EMBEDDED PROCESSORS

- **DSP Processors**
  - Many embedded applications do quite a bit of **signal processing**
  - A signal is a collection of sampled measurements of the **physical world**, typically taken at a regular rate called the sample rate
  - A motion control application, for example, may read position or location information from sensors at sample rates ranging from a few Hertz (Hz, or samples per second) to a few hundred Hertz
  - Audio signals are sampled at rates ranging from 8,000 Hz (or 8 kHz, the sample rate used in telephony for voice signals) to 44.1 kHz (the sample rate of CDs)
  - Ultrasonic applications (such as medical imaging) and high-performance music applications may sample sound signals at much higher rates

EMBEDDED PROCESSORS

- **DSP Processors**
  - **Video** typically uses sample rates of **25 or 30 Hz** for consumer devices to **much higher** rates for specialty measurement applications. Each sample, of course, contains **an entire image** (called a ***frame***), which itself **has many samples** (called *pixels*) distributed in space rather than time
  - **Software-defined radio** applications have sample rates that can range from **hundreds of kHz** (for baseband processing) to **several GHz** (billions of Hertz)
  - Other embedded applications that make heavy use of signal processing include interactive games; **radar**, **sonar**, and **LIDAR** (light detection and ranging) imaging systems; video analytics (the extraction of information from video, for example for surveillance); **driver-assist systems** for cars; medical electronics; and scientific instrumentation

EMBEDDED PROCESSORS

- **DSP Processors**
  - Specialized computer architectures for signal processing have been around for quite some time
  - Single-chip DSP microprocessors first appeared in the early 1980s, beginning with the Western Electric DSP1 from Bell Labs, the S28211 from AMI, the TMS32010 from Texas Instruments, the uPD7720 from NEC, and a few others. Early applications of these devices included voiceband data modems, speech synthesis, consumer audio, graphics, and disk drive controllers
  - Central characteristics of DSPs include a hardware multiply-accumulate unit; several variants of the Harvard architecture (to support multiple simultaneous data and program fetches); and addressing modes supporting auto increment, circular buffers, and bit-reversed addressing (the latter to support FFT calculation)

EMBEDDED PROCESSORS

- **DSP Processors**
  - Most support fixed-point data precisions of 16-24 bits, typically with much wider *accumulators* (40-56 bits) so that a large number of successive multiply-accumulate instructions can be executed without overflow. A few DSPs have appeared with floating point hardware, but these have not dominated the marketplace.
  - DSPs are difficult to program compared to RISC architectures, primarily because of complex specialized instructions, a pipeline that is exposed to the programmer, and asymmetric memory architectures. Until the late 1990s, these devices were almost always programmed in assembly language. Even today, C programs make extensive use of libraries that are hand-coded in assembly language to take advantage of the most esoteric features of the architectures.

EMBEDDED PROCESSORS

DSP Processors

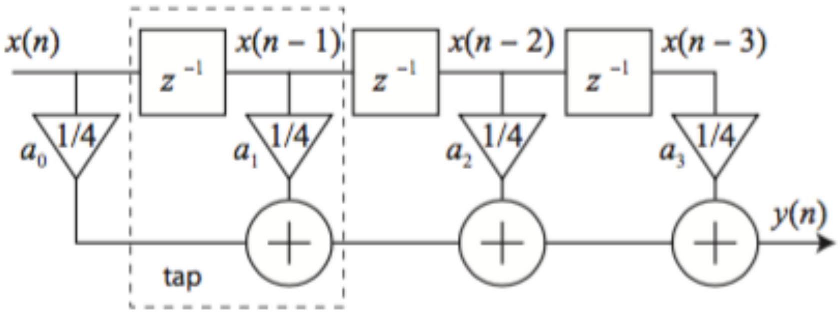
- Finite Impulse Response (FIR) filter

$$y(n) = \sum_{i=0}^{N-1} a_i x(n-i) \qquad x : \mathbb{Z} \to D \qquad x(n) = 0 \text{ for all } n < 0.$$

tapped delay line

$$y(n) = (x(n) + x(n-1) + x(n-2) + x(n-3))/4$$

$$N = 4 \; a_0 = a_1 = a_2 = a_3 = 1/4$$



E. A. Lee and S. A. Seshia, Introduction to Embedded Systems