# [537] Smaller Page Tables

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9/24/14

# Worksheets

Problem 1: how many accesses with TLB?

Problem 2: how large are PTEs?

- tip, use indexes to save memory

Problem 3: how large are PTs?

## Smaller Page Tables

## Paging Problems

Too slow [last time]

Too big [today’s focus]

## Motivation

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Make pages bigger

Worksheet: Problem 4

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Worksheet: Problem 4

Why are 4 MB pages bad?  Internal fragmentation.

# Mixed Page Sizes

Some systems support multiple page sizes
- better TLB is bigger motivation, though

Mechanisms: what are implications for
- PTs?
- TLBs?

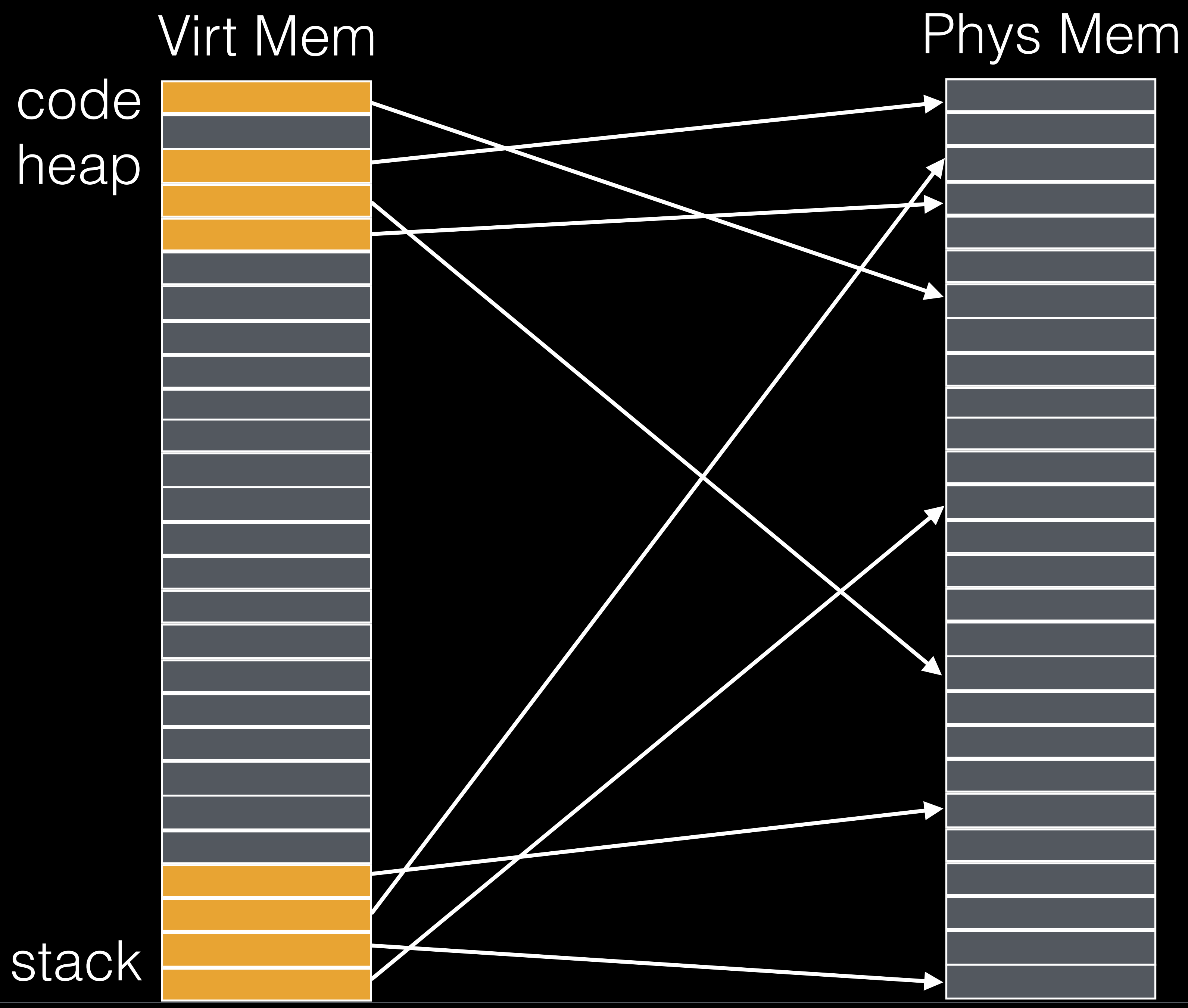
Policy: when to use large pages?

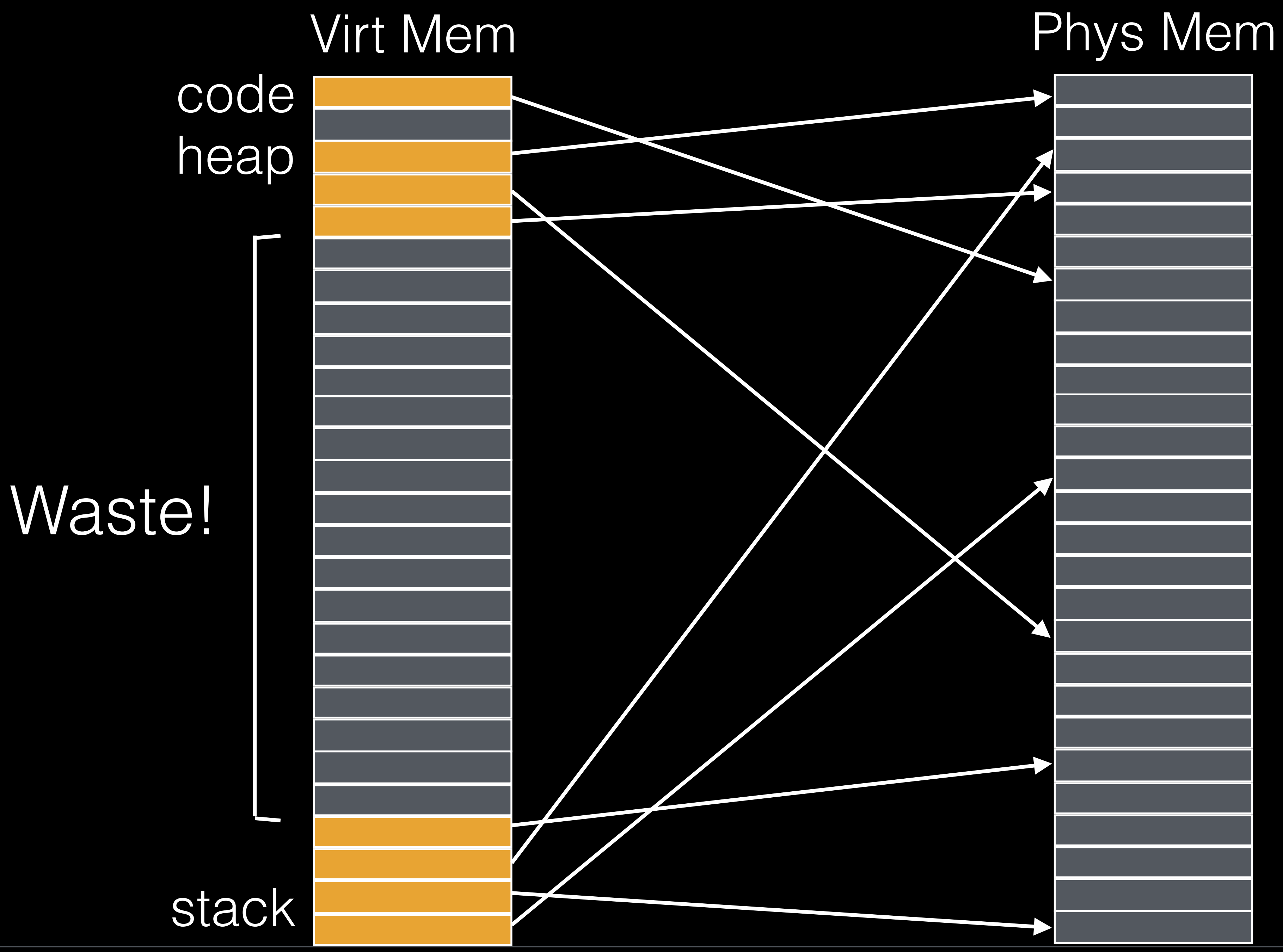
## Approach 2: abandon simple linear page tables

Use more complex PTs, instead of just a big array.

Suggestions?

Look at problem more closely…


Virt Mem
Phys Mem
code
heap
stack


Virt Mem
Phys Mem
code
heap
Waste!
stack

# Many invalid PT entries

| PFN | valid | prot |
|---|---|---|
| 10 | 1 | r-x |
| - | 0 | - |
| 23 | 1 | rw- |
| - | 0 | - |
| - | 0 | - |
| - | 0 | - |
| - | 0 | - |
| *…many more invalid…* | | |
| - | 0 | - |
| - | 0 | - |
| - | 0 | - |
| - | 0 | - |
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how to avoid storing these?

## Approach 2a: hash-table lookup

Called an inverted page table.

Pros/Cons?

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Nice if we trapped on TLB misses…

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How did we fix holes in phys memory before?
- segmentation
- paging

# Approach 2

**Approach 2a**: hashtable

**Approach 2b**: segments over PTs

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**Approach 2d**: PTs over PTs over PTs over PTs

**for fun!**

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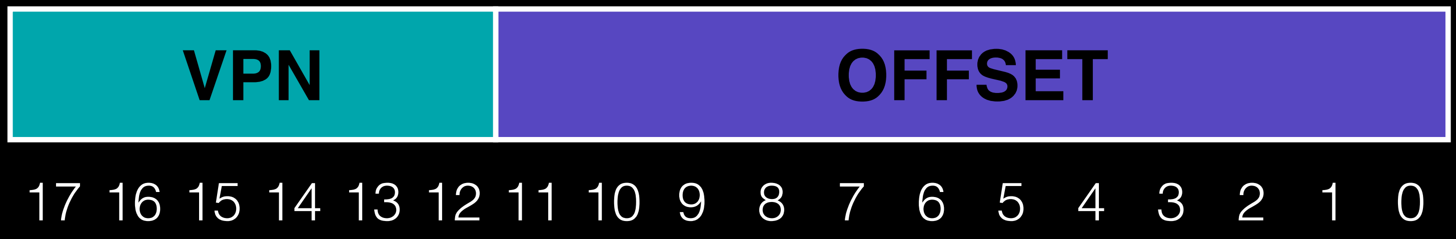
Before:



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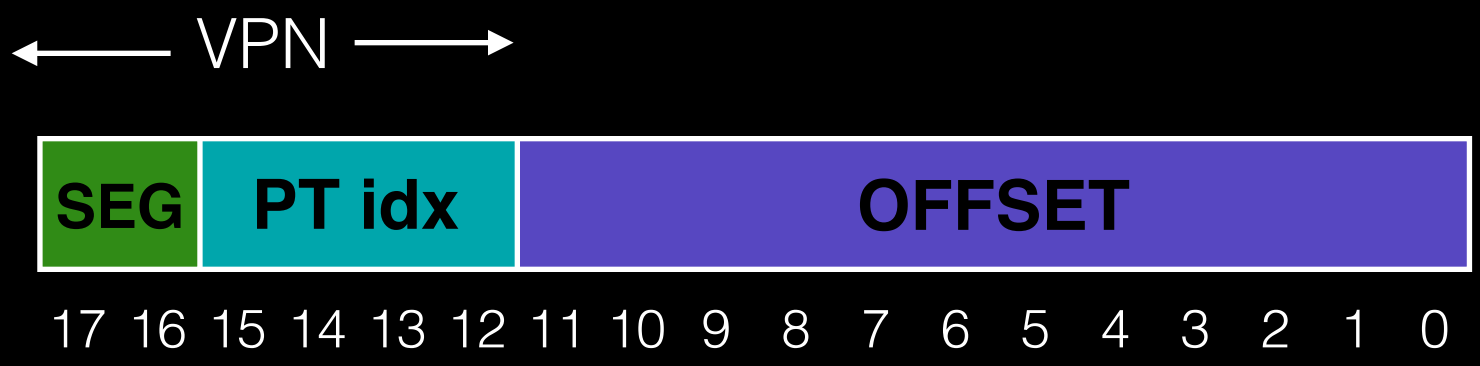

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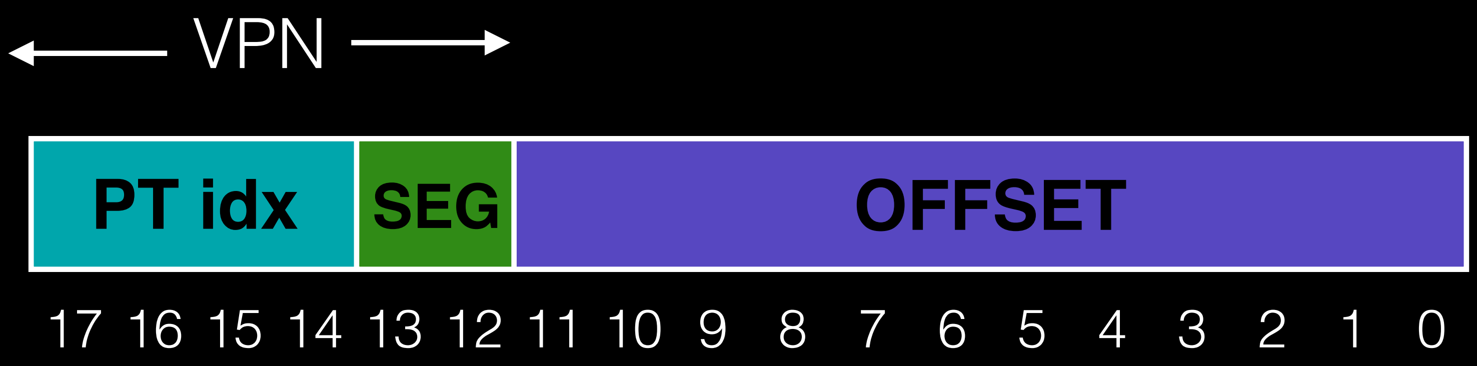

why not?

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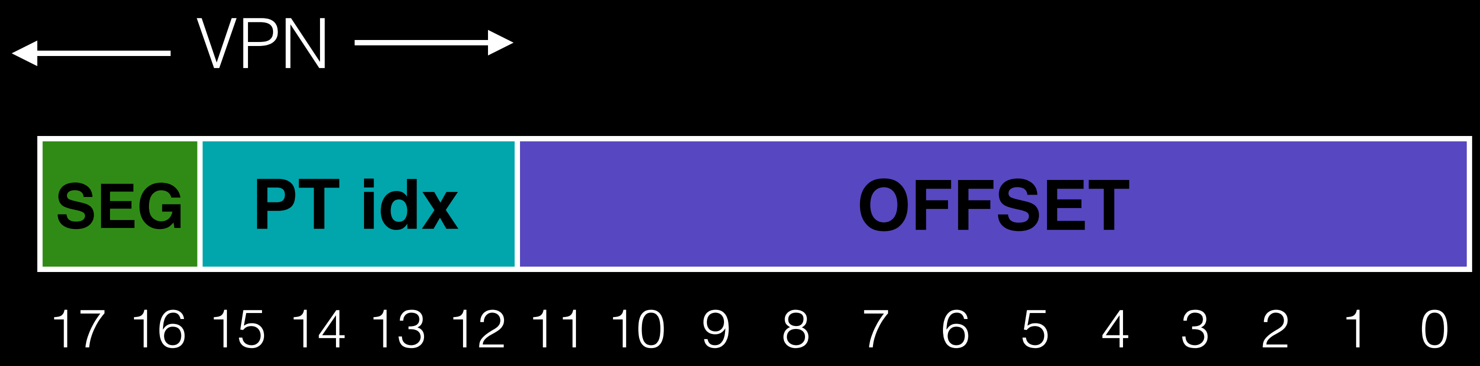

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segment 00: code

| PFN | valid | prot |
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| 0x15 | 1 | r-x |
| 0x12 | 1 | r-x |
| … | | |

segment 01: heap

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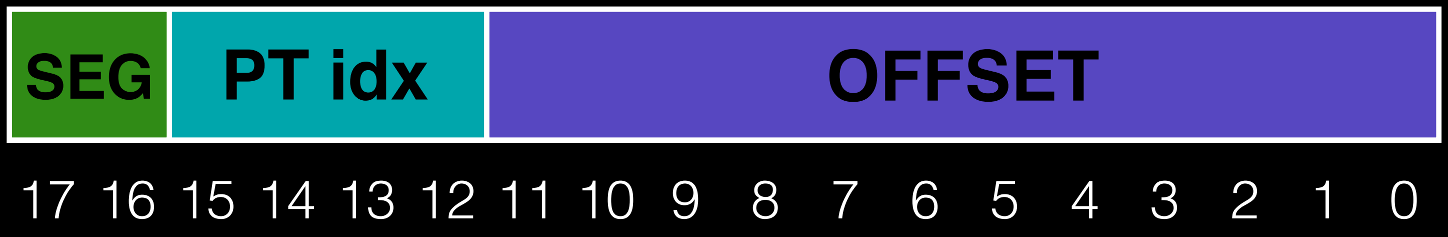

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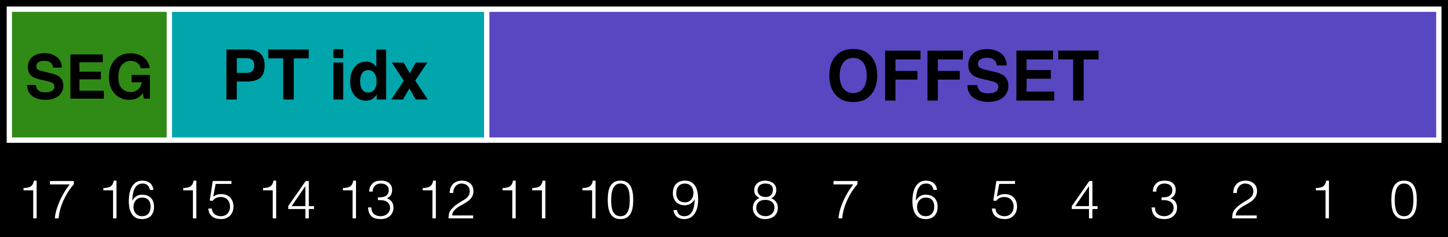

Problem 5
(worksheet)

# Segmentation/Paging Hybrid

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| 0x12 | 1 | r-x |
| … | | |

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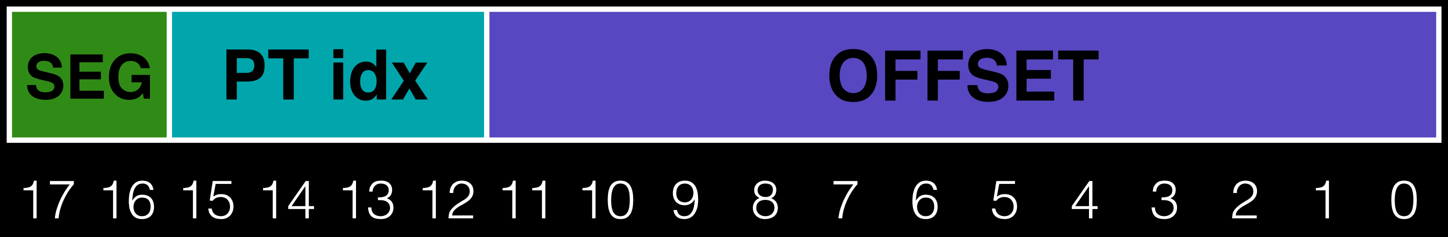

What about the stack?
(OSTEP skips this)

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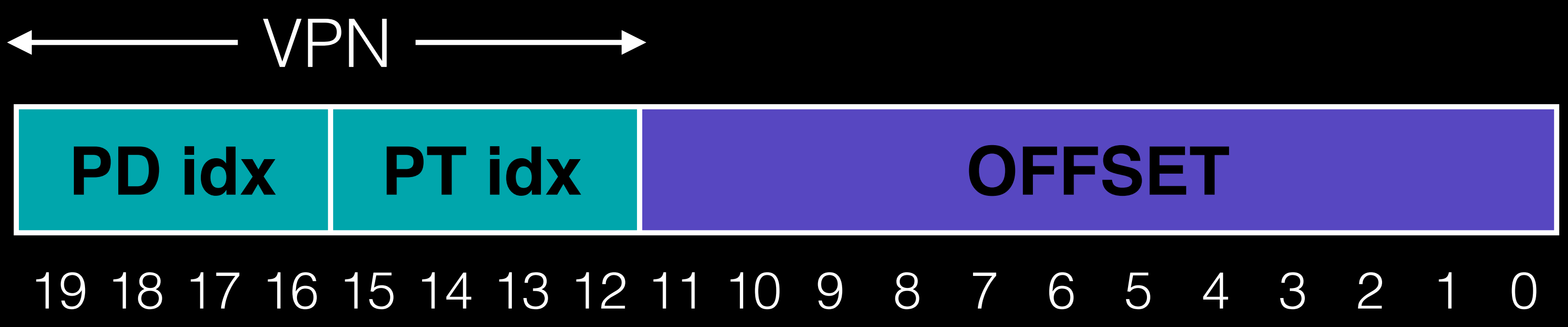

**page directory**

| PFN | valid |
|---|---|
| 0x3 | 1 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| 0x92 | 1 |

**page of PT (@PFN:0x3)**

| PFN | valid |
|---|---|
| 0x10 | 1 |
| 0x23 | 1 |
| - | 0 |
| - | 0 |
| 0x80 | 1 |
| 0x59 | 1 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |

**page of PT (@PFN:0x92)**

| PFN | valid |
|---|---|
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| - | 0 |
| 0x55 | 1 |
| 0x45 | 1 |

Problem 6
(worksheet)

assume 20-bit virtual addrs

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Paging goals:

- space efficiency (don’t waste on invalid data)
- **simplicity (no bookkeeping should require contiguous pages)**
  - page directories are too big!

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Problem: page directories may not fit in a page

Solution: split page directories into pieces.
Use another page dir to refer to the page dir pieces.

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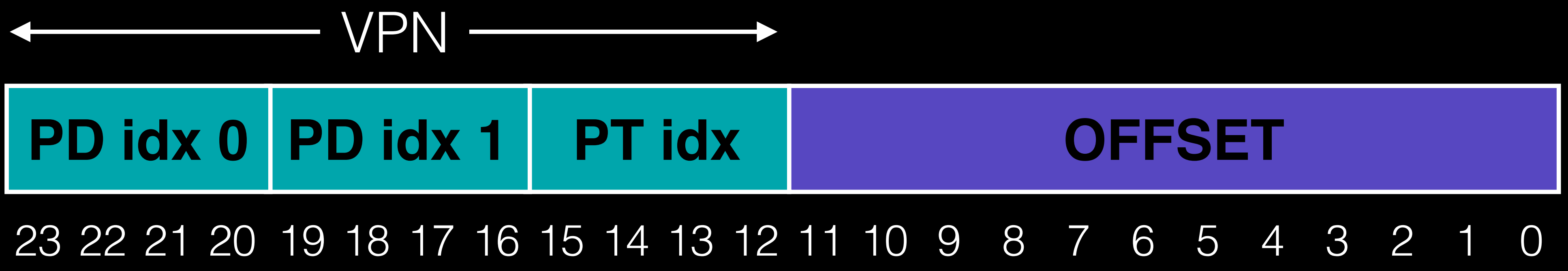

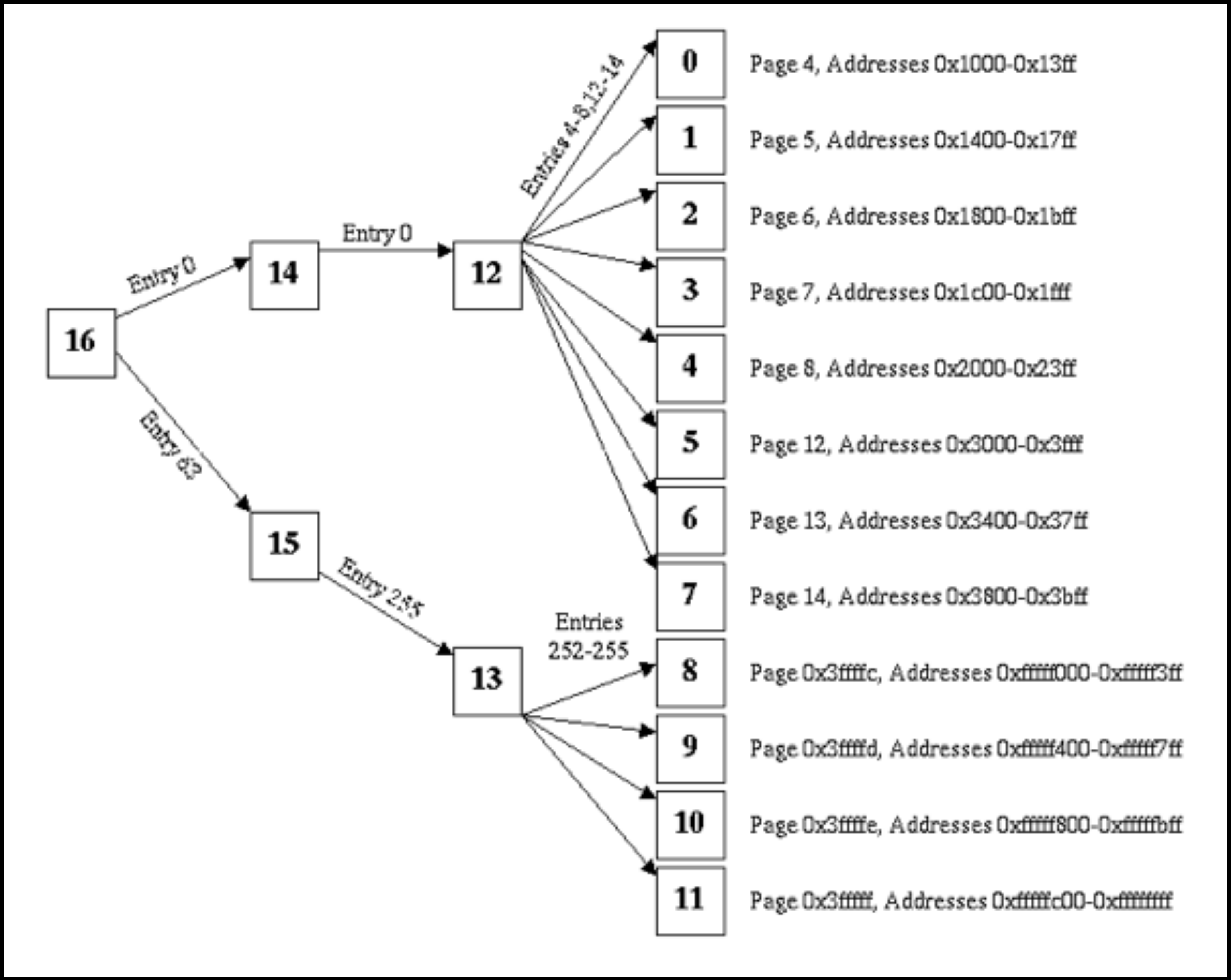
16
Entry 0
14
Entry 0
12
Entries 4-8,12-14
Entry 63
15
Entry 255
13
Entries 252-255
0
Page 4, Addresses 0x1000-0x13ff
1
Page 5, Addresses 0x1400-0x17ff
2
Page 6, Addresses 0x1800-0x1bff
3
Page 7, Addresses 0x1c00-0x1fff
4
Page 8, Addresses 0x2000-0x23ff
5
Page 12, Addresses 0x3000-0x3fff
6
Page 13, Addresses 0x3400-0x37ff
7
Page 14, Addresses 0x3800-0x3bff
8
Page 0x3ffffc, Addresses 0xfffff000-0xfffff3ff
9
Page 0x3ffffd, Addresses 0xfffff400-0xfffff7ff
10
Page 0x3ffffe, Addresses 0xfffff800-0xfffffbff
11
Page 0x3fffff, Addresses 0xfffffc00-0xffffffff

http://web.eecs.utk.edu/~mbeck/classes/cs560/560/oldtests/t2/2003/Answers.html

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How many levels do we need? (Problem 7)

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# What about TLBs?

Lookups in multiple levels more expensive.

How much does a miss cost? (problem 8)

Time/Space tradeoffs.

## Summary

Many PT options are possible.

Time/Space/Complexity tradeoffs.

OS traps on TLB misses would be ideal.

x86 walks multi-level PTs.

## Announcements

P2a due in 9 days!

Discussion tomorrow…

FB tech talk tonight.