Cyber Security

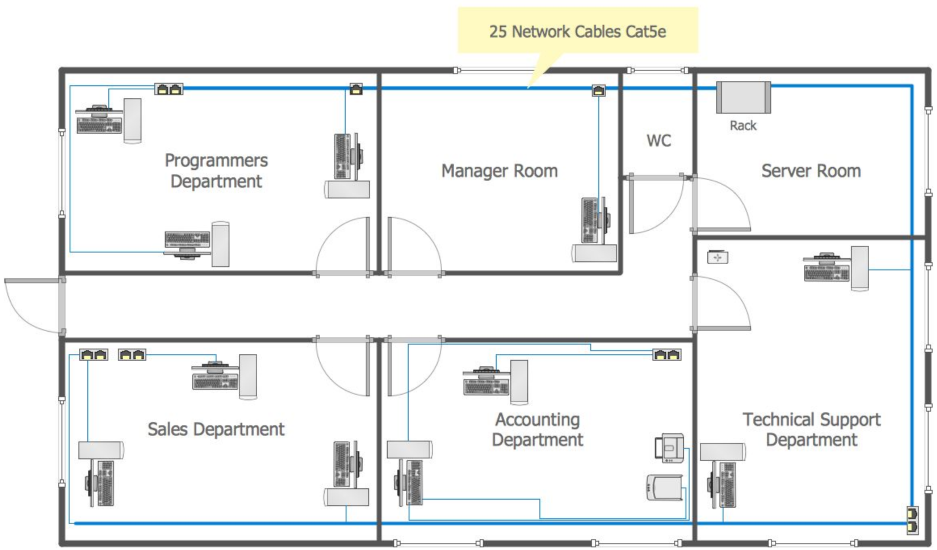
Understanding the platform

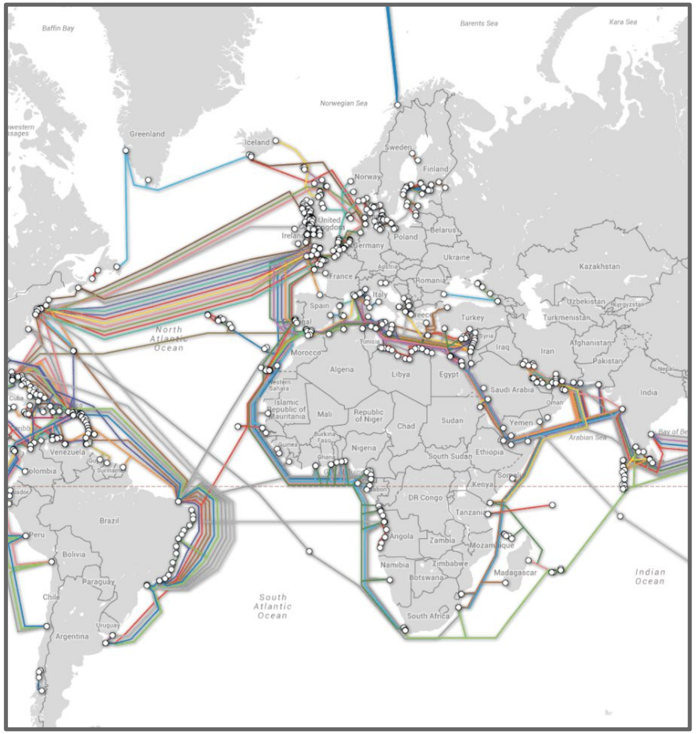
Chris G. Willcocks
Durham University

Recap Knowing the battlefield and the threat landscape

With the internet, the battlefield is much larger and more complex than in traditional warfare.

- Think hierarchically





https://www.submarinecablemap.com

Hilda

Computer architectures are simple, but with clever wiring

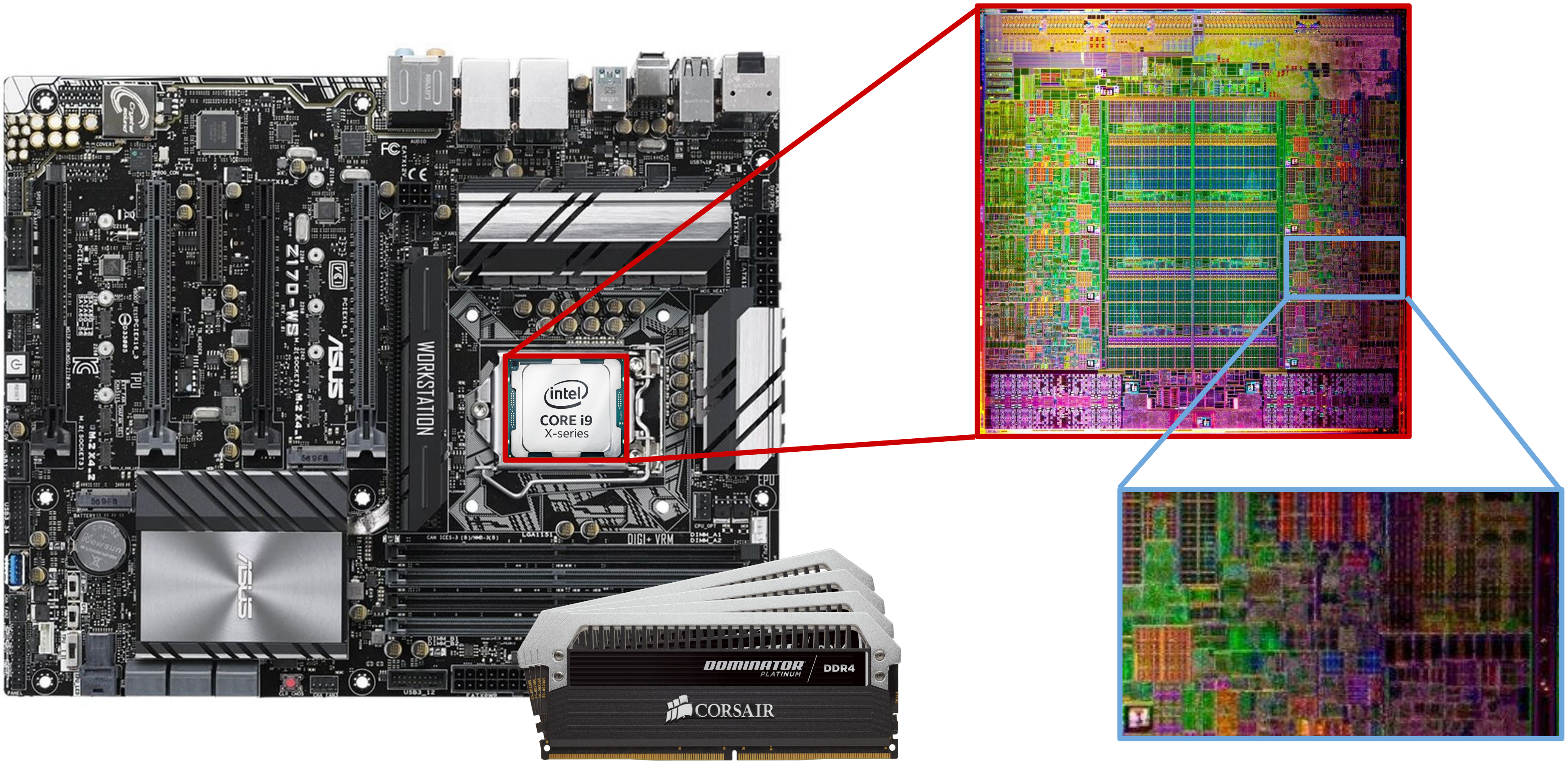
Today Zooming in on the threat landscape

1. Understanding the computer architecture (getting close to the metal)
2. Understanding the stack
3. Stack and heap memory vulnerabilities
4. Smashing the stack
5. Dangerous system calls
6. Race condition attacks
7. Timing attacks

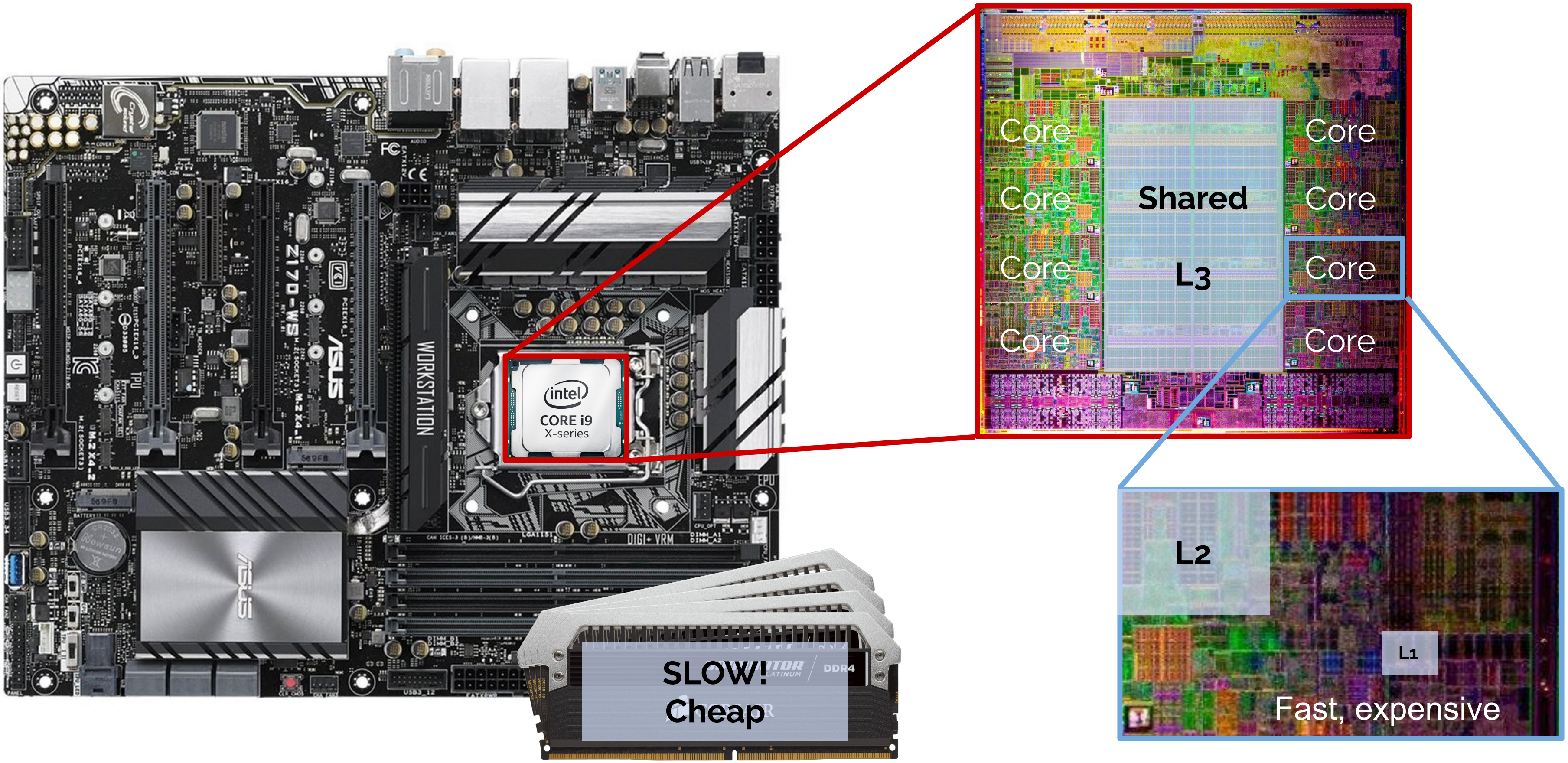
Today

Coming up

Getting Close to the Metal

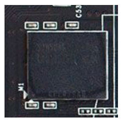


Getting Close to the Metal

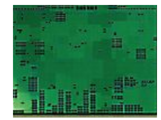


Getting Close to the Metal

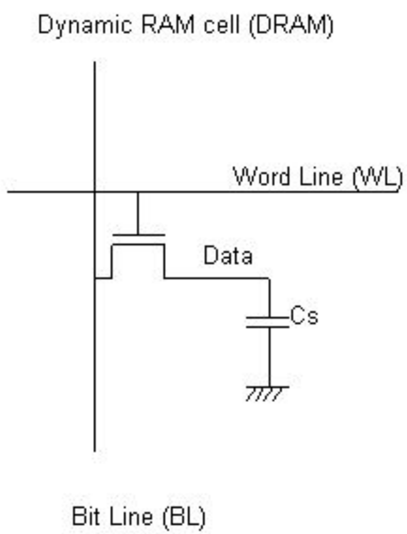
Two types of memory: DRAM & SRAM

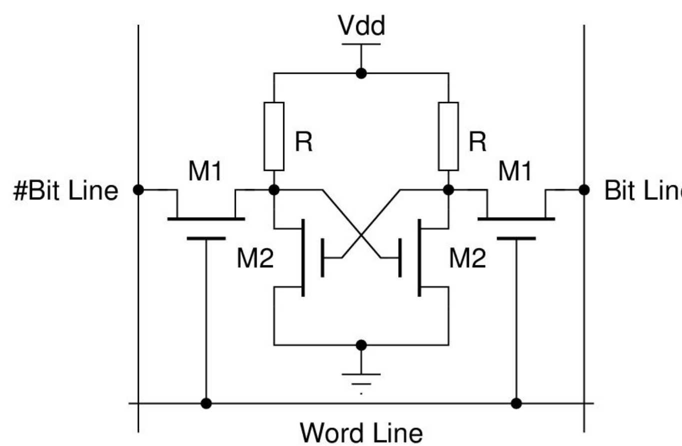


1 transistor per bit
- “slow”
- cheap



4+ transistors per bit
- fast (~4 clock cycles)
- expensive
- takes up space on die





Computer Architecture

Fast, expensive,
close to core(s)

Cheap, slow, far
from core(s)

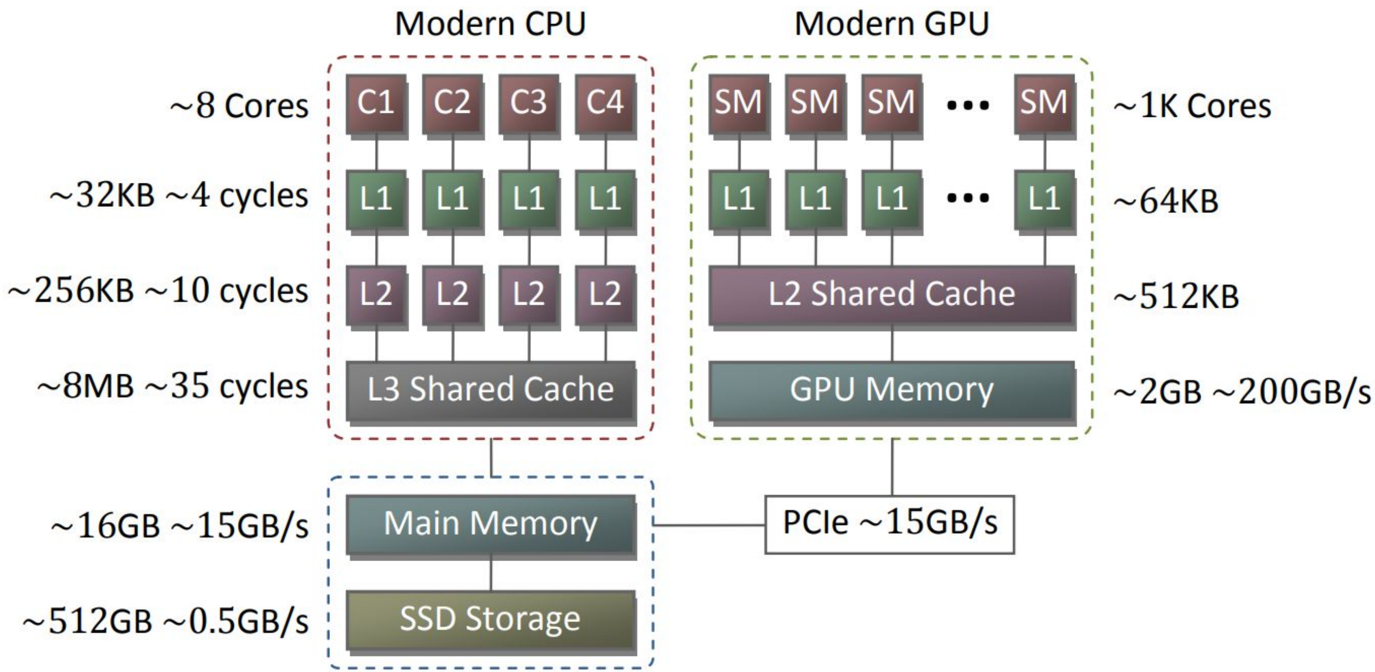
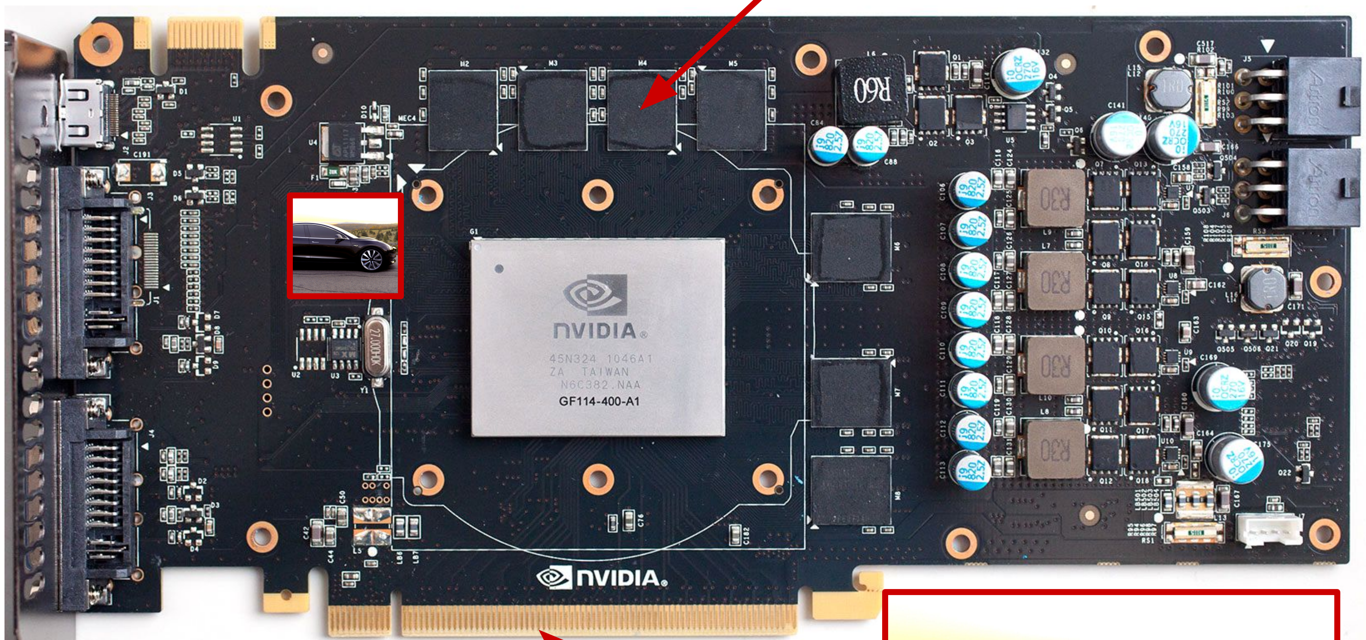


Figure 11: Abstraction of the basic memory hierarchy for a modern CPU and GPU.

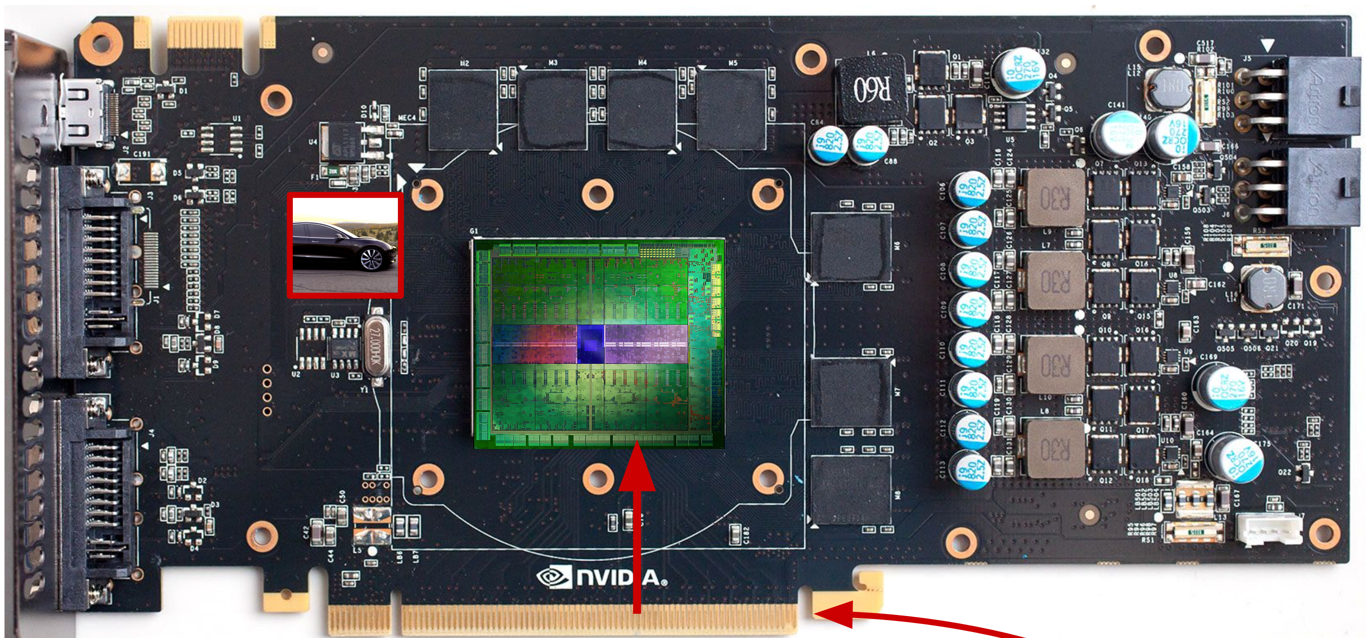
Getting Close to the Metal (GPU)

GDDR5 “SLOW”, Cheap



0,0,1,1,0,1,0,1,0,0,1,1,1,
1,0,0,1,0,0,1,1,1, ...

Getting Close to the Metal (GPU)




```
Vector car_image
Vector output
Kernel( int core_index )
{
        float some_value = 0.001 * ...
```

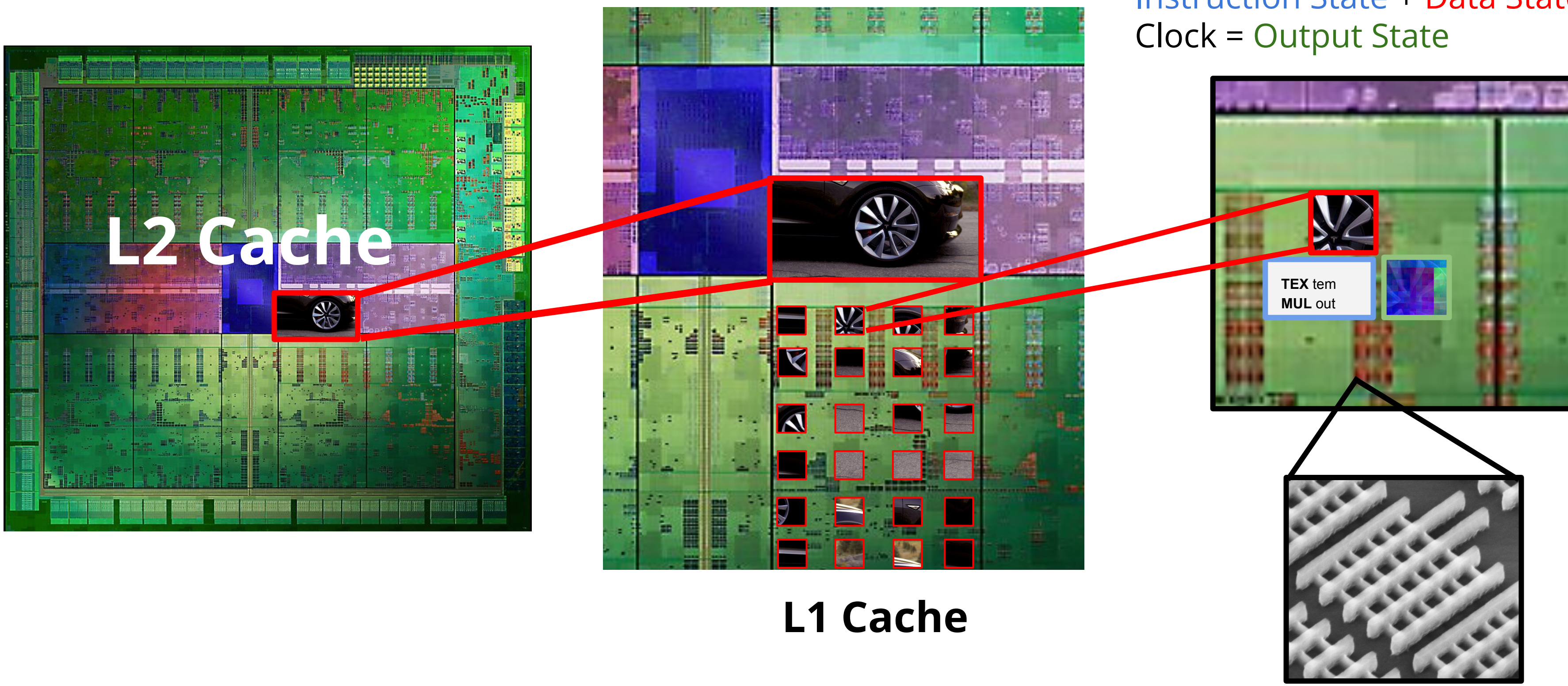
compile

```
TEMP temp
ATTRIB col0 = fragment.color
OUTPUT out = result.color
TEX temp, tex0, texture[0], 2D
MUL out, col0, temp
...
```

0,0,1,1,0,1,0, ...

Getting Close to the Metal (GPU)

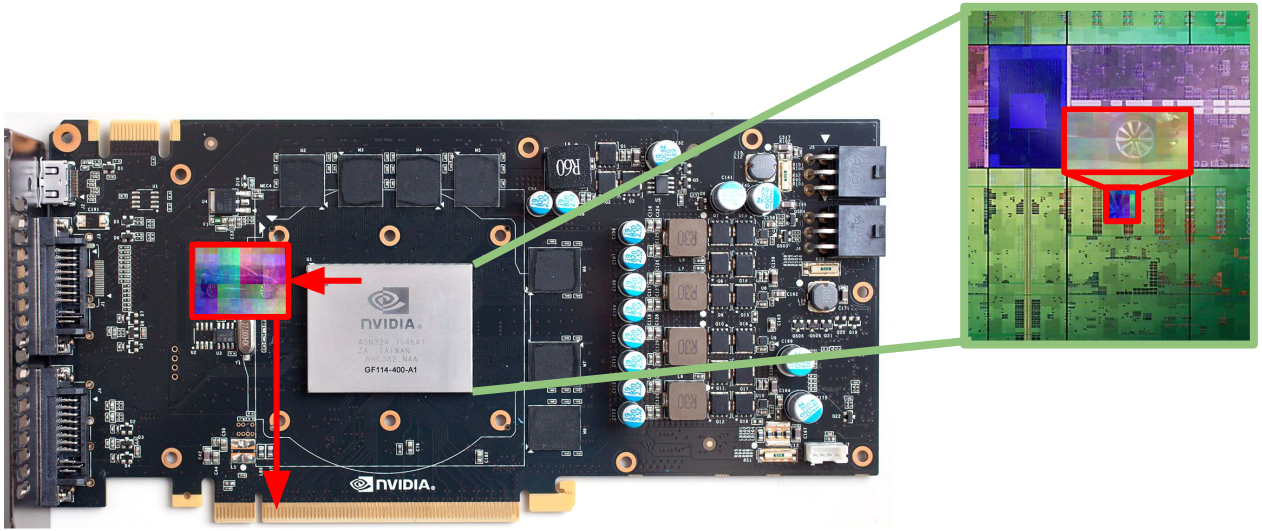
Instruction State + Data State + Clock = Output State



L1 Cache

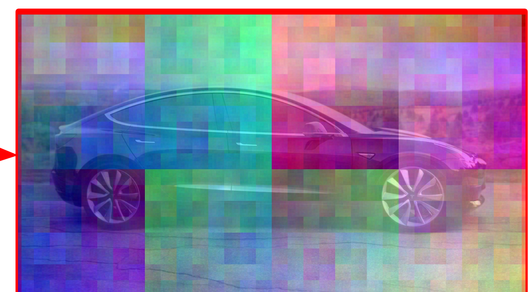
~25 billion transistors on a GPU die

Getting Close to the Metal (GPU)

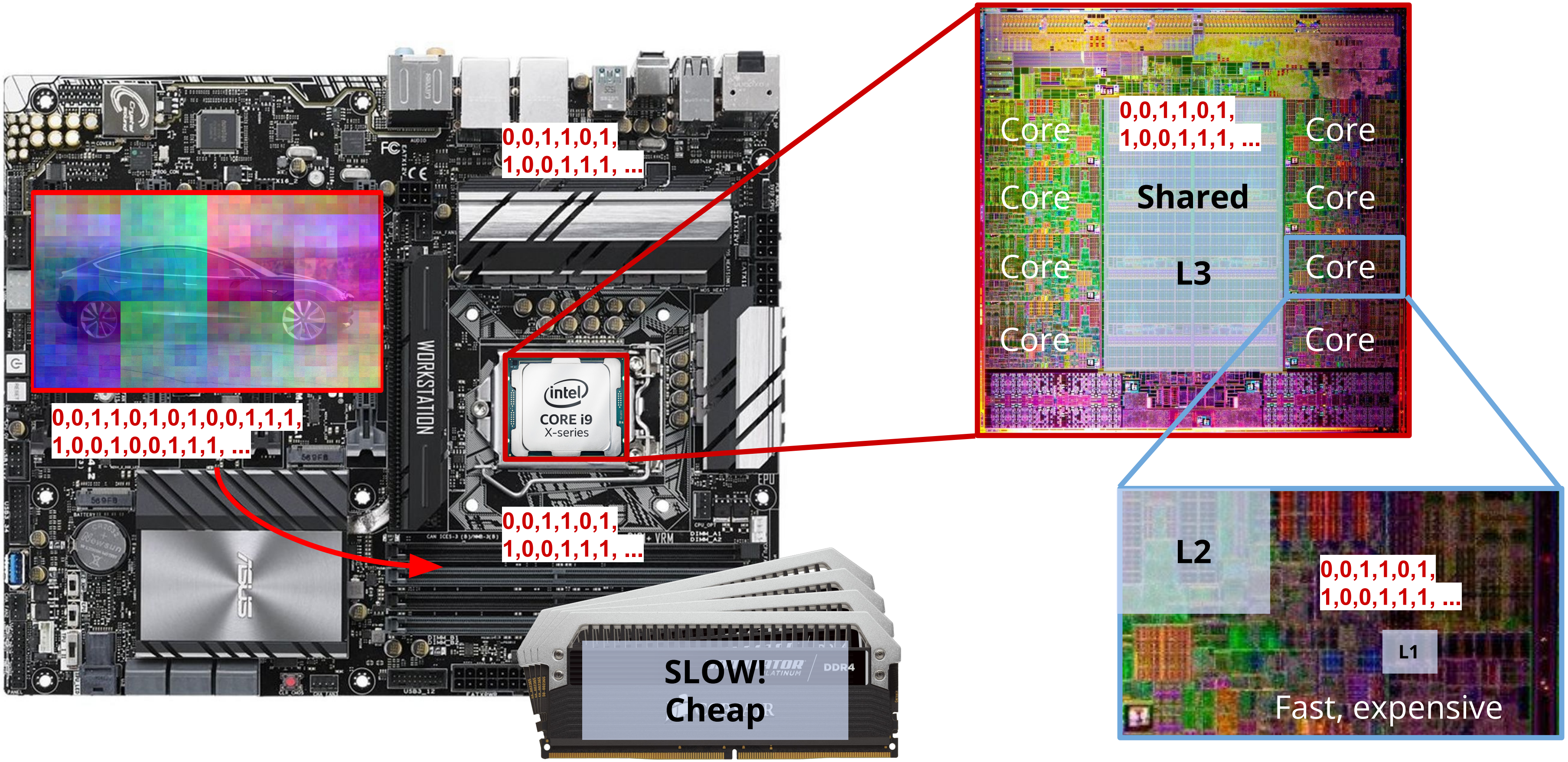


0,0,1,1,0,1,0,1,0,0,1,1,1,
1,0,0,1,0,0,1,1,1, ...

Program output:



Data, Instructions & Transforms



A simple C program

```c
#include <stdio.h>

int w;

int absolute(int x)
{
   if (x<0)
       return -x;
   return x;
}

int abs_mul(int x, int y)
{
   return absolute(x*y);
}

int main()
{
   int a;
   int b;

   a = 5;
   b = -2;
   w = abs_mul(a,b);
   printf("output = %d\n", w);

   return 0;
}
```

Global variable

Function

Local variables

```
 chris@chris-lab  ~/security  master ●  ls
main.c
 chris@chris-lab  ~/security  master ●  gcc -std=c89 -pedantic main.c -o main.o
 chris@chris-lab  ~/security  master ●  ls
main.c  main.o
 chris@chris-lab  ~/security  master ●  ./main.o
output = 10
 chris@chris-lab  ~/security  master ●  objdump -S -M intel main.o > main.asm
 chris@chris-lab  ~/security  master ●  ls
main.asm  main.c  main.o
 chris@chris-lab  ~/security  master ●  
```

1. Compile .c source to object file
2. Execute program
3. Disassemble object to assembly form
4. View assembly

Compiling and Executing

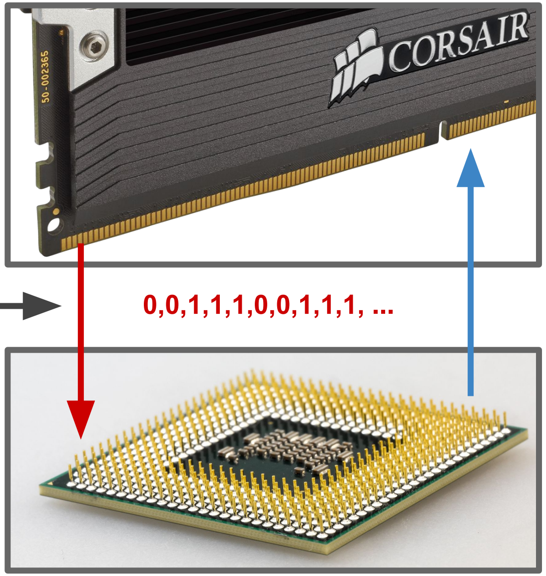
Source code

```c
#include <stdio.h>

int w;

int absolute(int x)
{
   if (x<0)
       return -x;
   return x;
}

int abs_mul(int x, int y)
{
   return absolute(x*y);
}

int main()
{
   int a;
   int b;

   a = 5;
   b = -2;
   w = abs_mul(a,b);
   printf("output = %d\n", w);

   return 0;
}
```

Machine Instructions

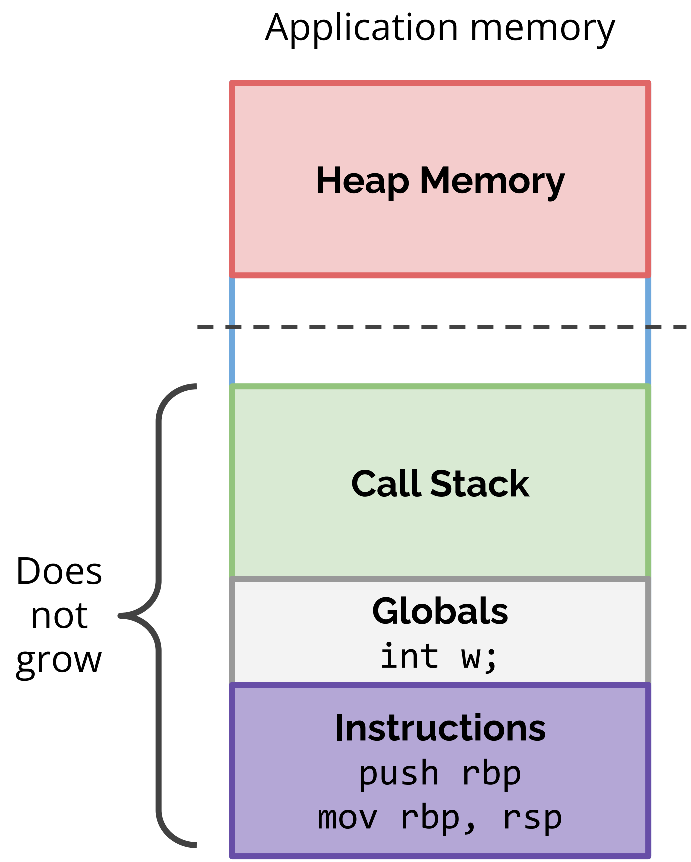
```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```

Voltage signals



Understanding Application memory

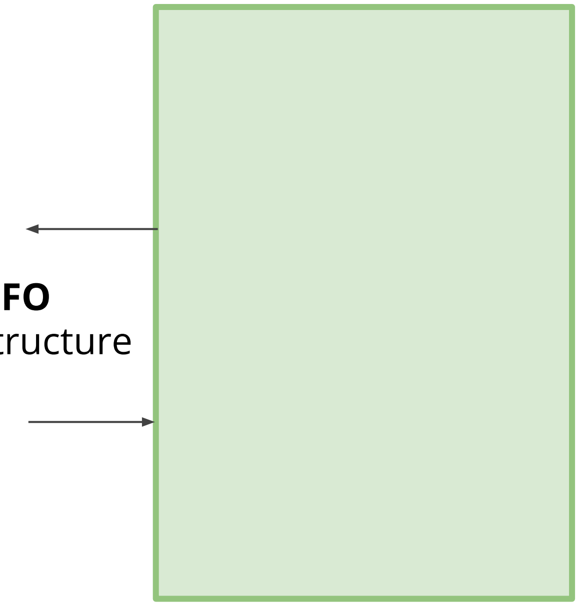
```c
#include <stdio.h>

int w;

int absolute(int x)
{
   if (x<0)
       return -x;
   return x;
}

int abs_mul(int x, int y)
{
   return absolute(x*y);
}

int main()
{
   int a;
   int b;

   a = 5;
   b = -2;
   w = abs_mul(a,b);
   printf("output = %d\n", w);

   return 0;
}
```



Understanding the Stack

```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```

The Stack

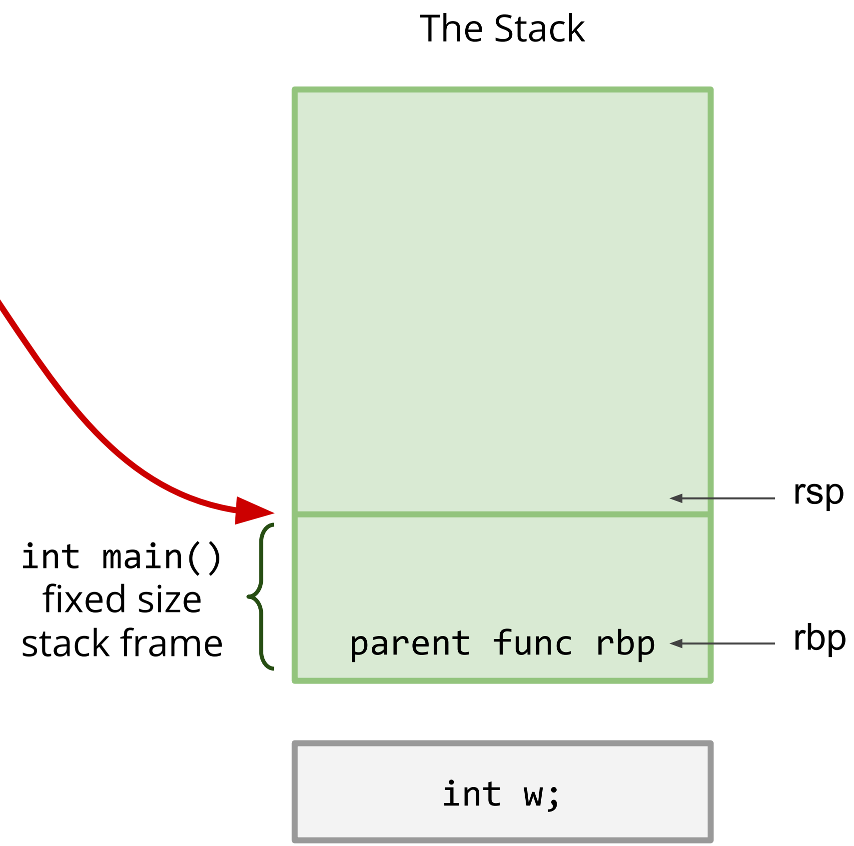


LIFO
data structure

```
int w;
```

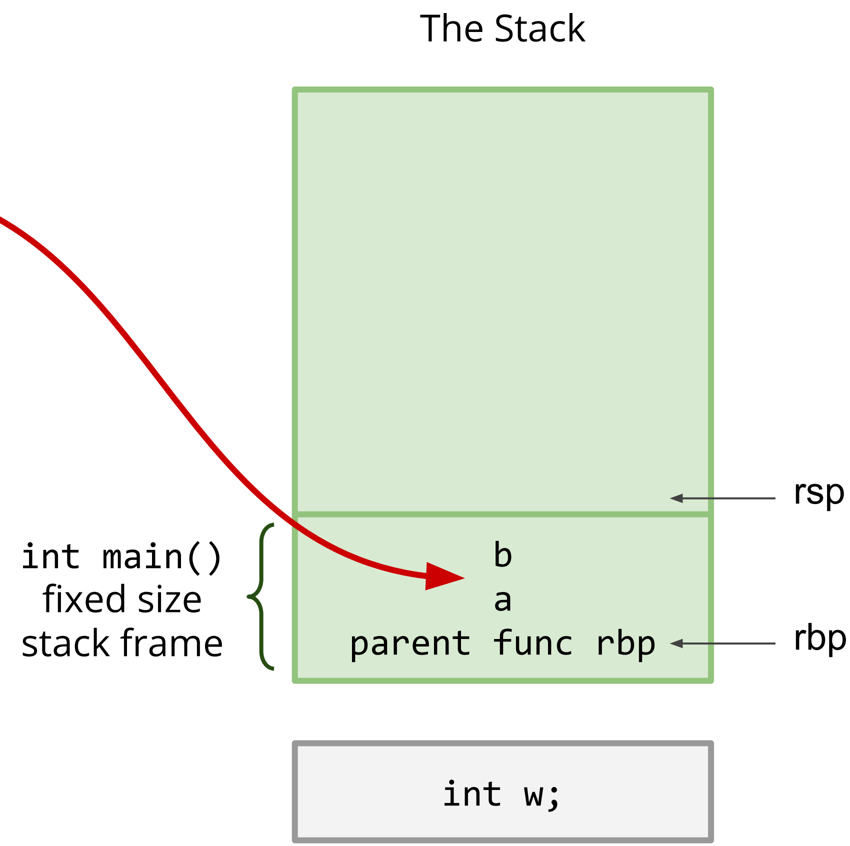
Understanding the Stack

```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```



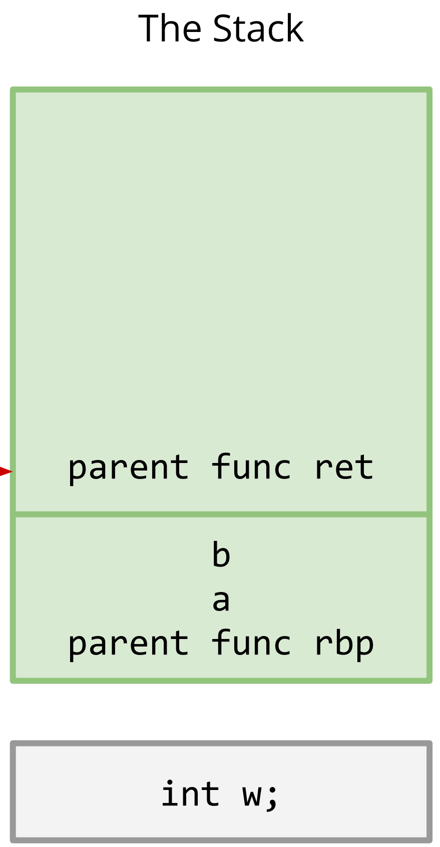
Understanding the Stack

```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```



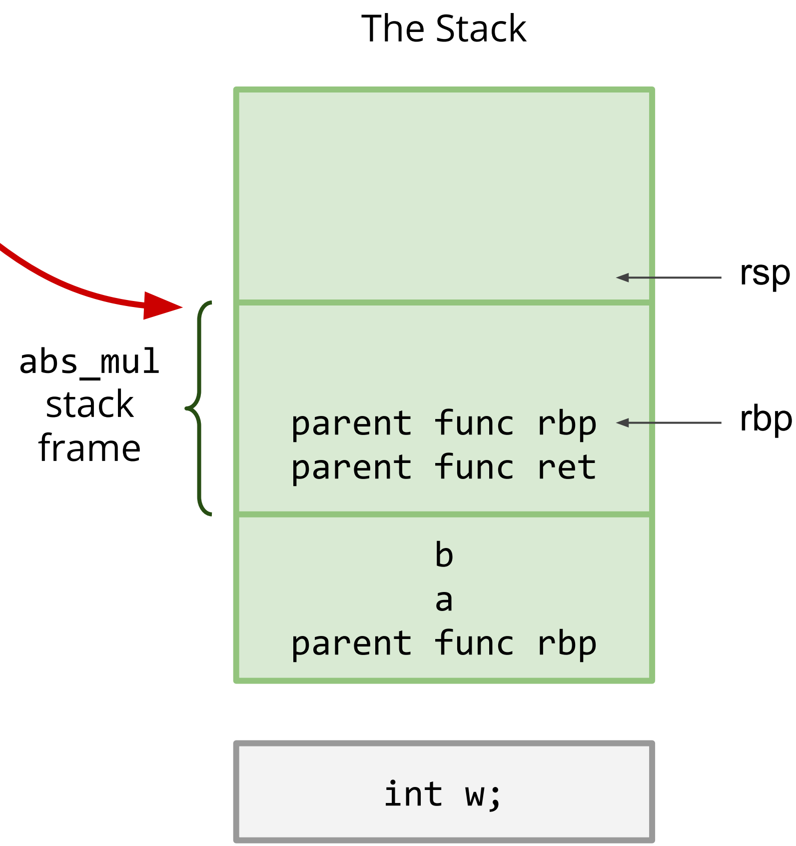
Understanding the Stack

```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```



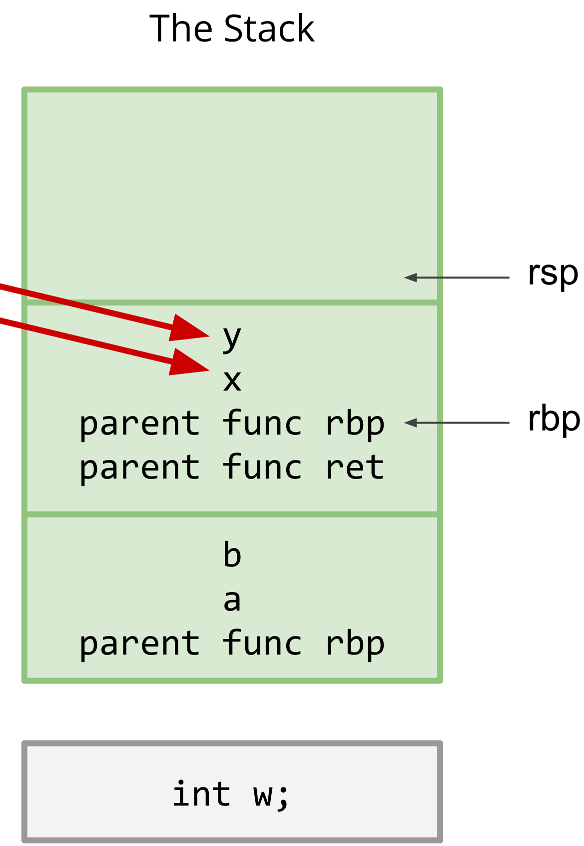
Understanding the Stack

```
0000000000000663 <abs_mul>:
663:   55                    push   rbp
664:   48 89 e5              mov    rbp,rsp
667:   48 83 ec 08           sub    rsp,0x8
66b:   89 7d fc              mov    DWORD PTR [rbp-0x4],edi
66e:   89 75 f8              mov    DWORD PTR [rbp-0x8],esi
671:   8b 45 fc              mov    eax,DWORD PTR [rbp-0x4]
674:   0f af 45 f8           imul   eax,DWORD PTR [rbp-0x8]
678:   89 c7                 mov    edi,eax
67a:   e8 cb ff ff ff        call   64a <absolute>
67f:   c9                    leave
680:   c3                    ret
```



Understanding the Stack

```
0000000000000663 <abs_mul>:
663:   55                      push   rbp
664:   48 89 e5                mov    rbp,rsp
667:   48 83 ec 08             sub    rsp,0x8
66b:   89 7d fc                mov    DWORD PTR [rbp-0x4],edi
66e:   89 75 f8                mov    DWORD PTR [rbp-0x8],esi
671:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
674:   0f af 45 f8             imul   eax,DWORD PTR [rbp-0x8]
678:   89 c7                   mov    edi,eax
67a:   e8 cb ff ff ff          call   64a <absolute>
67f:   c9                      leave
680:   c3                      ret
```



Understanding the Stack

```
0000000000000663 <abs_mul>:
663:   55                  push   rbp
664:   48 89 e5            mov    rbp,rsp
667:   48 83 ec 08         sub    rsp,0x8
66b:   89 7d fc            mov    DWORD PTR [rbp-0x4],edi
66e:   89 75 f8            mov    DWORD PTR [rbp-0x8],esi
671:   8b 45 fc            mov    eax,DWORD PTR [rbp-0x4]
674:   0f af 45 f8         imul   eax,DWORD PTR [rbp-0x8]
678:   89 c7               mov    edi,eax
67a:   e8 cb ff ff ff      call   64a <absolute>
67f:   c9                  leave
680:   c3                  ret
```

The Stack

parent func ret

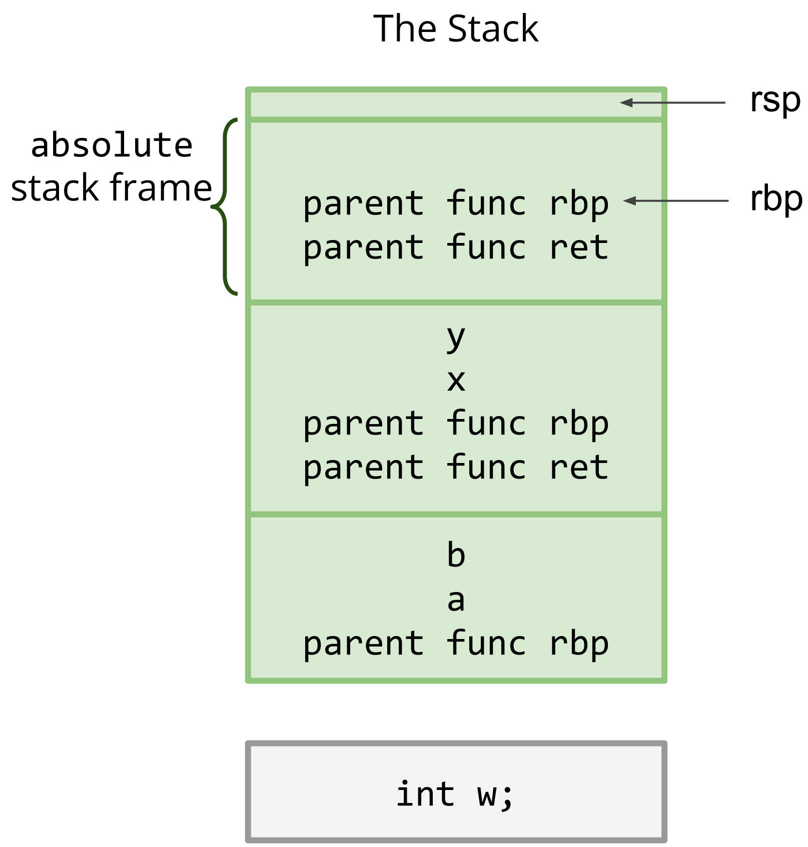
y
x
parent func rbp
parent func ret

b
a
parent func rbp

int w;

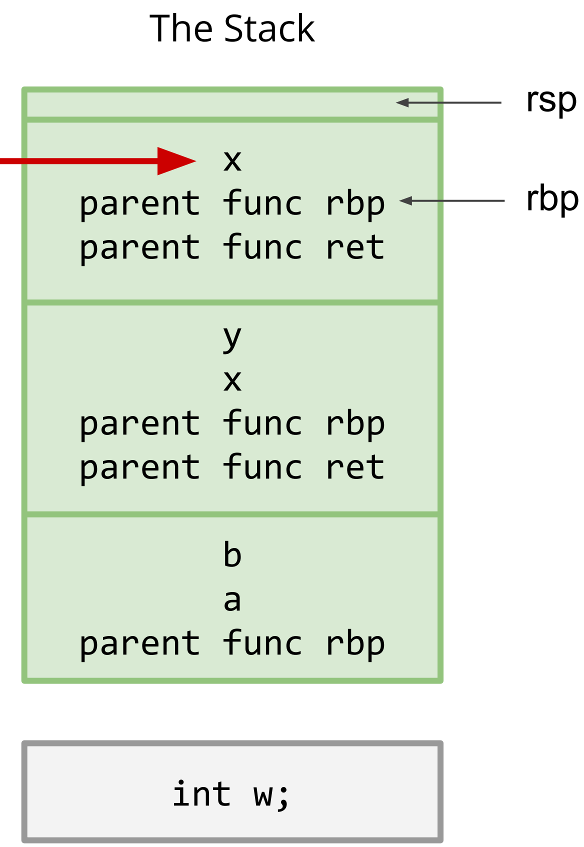
Understanding the Stack

```
000000000000064a <absolute>:
64a:    55                      push   rbp
64b:    48 89 e5                mov    rbp,rsp
64e:    89 7d fc                mov    DWORD PTR [rbp-0x4],edi
651:    83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
655:    79 07                   jns    65e <absolute+0x14>
657:    8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
65a:    f7 d8                   neg    eax
65c:    eb 03                   jmp    661 <absolute+0x17>
65e:    8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
661:    5d                      pop    rbp
662:    c3                      ret
```



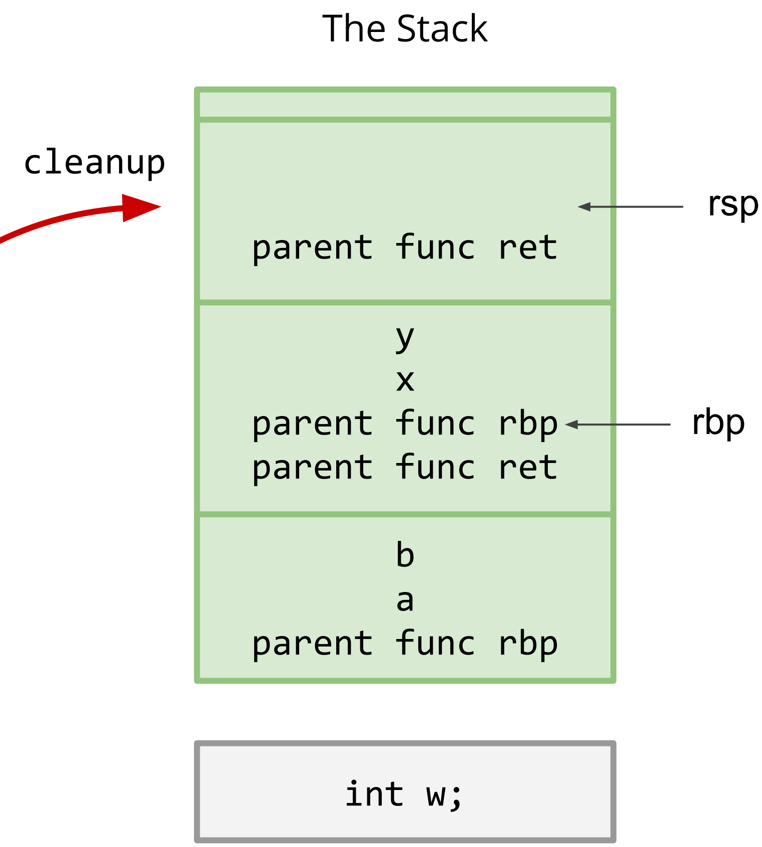
Understanding the Stack

```
000000000000064a <absolute>:
64a:   55                      push   rbp
64b:   48 89 e5                mov    rbp,rsp
64e:   89 7d fc                mov    DWORD PTR [rbp-0x4],edi
651:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
655:   79 07                   jns    65e <absolute+0x14>
657:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
65a:   f7 d8                   neg    eax
65c:   eb 03                   jmp    661 <absolute+0x17>
65e:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
661:   5d                      pop    rbp
662:   c3                      ret
```



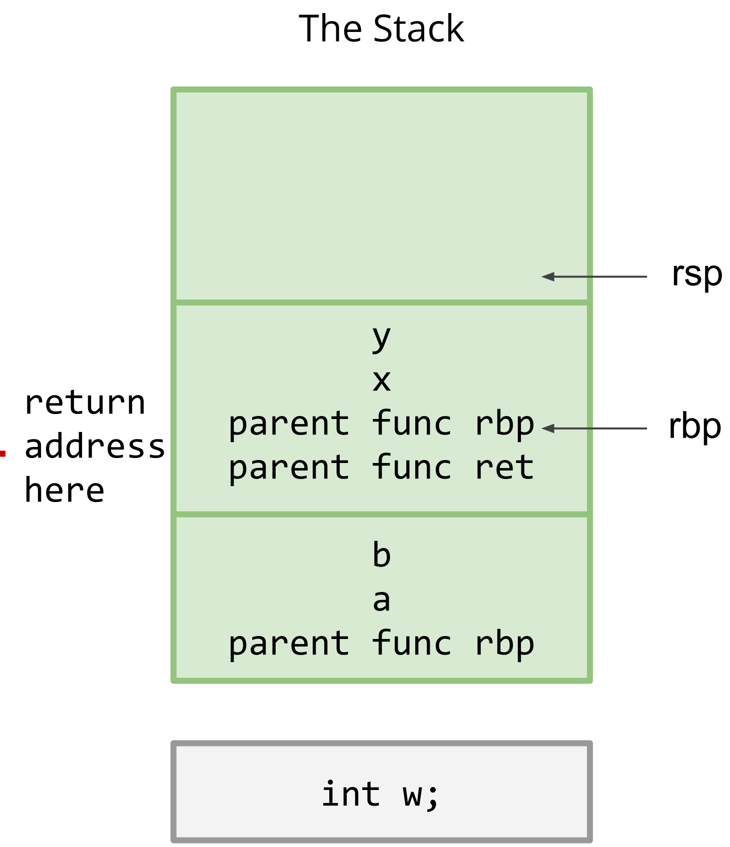
Understanding the Stack

```
0000000000000064a <absolute>:
64a:   55                      push   rbp
64b:   48 89 e5                mov    rbp,rsp
64e:   89 7d fc                mov    DWORD PTR [rbp-0x4],edi
651:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
655:   79 07                   jns    65e <absolute+0x14>
657:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
65a:   f7 d8                   neg    eax
65c:   eb 03                   jmp    661 <absolute+0x17>
65e:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
661:   5d                      pop    rbp
662:   c3                      ret
```



Understanding the Stack

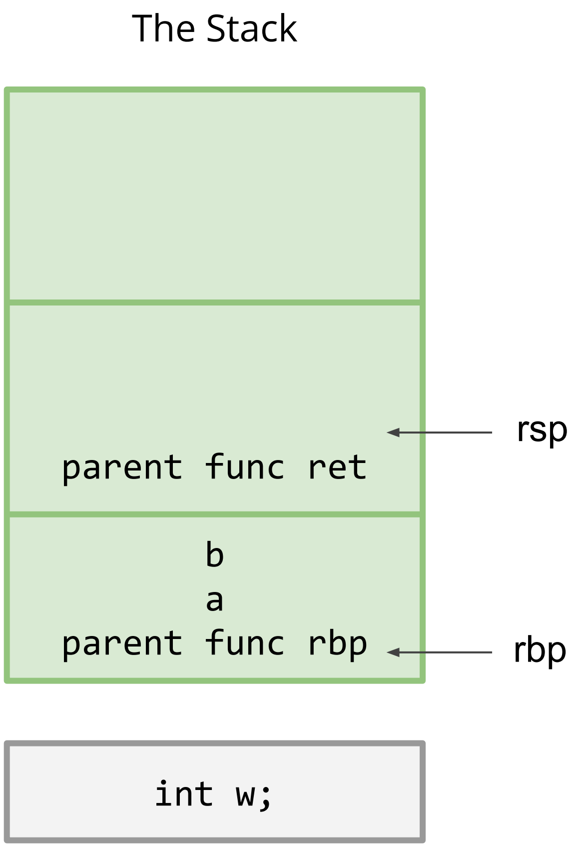
```
0000000000000663 <abs_mul>:
663:   55                      push   rbp
664:   48 89 e5                mov    rbp,rsp
667:   48 8d a4 24 d8 ef ff    lea    rsp,[rsp-0x1028]
66e:   ff
66f:   48 83 0c 24 00          or     QWORD PTR [rsp],0x0
674:   48 8d a4 24 20 10 00    lea    rsp,[rsp+0x1020]
67b:   00
67c:   89 7d fc                mov    DWORD PTR [rbp-0x4],edi
67f:   89 75 f8                mov    DWORD PTR [rbp-0x8],esi
682:   8b 45 fc                mov    eax,DWORD PTR [rbp-0x4]
685:   0f af 45 f8             imul   eax,DWORD PTR [rbp-0x8]
689:   89 c7                   mov    edi,eax
68b:   e8 ba ff ff ff          call   64a <absolute>
690:   c9                      leave
691:   c3                      ret
```



Understanding the Stack

```
0000000000000663 <abs_mul>:
663:   55                     push   rbp
664:   48 89 e5               mov    rbp,rsp
667:   48 8d a4 24 d8 ef ff   lea    rsp,[rsp-0x1028]
66e:   ff
66f:   48 83 0c 24 00         or     QWORD PTR [rsp],0x0
674:   48 8d a4 24 20 10 00   lea    rsp,[rsp+0x1020]
67b:   00
67c:   89 7d fc               mov    DWORD PTR [rbp-0x4],edi
67f:   89 75 f8               mov    DWORD PTR [rbp-0x8],esi
682:   8b 45 fc               mov    eax,DWORD PTR [rbp-0x4]
685:   0f af 45 f8            imul   eax,DWORD PTR [rbp-0x8]
689:   89 c7                  mov    edi,eax
68b:   e8 ba ff ff ff         call   64a <absolute>
690:   c9                     leave
691:   c3                     ret
```

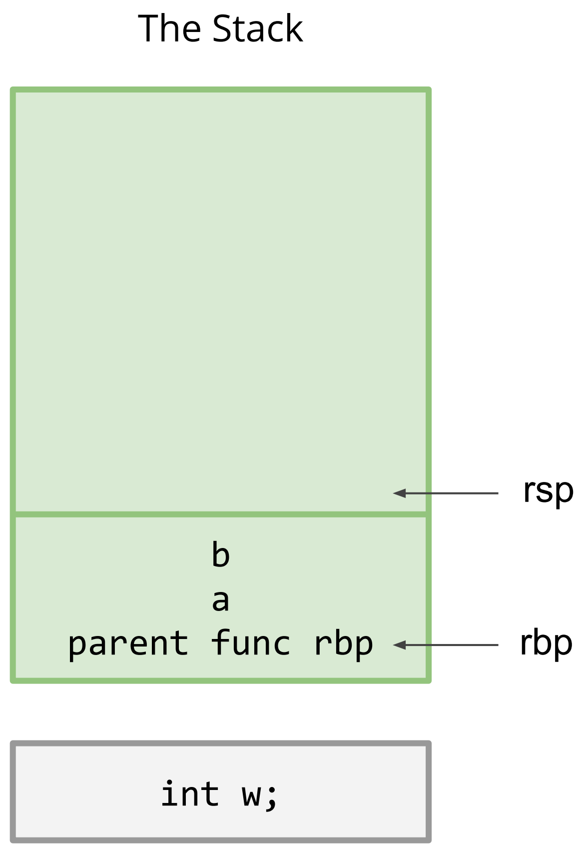
cleanup



Understanding the Stack

```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```

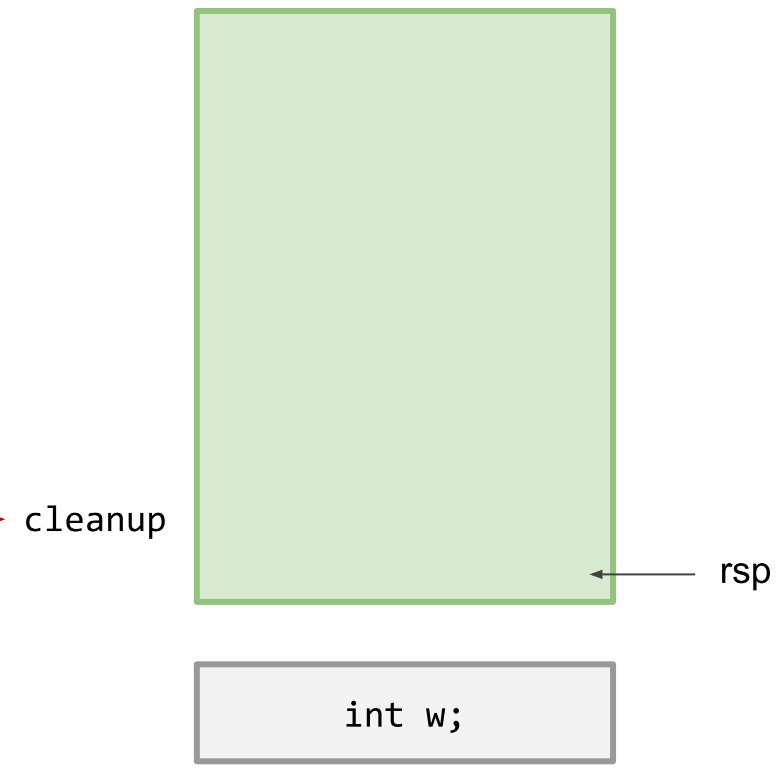
return
address
here



Understanding the Stack

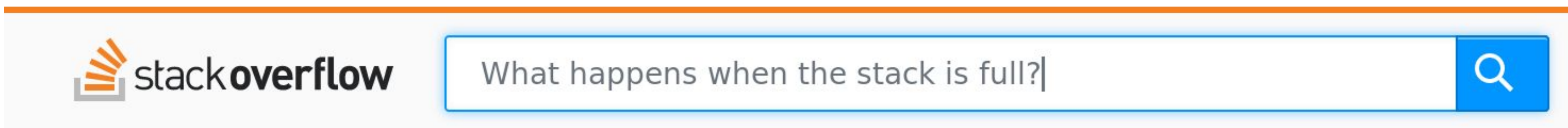
```
0000000000000681 <main>:
681:   55                      push   rbp
682:   48 89 e5                mov    rbp,rsp
685:   48 83 ec 10             sub    rsp,0x10
689:   c7 45 f8 05 00 00 00    mov    DWORD PTR [rbp-0x8],0x5
690:   c7 45 fc fe ff ff ff    mov    DWORD PTR [rbp-0x4],0xfffffffe
697:   8b 55 fc                mov    edx,DWORD PTR [rbp-0x4]
69a:   8b 45 f8                mov    eax,DWORD PTR [rbp-0x8]
69d:   89 d6                   mov    esi,edx
69f:   89 c7                   mov    edi,eax
6a1:   e8 bd ff ff ff          call   663 <abs_mul>
6a6:   89 05 88 09 20 00       mov    DWORD PTR [rip+0x200988],eax
6ac:   8b 05 82 09 20 00       mov    eax,DWORD PTR [rip+0x200982]
6b2:   89 c6                   mov    esi,eax
6b4:   48 8d 3d 99 00 00 00    lea    rdi,[rip+0x99]
6bb:   b8 00 00 00 00          mov    eax,0x0
6c0:   e8 6b fe ff ff          call   530 <printf@plt>
6c5:   b8 00 00 00 00          mov    eax,0x0
6ca:   c9                      leave
6cb:   c3                      ret
6cc:   0f 1f 40 00             nop    DWORD PTR [rax+0x0]
```

The Stack



Understanding the Stack

- When program thread starts, the operating system reserves some amount of space for the stack.
    - Stack memory does not grow during runtime.

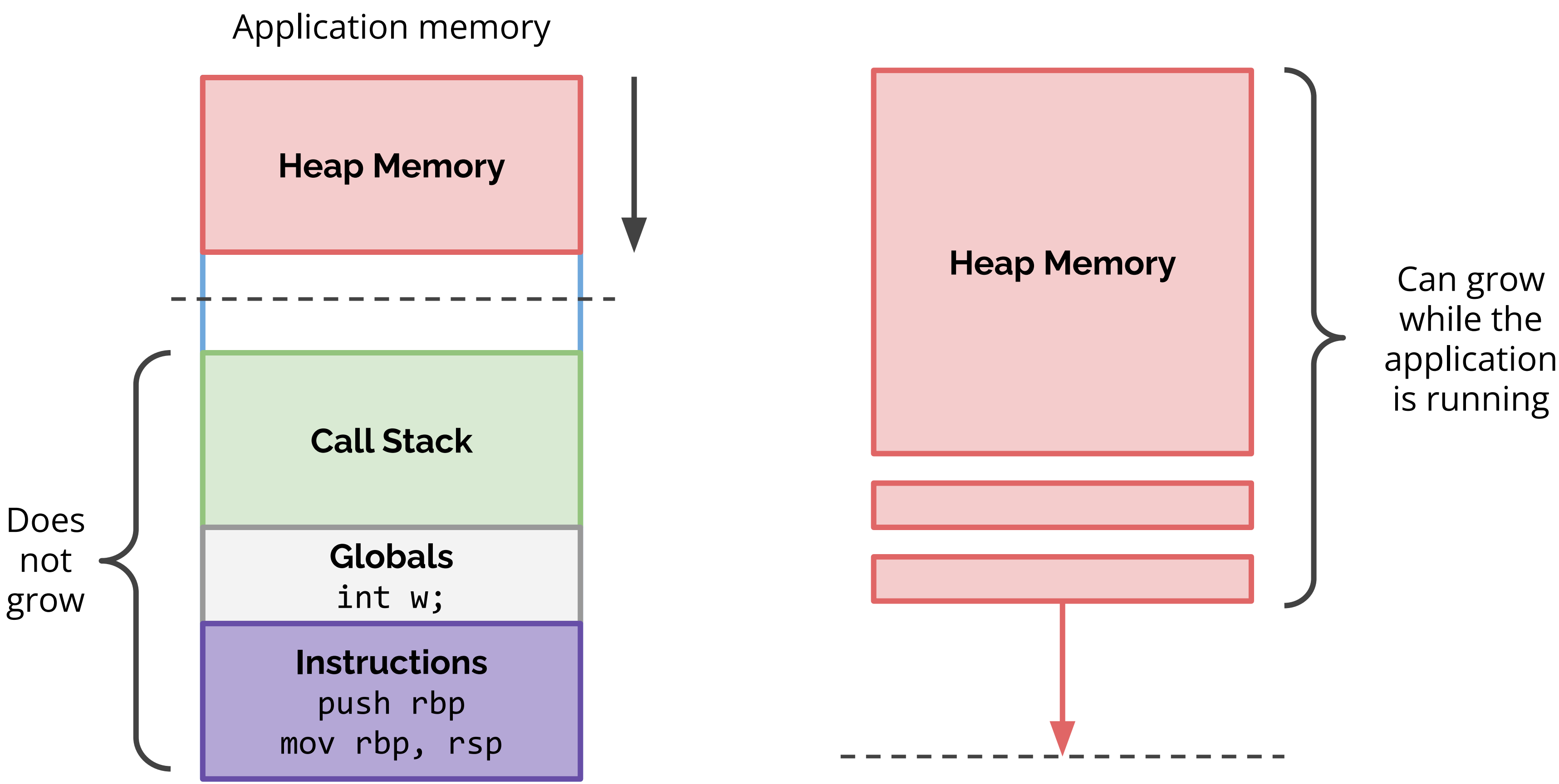



```c
int stack_overflow() {
    return stack_overflow();
}
```

```
chris@chris-laptop  ~/security  master ●  gcc main.c -o main.o
chris@chris-laptop  ~/security  master ●  ./main.o
[1]    11796 segmentation fault (core dumped)  ./main.o
 ✘ chris@chris-laptop  ~/security  master ●
```

- Caused by...
    - Badly written recursive functions
    - Too much local memory allocated (esp with multi-threading)
- What happens if we need to allocate a large amount of local memory?
    - We would need to know the size of it at compile time.
    - But what if you wanted it to grow dynamically at runtime without know it beforehand?

Introducing the Heap also called Dynamic Memory



Pointers

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

int main()
{
   int *p;
   int x;

   p = &x;
   x = 4;

   printf("ex1 = %p\n", p);
   printf("ex2 = %d\n", *p);
   printf("ex3 = %d\n", p[0]);
   printf("ex4 = %d\n", p[ 1]);
   printf("ex5 = %d\n", p[-1]);
   printf("ex6 = %p\n", &p[1]);
   printf("ex7 = %p\n", &p[2]);

   return 0;
}
```

- Pointers ***x** are just integer numbers that point to the memory address.
- We can assign pointers to “the address of” **&x** variables.

```
chris@chris-lab  ~/security  master ●  ls
main.c
chris@chris-lab  ~/security  master ●  gcc main.c -o main.o
chris@chris-lab  ~/security  master ●  ./main.o
ex1 = 0x7fff398c4f2c
ex2 = 4
ex3 = 4
ex4 = 965496620
ex5 = 1733957040
ex6 = 0x7fff398c4f30
ex7 = 0x7fff398c4f34
chris@chris-lab  ~/security  master ●
```

- We can read memory from outside

Using the Heap

- C
  - **malloc**
  - **free**

  } functions
- C++
  - **new**
  - **delete**

  } operators
- Java
  - **new**
  - lots of stuff resides on the heap
- Python
  - In CPython, all objects live on the heap

```c
#include <stdlib.h>

int main()
{
   float *ptr;

   ptr = (float*)malloc(3*sizeof(float));
   *ptr = 42;
   free(ptr);

   return 0;
}
```

malloc manages a pool of memory and *sometimes* makes calls to **sbrk** which zeros out new requests

Using the Heap

- C
  - **malloc**
  - **free**

functions

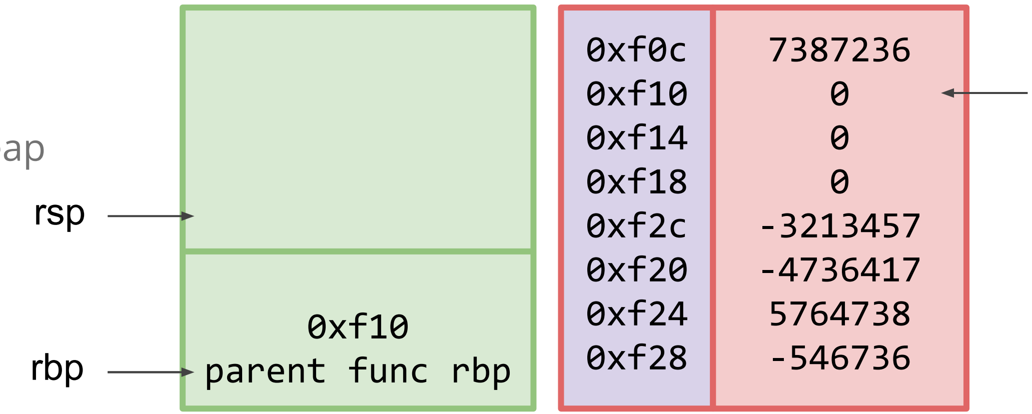
- C++
  - **new**
  - **delete**

operators

- Java
  - **new**
  - lots of stuff resides on the heap
- Python
  - In CPython, all objects live on the heap

```c
#include <stdlib.h>

int main()
{
   float *ptr;

   ptr = (float*)malloc(3*sizeof(float));
   *ptr = 42;
   free(ptr);

   return 0;
}
```

malloc manages a pool of memory and *sometimes* makes calls to **sbrk** which zeros out new requests



Using the Heap

- C
  - **malloc**
  - **free**

functions

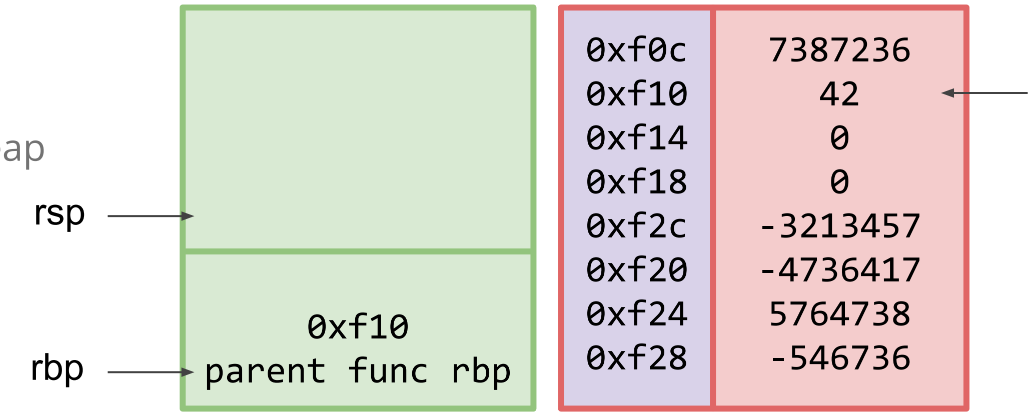
- C++
  - **new**
  - **delete**

operators

- Java
  - **new**
  - lots of stuff resides on the heap
- Python
  - In CPython, all objects live on the heap

```c
#include <stdlib.h>

int main()
{
   float *ptr;

   ptr = (float*)malloc(3*sizeof(float));
   *ptr = 42;
   free(ptr);

   return 0;
}
```

malloc manages a pool of memory and *sometimes* makes calls to **sbrk** which zeros out new requests



Using the Heap

```c
#include <stdio.h>
#include <stdlib.h>
int main()
{
   float *p;
   int i;

   p = (float*)malloc(100*sizeof(float));
   for (i=0; i<100; ++i)
       p[i] = (float)rand()/(float)RAND_MAX;
   free(p);

   p = (float*)malloc(100*sizeof(float));
   p[0] = 6.283185;
   p[3] = 5.0;

   printf("p[0] = %f\n", p[0]);
   printf("p[1] = %f\n", p[1]);
   printf("p[2] = %f\n", p[2]);
   printf("p[3] = %f\n", p[3]);

   free(p);
   return 0;
}
```

Same size, so likely to get same memory

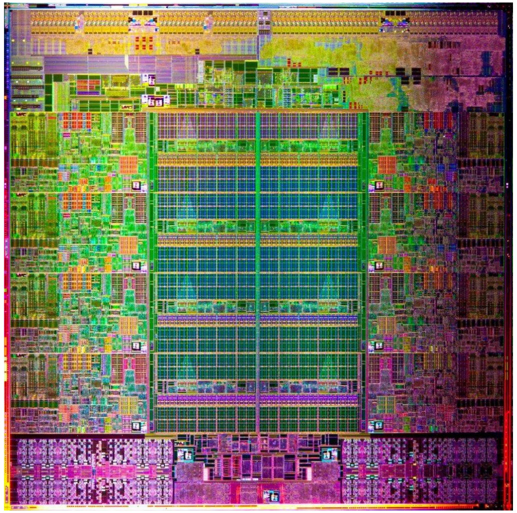
- Memory not guaranteed to be initialized to zero
- Can malloc memory to same size of some sensitive data

```
 chris@chris-lab  ~/security  master ●  ls
main.c
 chris@chris-lab  ~/security  master ●  gcc main.c -o main.o
 chris@chris-lab  ~/security  master ●  ./main.o
p[0] = 6.283185
p[1] = 0.000000
p[2] = 0.783099
p[3] = 5.000000
 chris@chris-lab  ~/security  master ● 
```

Where did that come from?

Questions

- Which memory type is faster?
    - Stack or Heap?
- Where does heap memory reside physically?
- Where does stack memory reside physically?
- What happens when stack memory leaves scope?
- What happens when heap memory leaves scope?
    - In Java?
        - **ArrayList**<Integer> v = **new ArrayList**<Integer>();
        - v.add(1); v.add(2); v.add(3); ... ;
    - In C++?
        - **std::vector**<int> v;
        - v.push_back(1); v.push_back(2); v.push_back(3); ...



Principles of good software?

… fast, secure, efficient, withstands the test of time, simple, intuitive, …

- https://wiki.owasp.org/index.php/Security_by_Design_Principles
  - Minimize attack surface area, fail securely, keep security simple, …
- https://github.com/nothings/stb
  - Sean Barrett, a legendary software veteran, creator of the famous stb libraries such as stb_image, a tiny single file public domain header that enables you to read JPG, PNG, TGA, BMP, PSD, … instead of including huge monolithic libraries.
  - **“Make it easily usable”.**
  - **“Do anything you want with it”.**
- https://suckless.org/philosophy
  - The suckless group, developers of well-written and extendable software, such as the DWM window manager - just 2149 lines of easy-to-understand C code.
    - “**Simplicity, clarity, frugality**”
    - **“Do one task, do it well”**
- https://www.archlinux.org/ “Keep It Simple, Stupid!”
- **Writing secure software involves understanding the platform, and all the things that come between you (the developer) and the platform.**

Understanding the Platform

- The key to writing good, secure, software is to understand the platform.
- Hardware is the base platform (for software).
- Lots of things get in the way:
  - Compilers, Abstractions, Software Libraries, GUIs,
  - Operating Systems, User Patches, Web Browsers, ...

Offtopic but relevant, assuming Lemi was a Durham University computer science student, what should Lemi have done?

- "Stealing Webpages Rendered on Your Browser by Exploiting GPU Vulnerabilities"
  - http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6956554