

SOFTENG370 Notes 2017

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1 Lecture 1

1.1 Generics

Operating System The software that makes the computer usable. Using modern computers without an OS is "impossible"

Examples: Windows, OSX, Linux, Unix, iOS, Android, etc...

1.2 Approaches to Understanding

Minimalist

- mostly going to be using this one
- OS contains minimum amount of software to function
- archlike

Maximalist

- All software comes with standard OS release.
- Contains many utilities and programs.
- ubuntuish

1.3 Usable vs Efficient

- make sure you make OS suited for needs
- either specialised or more general purpose
- Think of who you expect to use the system
- If creating a realtime system with potentially thousands of operations in a short amount of time, have to consider efficiency
- Same with battery life if you expect the system to be used in a mobile setting.

1.4 OS themes

Manager Model

- OS is collection of managers, ensuring proper use of devices.
- Managers are independent.
- look out for everything associated with computer
- tie in with hardware. Current state of HW lets OS do more/less things

Onion Model

- Onions have layers (Abstractions)
- resources contained in lower layers.
- Lower layers can't access higher level layers but other way around possible
- Very difficult to get these layers 'right'
- can use in terms of security. Very good idea

Resource Allocator Model

- similar to manager model
- emphasis on fairness and providing services

Dustbin Model

- contains middleware that not considered part of OS
- Sees OS as bits no-one wants to do

Getting Work Done Model

- Idea of it is we use computers to do something else.
- Goal for OS is to help be able to get it all done.

1.5 OS design

1.5.1 Themes

All in one

- All OS components freely interact with each other
- MS-DOS and Early Linux

Separate Layers (Onion Model)

- Simplify verification and debugging
- Correct design difficult to get

Modules

- All in one with modules for some features
- Linux and Windows.

Microkernels

- Client/Server model
- make OS as small as possible
- **Exokernel** puts kernel outside. OS's job only need to authenticate people to use hardware.

VMs

- Java is an example of this

1.5.2 MS-DOS

- Written to provide the most functionality in the least amount of space
- not divided into modules
- Something exokernels trying to do. Make application program access hardware directly.

1.5.3 Early Unix

- UNIX OS in 2 parts. **Kernel** and **System Programs**
- Provides:
 - File System
 - CPU scheduling
 - Memory management
 - Other OS functions

- Ken Thompson and Dennis Ritchie
- Make OS as simple as possible.
- Simple 2 letter commands.
- Ideas of pipelining and process communication

1.5.4 THE Multiprogramming System

- THE was the first to use the layered system
- Contains 6 layers:
 - 5 User programs
 - 4 Input/Output buffering
 - 3 Operator-Console device driver
 - 2 Memory Management
 - 1 CPU scheduling
 - 0 Hardware

1.5.5 WinNT and Client/Server

- WinNT still being still run
 - Win10 now has Windows Subsystem for Linux
- NT provide env subsystem to run code written for differnt OS
- NT and successors are hybrid systems. Parts are layered but some merged to improve performance.

2 Lecture 2: History of OS

- Started at mainframes.
 - Early PDAs were similar to mainframes. Had no memory protection.
- Then go to Minicomputers
- And then desktop
- And how handheld computers

Each of these stages go through cycle of:

1. No software
2. Compulers
3. Multiuser
4. Networked
5. Clustered
6. Distributed Systems
7. Multiprocessor & Fault tolerant.

2.1 Total Control

- Computers expensive in 50s. Data and programs were saved on paper tape.
- Programmers knew how the computer worked. They were very knowledgable about computers.
 - Prepared program and data cards
 - do setup
 - control computer
 - debug
- Computers did 10,000s instructions per second, but were idle a lot of the time.

2.2 Properties of old OS

- **IO polling**, since no other programs running in background, therefore just waiting on input and able to just poll.
- No file system
- No memory management or security
- OS defined by decisions made by user.
- Single program at a time

2.3 Progression: Operators & Offlining

Operators

- Goal is to reduce the time CPU was doing nothing.
- Operators now just "use" the computer. No need for programmer.
 - If something crashes, then just start the next program.
 - Batch similar jobs together, maximise usage of computer.

Offlining

- Form of parallelism in early computing.
- With Big Expensive Computer BEC, but they are just waiting for IO a lot of time. Therefore want to make IO as fast as possible.
- Use smaller computers to convert slower paper to faster magnetic tape. Then that magnetic tape is used as IO for the BEC
- This is the same for output. Have another smaller cheaper computer offload the output magnetic tape from BEC to a printer.

Resident Monitor

- Keep some code in memory.
- It did the work that some operators were doing.
 - clearing memory
 - reading start of new program that needs to be loaded.
 - Can also do some of the IO routines.

Control Programs Standardise the language to communicate with the Resident Monitor. Had tags for things such as \$JOB (for signifying jobs), \$FTN (When fortran compiler needed), and \$END (signifying end of program)

Conclusions from this

- Memory management and file system still not present. Therefore still need to reset if anything bad happens.
- Security patchy at best
- Still need IO polling
- Standard IO routines for programmers
- 2 programs in memory, but one executed
- User interface was JCL (Job Control Language)
- Output of program can be input of another.

2.4 Changes in Hardware

- **Disk drives** provide faster IO.
- Processors that you can **interrupt** also means that there is no more reliance on polling.
- IO devices and CPU concurrent execution, and use local buffer.

SPOOLING (Simultaneous Peripheral Operation On-Line) Meaning that when interrupt, contents of cards read to disk. Therefore current program interrupted.

2.5 Multiprogramming

- Putting multiple programs on at once. Need more memory to do this.
- Now also need for scheduler to manage multiple users' program needs.
 - Need to figure out how to manage stuff. Priority of jobs, how much time to allocate for these jobs, etc...
- No memory protection, so programs could overwrite other program's chunk of memory.
 - Java is an example of something that doesn't give you direct access to memory in JVM.
 - Memory Protection better done by hardware than having software impose limits.
- **Requirements** Limited address range and Operating modes.

Memory Protection Modes

1. User/Restricted Mode
 - Execution is done on behalf of the user.
 - User should not have access to privileged instructions
2. Kernel Mode (SU)
 - Execution done on behalf of the operating system
 - Full access to all instructions.

A **mode bit** can be used to signify what mode a certain program is running in. If something in user mode tries to access memory it is not allocated to, it will go to Kernel mode and throw exception before going back to User mode.

Why we need both We need both because:

If modes existed with relevant instructions, but full memory access; there will still be a lack of memory protection, but also no privilege instruction protection. You can put whatever code you want anywhere.

If memory access limited but no modes or privilege access; then the user will be able to modify amount of memory available for programs.

Memory Protection

- Process gets fixed area of memory that it can use
- If tries to access address out of that range then exception will be thrown.
- Base and Limit register set for each process and how much memory it can have.

2.6 Batch Systems

Memory protection and Processor modes allow you to safely put multiple programs in memory.

Features

- Jobs have their own protected memory
- Disks have file systems. Files linked to owners
- Automated Scheduling. Utilise hardware as much as possible, as operators are slow. Also allows fine tuning of how scheduler works.
- Computer consoles

Not much has changed from programmer's point of view.

3 Lecture 3: History Continued

3.1 Scheduling

- Aims to maximise use of computing machinery OS knows
- Need to know details about device and file processes. What how much resources to allocate.
- Also has to take into account timing and output size.

SOMETHING ABOUT UNIVERSITY OF AUCKLAND SYSTEM

3.2 Power to the people

- Due to hardware becoming cheaper, can have general public own personal computers
- Used to use teletypewriters, but used CRT TVs after a certain point. Editing text was difficult.
- At early 1970s, can code in similar style then you do now.

3.3 Time Sharing System

- People don't like waiting.
 - 200ms+ noticable
 - 5000ms+ unacceptable
- Difficult for scheduler to figure out how to allocate resources. People use different computer differently with differing IO demands.
- Users expect command to run as soon as you press Enter.
- Don't want to have everything run at 100%, otherwise it feels too slow.
- Security an issue for all of these people writing on terminal. Have to increase this and have authentication.

Remnants of Batch Programming

- Has way to run process at given time
- Terminal looked like cards until better graphics came

3.4 1980s computers

- Cycle starts again, started with Resident Monitor Systems.
- Simple single layer file systems
- No security, everything stored on disks. Didn't bother as it was aimed at individual users.
- Did spooling later, for printer output.
- Putting more than one program in memory, using similar system to resident monitor.
- Higher definition screens, pixel addressing for graphics.
- Cycle continues, things like time-sharing features and implementation of UNIX.

Xerox created GUI elements for Office use. Then Apple engineers used ideas to create their Mac.

Features

1. Virtual memory
2. Multiprogramming
3. Complex file system
4. Networking
5. Multi-user

3.5 1980s Networking

Security, Transparency and Protocols/Standardisation create new problems.

Network OS: File sharing, communication scheme, running independent to other machines on network.

Distributed OS: Sharing processing power and resources of lots of computers to make it look like only single system.

3.6 Multiprocessor Systems

Heat is an issue, kind of a soft cap on processor frequency. Therefore can add more cores instead of trying to make each core faster.

Tightly Coupled System Processors sharing memory and clock. Communication through this shared memory. Most computers are now this.

Parallel Systems Mean increased throughput and cheaper way to increase performance. With increased reliability and rate of degradation.

Symmetric Multiprocessing: All core running same OS, most modern systems run this way

Asymmetric Multiprocess Different cores allocated to different jobs/section. Used in very large systems.

3.7 Realtime System

Timing constraints very important.

Hard real-time

- must run within time, or failure happens
- Has to be specifically designed to be hard realtime
- Nuclear plants, air traffic control

Soft real-time

- Doesn't matter too much, more lax.
- Most OS handle soft realtime
- Phone system, multimedia

3.8 Pocket Computer & Smartphones

- Started as PDA/Pocket computers.
- Went through cycle again. Started as resident monitors.
 - Due to hardware limitations, so have to start at the basic level again.
- Battery life and power consumption very important factors.

PalmOS Operating system that PalmPDAs ran on.

Small memory with slow processor.

Efficiency very important factor, to just get passable performance.

Android Popular operating system for current smartphones.

Linux based, application programming in Java.

Google trying to build their own kernel to replace Linux (Fuchsia)

iOS Operating systems that mobile Apple products run on.
Based on OSX (Their desktop OS)
virtual memory and paging for code but not data as writing to flash degrades it.

4 Assignment Notes

- Use standard UNIX symbols to control the threads
- `setupstacktransfer()`
 - **siguser1** represents the user's signal. Let you send stuff to yourself similar to interrupt, but done in software and not hardware
 - **sigaction** is a struct that holds information. Kind of like an object is global due to process having to be able to get to it at any time
 - Has a separate, special stack for that signal handler to use.
 - **man pages** are really important for this assignment.
 - If want to get all man pages relevant to signal then use *man -ksignal*
- Threads need their own stack
 - Running independently of each other and calling their own functions so to guarantee proper functioning it is best for them to have their own stack
- **&setupaction** address of instructions for the signal handler
- **thread1()** contains code that will be executed in the thread
- `threadfuncts` is array of names of functions that should be called for all threads If add more then you need to add to the array
- In task 2; 3 threads but 2 of them running the same logic from `thread2()`
- Information about thread structure found in `littleThread.h`
- static variables aren't allocated on the stack. And preserve value throughout multiple function calls
- MISSED UP TO LIKE 35min in
- **sigaltstack** lets you use that special alternate stack for different threads
 - have `malloc` some memory and will use it
 - When you call `associateStack()` when making new process you make a new alternate stack
- **kill(getpid(), SIGUSR1);**
 - KILL is system call to get signals. Set it up but haven't associated it with anything it yet
 - KILL sending pid of process you want to send it to. Send signal to yourself (try to kill yourself).
- make local copy of thread in function and set it to READY.
- C doesn't have exception handling. Therefore if error happens in a stack then need the ability to jump to part of memory to give error.
 - **setjmp**: Take snapshot of where you are. Registers of processor (PC will contain this). Can also be used to "freeze" state of a given thread if need to be suspended.
 - **longjmp**: Jump back to state where `setjmp` called. Can be used to "unfreeze" an already suspended thread to resume it. [Line34 in OSA.c]
 - Copy stack information/register information and when jump back then recopy it back to "jump back to where you were"
 - variable states preserved if stored on the stack
 - if `setjmp` return 0 then returned directly, or nonzero if from `longjmp`. Will be used later for forking to create new processes, to check if from parent or child
- **Switches** Pass it your current thread and the thread you want to go to.
- Only one thread running at a time, other ones will be READY due to only using a single processor.
- can get this assignment to work without understanding it

5 Lecture 4: Virtual Machines

./ used to signify that it isn't an internal command

MISSED TO VIRTUALISATION

Virtualisation if running on hardware then want to be as close to 90% performance as possible. Preferably 95-98 but not always possible

Design of IBM vm make each user feel like they have own cpu minidisk = lets user feel like they have access to whole drive problem is you don't want actual kernel mode to be accessible to all guests solution is each user has their own virtual kernel mode, but this kernel mode actually runs on the user level. Privileged instructions actually needed to be passed down as not all things kernel does need that mode

Hypervisor Types Allocating resources to VM - like actual CPU cores - or chunks of memory allocated for it Can have "nested" vms

Type 1 Special purpose OS have support for bunch of tools to make using it easier

Type 2 Ones that you install yourself. (virtualbox, parallels) Run applications on host

Problems trap and emulate couldn't be run on x86 up to a point.

Hardware virtualisation x86 Most OS only use level 0 (kernel mode) and level 3 (user mode) Problem with VM in real machine, then you need to keep track about process and registers. Have to keep track of this for all processes. Hardware system lets you change processor for one VM to another

each VM page tables for their own processors used to have nested page table system. VMs create their own virtual page tables and some will exist in real memory

Solutions Binary translation Look at instructions before execution, problem instructions get translated to be safer to be run in kernel mode

These translations are similar Only translated code is run

OS level virtualisation If lots of machines running same OS, then can use containers that make it seem like they are all separate. Useful for servers Simpler than VMs as they are sharing same copy of OS

More Styles paravirtualisation - XEN modify source code of OS you want to run increase efficiency to allow calls to be made straight to VMM instead of process

Application Virtualisation WINE Want to run something made for an OS on another OS Makes the application think like its running on intended OS

Windows Subsystem for Linux Not really virtual machines If app makes linux kernel call, kernel figures it out and sends it to subsystem Tied into kernel level, applicaiton doesn't really know about it. It just functions as normal and kernel does all of the work.

C and OS implementations

Week 2 friday MISSED 10 MINUTES OF LECTURE

Direct access to memory: address.c Whenever you run the program, the stack address space is different This is for security ASLR address space layout randomisation. Stack, heap and libraries put in different addresses. Helps add level of security

Accessing Registers Can choose to store something in a register Use keyword 'register' prefacing variable type on initialise Can't get address of register, so if set to register OS may put it out of register into memory if you try get address of variable

Volatile Another keyword prefacing variable type Don't do any clever tricks When you don't know if variable value will have changed due to non-local reason due to things like interrupt.

Whenever you use this variable, you have to go back to memory and check its value again as it may have changed.

Memory Management No memory management Static memory allocated at runtime, no malloc. But hard to get rid of them

Dynamic memory Garbage collection doesn't inherently exist. As it is unpredictable

Allocating stack space can be done by calling 'free' Free knows how much memory to free up since malloc uses a little bit more space just above for length of bit of stuff stored

Inline assembly Example code is 32bit OS dependant Can put assembly language directly in C code

Running commands from C program system() lets you put string of command you want to use

Alternatives (languages for OS) C++ similar to C but with object stuff too Windows has C kernel with some C++ and C# Objective C MacOS written with ObjC, but trying to move to Swift Java Can't exclusively use java, need stuff with other stuff as well Assembly old school if you need even more fine tuning

More assignment stuff Part 1 create a lot of threads, link them together (linked list) circular linked list (doubly) keep going around cycle of threads until all finished executing. Only 2 threads given, but should be able to do with n threads Part 2 Add thread.yield() This will call transition system like in part 1. Stop current thread (not finished) and pausing itself to allow another thread to run. Part 3 Interrupt the thread with external source use set.itimer, send signal to processor to signify event happening. (timer has run out, every 20ms) Tells current thread to pause externally and start next thread.

Processes Instance of program execution Thing OS uses as construct to control work

Two parts Resources/Task/Job files open and using windows on screen restrictions on process Code that's running what process is actually doing these days have threads for multiple streams of instructions

Thread sequence of instructions executing without interruption this does happen, but not from thread's point of view. Thread can't tell if it has been paused or not Can run multiple threads but share resources

Typical uses split work accross processors/cores thread for user response, another for some computation task GUI threads and process threads Server applications, have threads for clients. Server preallocates set of threads for handling requests

Thread implementations user level OS sees one thread per process

advantages work if os doesn't support threads easier to make, no system calls application specific control switching is easier (some have register files for threads)

System level operating system knows about it controlled by system calls System knows about state of thread as well. Therefore will schedule based on their state

advantages Threads treated separately If multiprocessor, then can schedule different threads on different processors thread blocking in kernel doesn't stop all thread on same process for example if doing read on file, usually code will wait for result and therefore block can allocate cpu to do something in the meantime in this case

Jacketing Check "will I block" before doing something that may block check to see if data already exist in memory. If already there can just get it without having to block. if have to get it, then let processor do something else while it tries to get data

Best of Both worlds Solaris had both system and user level threads before ver9 Uses one to one mapping of user level to kernel level threads. Mapping of single lightweight process to kernel threads. lightweight processes If something on user level thread makes blocking call, other threads on that lightweight process gets to do its thing system makes its own kernel thread and new lightweight process to allow this to happen Windows 7 threads Since Win7 then have user mode scheduling. This also tries to get the best of both world Linux threads Used to not have threads, everything put on one thread Clone call makes a new process. Shares memory, open files and signal handlers Saw them as processes and not threads, so scheduled them Can't signal whole thread, therefore since cloned you aren't sending it to all of them and only the one you specify Killing threads dangerous, due to them sharing memory, then if killed then blocking may cause memory to be in inconsistent state as lock has not been released yet In POSIX, don't actually kill threads. You tell it to cancel itself instead, telling it to die at some point Threads are written in such a way that before it makes a blocking system call, it does some tidying so cancellations can happen Cloned threads can't block if other clone made blocking system call

Week 3 Wednesday More on threads and processes Part 3 assignment numthreads constant will be correct can initialise arrays with that size if you want

Lecture 6 Process Control Blocks Things os should know about process BIG LIST GOES HERE process state turns out to be thread state priority used by scheduler owner - security considerations process generally on one processor (306 core moving cost) process group - processors working together memory and resource considerations see if process result can be piped to another process, or that it is waiting for result of this process

UNIX process parts can be scattered as parts somewhere else process structure some of

information of process held here

user structure not instant access to this in user space some of information of process held here

In UNIX, text = code

WIndows NT split it up into lots of things in ANOTHER BIG LIST TO COPY YAY
MISSED SLIDE 3 TO END OF LECTURE EMPHASIS ON FORKS

6 Lecture 7

6.1 Runnable

- On one core, only one thread/process at the same time. (Exception SMT)
- Other processes/threads may be ready to run, or already running

6.2 Multitasking

Pre-emptive Multitasking

- OS uses some kind of criteria to determine how large of a time slice that task
- The more you call yield and switch processes, the more time is wasted and less actual work is done by CPU

Cognitive multitasking Threads know that may have thread.yield() called on it and therefore are coded in a way such that when yield() is called, issues are less likely to occur

Advantages

- – Control
- – Predictability

Disadvantages

- Critical Sessions
- Efficiency

Co-operative Multitasking

- Two main ways to approach
 1. Process yields right to run
 2. System stop process when system call made
- Doesn't mean task won't run and complete in one go.
- Old UNIX (before 2.6) didn't allow pre-emptive calls when making system calls
 - pre-emptive multitasking always at user level
 - hasn't always been preemptive at system level
 - Actually used to be cooperative in the past
 - Unix was written simpler in the past, expected it to be simple with blocking calls made.

6.3 Context Switch

- Change from one process running to another on same processor, or to handle an interrupt
- Has to save the process state before this can occur
- Context changes as process executes
- Context contains:
 1. Registers
 2. Memory (dynamic elements like call stack)
 3. Files & Resources
 4. Caches

6.4 Returning to Running

State Transition

- Store process properties so it can begin again where it left off
- Page table to be updated if changing processes
- Environment must be restored
- If changing threads on same process then may can just restore registers
- If system has multiple register sets then could thread change with 1 instruction

6.5 OTHER STATES

6.5.1 Waiting

Waiting To stop unnecessary resource consumption Status changed from running to waiting
Suspended Different form of waiting

Java Always had Threads from the start Threads have generally been user level Although Thread.suspend existed that froze thread on system level Thread.resume() to restore it Issue was some resources are tied to one process, and therefore gets a lock Therefore if frozen then other threads can't access it Threads.stop() kill thread and force it to release locks that it may have But may cause data to be left in inconsistent state

Waiting in UNIX WCHAN can contain numbers, represents address in kernel Uses a queue to create a queue for processing Queue associated with hash value or kernel address
HERE GOES SOME PROCESS OF HOW IT ALL WORKS

Finishing Resources used by process need to be accounted for Shared resources usage lowers due to process finishing Make sure tidying up is done, if not done already Don't rely on this, should do this yourself

"When you log out, you want all your processes to finish too" Create a cascading effect, one process shutting down causes other ones associated with it to shut down too

Reasons to Stop Normal Stop must call exit routine does all required tidyup

Forced Stop Only want some processes to be able to kill specific processes. Parents can kill children Children can "generally" kill parents since same owner

UNIX stopping Has 'zombie states' Process that is finished, until parent checks exit status This is a return state/value of a process Used so next process/processes can find out how child finishes and continue execution based on this result If parent is around and child finishes, child becomes a zombie

If parent never calls wait if parent finishes then zombie is freed

Another FSM

Info from Linux Process Table NI = nice value can be positive a negative used to change priorities the lower the number, the higher the priority negative numbers are super priority Only SU can change nice values Normal users can only change nice values to positive values RSS = resident set size memory allocated to it TT = teletype TIME = how long process has been running for CMD = actual command that was executed

7 Lecture 8

7.1 Scheduling Processes/Threads

- **CPU burst time:** time takes for thread running to have to wait for some reason
- Basically, the majority of threads stop after processing for not very long time
- Therefore if we stop them frequently it doesn't make too much of a difference as they are probably waiting anyway

7.2 Levels of Scheduling

Batch Systems

1. Very long term scheduler

- outside OS, more admin level
 - STUFF
2. Long term scheduler
 - Have multiple queues
 - STUFF
 3. medium term scheduler
 - Still programmer dependent how its done
 - STUFF
 4. short term scheduler
 - Will mainly look at this one
 5. Dispatcher
 - Does the switching from thread/process to another

7.3 Scheduling Algorithms

7.3.1 FCFS - First Come First Served

- No wasting time by determining how to allocate
- Use average waiting time and the CPU burst times for processes
- Produces Gantt chart looking thing
- Weight times are when the processes start

7.3.2 Round Robin

- Pre-emptive version of FCFS
 - Still don't let them run to completion
 - Use of pre-empting them and time slices
- Hard to determine what size time slices to allocate
- Some processes are CPU intensive and require longer time slice
 - But if let these processes do its thing, user may feel slowdown.
 - Interactive processes affected by this
- If short time slice then good in terms of interaction as its jumps around to lots of processes.
 - However, CPU intensive tasks take longer to complete
- Still doesn't have concept of priority
- If task takes shorter time than time slice, instantly schedule another task as to not waste CPU cycles.
- Average wait time reduced due to forced time slices
- Making time slices smaller reduces the average wait time

7.3.3 Minimising Average Wait Time

- Need to know how long CPU bursts are

Shortest Job First

- Gets minimum average waiting time
- But don't always know all CPU burst times
- Therefore use an estimation algorithm. Basing it off previous CPU bursts to estimate how long subsequent bursts will approximately be.

Pre-emptive SJF

- Uses arrival time and burst time

- Short it not because of CLK interrupt, but because another processor came in with a shorter CPU burst time.
- Use remaining CPU burst time remaining if trying to determine if you are going to stop and schedule another process
 - If a process has CPUburst = 7
 - Something with CPUburst=4 comes at time=2
 - Compare 5 (7-2) with incoming CPUburst=4
 - Therefore will stop original processor and run new one since $5 > 4q$
- If has 2 options with same weight, then up to programmer to choose. Theoretically similar, but in reality will have some weighting choosing one over the other

7.4 Handling Priorities

Explicit Priorities

- If have very low priority, then there is chance that some priorities will never actually run **Starvation**
-

Variable Priorities

- Processes get higher priorities the longer they've existed (aging)
- Solves the starvation problem

Multiple Queues Multiple queues exist for things that require different time slices and CPU cycles Kind of a hierarchy of these processors Still assumes single processor

UNIX processor Scheduling Every process has priority associated with it Larger number = worse Can nice a process, adds priority for process (nicer to everybody else) Aging exists, priorities get worse the longer they run Worst level exists, so this doesn't continue forever For every process at worst level, are scheduled in round robin The longer a process spends waiting, the lower its priority level becomes and therefore higher chance of being executed

Old Linux Process Scheduling **WILL NEED TO GO OVER AGAIN**

Realtime Scheduling FIFO processes, highest priority, go in and finish executing Nothin preempt FIFO process

New Linux **Processing**