CS 134: Operating Systems
Disk Deja-vu
Overview

Working Sets
   Allocation Policies
   Thrashing

Secondary Storage
   Allocation Methods
How do you know if you have enough frames to work with...?
Working Sets

With fewer pages, page fault rate rises.  

- If a process “almost always” page faults, it needs more frames  
- If a process “almost never” page faults, it has spare frames
How can we keep track of the working set of a process?

Formal definition is “pages referenced in last $k$ accesses.” Close approximation is “pages referenced in last $n$ ms.” Note that this is pretty close to what the CLOCK algorithm does, except that other processes can interfere. Which leads to...
Local vs. Global

Whose pages do we take?
So far, we’ve examined paging without thinking about processes—but what about processes?

- Each process needs a bare minimum number of pages (set by hardware characteristics of machine)
- Frames need to be shared out *fairly* between processes
Give each of the $n$ processes $1/n$ of the available frames

- Each process can only take frames from itself

**Class Exercise**

What do you think?
Local, Proportional Frame Allocation

Give each process frames in proportion to the amount of *virtual* memory they use

**Class Exercise**

What do you think?

- Some processes use a lot of VM, but don’t access it often
- Some processes use a little VM, but access it often
- Not fair
Global, Variable Allocation

Just take the “best” (e.g., LRU) page, no matter which process it belongs to . . .

Class Exercise
Is this policy fair?
If not, why not?
Each program has a frame allocation

- Use *working set* measurements to adjust frame allocation from time to time.
- Each process can only take frames from itself.

**Class Exercise**

What’s wrong with this policy?

- I.e., what assumptions are we making that could be wrong?

Wrong assumptions: that we can measure working sets properly. That we can fit all working sets in memory.
Local, Variable Allocation

Each program has a frame allocation

- Use *working set* measurements to adjust frame allocation from time to time.
- Each process can only take frames from itself.

**Class Exercise**

What’s wrong with this policy?

- I.e., what assumptions are we making that could be wrong?

What should we do if the working sets of all processes are more than the total number of frames available?

Wrong assumptions: that we can measure working sets properly. That we can fit all working sets in memory.
Thrashing

If we don’t have “enough” pages, the page-fault rate is very high—leads to thrashing...

- Low CPU utilization
- Lots of I/O activity
Under local replacement policy, only problem process is affected (usually)

- Can detect and swap out until can give bigger working set
- If can’t give big enough, might want to kill.

Under global replacement policy, whole machine can be brought to its knees!

. . . But even under local policy, disk can become so busy that no other work gets done!
Secondary Storage

I.e., Storing stuff on disk, SSD, or network—why?

Class Exercise

What properties does disk have that differentiate it from RAM?

What properties are similar?
Disks—Properties

- Large array of logical blocks (cf., page frames)
- Block-based structure (partially) hidden in file APIs
- Logical block = smallest unit of transfer (cf., page size)
- Logical blocks mapped to disk sectors sequentially
  - Block zero is first sector, first track outermost cylinder
  - Mapping proceeds in order through:
    - Sectors in track
    - Tracks in cylinder
    - Cylinders on disk
- Access is slow, but sequential access faster than random
- Disk space → files (cf., memory → processes)
Like giving all memory to one process

- Entire disk used for one “file”
- File is seen as big stream of bytes
- Usually fixed size, writes overwrite old data
- To read data at position $p$,
  - block = $p / \text{BLOCK\_SIZE}$
  - offset = $p \% \text{BLOCK\_SIZE}$

**Class Exercise**

What kind of performance can we expect?

When might such a design be useful?

Random access is fast (as possible). Sequential is fast. Best for special cases, such as databases, paging/swap files.

OS still has work to do, preserving illusion of byte stream of bytes rather than discrete blocks.
Disk as One File

Like giving all memory to one process

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- File is seen as big stream of bytes
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Class Exercise

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Fixed Partitioning

Support $N$ files, each with $1/N^{th}$ of the available space

Pretty much the same...
Dynamic Partitioning (aka Contiguous Allocation)

More than one file per disk; all space per file is contiguous

- Each file occupies set of contiguous blocks on disk
- For each file $f$:
  - $\text{start\_of}(f)$ — block where $f$ begins
  - $\text{length\_of}(f)$ — current size of $f$
- To read data at position $p$ in file $f$
  - $\text{block} = \text{start\_of}(f) + \frac{p}{\text{BLOCK\_SIZE}}$
  - $\text{offset} = p \mod \text{BLOCK\_SIZE}$

Class Exercise

What kind of performance can we expect?

What’s missing? What problems can we expect?

Random & sequential access fast. External fragmentation when files deleted. What about compaction? Files can’t grow unless there’s empty space next to them.
Dynamic Partitioning (aka Contiguous Allocation)

More than one file per disk; all space per file is contiguous

- Each file occupies set of contiguous blocks on disk
- For each file \( f \):
  - \( \text{start} \_\text{of}(f) \) — block where \( f \) begins
  - \( \text{length} \_\text{of}(f) \) — current size of \( f \)
- To read data at position \( p \) in file \( f \)
  - block = \( \text{start} \_\text{of}(f) + p \)/ BLOCK_SIZE
  - offset = \( p \) % BLOCK_SIZE

Class Exercise

What kind of performance can we expect?

What’s missing? What problems can we expect?
Linked Allocation
Linked Allocation

Make each file block point to next one:

- For each file $f$,
  - $\text{start}_o(f)$ — block where $f$ begins
  - each block, $b$, has a pointer (size $\text{PTR}_\text{SIZE}$), such that
  - $\text{next}_b(b)$ — block that comes after $b$

- To read data at position $p$, in file $f$
  - block =
  - offset =

Class Exercise

What kind of performance can we expect?

Find_block is a linear search. No external fragmentation. Random access is slow. Sequential access is okay (but not great.)
Linked Allocation

Make each file block point to next one:

- For each file $f$,
  
  $\text{start}_\text{of}(f)$ — block where $f$ begins
  
  each block, $b$, has a pointer (size $\text{PTR\_SIZE}$), such that
  
  $\text{next}\_\text{block}(b)$ — block that comes after $b$

- To read data at position $p$, in file $f$
  
  $\text{block} = \text{find\_block}(\text{start}_\text{of}(f), \frac{p}{\text{BLOCK\_SIZE} - \text{PTR\_SIZE}})$
  
  $\text{offset} = p \% (\text{BLOCK\_SIZE} - \text{PTR\_SIZE})$

Class Exercise

What kind of performance can we expect?
Linked Allocation

- File start
- jeep: 9

Directory:

- 0: 1
- 1: 10
- 2: 3
- 3: 4
- 4: 5
- 5: 6
- 6: 7
- 7: 8
- 8: 9
- 9: 10
- 10: 11
- 11: 12
- 12: 13
- 13: 14
- 14: 15
- 15: 16
- 16: 17
- 17: 18
- 18: 19
- 19: 20
- 20: 21
- 21: 22
- 22: 23
- 23: 24
- 24: 25
- 25: 26
- 26: 27
- 27: 28
- 28: 29
- 29: 30
- 30: 31

Linked Allocation
Adding an end pointer makes appends much cheaper.
Make each block in an array \((\text{fat})\) point to the next one block in file

- For each file \(f\),
  - start\(_\text{of}(f)\) — block where \(f\) begins
  - fat\([b]\) — block that comes after \(b\)
- To read data at position \(p\) in file \(f\)
  - block = find\_block(start\_of\((f\)), p / \text{BLOCK\_SIZE})
  - offset = p % \text{BLOCK\_SIZE}

**Class Exercise**

What are the problems with this approach?
Make each block in an array ($fat$) point to the next one block in file

- For each file $f$,
  - $\text{start}_\text{of}(f)$ — block where $f$ begins
  - $fat[b]$ — block that comes after $b$

- To read data at position $p$ in file $f$
  - $\text{block} = \text{find\_block}(\text{start\_of}(f), \ p \ / \ \text{BLOCK\_SIZE})$
  - $\text{offset} = p \ % \ \text{BLOCK\_SIZE}$

Class Exercise

What are the problems with this approach?

Here, $\text{find\_block}$ is a list search through the FAT, which is stored in memory: no (or few) extra disk accesses.

Problems: you still have essentially random allocation on the disk.
Indexed Allocation
Indexed Allocation

Bring all pointers together in an index block (cf., page table)

- For each file \( f \),
  \[ \text{index} \_ \text{block}(f) \] —block where \( f \)'s index block is stored
  each index block \( b \) has pointers to \( f \)'s blocks
  \[ \text{index}(b, i) \] —the \( i \)th entry in index block \( b \)

- To read data at position \( p \) in file \( f \)
  - block =
  - offset =

Class Exercise

What are the problems with this approach?
Secondary Storage
allocation Methods

Indexed Allocation

Bring all pointers together in an index block (cf., page table)

- For each file \textit{f},

  \begin{itemize}
  \item \texttt{index\_block(f)} — block where \textit{f}'s index block is stored
  \item each index block \textit{b} has pointers to \textit{f}'s blocks
  \begin{itemize}
  \item \texttt{index(b, i)} — the \textit{i}th entry in index block \textit{b}
  \end{itemize}
  \end{itemize}

- To read data at position \textit{p} in file \textit{f}

  \begin{itemize}
  \item \texttt{block = index(index\_block(f), p / BLOCK\_SIZE)}
  \item \texttt{offset = p \% BLOCK\_SIZE}
  \end{itemize}

Class Exercise

What are the problems with this approach?

Random and sequential access are okay; you have dynamic access without external fragmentation. But the index block is overhead, and limits on the size of the index block also limit the sizes of files.
This has long been the standard in Unix-like systems. But it's not the only way!
Allocate file in chunks:

- For each file $f$,
  - $\text{extent}_\text{start}(f, i)$ — block where chunk $i$ begins
  - $\text{extent}_\text{len}(f, i)$ — length of chunk $i$ in blocks

- To read data at position $p$, in file $f$
  - block =
  - offset =

Where $\text{find\_block}$ is defined as:

- $\text{find\_block}(b, i) = b + \text{extent}_\text{start}(f, i)$
  if $b < \text{extent}_\text{len}(f, i)$
- $\text{find\_block}(b, i) = \text{find\_block}(b - \text{extent}_\text{len}(f, i), i+1)$ otherwise
Allocate file in chunks:
  ▶ For each file \( f \),
    
    \[
    \text{extent_start}(f, i) \quad \text{— block where chunk } i \text{ begins}
    \]
    
    \[
    \text{extent_len}(f, i) \quad \text{— length of chunk } i \text{ in blocks}
    \]
  ▶ To read data at position \( p \), in file \( f \)
    
    \[
    \text{block} = \text{find_block}(p \div \text{BLOCK_SIZE}, 0)
    \]
    
    \[
    \text{offset} = p \mod \text{BLOCK_SIZE}
    \]
    
    Where \( \text{find_block} \) is defined as:
    
    \[
    \text{find_block}(b, i) = b + \text{extent_start}(f, i)
    \]
    
    \[
    \text{if } b < \text{extent_len}(f, i)
    \]
    
    \[
    \text{find_block}(b, i) = \text{find_block}(b - \text{extent_len}(f, i), i + 1)
    \]
    
    otherwise
Non-Contiguous Allocation Summary

All the techniques we’ve looked at

- Allow a file’s blocks to be scattered all over the disk
- Allow free space to be scattered all over the disk

So how are you going to know where the free space is?

Desirable properties:

- Try to locate the file (or large pieces of the file) in the same region of the disk
  - Requires enough free space to be able to pick a region of the disk that has chunks of space free
- Minimize head movement
Free-Space Management—Bit Vector

Bit map for $n$ blocks:

$$\text{bit}[i] = \begin{cases} 0 & \text{block}[i] \text{ free} \\ 1 & \text{block}[i] \text{ occupied} \end{cases}$$

Class Exercise
Compare against a linked representation...