Security Vulnerability in Format String

Escape sequences are essentially instructions.

- `printf` has no idea how many arguments it actually receives.
- It infers the number of arguments from the format string: number of arguments should match number of escape sequences in the format string.
- What if there is a mismatch?

A vulnerable program

- Users control both escape sequences and arguments in `user_input`.
- An attacker can deliberately cause mismatch between them.

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

int main(int argc, char* argv[]) {
  char user_input[100];
  scanf("%s", user_input);
  printf(user_input);
}
```

What potential consequences could this mismatch cause?

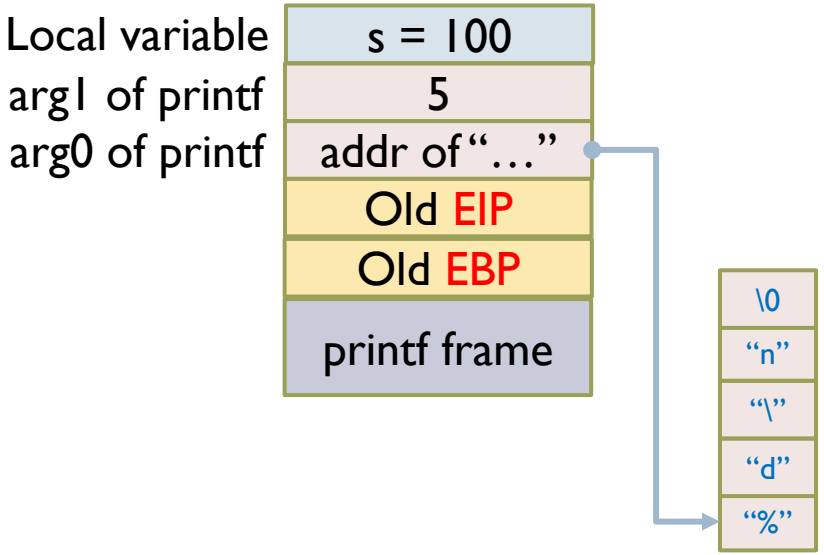
Attack 1: Leak Information from Stack

Correct usage of **printf**

- Two arguments are pushed into the stack as function parameter

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

int main(int argc, char **argv){
    int s = 100;
    printf("%d\n", 5);
    return 0;
}
```



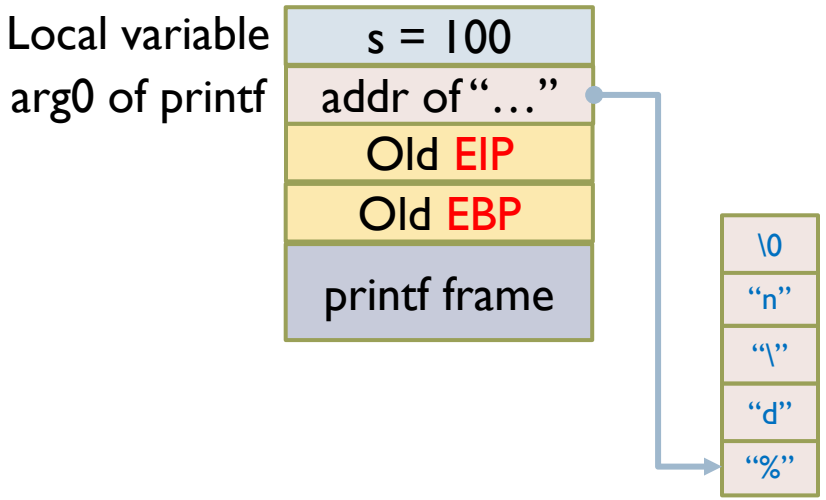
Attack 1: Leak Information from Stack

Incorrect usage of `printf`

- The stack does not realize an argument is missing, and will retrieve the local variable as the argument to print out.
- Data that do not belong to the user are thus leaked to the attacker.
- The attacker can print out any types of data, including integer (**%d**), floating point (**%f**), string (**%s**), address (**%p**)…

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

int main(int argc, char **argv){
    int s = 100;
    printf("%d\n");
    return 0;
}
```



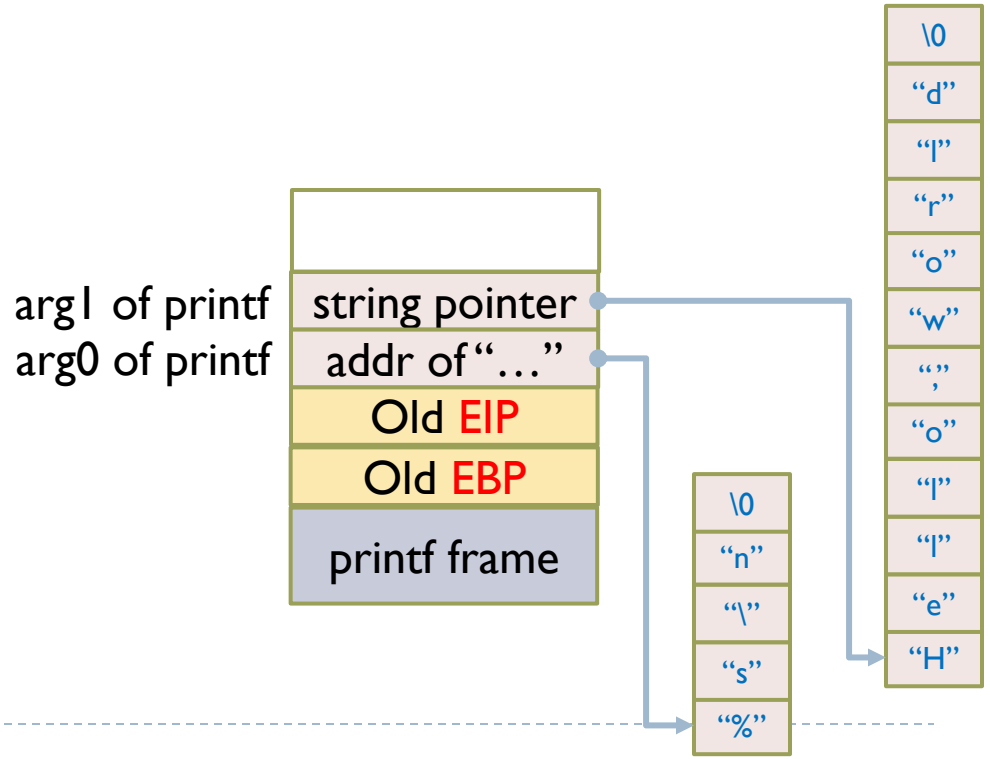
Attack 2: Crash the Program

Correct usage of **printf**

- For format specifier **%s**, a pointer of a string is pushed into the stack as the corresponding function parameter

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

int main(int argc, char **argv){
    printf("%s\n", "hello, world");
    return 0;
}
```



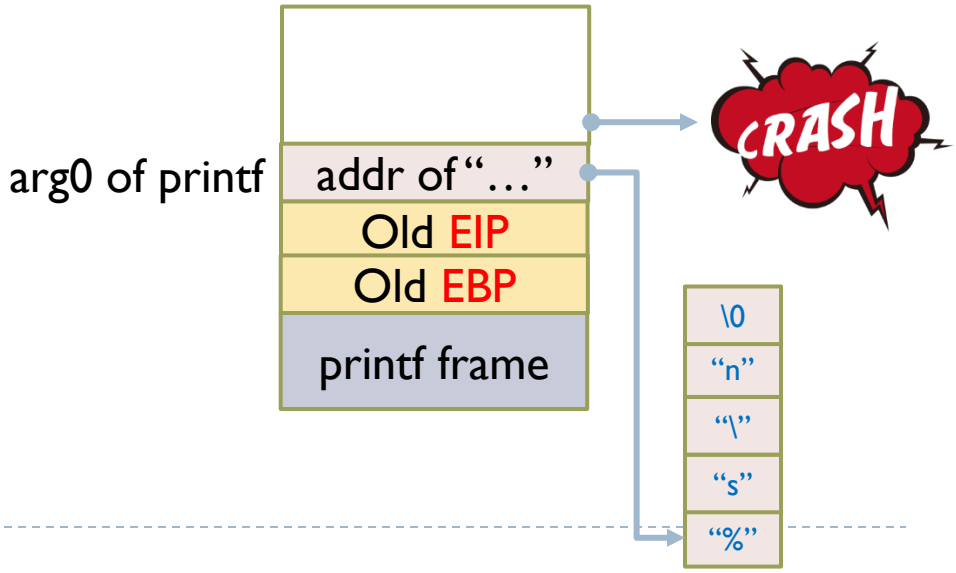
Attack 2: Crash the Program

Incorrect usage of `printf`

- The stack does not realize an argument is missing, and will retrieve other stack values as addresses, and access data there.
- This address can be invalidated, and then the program will crash
  - No physical address is assigned to this address
  - Protected memory, e.g., kernel.
- Can include more `%s` to increase the crash probability

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

int main(int argc, char **argv){
    printf("%s\n");
    return 0;
}
```



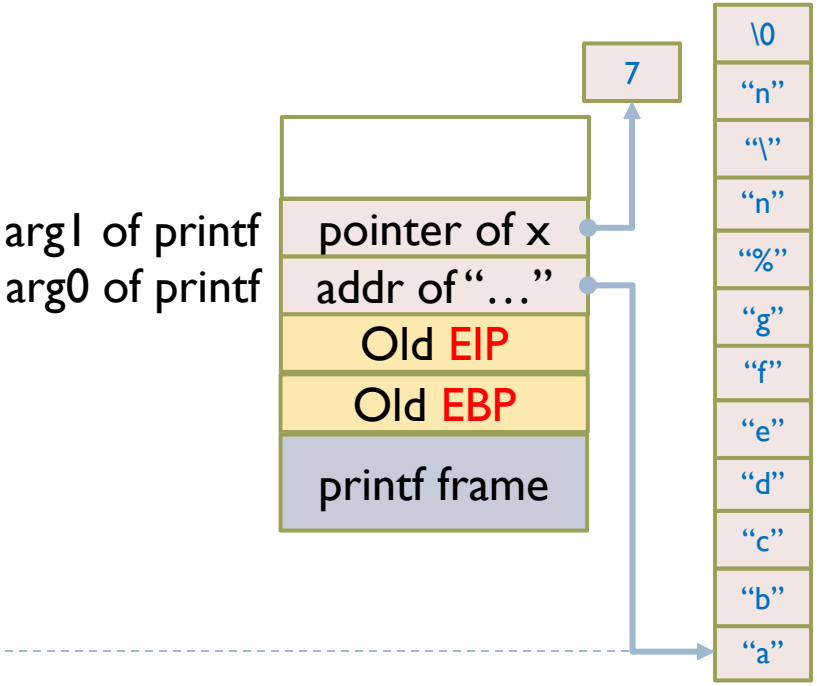
Attack 3: Modify the Memory

Correct usage of `printf`

- For format specifier **%n**, a pointer of a signed integer is pushed into the stack as the corresponding function parameter.
- Store the number of characters written so far into that integer

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

int main(int argc, char **argv){
    int *x = (int *)malloc(sizeof(int));
    printf("abcdefg%n\n",x);
    return 0;
}
```



Attack 3: Modify the Memory

Incorrect usage of **printf**

- The stack does not realize an argument is missing, and will retrieve the data from the stack and write 7 into this address.
- Attacker can achieve the following goal:
  - Overwrite important program flags that control access privileges
  - Overwrite return addresses on the stack, function pointers, etc.

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

int main(int argc, char **argv){
    int *x = (int *)malloc(sizeof(int));
    printf("abcdefg%n\n");
    return 0;
}
```