Operating Systems and Concurrency

Memory Management 3

COMP2007

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Recall

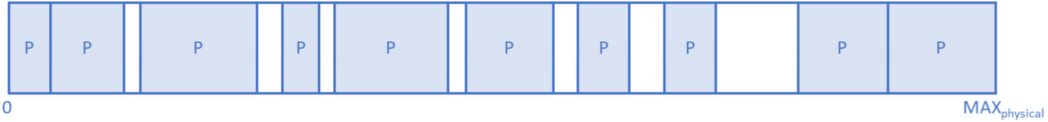
Last Lecture

- **Dynamic relocation** & **protection**, **base** & **bound** registers (**logical** $\Rightarrow$ **physical** address)
- **Dynamic partitioning & segmentation** (**internal** $\Rightarrow$ **external** fragmentation)
- **Free space** management (bitmaps and linked lists)

Sketch of the Scene

Where Did we Get To?

- **Contiguous memory allocation** methods:
  - Fixed (non-)equal size partitions
  - Dynamic partitioning
  - Segmentation (individual segments are contiguous)
  - `malloc(), free()`
- The **amount of memory** requested by processes can be **differ**
- Memory will become **fragmented** over time



Sketch of the Scene

What do we Need?

- A method to **keep track** of free memory
- A strategy to **allocate free** memory when requested by a process
- Approaches to **prevent fragmentation** whenever we can

Overview

Goals for Today

- **Memory allocation:**
  - First fit, best fit, next fit, worst fit, quick fit
  - Buddy algorithm
- **Prevent fragmentation** - **non-contiguous** memory management
  - **(Segmentation)**
  - **Paging** - page tables, address translation

Memory Allocation

First Fit

- **First fit** scans **from the start** of the list until an **sufficiently large gap** is found
  - `if` the space is **the exact size** then all the space is **allocated**
  - `else` the space is **split**:
    - The first entry is set to the **size requested** and marked “**used**”
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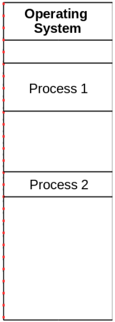

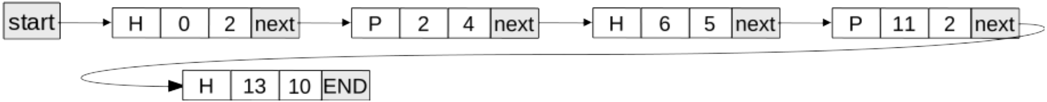

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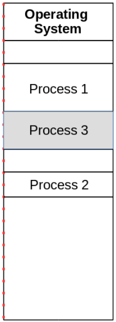
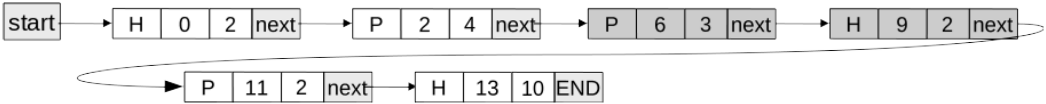
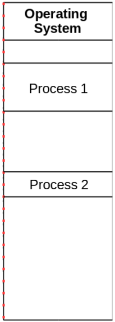


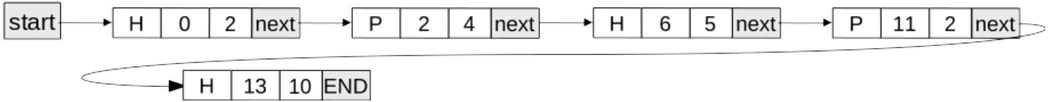


Memory Allocation

Next Fit

- The **next fit algorithm** maintains a record of where it got to:
  - It **restarts its search** from **where it stopped last time**
  - It gives an **even chance to all memory** to get allocated (first fit concentrates on the start of the list)
- Simulations have shown that next fit **performs worse** than first fit





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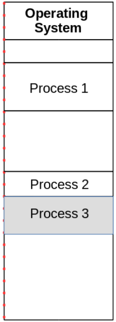
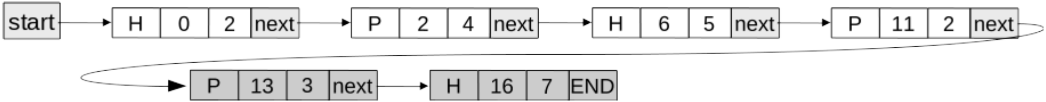




Memory Allocation

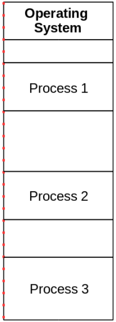
First vs. Next Fit

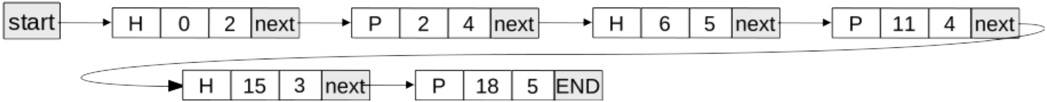
- **First fit** is a fast and looks for the **first available hole**
  - It does **not account** for a **better fitting** hole later
  - It may **break up** a **large holes** early in the list
- **Next fit** does not change this

Memory Allocation

Best Fit

- **Best fit** searches the **entire linked** list for the **smallest hole** big enough to satisfy the request
  - It is **slower** than first fit
  - Result in **small leftover holes** (wastes memory)





Memory Allocation

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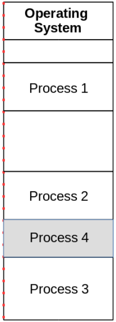
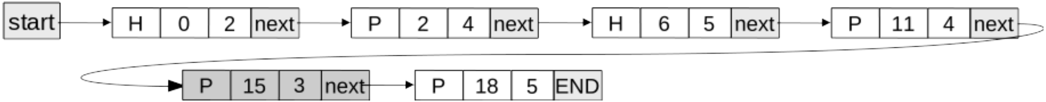
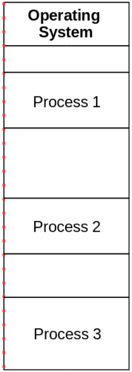


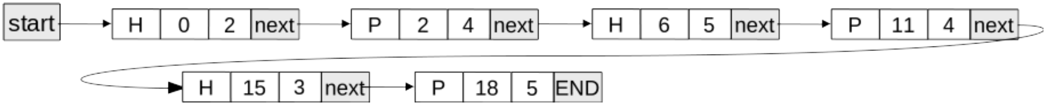


Memory Allocation

Worst Fit

- **Best fit** split an empty partition in **small holes**
- **Worst fit** finds the **largest available partition** and splits it
  - The left over part **will still be large** (potentially more useful)
  - Simulations have shown that **worst fit** is **not good** in practice

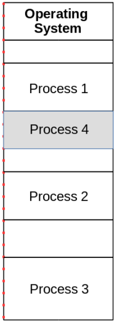


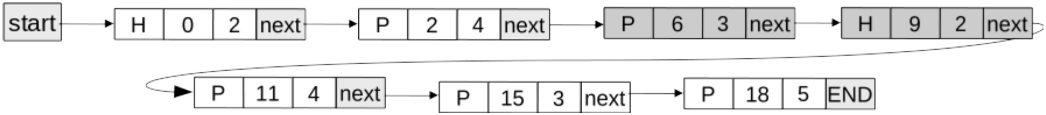


Memory Allocation

Worst Fit

- **Tiny holes** are created when **best fit** split an empty partition
- The **worst fit algorithm** finds the **largest available empty partition** and splits it
  - The **left over part will still be large** (and **potentially more useful**)
  - Simulations have also shown that worst fit is **not very good either**!





Memory Allocation

Summary

- **First fit**: allocate **first block** that is **large enough**
- **Next fit**: allocate **next block** that is large enough, i.e. **starting from the current location**
- **Best fit**: choose block that **matches** required size **closest** - O(N) complexity
- **Worst fit**: choose the **largest possible block** - O(N) complexity

Dynamic Partitioning

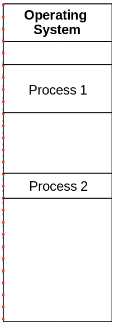
Allocating Available Memory: Quick Fit and Others

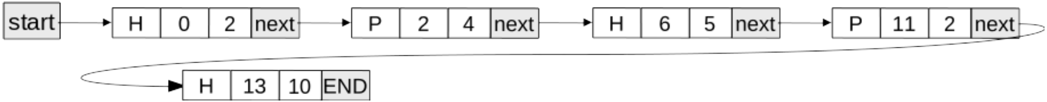
- **Quick fit** maintains **lists of commonly used sizes**
  - For example a separate list for each of 4K, 8K, 12K, 16K, etc., holes
  - **Odd sizes** can either go into the **nearest size** or into a **special separate list**
- It is **much faster** to find the required size hole using **quick fit**
- Similar to **best fit**, it has the problem of creating **many tiny holes**
- Finding neighbours for **coalescing** (combining empty partitions) becomes more difficult/time consuming

Memory Allocation

Coalescing

- **Coalescing** (joining together) takes place when two **adjacent entries** in the linked list **become free**
- Both **neighbours** are examined when a **block is freed**
  - `if` either (or both) are **also free**
  - `then` the two (or three) **entries are combined** into one larger block by adding up the sizes
    - The earlier block in the linked list gives the **start point**
    - The **separate links are deleted** and a single link inserted





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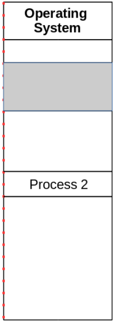

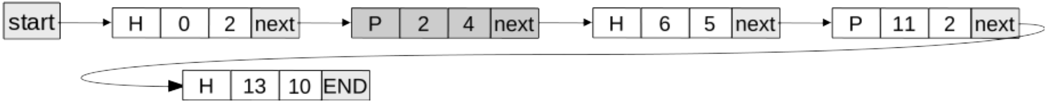

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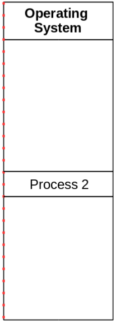

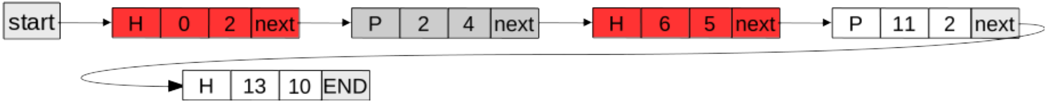

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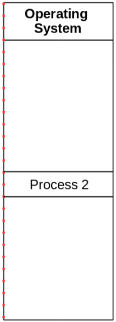

start → | H | 0 | 11 | next | → | P | 11 | 2 | next | → | H | 13 | 10 | END |

Memory Allocation

Compacting

- Even with coalescing, **free blocks** may still **distributed** across memory
- **Compacting** can be used but is harder to implement and **time consuming**
- Processes may have to be **moved/swapped out**, **free space coalesced**, and processes **swapped back in** at lowest available location

Contiguous Allocation Schemes

Overview and Shortcomings

- Different contiguous memory allocation schemes have different advantages/disadvantages
  - **Mono-programming** is easy but does result in **low resource utilisation**
  - **Fixed partitioning** facilitates **multi-programming** but results in **internal fragmentation**
  - **Dynamic partitioning & segmentation** facilitate **multi-programming**, reduce **internal fragmentation**, but result in **external fragmentation** (allocation methods, coalescing, and compacting help)
- Can we design a memory management scheme that **resolves the shortcomings** of **contiguous memory schemes**?

Paging

Principles

- **Paging** uses **fixed partitioning** and **code re-location** to devise a new ***non-contiguous*** management scheme:
  - Memory is split into **much smaller blocks**
  - A process is allocated **one or more blocks** (e.g., a 11KB process would take up three 4KB blocks)
  - Blocks do **not** have to be stored **in contiguous in physical memory**
  - The process **perceives** them to be **contiguous**
- Benefits of non-contiguous schemes include:
  - **Internal fragmentation** is reduced to the **last "block"** only
  - **No external fragmentation** (blocks in physical address space are **stacked** directly on top of each other)

Paging

Principles (Cont'ed)

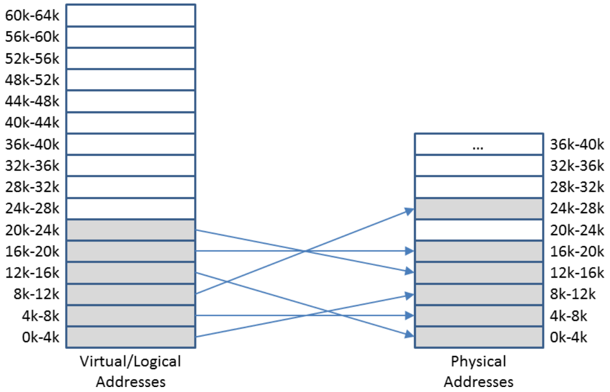

Figure: Paging in physical memory with multiple processes

Paging

Principles (Cont'ed)

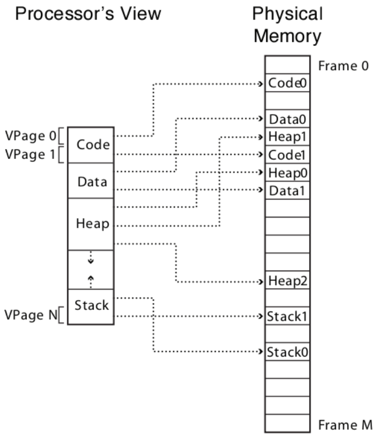

Figure: Paging in main memory with multiple processes (Anderson)

Paging

Principles (Cont'ed)

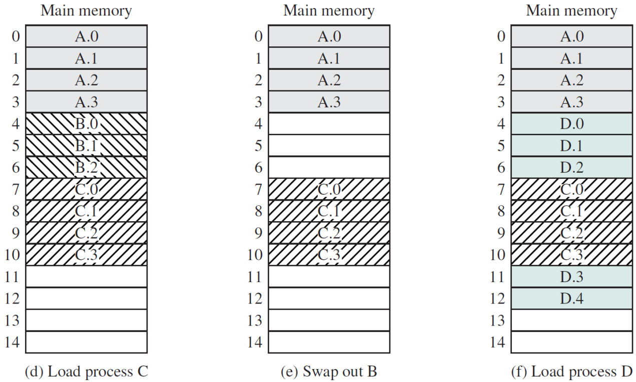

Figure: Concept of Paging (Stallings)

Paging

Principles: Definitions

- A **page** is a small block of **contiguous memory** in the **logical address space**, i.e. as seen by the process
- A **frame** is a **small contiguous block** in **physical memory**
- Pages and frames (commonly) have the **same size**:
  - The size is usually a power of 2
  - Sizes range between 512 bytes and 1Gb

Paging

Relocation

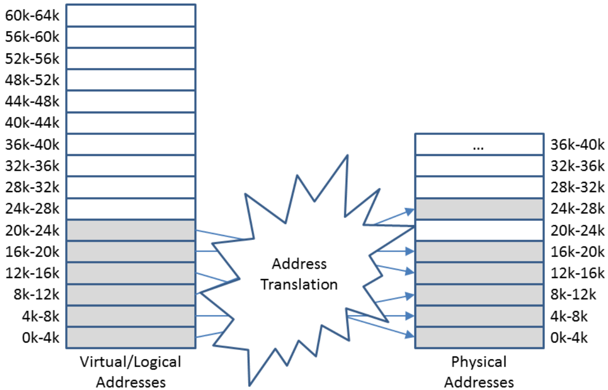

Figure: Address Translation

Segmentation

Segmentation Table

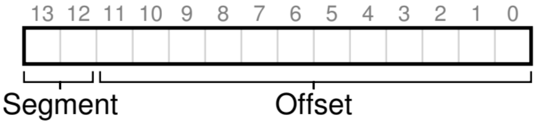

Figure: Logical address for segmentation (offset = position relative to start of segment)

Segment	**index**	**Base**	**Bound**	**RWX**
Code	00	...	...	...
Data	01	...	...	...
Heap	10	...	...	...
Stack	11	...	...	...

Paging
Page Table

Figure: Logical address for page (offset = position relative to start of segment)

Page Number	**Frame Number**	**...**	**...**	**RWX**
0000	1010	...	...	...
0001	0100	...	...	...
0010	1111	...	...	...
...	...	...	...	...

Paging

Page Table

Figure: Logical address for page (offset = position relative to start of segment)

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Paging

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Paging

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0001	0100	. . .	. . .	. . .
0010	1111	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .

Paging

Relocation

- **Logical address** (page number, offset within page) needs to be **translated** into a **physical address** (frame number, offset within frame)
- **Multiple "base registers"** will be required:
  - Each **page** has a **"base register"** that identifies the start of the associated **frame**
  - A **set of base registers** must be maintained for every process
- The **set of base registers** is stored in the **page table**

Paging

Relocation: Address Translation

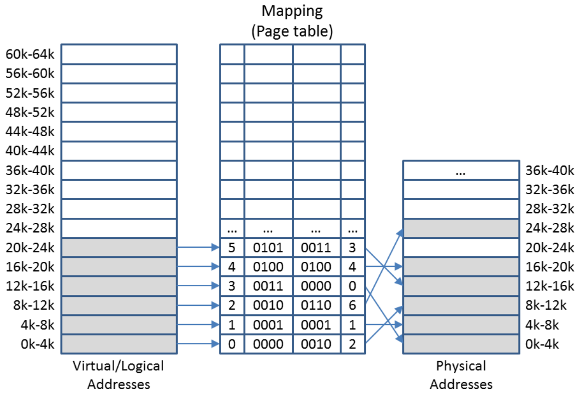

Figure: Address Translation

Paging

Relocation: Page Tables

- The page table maps the **page number** onto the **frame number** (logical $\Rightarrow$ physical address)
  - frameNumber=f(pageNumber)
- The **page number** is used as **index to the page table** that lists the **number of the associated frame**
- From the **frame number** one can calculate the base (offset remains unchanged)is used as **index to the page table** that lists the **number of the associated frame**
- Every process has its **own page table** containing its own **set of "base registers"**
- The **operating system** maintains a **list of free frames**

Paging

Address Translation: Implementation

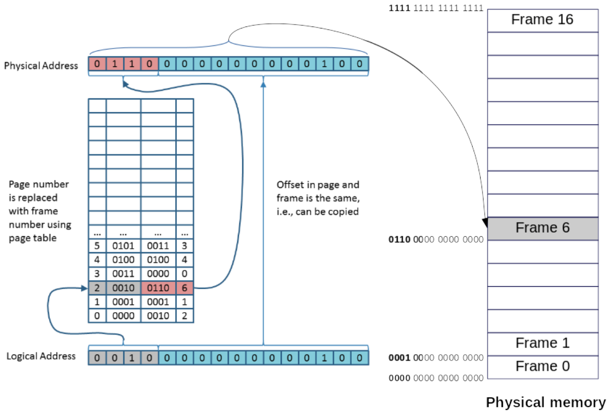

Figure: Address Translation

Test Your Understanding

Page tables and memory addressing

Page Tables

Given a **64-bit machine** that uses paging, and a page/frame size of **4KB**.

- What would be the maximum **number of frames**? 2^64 / (4*1024)
- How many **entries** will we have in the **page table**? 2^64 / (4*1024)
- How many **pages** do we have in a **17KB process**?
- How much **memory is wasted** in the last frame?

Recap

Take-Home Message

- Memory **allocation**, **coalescing** and **compacting** in dynamic partitioning
- **Paging**, **page tables**, and **address translation**