ECEN 5653
Terminology Guide

Sam Siewert
8VSB - the modulation method used for broadcast in the ATSC digital television standard used primarily in North America, the modulation method specifies how the radio signal fluctuates to convey information; 8VSB is an 8-level vestigial sideband modulation capable of transmitting three bits ($2^3=8$) per symbol by amplitude modulating a sinusoidal carrier to an intermediate frequency. The resulting signal is then band-pass filtered with a Nyquist filter to remove redundancies in the side lobes, and then again modulated to the broadcast frequency.

**ABI – Application Binary Interface** - ABIs enable binary compatibility, whereas APIs enable source code compatibility. POSIX is an API allowing applications to be hosted on various operating systems without source changes, but does require recompilation for the new target OS. An ABI allows compiled object code to be re-hosted without changes on any system implementing that ABI.

**ADC** - Analog to Digital Converter, encodes analog signals into digital values.

**Altivec** - a floating point and integer SIMD instruction set designed and owned by Apple, IBM and Freescale Semiconductor, implemented on versions of the PowerPC including Motorola's G4, IBM's G5 and POWER6 processors.

**A-periodic** – lacking a distinguishable frequency or period, having irregular occurrence. Faults and processing exceptions are in real-time systems are aperiodic due to unpredictability of when or how often they might occur.

**API** - Application Programmer’s Interface, provides function call interface to lower level software and/or hardware functionality.

**Asynchronous** - An event or stimulus that occurs at any point in time rather than at known predictable points in time - e.g. an external interrupt may occur at any time and will immediately change the thread of execution on a CPU.

**Atomic Operation** - A non-interuptable CPU instruction - i.e any instruction that can be fetched and completed before the CPU can be interrupted.
**ATSC** - standards developed by the Advanced Television Systems Committee for digital television transmission over terrestrial, cable, and satellite networks, developed in the early 1990s by a consortium of electronics and telecommunications companies that assembled to develop a specification for what is now known as HDTV. Mostly used in 8VSB modulated OTA (Over The Air) digital transmission today in the United States - ATSC replaced analog NTSC television in the United States on June 12, 2009 and will replace NTSC by August 31, 2011 in Canada, and December 31, 2015 in Mexico.

**AVC** - H.264/MPEG-4 AVC, Advanced Video Coding, a digital video compression format, see H.264.

**Bandwidth** - data transfer per unit time, e.g. bytes/second.

**Best Effort** - scheduling policy that does not guarantee any particular response time for a service request, but attempts to make progress on all such requests and maximize total throughput.

**B-Frame (MPEG)** – a Bi-predictive frame saves even more space than an I-frame or P-frame by using differences between the current frame and both the preceding and following frames to specify its content.
**Binary Semaphore** - a *semaphore* that has only 2 states: full and empty; a take on an empty binary *semaphore* will *block* the calling *thread* and a take on a full binary *semaphore* will change the state to empty; a give on an empty binary *semaphore* will change the state to full and a give on a full *semaphore* has no effect.

**Block Transfer** - transfer of data (typically contiguous, but may be a *scatter/gather list*) that includes multiple memory words/bytes on a bus with automatic addressing of each element in the block - rather than addressing and performing a full bus cycle to transfer each word.

**Blocking** - when a *thread* of execution has been *dispatched* on the CPU for execution, but it needs some other resource such as memory access, an I/O interface, or some other external condition to be true such that it must give up the CPU and wait, the *thread* is said to be blocked.

**Block-Oriented Driver** - A software I/O device interface which enables memory blocks to be transferred to and from the I/O device - rather than one memory word at a time.

**Bottom Half (BH)** – In Linux the BH is a routine that is scheduled by the Top Half (TH) to be executed later, at a safer time. This is to avoid lengthy interrupt handlers.

**BSS** - uninitialized global C program data - because the data is not initialized, this data need not take up space in non-volatile memory, but must be allocated a data segment in working main memory.
**Burst Transfer** - A bus transaction which involves an initial address cycle followed by many data read/write cycles terminated by the *bus master* (similar to *Block Transfer*, but of unlimited length).

**Bus** - a parallel interface for reading/writing data words from/to addresses and includes: digital data lines, address lines, and control lines - note that address and data lines may be multiplexed rather than separate lines.

**Bus Master** - a device which can initiate bus cycles to address a target device and then read/write data to the target device which supplies data or receives data.

**Bus Analyzer** - a passive device which snoops on a bus to capture a record of all bus cycles - typically acts like a specialized *logic analyzer* and can be setup to trigger and start collecting a bus cycle trace when a particular address, data, or control bit pattern is active on the bus.

**C (in RMA)** - the execution time required by a *service* to provide a response not including any time spent blocking (only time where the CPU was in fact being used to compute a response output).
**Cache** - high speed access memory which typically can be read or written in a single CPU cycle, but due to high cost per storable word, is used as an efficient copy of a much larger main memory device - hardware functionality is typically included to aid with cache memory management including maintenance of cache/memory coherency, mapping of main memory addresses to cache lines (*Direct Mapped, Set Associative, Fully Associative*), and loading/write-back of data between cache and main memory.

**Cache Coherency** - a cached copy of data at a given address will be different than the data at the same address in main memory after a cached write to this address - when this happens the cache control hardware/software must restore agreement between the data in cache and main memory sometime before data would otherwise be corrupted. Two main policies are used to maintain coherency - *write-back* and *write-through* - however, when memory addresses are cached and also used for DMA or other types of I/O, special care must also be taken by application code to ensure that data is not corrupted by intelligently performing write-backs and re-loads of cache lines as needed.
- **Cache Hit** - when a read or write is performed by an application on data cached at the address accessed/updated, then this is said to be a cache hit.

- **Cache Miss** - when a read or write is performed by an application on data that is not presently in cache and therefore the CPU must first load the data at the address being accessed/modified, this is said to be a cache miss.

- **Cache Line Eviction** - a system event where data that is written back to memory, freeing up a cache line.

- **Cache Line Invalidation** - a system event where a cache line is marked, typically with a status bit called “dirty”, which indicates that the cache line must be reloaded from memory before data is read from it.

- **Cache Line Locking** - Many caches have control features allowing a program to lock a particular address into a line of cache preventing this line from being replaced when other addresses are loaded (makes most sense for *set associative* caches rather than direct mapped) - cache line size varies, but is often 16-64 bytes.
**Cache Line Pre-fetch** - Many caches have a feature allowing a program to request the cache to load a cache line despite the fact that the associated address has not been accessed yet - the idea is that this address will eventually be accessed in the future and rather than stalling the *CPU pipeline* at the time it is accessed, intelligent applications can plan ahead.

**Cache Miss Penalty** - The number of CPU core cycles that the CPU pipeline must be stalled when a cache line must be loaded after a cache miss in order for a thread of execution to continue.

**Call-back** - a programming technique where a pointer to a function is passed to a different function (registered) so that the function which obtains this pointer can call the function passed to it by reference later on - a technique commonly used in user interfaces so that an event such as a mouse click can be handled generically by code which however will call any number of user application callbacks when the mouse click event is detected.
**Canonical Mode** – When a terminal command line is sent from a remote client to a server only after return is entered instead of one character at a time.

**CCTV** – Closed Circuit Television, an analog composite NTSC camera and frame grabber signal format.

**CFD** - Control Flow Diagram, a diagram used in Structured Analysis/Design which indicates where control signals in the system originate, where they terminate and how they change the flow of data and/or the processing of data in a *DFD*. (Note that a CFD is typically a subset of a DFD which shows both data flow and control flow).

**Chromanance** - the signal used in digital video systems to convey the color information of the picture, separately from the accompanying luma signal/value (or Y for short). Chrominance is usually represented as two color-difference components: \( U = B' - Y' \) (blue – luma) and \( V = R' - Y' \) (red – luma). Each of these difference components may have scale factors and offsets applied to it, as specified by the applicable video standard.
- **Circuit Switched I/O** - an I/O channel that is dedicated to one and only one data source and sink - often the channel may be point-to-point, but may be switched before the circuit is established. This stands in contrast to much more widely deployed packet switched digital transport protocols in use today for digital media.

- **CLI** - Command Line Interface, a simple ASCII terminal type interface that can operate over serial or any other byte-stream I/O interface to provide the ability to command a device and obtain basic status information.

- **CODEC** - Coder/decoder - a device that converts analog signals to digital to be read by a computer or transmitted over a network, and converts the digital signals back to analog. Sound cards and video cards use this kind of codec. Also, compression/decompression - a two-step process used on very large multimedia files. Files are compressed for storage and then expanded to their original size in order to play them back on the computer.

- **Computational Complexity** - the mathematical magnitude of operations required to successfully execute a given algorithm - e.g. searching a data set can take N operations for N items linearly searched or log(N) operations for a balanced tree search of N items, or even constant C operations for N items with a perfect hashing function.
Composite (analog video) - format of an analog television (picture only) signal before it is combined with a sound signal and modulated onto an RF carrier. In contrast to component video (YPbPr or RGB) it contains all required video information, including colors in a single line-level signal; it is usually in a standard analog video format such as NTSC.

Component (analog video) - a video signal that has been split into two or more components. In popular use, it refers to a type of analog video information that is transmitted or stored as three separate signals. When used without any other qualifications the term component video generally refers to analog YPbPr component video with sync on luma, but S-Video (separate luma and chroma), RGB and YPbPr signals comprise two or more separate signals: hence, all are component-video signals.

Context Switch - When a CPU is multiplexed (shared) by more than one thread of execution and the scheduler provides preemption, when the scheduler does preempt a thread in order to dispatch another, it must save state information associated with the currently executing thread (e.g. register values including PC) so that this thread can later be dispatched again to restore its thread of execution without a state error. The process of preempting a running task in response to an interrupt or kernel event followed by dispatch of a new task is a Context Switch. In some scenarios a thread will exit, suspend or enter a delayed or pending state and will yield the CPU which will be followed by a dispatch of another thread from the ready queue – this is also considered a context switch despite the lack of a priority preemption of an executing thread.
Context Switch Overhead - the number of machine code instructions (and clock cycles) required to perform a context switch.

Continuous Media - I/O stream that requires isochronal deliver of data between a source and sink - e.g. video stream, audio stream, and possibly a telemetry stream.

Control Flow - A control flow is a CFD unidirectional association between two processes and/or external entities that indicates an asynchronous mechanism used to control a process or data source/sink.

Control Plane - the bus or network transport and memory buffer path for control flow in an architecture which strictly separates data and control. Control data and commands are processed to determine data flow parameters, context, and sequencing in the separated data plane.

Cooperative Scheduling – A method for scheduling threads of execution through the threads themselves which make calls to transfer from one thread execution context to another rather than relying upon a centralized scheduler.

Co-Processor – a special purpose processor used to supplement the functions of the primary processor (the CPU), such as floating point arithmetic, graphics, signal processing, string processing, or encryption.

CPI - Clocks Per Instruction, a measure of CPU efficiency with the ideal that a CPU pipeline should have a CPI of 1.0 or less if the pipeline can retire an instruction every clock - if the pipeline is also superscalar such that multiple instruction pipelines may execute, then this type of microparallelism can theoretically yield a CPI less than 1.0.
**CPU** - Central Processing Unit, a processor core providing arithmetic and logic operations, possibly floating point arithmetic, and basic register and memory operations.

**CPU Bound** - When an application program is unable to execute any faster due to the clock rate of the CPU and the CPI.

**CPU Pipeline** - The use of micro-parallelism in the CPU core to provide a stage of instruction processing every clock such that once the parallel pipeline is started, an instruction is completed every clock - stages typically include: fetch, decode, execution, and write-back as a minimum. The key to pipelining is that it is possible for the pipeline to fetch, decode, execute, and write-back all at the same time for 4 instructions at various stages - each instruction will actually take multiple cycles to complete, but in the aggregate one instruction is completed every clock. (Note that pipelines may also be superscalar such that whole pipelines may be run in parallel as well).

**CRT** - a vacuum tube containing an electron gun and a fluorescent screen, with internal or external means to accelerate and deflect the electron beam, used to create images in the form of light emitted from the fluorescent screen used for TV, radar, oscilloscopes and numerous other analog image displays.
**Critical Instant** - This assumption made by Liu and Layland when they formalized fixed priority RM describes a worst-case scenario where all services in a system would be released simultaneously.

**Critical Section** - When two independent threads of execution share a resource, such as a shared memory location, the section of code which accesses and possibly updates this shared resource in each thread is called a critical section - to ensure correctness, both threads will employ a synchronization mechanism such as a *mutex* *semaphore* to protect the critical section.

**Critical Time Zone** – A time interval in RM theory which extends from the last release of an interfering service to the end of the larger period containing it.

**CSMA/CD** - Carrier Sense Multi-Access / Collision Detection, a protocol used in ethernet to detect when a node is already transmitting on the shared link and to back off and attempt to use the network later.

**Cycle-Based Profiling** - profiling code executing on a processor by periodically saving off the current PC in a trace buffer - most often implemented by an interrupt generating counter that counts cycles and can be programmed to raise an interrupt every N cycles - the ISR associated can then service the interrupt and save off the PC each time into a trace buffer.
D (in RMA) - The service deadline relative to request for service.

DAC - Digital to Analog Conversion, most often used to provide analog output to an actuator from a digital I/O interface - e.g. a motor or speaker.

Data Flow Diagram - Data Flow Diagram, a diagram used in Structured Analysis/Design which indicates where data in the system originates, where terminate and how it is processed in between. (Note that a DFD typically includes a CFD and therefore shows both data flow and control flow).

Data Plane – the bus or network transport and memory buffer path for data flow, most often DMA transfer blocks, in an architecture which strictly separates data and control. Payload data passes through the system untouched or minimally modified according to commands and context for the flow maintained in the separated control plane.

Data Segment - a memory region reserved for global variables and constants in a C program thread - most often each thread has its own data segment. (Note, most programs include a Stack, Data, and Text segment as a minimum).

Datagram Transport - transmission of packets on a link such that errors in transmission can be detected, but are not automatically corrected nor is there automatic retransmission of lost data - furthermore, there is no concept of a connection (real or virtual) such that multiple messages are unrelated and if fragmented will not be reordered or reassembled automatically.
**DDR** - Double Data Rate, a bus data encoding technique where read or write data is transferred on both edges of a reference clock rather than just one (rising edge and falling edge) - this doubles the data rate.

**Deadline** - a time relative to a request for service when the service must be completed to realize full utility of the service.

**Deadline Driven Scheduling** – Dynamic preemptive priority assignment scheduling using policies such as Earliest Deadline First or Least-Laxity First. As presented by Liu and Layland, this is EDF scheduling, however since its introduction, a number of different policies have been proposed in addition to EDF.

**Deadlock** - a multi-thread condition where 2 or more threads of execution are waiting on resources held by another and the graph of wait-for associations is circular - e.g. if A is waiting on resource R1 to produce resource R2; and B is waiting on resource R2 to produce resource R1 - this is a deadlock.

**Decoder** - a digital device which takes a bit-encoded input and produces an analog actuator output - e.g. audio playback decoder which drives a speaker - hardware or software that translates an encoded signal back to its original form.

**Deterministic** – causal events that are fixed in form, position, and character apriori; in real-time systems this describes services that provide invariant responses with no irregularity in timing of response, execution or behavior.

**DFD** - Data Flow Diagram, a diagram used in Structured Analysis/Design which indicates where data in the system originates, how it is processed, and where it terminates (from data source to data sink).
Direct-Mapped Cache - a cache memory which is has cache lines directly mapped to main memory locations such that a given main memory address can be loaded into one and only one cache line, yet a set/range of main memory locations may be loaded into that particular line.

Digital Media - (compared to analog media, e.g. LP record) are electronic or optical media that record digital codes most often based on the binary numeral system (discrete states), and include information formats like digital audio, digital video and other digital content that can be created, decoded and distributed via digital information processing machines with no information loss once encoded - a profound change from previous (analog) media.

Dispatch – when the Linux scheduler selects a thread ready to run, restores state associated with the thread, and transfers execution control back to the thread’s last PC if it was preempted earlier (or to its entry point if the thread is ready to run for the first time).

DLP - a trademark owned by Texas Instruments, representing a technology used in some TVs and video projectors, originally developed in 1987. DLP is used in DLP front projectors (small standalone projection units) and DLP rear projection television. DLP, along with LCD and LCoS, are the current display technologies behind rear-projection television, having supplanted CRT rear projectors. These rear-projection technologies compete against LCD and plasma flat panel displays in the HDTV market.
DMA - Direct Memory Access, a hardware state machine independent of the CPU core which is able to transfer data in or out of memory without directly executing core instructions, thus allowing the core to continue execution while regions of memory are copied, updated by an I/O device, or read out to an I/O device.

Double-Bufferring - a technique often used in continuous media applications to allow for data acquisition into one buffer while another is being read-out and processed - when the acquisition buffer is full, the buffer pointers are swapped such that the newly acquired data is processed and the already processed buffer can now be used for acquisition.

Driver - a driver is software composed of code which interfaces to a hardware device and provides buffering, control, and status and which also interfaces to RTOS threads/applications and provides controlled access to the hardware device for I/O.

DSP - Digital Signal Processing, a specialized embedded processor core which includes parallel mixed analog and digital processing for typical signal processing functions - e.g. for a Fourier transform.

Dude - Etymology: origin unknown
1: a man extremely fastidious in dress and manner: DANDY
2: a city dweller unfamiliar with life on the range; especially: an Easterner in the West – webster.com
- **Dynamic Linking** - a technique where *PIC* software compiled into an object file format such as *ELF* can be loaded and linked into existing software on the fly either as a dynamically linked library or as a kernel module.

- **Dynamic Priority** - when thread or interrupt processing priorities are changed during run time by code, they are said to be dynamic.

- **Earliest Deadline First** - a dynamic priority scheme for scheduling where services are assigned priority dynamically every time the ready queue is updated, with highest priority given to the service with the earliest impending deadline - the scheme requires not only dynamic priority, but *preemption* to work.

- **EFSM** - Extended Finite State Machine, a formal method based upon state machines which extends the basic state transition on I/O to include side effects on transitions such as global data update and data processing.

- **ELF** - Executable and Linking Format, an object file format which includes significant annotation and is PIC such that these files can be dynamically loaded and linked and such that they can serve for supporting debug and trace analysis to map addresses back to source code.

- **Elementary Stream** - defined by MPEG communication protocol is usually the output of an audio or video encoder. ES contains only one kind of data, e.g. audio, video or closed caption. An elementary stream is often referred to as "elementary", "data", "audio", or "video" bitstreams or streams. The format of the elementary stream depends upon the codec or data carried in the stream, but will often carry a common header when packetized into a packetized elementary stream.

- **Embedded System** - a digital and analog computer system which provides a specific set of services, driven by sensor inputs, and producing sensor outputs to provide services - e.g. digital control in an anti-lock braking system or call switching and billing management for a telecommunications main trunk (Note that the scale of the services provided and of the hardware itself does not matter).
**Encoder** - a circuit which takes analog signal inputs and using and ADC converts them to digital and bit encodes them - e.g. an audio recorder which takes analog microphone input and encodes the input signal into 255 different tones - a sensor or transducer for converting rotary motion or position to a series of electronic pulses.

**Entry Point** - an address in a *text segment* which is the first instruction in a function and serves as the starting point for a thread such that a scheduler can simply set the *PC* to this address in order to start execution of this thread.

**Event-Based Profiling** - a profiling technique where the PC is saved into a trace buffer whenever events of a specific type exceed a threshold - e.g. when data cache misses exceed N misses, the PC is saved into a trace buffer.
Exception (NMI) - an exception is normally a non-maskable interrupt because it signifies a serious error condition which must be handled before any program should continue execution - e.g. a bus error.

Execution Jitter - when a service is dispatched and the number of cycles and/or instructions required to complete the service varies on each release, this service is said to have execution jitter.

Extended Finite State Machine - an FSM (Finite State Machine) with more features than just states and I/O transitions so that the Von Neumann architecture and general programs may be modeled formally - e.g. on a state transition a procedural function may be called and or global memory updated.

External Fragmentation - when blocks of a resource such as memory are allowed to be arbitrarily sized, small sections of the resource between used sections may evolve from successive allocations and frees such that significant resource exists, but is unusable unless allocations are moved to provide larger contiguous free spaces from small many non-contiguous spaces. (fragmentation outside of blocks).
**FCFS** - First Come, First Served, the policy often used by an RTOS when services/threads are at the same priority level - i.e. the first service ready is the first one dispatched.

**Feasibility Test** - An algorithmic or formulaic operation that takes a set of services and their \( RM \) characteristics and will provide a binary output indicating whether this service set can be scheduled given resources available and resources required by the service set.

**Feedback** - a signal used in control systems which provides sensor inputs to compute the difference between desired and actual plant state such that a control law can drive the plant to a desired target control point.

**FIFO** - First In, First Out, a policy for queues (e.g. a dispatch queue) where the first element queued is always the first element de-queued. For POSIX (NPTL) threads, this means thread scheduling where threads are dispatched to run to completion from the ready queue in FIFO order.

**Fixed Priority Scheduling** - a scheduling policy whereby threads on the ready queue are dispatched in priority order and the priority of any given thread is not modified over time.

**Floor** - The floor is a mathematical operation that can be performed on a real number (floating point) - the floor\( (n) \) is the closest integer whole number less than or equal to \( n \) - e.g. floor\( (1.1) = 1 \). (note that floor\( (1.0) = \) ceiling\( (1.0) \) assuming that the significance is 1, which is the the typical definition of floor and ceiling unless otherwise noted).
**Flow Control** - signals between a data transmitter and receiver used to indicate buffer capabilities on each side so that a transmitter does not overdrive a receiver resulting in data loss when the receiver is unable to buffer incoming data.

**Flynn’s Taxonomy** - is a classification of computer architectures, proposed by Michael J. Flynn in 1966, which classifies processor architecture in terms of whether it applies single or multiple instructions to single or multiple data operands. The cross product of these two dimensions therefore leads to SISD (Single Instruction Single Data), MISD (Multiple Instruction Single Data), SIMD (Single Instruction Multiple Data), and MIMD (Multiple Instruction Multiple Data) processors.

**Fixed Priority Scheduling** - a scheduling policy whereby threads on the ready queue are dispatched in priority order and the priority of any given thread is not modified over time (except by the application itself).
**Fully Associative Cache** - A cache which allows main memory addresses to be loaded to any cache line - this is the ideal cache since replacement is not constrained at all, but associative memory is complex and expensive - by comparison a *direct mapped cache* is completely constrained and a *set associative* is a compromise.

**Gather Read List** - A list of not necessarily contiguous addresses in memory that are to be read into a contiguous buffer - e.g. a host memory may have multiple blocks in memory scattered through memory space that are to be read by an I/O device which will gather all these blocks into a single contiguous buffer before an I/O operation.

**GDT** – Global Descriptor Table - a data structure used by x86 IA32 to define characteristics of memory regions used during program execution (base address, the size and access privileges execute/read/write) and Task State Segments (TSS) including register state, IO port state, and stack pointers.

**Geek** - a carnival performer whose act usually includes biting the head off a live chicken or snake; or more recently, a person often of an intellectual bent who is disapproved of by others.

**GOP** – Group of Pictures, specifies the order in which intra- and inter-frames are arranged in MPEG encoding, including I, P, and B frames.
GPU – Graphics Processing Unit, a specialized microprocessor that offloads and accelerates graphics rendering from the central CPU, designed to provide 2D and 3D vector processing (4D for shading and other advanced rendering features), and to drive common displays (LCD, CRT, DLP).

GP-GPU – General Purpose GPU, an extension to 4D vector processing for more general use in grid and mesh algorithms such as finite element methods, graph theory, image processing, and HPC (High Performance Computing) in general for algorithms that are embarrassingly parallel by nature of their grid/mesh formulation.

H.264 - MPEG-4 Part 10 or AVC (Advanced Video Coding) standard for video compression, currently one of the most commonly used formats for the recording, compression, and distribution of high definition video. The final drafting work on the first version of the standard was completed in May 2003. The codec is block-oriented motion-compensation-based codec standard developed by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC Moving Picture Experts Group (MPEG). It was the product of a partnership effort known as the Joint Video Team (JVT). The ITU-T H.264 standard and the ISO/IEC MPEG-4 AVC standard (formally, ISO/IEC 14496-10 - MPEG-4 Part 10, Advanced Video Coding) are jointly maintained so that they have identical technical content. The codec is best known as being one of the codec standards for Blu-ray Discs and is widely used by streaming internet sources, such as YouTube, web software such as the Adobe Flash Player, broadcast services for DVB, direct-broadcast satellite television services, cable television services, and real-time videoconferencing.
Hacker - a person who is inexperienced or unskilled at a particular activity: an expert at programming and solving problems with a computer: a person who illegally gains access to and sometimes tampers with information in a computer system – webster.com

Hard Real-Time - A service or set of services which are required to meet their deadlines relative to request frequency - if such deadlines are missed, there is not only no utility in continuing the service, but in fact the consequences to the system are considered fatal or critical.

Harmonic - When the relative periods of services are all common multiples of each other - this characteristic can yield cases where the CPU resource can be deterministically scheduled to full utility. For example, T1=2, T2=5, T3=10 has a base frequency of 1/10th Hz and has the harmonic sequence of 1x, 2x, 5x for the base frequency.

Harvard Architecture - a core CPU architecture which splits the memory hierarchy into separate instruction and data streams - typically including an L1 instruction cache which is independent of an L1 data cache.
**HDTV** - refers to video having resolution substantially higher than traditional television systems (standard-definition TV, or SDTV, or SD). HD often has millions pixels per frame, often more than five times that of SD 640x480 and also includes non-interlaced progressive raster modes.

**Heap** - A memory space used for dynamic buffer management and/or dynamic allocation of memory as requested by an application - heap space is memory outside the data, text, and stack segments and is most often accessed in Linux using malloc and related dynamic memory allocation functions.

**High Availability** - A system which guarantees that it will be ready to provide services with a quantifiable reliability - e.g. a system is said to provide 5 9’s availability if it is ready to provide service upon request 99.999% of a given year (i.e. is only unavailable for a total of about 5 minutes per year). Note that HA systems can crash, but they can’t be out of service very long if they do.
High Reliability - A system which has been designed to have a very low probability of failure to provide services - typically measures such as redundancy, cross strapping, and fail safe modes are designed in to ensure that critical services have an extremely low likelihood of failure.

Host - Desktop development computing system used in IDE for cross compilation, cross debugging, connection to the target agent, trace tools and any number of other tools that connect to a target server on the host to communicate with target agent software resident on the embedded system.

HSV (color model) – Hue, Saturation, Value, common cylindrical-coordinate representations of points in an RGB color model, which rearrange the geometry of RGB in an attempt to be more perceptually relevant than the cartesian representation. They were developed in the 1970s for computer graphics applications, and are used for color pickers, in color-modification tools in image editing software, and less commonly for image analysis and computer vision.

I-Frame (MPEG) - Intra-frame coding is used in video coding (compression). It is part of group of pictures with inter frames, where an intra-frame applies only compression techniques relative to information that is contained only within the current frame, and not relative to any other frame in the video sequence.

Image Processing (digital) - any form of digital signal processing for which the input is an 2D digital image array, such as a photograph or video frame; the output of image processing may be either an image or, a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional digital image and applying standard signal-processing techniques to it.
**Importance** - in real-time systems theory services with low priority based upon RM policy may still be critical to system operation - they are important despite being low priority.

**Interference** - when a higher priority thread preempts a lower one in a fixed priority preemptive system the time that the CPU is unavailable to lower priority threads is referred to as interference time.

**Internal Fragmentation** - When a resource such as memory is made available in minimum sized blocks, this can help reduce *external fragmentation*, but when a user of the resource requires less than a full block, this causes internal fragmentation.

**Interrupt** – A hardware signal assertion into the CPU core from an IO device to indicate that an event has occurred such as data available on an input interface (e.g. a sensor sample or DMA transfer has been completed).

**Interrupt Handler** - during the normal CPU pipeline processing (fetch, decode, execute, write-back) an external device may assert an signal input or an internal sub-block may also assert a signal input to the CPU core which causes it to asynchronously branch to an interrupt vector (a memory location) where basic code called the handler acknowledges and services the hardware and then calls application ISRs.

**Interrupt Latency** - the delay between assertion of an interrupt signal by a device and the time at which the PC is vectored to an interrupt handler is known as the interrupt latency.
**Interrupt Vector** - an address in memory where the CPU sets the PC after an interrupt signal is asserted, causing the CPU to asynchronously branch to this location and to execute the instruction there - normally a CPU will have a number of interrupt inputs (e.g. x86 IRQ0-15) and each signal asserted causes the CPU to vector to a different address such that different handlers can be associated with each interrupt signal.

**Interval Timer** - a double-buffered state machine in a CPU core which allows software to set a value in a register that is loaded into a separate count-down register which asserts an interrupt at zero (or perhaps all F’s if it counts up) and automatically is reloaded with the interval register value to repeat the process over and over - this hardware is used for non-realtime Linux process round-robin time-slice scheduling of all user processes.

**IO Bound** - a condition where an application does not have sufficient I/O bandwidth to meet throughput goals or real-time deadlines.
ISA Legacy Interrupt - Industry Standard Architecture Legacy Interrupt, specifically refers to x86 architecture IRQ0-15 which have been part of the x86 architecture from the beginning (8086) and support a number of well-known PC devices and services such as booting from a hard drive.

Isochronal - uniform in time, having equal duration, recurring at regular intervals; literally the same in time, which in real-time systems means that a service is required to produce a response at a precise time relative to a service request - not too early and not too late. This is important to continuous media applications and digital control which are sensitive to jitter. Most often isochronal services hold a response computed ahead of deadline that is delivered to an interface within a narrow band around the optimal time. For data transport, isochronal channels provide guaranteed bandwidth and latency characteristics so that the transmission of continuous media is provided with a constant bit, byte, or frame rate per unit time.

ISR - Interrupt Service Routine, the application level of an interrupt handler which is often a call-back function registered with an RTOS that installs the interrupt handler at an interrupt vector.
**Jiffy** - a term to describe the tick of a hardware interval timer – in Linux it is the count of interval timer interrupts since the system started and the smallest unit of time that Linux can track - e.g. on x86 architecture the standard interval timer ticks about every 0.45 microseconds. The Linux OS typically loads an interval timer count-down to generate interrupts such that it can control processes on a 10 millisecond software tick, thus most often the number of jiffies is the number of ticks the system has had since start and the definition can be found in `<linux/jiffies.h>`.

**Jitter** - when latency and/or timing of an operation or process changes with each iteration, this is jitter - i.e. when latency/timing is not constant. Jitter as a term can be used to describe many different types of operations or processes - e.g. execution jitter, period jitter, response jitter.

**Join (pthread)** – When POSIX (NPTL) threads are configured to rendezvous at a common barrier with the main thread that created and spawned/forked them (otherwise they should be detached to run to completion and exit with no rendezvous with their parent thread).
**Keep-alive** - an indication from a thread/process/task on a system that it is functioning normally or perhaps similar indication from a subsystem in a larger system - the keep-alive is most often a simple ID and count indicating that the subsystem/thread/process/task is advancing through its service loop - often referred to as a heartbeat as well.

**Kernel** - the software in Linux which directly controls all critical resources such as CPU, memory, and device I/O - the kernel is typically interfaced to by applications through drivers, system call traps, and mapped interfaces like /proc only. All kernel code executes in a privileged CPU mode and is protected from user code by the MMU.

**Kernel Image** - the Linux bootable system image including the scheduler and linked-in drivers.

**Kernel Instrumentation** - tools like LTT which provide active tracing of C code and/or kernel events.

**Kernal Module** – A dynamically linked object code module in Linux which can be loaded and linked into kernel space (with `insmod`) for execution in kernel space to extend the kernel or provide an IO driver function.
- **L1 Cache** - Level 1 Cache, a high-speed memory integrated on-chip with a CPU core - on the same ASIC for data access that can most often be completed in a single clock.

- **L2 Cache** - Level 2 Cache, a high speed memory off-chip which can be accessed in several clocks.

- **Latency** - delay in an operation or process due to physical limitations such as electronic propagation delay, the speed of light, the number of clock cycles required to execute instructions, or time to modify a physical memory device.

- **Laxity** - Laxity = (Time-to-Deadline - Time-to-Completion), but the time to the completion of a service can be difficult to determine, so most often an estimate of the Time-to-Completion is used which is derived from (WCET - Computation-Time-So-Far).

- **Layered Driver** - a layered driver includes distinct code modules which communicate only through (registered) functions in a well defined API where each module is potentially a separately loadable kernel module in Linux.
LCD – a liquid crystal display is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly, but rather made up of any number of pixels filled with liquid crystals arrayed in front of a light source or reflector to produce images in color or monochrome. LCD projectors use transmissive LCD chips, allowing light to pass through the liquid crystal.

LCM - Least Common Multiple, the LCM is the smallest number which is also multiple of 2 different numbers - e.g. given x=3, y=5, the LCM(x,y)=15. This concept is key to periodic service analysis in real-time theory because it is necessary to diagram service times over the LCM of all periods in order to fully analyze timing demands upon a resource. Note that the LCM for numbers that are prime can be very large compared to harmonic numbers.

LCoS - Liquid crystal on silicon is a micro-display technology typically applied in projection televisions, a reflective technology similar to DLP, however, it uses liquid crystals instead of individual mirrors. In LCoS, liquid crystals are applied directly to the surface of a silicon chip coated with an aluminized layer, with a passivation layer, which is highly reflective. LCoS technology can typically produce higher resolution and higher contrast images than standard liquid crystal display and plasma display technologies, which makes it less expensive to implement in such devices as televisions.

Least Laxity First (LLF) - a dynamic priority policy where services on the ready queue are assigned higher priority if their laxity is the least (where laxity is the time difference between their deadline and remaining computation time) - this requires the scheduler to know all outstanding service request times, their deadlines, the current time, remaining computation time for all services, and to re-assign priorities to all services on every preemption. Estimating remaining computation time for each service can be difficult and typically requires a worst-case approximation.

Lehoczky, Sha, and Ding Theorem (a.k.a Theorem 2) - If a set of services can be scheduled over the period of the longest period service after a critical instant, then the system is feasible (i.e. is guaranteed not to miss a deadline in the future).
**Linking (Dynamic or Static)** - Linking is the process by which an executable image is assigned addresses for all function entry points, all global variables, and all constants which may be referenced by other software modules - these addresses can be statically assigned once and for all at a pre-determined offset in physical memory (static linking) or may be position independent such that only relative addresses are assigned until the module is loaded, at which time physical addresses are derived from the relative (dynamic linking).

**Live-lock** - related to deadlock, this situation arises when a circular wait for resources evolves and an attempt to break the deadlock is made by having each requester drop their requests and then re-request them - if the requests are well synchronized, then the system may cycle between deadlock and dropping requests over and over.
**LSP** - Linux Support Package, an embedded Linux term, much like a BSP, which refers to code required to boot Linux on a given architecture and platform - e.g. the PowerPC 750 LSP.

**LTT** – Linux Trace Toolkit – a tool that traces events in the Linux kernel, encodes them, and stores a trace of event codes in memory. The event trace can be loaded later into a tool for timing analysis.

**Luminance** - a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square meter (cd/m²).
Memory Hierarchy - the whole memory system design from the fastest and typically smallest devices to the slowest and typically largest devices - e.g. L1/L2 cache, main memory, and flash.

Memory Mapped I/O - I/O devices which can be read or written can be mapped into the address space of a processor allowing software to simply update an address in order to write to the device or read an address to read from the device - the device must respond to the addressing by the CPU, i.e. decode it and then read/write data on a bus which both the device and CPU interface with.

Mmap – In Linux this means associating a range of user-space addresses to device memory using /dev/mem, which can be observed in Linux by “cat /proc/iomem” for example. For performance critical applications like video card interfaces, mmap can make device access by user applications much more efficient.
Memory Protection - an MMU feature which allows address ranges on page boundaries (a minimum size memory block) to be specified as read-only - if an update to such a range is attempted, the MMU will assert an NMI exception.

Message Queue – a POSIX mechanism which provides a message FIFO, with priority if desired, and atomic en-queue and de-queue of messages within threads of execution in a process.

Message Sequence Chart - a diagramming method used in the Specification and Design Language (SDL) as well as UML (Universal Modeling Language) which shows threads of execution and all messages (or function call interfaces) which associate the threads in a protocol.
**Micro-code** - machine code which executes on a state machine internal to a processor or on a simple state machine device that is independent of the main execution pipeline - e.g. the Bt878 RISC processor executes code fetched from the x86 processor’s memory over the PCI bus - this code is micro-code from the viewpoint of the x86 system.

**Micro-parallelism** - parallel processing inside the CPU core.

**MIMD** - Multiple Instruction Multiple Data processing in Flynn’s architecture types such as distributed systems, clusters with message passing, and in general any AMP (Asymmetric Multi-Processor) or SMP (Symmetric Multi-Processor) CPU with more than one core.

**MISD** – Multiple Instruction Single Data processing Flynn architecture type, e.g. TMR (Triple Mode Redundancy) voting schemes and active-active controllers used for high availability.

**MMU** - Memory Management Unit, a block in most CPU cores which provides virtual to physical address mapping, address range checking, and can protect read-only address ranges from unintentional update.

**MMX** – Multi-Media Extensions, a single-instruction, multiple-data instruction set designed by Intel.

**MPMD** – Multi-Program Mutliple Data, a find distinction in MIMD whereby more than one GP-GPU kernel (program) executes vectorized instructions in parallel.

**Module Loading** - when an ELF module is loaded and dynamically linked into the kernel during run time using “insmod”.

MPEG2 - a standard for "generic coding of moving pictures and associated audio information, which describes a combination of lossy video compression and lossy audio data compression methods which permit storage and transmission of movies using currently available storage media and transmission bandwidth. Commonly used for DVD (Digital Video or Versatile Disc) and DVB (Digital Video Broadcast), ISO/IEC Standard 13818 with 11 parts for definition of specific features (e.g. part 2 = Video, part 3 = Audio).

MPEG4 – methods for compression of audio and visual (AV) digital data introduced in late 1998 mad a set of standards for a group of audio and video coding formats and related technology agreed upon by the ISO/IEC Moving Picture Experts Group (MPEG) as the formal standard ISO/IEC 14496 . Uses of MPEG-4 include compression of AV data for web (streaming media) , voice (telephone, videophone) and broadcast television applications. Specific parts of the 14496 standard include: MPEG-4 part 10 (MPEG-4 AVC/H.264 or Advanced Video Coding) and 26 more parts including 3D graphics.

MPTS – Multi Program Transport Stream, is a standard format for transmission and storage of audio, video, and data, and is used in broadcast systems such as DVB and ATSC. The Transport Stream is specified in MPEG-2 Part 1, Systems (13818-1). Transport stream specifies a container format encapsulating packetized elementary streams, with error correction and stream synchronization features for maintaining transmission integrity when the signal is degraded.
**Multi-access Network** - a network such as ethernet where more than one device can use the physical and link layer of the network, thus requiring a *CSMA/CD* protocol for shared use.

**Multi-tasking** - when a CPU is shared and multiplexed by a scheduler in order that multiple threads with state information may execute on a single CPU or may be mapped onto a set of CPUs dynamically. Tasks include state information that goes beyond the minimal requirements of register state, stack, and PC for a thread - e.g. task variables, a task error indicator, name, and many other elements of a VxWorks *TCB*.

**Multi-threaded** - when a CPU is shared and multiplexed by a scheduler with the minimal management of execution state for each thread of execution (register state, stack, and PC).

**Mutex Semaphore** - a specialized semaphore (compared to a binary semaphore) which is specifically used to protect critical sections of code for multi-thread safety - this semaphore is used to guarantee mutually exclusive access to a shared resource such that only one thread may access a common resource at a time - with shared memory this prevents data corruption that could be caused by multiple readers/writers - e.g. if a writer has partially updated a shared data structure, is preempted/interrupted, and then a reader accessed the partially updated data, the data may be completely inconsistent.
**Necessary and Sufficient** - a feasibility test in real-time theory which will pass all service sets that can be scheduled and will never fail a set that can be scheduled (more precise than a sufficient test which may falsely reject some service sets, but will never falsely ok a service set that can not be safely scheduled).

**Nerd** – may be based on a creature portrayed in *If I Ran the Zoo* by Dr. Seuss: an unstylish, unattractive, or socially inept person; one slavishly devoted to intellectualism or academics to the point of their own detriment.

**Nesting** - when a construct is used inside the same sort of construct - one inside the other - e.g. if a critical section encloses another critical section the critical sections are said to be nested.

**Non-Blocking** - when a request for a resource can not be met immediately, the scheduler can either block the calling thread until it is available or return it an error code indicating why the request can not be met and letting the thread go on - the latter is non-blocking.

**Non-Preemptive** – when all threads run to completion without interruption by other requests for service or the scheduler during execution.

**NPTL – Native POSIX Threads Library** - threads created by the user (via pthread_create) correspond directly to schedulable entities in the kernel rather than a user space scheduling mechanism.
**NTSC** - National Television Systems Council, the standard for analog color television transmission with 640x480 pixels. NTSC was originally grayscale only, with an even/odd interlaced CRT rastering scheme to illuminate the pixels with a given luminosity. Color information was added to the black-and-white image by adding a color subcarrier of $4.5 \times 455/572$ MHz (approximately 3.58 MHz) to the video signal. To reduce the visibility of interference between the chrominance signal and FM sound carrier required a slight reduction of the frame rate from 30 frames per second to $30/1.001$ (approximately 29.97) frames per second.

**Object Code** - machine code annotated with symbol information (variable and function names and addresses) and information to support debugging (source file names and locations).
**Offloading** - the concept of taking a software service and re-allocating it to a hardware implementation on a parallel processing unit in order to free the main CPU of loading - e.g. a network interface card may perform functions basic to TCP/IP such as checksums in order to offload those operations from the host CPU.

**On-line Admission** - when a system can run a feasibility test while currently providing other services in order to determine whether new services can safely be added to the current safe set.

**On-Off Control** - the use of relays to turn on and off motors to control a mechanical device.

**Optimal Policy** - a fixed priority assignment policy which will successfully schedule any set of services which can be scheduled by any other fixed priority policy.
**OLED** - organic light emitting diode is a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compounds which emit light in response to an electric current. This layer of organic semiconductor material is situated between two electrodes. OLEDs are used in television screens, computer monitors, small, portable system screens such as smartphones, advertising, information and digital signage.

**Over-run Policy** - how a system handles a service which attempts to continue execution beyond its advertised deadline - e.g. the scheduler could terminate the service.

**Packet Switched** - a network protocol which allows links to be shared by multiple datagram or virtual circuit protocols and routes packets between end-points based upon their header information.

**PC (program counter)** - The Program Counter is normally a register used by a CPU to track the current or next address of main memory which contains a machine instruction to execute. (Note that a trace of the PC over time provides the definition of the *thread of execution* until a *context switch* occurs, if it does at all).

**PCI** - Peripheral Component Interconnect, a standard defined by the PCI Special Interest Group to provide CPU, memory, and IO device interconnection for data transport.

**PCI Bus Probing** - A process that allows a BIOS or OS software to find all PCI devices and functions on a given PCI bus using configuration space registers.
**PCI Configuration Space** - A well known port address on x86 architecture where a PCI bus master can read/write registers in order to find other PCI devices and their functions and configure them as far as memory mapping and interrupts as a minimum.

**PCI Interrupt Routing** - PCI interrupts A-D can be routed onto x86 legacy interrupts IRQ0-15 in order to allow PCI devices to interrupt an x86 core.

**PCI-Express** - previously known as 3GIO, this standard is a scalable differential serial bus architecture for 2.5 Gbps main-board interconnection and peripheral connection.

**PCM** - Pulse-code modulation is a method used to digitally represent sampled analog signals, which was invented by Alec Reeves in 1937. It is the standard form for digital audio in computers and Blu-ray, Compact Disc and DVD formats, as well as other uses such as digital telephone systems. A PCM stream is a digital representation of an analog signal, in which the magnitude of the analogue signal is sampled regularly at uniform intervals, with each sample being quantized to the nearest value within a range of digital steps. PCM streams have two basic properties that determine their fidelity to the original analog signal: the sampling rate, which is the number of times per second that samples are taken; and the **bit depth**, which determines the number of possible digital values that each sample can take.
**Period Jitter** - when the period of a service request is not constant.

**Period Transform** - a real-time theory adjustment to service characteristics to simplify analysis or to elevate importance of a service whereby the service period is assumed to be shorter than it really is.

**Pessimistic Assumption** - RM is full of assumptions that are worst case and therefore make it a very safe form of analysis, but also may lead to excessive resource margin in order to guarantee deadlines - e.g. *WCET*.

**P-Frame (MPEG)** – predicted frame, can use data from previous frames to decompress and are more compressible than I-frames and holds only the changes in the image from the previous frame.

**Pipeline Hazard** - A condition in a CPU pipeline that forces it to stall - e.g. a cache miss.

**Pipeline Stall** - when a CPU pipeline must stop until a resource is made available.

**PIT** – See Programmable Interval Timer.
Pixel - A picture element - an array of picture elements forms an NxM image where each pixel encodes the XY position, brightness and RGB color mix for the picture element in the image.

Plasma Display - flat panel display common to large TV displays where the pixels rely on plasma cells, tiny fluorescent lamps in the compartmentalized space between two panels of glass. These compartments hold a mixture of noble gases and a minuscule amount of mercury and when the mercury is vaporized when a voltage is applied across the cell, the gas in the cells form a plasma. With flow of electricity, some of the electrons strike mercury particles as the electrons move through the plasma, momentarily increasing the energy level of the molecule until the excess energy is shed as ultraviolet (UV) photons that strike phosphor that is painted on the inside of the cell, which raises the energy level of an outer orbit electron in the phosphor which sheds the excess energy as a photon at a lower energy level than UV light; the lower energy photons are mostly in the infrared range but about 40% are in the visible light range. Thus the input energy is shed as mostly heat (infrared) but also as visible light. Depending on the phosphors used, different colors of visible light can be achieved. Each pixel in a plasma display is made up of three cells comprising the primary colors of visible light. Varying the voltage of the signals to the cells thus allows different perceived colors.

Point-to-Point - a network topology which connects nodes one-to-one.

Polling - when status is checked periodically (synchronously) by a looping construct.

Polling Interrupt Service Routine - an ISR which must determine the source of an interrupt by reading status registers when a hardware interrupt is shared by multiple devices (note that most polling ISRs also provide ISR chaining).

Position Independent Code - code which is base address independent such that it can be mapped in at any base address and all other entry points, jumps, and memory locations are set relative to the dynamically determined base address.
POSIX - Portable Operating Systems Interface, a standard for operating system mechanisms and APIs. POSIX includes a number of sub-standards such as 1003.1b which covers basic real-time mechanisms.

Power-on Reset - a CPU state after initial power-on, which most often causes the CPU to branch to a known address and perform basic operations like resetting the memory controller, bus, and other basic interfaces.

PPM – Portable Pix Map, The **portable pixmap format** (PPM), the **portable graymap format** (PGM) and the **portable bitmap format** (PBM) are image file formats originally designed to be easily exchanged between platforms.

Preemption - when the current thread executing on a CPU is placed back on the ready queue by the scheduler and state information saved so that a different thread can be allocated the CPU.

Predictable Response – compared to **deterministic** response, predictable means that the response behavior is bounded and characterized by a statistical distribution of response times rather than having an invariant response time.

Priority - an encoding which controls the order of dispatch for threads by a scheduler when more than one is ready to use the CPU resource.

Priority Ceiling - a priority is defined that is the highest priority a thread can have that may lock a resource, this priority level is stored as the resource’s priority ceiling - a thread which has locked the resource is given priority as high as the highest priority thread blocking on the resource up to the ceiling value - i.e. the thread holding the resource always has a priority higher than or equal to all threads waiting to obtain the resource.
**Priority Inheritance** - If a thread is holding a resource and another thread of higher priority is blocking on the same resource, the thread holding the resource inherits the blocked threads priority for the duration of the *critical section*. There is no limit on the priority level that may be inherited.

**Priority Inversion (Unbounded)** - whenever a thread is unable to obtain the CPU and a thread of lower priority is holding it, this is called priority inversion. The condition is most often caused by a secondary resource needed by a thread such as a shared memory critical section - in a simple two thread case, if a lower priority thread is in a critical section, then a higher priority thread experiences priority inversion for the duration of the critical section, however, if the low priority thread suffers interference from a medium priority thread, the high priority thread could potentially be blocked for an indeterminate amount of time, an unbounded priority inversion.
Priority Preemptive Run-to-Completion - A scheduling mechanism which dispatches any thread ready to run based on priority as soon as the set of ready threads is updated (preemptive) and allows a dispatched thread to run indefinitely unless another higher priority thread is ready – this can be approximated in Linux using NPTL or kernel threads, but the Linux kernel is not fully pre-emptable itself, so in Linux this is not fully deterministic and only soft real-time systems should be built.

Priority Queue - A mechanism for implementing a first-in-first-out policy, but with N levels of priority such that all items at the highest priority level are de-queued first first-in-first-out before all items at the next lower priority level.

Process - a thread of execution with stack, register state, and PC state along with significant additional software state such as copies of all I/O descriptors including a protected memory data segment (protected from writes by other processes).

Programmed IO - a technique where software reads and writes each word to and from a device interface involving the CPU in each and every transfer.

Programmable Interval Timer (PIT) – A CPU core timer that can be loaded with a value to count down with a known decrement period so that when it reaches zero an interrupt is asserted and the counter optionally reset automatically. In some cases it may count up to 0xFFFF_FFFF.

Protocol Stack - a layered driver which includes data processing between the layers - each layer can be separated and has a distinct interface - e.g. TCP/IP.
Pure Function – a function coded so that it only uses stack (no global data at all), depends only in input parameters, and calls only other pure functions is a pure function and is also thread safe.

QAM – Quadrature Amplitude Modulation, a modulation scheme used for digital video carriers in digital cable systems; QAM conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme. These two sinusoidal waves are out of phase with each other by 90° and are called quadrature carriers.

Quality of Service - definition of service levels based upon guarantees of resource availability for each service - e.g. processor capacity can be reserved for each service in advance (say 10%) and the system guarantees that this capacity will be available within in a worst case period of time, however may not guarantee all services will meet their deadlines.

RAMDAC - Random Access Memory Digital-to-Analog Converter , a combination of three fast DACs with a small SRAM used in computer graphics display adapters to store the colour palette and to generate the analog signals (usually a voltage amplitude) to drive a colour monitor.

RAS – Reliability, Availability, Serviceability

Raster - image or bitmap is a data structure representing a generally rectangular grid of pixels, or points of color, viewable via a monitor, paper, or other display medium. Raster images are stored in image files with varying formats (e.g. PPM, the Portable Pixel Map).
Rate Monotonic - a hard real-time theory for fixed priority preemptive run-to-completion systems where priority is assigned according to service request period (higher priority for shorter period) and where feasibility of a set of services can be determined by the RM least upper bound or an iterative test such as the completion test.

Ready Queue – a FIFO queue of processes or threads that are ready to execute on the CPU in the case of a process or within a process scope in the case of a thread.

Real-Time (System) – an event driven system (sensors provide input through ADCs) for which services provide computation to produce a response (output to actuators interfaced with DACs) before a deadline relative to the request for service. A hard real-time system must never miss a deadline, but a soft or best effort system may be allowed to miss occasional deadlines.

Real-Time Clock - a hardware clock circuit which maintains an absolute date and time (e.g. Gregorian or Julian date), often employing a battery-backed clock circuit and/or a method to synchronize with an external time source such as Universal Coordinated Time.

Real-Time Correctness - a real-time service must produce functionally correct outputs and also provide the outputs prior to a relative deadline to be real-time correct.
**Re-boot** - when a system is commanded or as a part of a recovery mode re-enters the boot code entry point causing re-initialization of memory, I/O interfaces, and re-start of all services.

**Recovery** - a key feature of a high availability system, this is the mechanism by which a system which is experiencing system failures restarts those services. A system may need to start a recovery process for a number of reasons - e.g. deadlock, priority inversion, livelock, resource exhaustion. Often recovery is achieved by the hardware *watch dog* which reboots the system.

**Reentrant Function** – a reentrant function must be designed so that it can be called from multiple execution contexts (threads) and still provide correct results. A reentrant function must either allocate unique copies of global data for each execution context, provide mutex protection for global data, or avoid the use of global data completely as a *pure function*.

**Regression Test** - re-running a test to verify that features previously verified still work after bug fixes or feature addition - intended to prevent unintentional interactions between software modifications that might introduce new problems.
**Reliable Transport** - a data transport protocol on a network which includes error detection/correction, retransmission and supports diverse routing such that overall data is delivered if at all possible.

**Resource Arbiter** - a sub-system which implements a resource grant policy - e.g. a bus arbiter coordinates bus grants for bus requests from multiple masters and targets.

**Response Time** - the latency between a request for service (typically by an ISR) and the generation of a response output.

**RGB (color model)** – Red, Green, Blue intensity thought of as a cube or 3D unit vector in RGB space that is mixed to form a palette of colors (e.g. 8-bits per primary R, G, B value for a 24-bit mixed resultant color) where a color pixel is the additive combination through the illumination of three adjacent sub-pixels for each raster pixel.

**Ring Buffer** - a data structure which provides multiple serially reusable buffers - most often used to buffer incoming data from a device interface before it can be processed - likewise for output data before it can be transmitted.

**RISC** - Reduced Instruction Set Computer.

**RM** - Rate Montonic, the basic theory formulated by Liu and Layland for fixed priority multiplexing of a single CPU that is intended to provide multiple services over time.
**RMA** - Rate Monotonic Analysis, the process of analyzing the $C$, $T$, and $D$ characteristics of a set of services to be executed on a CPU and determination of priorities according to **RM policy** and **feasibility** according to a sufficient or better yet, necessary and sufficient test.

\[
U = \sum_{i=1}^{m} \left( \frac{C_i}{T_i} \right) \leq m \left( \frac{1}{2^m} - 1 \right)
\]

**RM Least Upper Bound (a.k.a. Theorem One)** – This bound derived from the critical time zone for a set of services released at a critical states that the sum of the service resource requirements must be less than $m\left(2^{1/m} - 1\right)$ where $m$ is the number of services in the set.

**RM policy** - services with shorter period are assigned higher priority.

**Round Robin** - a best effort scheme with preemptive time-slicing where the scheduler assigns threads a slice in a fair fashion where all ready threads are given a slice of CPU and put back on the end of the queue if needed.
**S-Video** - also called Y/C is an analog video transmission scheme, in which video information is encoded on two channels: *luma* (luminance, intensity) and *chroma* (color). The luminance (Y; gray-scale) signal and chrominance (C; color) information are carried on separate, synchronised signal and ground pairs; the color has to be encoded in some way such as NTSC.

**Scatter Write List** - A list of not necessarily contiguous addresses in memory that are to be written from a contiguous buffer - e.g. a host memory may have multiple blocks in memory scattered through memory space that are updated by an I/O device which contains all of the data to be updated in a single contiguous buffer.

**Scheduler** – A kernel service loop which monitors the Ready Queue and will preempt and dispatch a task in place of the currently running task according to priorities, providing a context switch. The scheduler is executed as a result of making a kernel API call from task and interrupt contexts and also executes in a polling mode when there are not other tasks to execute.

**Scheduling Point** - a necessary and sufficient test based upon the Sha, Lehoczky, and Ding theorem which determines whether all services can be scheduled within the longest period.

**SDRAM** - Synchronous Dynamic Random Access Memory.
Semaphore – an OS mechanism which can be used for synchronization of otherwise asynchronous tasks in order to coordinate resource usage such as shared memory, or to simply indicate a condition such as data is available on an interface.

Semaphore Take - a semaphore operation which allows a thread to check and see if a resource is available - if not, the OS can either block the calling thread until it is, or simply return an error code.

Semaphore Give - a semaphore operation which allows a thread to indicate that a resource is available - if another thread is blocking on this resource, then this will un-block that thread.

Sensor - a transducer device which indicates physical status of a system or the environment in which it operates with an electrical signal to encode the system/environment characteristic it is designed to measure - e.g. a thermistor, a position encoder, limit switch, stress/strain gauge, pressure transducer, ...
Service - a specific computation provided for inputs which produces required output in order to meet a system requirement. Real-time systems include periodic or sporadic services that are requested on a periodic or sporadic basis triggered by externally sensed events.

Service Release - when an external event sensed by an embedded system indicates a request for service, the thread which provides the service is released - e.g. an ISR can do a semaphore give to indicate sensor data is available for processing.

Set Associative Cache - A cache which allows main memory addresses to be loaded in N different cache lines - a set associative cache is said to be N ways, where each way is a different cache line which the same address data may be loaded - e.g. 32 way set associative cache.
**Shared Interrupt** - when an interrupt can be asserted by multiple devices, it is shared and requires the interrupt handler to poll status - i.e. the handler must read the status of every device that may have asserted the interrupt to figure out which device in fact did.

**Shared Memory** - when more than one thread on a single CPU or on multiple CPUs can access the same memory locations, this memory is shared, and shared memory must be protected by a synchronization mechanism if reads and writes are allowed. In Linux “shm” operations must be used to create shared memory between processes which protect memory, but for threads within a process, the memory owned by that process is inherently shared by all threads owned by that same process.

**Signal (Software)** - a software signal is often also called a software interrupt and in fact functions much like a hardware interrupt does but at the scheduler/thread level - when a signal is thrown by one thread to another, the throw call causes the OS to potentially dispatch the catching thread’s handler instead of the code it is currently executing after the catch kernel code is executed - so, a signal can be used to asynchronously interrupt a running thread.
**Signal Catch** - when a signal is received by a thread by the OS scheduler on behalf of the thread or process - the catch modifies the catching thread’s state such that the PC, registers, and stack are saved and when the thread is dispatched next, the scheduler dispatches the threads registered signal handler rather than where it was last preempted.

**Signal Throw** - when a thread wants to asynchronously interrupt the normal flow of execution of another thread, it can call an OS mechanism to throw a signal to the other thread instructing the OS to dispatch the other thread’s signal handler rather than it’s last context.

**SISD** - Single Instruction Single Data Flynn architecture type, e.g. single core traditional pipelined CPU.

**SIMD** – Single Instruction Multiple Data Flynn architecture type, e.g. a vector processor or vectorized instruction that applies on a string of operands rather than just one, such as 128-bit XOR on two operators on a 32-bit architecture.

**Slack Time** - on a real-time system, when no real-time services are requesting CPU time (i.e. waiting on the ready queue or actively running), this unused CPU time is called slack time and often can be used for non real-time best effort processing. Slack time is often created by service releases where the actual execution time taken is much shorter than WCET due to execution jitter.

**SoC** - System On-a-Chip, an ASIC which includes one or more CPU cores, a bus, and I/O interfaces such that it essentially places devices previously on a board in earlier products on a single ASIC.
Soft Real-Time - when a service can occasionally miss a deadline and over-run it or terminate and drop a service release without system failure, these services are considered soft - e.g. a video encoder compression and transport service might occasionally drop a frame when compression takes too long - as long as the video stream is not critical and an occasional drop-out is acceptable w.r.t. system requirements, this service can be considered a soft real-time service.

Software Profiling - periodically tracing the cycle count and the current PC or actively tracing it by instrumenting all function entry and exit points to save cycle count to a trace buffer allows for determination of where most of the execution time is spent and how many cycles basic blocks of code such as functions requires - this type of tracing provides a profile of the software. Profiles can be at a function level, basic code block level (bounded by branches) or at a C statement level - overhead is higher for lower level profiling.

Software Sanity - software is said to be sane when embedded services check in with a sanity monitor by posting a keep-alive - the sanity monitor itself is known to be sane (functioning correctly) if it resets the hardware watchdog timer.

Sporadic – an event that occurs occasionally, singly, or in scattered instances, infrequently, without a deterministic period, but not aperiodic.
SRAM - Static Random Access Memory.

SSE - Streaming SIMD Extensions is a SIMD instruction set extension to the x86 architecture, designed by Intel and introduced in 1999 in their Pentium series processors including 70 new instructions, which extended earlier MMX vector instruction set that had two main problems: it re-used existing floating point registers making the CPU unable to work on both floating point and SIMD data at the same time, and it only worked on integers.

Stack Segment - a segment of memory allocated for a thread which provides buffer space for function arguments and local variables - each application thread, the kernel thread, ISRs, and signal handlers typically all have their own stack space for the purpose of parameter passing and local variable instantiation. In Linux a process stack can be grown dynamically with the sbrk system call and is also done automatically as needed within a process.

State Machine - a formal design notation which includes a start state, state transitions driven by inputs made while in a specific state, and outputs on transitions.
**Stereo Vision** - the use of two cameras separated by a known constant distance to judge distances to objects of unknown physical dimensions through the use of triangulation.

**Superscalar** - A *CPU pipeline* feature that employs parallel hardware within a single CPU core to allow for 2 or more instructions to be fetched, executed and retired concurrently. Note that this feature of a *CPU pipeline* can yield a *CPI* less than 1.0 for the CPU core.

**Symbol Table** - an array of function and global variable names and addresses where they are stored in their text and data segments respectively.

**Synchronous** - An event or stimulus that occurs at a specific point in time relative to other events in the system rather than at any time - e.g. a thread of execution can perform a *semaphore take* to synchronize with an *ISR* - the ISR will execute asynchronously, but the processing provided by the thread performing the semaphore take will be *synchronous* since it is known that this processing will only be provided after the *semaphore take* AND the *semaphore give* performed by the *ISR*. 
**Synchronous Bus** - a bus that has clocked address, data, and control cycles.

**System Lifecycle** - the process of turning an embedded system concept into a working maintained system. The steps potentially include: concept, requirements, high-level design, detailed design, implementation of units and subsystems, unit/subsystem test, integration, system test, acceptance testing, fielding, maintenance, and unit/system regression testing.

**System Test** - end-to-end and feature tests performed after the units and subsystems in a larger system have been unit tested and are integrated for the first time.

**T (in RMA)** - the period of a service request type. In many cases this will be based upon the worst case frequency of the event(s) that cause a service to be released.

**Text Segment (Code Segment)** - a segment of memory used for storing the machine code associated with an application, kernel image, or boot image.

**TFTP** - Trivial File Transfer Protocol, a simplified FTP (File Transfer Protocol) which allows a client to download files from one known directory in a file system.
**Thread (of execution)** - a thread is simply the trace of a CPU’s PC over time. Linux includes kernel threads and NPTL (Native POSIX Threads Library). Kernel threads execute entirely in kernel space with kernel privilege, subject to interrupt only by kernel interrupt service routines. NPTL threads run in user space within a process context in Linux, but are mapped onto kernel threads – the pre-emptability of a NPTL depends upon the scheduling policy chosen – if it’s FIFO, then a such a thread acts much like a true kernel thread, but in a user space process context. In the case of round robin, it time slices the processors allocated execution time with all other threads in that same process.

**Thread Safe** – code is thread safe only if it functions as expected when executed simultaneously by multiple threads. A function that is designed to be *reentrant* or a *pure function* is thread safe.

**Throughput** - an aggregate measure of speed and efficiency for a device - e.g. for a processor the measure is MIPS (Millions of Instructions Per Second) and for an I/O device the measure would be Mbps or Gbps (Mega bits/sec or Giga bits/sec).

**Timeout** - when making a blocking call, in order to avoid “wedging”, where a thread is blocked indefinitely, it is most often advisable to specify a timeout for any blocking call at which time the thread will be asynchronously awoken and will continue execution - this can be done by setting a timer that is set up to throw a signal to a timeout handler prior to making a blocking call if the API does not directly support a timeout option.
Timer Services - an interrupt handler set up by the OS which counts jiffies in the case of Linux on each interval timer interrupt and signals any threads that have reached a timeout threshold.

Time-slice - a unit of CPU called a quantum which can be allocated to a thread in a preemptable best effort system - in these systems timer services often makes a call into the scheduler on each system tick in order to provide quantum preemption – so a quantum, and timeout resolution are typically all the same - e.g. Linux scheduling.

Top Half (TH) - the Linux routine that actually responds to an interrupt and is registered with request_irq.

Trace - a linear buffer with records that include time (cycle count) and state information for a processor core and/or application code.

Unbounded - when a condition can persist for a non-deterministic amount of time - e.g. unbounded priority inversion where the set of middle level priority interference tasks may cause the inversion to persist for an arbitrary time.

Unit Test - a test designed to validate and verify a software and/or hardware unit that is a building block for a larger system in isolation.

Utility Curve - an XY graph which shows time on the X axis between a service release and relative deadline and shows utility or damage caused to the system caused by service response generation.
Virtual Timer - a timer which is not directly supported by a hardware interval timer, but rather is a software tick counter that can generate a signal after the passing of N software ticks.

VoIP - Voice over IP, a protocol for transporting voice duplex audio over the Internet protocol.

WCET - Worst Case Execution Time, the longest number of CPU cycles required by a service release ever observed and/or theoretically possible given the hardware architecture and algorithm for data processing used.


Write-Back - when a processor updates memory from registers or cache.

Write-Through - when a processor maintains cache/memory coherency by always writing cache and the corresponding memory location on all writes to locations which are cached.

Yield – when a thread of execution gives up the CPU resource voluntarily through a system API call – e.g. pause().