Realtime and Multimedia

Time Sensitive-Linux

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* Time Sensitive-Linux Introduction
    - Traditional operating systems catered to databases and scientific
    applications which are throughput oriented
    - Modern workloads support A/V and video games, which have more strict
    latency requirements and real time guarantees
    - How do you provide guarantees for real time applications in the
    presence of background throughput-oriented applications such as
    databases?
    - How do you bound the performance loss of throughput-oriented
    applications in the presence of latency-sensitive applications?
* Sources of Latency
    - Time sensitive applications require quickly responding to an event
        + Playing a video game
    - Three sources of latency for time-sensitive events
        1. Timer latency: Inaccuracy of timing mechanism; delta between
        timer event and timer interrupt due to the granularity of the timing
        mechanism (10ms in Linux)
        2. Preemption latency: Interrupt could occur when kernel is in the
        middle of doing something and cannot be preempted (handler disabled)
        3. Scheduler latency: Already a higher priority task in the
        scheduling queue
    - Latency = Activation of event - Happening of event
        + Latency = Ta - Th
* Timers Available
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Choice of Timer	Pro	Con
Periodic	Periodicity	Event recognition latency
One-shot	Timely	Overhead
Soft	Reduced overhead	Polling overhead, latency
Firm	Combines all	

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* Firm Timer Design
    - Goal: accurate timing with low overhead
    - Combine one-shot and soft timers
    - Overshoot: Knob between hard and soft timers
        + Time between timer expiring and interrupt being triggered
        + If a syscall occurs during this period, we dispatch the expired
        timers and reprogram the one-shot timers
        + Advantage: The point at which the timer is programmed to interrupt
        will not actually cause an interrupt
    - Firm timer provides accuracy without additional overhead
* Firm Timer Implementation
    - Task: Schedulable entity (T1, T2, T3)
    - Timer-q data structure: Queue of tasks sorted by expiry time
    - APIC timer hardware
        + APIC: Advanced Programmable Interrupt Controller
        + Reprogramming a one-shot timer only takes a few cycles
        + Sets a value in a register and decrements it each cycle
        + Allows for the implementation of very fine-grained timers
    - When the APIC timer expires, the interrupt handles traverses timer-q
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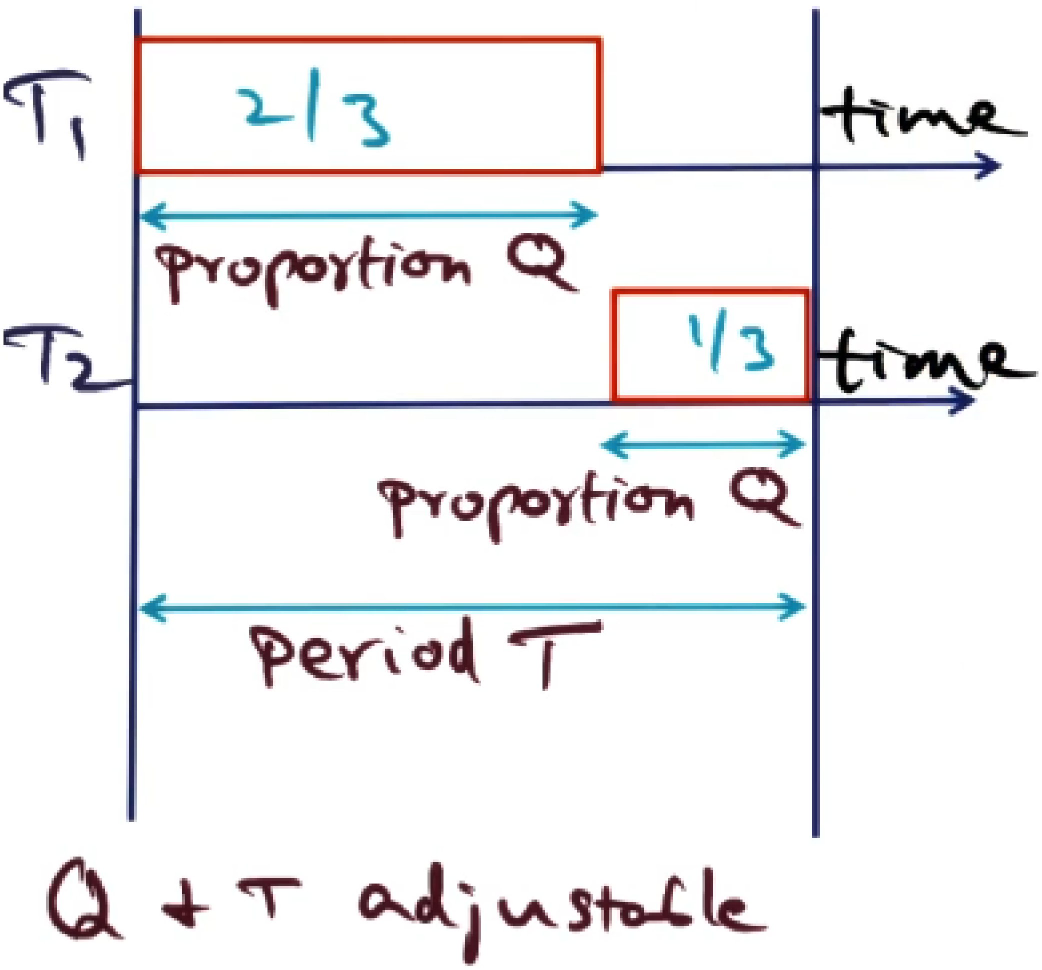
data structure and look for tasks whose timers have expired
  + Callback handler associated with each event are called
  + Tasks are removed from the timer-q
  + If the task is periodic, the handler will re-enqueue the task
- Soft timers: Eliminates need for fielding one-shot interrupts
- If there's a long time between one-shot events and many periodic events occurring in between, we can process an upcoming one-shot event at the preceding periodic event
  + Processing an event early is fine, just don't want to be late
  + Periodic events are much more efficient in the kernel (O(1))
  + One-shot events are O(logN) where N is is the number of timers
- Reduces the timer latency of event handling

* Reducing Kernel Preemption Latency
  - Approaches
    + Explicit insertion of preemption points in kernel (look for events and take action)
    + Allow preemption anytime the kernel is not manipulating shared data structures (prevents race conditions)
  - Lock-Breaking Preemptive Kernel
    + Combines the above ideas to reduce spin lock holding time
    + Replace long critical section with two shorter critical sections
    + acq() -> rel() vs acq() -> rel() -> reacq() -> rel()
    + Can preempt the kernel after the first release
* Reducing Scheduling Latency
  - Proportional period scheduler
    + Can reserve a portion of the time quantum for throughput-oriented tasks to guarantee that their requirements are still satisfied in a timely manner
  - T is a time window/quantum (exposed to an application)
    + Task requests Q, a proprtion of T
    + Both are adjustable using a feedback control mechanism
  - Scheduler attempts to satisfy multiple requests within a quantum
    + If one task needs 2/3 T and another needs 1/3 T, both can be satisfied within a single quantum
  - Priority inversion
    + High priority C1 task issues a blocking call to a low priority server
    + Until the server finishes, high priority task cannot proceed
    + While the low priority task is executing, another task C2 can become runnable which will preempt the lower priority (priority C1 > C2)
    + This results in priority inversion for C1
  - Priority-based Scheduling
    + Server assumes the priority of C1 while it is executing its task
    + Therefore, no priority inversion occurs
  - How TS-Linux deals with time-sensitive tasks
    1. Firm timer design that increases the accuracy of the timer without additional overhead
    2. Using a preemptable kernel to reduce kernel latency
    3. Using priority based scheduling to avoid priority and inversion and guaranteeing a portion of the CPU for throughput-oriented tasks



Proportional Period Scheduler

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* Time Sensitive-Linux Conclusion
    - TS-Linux is able to provide quality of service guarantees for realtime
    applications running on commodity operating systems
    - Admission control using proportional period scheduling ensures that
    throughput-oriented tasks receive adequate time to execute
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Persistent Temporal Streams

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* Persistent Temporal Streams Introduction
    - Focus on middleware between commodity operating systems and realtime,
    distributed multimedia applications
* Programming Paradigms
    - Parallel programs: Pthreads
    - Distributed programs: Sockets (NFS, RPC)
* Novel Multimedia Apps
    - Novel distributed applications tend to be sensor-based
        + Cameras, radars, microphones, temperature sensors, etc.
        + Access sensor data through the Internet
        + Want to do live stream analysis of sensor data
        + Sense -> Prioritize -> Process -> Activate actuators
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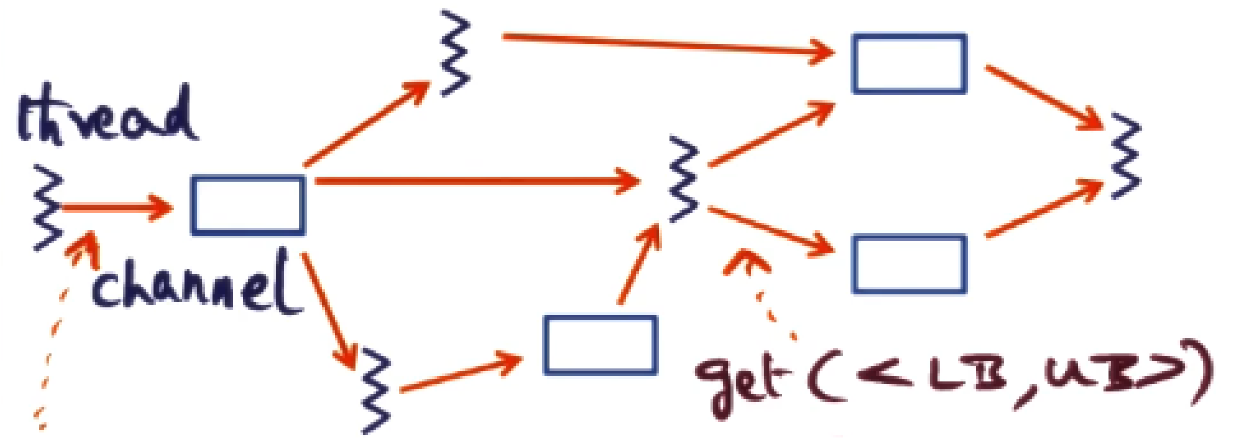
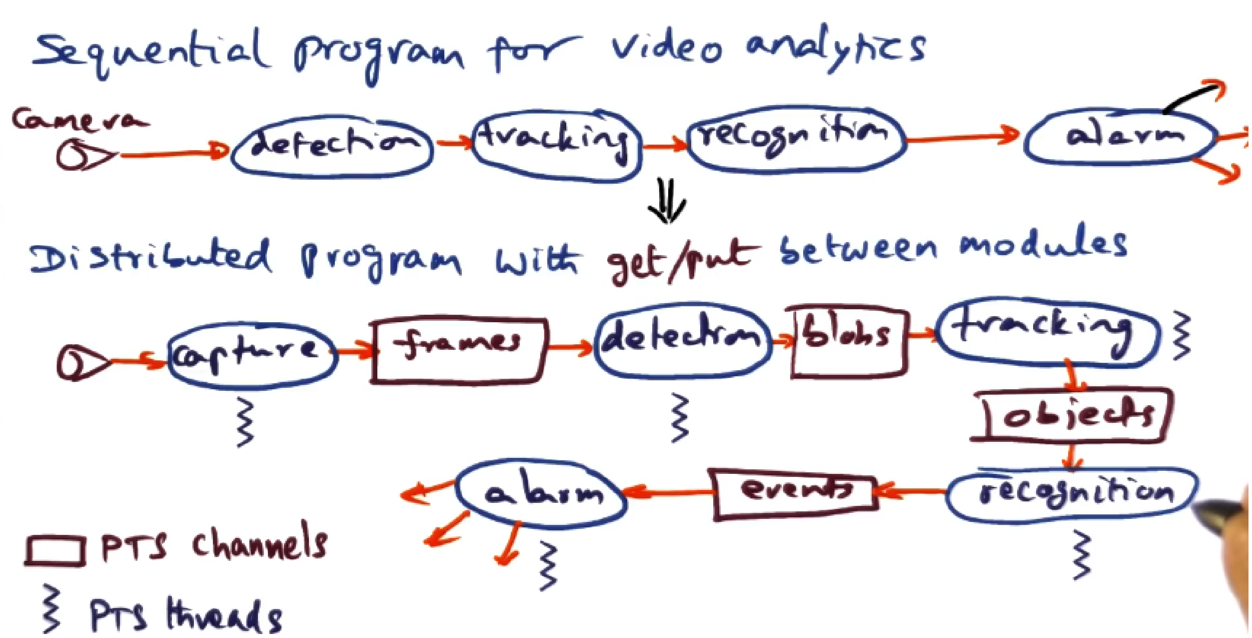
    - These computations are intensive and real-time
        + Want to reduce latency as much as possible
* Example - Large Scale Situational Awareness
    - Monitoring activities in an airport, anything anomalous causes an alert
        + London has over 400,000 cameras to monitor
    - Need to prune the data to deal with this many sensors
        + Can't rely on humans to monitor thousands of cameras
        + Avoid false positives and false negatives
        + Programming infrastructure must facilitate domain expert
    - Pain points
        1. Right level of abstraction to promote ease of use
        2. Propagate temporal causality
        3. Correlate live data with historical data to draw inferences
* Programming Model for Situational Awareness
    - Sequential program for video analysis
        + Camera -> Detection -> Tracking -> Recognition -> Alarm
    - Objective in situational aware applications: Process streams of data
    for high level inference (not watching a video)
    - How does this scale to thousands of cameras?
        + PTS is an example of a distributed programming system catering to
        the needs of situational awareness applications
* PTS Programming Model
    - Similar to Unix socket API
    - Distributed application with threads and channels
        + Channel holds time-sequenced data objects, allows many-to-many
        connections
        + Thread is generating time-sequenced data objects and inserting
        into the channel
        + Can be multiple producers inserting into a channel and multiple
        consumers receiving from a channel
        + Channel shows temporal evolution of what is being produced by a
        particular thread (one frame from a camera)
    - put(item, <timestamp>)
    - get(<lowerbound, upperbound>)
        + Can specify time in an abstract way (oldest, newest) in addition
        to explicit lower/upper bounds
    - Channel ch1 = lookup("VideoChannel");
    - while(true) {
        + response r = ch1.get(<LB, UB>);
        + // process data
        + // produce output
        + ch2.put(item, <ts>); }
    - PTS model allows for the ability to associate timestamp with data
    items produced by a computation
        + Allows for temporal causality
        + Every stream is temporally indexed, so a computation can correlate
        incoming streams and recognize which data items are temporally
        related to one another



Proportional Period Scheduler

* Bundling Streams
    - Might need data from multiple data streams simultaneously
    - Can create a "stream group" which is a bundle of different streams
        + Video, audio, text, gesture
        + One is the anchor stream, the other are dependents
    - groupget: Get corresponding time-stamped items from all the streams in the group
        + Gets temporally related items from all streams in a group at once
* Power of Simplicity
    - Interpose channels between modules to get/put data
    - Convert from sequential program to distributed using the channel abstraction and get/put primitives

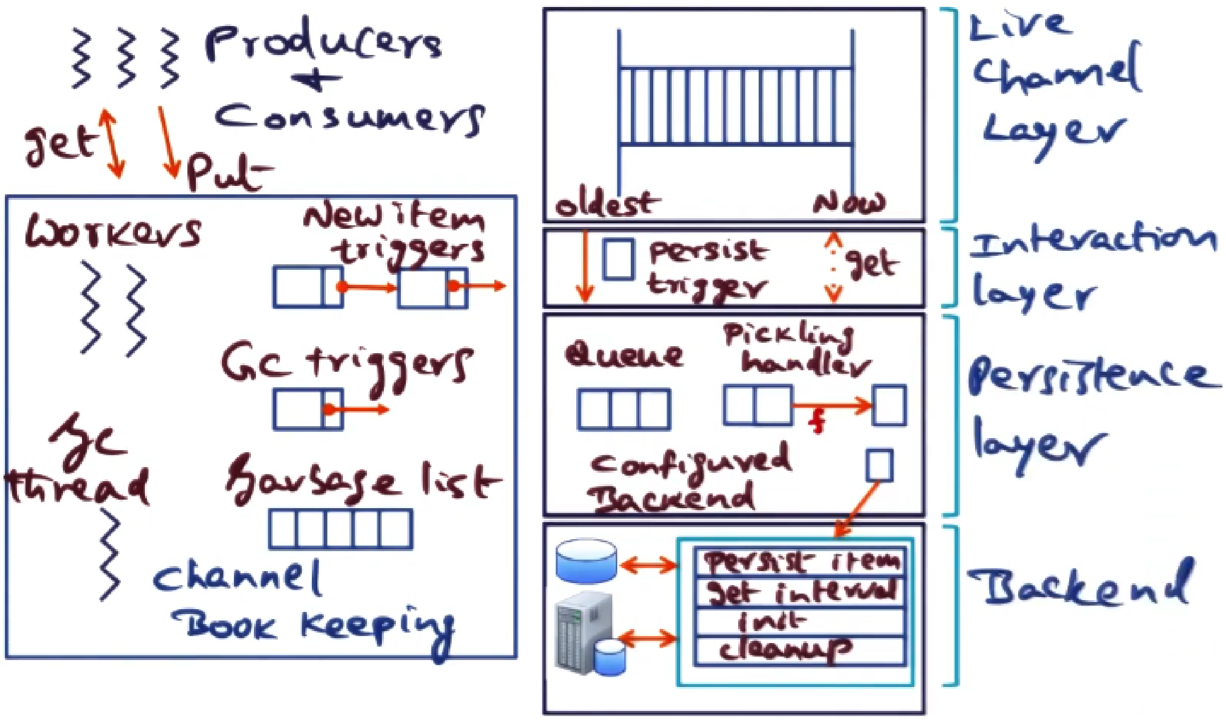


PTS Program Workflow

* PTS Design Principles

- PTS provides simple abstractions and interfaces
    + Channel and get/put
- Do the heavy lifting (systems) under the covers
- PTS channels
    + Can be anywhere (similar to Unix sockets)
    + Can be accessed from anywhere (similar to Unix sockets)
    + Network-wide unique (similar to Unix sockets)
    + Time is a first class entity: Time is manipulated by the application in the way it specifies items to the runtime system and queries the runtime system using time as the index into the channel
    + Persistet streams under application control: Data is continuously being produced, can't hold it all in memory. Stored to archival storage
    + Seamlessly handle live and historical data
- PTS is simple to use, but provides the necessary handles to make the life of a domain expert developing a situation awareness application

* Persistent Channel Architecture
    - How does PTS support this simple get/put programming model?
    - Everything is either a producer or a consumer
    - Threads
        + Workers: Produce new data
        + Garbage collection: Delete data from garbage list
    - Triggers
        + New item triggers occur every time a producer in a worker thread creates a new piece of data
        + Garbage collection triggers: Might specify channel to only keep last 30 seconds of data, throw everything else away. Move data into garbage list (no longer relevant to application)
        + Persist triggers indicate that an item has become old and should be moved from memory to archive
    - Implementation of channel is a three-layer architecture
        + Top: Live channel layer; reacts to new item triggers coming from worker threads
        + Middle: Interaction layer; Go between the live channel and persistence layer
        + Bottom: Persistence layer; receives persistence triggers and moves items from the channel according to the pickling handler. Persisted items must go to some non-volatile storage device
    - Pickling handler: Developer specifies a function to be used every time some of the items are persisted (might condense in some way)
    - Backend layer determines how to keep data in non-volatile storage
        + Application choice as to which backend layer it wants to use
        + Backend layers: MySQL, Unix filesystem, IBM GPFS



PTS Persistent Channel Architecture

* PTS Conclusion
    - Map reduce is to big data applications as PTS is to live stream analysis applications
    - Unique features
        1. Time-based distributed data structures for streams
        2. Automatic data management
        3. Transparent stream persistence