Memory Management Basics

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Portions courtesy Emmett Witchel and Kevin Jeffay
Review: 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?

```
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.
Address Space Generation

- The compilation pipeline

```
prog P:
  : foo():
  : push ...
  inc SP, x
  jmp _foo
  : foo: ...
```

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

```
: push ...
: inc SP, 4
: 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…
2 register translation

CPU

Logical Addresses

≤

no

yes

Physical Addresses

MEMORY EXCEPTION

500

Limit Register

1000

Base Register

MAX_{sys}

Program P’s physical address space

MAX_{prog}

Program P’s logical address space

Instructions
• With base and bounds registers, the OS needs a hole in physical memory at least as big as the process.
  – A. True
  – B. False
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
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
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.
First Fit: Rationale and Implementation

- Simplicity!

- 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)
Best Fit: Rationale and Implementation

- 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

**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 *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).
Worst Fit: Rationale and Implementation

- 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
Allocation strategies

• First fit, best fit and worst fit all suffer from external fragmentation.
  – A. True
  – B. False
Eliminating Fragmentation

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

- **Swapping**
  - Preempt processes & reclaim their memory

Diagram:
- **Ready**
- **Running**
- **Waiting**
- **Suspended**

Queues:
- Suspended queue
- Semaphore/condition queues

Programs:
- Program $P_1$
- Program $P_2$
- Program $P_3$
- Program $P_4$
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 (sub) Name Spaces

- Heap
- Run-Time Stack
- Program Text (shared)
- Program Text (not shared)
- Run-Time Stack (not shared)
- Program Data (not shared)
- Libraries
- User Code

$2^{n_1} - 1$
$2^{n_2} - 1$
$2^{n_3} - 1$
$2^{n_4} - 1$
$2^{n_5} - 1$
$2^{n_6} - 1$
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?

Two ways to encode a virtual address
Implementing Segmentation

- Add a segment table containing base & limit register values

```
Logical Addresses

Program P

CPU

STBR

Segment Table

Limit Register

Base Register

MEMORY EXCEPTION

yes

no

≤

1000

≤

1500

Physical Memory

Program P' s Segment

Program
```
Are we done?

• Segmentation allows sharing
  – And dead simple hardware
    • Can easily cache all translation metadata on-chip
  – Low latency to translate virtual addresses to physical addresses
    • Two arithmetic operations (add and limit check)

• … 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?
  – stay tuned…