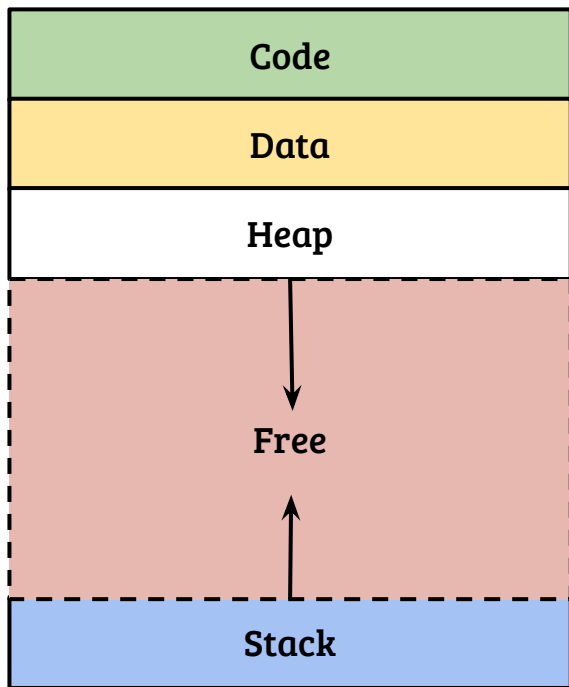


CS330: Operating Systems

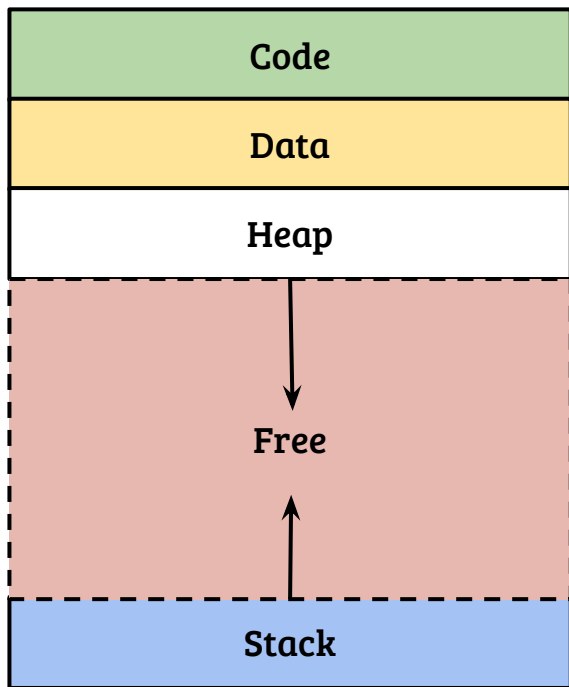
Virtual Memory: Address translation

Recap: Process address space



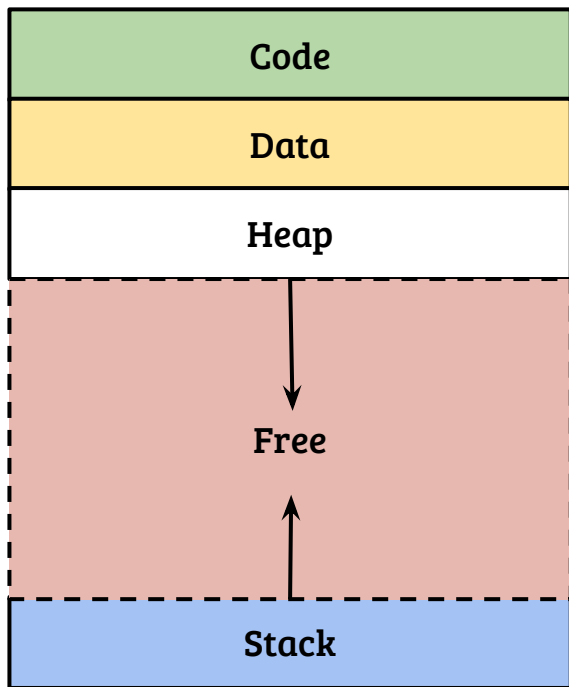
- Address space abstraction provides the same view of memory to *all processes*
 - Address space is virtual
 - OS enables this virtual view

Recap: Process address space



- Address space abstraction provides the same view of memory to *all processes*
 - Address space is virtual
 - OS enables this virtual view
- User can organize/manage virtual memory using OS APIs
 - No control on physical memory!

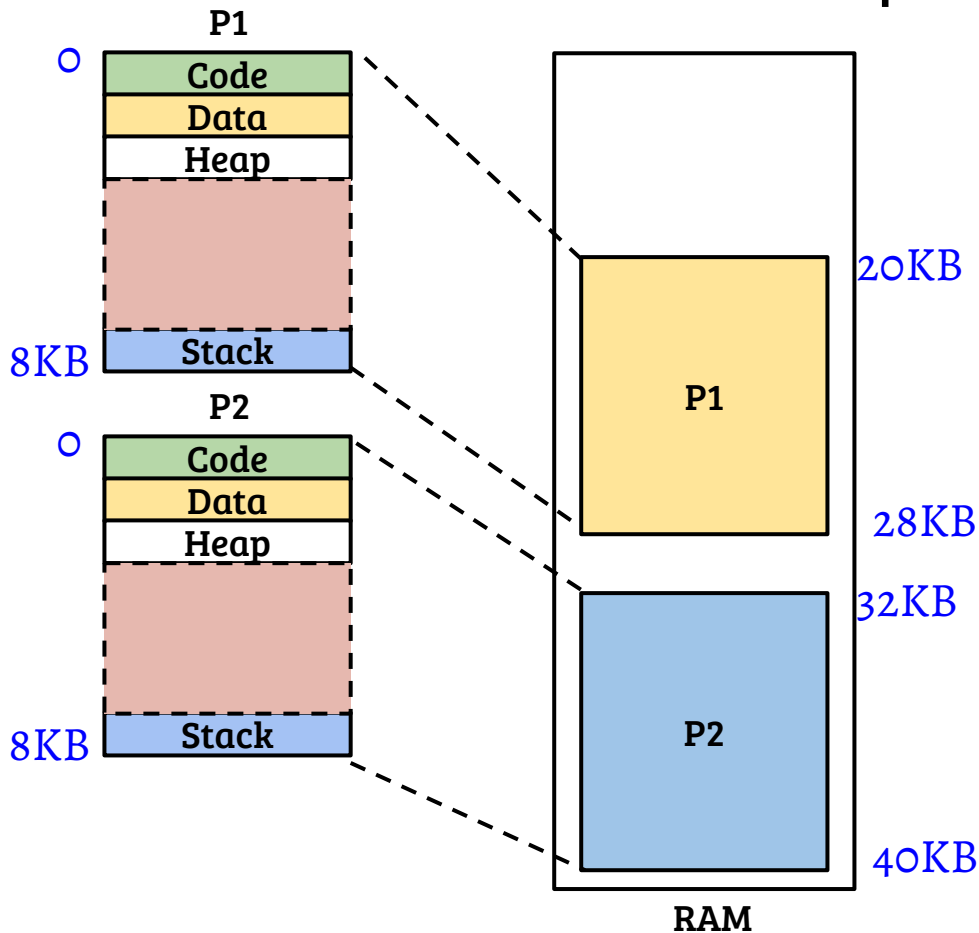
Recap: Process address space



- Address space abstraction provides the same view of memory to *all processes*
 - Address space is virtual
 - OS enables this virtual view
- User can organize/manage virtual memory using OS APIs
 - No control on physical memory!

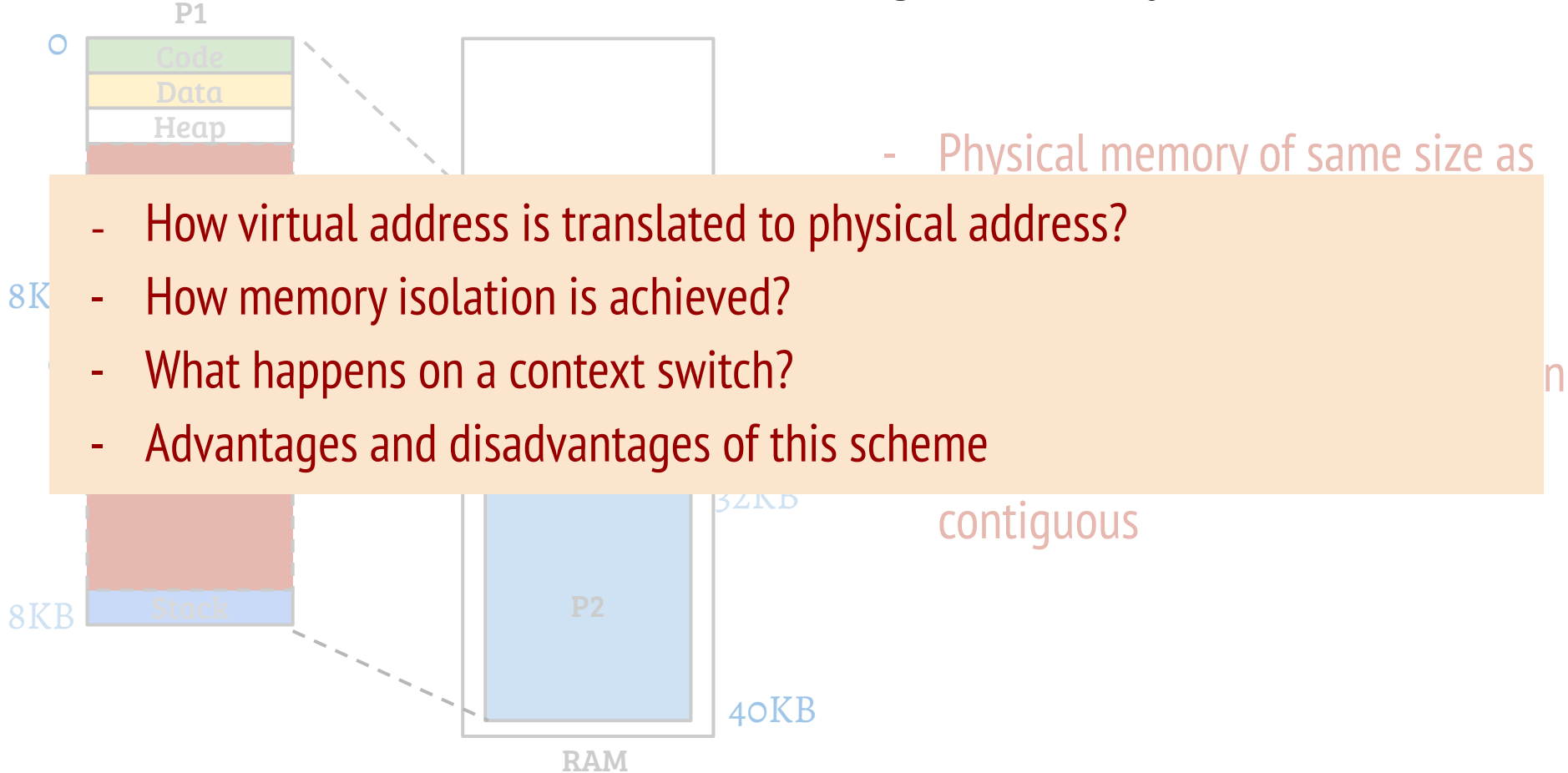
Agenda: Virtual to physical address translation

Translation at address space granularity



- Physical memory of same size as the address space size is allocated to each process
- Physical memory for a process can be at any address, but should be contiguous

Translation at address space granularity



ISA: commonly used addressing modes (x86)

- At a high-level, instructions contains two parts: opcode and operand
 - ISA defines binary encoding of opcodes, mode and register operands (more complex in practice)
- Operands can be specified in multiple ways
 - Register: `mov %rcx, %rax`
 - Immediate: `mov $5, %rax`
 - Absolute: `mov 8000000, %rax`
 - Indirect: `mov (%rcx), %rax`
 - Displacement: `mov -16(%rbp), %rax`

X86 ISA: examples

- Access local variables using %rbp (examples)
- long a = 100, b = 20, c;
 - mov \$100, -8(%rbp); mov \$20, -16(%rbp)
- c = a + b;
 - mov -8(%rbp), %rax; mov -16(%rbp), %rcx;
 - add %rcx, %rax; mov %rax, -24(%rbp)
- PC relative jump/call
 - jmp 0x20(%rip)
 - call -0x20(%rip)

Role of the compiler

Simple function

```
func()  
{  
    long a = 100;  
    a+ = 10;  
}
```

Compiled assembly

```
func:  
10:  push %rbp;  
12:  mov %rsp, %rbp;  
16:  mov $100, -8(%rbp);  
20:  mov -8(%rbp), %rax  
24:  add $10, %rax  
29:  mov %rax, -8(%rbp)  
33:  pop %rbp;  
35:  ret;
```

- Compiler can generate code assuming start the code address as
- Compiler does not know the stack address, but uses the registers (rbp)

OS during binary load (simplified fork + exec)

```
load_new_executable( PCB *current, File *exe)
```

```
{
```

```
    verify_executable(exe);
```

```
    reinit_address_space(current → mm_state);
```

```
    allocate_phys_mem(current);
```

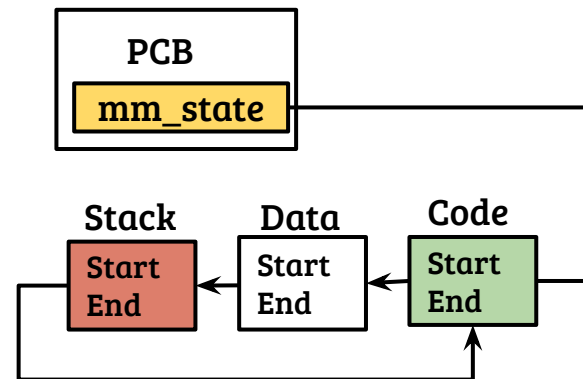
```
    load_exe_to_physmem(current, exe);
```

```
    set_user_sp(current → mm_state → stack_start);
```

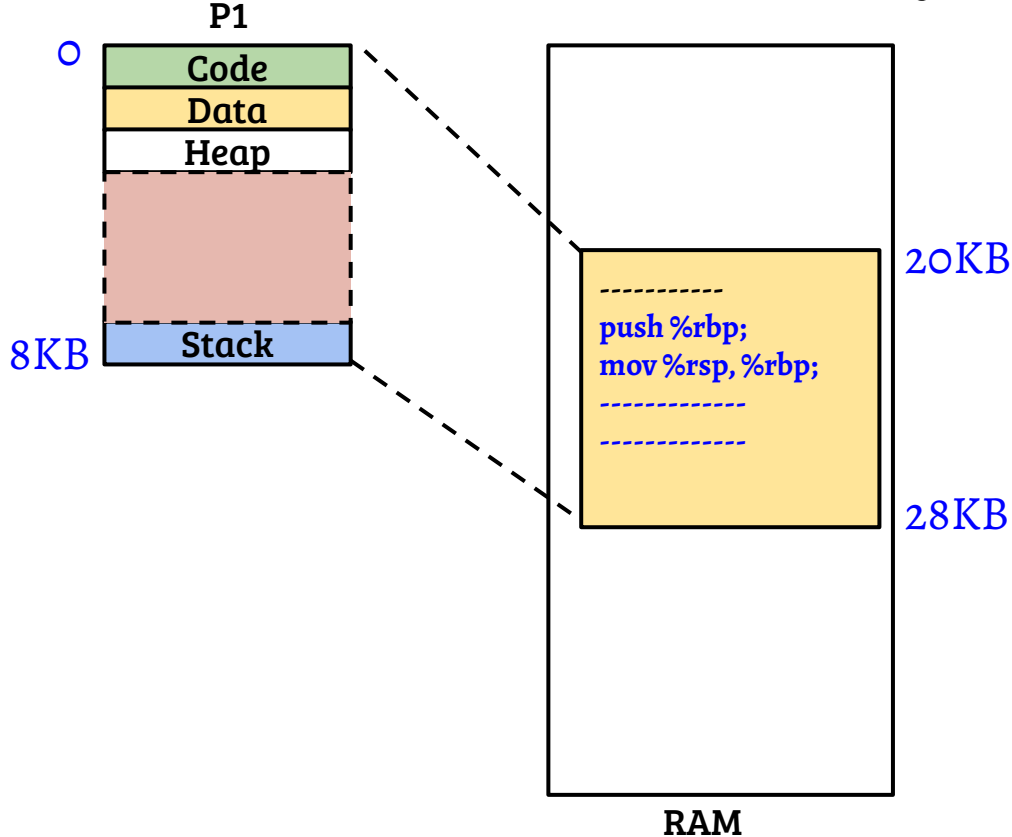
```
    set_user_pc(current → mm_state → code_start);
```

```
    return_to_user;
```

```
}
```

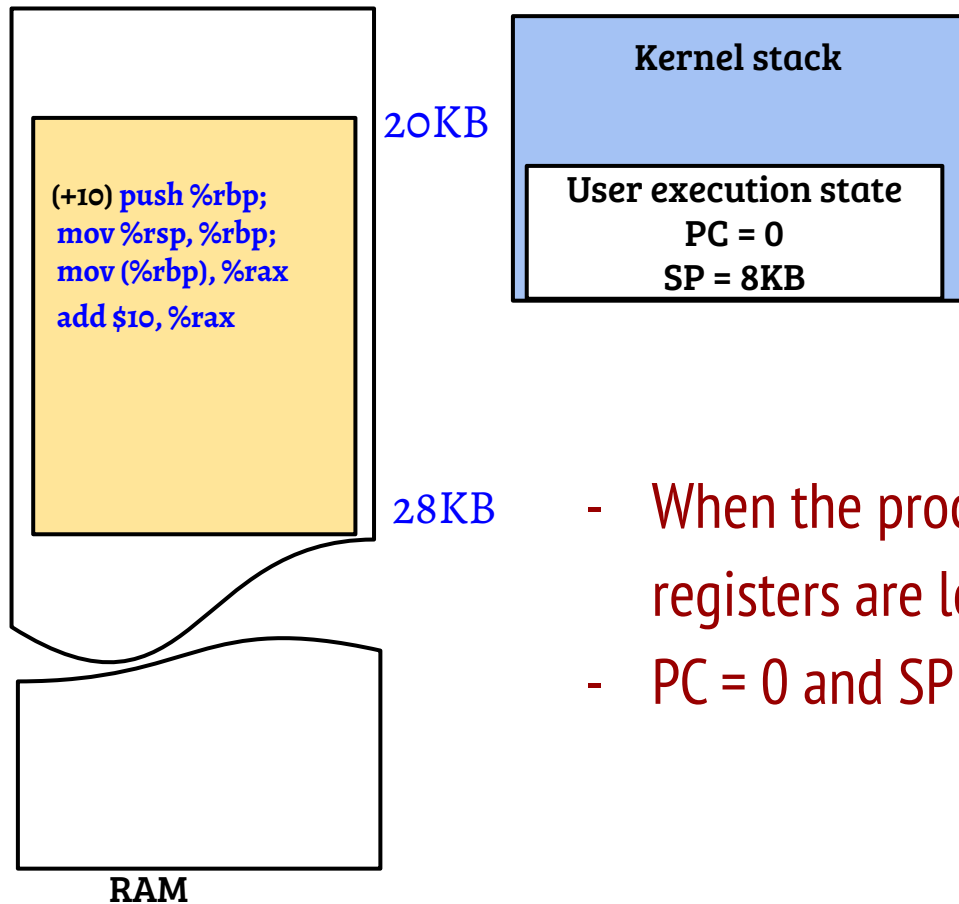


Address space to memory translation



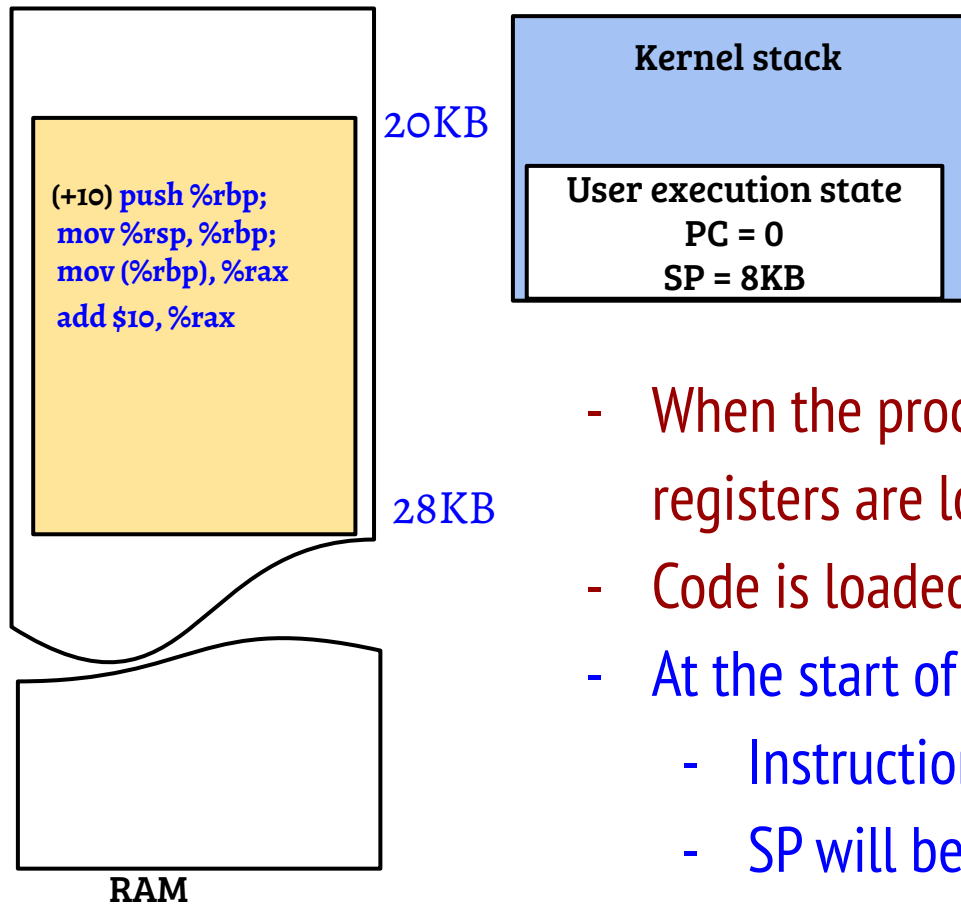
- Physical memory of 8KB is allocated and the code is loaded
- The PCB memory state is updated based on the executable format

Process state after exec()



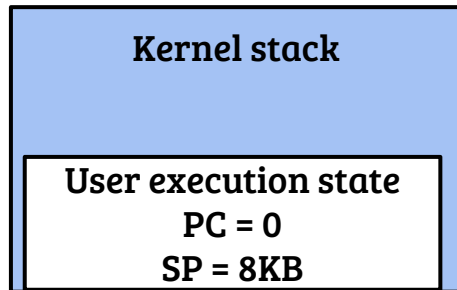
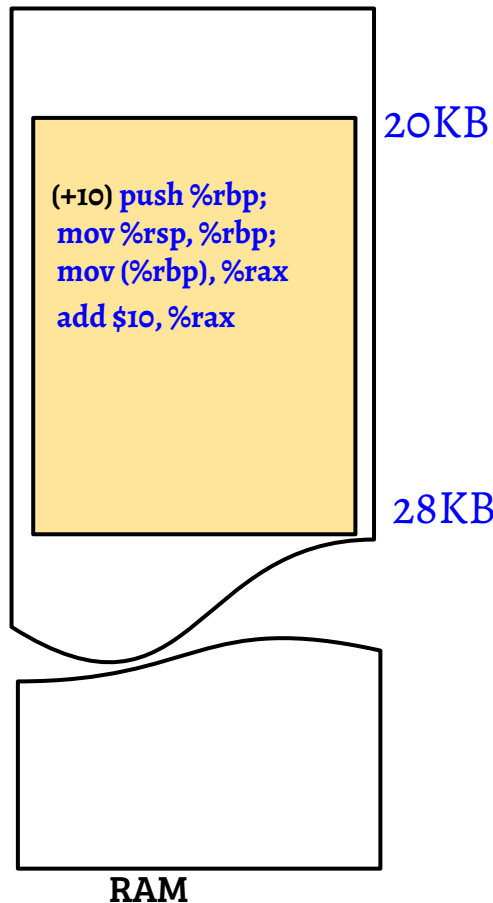
- When the process returns to user space, the registers are loaded with virtual addresses
- PC = 0 and SP = 8KB

Process state after exec()



- When the process returns to user space, the registers are loaded with virtual addresses
- Code is loaded into physical memory (@20KB)
- At the start of "func" execution
 - Instruction fetch address is 10 (PC = 10)
 - SP will be around 8KB

Process state after exec()

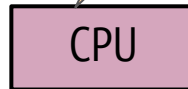
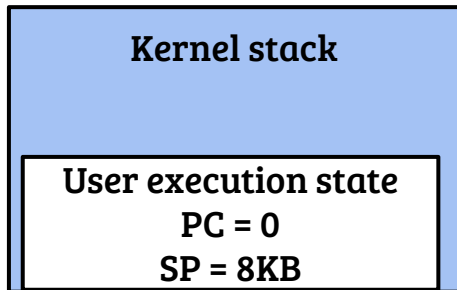
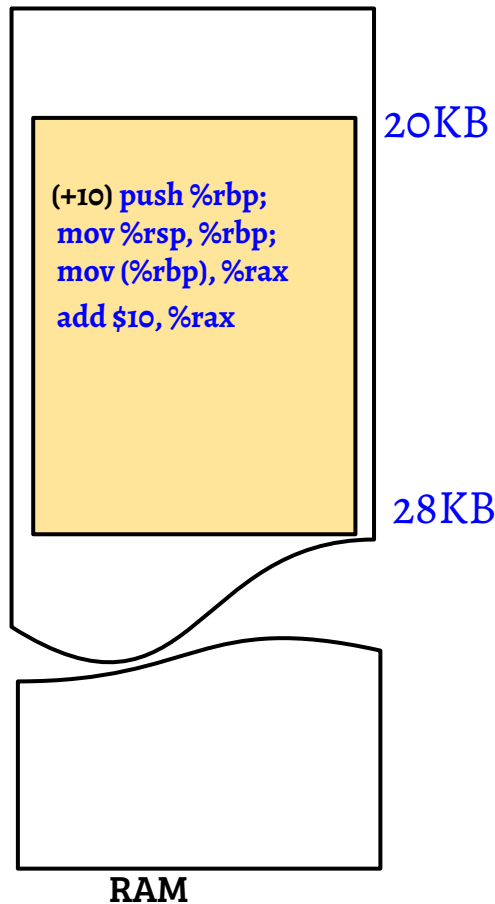


Dear HW! I have done my part. Help me with the translation, please!



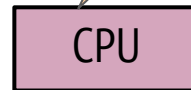
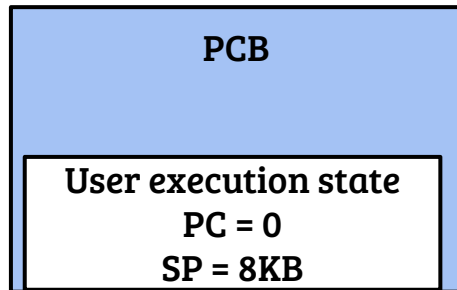
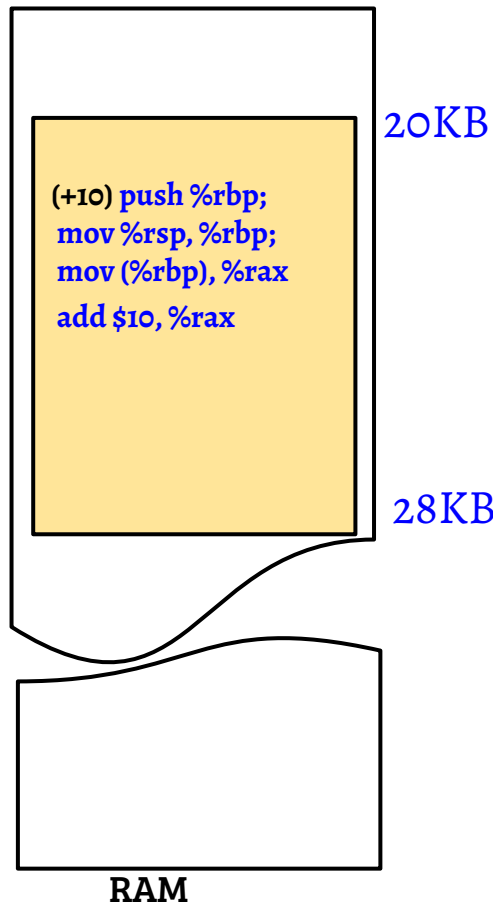
- When the process returns to user space, the registers are loaded with virtual addresses
- Code is loaded into physical memory (@20KB)
- At the start of “func” execution
 - Instruction fetch address is 10
 - SP will be around 8KB

Process state after exec()



Here is a base register. I will add the value of base register with the virtual address generated by the program to get the physical address. All yours buddy!

Process state after exec()

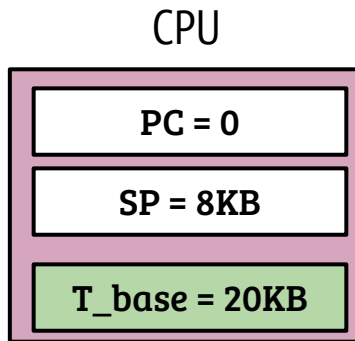
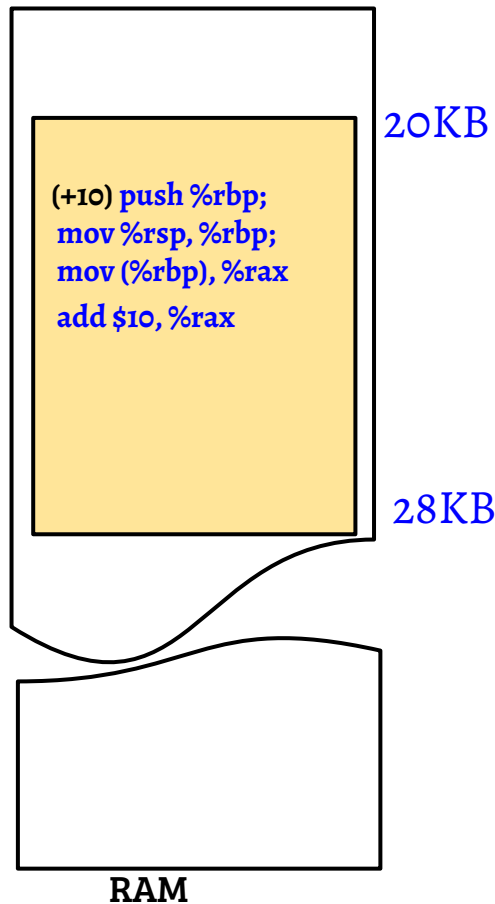


Here is a base register. I will add the value of base register with the virtual address generated by the program to get the physical address. All yours buddy!



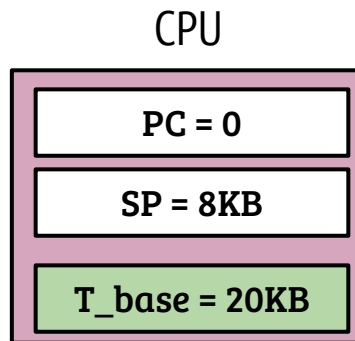
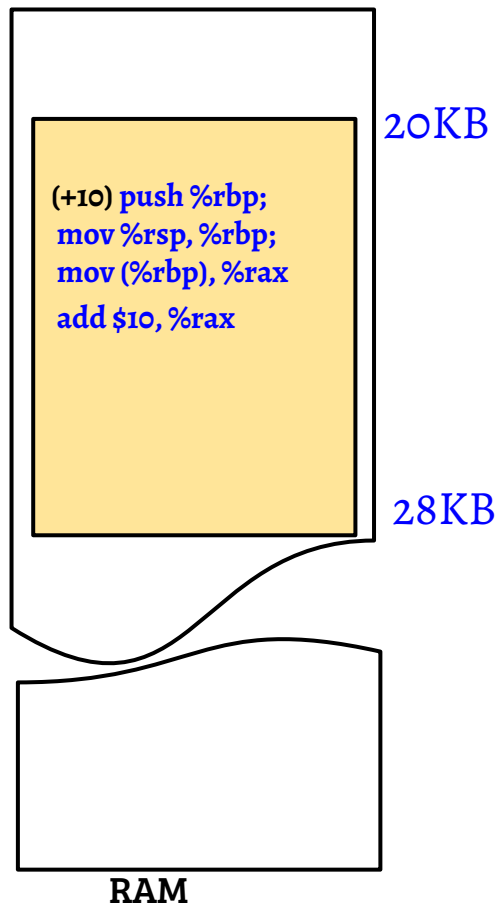
Hurray! I will configure the value of base register as per my need. I see some light atlast!

Translation



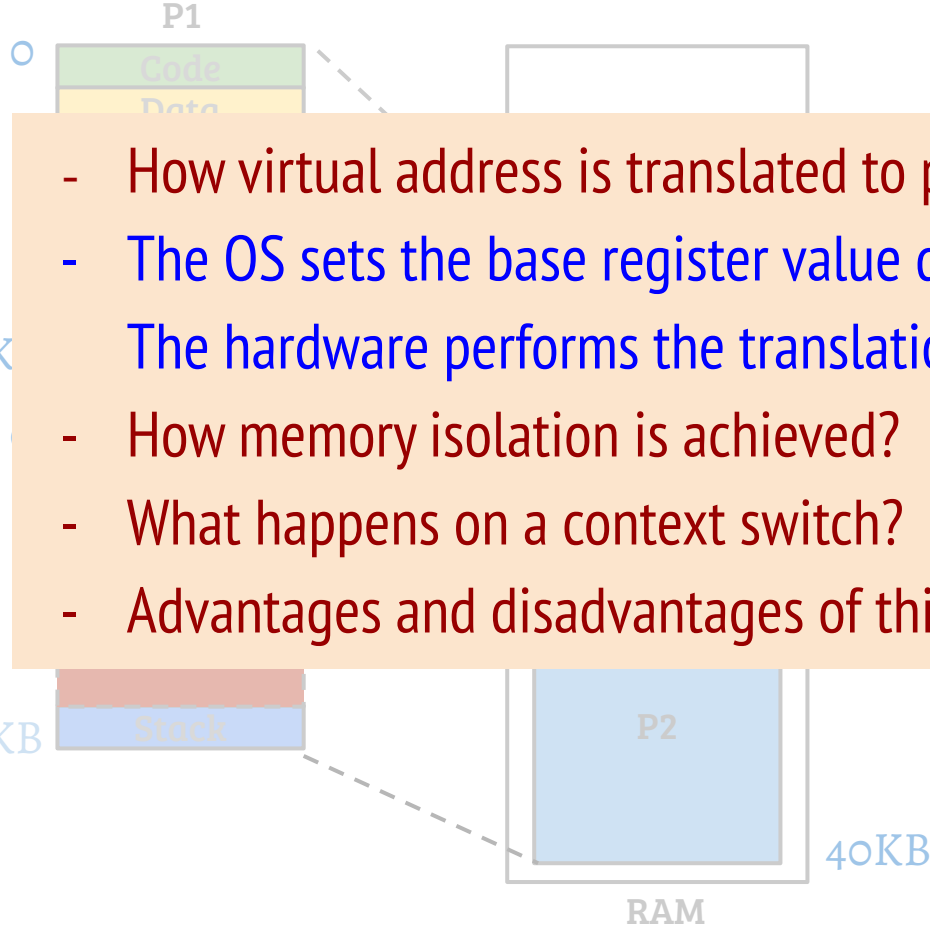
- In this case, base register value should be 20KB
- InsFetch (vaddr = 10) \Rightarrow InsFetch (paddr = 20KB + 10)
- How "push %rbp" works?

Translation



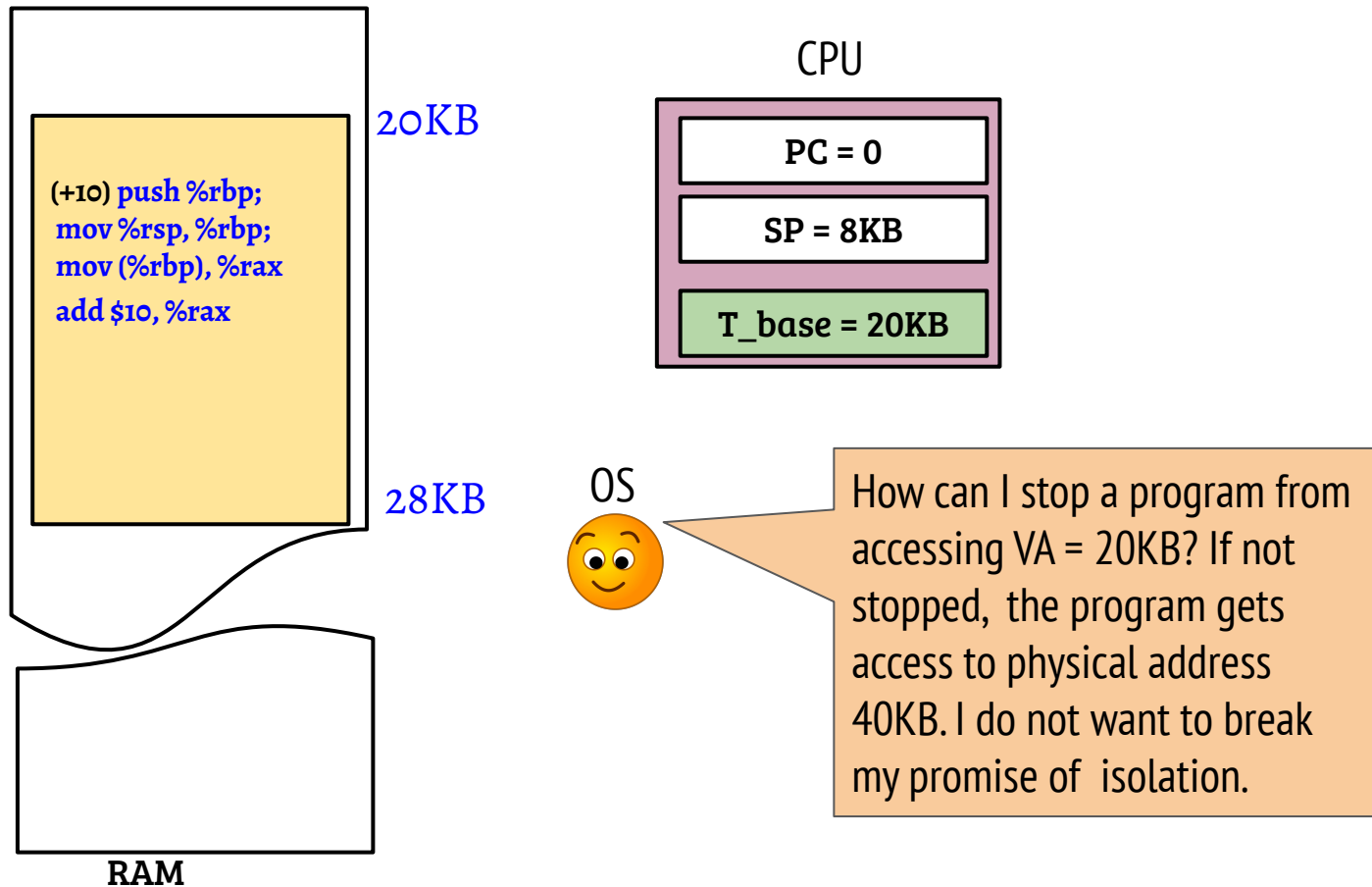
- In this case, base register value should be 20KB
- InsFetch (vaddr = 10) \Rightarrow InsFetch (paddr = 20KB + 10)
- How “push %rbp” works?
- Assuming RSP = 8KB, “push %rbp” results in a memory store at address (8KB - 8)
 - CPU translates the address to (28KB - 8)

Translation at address space granularity

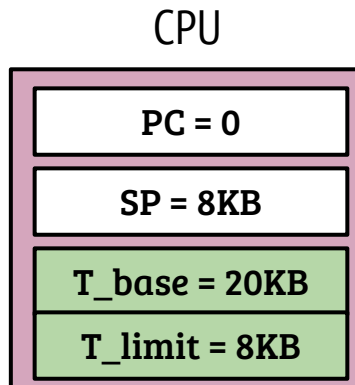
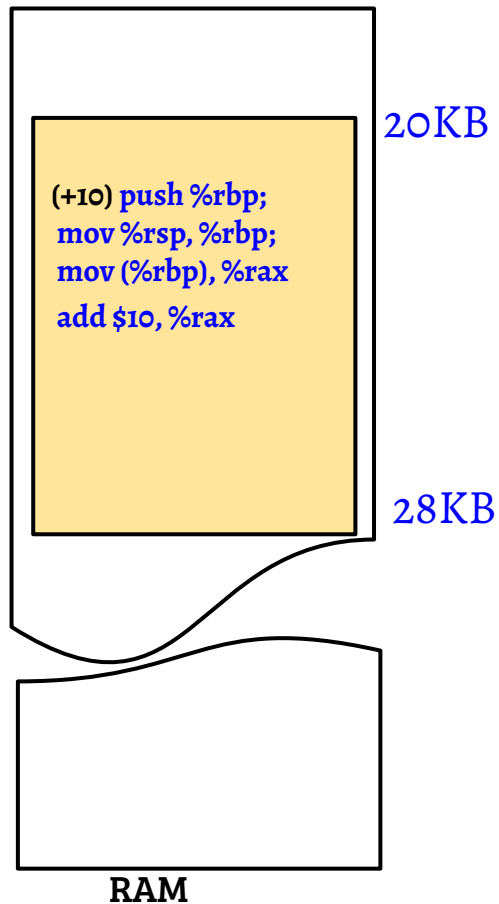


- How virtual address is translated to physical address?
- The OS sets the base register value depending on the physical location.
The hardware performs the translation using the base value.
- How memory isolation is achieved?
- What happens on a context switch?
- Advantages and disadvantages of this scheme

Isolation: How to stop illegal access?

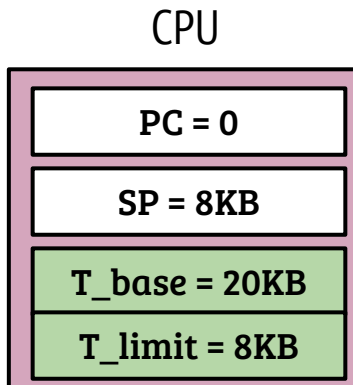
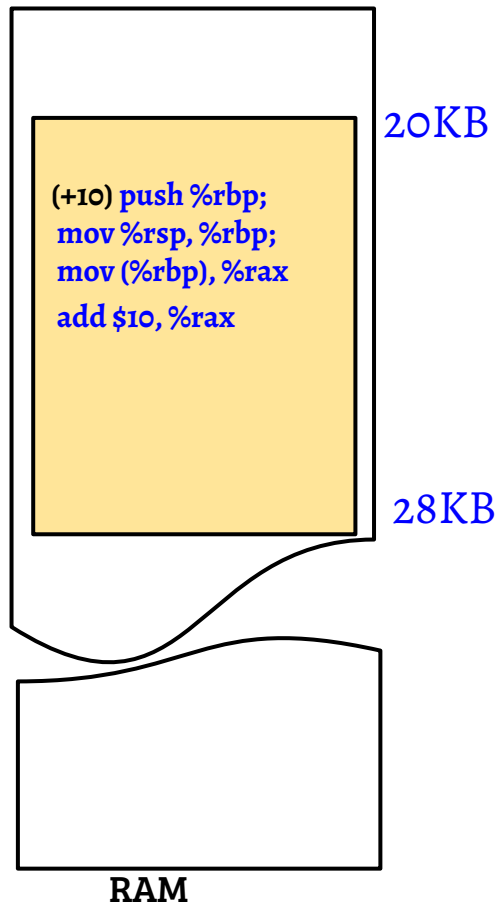


Isolation: How to stop illegal accesses?



Once a cry baby always a cry baby! I also provide a limit register to enforce the limit during translation. Before you ask, these registers can only be changed from privileged mode

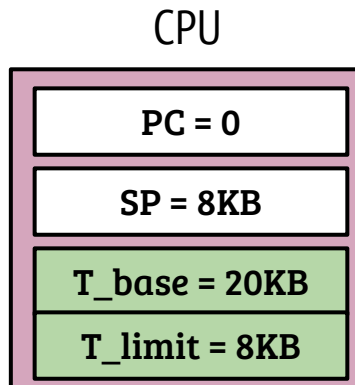
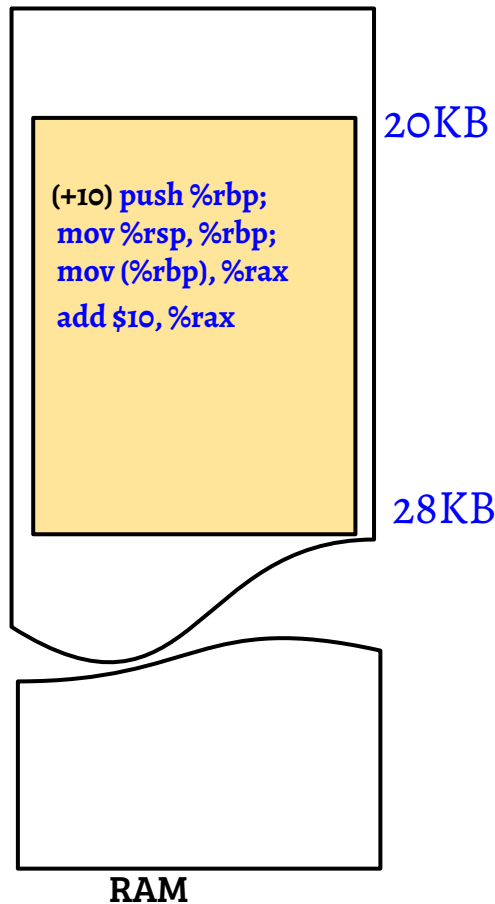
Isolation: How to stop illegal accesses?



Once a cry baby always a cry baby! I also provide a limit register to enforce the limit during translation. Before you ask, these registers can only be changed from privileged mode

- The hardware raises a fault if some program violates the limit.
- The OS fault handler may kill the process

Isolation: How to stop illegal accesses?



Once a cry baby always a cry baby! I also provide a limit register to enforce the limit during translation. Before you ask, these registers can only be changed from privileged mode

- The hardware raises a fault if some program violates the limit.
- The OS fault handler may kill the process
- (WE-1) `T_base` and `T_limit` values across processes

Translation at address space granularity



- How virtual address is translated to physical address?
- The OS sets the base register value depending on the physical location.
The hardware performs the translation using the base value.
- How memory isolation is achieved?
- Limit register can be used to enforce memory isolation
- What happens on a context switch?
- Advantages and disadvantages of this scheme



Context switch and translation information

- The base and limit register values can be saved in the outgoing process PCB during context switch
- Loaded from PCB to the CPU when a process is scheduled

Context switch and translation information

- The base and limit register values can be saved in the outgoing process PCB during context switch
- Loaded from PCB to the CPU when a process is scheduled
- (WE-2) User-to-OS context switching

Translation at address space granularity

P1

- How virtual address is translated to physical address?
- The OS sets the base register value depending on the physical location.
The hardware performs the translation using the base value.
- How memory isolation is achieved?
- Limit register can be used to enforce memory isolation
- What happens on a context switch?
- Save and restore limit and base registers
- Advantages and disadvantages of this scheme

RAM

Translation at address space granularity: Issues

- Physical memory must be greater than address space size
 - Unrealistic, against the philosophy of address space abstraction
 - Small address space size \Rightarrow Unhappy user

Translation at address space granularity: Issues

- Physical memory must be greater than address space size
 - Unrealistic, against the philosophy of address space abstraction
 - Small address space size \Rightarrow Unhappy user
- Memory inefficient
 - Physical memory size is same as address space size irrespective of actual usage \Rightarrow Memory wastage
 - Degree of multiprogramming is very less