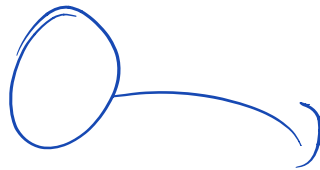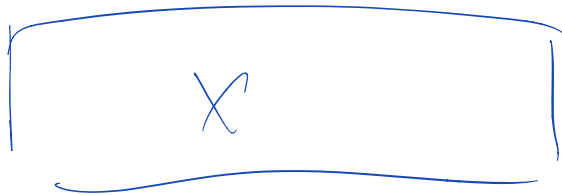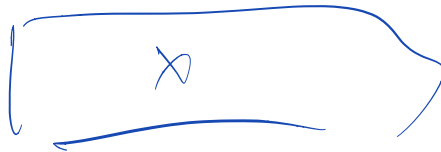X

X

X

X   some
address

[00DEADBEEF]

64 bits

00000-a

globals

stack

heap

FFFFFF
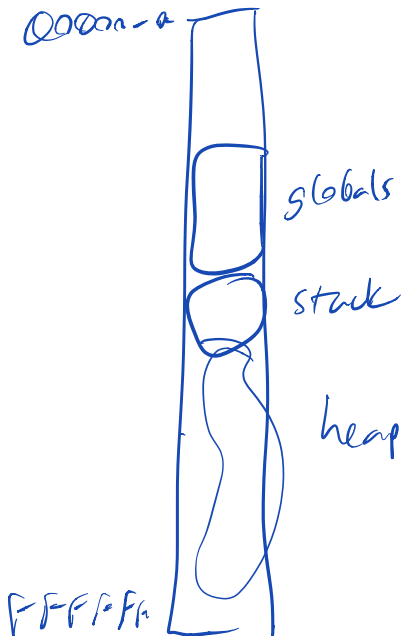
X = 12;

MOV [00DEADBEEF], AX

void foo (int x) {
    int x;   ← STACK
    int * z = new int;
                      ↑ HEAP
}

0 64 bits   " word" size
(8 bytes)

"memory"

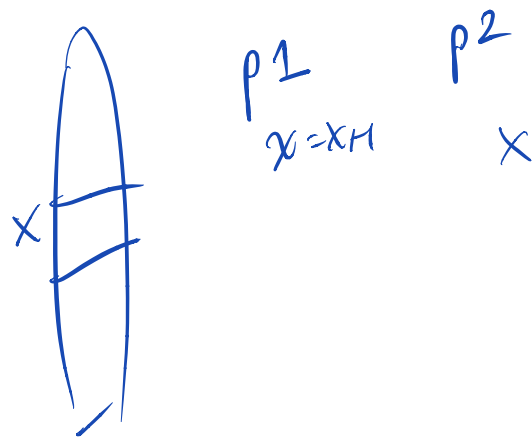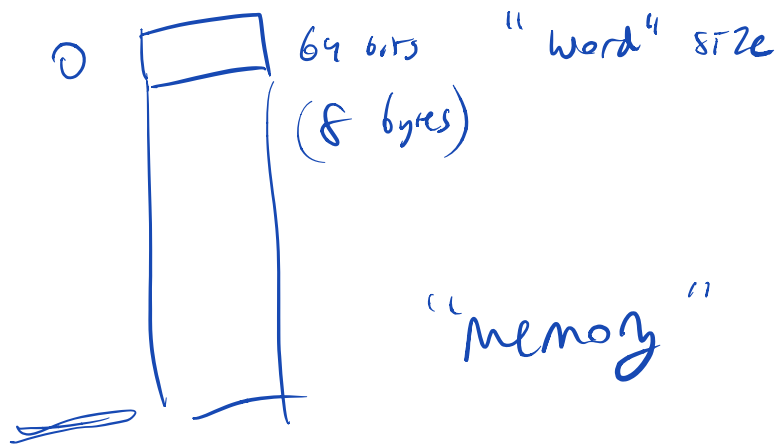P1   P2
x=xH   x

x

— portability
— isolation
— limited memory (<< 2B 6B)

"virtual memory"
↓
physical memory ← OS

2^{61} words
2^{64} bytes

16 GB
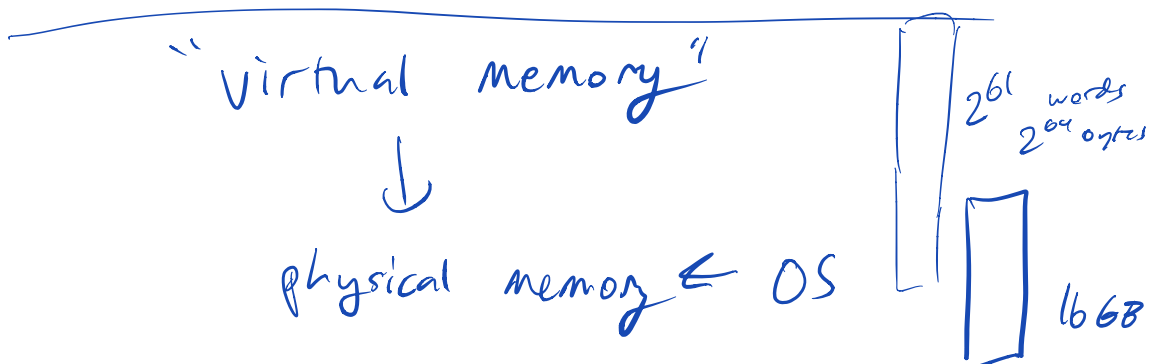
"all problems in CS
solved by adding one level
of indirection"

process 1

1,000,000
1,000,001

page
(4K)

virtual
mem.

x

300,000
300,001
:
400,000

physical
mem

P2

1,000,000 x

translation

1,000,000

3   →   300,000 → physical
                              memory

virt   phys

$\left(\begin{array}{cc} 1,000,000 & 300,000 \end{array} \right)$

Swapping

demand
paging

RAM

200100

DISK

900000 swap partition
swapfile
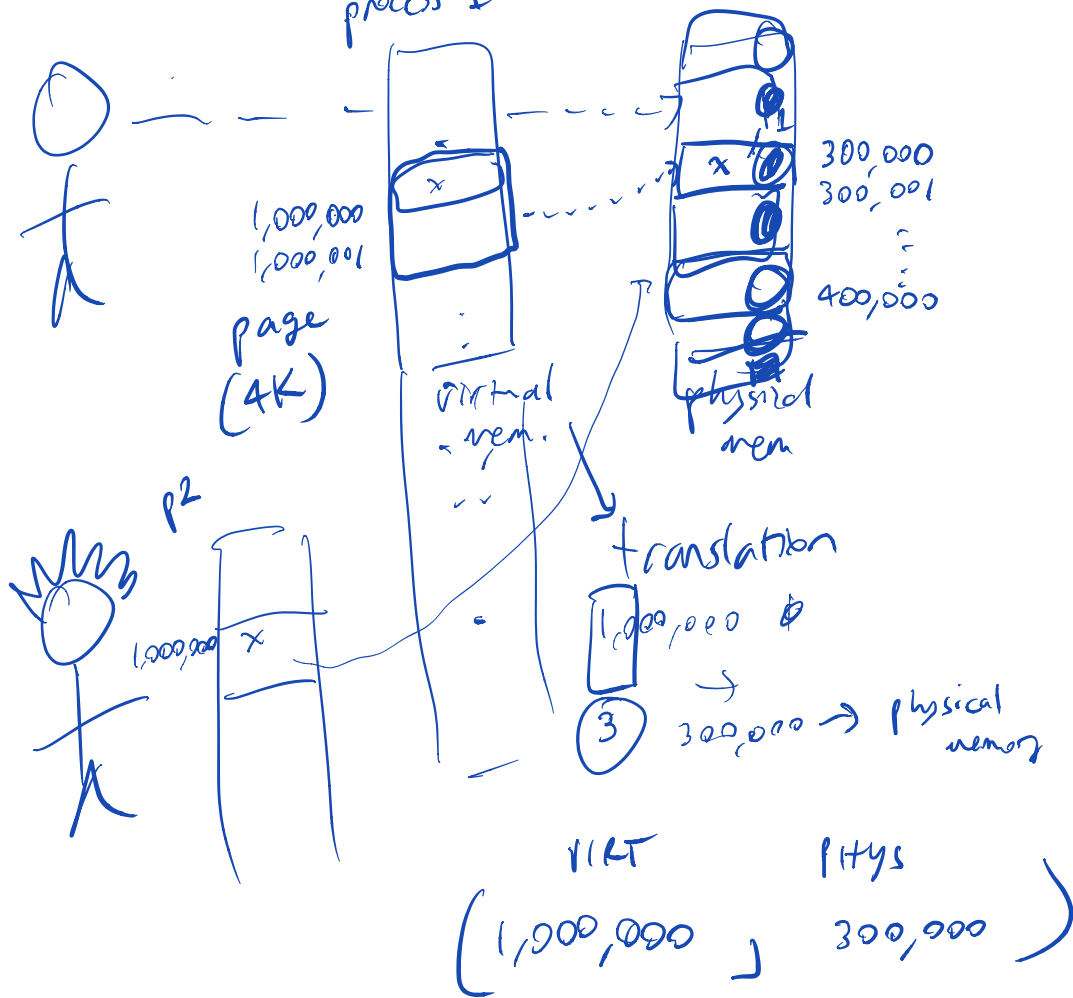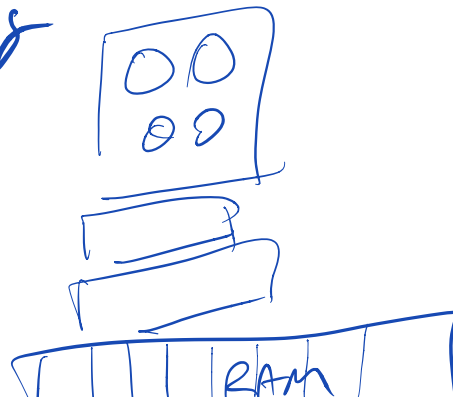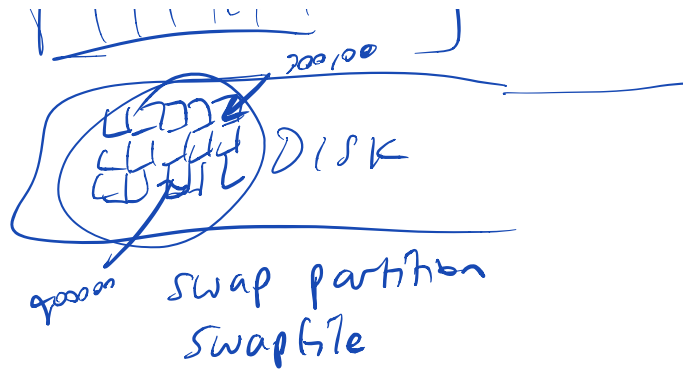
eviction

— random

— LRU
(least recently used

recency

" CLOCK "

Redline
OSDI 2006

O O O

Φ Φ Φ saturation

O O Φ

(OOO)

| 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
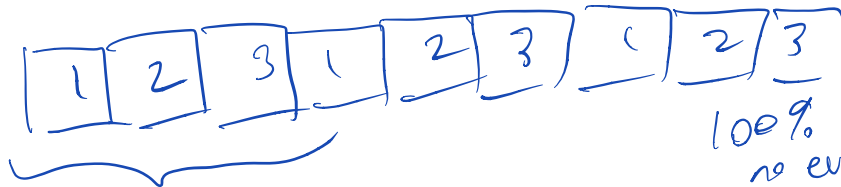
100% hit rate
no eviction
no misses

| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | . . .

0% hit rate
alleviation

LRU

$$\lim_{n \to \infty} \left(\frac{1}{3}\right)^N = 0$$

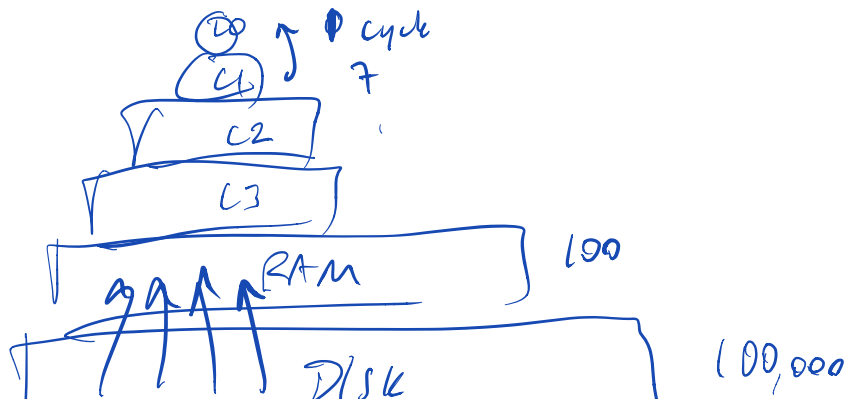MRU   LFU
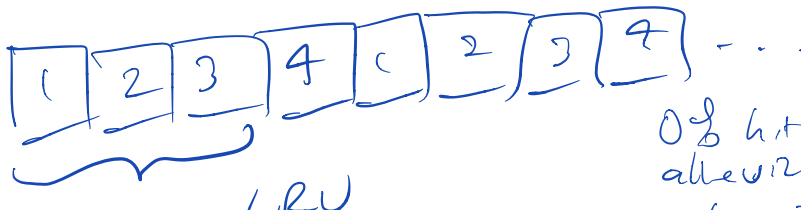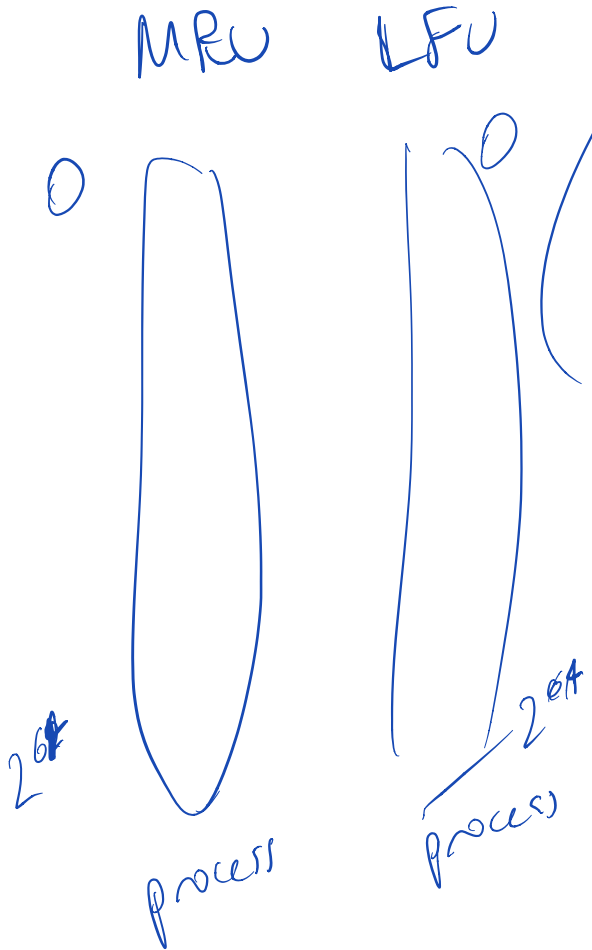
Chrome

— memory leak

C++
each
— tab new process

— V8

— Cache

O

O

2^{64}

process

2^{64}

process

hw $\Big\lbrace$ TLB
L0 L1 L2 L3

OS $\Big\lbrace$ buffer cache

app $\Big\lbrace$ caches

cycle
7

C2

C3

RAM   100

DISK   100,000

WEB

1,000,000

Akamai
CloudFlare
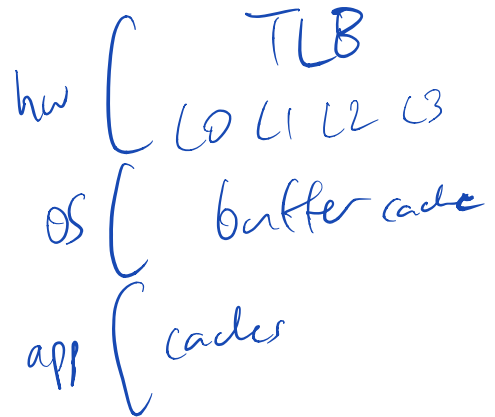
CDN
Content
distrib.
networks

Optimizely

ALU   CPU   TLB

translation
lookaside
buffer

MMU
mem mgmt
unit

Caches mappings

(virt, phys)

(1,000,000, 300,000)

"page table"

1,000,000 $\longrightarrow$ (f)

1,000,000

1,000,000

$\downarrow \downarrow \downarrow \downarrow$

$\downarrow$

$V_1 P_1$
$V_2 P_2$
$V_3 P_3$
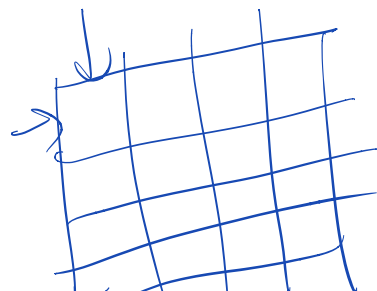
TLB
256
512 entries

[unin]

high TLB pressure

Working set

4K   8K

4K   2MB   1GB

huge pages
yuse pays

Superpages