第五讲物理内存管理: 非连续内存分配

第 6 节 RISC-V 页映射机制

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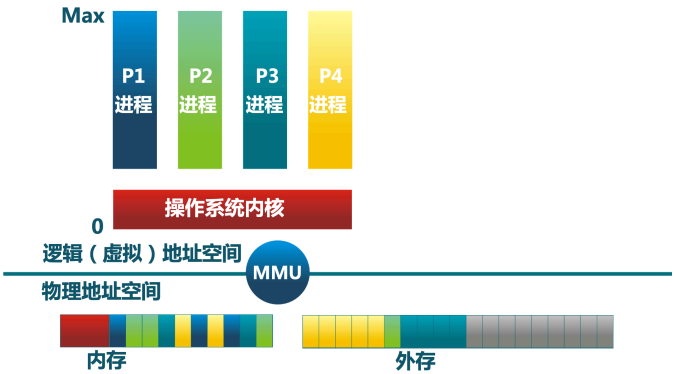
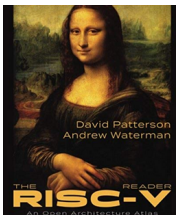
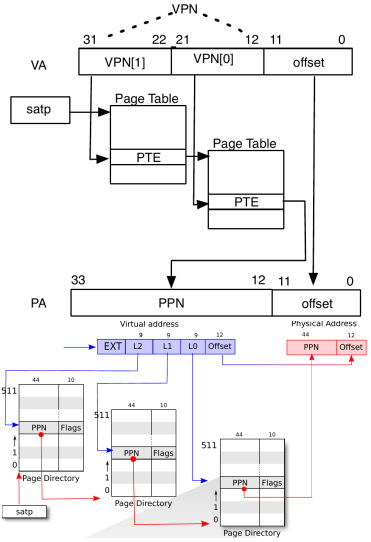
回顾



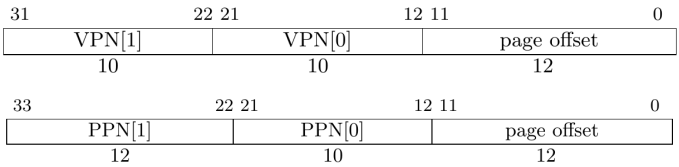
- 通过页表来实现隔离与共享
  - 运行的应用程序之间的隔离与共享
  - 应用与内核之间的隔离与共享
  - 便于非连续内存管理
  - RISC-V Privileged Architecture Version 1.10 (RV32/64)
  - The RISC-V Reader 第 10.6 节



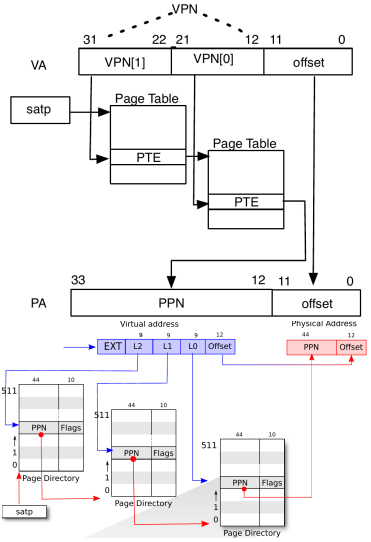
RISC-V 页映射机制



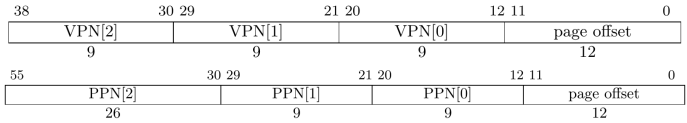
- RISC-V 对页表的硬件支持
  - RISC-V 32 的 Sv32 虚地址与物理地址



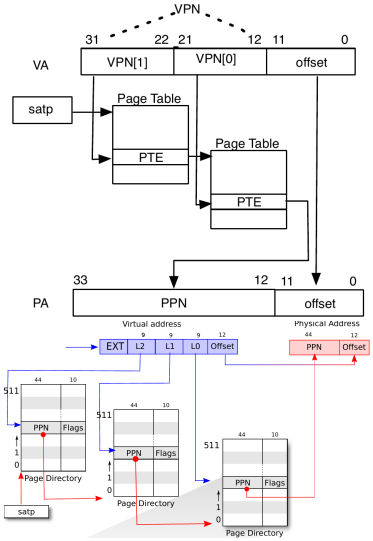
RISC-V 页映射机制



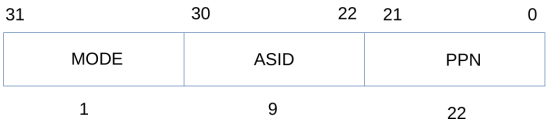
- RISC-V 对页表的硬件支持
  - RISC-V 64 的 Sv39 虚地址与物理地址



RISC-V 页映射机制

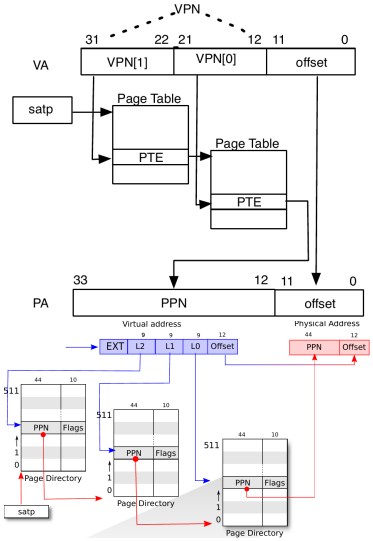


- RISC-V 对页表的硬件支持
  - 页表基址：satp in RISC-V 32
  - Supervisor Address Translation and Protection (satp) Register

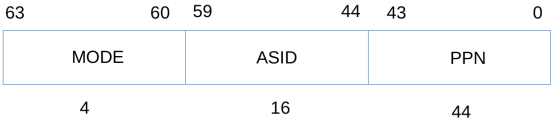


RV32 Supervisor address translation and protection register satp

RISC-V 页映射机制

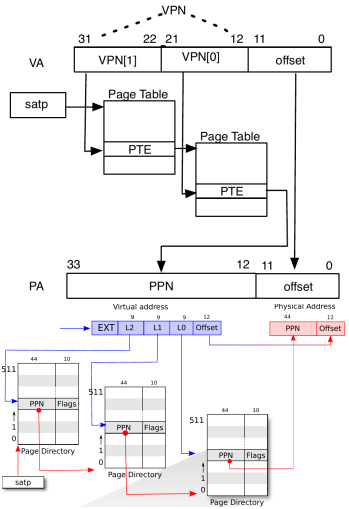


- RISC-V 对页表的硬件支持
  - 页表基址: satp in RISC-V 64
  - Supervisor Address Translation and Protection (satp) Register



RV64 Supervisor address translation and protection register satp

RISC-V 页映射机制

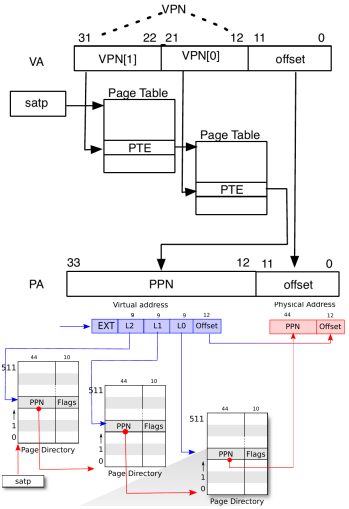


- RISC-V 对页表的硬件支持
  - 页表基址: satp in RV32/64
  - Supervisor Address Translation and Protection (satp) Register

RV32		
Value	Name	Description
0	Bare	No translation or protection.
1	Sv32	Page-based 32-bit virtual addressing.

RV64		
Value	Name	Description
0	Bare	No translation or protection.
1–7	—	*Reserved*
8	Sv39	Page-based 39-bit virtual addressing.
9	Sv48	Page-based 48-bit virtual addressing.
10	*Sv57*	*Reserved for page-based 57-bit virtual addressing.*
11	*Sv64*	*Reserved for page-based 64-bit virtual addressing.*
12–15	—	*Reserved*

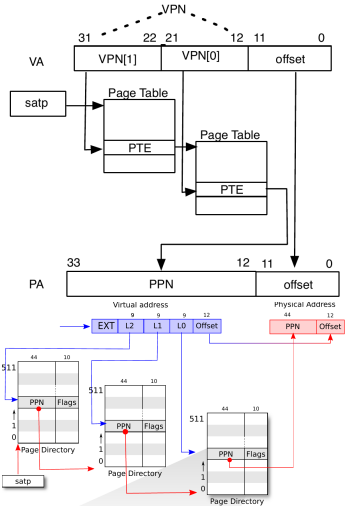
RISC-V 页映射机制



- RISC-V 对页表的硬件支持
  - 地址保护
  - 页表项（page table entry）

X	W	R	Meaning
0	0	0	Pointer to next level of page table.
0	0	1	Read-only page.
0	1	0	*Reserved for future use.*
0	1	1	Read-write page.
1	0	0	Execute-only page.
1	0	1	Read-execute page.
1	1	0	*Reserved for future use.*
1	1	1	Read-write-execute page.

RISC-V 页映射机制



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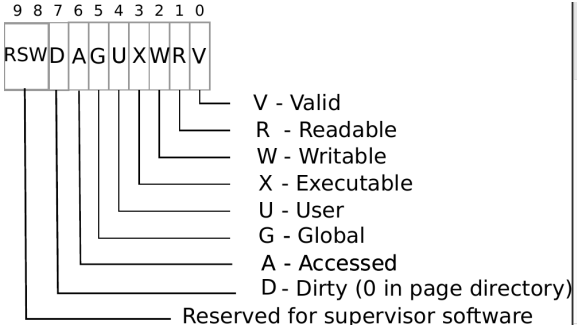
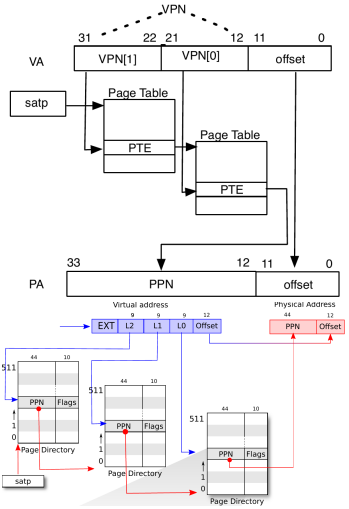
  - 地址保护
  - 页表项（page table entry）



RISC-V 页映射机制

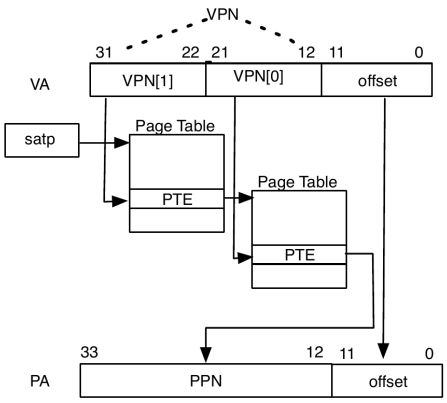


- RISC-V 对页表的硬件支持
  - 地址保护
  - 页表项（page table entry）

31 20	19 10	9 8
PPN[1]	PPN[0]	RSW
12	10	2

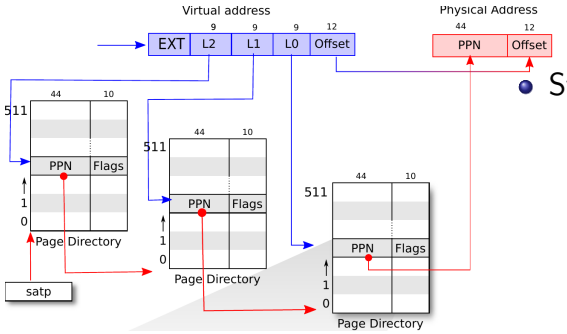
63 54	53 28	27 19	18 10	9 8
Reserved	PPN[2]	PPN[1]	PPN[0]	RSW
10	26	9	9	2

RISC-V 地址转换



- Sv32 in RV32
  - 当在 satp 寄存器中启用了分页时, 虚拟地址映射启动。
  - 1. satp.PPN 给出一级页表基址,VA[31:22] VPN[1] 给出一级页号,CPU 会读取位于地址 (satp. PPN $\times$ 4096 + VA[31: 22] $\times$ 4) 的页表项。
  - 2. 该 PTE 包含二级页表的基址,VA[21:12] 给出二级页号,CPU 读取位于地址 (PTE. PPN $\times$ 4096 + VA[21: 12] $\times$ 4) 的叶节点页表项。
  - 3. 叶节点页表项的 PPN 字段和页内偏移 (原始虚址的最低 12 个有效位) 组成了最终结果: 物理地址就是 (LeafPTE. PPN $\times$ 4096 + VA[11: 0])

RISC-V 地址转换



- Sv39 in RV64
  - 地址映射要计算三次
  - (satp.PPN $\times$ 4K $+$ L2 $\times$ 8) 的页目录项
  - (PTE.PPN $\times$ 4K $+$ L1 $\times$ 8) 的二级页目录项
  - (LeafPTE.PPN $\times$ 4K $+$L0 x 8) 叶节点页表项
  - 叶节点页表项的 PPN 字段 $\times$ 4K $+$ Offset

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第 7 节使能 RISC-V 页表

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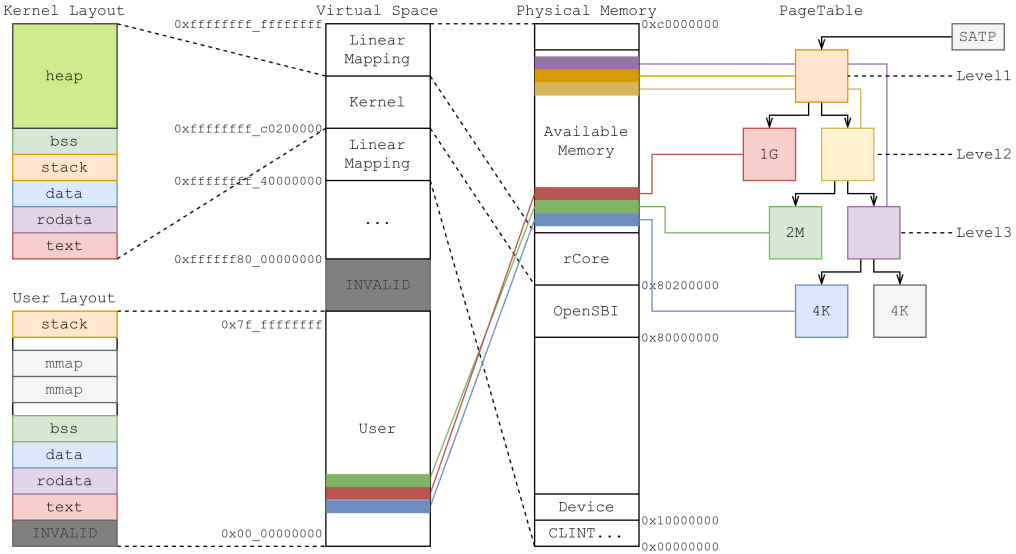
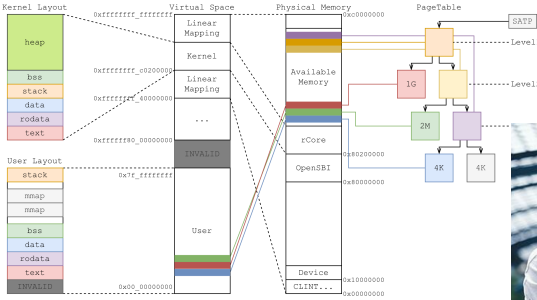
使能 RISC-V 页表


Kernel Layout
heap
bss
stack
data
rodata
text
User Layout
stack
mmap
mmap
bss
data
rodata
text
INVALID
Virtual Space
0xffffffff_ffffffff
Linear Mapping
Kernel
0xffffffff_c0200000
Linear Mapping
0xffffffff_40000000
...
0xffffff80_00000000
INVALID
0x7f_ffffffff
User
0x00_00000000
Physical Memory
0xc0000000
Available Memory
rCore
0x80200000
OpenSBI
0x80000000
Device
0x10000000
CLINT...
0x00000000
PageTable
SATP
Level1
1G
Level2
2M
Level3
4K
4K

OS 配置页表的流程



- 为页表分配物理内存
- 确定映射的物理空间与虚拟空间
- 创建页表
- 设置 satp，刷新 TLB，使能页表