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What is a soft link how is it different from a hard link? Assume you have a file /home-/lucas/Documents/importantStuff.txt and you create both a hardlink and a softlink to it. What happens when I write, change the name or delete the orginial file?

A soft link is a file containing a reference (usually a path) to the hard link for a file. In this case the soft link would be /home/lucas/Documents/importantStuff.txt.

A hard link is a file containing a reference to the memory address of the file itself.

If you write to the original file, both links will still work. The hard link will change its contents if the file is reallocated to a different place when it is written back to memory ie because the space it was previously in is not large enough.

If you change the name of the file then the soft link will no longer work – the soft link references the path of the file which includes the name. If the file name is changed then the soft link is "hanging" and references nothing. The hard link will still work – hard links relate names to files – the file has not changed in any way. If the name changes *this* specific hard link then the name which the hard link relates to the file will change.

To delete a file, check whether the user who called this function has sufficient permissions to delete the file in the directory. If they do then delete the hard link through which the file is being referenced and decrement the reference count in the inode. If this is zero then mark free the idode and deallocate the memory storing the file. The soft link is not changed and will be left "hanging" once the file is deleted.

1 2012 Paper 2 Question 4

https://www.cl.cam.ac.uk/teaching/exams/pastpapers/y2012p2q4.pdf

Consider the following scheme for structuring a file from a set of disk blocks. A disk block contains 4096 bytes and a block address is 32 bits. The first block of the file contains the following information:

control information:	1024 bytes
direct block pointers:	1024 bytes
indirect block pointer:	4 bytes
double indirect block pointer:	4 bytes
immediate data:	2040 bytes

The data bytes of the file start at the beginning of the immediate data. After the immediate data, the file data is found on the block addressed by the first direct block pointer and then carries on in a fashion similar to the structure defined by a Unix inode. We consider the first byte of the file to be byte 0, then byte 1, etc.

(a) For each of the following describe the actions taken to fetch the indicated byte of a file, and state how many disk blocks may need to be read:

(i) byte 70 of the file

Byte 7 is in the control information. This is data – not a pointer. So we read this immediately. Only one disk block needs to be read.

(ii) byte $2^{20} + 2044$

This is the 2044^{th} byte in the $2^8 = 256^{\text{th}}$ disk block. This is the last direct block pointer. So we read the pointer held here. Then access the disk block on which it points to and read the byte it points to. This requires reading two disk blocks.

(b) How large can a file be if it is to be guaranteed that only three disk blocks need to be read in order to access any given byte of the file?

If we must do ≤ 3 disk reads then we can use immediate data, direct block pointers and indirect block pointers. Each pointer is 4 bytes. So although we have 1028 bytes of pointers, this is only 257 pointers. So we can access 257 disk blocks in less than three disk block reads. Each disk block has 4Kb of memory plus the $\approx$ 2Kb of data stored on the first block – we can read a total of 1030Kb of memory of with ≤ 3 disk reads.

(c) Information about a file can be stored in a directory that references the file or in the control part of the first block of the file (i.e. inode in Unix). Which of these is used in the Unix file system to store the following information and why?

(i) time of creation

The time of creation is stored in the control part of the first block of the file. This is because each file has a single time of creation which should be universally shared across all links to that file. We do not wish to have different times of creation associated with different directories which is what would happen if we had the time of creation associated with a directory.

(ii) file name

The file name is stored in the directory which accesses the file. This is because each directory has a different hard link to the file. Each hard link relates a name to the file these names do not have to be the same name. So the file can have as many names as it has hard links. If the file name was associated with the control part then the computer would be restricted to having one name per file.

(iii) file access right

File access rights are stored in the directory. The file can have multiple hard links from different user spaces. These users may have different access rights to the same file. To allow this we have to make access rights stored in the directory. If access rights were associated with the control part then we would only be allowed one single access right per file. So we would not be able to enable for example /students/john/examresults.csv to be read-only while making /teachers/mrsmith/examresults.csv read-write.

(d) Another way to structure files on a disk is to use physically contiguous blocks (with contiguous addresses), so that if the first block of a file is block b, then the next block of the file is $b + 1$. Suppose we use this method, retain the control information on the first block, but include the first 3 KBytes of the file in the first block. Comment on the performance of such a system, considering reading, writing, and creating files.

The bottleneck with reading and writing to HDD's is seek. HDD's are sequential access devices. Due to spatial locality most of the data which we access will the same few files. If these files are located on disk blocks far apart, then seeking the disk block will take a very high amount of time. By ensuring that disk blocks are adjacent we greatly reduce the seek time. This makes reading significantly more efficient. Writing to this structure will usually be easy – however if the memory required to write the new memory exceeds that of the disk blocks already allocated then we will have to allocate the process a new disk block. However, if the next disk block is not available then we would have to copy every block over to a new space to find enough continuous memory.

Creating files is extremely problematic. We have to find large contiguous blocks of memory – the same problem as segmentation. Note that this scheme for memory allocation suffers from *both* internal and external fragmentation.

Note that many processes are comparatively small. By allocating 3Kb of data in the first block we attempt to make many small processes cover only one disk block. This means that we can read the whole process into memory in only one read.

2 2010 Paper 2 Question 4

https://www.cl.cam.ac.uk/teaching/exams/pastpapers/y2010p2q4.pdf

(a) The virtual address space of a UNIX V7 process contains a text segment, a data segment and a stack segment.

(i) What is contained in the text segment? How does this change as the process executes?

The text semgent contains the programs machine instructions. This is static (read-only) and so does not change during process execution.

(ii) What is contained in the data segment? How does this change as the process executes?

The data segment contains global variables and static local variables – all variables which can be created and assigmed values at compile time. These variables can be read from and written to at runtime. However, the size of each variable is constant and so the data segment does not grow or shrink in size although the values it contains may change as the process executes. The data segment is read-write.

(iii) What is contained in the stack segment? How does this change as the process executes?

The stack segment (commonly known as "the stack") contains local variables, parameters and information about function calls such as which function called which and which function return values should go to. This grows and shrinks dynamically as the process executes since we call new functions which have new local variables and need other data. The stack segment is read-write.

(b) The UNIX kernel is also present in the virtual address space of every process. Describe how the operating system can ensure that this memory region is protected from access by an executing process. Under what circumstances can a process gain access to this region of virtual memory?

The process should have execute priviliges for the kernel instructions which it is allowed to call and the rest should be kernel execute mode only. This means that if the process calls the kernel then they can use all the kernel functions and memory – however it cannot otherwise.

A process should gain access to this region of virtual memory only if it calls a kernel function which it is priviliged enough to call – this yields control to the kernel. And the kernel should have access to this region of virtual memory.

(c) Compare and contrast blocking, non-blocking and asynchronous I/O.

Blocking IO stops all execution until the IO has been completed. This is very simple to program and easy-to-use. However, it wastes CPU time and is unsuitable for many applications – ie real-time applications.

Nonblocking IO polls the device and on every poll the device will return everything which has been input: which can be nothing. This is relatively fast and simple, however when waiting for multiple IO this can waste time since the CPU has to poll many devices.

Asynchronous IO allows processes to run while the IO takes place. When the IO has completed, the device sends a signal to the CPU. The CPU then addresses the IO. This is very efficient since the CPU is never waiting for long IO; suitable for many circumstances; but complicated to implement and use.

(d) You are asked to write a device driver for a hard-disk drive.

(i) Under what circumstances will you issue requests to the drive?

We will issue requests to the drive when we wish to read data from the drive into memory, when we wish to write changes back to the drive and when we wish to write a new file to it.

(ii) What steps will you need to take when an interrupt occurs?

The device raising the interrupt writes the data which is needed to handle the interrupt into memory (this is not necessary – however if the device does not do this then the CPU has to first do this and is idle while waiting for the interrupt to be written to memory). Then raises an interrupt. After the CPU has finished its current instruction, it polls the interrupt input signal to see whether there is an interrupt. Since there is, the CPU will need to flush the pipeline and load it's current state and the state of the processes it is currently executing into PCB's in memory (register contents and point of execution etc). It will then load the appropriate ISR in. The ISR will then be executed and on completion the CPU will load the previous process back and resume execution where it was interrupted.

(iii) Given that the hard-disk drive is not really a random access device, what steps could you take to improve performance?

When there are multiple free disk blocks, we could write to the disk block which is nearest to the process's other disk blocks. This would greatly decrease the seek time and speed up the overall speed of the file system. Although this would require a large one-off cost of parsing through the hard drive to find free disk blocks which are close to the processes other disk blocks.

3 2009 Paper 2 Question 4

https://www.cl.cam.ac.uk/teaching/exams/pastpapers/y2009p2q4.pdf

(a) In the context of virtual memory management:

(i) What is demand paging? How is it implemented?

Demand paging is a page allocation scheme wherein when pages are moved into and out of memory is decided at runtime when page faults occur (when pages which are not in memory are requested).

When page faults occur, a page allocation algorithm will run to decide which page to move out of memory based on criteria such as "when it was last acccessed", "how many times has it been accessed recently" and "has it been written to"? This will then page out the best choice freeing a page frame to load in the page which has been requested.

(ii) What is meant by temporal locality of reference?

A recently referenced page is more likely to be referenced in the near-future than an arbitrary page. This is because processes are likely to use variables and call functions multiple times and so access the same page many times.

(iii) How does the assumption of temporal locality of reference influence page replacement decisions? Illustrate your answer by briefly describing an appropriate page replacement algorithm or algorithms.

Since we know that we are more likely to use a page which we have used recently, when replacing pages we try not to replace pages which have been recently used.

An example of this is Not Recently Used (NRU):

In NRU we have two additional bits per page frame: a "referenced" bit and a "dirty" bit. If we reference a page then we will set the referenced bit to 1. If we write to a page then we set the dirty bit to one. We will intermittently scan through memory and remove pages – due to the assumption of temporal locality of reference, we prefer to remove pages which have not been referenced since they are less likely to be used again in the near future. Our secondary preference in this scheme of paging is for pages which have not been written to (since pages which have been written to have to be written back to memory – which takes longer).

In Second-Chance FIFO, we have a pointer (known as the clock) and arrange the page frames in a circular linked list. Each page frame has one additionl "reference bit". When searching for the page to page out, we search through the list. We will page out the first page with a reference bit of 0. After passing a page with a reference bit of 1, we should set its reference bit to 0 and proceed to the next page (giving it a "second chance"). Note that under this scheme we only give a second chance to pages which have been referenced recently since we know they have a higher chance of being referenced again shortly due to temporal locality of reference.

(iv) What is meant by spatial locality of reference?

If an address A is accessed, then addresses near A have a higher liklihood of being accessed in the near-future.

(v) In what ways does the assumption of spatial locality of reference influence the design of the virtual memory system?

We should try to store virtual addresses which are close to each other in physical addresses which are close to each other on disk. HDD's are sequential access devices, so it is faster to acccess pages which are near to each other. This means we can use the assumption of spatial locality of reference to reduce seek times in HDD's.

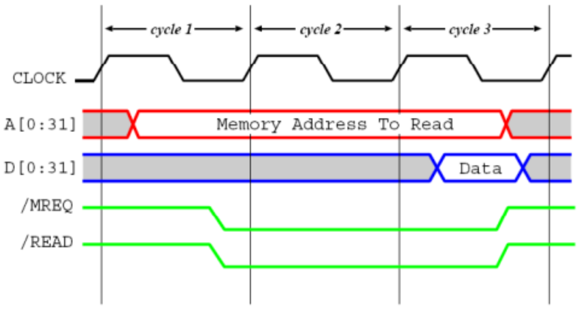
(b) Buses are used to connect devices to the processor.

(i) Describe with the aid of a diagram the operation of a synchronous bus.

A bus allows two a component to communicate with the CPU. There is a master-slave configuration between the CPU and the device being called. At the start the CPU loads onto the bus the data which is required to perform the operation it wants and asserts the necessary control signals (in the case of reading from memory – read/write).

The device is listening for signals down the bus. When data comes, it then waits one clock cycle for the control signals requried to know *what* to do with the data given. The device then processes the data (most commonly reading from or writing to memory) and returns the return value down another bus. The CPU then copies this into a register (buffer) and we are done.

Note thay synchronous buses are easy to implement – however the bus clock (which is distinct from the CPU clock) must run at the speed of the slowest device on the bus which can limit performance.



(ii) In what ways does an asynchronous bus differ?

Asynchronous buses do not have a master-slave configuration. Rather they use handshaking – wherein the CPU sends a ready-signal, the device responds with a data-accept signal. This triggers the ready-signal to go low which in turn triggers to data-accept signal to go low. Data is then sent by the CPU to the device. The process is then reversed for sending the devices response to the CPU.

There is no bus clock so each device can send data as fast as they want – this means that buffering is needed since one device may be faster than the other. Synchronous buses have a clock and do not require buffering.