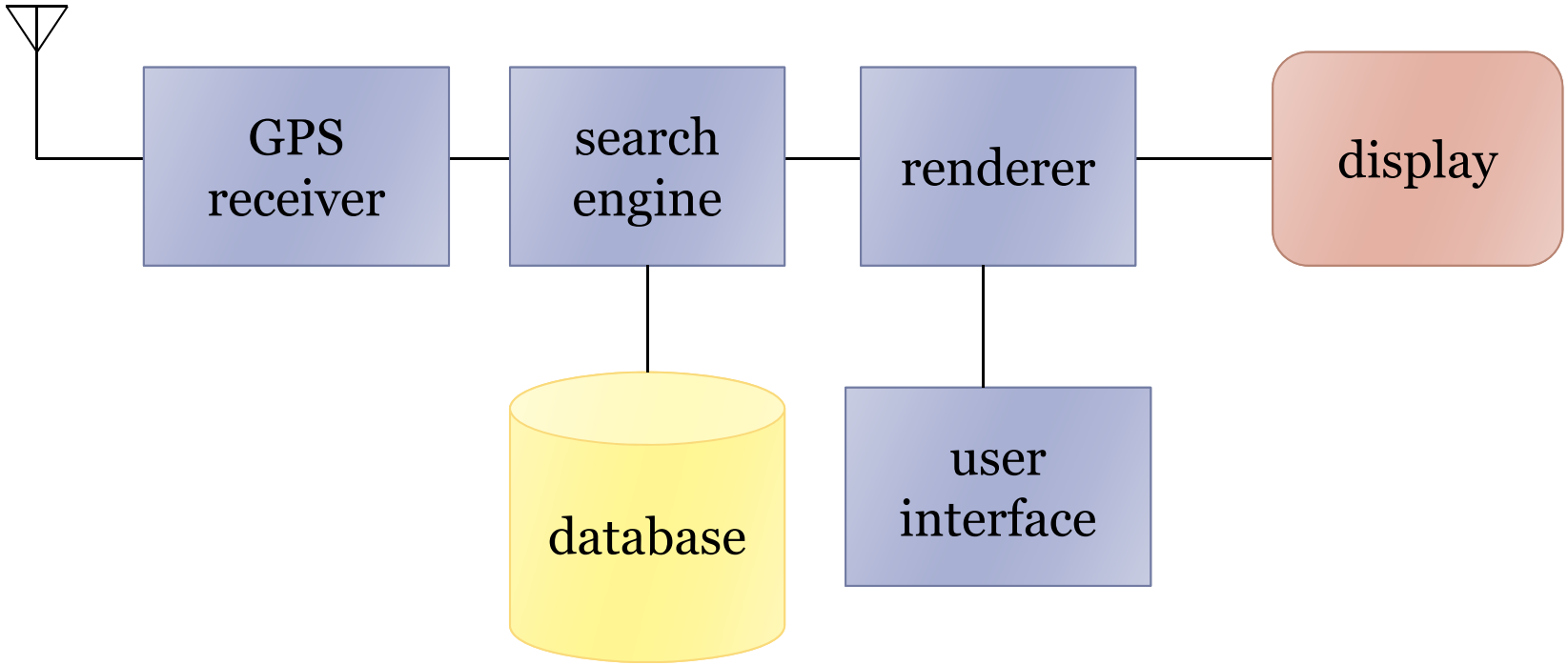
GPS-MM Specification

- Should include
  - What is received from GPS
  - Map data
  - User interface
  - Operations required to satisfy user requests
  - Background operations needed to keep the system running

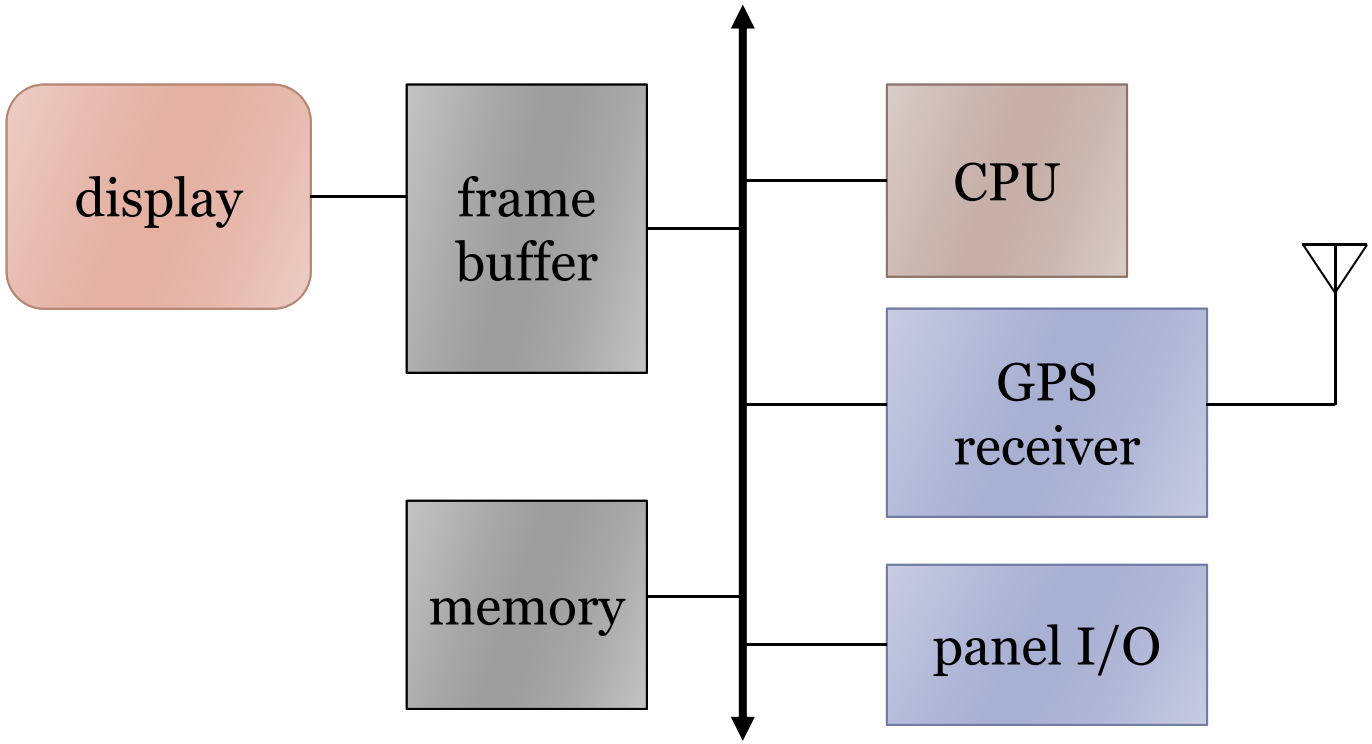
Architecture Design

- What major components go satisfying the specification?
- Hardware components:
  - CPUs, peripherals, etc.
- Software components:
  - Major programs and their operations
- Must take into account functional and non-functional specifications

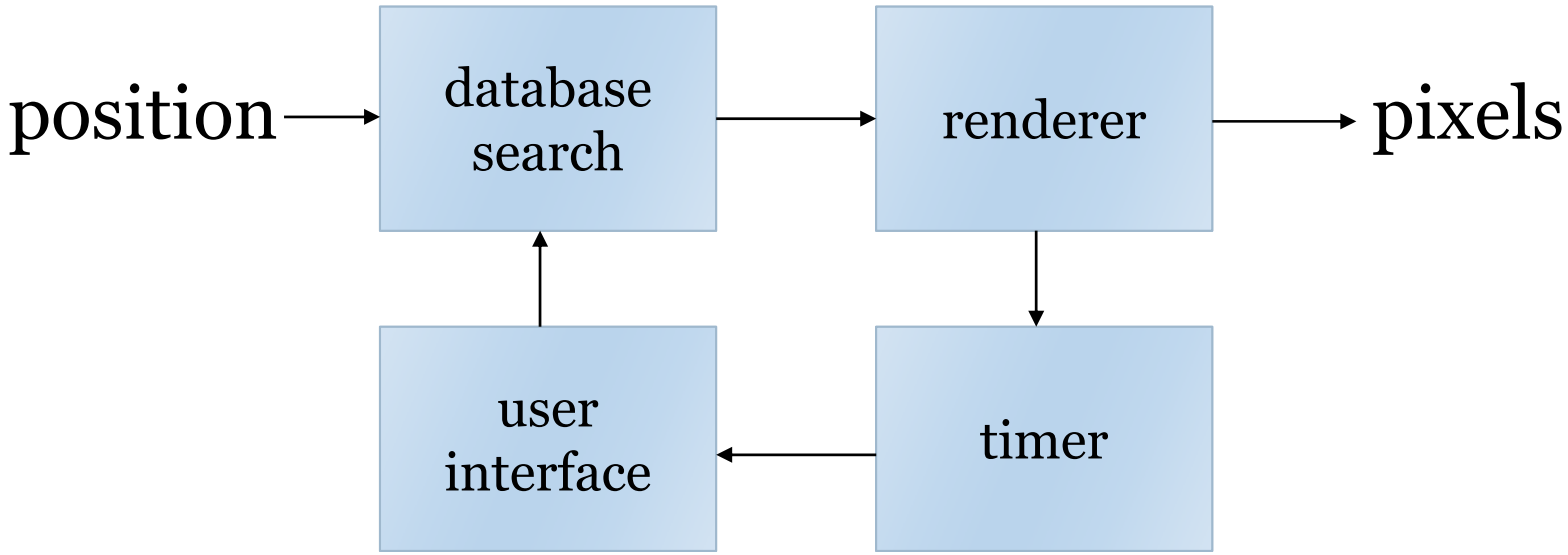
GPS-MM Block Diagram



GPS-MM HW Architecture



GPS-MM SW Architecture



Component Design

- Hardware and software components
- Must spend time architecting the system before you start coding
- Some components are ready-made, some can be modified from existing designs, others must be designed from scratch

System Integration

- Put together the components
  - Many bugs appear only at this stage
- Have a plan for integrating components to uncover bugs quickly, test as much functionality as early as possible