Memory Management Basics
Basic Memory Management Concepts

Address spaces

- **Physical address space** — The address space supported by the hardware
  - Starting at address 0, going to address $\text{MAX}_{\text{sys}}$

- **Logical/virtual address space** — A process’s view of its own memory
  - Starting at address 0, going to address $\text{MAX}_{\text{prog}}$

But where do addresses come from?

```c
MOV r0, @0xffffa620e
```
Which is bigger, physical or virtual address space?

- A. Physical address space
- B. Virtual address space
- C. It depends on the system.
Basic Concepts
Address generation

The compilation pipeline

prog P:
  ...
  foo():
  ...
end P

P:
  ...
  push ...
  inc SP, x
  jmp _foo:
  foo: ...

P:
  ...
  push ...
  inc SP, 4
  jmp 75
  ...
  jmp 1175

Library Routines:
  ...
  jmp 175
  ...

Library Routines:
  ...
  jmp 1175
  ...

Compilation  Assembly  Linking  Loading
Program Relocation

- Program issues virtual addresses
- Machine has physical addresses.
- If virtual == physical, then how can we have multiple programs resident concurrently?
- Instead, relocate virtual addresses to physical at run time.
  - While we are relocating, also bounds check addresses for safety.
- I can relocate that program (safely) in two registers…
Basic Concepts (Cont’ d.)

Address Translation

- **Logical Address Space**
  - CPU
  - Instructions
  - Program $P$’s logical address space

- **Limit Register**
  - ≤
  - 500

- **Base Register**
  - +
  - 1000

- **Physical Address Space**
  - Memory Exception
  - yes
  - no

- **Program $P$’s physical address space**
  - $MAX_{sys}$
  - $MAX_{prog}$
With base and bounds registers, the OS needs a hole in physical memory at least as big as the process.

- A. True
- B. False
Evaluating Dynamic Allocation Techniques
The fragmentation problem

- **External fragmentation**
  - Unused memory between units of allocation
  - E.g., two fixed tables for 2, but a party of 4

- **Internal fragmentation**
  - Unused memory within a unit of allocation
  - E.g., a party of 3 at a table for 4
Simple Memory Management Schemes
Dynamic allocation of partitions

- Simple approach:
  - Allocate a partition when a process is admitted into the system
  - Allocate a contiguous memory partition to the process

OS keeps track of...
- Full-blocks
- Empty-blocks ("holes")

Allocation strategies
- First-fit
- Best-fit
- Worst-fit
First Fit Allocation

To allocate $n$ bytes, use the *first* available free block such that the block size is larger than $n$.

To allocate 400 bytes, we use the 1st free block available.
Rationale & Implementation

- Simplicity of implementation

- Requires:
  - Free block list sorted by address
  - Allocation requires a search for a suitable partition
  - De-allocation requires a check to see if the freed partition could be merged with adjacent free partitions (if any)

Advantages
- Simple
- Tends to produce larger free blocks toward the end of the address space

Disadvantages
- Slow allocation
- External fragmentation
Best Fit Allocation

To allocate $n$ bytes, use the smallest available free block such that the block size is larger than $n$.

To allocate 400 bytes, we use the 3rd free block available (smallest).
Rationale & Implementation

- To avoid fragmenting big free blocks
- To minimize the size of external fragments produced
- Requires:
  - Free block list sorted by size
  - Allocation requires search for a suitable partition
  - De-allocation requires search + merge with adjacent free partitions, if any

**Advantages**
- Works well when most allocations are of small size
- Relatively simple
- Doug Lea’s malloc “In most ways this malloc is a best-fit allocator”

**Disadvantages**
- External fragmentation
- Slow de-allocation
- Tends to produce many useless tiny fragments (not really great)
Worst Fit Allocation

To allocate \( n \) bytes, use the \textit{largest} available free block such that the block size is larger than \( n \).

To allocate 400 bytes, we use the 2nd free block available (largest).
Rationale & Implementation

- To avoid having too many tiny fragments

- Requires:
  - Free block list sorted by size
  - Allocation is fast (get the largest partition)
  - De-allocation requires merge with adjacent free partitions, if any, and then adjusting the free block list

Advantages
- Works best if allocations are of medium sizes

Disadvantages
- Slow de-allocation
- External fragmentation
- Tends to break large free blocks such that large partitions cannot be allocated
First fit, best fit and worst fit all suffer from external fragmentation.

A. True
B. False
Dynamic Allocation of Partitions
Eliminating Fragmentation

- **Compaction**
  - Relocate programs to coalesce holes

- **Swapping**
  - Preempt processes & reclaim their memory
Memory Management
Sharing Between Processes

- Schemes so far have considered only a single address space per process
  - A single *name space* per process
  - No sharing

How can one share code and data between programs without paging?
Multiple Name Spaces

Example — Protection/Fault isolation & sharing

\[ 2^n - 1 \]

- Heap
- Run-Time Stack
- Program Data
- Program Text

\[ 2^{n_1} - 1 \]

\[ 2^{n_2} - 1 \]

- Program Text
- Program Data

\[ 2^{n_3} - 1 \]

- Run-Time Stack
- Libraries

\[ 2^{n_4} - 1 \]

- Heap

\[ 2^{n_5} - 1 \]

- User Code

\[ 2^{n_6} - 1 \]
Supporting Multiple Name Spaces

Segmentation

- New concept: A *segment* — a memory “object”
  - A virtual address space

- A process now addresses objects — a pair \((s, addr)\)
  - \(s\) — segment number
  - \(addr\) — an offset within an object
  - Don’t know size of object, so 32 bits for offset?

Segment + Address register scheme

Single address scheme
Implementing Segmentation
Base + Limit register scheme

- Add a segment table containing base & limit register values
Segmentation allows sharing

… but leads to poor memory utilization
- We might not use much of a large segment, but we must keep the whole thing in memory (bad memory utilization).
- Suffers from external fragmentation
- Allocation/deallocation of arbitrary size segments is complex

How can we improve memory management?
- Paging